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ORIGINAL INVESTIGATION

Spatial ecology of monito del monte (*Dromiciops gliroides*) in a fragmented landscape of southern Chile

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Abstract

Habitat loss is one of the most important causes of biodiversity loss in South American temperate rainforests, where many endemic species exist. Among these is the monito del monte (*Dromiciops gliroides*), an arboreal marsupial with restricted distribution, and the only extant species of the order Microbiotheria. Current knowledge about monito del monte habitat use and its responses to human disturbances is scarce. To help fill this gap we investigated its habitat use and selection patterns in a fragmented landscape in southern Chile. Monito del monte individuals were abundant in a large and a small fragment, but rare or undetected in forest strips. Using telemetry data from 12 neighboring individuals in a large fragment and 2 individuals in a small fragment, we estimated their mean home range size of 1.6 ha ± 0.6 (1SD). Monitos del monte had a spatial overlap among individuals of 50 ± 4%. Tracked individuals used old- and second-growth habitats as available, did not use the prairie habitats, and strongly avoided the scrublands. In the large fragment we estimated a relative population density of 21 ± 5 individuals/ha (mean ± 1SD), whereas in the small fragment it was of 19 ± 6 individuals/ha. This is, to our knowledge, the first study of the spatial ecology of the monito del monte based on telemetry data, and evidence presented here could have conservation and planning implications, not only for the target species but also its habitat.
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Keywords: *Dromiciops gliroides*; Home range; Habitat use; Temperate forest; Southern Chile

Introduction

The temperate forest of southern South America (TFSSA) is considered a biodiversity hotspot due to its high levels of endemism (Aizen et al. 2002; Smith-Ramírez 2004). Nevertheless, it is also one of the most threatened ecosystems on Earth (Chapin III et al. 2000) as a consequence of the increasing and rapid deforestation associated to firewood collection, livestock farming,

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and the development of new human settlements (Echeverria et al. 2006, 2007). Forest loss and fragmentation seem to be among the major factors driving the decline of several species. Research has revealed that anthropogenic habitat types such as pastures tend to be strongly avoided by several endemic species (Eldridge et al. 1987; Sieving et al. 1996, 2000). Understanding the spatial ecology of these species seems fundamental to understand the effects of habitat loss and fragmentation on biodiversity loss. For example, the endemic chucao tapaculo (*Scelorchilus rubecula*) is known to strongly avoid open areas (Sieving et al. 1996), to be more frequent in large forest fragments (Castellón and Sieving 2006a) and to be able to use corridors composed by native vegetation (Castellón and Sieving 2006b). While an important body of evidence (such as the data for chucaos) has been developed in the area for endemic birds, similar kinds of information are lacking for several endemic mammals, and as a consequence the effects of habitat loss on their ecology and conservation are not well understood.

A peculiar species living in the TFSSA is the monito del monte (*Dromiciops gliroides* Thomas 1894), a small-sized (16.7–31.4 g, Marshall 1978) arboreal marsupial, endemic of these forests and with a restricted distribution ranging from 35°59'S to 44°00'S (Saavedra and Simonetti 2001; Lobos et al. 2006). Monito del monte is the only extant species of the Microbiotheria order (Marshall 1978). This species also seems to be of major importance to the functioning of the temperate forests, due to its function as the most important disperser of the mistletoe *Tristerix corymbosus*, a plant that seems to play key roles in the function of the forest (Amico and Aizen 2000; Aizen 2003; Rodríguez-Cabal et al. 2007). The phylogenetic uniqueness as well as the keystone role that monito del monte plays in the TFSSA makes its preservation a high priority for the conservation of biodiversity (Amico and Aizen 2000; Rodríguez-Cabal et al. 2007).

