

Geographic distribution of *Rhyncholestes raphanurus* Osgood, 1924 (Paucituberculata : Caenolestidae), an endemic marsupial of the Valdivian Temperate Rainforest

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Abstract. The Chilean shrew opossum (*Rhyncholestes raphanurus*) is the southernmost representative of the family Caenolestidae (Marsupialia : Paucituberculata). The species lives in temperate forests of southern Chile and Argentina and is currently known from <25 localities, spanning a latitudinal and longitudinal range of 2°44' (~320 km) and 2°20' (~190 km), respectively. Species distribution was analysed in a historical, geographic and biogeographic context, with the use of maps at different scales (region, subregion, province, ecoregion, forest types), and two potential distribution models were generated with MaxEnt. The models show a few isolated areas of high prediction values (>50%) in coastal Chile and the Andes from 39°30' to ~42°S, and most of Chiloé Island, plus a northern and southern expansion of medium to low (<50%) prediction values. The most important environmental variables identified from the models include precipitation and some temperature-related variables. The species occurrence lies within the Andean region, Subantarctic subregion, and Valdivian biogeographic province. At a smaller scale, most of the localities occur in eight of the 22 forest types described for the Valdivian ecoregion, implying narrow ecological requirements. Identification of critical areas through potential distribution modelling may have implications for species conservation and identification of biogeographic patterns.

Additional keywords: Chilean shrew opossum, distribution records, forest types, marsupial biogeography, MaxEnt, Valdivian Temperate Forests ecoregion.

Introduction

Living shrew opossums of the order Paucituberculata are small (<100 g) South American marsupials restricted to extreme environments associated with the Andean range. The highest species richness ($n=5$) is located in the 'Páramos' and 'Subpáramos' between 8°N and 15°S, mostly in and above the cloud forests at the eastern slope of the Andes mountains where several species of *Caenolestes* and *Lestoros inca* occur (Brown 2004; Timm and Patterson 2007). A single species, *Rhyncholestes raphanurus* Osgood, inhabits the most humid portions of the temperate rainforests of Chile and adjacent Argentina, isolated by more than 2000 km from its nearest relative, *Lestoros inca*, in the Bolivian 'Páramos' (Anderson 1997; Martin 2008).

The distribution of *R. raphanurus* is known from only a few (<25) localities and very little information is available on its ecology. Despite considerable sampling efforts in many areas that appear suitable for the species, no specimens have been captured in the last 14–15 years.

My objectives were to (1) present a map of the species distribution, (2) analyse its historical records, (3) generate potential distribution models that would help identify areas where the species has not been recorded but might occur, (4) identify which environmental variables have a higher influence on the potential distribution models, and (5) analyse the species' distribution in a biogeographic context.

Materials and methods

Recording localities for *R. raphanurus* were taken from previous works and collection specimens (Martin 2008), which were used to generate a distribution map at a regional scale (Fig. 1). Records were incorporated into a geographic information system by converting them into decimal degrees using the formula $(\text{degrees} + \text{min}/60 + \text{s}/3600) * -1$ and later exporting the file in .txt or .csv formats. Latitude and longitude for each record were verified with maps (e.g. Turiscom 2001) and gazetteers (*GEOnet* [<http://earth-info.nga.mil/gns/html/index.html>] and *Global Gazetteer* [<http://www.fallingrain.com/world/index.html>]), or both. If records lacked precise coordinates, these were assigned by plotting them into a geographic information system with different shapefiles of Chile and Argentina (e.g. roads, lakes, political divisions, cities and towns, etc.) through the software DIVA-GIS ver. 5.4 (Hijmans *et al.* 2005b), and complemented with maps and gazetteers. Subsequently, localities were used to analyse the distribution in a historical perspective, and generate potential distribution models. These models were generated with MaxEnt ver. 3.3.3 (Phillips *et al.* 2006), using species localities (Table 1) and WorldClim environmental variables with a spatial resolution of 30 arc-seconds, from the period 1950–2000 (Hijmans *et al.* 2005a). MaxEnt was chosen over other modelling algorithms due to its better performance with lower sample data and excellent predictive ability (Wisz

