

Habitat use of remnant forest habitats by the threatened arboreal marsupial *Dromiciops gliroides* (Microbiotheria) in a rural landscape of southern Chile

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Abstract

Context. Remnant forest patches in rural landscapes may be important sites for maintaining viable populations of restricted forest species, especially when these remnant habitats maintain some connectivity, for instance through riparian vegetation strips and other forest patches.

Aims. We assessed the use of remnant forest habitats in a rural landscape of southern Chile (40°S) by the ‘near threatened’ arboreal marsupial *Dromiciops gliroides* (Microbiotheria), in relation to habitat type (riparian strips, forest fragments and continuous forests), width of the riparian forests, and the presence and abundance of the hemiparasite *Tristerix corymbosus*, whose fruits are readily eaten by *D. gliroides*.

Methods. In two summers, 2004 and 2008, we set up grids of 96 live traps for three consecutive nights at each of 16 sites along two riparian forest strips, four additional sites in remnant, non-riparian forest patches, and four more within continuous pre-Andean forest. We counted hemiparasites on trees in the trapping grid area, and estimated their individual volumes.

Key results. In total, 48 individuals of *D. gliroides* were captured at all sites during the 2 years. We documented a significant positive relationship between the width of riparian vegetation and the number of individuals captured ($r_s = 0.78$, $P = 0.02$, $n = 8$) for one riparian strip, but not for the second one. Neither habitat type nor the frequency of hemiparasites related statistically to *D. gliroides* abundance.

Key conclusions. We conclude that in the rural landscape of the Chilean Lake District, narrow riparian forest strips, in a highly inter-connected mosaic of remnant forest patches may be as important as large patches and continuous Andean forests to sustain viable populations of this threatened, strictly arboreal, marsupial.

Implications. The present study reports, for the first time, the presence in narrow riparian forests immersed in a pasture-dominated agricultural matrix of this forest-specialist marsupial, which was previously known only from continuous pre-Andean forests.

Introduction

Habitat fragmentation resulting from the expansion of human land use into natural areas poses a great threat to the conservation of biodiversity worldwide (Hilty *et al.* 2006). Therefore, conservation targets are often related to the protection and connectivity of remnant habitats supporting high species richness, diversity or endemism (Sabo *et al.* 2005). As a part of this conservation effort, remnant forest patches in rural landscapes may be valuable sites for maintaining viable populations of specialised forest species, especially when these remnant habitats maintain some connectivity (Perault and Lomolino 2000; Hilty *et al.* 2006), for instance through riparian vegetation strips and forest fragments. Accordingly, assessing the

capacity of rural areas to support regional biodiversity is of critical importance to enhance global and regional conservation, especially where limited land can be allocated to new reserves (Daily *et al.* 2003; Chan and Daily 2008). In studies of landscapes under intense anthropogenic use, it has been proposed and shown that riparian vegetation strips serve as transit paths and habitats for wildlife (Simberloff *et al.* 1992; Tewksbury *et al.* 2002; Haddad *et al.* 2003; Hilty and Merenlender 2004; Sabo *et al.* 2005; Gentry *et al.* 2006; Hilty *et al.* 2006). Despite the value of riparian forest strips for habitat connectivity in human-dominated landscapes, interruptions of their continuity by larger corridor gaps or highly modified or exotic vegetation can create barriers to dispersal and tend to reduce the abundance of forest-

specialist species (Beier and Noss 1998; Laurance and Laurance 1999; Hilty and Merenlender 2004; Laurance *et al.* 2008). In addition, the agricultural matrix surrounding riparian forest strips often creates inhospitable conditions for forest-specialist species, limiting their dispersal across the landscape. For example, terrestrial mammals and arboreal marsupials tend to be equally or more abundant in riparian forests than in continuous forest habitats and absent from the surrounding anthropogenic matrix (Lindenmayer *et al.* 1993, 1994; de Lima and Gascon 1999; Hilty and Merenlender 2004).

