

# Nevado de Toluca: habitat for *Romerolagus diazi*?

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## Abstract

*Nevado de Toluca: habitat for Romerolagus diazi?* The volcano rabbit (*Romerolagus diazi*), also known as teporingo or zacatuche, is a small rabbit that is endemic to Mexico. In this study we characterized its potential habitat in the Area of Protection of Flora, and Fauna Nevado de Toluca, Mexico. Between April 2016 and November 2017, we sampled 1,807 units to determine the presence of this species using indirect evidence. We found dung pellets that could be attributed to *R. diazi* in 41 (2.27 %) of the sampled units. In 10 % of these units, we set up camera traps to confirm the presence of the species. Sites with presumed *R. diazi* pellets were characterised by rocky terrain, with *Pinus hartwegii* as the dominant tree species, and *Festuca tolucensis* as the dominant grass. Overall herbaceous cover was over 70 %. Sites observed to have a negative effect on the presence of the pellets were areas with livestock grazing and induced burning. The results of camera trapping did not reveal the presence of *R. diazi* in Nevado de Toluca.

Key words: Teporingo, Conservation, High mountain forest

## Resumen

*El Nevado de Toluca: ¿un hábitat para Romerolagus diazi?* El conejo de los volcanes (*Romerolagus diazi*), también conocido como teporingo o zacatuche, es un pequeño conejo endémico de México. En este estudio se caracterizó su hábitat potencial en el Área de Protección de Flora y Fauna Nevado de Toluca, en México. Entre abril de 2016 y noviembre de 2017, se analizaron 1.807 unidades de muestreo para determinar la presencia de esta especie de forma indirecta. Encontramos excrementos atribuibles a *R. diazi* en 41 unidades de muestreo (el 2,27 %). En el 10 % de estas unidades se colocaron cámaras de trapeo para confirmar la presencia de la especie. Los sitios con presencia de excrementos supuestamente pertenecientes a *R. diazi* están en terrenos rocosos, donde la especie dominante arbórea es *Pinus hartwegii* y la herbácea, *Festuca tolucensis*. El porcentaje de cobertura herbácea fue superior al 70 %. Se observó que el pastoreo y los incendios inducidos tienen un efecto negativo en la presencia de los excrementos. Los resultados del muestreo con cámara no revelaron la presencia de *R. diazi* en el Nevado de Toluca.

Palabras clave: Teporingo, Conservación, Bosque de alta montaña

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## Introduction

The diversity of hares and rabbits (Order Lagomorpha, Family Leporidae) is high in Mexico, with 15 species. Seven of these are endemic (Farías, 2011). The volcano rabbit, (*Romerolagus diazi* Ferrari–Pérez 1893), also known as zacatuche or teporingo, is a small, monospecific rabbit found only in the mountains around the southern part of Mexico City. It lives in small groups in runways among grass tussocks, typical of its distribution area. The volcano rabbit is considered endangered (SEMARNAT, 2010; IUCN, 2017). It is threatened by the loss and fragmentation of its habitat (Hoth et al., 1987; Velázquez et al., 2011), introduced species (dogs and cats), hunting, and more recently, climate change (López et al., 1996; Anderson et al., 2009). The main causes for the loss of habitat are anthropogenic fires, livestock grazing, and logging (López et al., 1996).

The volcano rabbit is known to occur along the central Trans–Mexican Volcanic System (TMVS) in discontinuous patches in four volcanoes (Popocatepetl, Iztaccíhuatl, El Pelado and Tláloc) that cover approximately 386 km<sup>2</sup> (Velázquez, 1994). Although there is no historical evidence of sightings of the species, some researchers (Velázquez et al., 1996a) have argued that the rabbit could potentially be found in areas of similar habitat in other volcanoes and mountains in the TMVS such as the Nevado de Toluca, Nevado de Colima, Volcán Tancítaro, Cofre de Perote and Pico de Orizaba. However, credible evidence of their presence in these sites is lacking (Velázquez et al., 1996a; Olascoaga et al., 2015).

Volcano rabbits are strongly associated with pine–grassland habitat (Cervantes et al., 1990; Fa et al., 1992; Velázquez, 2012). They are generally found where tussock grasses, genera *Muhlenbergia*, *Festuca* and *Jarava* (Velázquez, 1994), are denser in cover and taller (Fa et al., 1992; Rizo et al., 2015), providing the species not only with a source of food but also shelter (Trigo et al., 2003). They may also use trunks and stony mounds as refuge (Cervantes and Martínez, 1996). Volcano rabbits have been found in areas with no or moderate slopes (Martínez–Calderas et al., 2016) where dominant vegetation is *Festuca tolucensis* (70% cover)/*Pinus* spp. (10%), and *Muhlenbergia macroura* (70%)/*Pinus* spp. (20%, Velázquez et al., 1996b).