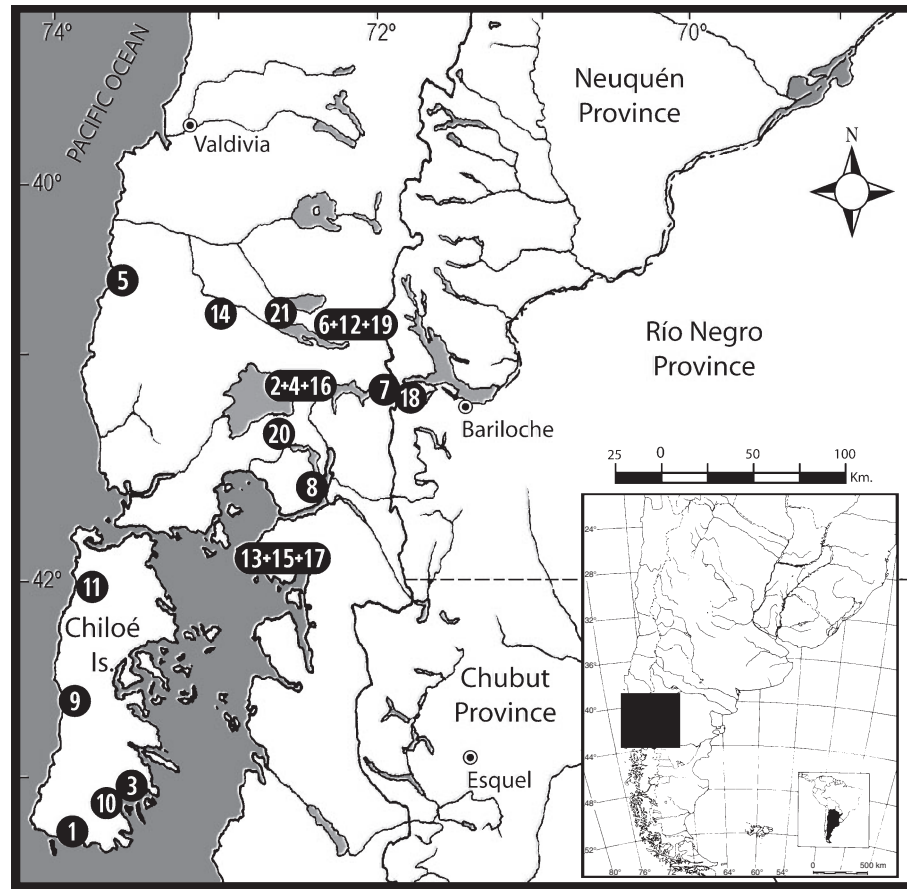


Fig. 1. Recording localities for *Rhyncholestes raphanurus* throughout the species range and organised by date (see Table 1 for place names and geographic coordinates).

et al. 2008). The variables used in the analyses included altitude; monthly precipitation; mean, maximum, and minimum monthly temperatures; and 19 other variables (Hijmans *et al.* 2005a). These variables were used at their highest resolution available (grid size <1 km²), which, coupled with the strong climatic gradient, should very much compensate for the uncertainty in grids of mountainous areas, as discussed by Hijmans *et al.* (2005a). The potential distribution of *R. raphanurus* was modelled using two different approaches, one with all localities known for the species (All Model, $n = 21$), and the other using only the records after 1950 (1950 Model, $n = 19$). This was done to test for differences in total area and general potential distribution patterns with the two different datasets, the second one having temporal correspondence with the climatic dataset (Phillips *et al.* 2006). The following selections to the MaxEnt software were made: 25% test data, 500 iterations, random seed, and 10 000 background points (Phillips and Dudik 2008). Ten replicates for each dataset were made, from which the average model was used, taking advantage of the new possibilities of the MaxEnt software (see <http://www.cs.princeton.edu/~schapire/maxent/>). Models were generated with a continuous output, which was used to generate maps in which prediction values range from 0 to 100. Three intervals were distinguished (Fig. 2): high prediction values (51–100, black

shading), medium prediction values (11–50, light grey shading), and low prediction values (1–10, dark grey shading) (this selection of shades was done to maximise contrast in the black/white figures). Areas having zero probabilities of species presence were also recognised and are not coloured (i.e. appear white in Fig. 2). The intervals were selected to maximise lower prediction levels and therefore reflect critical areas where the species has yet to be recorded (Phillips *et al.* 2006). The main environmental variables and heuristic estimates of their relative contribution to the models, and a jackknife test for variable importance are presented. Information from the models is also presented quantitatively, as threshold-dependent and -independent tests (Phillips *et al.* 2006). This is done to test for better predictions in the models than those randomly generated through the binomial omission test (Phillips *et al.* 2006). These include: (1) to determine within which limits omission values fluctuate (preferably, they should be low or close to zero); (2) to estimate the potential area of each model in relation to the total analysed area; and (3) to assess whether area-under-curve values indicate better predictions than random and can be considered useful (Phillips and Dudik 2008).