Discontinuous and disturbed strips of riparian vegetation associated with streams and rivers are the main remnants of extensive forests that once existed in the presently strongly human-dominated landscapes of the central valley, in the lowlands of the Chilean River and Lake District (40°S). Massive land-use change in this region started in the past 100–150 years, when large expanses of continuous rain forest were cleared or burned to open land for human settlements, agriculture and livestock grazing pastures (Otero 2006).

We studied the use of remnant forest patches in this greatly transformed rural landscape by *Dromiciops gliroides*, a small arboreal marsupial, which is largely restricted to wild-forested habitats. This marsupial is known as a relict species, because it is phylogenetically isolated, it belongs to an ancient branch among world marsupials, and it is endemic to the temperate rainforests of southern South America (Hershkowitz 1999). The species is presently classified as ‘near threatened’ by IUCN standards, because of considerable reduction of its regional populations as a consequence of habitat transformation (Díaz and Teta 2008). Furthermore, it has recently been reported that *D. gliroides* may play a significant role as a mutualistic seed disperser of shrubs, vines, epiphytes and the hemiparasite *Tristerix corymbosus*, contributing significantly to the regeneration of forest species

in remnant patches (Armesto *et al.* 1987; Amico and Aizen 2000; Amico *et al.* 2009; Celis-Diez 2010). Amico and Aizen (2000) described a strong, specialised interaction between the fleshy fruits of the *T. corymbosus* (Loranthaceae) and its only disperser, *D. gliroides*, and García *et al.* (2009) documented that *D. gliroides* and the mistletoe *T. corymbosus* were spatially associated in forest fragments in pre-Andean forests in Argentina.

We tested the following three predictions about the presence and abundance of *D. gliroides* in remnant forest habitats of the rural landscapes of the Chilean River and Lake District: (1) the abundance of *D. gliroides* should be greater or similar in riparian habitats than in forest fragments or continuous forests; (2) riparian strip width should correlate with the local abundance of *D. gliroides*; and (3) the abundance of the mistletoe *Tristerix corymbosus* in riparian forest patches should correlate with the abundance of *D. gliroides*.

Materials and methods

Study area and species

We studied the abundance of the marsupial *D. gliroides* in vegetation strips associated with two rivers, Llolelhue and Contra (Fig. 1), both of which are major tributaries of the larger Bueno River, originating in the Andean Range and crossing the lowlands in the central valley in an east–west direction. These two rivers are separated from one another by an average of 22 km in the central valley between the Andean and coastal ranges. All forest sites sampled belong to patches or riparian strips immersed in an intensive agricultural landscape, dominated by grazing pastures. Within each riparian forest strip, we selected eight sampling sites at roughly regular intervals (4–7 km) along both rivers (i.e. from C1 to C8 at Contra River and from L11 to L18 at Llolelhue River, Fig. 1); some sampling