In light of extensive forest loss within its area of occurrence the monito del monte is considered a near threatened species (Díaz and Teta 2008), but the actual effects of forest loss are not fully understood given the scarce data available on its spatial ecology. The species is thought to be associated with old-growth forest stands dominated by southern beech (*Nothofagus* spp.) and bamboos (*Chusquea* spp.) (Marshall 1978; Jiménez and Rageot 1979; Hershkovitz 1999). Recent studies have also found association between mistletoes and the distribution of monito del monte (Rodríguez-Cabal 2008; García et al. 2009) and have reported its absence in some small sized forest fragments (Rodríguez-Cabal et al. 2007). Space use at the scale of individuals has not been assessed, and as a consequence home-range size is unknown and habitat use has not been described at that scale.

The objective of our study was to describe the use of space of monito del monte in a fragmented landscape in southern Chile. In particular, we estimated its abundance in four forest fragments. Using telemetry data we estimated home range sizes and space overlap between individuals, and assessed habitat preferences in an area where native (old- and second-growth forests) and anthropogenic (scrublands and prairies) habitats occur.

Material and methods

Study site. – The study was conducted from March to December 2008, in a fragmented landscape in southern Chile, located 5 km south of the town of Cascadas, in the foothills of the Osorno volcano (41°07'S, 72°36'W). We chose four forest patches as our study sites: a 20 ha old-growth-dominated forest remnant, a 3 ha second-growth forest remnant, a forest strip of 40 by 50 m, connected to a second-growth forest and adjacent to a prairie, and an isolated forest strip of 15 by 100 m (Fig. 1).

The old-growth forest remnant (hereafter "large fragment") is well preserved, and is the largest forest remnant in the study area. The large fragment was delimited to the north by a rocky cliff, to the east by a stream, and to the south and west by some buildings and a dirt road. The second-growth remnant ("small fragment") and the connected forest strip ("connected strip") have experienced recurrent disturbance at least during the last 15 years due to logging, and livestock grazing. The small fragment and the connected strip were limited to the north by an agricultural field, to the west by a dirt road and to the south and east by a river. The isolated forest strip ("isolated strip") divided two open private properties, with high disturbance levels due to clearings, fires, and constructions.

The large fragment was dominated by the trees *Gevuina avellana*, *Caldcluvia paniculata*, *Eucryphia cordifolia*, *Embothrium coccineum* and *Nothofagus dombeyi*. The small fragment and the connected strip were dominated by abundant juvenile (DBH < 5 cm) trees of *Luma apiculata*, *Raphitamnus spinosus*, the shrub *Ugni molinae* and scattered bamboo *Chusquea quila*. The adjacent prairie was dominated by exotic grasses, with occasional *Rosa moschata* shrubs, and many introduced *Rubus ulmifolium* shrubs along the forest edges. The isolated strip was dominated by juvenile trees of *L. apiculata*, *Aristotelia chilensis*, and *U. molinae* shrubs, in association with a dense *C. quila* thicket; and some remnant mature *N. dombeyi* and *E. coccineum*.

Sampling protocol. – For estimating population abundances and relative densities of monito del monte we used a trapping grid design. We trapped monitos del monte with small Tomahawk style traps for arboreal