The distribution of the species was analysed in a biogeographic context using shapefiles of regions, subregions, and provinces (Morrone 2001, 2006); ecoregions (Olson *et al.*

Table 1. Occurrence localities for *Rhyncholestes raphanurus* Osgood ordered by publication date

All localities are shown in Fig. 1, and all are from Chile except where noted. Forest Type (Lara *et al.* 1999) is shown within parentheses. See Appendix 1 for complementary information

Locality no.	Locality	Latitude	Longitude	Reference
1	Mouth of Río Inio (FT14)	43°20'03"S	74°08'08.5"W	Osgood (1924)
2	Refugio Volcán Osorno (FT14)	41°04'S	72°28'W	Osgood (1943)
3	Near mouth of Río Yaldad, 15 SW from Quellón (FT7)	43°04'40"S	73°44'59"W	Pine <i>et al.</i> (1979)
4	La Picada, Volcán Osorno (FT20)	41°06'S	72°30'W	Gallardo and Patterson (1987)
5	Maicolpué (FT7)	40°35'47.2"S	73°44'14"W	Patterson and Gallardo (1987)
6	Puyehue National Park (FT7)	40°44'54"S	72°08'17"W	Patterson and Gallardo (1987)
7	Peulla (FT7)	41°06'S	72°02'W	Patterson and Gallardo (1987)
8	Southern margin of Lago Chapo (FT1)	41°31'09.5"S	72°25'43.3"W	Patterson and Gallardo (1987)
9	Cucao (FT16)	42°37'59"S	74°06'25"W	Patterson and Gallardo (1987)
10	Puerto Carmen (FT7)	43°08'15"S	73°46'13"W	Patterson and Gallardo (1987)
11	Fundo El Venado, 5 km W of Palomar (FT14)	42°03'S	73°58'W	Patterson and Gallardo (1987)
12	Puyehue National Park, Anticura sector (FT16)	40°46'01"S	72°10'41"W	Rau <i>et al.</i> (1995)
13	Contao, 19.7 km N Río Negro and 26.7 km S Contao (FT7)	41°56'19"S	72°42'53"W	Albuja and Patterson (1996)
14	Osorno, 32 km SSE and Puerto Octay, 14.5 km NNW (FT16)	40°40'S	73°01'W	Albuja and Patterson (1996)
15	Río Negro, 11.1 km WNW (FT16)	41°58'S	72°29'W	Albuja and Patterson (1996)
16	Osorno, 84 km SSE, 32 km ESE from Puerto Octay (FT7)	41°04'32"S	72°37'38"W	Albuja and Patterson (1996)
17	Río Negro, 12.4 km WNW (FT7)	41°56'S	72°31'W	Albuja and Patterson (1996)
18	Puerto Blest [Argentina] (FT5)	41°02'S	71°49'W	Birney <i>et al.</i> (1996)
19	Anticura (FT16)	40°40'50"S	72°10'W	Martínez and Jaksic (1997)
20	Lago Chapo, 12.4 km WNW, 19.7 km N (FT7)	41°20'S	72°44'W	Brown (2004)
21	Entre Lagos (FT16)	40°40'S	72°37'W	This work

2001); and forest types (FT) (Lara *et al.* 1999; Appendix 1), providing the first biogeographic scheme for the species. This allowed for a characterisation from a broader to a finer scale in the progression of biogeographic region → subregion → province → ecoregion → forest type (Lara *et al.* 1999; Morrone 2001, 2006; Olson *et al.* 2001). Localities were assigned to the different biogeographic categories on a geographic basis.

Results

Chronology and occurrence

A total of 21 localities have been recorded for the species since its description in 1924, all but one from Chile (Table 1, Fig. 1). The latitudinal and longitudinal range for the species are 2°44' (~320 km) and 2°20' (~190 km) respectively.

Excluding the easternmost record (Puerto Blest, Río Negro Province, Argentina, 41°02'S, 71°49'W), marginal occurrence localities in Chile are bounded to the north by Maicolpué (40°35'47.2"S, 73°44'14"W), and to the south and west by the mouth of Río Inio, Chiloé Island (43°20'03"S, 74°08'08.5"W) (Table 1).

All localities from Chile are located in the X Region (Los Lagos), 15 (71.4%) are from continental Chile, and five (23.8%) from Chiloé Island. Only three specimens have been collected in Argentina, all from the same locality of Puerto Blest at Parque Nacional Nahuel Huapi (Río Negro Province, Argentina). The new locality presented herein (Entre Lagos) comes from a specimen housed at the Instituto de Ecología y Evolución, Universidad Austral de Chile (Valdivia), which has remained undescribed.

Taken in equal periods of 21 years since the species description to 2010, historical occurrence is concentrated in the last 40 years, with most of the records coming from the period 1987–96. Thirty-

nine years after it was first recorded on the continent, the species was recaptured in 1978 at Refugio de La Picada, in the vicinity of Osorno volcano (Osgood 1943; Gallardo 1978). No fossils or subfossil specimens have been recovered so far.

