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UNDERESTIMATION OF ABUNDANCES OF THE MONITO DEL MONTE (*DROMICIOPS GLIROIDES*) DUE TO A SAMPLING ARTIFACT

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The monito del monte (*Dromiciops gliroides*) is an arboreal marsupial found only in austral South American temperate rain forests. Its conservation is a priority as the only extant species of the order Microbiotheria. We investigated whether the apparent low abundances reported for *D. gliroides* are real, or reflect a sampling artifact. We used wire-mesh and Sherman live traps, devices for recording tracks and hair, 2 types of bait, and 2 trap placements (ground level and 1.5–2.5 m high) in an old-growth forest in southern Chile. Type of bait and placement height affected captures of *D. gliroides*. The most efficient trapping combination (wire-mesh traps baited with banana, and placed above ground) yielded capture rates of up to 11%, and a relative population density of 21 ± 5 individuals/ha (mean ± *SE*), whereas traditional methods used for sampling small mammals were not effective. The sampling artifact uncovered here may have important future management and conservation implications.

Key words: abundance, capture efficiency, *Dromiciops gliroides*, sampling artifact, South American temperate rain forest

An unusual component of the small mammal community of South American temperate rain forests is the monito del monte (*Dromiciops gliroides* Thomas, 1894), an endemic marsupial with arboreal habits (Jiménez and Rageot 1979; Marshall 1978). This species is restricted to the temperate rain forest of southern Chile and Argentina (Hershkovitz 1999) and has a narrow distribution from 35°59′S to 44°00′S (Lobos et al. 2006; Saavedra and Simonetti 2001), including the coast range, the Andes, and the intervening depression (Kelt and Martínez 1989).

Dromiciops gliroides is a conservation priority species because of its phylogenetic status as the only extant species of the Gondwanian order Microbiotheria, which is more related to Australidelphia than to Ameridelphia (Kirsch et al. 1997; Spotorno et al. 1997). It is considered a rare species because of the low abundances reported when small mammals are assessed with traditional methods (Kelt 2000; Meserve et al. 1988; Patterson et al. 1989). However, low capture occurrence may be due to estimation bias related to sampling methods that are inadequate for mammals that are arboreal (Kelt and Martínez 1989; Lindenmayer et al. 1999; Rau et al. 1995), or those that are insectivorous–frugivorous (Amico et al. 2009; Jiménez and Rageot 1979), or both.

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Trapping-method bias for arboreal small mammals has been little discussed in the literature. Bias due to trap height was addressed formally for the 1st time by Malcolm (1991), who improved capture efficiencies of some neotropical small mammals in Brazil by setting pitfall and platform traps above 2 m in the canopy. A few studies in which traps were placed above the ground reported increased efficiencies of capture of arboreal opossums such as didelphids (Cunha and Vieira 2002; Lira and Fernández 2009; Umetsu and Pardini 2007) in tropical forests. Nevertheless, to our knowledge, this issue has not been formally addressed for temperate forest fauna, despite previous use of elevated traps for capturing *D. gliroides* (e.g., Amico et al. 2009; Rodríguez-Cabal et al. 2007). In addition to the phylogenetic uniqueness of *D. gliroides*, its conservation is a priority because of its keystone ecological role as a seed disperser in the South American temperate rain forest (Amico and Aizen 2000; Amico et al. 2009). Thus, it is important to accurately estimate population abundance for this species.

We evaluated the effects of setting different types of traps, using different types of bait, setting traps at different heights, and the influence of some habitat characteristics on the capture success of *D. gliroides*. We hypothesized that the sampling protocols will affect the capture rate and the estimated abundances. We also estimated abundance and density at our study site with the most efficient sampling protocol, to clarify the issue of the reported rarity of *D. gliroides*.

Materials and Methods

Study site.—Our study site was an approximately 20-ha old-growth forest remnant, close to the broad-leaved rain forests of Osorno Volcano, near Las Cascadas, Llanquihue Lake, and the Vicente Pérez Rosales National Park, in southern Chile (41°07′05″S, 72°36′50″W). The remnant was embedded within a complex agricultural and farmland mosaic, and was the only extant old-growth forest patch in good condition in the area.