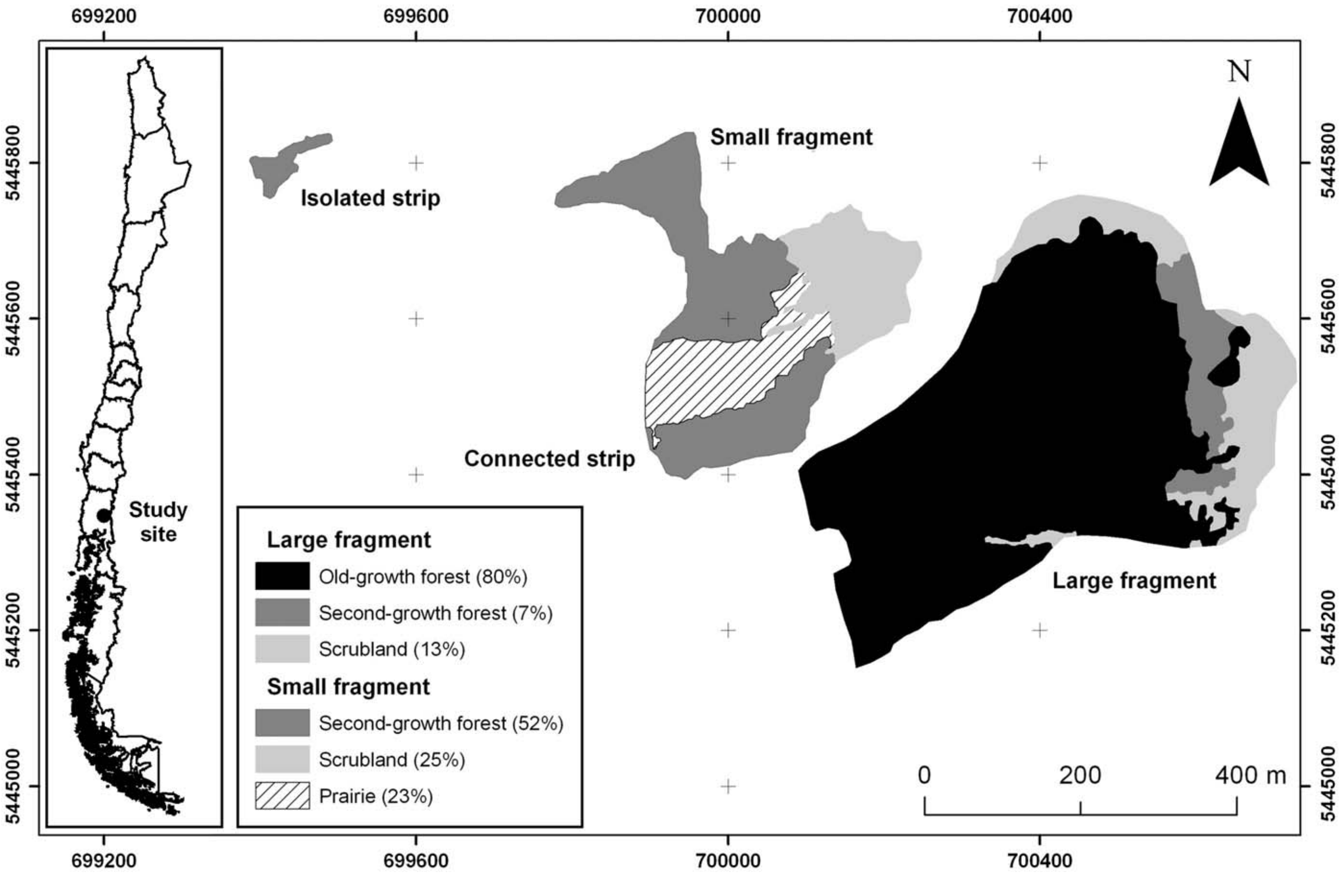

Fig. 1. Study site location in Chile and habitat composition of a large and a small fragment.

small mammals (26 × 13 × 13 cm), placed above the ground (1.5 to 2.5 m) (Fontúrbel 2009). Traps were set along four lines; with lines and traps separated by 5 m. Traps were baited with fresh banana slices, operated for 5 consecutive days, and checked daily during mornings. For estimating population abundances, in both large and small fragments we placed grids of 4 × 12 traps. In each of the connected and isolated strips we placed a different trapping grid composed by two trap lines, each having 8 traps above the ground and 8 at the ground level along the strip, and another two adjacent lines of 8 traps each one placed in the prairie matrix, at the ground level. We used 240 trap-nights effort per grid, with 960 trap-nights of total effort.

The captured individuals were identified, measured, weighed, marked with a unique pelage cut and released where captured. All animal capturing and handling, procedures followed the guidelines of the American Society of Mammalogists (Gannon et al. 2007), and was authorized by permit resolution No. 2073 from the Chilean Agriculture and Livestock Bureau (SAG).