Habitat

Rhyncholestes raphanurus is restricted, in the temperate rainforest, to sites with dense vegetation, abundant fallen and decomposing logs and generally colder, with more humid climates (Osgood 1924; Pine *et al.* 1979; Patterson and Gallardo 1987; Patterson *et al.* 1989, 1990; Birney *et al.* 1996; Kelt *et al.* 1999). Specimens captured at La Picada (Chile) showed a positive selection for sites with high foliage density (at 15 cm) during the summer, and high cover of shrub species but low shrub diversity during the winter (Kelt *et al.* 1994). High correlation of species abundance with bare soil, bryophytes and fallen logs with a diameter larger than 15 cm was found (Patterson *et al.* 1990). In Argentina, specimens were trapped in dense *Nothofagus dombeyi* forest with an understorey of small *Podocarpus nubigena* and *Saxegothaea conspicua*, along with abundant bamboo (*Chusquea culeou*) (Birney *et al.* 1996).

The altitudinal range for the species, as documented from its localities in Chile, is from sea level at Chiloé Island to below 1200 m at La Picada (Osgood 1924; Patterson and Gallardo 1987; Patterson *et al.* 1990). A peak in occurrence at ~500 m, declining at higher and lower elevations, was described by Patterson *et al.* (1989); similarly, high correlation with altitude was described by Kelt *et al.* (1994). The Argentine locality is at ~790 m, within the species' known altitudinal range (Birney *et al.* 1996).

Potential distribution

The two models generated for *R. raphanurus* (All and 1950) show three areas of high (>50%) prediction: most of Chiloé Island,