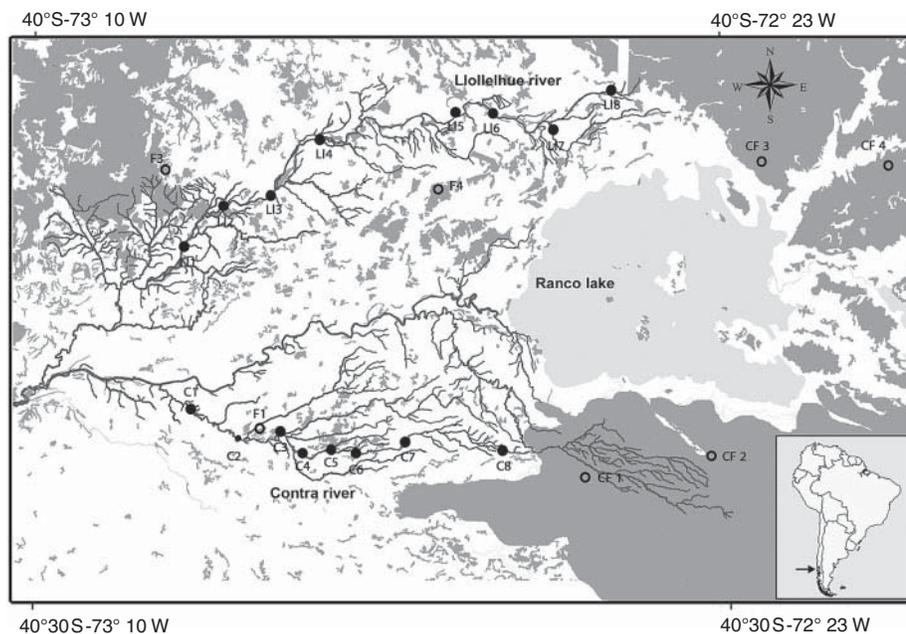


Fig. 1. Sample points of *Dromiciops* in Llolelhue (L) and Contra (C) rivers, with forest fragments (F, in grey) and continuous forest (CF, in white). The agricultural matrix is shown in white.

sites were selected because of the different widths of the riparian vegetation. We also surveyed four non-riparian forest patches immersed in the agricultural matrix (i.e. F1–F4, Fig. 1) that were connected to the riparian vegetation of the two focal rivers studied, either directly or through other riparian strips. The two forest patches sampled near Contra River were 80 and 300 ha in size (the only remnant patches connected to the vegetation of this river). We also sampled two other remnant forest patches, 450 and 502 ha in size, connected to Llollehue River via other riparian strips. In addition, four sites were sampled in the continuous Andean forest (i.e. C1–C4, Fig. 1), above 400 m, directly to the east of the riparian forests studied. The history of forest fragmentation in the area is not known in detail; however, most of the deforestation of the lowlands of the River and Lake District took place between 150 and 100 years ago, and the land-clearing processes has extended in the past century towards higher elevations in the Andes. Farmers indicated that riparian strips closest to the Andes (Fig. 1) resulted from deforestation occurred ~30–35 years ago.

Habitat characterisation

Riparian forest strips were all dominated by tall (10–30 m) evergreen broad-leaved trees, and varied in structure and tree species composition depending on the forest type and the past disturbance. The following three forest types were identified in riparian strips (Table 1): (1) second-growth, logged forest, with a canopy of *Maytenus boaria*, *Aristolelia*

chilensis, *Rhaphithamnus spinosus* and *Luma apiculata*, and an understory of native bamboo, *Chusquea* sp., invaded by the exotic *Rubus ulmifolius*; (2) old-growth swamp forests (hualves), most commonly found in the middle course of the river, with a canopy dominated almost exclusively by Myrtaceae tree species, such as *Luma apiculata* and *Myrceugenia exsucca*; (3) old-growth, unlogged forest found only in the upper course of the river and in the Andean foothills. These forests have large adult trees in the canopy, including as canopy emergents the only deciduous tree species in the area, *Nothofagus obliqua*, along with the evergreens *N. dombeyi*, *Laureliopsis philippiana* and *Eucryphia cordifolia*, and a sparse understory of the native bamboo *Chusquea valdiviana*. We found no understory species that could provide food in the form of fleshy fruits for *D. gliroides* in these remnant forests. In general, few plant species grew in the dark forest understory, except for bamboo thickets in logged patches and under canopy gaps in the old-growth forests.

Llollehue River runs for 95 km along the central valley, maintaining a strip of riparian forest, occasionally discontinuous, for nearly 62 km, along which we conducted our sampling. Contra River runs for 47 km in the central valley and sampling of *D. gliroides* was conducted in a rather discontinuous riparian strip. Tree crowns often overlapped above the watercourse, interconnecting the vegetation strips on both sides of the river. We observed that individuals of *D. gliroides* were able to move across the river by using these overlapping crown branches. Old-growth swamp forest accounted for the majority of riparian forests along both the Llollehue and Contra Rivers (80% and 66% of the vegetation strips, respectively). The surrounding vegetation, or anthropogenic matrix of forest fragments and riparian vegetation, was exclusively pasture.

When the riparian strip where sampling was conducted had a width of less than 120 m, its vegetation width was measured directly in the field with 100-m-long measuring tapes; when the riparian vegetation strip was much wider than 120 m, we estimated its width from aerial photos, complemented with satellite images from Google Earth.

