THERYA NOTES 2022, Vol. 3 : 119-124 DOI: 10.12933/therya_notes-22-82 ISSN 2954-3614

Home range and movement ecology of the woolly opossum (*Caluromys derbianus*) in a Neotropical rainforest of Costa Rica

Ámbito hogareño y ecología del movimiento del zorro de balsa (*Caluromys derbianus*) en un bosque Neotropical de Costa Rica

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Understanding animal movement is critical to elucidate how non-sessile species survive and reproduce, as well as their influence in evolutionary and ecological processes and patterns. By characterizing the spatial movements of a Neotropical mammal, we aimed to generate information regarding the home range and movement ecology of the woolly opossum, *Caluromys derbianus*. Fieldwork was conducted in a Neotropical Rainforest of Costa Rica where animals were captured and fitted with collar mounted radio transmitters. Data on spatial locations were then analyzed to estimate the home range and the activity areas. Mean home range and activity areas of the opossums were concentrated in small patches (< 2 ha for home range, ≤ 1.1 ha for foraging areas and < 0.5 ha for core use areas). Overall, our results contribute to the growing knowledge on the natural history of Neotropical marsupials, as well as highlights that, as expected, *C. derbianus* is likely a species that might meets its most critical requirements within small activity areas. So, we argue that an opportunistic and omnivorous diet, and a well conserved habitat contribute to the observed patterns of animal movement. Further efforts should focus on increasing sample size and tracking periods to better comprehend habitat and resource use patterns.

Key words: Didelphidae; local convex hulls; marsupials; minimum convex polygon.

Comprender el movimiento de los animales es fundamental para dilucidar cómo las especies no sésiles sobreviven y se reproducen, así como su influencia en los procesos y patrones evolutivos y ecológicos. Al caracterizar los movimientos espaciales de un mamífero neotropical, nuestro objetivo fue generar información con respecto al ámbito hogareño y a la ecología del movimiento del zorro de balsa, *Caluromys derbianus*. El trabajo de campo se realizó en un bosque Neotropical lluvioso de Costa Rica donde los animales fueron capturados y equipados con un transmisor de radio montado en un collar. Los datos sobre las localizaciones espaciales fueron luego analizados para estimar el ámbito hogareño y las áreas de actividad para los animales. Las áreas de actividad y área promedio del ámbito hogareño de los zorros de balsa se concentraron en parches pequeños (< 2 ha para el ámbito hogareño, ≤ 1.1 ha para áreas de alimentación y < 0.5 ha para áreas de uso principal). En general, nuestros resultados contribuyen al conocimiento sobre la historia natural del zorro de balsa neotropical, además de destacar que, como se esperaba, *C. derbianus* es una especie que probablemente puede cumplir con sus requisitos más críticos dentro de las áreas con una actividad reducida. Así, argumentamos que una dieta oportunista y omnívora, además de un hábitat bien conservado contribuye a los patrones de movimiento del zorro de balsa observado. Los siguientes esfuerzos deben centrarse en aumentar el tamaño de la muestra y los períodos de rastreo para así mejorar la comprensión de patrones en el uso del hábitat y de los recursos.

Palabras clave: Didelphidae; marcos convexos locales; marsupiales; polígono mínimo convexo.

Non-sessile animals survive and reproduce by finding critical resources such as food, shelter, and mates at the same time as they avoid predators (Nathan *et al.* 2008). So, animal movement patterns are likely shaped by evolutionary and ecological processes that influence important phenomena such as density, ecological interactions, competition and ultimately diversity of the ecosystems (Patterson *et al.* 2008; Kays *et al.* 2015). Therefore, is not surprising that animal movement studies have been increasing (*i.e.*, more research) and enhancing (*i.e.*, smaller and more accurate devices such as "tags" equipped with Global Position System (GPS), implanted electronics, animal-mounted small cameras; Kays *et al.* 2015).