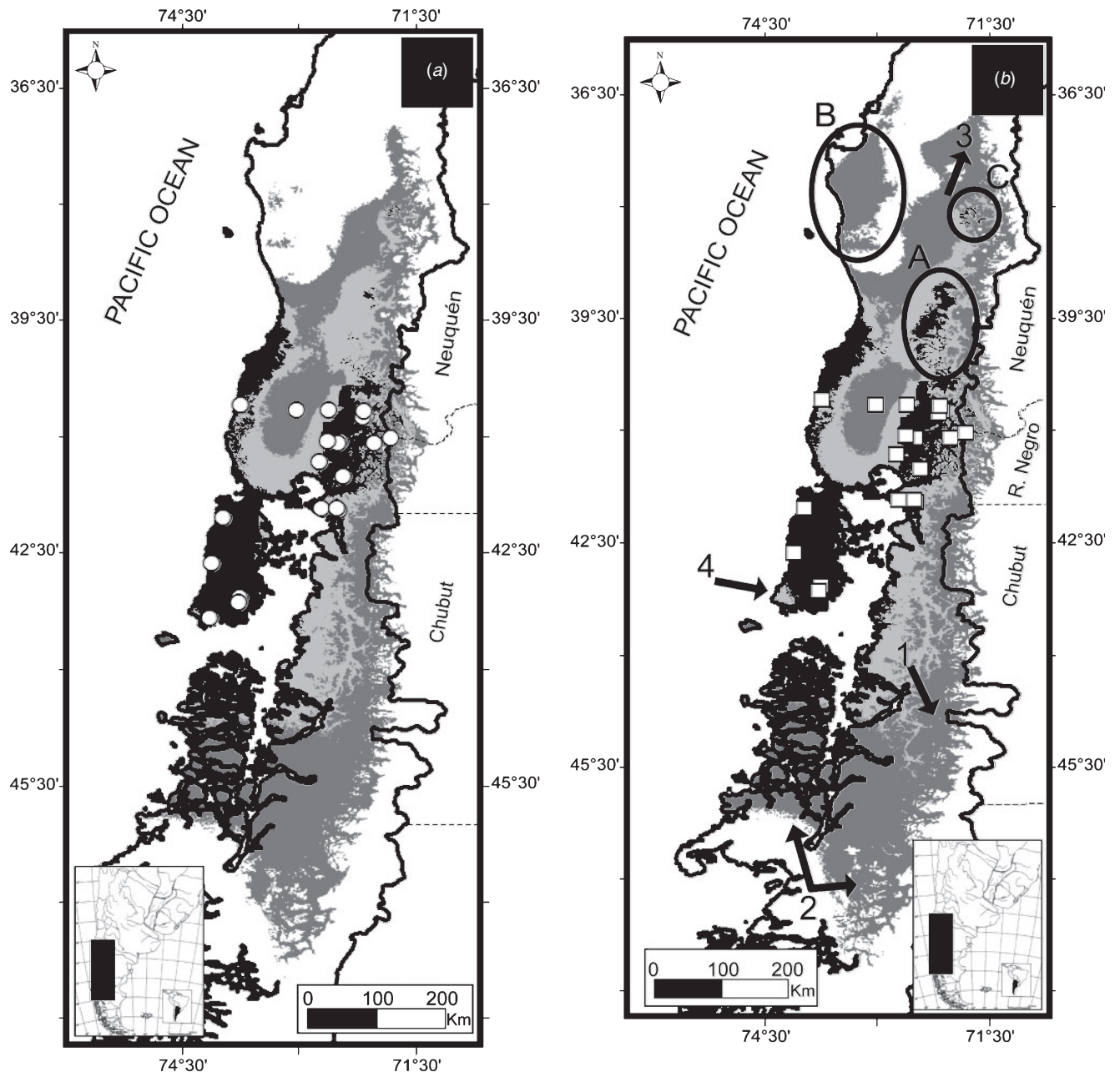


Fig. 2. (a) Potential distribution models generated for *Rhyncholestes raphanurus* using all known localities ($n = 21$), and (b) those recorded after 1950 ($n = 19$). High prediction values (51–100) are shaded black, medium values (10–50) light grey, and low values (1–10) dark grey. White was used for areas having zero probabilities of species presence. Important changes are marked by arrows or selected areas in the model (see ‘Potential distribution’ in the ‘Results’ section and general ‘Discussion’).

a coastal area between $39^{\circ}30'S$ and $41^{\circ}00'S$, and an area of the Andes between $40^{\circ}21'44''S$ and $41^{\circ}44'46''S$ (black shading in Fig. 2a, b). A high-prediction area between $39^{\circ}S$ and $40^{\circ}S$ was found in the model generated with post-1950 records (A in Fig. 2b). The most striking differences between models are the northern and southern extensions in medium- and low-prediction areas in the 1950 model (light and dark grey shading, B and arrows 1–2–3 in Fig. 2b).

Sixteen and 14 environmental variables (Table 2) with values $>1\%$ contributed the most to both models, 91.2% in All and 89.2% in 1950. Two of them together (i.e. July precipitation, mean temperature of wettest quarter) contribute $>50\%$ to each of the models (51.6% in All and 55.7% in 1950). The remaining variables, with smaller contributions, are directly related to precipitation and some temperature values (Table 2). Results of the jackknife test for variable importance show the same variables

Table 2. Heuristic estimates of relative contributions of the environmental variables and results of the jackknife test of variable importance and test gain to the MaxEnt models generated for *Rhyncholestes raphanurus*Worldclim (Hijmans *et al.* 2005a) environmental variables were used to generate the models. Values are indicated as percentages

Variable	All		1950	
	Contribution	Permutation	Contribution	Permutation
July precipitation	35.2	0	39.1	0
Mean temperature of wettest quarter	16.4	0	16.6	0
Precipitation of coldest quarter	7.9	0	5.6	0
August precipitation	4.6	3.2	5.4	13.3
Precipitation of driest month	4.3	0	2.4	0
Mean diurnal temperature range (Mean of monthly (max. temp.–min. temp.))	4	0	2.6	1.1
December precipitation	2.8	0	3.2	11.1
September precipitation	2.6	57.4	2.3	51.7
June precipitation	2.2	0	1.7	0
Precipitation of warmest quarter	2.2	11.6	2	0.1
October precipitation	1.9	1.5	3.6	0.5
January precipitation	1.7	6.4	–	–
June maximum temperature	1.7	0	–	–
Isothermality	1.6	5.1	1.2	2
October minimum temperature	1.1	0	–	–
August mean temperature	1	0	2	0
May precipitation	–	–	1.5	0
Total from the two variables with the highest contribution	51.6		55.7	
Total	91.2		89.2	
Jackknife test of variable importance				
Variable with the highest explanatory power	July precipitation		July precipitation	
Variable with the most 'unique' information	September precipitation		September precipitation	
Jackknife test of variable importance through test gain				
Variable with the highest explanatory power	August precipitation		August precipitation	
Variable with the most 'unique' information	September precipitation		September precipitation	

to be the most important for both models (July precipitation), and the variable containing information not present in the remainder (September precipitation) (Table 2). The jackknife test using test gain values (instead of training gain) recovered August precipitation as the variable with the most useful information in itself, and September precipitation as the variable with information not present in the others (Table 2). The information presented above shows a strong relationship between the potential distribution of *R. raphanurus* mostly with precipitation, and temperature during the coldest months.