Population abundance and density estimates. – Population abundance was estimated using a capture-mark-recapture method (Nichols and Pollock 1983; Southwood and Henderson 2000; Hopkins and Kennedy 2004) for each trapping grid, using the CAPTURE utility of 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 $c = p$), with and without considering the time effect. The absence of recaptures in the connected strip and the absence of records in the isolated strip grids precluded population estimations for these fragments.

We ran CAPTURE to estimate the population abundance using a Jackknife estimator. The models calculated the mean abundance ± one standard error, and the 95% confidence intervals. Relative population densities were estimated as the ratio of population abundance and the effective area, estimated as the grid area plus a buffer area of a width half-of the largest recapture distance (Parmenter et al. 2003), which resulted in effective areas of 0.63 ha for the large fragment and 0.54 ha for the small one.

Animal tracking. – Fourteen adult individuals were fitted with radio-transmitters (model A2445 from ATS,

Table 1. Estimated home range sizes of monito del monte (*Dromiciops gliroides)* in forest fragments at southern Chile. Individuals M1-M3 and F1-F9 were captured and tracked in a large fragment, whereas M4* and F10* were in a small fragment. Fixed Kernel (FK) estimators are shown for core areas (50%) and home ranges (90%).

Individual	Home range size (ha)		Total days monitored	Total locations	Monitoring period
	FK 50%	FK 90%			
F1	0.068	1.099	21	90	05 Mar-18 May
F2	0.267	1.775	20	66	07 Mar-17 Apr
F3	0.171	2.090	14	47	24 Nov-18 Dec
F4	0.223	2.226	14	42	24 Nov-18 Dec
F5	0.175	2.213	14	44	24 Nov-18 Dec
F6	0.281	1.405	14	37	24 Nov-18 Dec
F7	0.186	2.144	14	77	24 Nov-18 Dec
F8	0.318	2.085	14	32	24 Nov-18 Dec
F9	0.099	1.485	14	48	24 Nov-18 Dec
F10*	0.342	0.698	10	77	15 Apr-18 May
M1	0.140	0.727	10	43	04 Mar-22 Mar
M2	0.181	1.500	14	37	24 Nov-18 Dec
M3	0.215	1.516	14	43	24 Nov-18 Dec
M4*	0.150	0.898	10	60	15 Apr-18 May
Mean	0.201	1.562	14	53	
SD	0.079	0.550	3	18	

Isanti MN). Transmitters were glued to the animal's fur with acrylic glue, placed carefully in the center of the animal's back and leaving the antenna running dorsally along the body and the tail to minimize adverse effects on the animal. Transmitters were not removed, because they dropped during molting. Due to the short battery life of transmitters (up to 62 days), we tracked the marked individuals intensively from the day after its capture. During a preliminary study, the location error was measured with two transmitters with known stationary positions, which were tracked from 10 different points during seven times each. Triangulations were made using three bearing combinations with angular differences between 45 and 135°. Estimated locations were obtained using LOAS 3.0.3 and compared to the real transmitter locations (Withey et al. 1999). Estimated location error was 12 ± 3 m (mean ± 1 SD, n = 14).

Five individuals were tracked from March to May (two in the small fragment and three in the larger) and nine from November to December of 2008 (all in the large fragment, see Table 1). The decision of tracking animals only in the large fragment during spring was based on the fact that the data from fall did not show obvious differences in animals' density or in home range characteristics. We judged more profitable to concentrate the effort in understanding the spatial ecology of this species in only one of the fragments. We estimated the location of the animals by triangulating 3-6 bearings obtained within $\leqslant 15$ min using LOAS 3.0.3 (Ecological Software Solutions, Urnäsch, Switzerland).