The tree canopy composition was dominated by *Gevuina avellana*, *Caldcluvia paniculata*, *Eucryphia cordifolia*, and *Embothrium coccineum*, with several emergent *Nothofagus dombeyi*. The intermediate overstory stratum was composed of juvenile trees of *E. cordifolia*, *C. paniculata*, *Weinmannia trichosperma*, *Luma apiculata*, *Lomatia ferruginea*, *Raphitamnus spinosus*, *Aextoxicon punctatum*, *Aristotelia chilensis*, and the native bamboo *Chusquea quila*; vines included *Capsidium valdivianum* and *Pseudopanax valdiviensis*. Along edges, the shrub *Fuchsia magellanica* and introduced blackberry *Rubus ulmifolius* were very common. The understory was composed of tree saplings, mosses, several large ferns such as *Blechnum chilense* and *B. hastatum*, several small tree-climbing ferns (*Hymenophyllum*), abundant logs, and a thick leaf litter layer.

Sampling protocol.—We conducted the study during March and April 2008. To assess the effect of the monitoring technique on estimating abundance of *D. gliroides*, we used 2 types of live-capture traps: single-door, custom-made, wire-mesh traps, designed specifically for the capture of arboreal small mammals (26 × 13 × 13 cm), and standard Sherman traps (23 × 9 × 8 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida). We also used 2 types of sign-recording devices: track-recording tubes and hair-collecting tubes. Track tubes were made using polyvinyl chloride pipe (20 cm long × 7.5 cm diameter) with a smoked aluminum plate inside. Hair tubes were made using polyvinyl chloride pipe (20 cm long × 5 cm diameter) with double-sided adhesive inside. Furthermore, traps and sign-recording devices were baited with 2 different baits (banana slices or rolled oats), and placed either at ground level or 1.5–2.5 m above the ground. Aboveground traps were placed using a wire strap to secure the trap to 1 or more tree branches.

We placed traps in 6 lines, dispersed throughout the forest, each with 32 traps, and each of the 16 possible trap–bait–height combinations was used twice in each line (i.e., $n = 12$ for each combination) in a fully randomized, balanced design. Traplines were operated for 6 consecutive days, for a total effort of 1,152 trap-nights, and were checked daily early in the morning. Captured individuals were marked by unique patterns of fur excision. Captured individuals were measured and weighed; age (adult or juvenile) and sex were determined before release at the capture point. For sign-recording devices, we identified presence of *D. gliroides* based on characteristics of any tracks, hairs, or fecal pellets. All animal capture and handling procedures met guidelines approved by the American Society of Mammalogists (Gannon et al. 2007), and were approved and authorized by the Chilean Agriculture and Livestock Bureau (Servicio Agrícola y Ganadero).

To estimate density of *D. gliroides*, we used the most efficient sampling design (wire-mesh traps, banana bait, and arboreal placement; see ''Results'') set in a 4 × 12 trapping grid with 5-m spacing. Traps were operated for 5 consecutive days (Rodríguez-Cabal et al. 2008). Traps were checked daily early in the morning and data collection followed the procedures described above.

For each trap location in both traplines and the grid, we obtained geographic locations using a Garmin Vista Cx mapping global positioning system (Garmin Ltd., Olathe, Kansas), and measured the following 4 habitat characteristics (Brower et al. 1998; Rudran and Foster 1996): height of trap placement above the ground (in cm, using a measuring tape); tree branch diameter where the trap was set (in cm, using a caliper); branch slope (in degrees, using a protractor; for diameter and slope, a 0 value was assumed for traps placed on the ground); and the type of substrate where each trap was placed (litter, live tree branch, or dead tree branch).

Data analyses.—We evaluated the effect of each combination of trap type, bait, and height using logistic regression analyses with the trapline data. We defined the response variable as a binary variable (0 = no capture, 1 = capture); the categorical predictor variables were trap type, bait type, and height of placement. We ran separate analyses for the live-capturing (trap variable = wire-mesh or Sherman traps) and the sign-recording devices (trap variable = track- or hair-devices); we also performed a combined analysis for both trap categories pooled in a single variable (i.e., wire-mesh, Sherman, track-, or hair-devices). Recaptures were not included in the analyses; each trap was considered as an analysis unit. A similar logistic regression analysis was performed to evaluate the effect of habitat characteristics on the capture success of *D. gliroides*, using branch diameter, branch slope, height of placement (continuous), and substrate type (categorical) as predictors. Goodness-of-fit was estimated using a Hosmer–Lemeshow test (Agresti 2007); all procedures were run in STATISTICA 7 (StatSoft, Inc. 2004).

Based on goodness-of-fit data and the statistical significance of predictor variables, we ran logistic regressions again after removing nonsignificant variables. Optimal variable sets were determined by the combination that maximized the goodness-of-fit estimates. All combinations of predictor variables were tested separately as additive models, because interactions were not significant ($P > 0.05$) in any case. Competing models were evaluated using the Akaike information criterion (AIC). For interpretation, we present ΔAIC and AIC weights (w_is—Burnham and Anderson 2002); we only considered the $w_i \geq 90\%$ model subset.