The models produced with both datasets (All and 1950) showed better predictions than those randomly generated at cumulative threshold values of 1, 5, and 10, with high average values of area under the curve: All = 0.994 ± 0.004 (s.d.) and 1950 = 0.993 ± 0.002 (s.d.), respectively. Similar values in fractional predicted area and significant *P*-values were recovered for each of the average models (Table 3).

Distribution and forest types

The distribution of *R. raphanurus* is completely included within the Andean region, Subantarctic subregion and Valdivian biogeographic Province/Valdivian Temperate Forests ecoregion (Morrone 2001, 2006; Olson *et al.* 2001).

The species has been trapped in eight of the 22 Forest Type (FT) categories mapped for the Valdivian Forests ecoregion by Lara *et al.* (1999) (Table 1, Appendix 1). The most important FTs are FT7, with 38.1% ($n=8$) of the records, and FT16, with 23.8% ($n=5$) of the records, which comprise ~62% of all known

Table 3. Results of equalised predicted areas for cumulative threshold values of 1, 5, and 10 for the two models generated

Significance values of the binomial probabilities of test points used in the analyses are also shown

Cumulative threshold	All		1950	
	Fractional predicted area	<i>P</i>	Fractional predicted area	<i>P</i>
1	0.1517	0.0006	0.2039	0.0019
5	0.0481	0.0000	0.0670	0.0000
10	0.0239	0.0000	0.0301	0.0000

localities. Other FTs in which ≤ 2 localities were recorded include FT14 ($n=2$), FT5 ($n=2$), FT1, FT8, FT15 and FT20 (all these with only one record each). Localities within FT16 are, in general, due to the presence of this species in forest remnants surrounded by areas used for agricultural purposes (e.g. locality 14, 32 km SSE of Osorno, 14.5 km NNW of Puerto Octay: Albuja and Patterson 1996; Kelt 2000).

Discussion

Localities for *R. raphanurus* ($n=21$) are second in number to those for *Caenolestes fuliginosus* ($n \sim 40$), probably the best known species in the family, whereas other caenolestids are mostly known from fewer than 10 localities (Brown 2004). The species has a narrower latitudinal range than most *Caenolestes* spp. with the exception of *C. condorensis* (known only from its

type locality), and *Lestoros inca* (with a latitudinal range of 1.92°); and a narrower longitudinal range than all caenolestid species with the exception of *C. condorensis* (Albuja and Patterson 1996; Brown 2004; Myers and Patton 2007; Timm and Patterson 2007). The longitudinal extension of all other caenolestids might be an artefact of the oblique orientation of the Andes mountains in which they live, and may not reflect habitation of different environments at the same latitude. Whereas 'Páramos' and 'Subpáramos' (typical habitats for *Caenolestes* spp. and *Lestoros*) occur above the tree line in high tropical mountains and are highly insular and constrained ecosystems, Valdivian Temperate rainforests occurred historically from the coast of Chile to the eastern slope of the Andes. They were broadly distributed on two mountain ranges (the Cordillera de la Costa in Chile and the southern Andes between Argentina and Chile), and common in portions of the central valley (valle o llano central: Donoso 1995, 1996) or intermediate depression (depresión intermedia: Murúa 1997), now heavily logged and cleared for agricultural purposes (WWF *et al.* 1999).

The historical occurrence of *R. raphanurus* shows concentrated records in the last 40 years, coincident with the increased work in southern Chile, especially in the late 1980s and early 1990s, a pattern shared with most records for Temperate rainforest small mammals, e.g. *Dromiciops gliroides*, *Geoxus valdivianus* and *Irenomys tarsalis* (Patterson and Gallardo 1987; Patterson *et al.* 1989, 1990; Kelt 2000; see also Pearson and Pearson 1982; Pearson 1995; Birney *et al.* 1996).

Literature accounts for habitat preferences of *R. raphanurus* have pointed out its occurrence in cool and moist microhabitats of the Valdivian Temperate rainforest, mostly concentrated at mid-elevations in the Andes (Patterson *et al.* 1989, 1990; Kelt *et al.* 1994; Patterson 2007; but see also Kelt and Martínez 1989; Birney *et al.* 1996), and lower elevations in Chiloé and coastal areas (i.e. Maicolpué: Patterson and Gallardo 1987). The species has been captured in tall mature forests with abundant fallen trees and a high proportion of bare soil (Kelt and Martínez 1989; Patterson *et al.* 1990) but also in forests that have been disturbed by logging and overgrazing (Pine *et al.* 1979; Kelt and Martínez 1989; G. D'Elía, pers. comm.), amongst other human impacts. Apparently, *R. raphanurus* might be tolerant of human-induced disturbances but requires certain local (i.e. at a microhabitat scale) conditions, which would include: moderately closed canopy with abundant foliage density, portions of bare soil, high shrub cover and high humidity content. These conditions might even be found in small patches surrounded by agricultural areas, as reported by Kelt (2000). The presence of this species in habitats like the ones described above might also be related to the presence of fungi and soil-inhabiting invertebrates (especially annelids), which have been described as the main feeding items of *R. raphanurus* (Meserve *et al.* 1988).