Use of riparian forests by *Dromiciops gliroides*

During January 2004 and 2008, we set up a sampling grid for live-trapping *D. gliroides* at 16 sites along the riparian forest strips of Contra (2004) and Llollehue Rivers (2008) in the lowlands of the Chilean Lake District. Rodríguez-Cabal *et al.* (2007) found lower capture of *D. gliroides* in high Andean forests of Argentina during January, whereas in lowland Chilean forests, under a warmer climate, the most active months for *D. gliroides* are December and January, right after the breeding season has ended and juveniles become active (Celis-Diez 2010). Trapping grids were also set up in two non-riparian forest fragments near Contra River and two forest fragments near Llollehue River, as well as at four sites of continuous Andean forests where both rivers originate. Each trapping grid consisted of 48 tomahawk-like live-traps, placed in an area of 1200 m² on both sides of each river and at each sampling site (96 live-traps per site). Each trapping grid was formed by three rows of 16 live traps, separated from each other by 5 m. Live traps were placed on tree branches, 1–3 m above the forest floor. The grid was active for three consecutive nights at each site (a sampling effort of 288 traps per night per site), and all

Table 1. Sample points and characteristics of the sites where *Dromiciops gliroides* individuals were recorded

Sample point	Riparian-forest width (m)	Forest type	No. of <i>Dromiciops</i> recorded
Llollehue 1	25	Swamp Myrtaceae forest	2
Llollehue 2	104	Swamp Myrtaceae forest	3
Llollehue 3	43	Swamp Myrtaceae forest	0
Llollehue 4	77	Swamp Myrtaceae forest	3
Llollehue 5	34	Disturbed old-growth forest	1
Llollehue 6	270	Disturbed old-growth forest	2
Llollehue 7	216	Swamp Myrtaceae forest	0
Llollehue 8	179	Old-growth forest	2
Contra 1	252	Secondary forest	5 ^A
Contra 2	70	Swamp Myrtaceae forest	3
Contra 3	58	Swamp Myrtaceae forest	1
Contra 4	25	Swamp Myrtaceae forest	1
Contra 5	30	Swamp Myrtaceae forest	0
Contra 6	183	Disturbed old-growth forest	3
Contra 7	149	Disturbed old-growth forest	3
Contra 8	161	Disturbed old-growth forest	1
Fragment 1	–	Swamp Myrtaceae forest	2
Fragment 2	–	Swamp Myrtaceae forest	4
Fragment 3	–	<i>N. obliqua</i> secondary forest	2
Fragment 4	–	Old-growth forest	1
Quimán forest	–	Old-growth forest	0
Cerrillos forest	–	Old-growth forest	5
Ignao forest	–	Disturbed old-growth forest	1
Carilelfu forest	–	Old-growth forest	3 ^A

^AIn Contra 1 and Carilelfu forests, the same individual was captured during two nights, then the total numbers captured at these sites were 6 and 4.

traps were checked before 0800 hours the next day. In the same days, we activated two grids from different sampling sites, selected according to their access routes. All captured individuals were weighed and sexed. A small section of the ear lobe was removed with an ear-punch to identify the animals. In addition, in the area of each trapping grid, we searched for *D. gliroides* faecal samples.

To assess the relationship between the abundance of *D. gliroides* and the abundance of the fleshy-fruited hemiparasite *T. corymbosus* in the riparian and forest sites sampled, we counted each hemiparasite that was growing on trees in the trapping-grid area, and estimated its individual volume. Each individual of *T. corymbosus* was classified by its volume into one of the following three categories: $<20\text{ cm}^3$, $21\text{--}60\text{ cm}^3$ and $>61\text{ cm}^3$. Larger individuals of *T. corymbosus* were expected to offer more fruits to *D. gliroides* than did smaller individuals. Rodríguez-Cabal *et al.* (2007) established that the best descriptor of *T. corymbosus* age was the length of its main branches; hence, we considered larger plants of *T. corymbosus* to be older. When only older individuals of *T. corymbosus* were identified within a patch, a lower abundance of *D. gliroides* was expected, because we assumed that the main seed disperser of the *Tristerix* was absent or less abundant.