Among vertebrates such as mammals, multiple studies have been contributing to the knowledge on the movement ecology of hundreds of species around the globe, but many more efforts should be carried to document ecological information of highly diverse taxonomic clades with myriad of species (Kays *et al.* 2015). For instance, among highly diverse clades, and usually small-bodied size, such as bats, rodents and marsupials, surprisingly few information is available out there, which limits our understanding of basic biological aspects of unique species and their interaction with the environment (Kays *et al.* 2015).

The woolly opossum, *Caluromys derbianus* (Waterhouse 1841), is a 300 gr nocturnal and arboreal Neotropical marsupial (Figure 1A; Bucher and Hoffmann 1980). The natural history, ecology, and behavior of *C. derbianus* is poorly known (Bucher and Hoffmann 1980). Few observations indicate that the species are likely solitary and strictly arboreal, using symmetrical gaits in locomotion and their prehensile tail for balance and grip (Hall and Dalquest 1963). The natural diet seems to be comprised of fruits (Salas-Durán 1974; Bucher and Hoffmann 1980; Steiner 1981; Rasmussen 1988; Timm *et al.* 1989), nectar and pollen (Salas-Durán 1974; Steiner 1981; Tschapka and von Helversen 1999); and insects such as cockroaches, moths, cicadas and katydids (Salas-Durán 1974; Steiner 1981; Rasmussen 1988).

Through its distribution in lowland and highland rainforest from San Luis Potosí, south-central Veracruz to western Colombia and norther Ecuador, there is no information regarding the movement ecology of *C. derbianus* or many other animals (Pérez-Gracida and Serna-Lagunes 2021). Therefore, in order to contribute to the growing knowledge on the movement ecology of poorly understood mammals, our main was to document and understand the home range and the movement behaviors of the Neotropical marsupial *C. derbianus* in a Neotropical Rainforest of Costa Rica.

Fieldwork was conducted from March until September 2015, January to March 2016 on Tirimbina Biological Reserve (hereafter: Tirimbina), Sarapiquí, Heredia Province, Costa Rica (TBR; 10° 25′ 2″ N, 84° 7′ 32″ W). The study site is covered with tropical wet forest (Holdridge 1967). Elevation ranges from 40 to 150 m, and the average temperature and precipitation is 25.3 °C and 3,900 mm, respectively (McDale and Hartshorn 1994). Tirimbina is approximately 345 ha, composed of primary and secondary forest and a small proportion of abandoned cacao plantation (*Theobroma cacao*) surrounded by a complex matrix composed of man-made structures (*i.e.*, La Virgen de Sarapiquí town), pastures, diverse kinds of plantations (*e.g.*, trees, banana, pineapple) and tropical forest patches of differing size.

Woolly opossum were captured using Tomahawk live traps (6151 U.S. Hwy 51 Hazelhurst, WI 54531 USA) baited with ripe bananas and placed at 25 to 30 m aboveground using a pulley system. Upon capture, we used leather gloves to extract individuals from the traps and place them in soft cloth bags to further processing. Woolly opossums were classified as reproductive adults or immatures based on the sequence of eruption of the premolars and molars (Tyndale-Biscoe and McKenzie 1976) and on several external morphological variables such as body size and coloration. Reproductive status was determined based on enlarged testes on males and presence of litters on the pouch of females. Animals selected for radiotracking were adults of both sexes, and in case of females we only used individuals without litters. These animals were fitted with a 15 gr collar mounted radio transmitter (Figure 1A; model RI-2D, Holohil Systems, Carp, Ontario, Canada) which represented ≤ 7 % of the body mass of the smallest monitored woolly opossum. Individuals were then released at the site of capture within 30 min of seizure. We used a TRX-1000WR tracking receiver and a 5 element directional yagi antenna (Wildlife Materials, Murphysboro, Illinois, USA) to monitor the spatial movement of animals at night, usually between 17:30 hr and 00:00 hr. Azimuths from the position of the observer to the bearing determined with the directional antenna were measured to the nearest degree using a compass (Suunto, Helsinki, Finland) and a global position system (Garmin Corporation, Olathe, Kansas).