The two models generated with MaxEnt are the first attempt to approximate the potential distribution for *R. raphanurus* at a regional scale, providing reasonable representations of its distribution within the environments present in the area. Records within the Andean high-prediction area (black shading, Fig. 2) appear evenly distributed, but two other areas (i.e. Cordillera de la Costa between 39°30'S and 41°S, and Chiloé Island) show only a few records (Fig. 2). Although localities in Chiloé island are concentrated in the south and west, most of the island has high

prediction values, where suitable habitat still occurs (Fariás *et al.* 2008). Interestingly, extreme south-western Chiloé has medium prediction values in the model that excludes records before 1950 (Arrow 4, Fig. 2b), which includes the type locality. High-prediction areas in continental Chile are separated by medium- and low-prediction zones in the central valley/intermediate depression (Donoso 1995, 1996; Murúa 1997), which have been identified within the Valdivian Temperate Forests ecoregion as having the highest and/or very high priorities for conservation, and as potential habitat corridors (WWF *et al.* 1999). These high-prediction areas might also act as refuges and dispersal centres for the species towards other nearby zones, thereby increasing their conservation value. The presence of the species in patches between these areas might either be considered remnants of a more extended distribution, or dispersing individuals. Because very little is known of the ecology of *R. raphanurus* the importance of these areas in the species' distribution warrants further investigation. Extensions in areas of medium- and low-prediction values (light and dark grey, respectively) in the models generated with data after 1950 are more evident towards the south-eastern (Arrow 1), southern (Arrow 2), and north-eastern (C and Arrow 3) distribution (Fig. 2b). Because of the strong association between the potential distribution of *R. raphanurus* and precipitation, a northern expansion is at odds with the predictions of climate change for the central portions of Chile, which should become drier and therefore unsuitable for this species (Watson *et al.* 1998). This northern expansion in models with data after 1950 is also in contrast to the model generated for *D. gliroides* (the other marsupial living in the Valdivian Temperate Forests ecoregion), for which a clear southward expansion and/or northern contraction was documented (Martin 2010).

Despite the difference in potential distribution models generated for the two marsupial species that inhabit the Valdivian Temperate rainforests (*R. raphanurus* and *D. gliroides*), environmental variables with the highest contributions to the models appear to be similar (Table 2 herein; table 2 in Martin 2010). Similar variables, mostly related to precipitation, were also found in the models generated with a smaller number of records (Martin 2008). Heuristic estimates of relative contributions of environmental variables show that July precipitation and mean temperature of the wettest quarter account for more than 50% for both species, but with a higher percentage for *D. gliroides* (73.4% for All; 69.5% for 1950; table 2 in Martin 2010) than for *R. raphanurus* (51.6% for All; 55.7%; Table 2 herein). Other variables, which contribute with higher percentages in the models generated for *R. raphanurus* are not necessarily the same as in *D. gliroides*. Jackknife tests of variable importance show July precipitation to be the variable with the highest gain for both species, whereas September precipitation is the variable that contains the most valuable information by itself in both models for *R. raphanurus* and the 1950 model for *D. gliroides*, and September maximum temperature for the All model in *D. gliroides* (Table 2 herein; Martin 2008; table 2 in Martin 2010). The new version of MaxEnt used in this study also gives jackknife values of test gain, which showed August precipitation to be the variable with the highest gain and September precipitation with the highest gain by itself (Table 2). August precipitation appeared as one of the heuristic variables in *D. gliroides*, but with values

≤2.2% (Martin 2010). Birney and Monjeau (2003) proposed that the mean minimum temperature, along with other temperature-related variables, would determine species richness and has a strong influence on the southernmost living marsupials (i.e. *D. gliroides*, *Lestodelphys halli*, *R. raphanurus*). Therefore, variables related to minimum temperatures should be expected to contribute with higher percentages to the potential distribution models. Despite this, results presented herein and in Martin (2008, 2010) show that these variables contribute a very small or no percentage to the potential distribution models (the WorldClim database presents information for all months and minimum temperature for the coldest month: Hijmans *et al.* 2005a).