Home range estimation. – Study site patches and their respective habitat composition layers were digitized in ArcView GIS 3.2a (ESRI, Redlands CA) over a 2005 color aerial photograph of the area having 2 m spatial resolution. Home range estimations were computed using fixed Kernel (FK, Seaman and Powell 1996) algorithms in Biotas 1.03 alpha (Ecological Software Solutions, Urnäsch, Switzerland). To decrease the potential effects of temporal autocorrelation (Aarts et al. 2007) we estimated home ranges using only locations obtained with at least three hours of difference. As an estimate of home range area we used the 90% isopleth (Börger et al. 2008) and as an estimate of core area we used the 50% isopleth (Seaman and Powell 1996, but see Börger et al. 2008). Spatial home range overlaps were assessed by intersecting FK90% home ranges and the overlapped area was expressed as a percentage of the total home range area of each individual pair combination (Kernohan et al. 1999). The same procedure was conducted for FK50% core areas. Home range size was compared between males and females, and between spring and fall data using the non-parametric Mann Whitney U test, conducted in STATISTICA 7 (StatSoft 2004).

Habitat availability, use, and selection. – We used the large and small forest fragments as study units for habitat analysis purposes. Habitat types, defined as discrete entities with a particular structure and composition based on the vegetation forms, were digitized and available areas were estimated in ArcView and cross-validated with a recent aerial photograph. Habitat use values were estimated by intersecting habitat type covers with the FK90% home ranges polygons. We conducted a compositional analysis (Aebischer et al. 1993), by ranking the preference for each habitat type against the other types present in the fragment. Prairies were considered as "non-habitat" (Garshelis 2000), as no individuals were captured or tracked in this habitat type and there is no evidence indicating use of this habitat type by monitos del monte.

Results

Animal sampling and tracking. – During fall (March-April) we captured 10 individuals of monito del monte in the large fragment, seven in the small fragment, one in the connected strip, and none in the isolated strip. During spring (November), we captured nine individuals in the large fragment and trappings were not conducted elsewhere. Overall female:male ratio was 3.5:1 in fall (n = 18), and as well as in spring (n = 9). In fall juvenile : adult ratio was 2:1, whereas in spring all captured individuals were adults.

Population abundance and density. – Abundance estimate for the large fragment grid resulted in 13 ± 3.37 individuals (mean ± 1SE), with a 95% confidence interval of 11 to 27 individuals. The estimated capture probability on every trapping occasion was 0.23. For the small fragment grid, the abundance estimation was 10 ± 3.18 individuals, with a confidence interval of 8 to 23 individuals. For the small fragment the estimated capture probability per trapping occasion was 0.18. Dividing abundance values by the effective trapped area (0.63 and 0.54 ha for the large and small fragments respectively), relative abundance estimates were 20.63 ± 5.35 individuals/ha for the large fragment, and 18.69 ± 5.94 individuals/ha for the small fragment. Overall estimated capture probability for females was 0.16 and for males it was 0.20.

Home range size and spatial overlap. – Estimated home range sizes of the 14 monitos del monte ranged from 0.69 to 2.23 ha, and their core areas ranged from 0.07 to 0.34 ha (Table 1). Home range size did not differ between male and females (male = 1.16 ± 0.41 ha, n = 4, female = 1.72 ± 0.53 ha, n = 10; Mann-Whitney U = 10, p = 0.15). Similar results were observed when considering only the animals from the large fragment (Mann-Whitney U = 6, p = 0.16). However home ranges were larger for animals tracked during spring than for those tracked during fall (mean rank fall = 3.8, n = 5; mean rank spring = 9.6, n = 9; Mann-Whitney U = 4, p = 0.008). In the large fragment, home range overlap among pairs of individuals ranged from 12 to 79% (48 ± 13%, mean ± 1 SE; n = 3) in fall, from 20 to 69% (50 ± 3%, mean ± 1 SE; n = 9) in the spring, and from 55 to 84% (n = 2) in the small fragment (see Tables S1 and S2 in Supplementary material). Core area overlap, in the largest fragment, ranged from 0 to 40% (13 ± 11%, n = 3) in fall, from 0 to 100% (41 ± 8%, n = 9; Fig. 2) in spring, and there was no core area overlap in the small fragment.