Observers frequently moved to improve radio signal strength and proximity to the animal activity in order to reduce computational errors in determining spatial locations. When radio contact with a focal animal was lost, we quickly re-established radio contact by walking in the direction of the disappearing radio signal. We categorized the activity of animals in 2 behaviors: locomotion and stationary. Both behaviors were distinguished by detection of varying signal strength (*i.e.*, locomotion) or of a steady signal at a fixed directionality for at least 1 min (*i.e.*, stationary). Radio-fixes were recorded every 10 min in a digital voice recorder (Olympus VN-3100PC; Olympus Europa Holding GmbH, Hamburg, Germany). Each radio-fix included records of time, signal strength from an analogue meter, gain setting from gradations calibrated on the gain dial, the GPS position of the observer, and the activity of the opossum.

Spatial locations were estimated from single azimuths along with distance which was calculated using the relationship between signal strength and gain (Law and Lean 1999; Bonaccorso *et al.* 2015). Estimated relationship of signal strength to distance (± 30 m error) was calibrated from transmitters set at 15 m aboveground at standardized gain settings along measured reception distances to maximum 300 m. Azimuths were recorded always under the upper limit of reception from the transmitting animal (*i.e.*, 310 m) while avoiding topographical features potentially causing refraction or reflection of radio signals. Spatial locations of animals were calculated using the following equations: 1) $BN = (ON + D) \sin\Theta$; and 2) $BE = (OE + D) \sin\Theta$, where BN is the northing UTM location of the animal, ON is the northing UTM location of the observer, D is the estimated distance based on signal strength, Θ is the azimuth in radians from the observer to the animal, BE is the easting UTM location of the animal, and OE is the easting UTM location of the observer. Finally, all locations were then analyzed with the adehabitatHR package (Calenge 2015) in R software (R Development Core Team 2021). We employed the minimum convex polygon method (MPC; Mohr 1947; Harris *et al.* 1990) and the nonparametric kernel method (adaptive local convex hulls; Getz *et al.* 2007) to estimate the home range and the regions in space with different probabilities of usage (hereafter: isopleths). In this sense, we used 95 % of the data to identify the home range areas, the (90 %) isopleths to identify foraging areas and the (50 %) isopleths for core use areas.

We tagged 4 individuals (3 males and 1 female) during our study period. Individual woolly opossums were monitored between 3 and 12 consecutive nights (7 ± 2.12, *n* = 4) in which we obtained between 24 and 88 telemetry locations (51.25 ± 17.18, *n* = 4; Figure 1B). Mean home range area obtained through the minimum convex polygon method was 1.91 ± 0.56 ha, meanwhile the a-LoCoH method generated a mean area of 1.30 ± 0.35 ha (Table 1). Foraging and core use areas of opossums ranged between 0.52 and 1.33 ha (1.10 ± 0.27, *n* = 4) and between 0.093 and 0.46 ha (0.31 ± 0.08, *n* = 4), respectively (Table 1; Figure 2A-D). Available information did not allow us to compare movement areas between males and females. Moreover, based on plotted data of level (*i.e.*, amount of data) against movement areas, none of the monitored individuals has reached a stable home range area (Appendix 1).

This work represents an important piece of natural history information about a poorly known Neotropical mammal. Specifically, our work represents the first effort in studying the movement ecology of *C. derbianus* through its entire geographic distribution and one of the few endeavors to document and understand the spatial movements of any member of the genus *Caluromys* (but see Julien-Laferriere 1995; Lira *et al.* 2007).