Population abundance was estimated from the trapping grid data using a capture–mark–recapture method (Hopkins and Kennedy 2004). Population abundance was estimated with the CAPTURE module in MARK (White and Burnham 1999). We used a full-likelihood Closed Population model (Otis et al. 1978), with a logit link function to construct a model set with the parameters N (number of unique individuals encountered), p (encounter probability), and c (constant value, assumed as $c = p$), both with and without considering a temporal effect. The

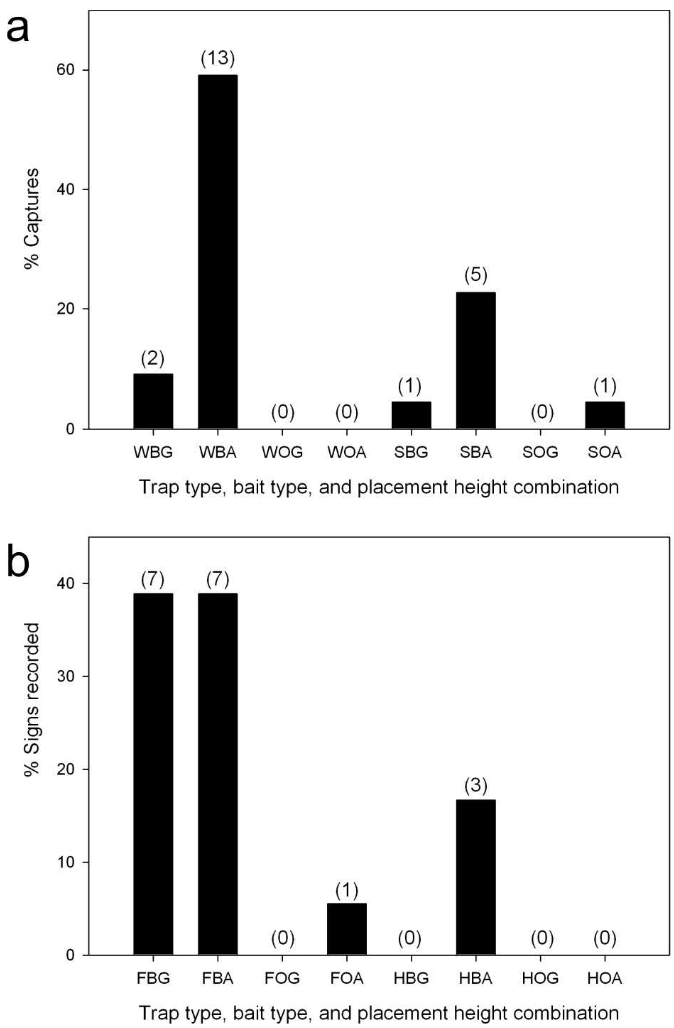

Fig. 1.—a) Captures of *Dromiciops gliroides* in relation to different live-capturing trap–bait type–height combinations. Number of individuals captured in 72 trap-nights of each combination are shown in parentheses. Traps are W = wire-mesh, S = Sherman; baits are B = banana, O = oats; and heights are G = ground level, A = above the ground. b) Signs recorded for *D. gliroides* by sign-recording devices set in the same bait and height combinations as the live traps. Sign-recording devices are F = track-recording, H = hair-recording; bait and height are as for top panel (a).

most-parsimonious model was selected using ΔAIC_c and w_i, and with this model, we ran CAPTURE to estimate the population abundance using the jackknife population estimator. Considering that the effective area of the grid (0.63 ha) is reduced to perform an accurate population density estimation, a relative density estimate was calculated as the ratio of population abundance over the area sampled, corresponding to the grid area surrounded by a buffer zone equal to one-half of the largest recapture distance (Parmenter et al. 2003).

Results

Differential captures.—During all livetrapping efforts, we had 22 capture events, corresponding to 18 different individuals and 4 recaptures in the transect lines (recapture rate of ~18%). The combination of trap type, bait type, and placement height with greatest success was wire-mesh traps, banana bait, and placement above the ground, accounting for 59% of the captures, followed by Sherman traps, banana bait, and placement above the ground, accounting for 23% of the captures. Other combinations of trap type, bait type, and placement height captured fewer individuals, and wire-mesh traps with oat bait and placement above the ground registered no captures (Fig. 1a). Additionally, we had 16 capture events (7 different individuals and 9 recaptures, recapture rate of ~56%) on the trapping grid using the most efficient trap type, bait type, and placement height combination (~7% trapping success).