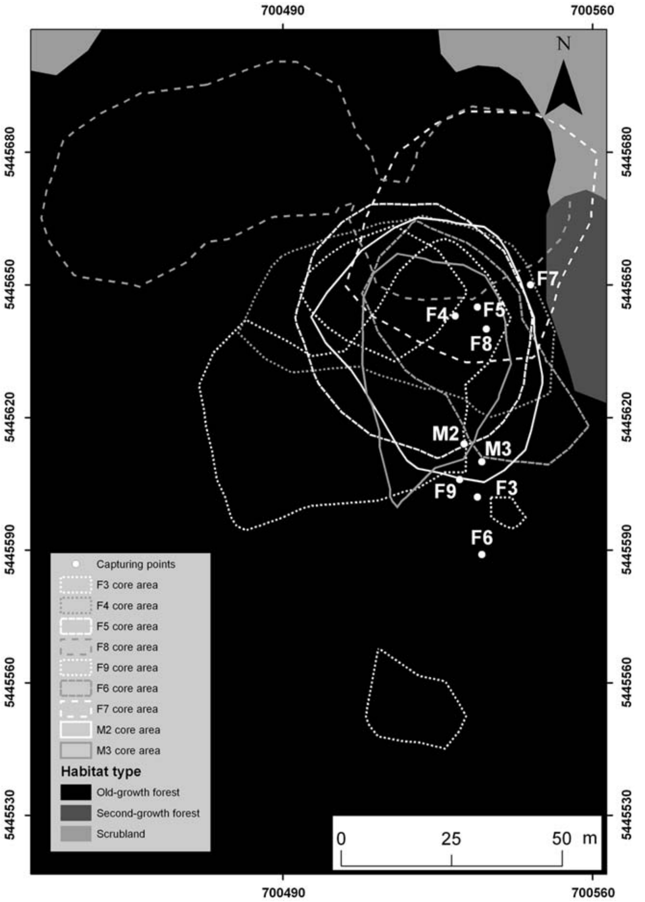

Fig. 2. Capture sites and core areas for nine monitos del monte (*Dromiciops gliroides*) monitored between November and December 2008 in southern Chile.

Habitat availability, use, and selection. – Estimated home ranges of the individuals tracked in the large fragment comprised three habitat types: old-growth forest, second-growth forest, and scrubland, whereas individuals tracked in the small fragment comprised second-growth forest, scrubland and prairie habitat types, which were all the habitat types available in each fragment. In large and small fragments, monitos del monte used the environment in similar ways and according to habitat types available. Compositional analysis showed the following trend in habitat use:

Table 2. Compositional analysis of habitat selection by monito del monte (*Dromiciops gliroides*) derived from data of 12 tracked individuals in a 20 ha fragment in southern Chile. Habitat types were: OGF = old-growth forest, SGF = second-growth forest, SL = scrubland.

Habitat types	Habitat types		
	Old-growth forest	Second-growth forest	Scrubland
a) Matrix of means and errors for all tracked individuals			
Old-growth forest		1.296 ± 0.806	2.644 ± 0.927
Second-growth forest	−1.296 ± 0.806		1.375 ± 0.848
Scrubland	−2.644 ± 0.927	−1.375 ± 0.848	

Habitat types	Habitat types			Rank
	Old-growth forest	Second-growth forest	Scrubland	
b) Ranking simplified matrix				
Old-growth forest		+ + +	+ + +	2
Second-growth forest	−		+	1
Scrubland	−	−		0

Means and errors for all tracked individuals are showed in a), and the simplified matrix with ranking is shown in b). Triple signs represent significant deviation from random at $p < 0.05$.

old-growth forest > second-growth forest > scrubland (Table 2). Within core areas, the habitat use was represented by primary forest 97% of the areas, compared to 2% of secondary forests and 1% of scrubland (Fig. 2).