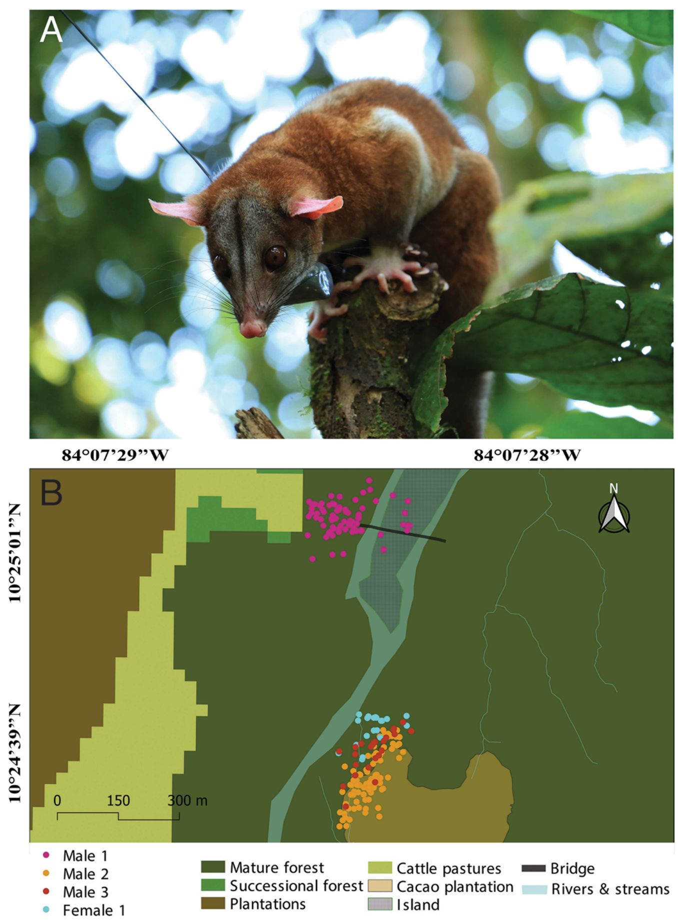

Figure 1. An adult woolly opossum (*Caluromys derbianus*) fitted with a radio-collar (A); and the telemetry location of the 4 radio-tracked individuals (B) at Sarapiquí, Costa Rica.

However, what ecological information can we gain from home range and activity areas estimations? Considering that any estimate of home range is, at best, a limited model of reality and that no universal home range estimation exists (Powell and Mitchell 2012), our data provide information on how *C. derbianus* uses its resources and where its willing to go to meet its requirements. For instance, most of our monitored animals (except for male 1) performed their activities on the cacao plantation and surroundings areas (Figure 1B), suggesting that despite the vegetation in this area is slightly dominated by one species (*i.e.*, *Theobroma cacao*), animals are still able to find their key resources (including food, potential mates, safe sites) to survive. These might also be related with the fact that most of the core use areas of these 3 animals (Figure 2B-D) were associated with the mature forest of TBR or the boundaries between these forests and the cacao plantations, habitats that likely provide more resources (*e.g.*, food) and vertical structure for locomotion than other types of vegetation (*e.g.*, pineapple or cattle pastures; Figure 2B-D).

Although food availability was not measured in this study, small home ranges, and activity areas (*i.e.*, foraging and core use areas) can also be related with few limitations on the food supply at Tirimbina. In this sense, considering the extent of information regarding feeding habits of *C. derbianus*, it seems that an opportunistic and omnivorous diet based on fruits (Timm *et al.* 1989; M. M-L pers. obs.), nectar and pollen (Tschapka and von Helversen 1999; E. R-V pers. obs.), insects (E. R-V pers. obs.) and even small vertebrates (D. V-C pers. obs.) might allow individuals to fulfill their food requirements in smaller, more numerous and more evenly distributed food patches.