From a biogeographic point of view, *R. raphanurus* can be considered a diagnostic 'element' of the Valdivian biogeographic province *sensu* Morrone (2000, and literature cited therein). Its distribution appears to be highly concentrated in continental Chile from 39°30'S to 42°S, and on most of Chiloé Island, and does not extend through most of the Valdivian Temperate Forests ecoregion of Olson *et al.* (2001). This restricted pattern is also shared, at least partially, by *Abrothrix sanborni* (Osgood 1943) and *Pearsonomys anectens* (D'Elia *et al.* 2006). Localities of *R. raphanurus* appear to be spatially restricted to a few FTs within the Valdivian Forests ecoregion (Lara *et al.* 1999; see also Appendix 1) when compared to *D. gliroides* (Martin 2010). A high proportion of records are from FT7, including areas of very humid conditions within the Valdivian Forests ecoregion, and forest patches inside FT5, which appear to be of importance to *D. gliroides* and other small mammals (i.e. rodents) living in areas with constant anthropogenic pressure. Other records in six different FTs account for less than 40% of the species' known localities, showing local restrictions to the species distribution in agreement with the information presented above for habitat preferences.

Conclusions

The number of records known for *Rhyncholestes raphanurus* are concentrated in latitude and longitude, in comparison to other living caenolestids. Most of these records come from the last 40 years of research, and provide very limited information on the species' habitat requirements.

The potential distribution models generated differ in extension despite using very similar record numbers; both show areas of high prediction values in different zones where suitable habitat for the species still exists. The models also show areas with medium and low prediction values of varying extension, and an expansion of suitable habitats north, east and south of the current species distribution, especially in the model generated with data from after 1950. Precipitation and precipitation-related variables appear to be the highest contributors to both models.

Biogeographically, *R. raphanurus* can be considered a diagnostic element of the Valdivian biogeographic province. It is restricted to a few Forest Types and can be found in small patches of varying size like other small temperate-rainforest mammals, although how these patches affect species distribution is currently unknown.

Today, *R. raphanurus* remains one of the most poorly known mammals of South America's temperate rainforests. This work

aimed to provide a framework for future studies that could focus on increasing the number of sampled localities throughout the species' known range, explore areas where the potential models suggest that the species might occur, and provide new and complementary information on FTs and smaller-scale occurrence. Other complimentary research should try to increase our knowledge on habitat preferences and other ecological aspects of this species at different levels (i.e. population, community).

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Appendix 1. List of Forest Types (FT) used in this work (Lara *et al.* 1999)

Translation and scientific names between brackets

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- FT1. Alerce [southern larch tree, *Fitzroya cupressoides*]
FT2. Araucaria [monkey-puzzle tree, *Araucaria araucana*]
FT3. Ciprés de las Guaitecas [*Pilgerodendron uviferum*]
FT4. Ciprés de la Cordillera [Chilean cedar, *Austrocedrus chilensis*]
FT5. Roble–Raulí–Coihue [*Nothofagus oblicua*–*Nothofagus nervosa*–*Nothofagus dombeyi*]
FT6. Coihue–Raulí–Tepa [*Nothofagus dombeyi*–*Nothofagus nervosa*–*Laureliopsis philipiana*]
FT7. Valdiviano [Valdivian, evergreen forest]
FT8. Lenga (Incluye las formaciones con porte arbóreo y achaparrado) [*Nothofagus pumilio*, includes formations of tree and shrub size]
FT9. Ñire o ñirre (Incluye formaciones dominadas por ñire/ñirre y matorrales mixtos en Argentina) [*Nothofagus antarctica*, includes stands dominated by *N. antarctica*/*N. antarctica* and mixed shrubland in Argentina]
FT10. Roble–Hualo [*Nothofagus oblicua*–*Nothofagus glauca*]
FT11. Coihue de magallanes [magellanic coihue or coigüe, *Nothofagus betuloides*]
FT12. Esclerófilo mixto [mixed sclerophytic, characterised by the presence of *Peumus boldus*, *Quillaja saponaria*, *Lithrea caustica* and *Cryptocarya alba*]
FT13. Estepa patagónica [patagonian steppe]
FT14. Humedales [locally called mallines, wetlands or marshlands]
FT15. Vegetación altoandina y otras áreas con vegetación rala [high andean vegetation and other areas with low plant cover]
FT16. Praderas y matorrales de origen antrópicos [prairies and shrublands of anthropogenic origins]
FT17. Plantaciones [plantations, mostly of *Pinus* spp. and *Eucaliptus* spp.]
FT18. Terrenos Agrícolas [cultivated lands]
FT19. Urbano [urban]
FT20. Nieves y glaciares [snow and glaciers]
FT21. Cuerpos de agua [water bodies]
FT22. Areas no reconocidas [unrecognised or uncharted areas]
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