Similar results were obtained with sign-recording devices. We recorded a total of 18 feasible signs of *D. gliroides* in track-recording and hair-sampling tubes, and 87 nonconfirmed possible signs (not considered in the analyses). Devices recorded more signs of *D. gliroides* when baited with banana (27% success for track-recording and 11% for hair-sampling tubes) irrespective of their placement height. Devices baited with oats were unsuccessful except for track-recording devices placed above the ground (Fig. 1b). Hair-sampling tubes performed poorly compared to the track-recording tubes.

Model selection.—Data in the logistic regression analyses fit the models adequately according to Hosmer–Lemeshow tests, all intercepts were significant, and all variables were independent from each other (correlation coefficients < 0.08). For live-capture data, bait and height variables were related to capture success (Wald $\chi^2 = 8.10$, $d.f. = 1$, $P = 0.004$, and Wald $\chi^2 = 7.61$, $d.f. = 1$, $P = 0.006$, respectively), and removing trap from the analysis maximized the goodness-of-fit (Hosmer–Lemeshow $\chi^2 = 0.11$, $d.f. = 2$, $P = 0.96$), rendering a single explicative model (Table 1a). For sign-recording data, trap and bait variables were related to capture success (Wald $\chi^2 = 5.61$, $d.f. = 1$, $P = 0.018$, and Wald $\chi^2 = 6.59$, $d.f. = 1$, $P = 0.010$, respectively), and removing height from the analysis maximized the goodness-of-fit (Hosmer–Lemeshow $\chi^2 = 0.16$, $d.f. = 2$, $P = 0.93$), rendering a single explicative model (Table 1b). When combining live-capture and sign-recording data, bait and height variables were related to capture success (Wald $\chi^2 = 13.93$, $d.f. = 1$, $P < 0.001$, and Wald $\chi^2 = 6.73$, $d.f. = 1$, $P = 0.009$, respectively), and removing trap from the analysis maximized the goodness-of-fit (Hosmer–Lemeshow $\chi^2 = 0.63$, $d.f. = 2$, $P = 0.73$), rendering also a single explicative model (Table 1c). In

Table 1.—Model selection for a) live-capturing data, b) sign-recording data, and c) combined live-capturing and sign-recording data for *Dromiciops gliroides* in southern Chile, March–April 2008.[a]

Model	Log-likelihood	K	AIC	ΔAIC	w_i
a) Model selection for live-capturing data					
Bait + height	−28.69	2	61.39	0.00	0.98
b) Model selection for sign-recording data					
Trap + bait	28.06	2	60.12	0.00	0.93
c) Model selection for live-capturing and sign-recording data					
Bait + height	−60.99	2	125.97	0.00	0.94

[a] AIC = Akaike information criterion; w_i = AIC weight.

all cases, odds ratios from the logistic regression were highest for bait type.

Influence of habitat characteristics.—Among the habitat characteristics we measured, only placement height was significantly related to capture success (Wald $\chi^2 = 14.96$, *d.f.* $= 1$, $P < 0.001$). Branch slope was included in the selected model despite not being significantly related to capture success on its own ($P = 0.391$) because its removal broke down the model. Thus, when both variables were included in the model, goodness-of-fit was maximized (Hosmer–Lemeshow $\chi^2 = 2.06$, *d.f.* $= 6$, $P = 0.91$). Model selection showed that *D. gliroides* captures were best explained by 2 models: height ($\Delta AIC_c = 0.00$, $w_i = 0.65$), and height + slope ($\Delta AIC_c = 1.25$, $w_i = 0.35$).

Abundance and density estimates.—Using MARK's model subset, the estimated population abundance was 13 ± 3 individuals (mean ± *SE*), with an estimated 95% confidence interval of 11–27 individuals. Dividing the abundance values by the grid area, the relative density estimate was 21 ± 5.35 individuals/ha, and the confidence interval ranged from 17 to 43 individuals/ha.

Discussion

According to our results, bait type had the greatest effect on trappability of *D. gliroides*, either for live-capturing or for sign-recording techniques. Bait preference by *D. gliroides* probably explains its previously reported low capture rates (in which sampling protocols used rolled oats as bait), ranging from 0.0001 to 0.0054 individuals/trap-night (Kelt 2000; Meserve et al. 1982, 1999; Patterson et al. 1989), compared to the 0.0583 individuals/trap-night obtained in this study. We recorded only 1 instance of a *D. gliroides* captured in an oat-baited trap, which may have been a chance event, because the bait was not eaten. Thus, the evidence here indicates that rolled oats are not an attractive bait for *D. gliroides*. Nevertheless, it is notable that previous studies found that Museum Special snap traps baited with rolled oats were more successful than Sherman live traps in capturing *D. gliroides* and that many individuals survived capture in the snap traps (e.g., Kelt and Martínez 1989; Meserve et al. 1988, 1991; Patterson et al. 1989, 1990).