Overall, the behaviors and food choices of *C. derbianus* in Costa Rica resembles the ecological information obtained by Julien-Laferriere (1995) regarding *Caluromys philander*. Here we argue that as both marsupials species are ecologically and morphologically similar, in addition to co-exist with other arboreal mammals such as *Potos flavus* (Julien-Laferriere 1995; Lira *et al.* 2007), their resemblance might not be a coincidence but most likely the result of analogous pressures and similitudes of their habitats. Additional information will be needed to understand the influence of other species on the movement patterns observed for *C. derbianus*, as well as the similitudes or differences between *C. derbianus* and *C. philander*. Finally, available data on overlapping home range areas among males and between males and females (Figure 1B) might point out that, as similar as other didelphids (Gentile *et al.* 1997; Pires and Fernandez 1999; Cáceres 2003; Martins 2004; Moraes and Chiarello 2005), *C. derbianus* may show a promiscuous mating system (Ostfeld 1990; Krebs and Davies 1996; Gentile *et al.* 1997) where the high overlapping home range suggests an absence of territorial behavior (Sandell 1989).

In conclusion, by providing novel information about the movement ecology of *C. derbianus* at a rainforest of Costa Rica, we contributed to the growing knowledge of the natural his-

Table 1. Size of movement areas used by 4 *Caluromys derbianus* in the Rainforest of Sarapiquí, Costa Rica. a-LoCoH = adaptive local convex hull method; MCP = minimum convex polygon method. Size of areas is displayed in hectares (ha). S. E. = standard deviation.

Sex-Ind.	Month/Year	Tracking nights (n)	Locations (n)	Isopleth's size- a-LoCoH						MCP (95 %)
				50 %	60 %	70 %	80 %	90 %	95 %	
Male 1	Apr/May-2015	12	73	0.45	0.71	0.71	1.33	1.78	2.27	3.38
Male 2	Jan/Mar-2016	9	88	0.46	0.68	0.71	1.00	1.30	1.34	2.20
Male 3	Jan/Mar-2016	4	24	0.25	0.44	0.37	0.58	0.83	0.59	1.24
Female 1	May-2015	3	20	0.093	0.28	0.21	0.52	0.52	1.26	0.84
	Mean ± S. E.	7 ± 2.12	51.25 ± 17.18	0.31 ± 0.08	0.44 ± 0.14	0.50 ± 0.12	0.85 ± 0.19	1.10 ± 0.27	1.30 ± 0.35	1.91 ± 0.56

tory of an elusive and poorly understudied neotropical marsupial. Although useful, we are also aware of the limitations of our data to reach strong conclusions regarding multiple aspects of the ecology of *C. derbianus* (*e.g.*, intraspecific differences, differences between males and females). Therefore, further steps should focus on increasing the sample size and the monitoring periods of the species (Appendix 1), as well as incorporating potential ecological and environmental pressures that might be influencing the documented behaviors (*e.g.*, food availability, predation, moon phase, reproductive season).

Acknowledgement

We are grateful to the Universidad de Costa Rica and the Reserva Biológica Tirimbina for providing equipment and the scholarship awarded to develop this research. Special thanks to T. Roman, T. Leandro-Espinoza, B. Naranjo, A. Quiros and all Tirimbina staff involved during fieldwork assistance, as well as two anonymous reviewers that improved the writing.