Statistical analyses

To assess the differences in *D. gliroides* abundance between forest habitats (i.e. riparian forest strips, non-riparian forest fragments and Andean continuous forest), and considering that differences in vegetation type (i.e. swamp forest, second-growth and old-growth forests) could affect the presence of the marsupial (Patterson *et al.* 1990; Celis-Diez 2010; Fontúrbel *et al.* 2010), a GLIM model selection with a Poisson distribution was performed using R project software (version 2.7.1; R Development Core Team 2010). A non-parametric Spearman rank correlation was used to relate the number of *D. gliroides* captures to the width of the riparian vegetation strips (as data did not satisfy the normality assumptions; Kolmogorov–Smirnov $P < 0.05$). Because of the relatively small number of sites sampled along each riparian corridor and the low capture rate, we constructed a series of correlations that sequentially eliminated one riparian site at Contra River at a time as a way to assess the relative contribution of each data point to the general trend.

Results

We captured 48 different individuals of *D. gliroides* at all forest sites sampled. From these, 25 animals were classified as female and 20 as male, whereas the rest were non-sexed subadults. Two individuals were recaptured (Table 1). In total, 30 animals were captured in riparian forest strips, 13 at Llolllehue River and 17 at Contra River (Table 1). Along the Contra River, animals were present in all forest types and all sites except one, although we found fresh faeces with mistletoe seeds at this latter site, indicating at least the presence of *D. gliroides*. At Llolllehue River, we documented two sites without captures; however, in one of these sites, we recorded fresh faeces containing mistletoe seeds, as an indicator of the presence of *D. gliroides*. A total of nine different individuals was captured in the four non-riparian

forest fragments and nine different individuals were also captured in the four sites of continuous, pre-Andean forest (Table 1). The abundance of *D. gliroides* was unrelated to the width of the riparian forest strips when all sampling sites from both rivers were considered ($r_s = 0.40$, $P = 0.12$, $n = 16$), or when only sites along the Llolllehue River riparian strip were considered ($r_s = -0.02$, $P = 0.96$, $n = 8$). However, the relationship was positive and statistically significant for sites along the riparian strip of the Contra River ($r_s = 0.78$, $P = 0.02$, $n = 8$). When we constructed a series of correlations that sequentially eliminated one riparian site at Contra River, as a way to assess the relative contribution of each data point to the general trend, the correlation was not statistically significant ($P > 0.05$) when data from sites C9, C13 or C14 were omitted. Because of this, we must interpret the possible relationship between the width of a forest strip and *D. gliroides* abundances with caution.

The mean number of animals captured per trapping grid per night was 1.88 ($n = 32$), 2.25 ($n = 8$) and 2.25 ($n = 8$) for riparian forests, non-riparian forest fragments, and continuous Andean forests, respectively. Neither habitat types (i.e. riparian strips, non-riparian forest fragments and Andean forests; GLM deviance = 0.37, $P = 0.8$) nor forest types (i.e. swamp, secondary growth and old-growth forest; GLM deviance = 0.6, $P = 0.7$) statistically affected the abundance of *D. gliroides*, and the number of captures had no relationship to the frequency of *T. corymbosus* at these forest sites ($R^2 = 0.001$; d.f. = 1.22; $P = 0.88$).