Discussion

Monito del monte abundances

The densities of monito del monte found in our study seem to be high, but not surprising in the context of densities reported for this species elsewhere. For example Rodríguez-Cabal et al. (2008) found that monito del monte was the most abundant understory small mammal, reporting a mean abundance of 54 ± 8.6 (mean ± 1SE) individuals for a-2-ha plot in Llao-Llao, Argentina. The same authors reported abundances that ranged between 0 and 45 individuals in 12 plots (of 0.25 ha each) also located in Llao-Llao (Rodríguez-Cabal 2008).These findings suggest that there is important spatial variation in monito del monte abundances, which could have influenced our data. The high densities observed in this study, as well as in other studies (e.g., Rodríguez-Cabal et al. 2008), could be the result of small home ranges or alternatively, of large home-range overlap. Our telemetry data seem to support the second alternative. In fact, most monitos del monte had large home range and even high core area overlap with at least two other coexisting individuals (Fig. 2). Future studies should attempt to evaluate the role of potential social behavior of this species on their distribution in space, and testing hypotheses that involve resource dispersion (e.g., mistletoe distribution, see Rodríguez-Cabal 2008) and other behavioral mechanisms, which we could not address given the nature of our data.

Habitat use and potential effects of habitat loss

As previously reported, our results showed that monito del monte is a forest specialist marsupial, and as such it used primary and secondary native forests. Core areas were composed almost exclusively by primary forest (see Fig. 2), supporting the idea that old-growth forest is an important habitat type for this species. According to the habitat analysis conducted, monitos del monte did not use pastures and rarely moved through shrubby vegetation (Table 2). This was shown both by telemetry, as well as by the results of captures in these habitats. It is possible then, that the interface between fragments and pastures constitute hard edges between habitat and non-habitat. The lack of use of pastures and scrublands was likely related to the scarce three-dimensional structure that shrubs and bamboo offers in addition to the lack or scarcity of food sources such as mistletoes and fruits (Amico et al. 2009), and possibly the higher exposure to predators. Furthermore, monito del monte seemed to avoid moving on the ground even within the forest as shown by its the extremely low trapping success at ground level (Fontúrbel and Jiménez 2009).

If movements between isolated fragments occur, these are likely rare events. This suggests that dispersal limitation in a fragmented landscape could be one of the most important challenges for the conservation of this species, as well as for the preservation of its keystone role. The lack of use of non-forest habitats seems to be the rule for several TFSSA endemics (Eldridge et al. 1987; Sieving et al. 1996, 2000). Thus, maintaining connectivity among fragments could be a good management alternative in fragmented landscapes such as these of southern Chile (Castellón and Sieving 2006a). Although our data suggest that linear strips of vegetation that are connected to fragments are infrequently used (i.e., only one capture), these rare events may be important to allow demographic rescue to avoid inbreeding depression, which is the ultimate objective of corridors (Lindenmayer and Nix 1993; Mech and Hallett 2001; Pardini et al. 2005). Furthermore, based on the habitat use and selection analyses, we also recommend preserving old- and second-growth remnants (in that order of priority), for habitat conservation purposes. A habitat-based conservation strategy will be helpful not only to monitos del monte populations, but also for many other native forest-dependent species (e.g., birds: Reid et al. 2004).

Conservation implications

The results of our study provide some important insights into the conservation of this species. First, the high densities reported in this as well as in other recent studies in other areas (Rodríguez-Cabal et al. 2008), suggest that -contrary to previous thoughts (Kelt 2006)- this species is not scarce in the TFSSA. The perception on the rarity of this species was likely related to the use of trapping methods that were inappropriate for this marsupial (Fontúrbel and Jiménez in press). Consequently, the recent reclassification of the conservation status of this species from Vulnerable (IUCN 2007) to Near Threatened (Díaz and Teta 2008) seems appropriate. Second, in spite of the high local abundances that this species can reach, the avoidance of open areas could compromise its long-term persistence in fragmented landscapes having mosaics of completely isolated subpopulations with no inter-fragment dynamics. This could lead to disruptions of keystone mutualisms in the temperate forest (see Rodríguez-Cabal et al. 2007). Future research should attempt to establish whether corridor-based conservation planning designed for other species (see Castellón and Sieving 2007) would also be useful to preserve this keystone species.

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Appendix A. Supplementary materials

The online version of this article contains additional supplementary data. Please visit doi:10.1016/j.mambio.2009.08.004

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