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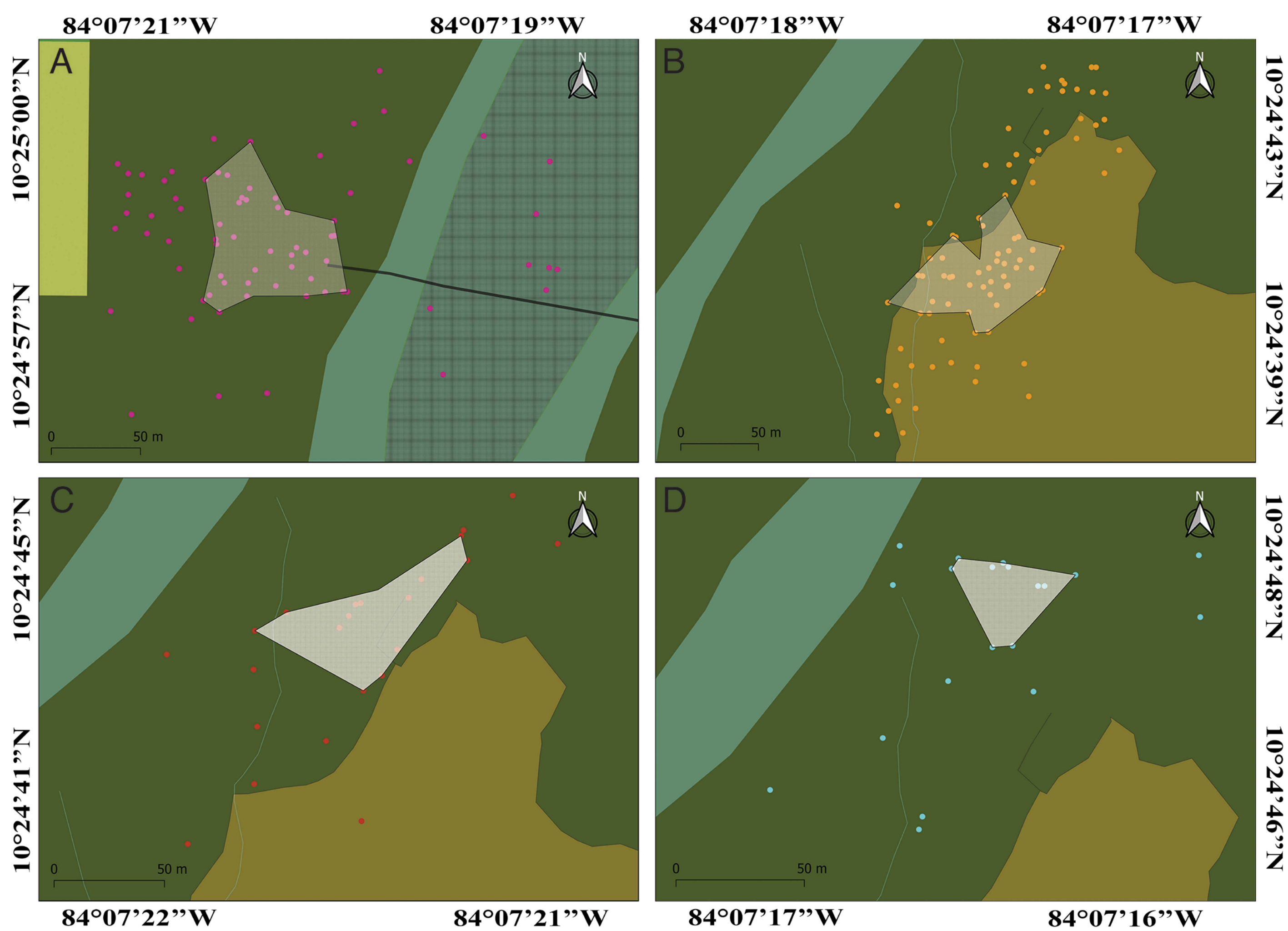

Figure 2. Telemetry locations and core use areas (a-LoCoh 50 %) of the 4 radio-tracked *Caluromys derbianus* at Sarapiquí, Costa Rica. Male 1 (A); Male 2 (B); Male 3 (C) and Female 1 (D).

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Associated editor: Beatriz Bolívar-Cimé

Submitted: February 16, 2022; Reviewed: May 17, 2022.

Accepted: June 1, 2022; Published on line: June 21, 2022.

Appendix 1

Home-range level (*i.e.*, percentage of calculated home range used) plotted against home range size (*i.e.*, size of the areas) of the 4 radio-tracked woolly opossums at Sarapiquí, Costa Rica. Male 1 (A); Male 2 (B); Male 3 (C) and Female 1 (D).