In 1975, a volcano rabbit was found in the Nevado de Toluca, in Central Mexico, about 80 km west of Mexico City and near the city of Toluca. It is now deposited in the Instituto Politécnico Nacional Museum (Galindo, C., pers. comm.). There is also anecdotal information regarding sightings in the 1980s, but no evidence was found during a field study in 1987 (Hoth et al., 1987). In 1998, Ceballos et al. (1998) reported finding dung pellets attributable to the species but no further details were given. On the basis of these previous uncertain findings, we attempted to confirm the presence of the volcano rabbit in the Protected Area of Flora and Fauna Nevado de Toluca, focussing on sites with environmental characteristics that are similar to those in its area of distribution.

## Material and methods

### Study area

The Protected Area of Flora and Fauna Nevado de Toluca National Park (PAFFNT) is located within the TMVS between 18° 51' 3" and 19° 19' 03" N and 99° 38' 54" and 100° 09' 58" W (Brunett et al., 2010). The PAFFNT, covering 53,590 ha (CONANP, 2016), is the fourth highest mountain (4,660 m) in the country (Candeau and Franco, 2007). The area is dominated by coniferous forests [29.5% pine (*Pinus* spp.), 35.7% fir (*Abies religiosa*)] with some oak *Quercus* (0.3%) and alder *Alnus jorullensis* (3.9%) and agriculture 17.4% (CONANP, 2016). In addition, 4.2% consists of alpine grassland communities (Candeau and Franco, 2007). Pine–grassland habitat occupies 12,924 ha.

### Sampling

Between 22 April 2016 and 05 July 2017 we searched for the presence of the volcano rabbit in pine–grassland habitat in the PAFFNT (fig. 1). We established 1807 sampling units (SU) above 3,000 m (Dauber, 1995) situated along every 100 m (3,100, 3,200, etc). Each SU consisted of a circular plot of 0.1 ha (17.86 m radius) to guarantee a minimum sampling intensity (recommended 0.44% for 12,924 ha (Dauber, 1995).

In each SU we noted the following qualitative variables: presence/absence of rocky outcrops, evidence of recent fire (< 1 year), livestock grazing, logging, and presence of ravines, trails or reforestation. We also recorded the dominant arboreal species (DAS), dominant herbaceous species (DHS), dominant shrub species (DSS) and density of the forest, classified as: dense (80–100%), semi–dense (50–79%) and open (< 50%; Regil, 2005). Quantitative variables analysed were altitude (m a.s.l.), slope and aspect (measured in degrees), percentage of herbaceous cover (PHC), percentage of shrub cover (PSC), number of seedlings, and number of tree stumps.

Two axes were drawn in the north–south and east–west directions crossing the central point of the SU. Within each SU, we searched for rabbit pellets. Two other lagomorph species are found in the area (*Sylvilagus floridanus* and *S. cunicularius*). Rabbit pellets found were photographed to determine whether they corresponded to *R. diazi* (Aranda, 2012). Using this indirect approach, we analysed each photographic record digitally (with ImageJ software) to verify the dorso–ventrally compressed spherical shape and maximum diameter of 10 mm that is typical for the species (fig. 2).

### Statistical analysis

We analysed the data by dividing the SUs into two groups: one with presence of pellets attributable to *R. diazi* (41 sites) and another without pellets (1,766 sites). To identify the variables that correctly classified the SU with and without pellets, we performed a stepwise discriminant analysis, with the quantitati-

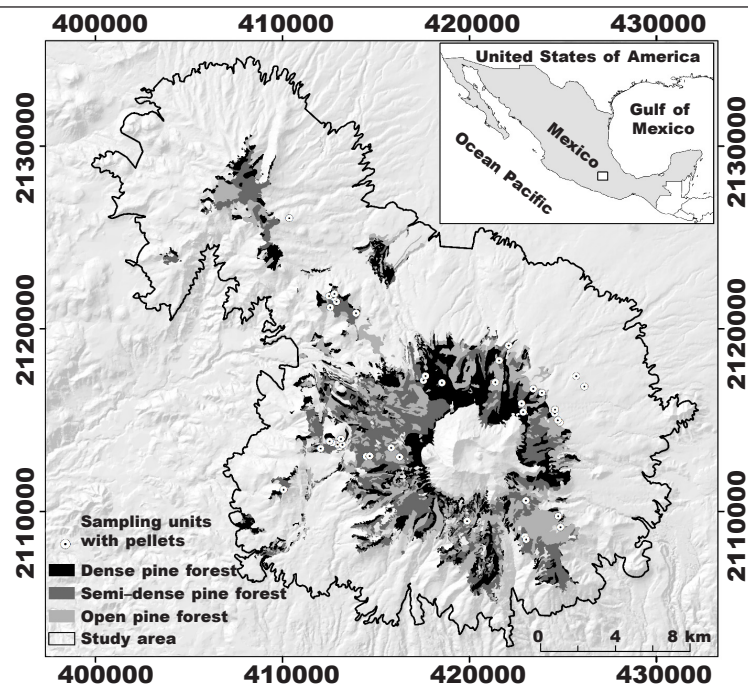


Fig. 1. Sampling units with pellets attributable to *Romerolagus diazi* in the Protected Area of Flora and Fauna Nevado de Toluca.