The 2nd variable in importance is the height of placements of the traps, which greatly improved the trapping success, but did not determine it as strongly as did the banana bait. The fact that there were 2 captures at ground level with wire-mesh, banana-baited traps, and 7 feasible signs recorded by traps at ground level, suggests that *D. gliroides*, despite being an arboreal species, also moves and forages on the ground. During 4 fieldwork trips, when releasing captured individuals, 39% escaped to the litter layer. Track-recording devices therefore may be a cheaper way to improve our understanding of 3-dimensional spatial use of the forest by *D. gliroides*.

Our results suggest that type of live trap did not have a significant effect on captures of *D. gliroides*. However, more individuals were captured with wire-mesh traps than with Sherman traps; this concurs with Hershkovitz's (1999) observations that *D. gliroides* has a phobia to solid-wall traps such as Sherman traps. When the effects of trap type, bait type, and placement height are combined, the most efficient species-specific sampling protocol for *D. gliroides* was wire-mesh traps, banana bait, and arboreal placement. With this methodology, it is possible to obtain up to 11% trap success as opposed to <1% with Sherman traps, rolled oat bait, and ground placement. However, in the absence of wire-mesh traps, Sherman traps baited with banana and placed above the ground may be useful as well, but with less capture efficiency. Based on the evidence presented here, previous sampling efforts using traditional protocols are biased against capturing *D. gliroides*.

Analysis of habitat characteristics provided little additional information to improve capture success in addition to the trap type, bait type, and height of placement combinations. Neither branch diameter nor substrate type had significant effects on capture success of *D. gliroides*. Branch slope had an important effect on the model, despite being statistically nonsignificant, because its removal reduced the model goodness-of-fit from 0.91 to 0.46. This is consistent with our field observations and with the findings of Gallardo-Santis et al. (2005), that climbing ability is influenced by branch characteristics. *D. gliroides* moved more easily along horizontal branches than along vertical ones.

Our population estimates suggest a high density of *D. gliroides* in the study area assessed (17–43 individuals/ha), consistent with the results of Rodríguez-Cabal et al. (2008) in Llao Llao Municipal Park (Argentina), again underscoring that previously documented low abundances may have been due to sampling bias as a result of inappropriate trapping protocols. However, there seems to be strong spatial heterogeneity among populations of *D. gliroides*, because it is abundant in some fragments (e.g., our study area or Llao Llao Park), but absent in many other forest areas. Consequently, it must be considered an uncommon species until we gather enough information at larger (regional) scales to allow us to make a well-substantiated judgment.

Finally, these findings may have important management and conservation implications. The densities reported as well as results of other studies (e.g., Kelt and Martínez 1989; Rodríguez-Cabal et al. 2007, 2008) show that *D. gliroides* may be more abundant in some habitat fragments than previously considered, but we need more research before we can draw conclusions about its rarity. We urge conservation biologists, managers, and researchers to improve their sampling protocols in order to gather accurate information about the real conservation status of *D. gliroides*. Nevertheless, habitat loss remains a threat for this species, considering that the South American temperate rain forest experiences an annual deforestation rate of 4.5% (Echeverria et al. 2006). No matter how abundant *D. gliroides* might be in some forest fragments, it will still be threatened as long its habitat is destroyed.

Resumen

El monito del monte (*Dromiciops gliroides*) es un marsupial arbóreo restringido a los bosques lluviosos templados de Sudamérica austral. Es considerado prioritario para la conservación por ser el único representante del orden

Microbiotheria. Se realizó la presente investigación para determinar si las bajas abundancias reportadas para esta especie eran reales, o un artefacto de muestreo. Para ello se utilizaron trampas de captura viva de malla y Sherman, y dispositivos de colecta de signos para huellas y pelos, 2 cebos distintos y 2 alturas distintas (a nivel del suelo y entre 1.5–2.5m sobre el suelo), en un bosque maduro del sur de Chile. El tipo de cebo y la altura de colocación afectaron las capturas de *D. gliroides*. La combinación más efectiva (trampas de malla, cebada con plátano y colocadas en altura) registró tasas de captura de hasta 11% y una densidad relativa de 21 $\pm$ 5 individuos/ha (media $\pm$ *EE*), mientras que los métodos tradicionales para pequeños mamíferos no fueron efectivos. El artefacto de muestreo aquí descubierto tiene importantes implicaciones para el manejo y conservación de esta especie.

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