Discussion

Our live-trapping survey of *D. gliroides* in the riparian strips of two major rivers and nearby non-riparian forest patches in a rural landscape in the Chilean River and Lake Districts showed similar abundances of this species, as inferred from the number of captures, at different remnant forest sites in the rural, pasture-dominated landscape, as well as in the nearest continuous Andean forests. This is an important result because *D. gliroides* had been reported only from Andean forest fragments and continuous forest. Arboreal species are often extremely sensitive to the loss and fragmentation of forest cover, as well as to changes in habitat quality of remnant and relatively isolated forest patches in rural environments (Laurance 1995; Lindenmayer *et al.* 1997). In Andean forests of the steppe-forest transition, east of the Andes, Rodríguez-Cabal *et al.* (2007) found a negative and marginal effect of forest-patch isolation on the population abundance of *D. gliroides* in three forest fragments studied (1–5 ha each). In another study, Fontúrbel *et al.* (2010), by using live trapping, found similar abundances of *D. gliroides* in forest fragments of 20 ha and 3 ha in area, although this arboreal marsupial was absent from one disconnected vegetation strip. In our case, the large sizes of remnant patches studied may represent rather continuous habitat for this small arboreal marsupial, considering its reduced home range (1.5 ha on average, Fontúrbel *et al.* 2010). We found similar *D. gliroides* abundances in all forested habitats, despite the differences in forest types. This result offers interesting possibilities to conserve this threatened arboreal species in human-dominated landscapes of the Chilean lowlands, where forest cover has been rapidly lost and originally extensive old-growth forest has been converted to

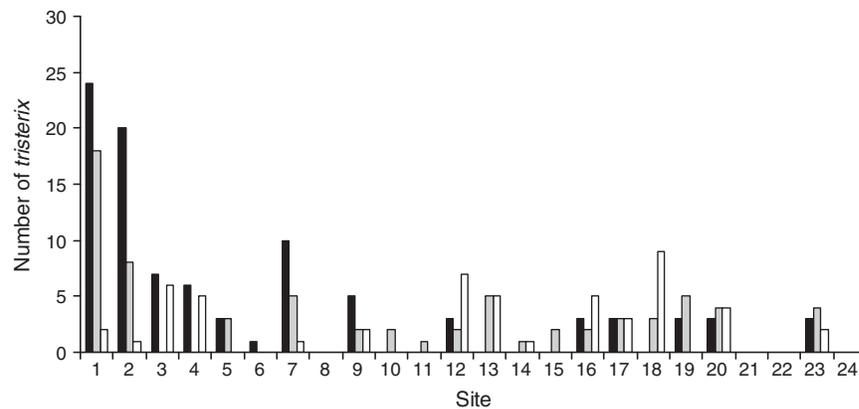


Fig. 2. Number of *Tristerix corymbosus* individuals by volume that represents age for each sample site. Sites 1–8 are from Llollehue River, 9–16 are from Contra River, 17–20 are from fragments, and 21–24 are from continuous forests. Black bars represent older individuals, grey bars medium-age individuals and white bars young individuals.

remnant second-growth forest fragments and narrow riparian vegetation strips (Echeverría *et al.* 2007; Armesto *et al.* 2009, 2010; Celis-Diez 2010). Contrary to the results of the present study, the effect of forest fragmentation in Australian landscapes showed a notable 97% decline in the abundance of arboreal marsupials in vegetation strips, compared with continuous forest (Laurance 1995). In fragmented lowland forests of the Chilean River and Lake Districts, the lack of a significant reduction in the probability of trapping *D. gliroides* in riparian vegetation strips suggests that large forest remnants in this rural area remain well connected through riparian vegetation strips, or that fragmentation of the forest cover has occurred too recently for population declines to take place. Although our data do not support a relationship between the width of riparian vegetation strips and the abundance of *D. gliroides*, it is remarkable that narrow riparian vegetation strips, only 25 m wide, can sustain or probably allow the movement of this arboreal marsupial.

Both the fleshy-fruited hemiparasite *T. corymbosus* and *D. gliroides* were present in nearly all forest sites sampled, although our data did not show a positive relationship between the frequency of infestation and captures of *D. gliroides*, as could have been expected on the basis of their inter-dependence. However, the lower frequency of small and presumably newly infesting individuals of *T. corymbosus* than that of older plants, in riparian forests of the Llollehue River (Fig. 2) could be an indirect evidence of declination of the *D. gliroides* population.

We conclude that in the rural landscape of the River and Lake Districts, predominantly converted to pastures for about one century ago, the availability of suitable habitat, such as riparian forest strips in a highly inter-connected mosaic of remnant forest patches, may be as important as large remnant forest patches and continuous Andean forests to sustain viable populations of *Dromiciops gliroides*, a threatened and strictly arboreal marsupial.

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