Fig. 1. Unidades de muestreo con excrementos atribuibles a *Romerolagus diazi* en el Área de Protección de Flora y Fauna Nevado de Toluca.

ve variables. We tested the independence of each qualitative variable and the presence of pellets, with contingency tables and  $\chi^2$ -tests.

#### Camera trapping

In 10% of the sites with pellets attributable to *R. diazi*, a camera trap was placed in front of latrines to obtain photographic records of the species using the latrine. The cameras were operated day and night for 6 months (July to December, 2017). The presence of different vertebrate species and their relative abundance was obtained using the following indices:

$$\text{IAR} = (\text{C}/\text{SE}) * 100 \text{ trap-days}$$

where: C is the number of photographic events and SE, the sampling effort (number of cameras per day of monitoring; Maffei et al., 2002; Jenks et al., 2011; Monroy-Vilchis et al., 2011).

#### Results

We compared the environmental variables with those from other studies with confirmed presence of *R. diazi*: Pelado volcano (Velázquez et al., 1996a), Tlaloc volcano (Velázquez and Heil, 1994), Popocatepetl (Velázquez et al., 1996b) and Iztaccíhuatl (Hunter

and Cresswell, 2015; table 1). We found pellets traditionally attributable to *R. diazi* in 41 SUs (2.27%), 36 of which were in *Pinus* spp. forest and 29 in zones with varying density of pine forest (fig. 1).

The 41 SUs with pellets attributable to *R. diazi* were found between 3,305 and 3,874 m, with a higher proportion between 3,500 and 3,700 m (fig. 2). Seven dominant tree species were recorded in these areas: *Pinus hartwegii*, *Alnus jorullensis*, *Cupressus lusitanica*, *Abies religiosa*, *Pinus montezumae*, *Pinus patula* and *Pinus pseudostrobus*. However, the presence of pellets attributable to the volcano rabbit was recorded in only four SUs (table 2), with *P. hartwegii* being the most frequent, in 36 SUs (87.80% of SUs with scat). Three of the seven dominant genera in the herbaceous layer were present in SUs with pellets: *Festuca* (56.10%), *Muhlenbergia* (39.02%) and *Calamagrostis* (4.88%). Within the shrub cover, 16 species were identified, but the pellets attributable to *R. diazi* were associated with six of these (table 2), in order of frequency: *Senecio cinerarioides* (26.83%), *Lupinus montanus* (24.39%), *Barkleyantus salicifolius* (21.95%), *Symphoricarpos microphyllus* (2.44%), *Acaena elongata* (2.44%) and *Baccharis conferta* (2.44%). Eight SUs did not have any shrub cover (19.51%).

Results of the stepwise discriminant analysis showed that only the percentage of herbaceous cover was a significant predictor for the presence of pellets attributable to the volcano rabbit (Wilk's

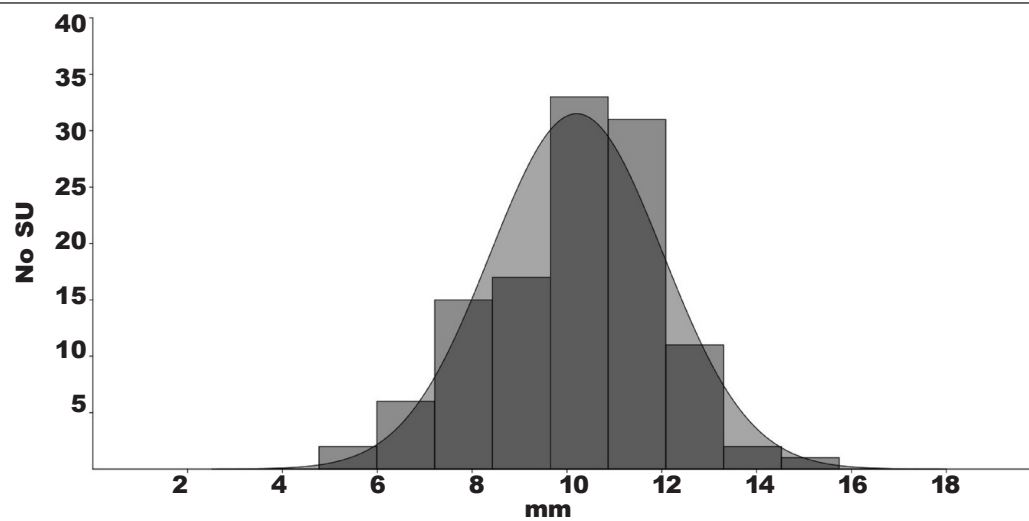


Fig. 2. Diameter of rabbit pellets found in 41 sampling units in the Protected Area of Flora and Fauna Nevado de Toluca.

Fig. 2. Diámetro de los excrementos de conejo encontrados en 41 unidades de muestreo en el Área de Protección de Flora y Fauna Nevado de Toluca.

Lambda = 0.99,  $F = 8.31$ ,  $p = 0.003$ ). The mean percentage of herbaceous vegetation in SU with pellets (74.85%) was higher than that in SUs without pellets (61.77%). Of the qualitative variables, only two had an influence on the presence of pellets: rocky outcrop ( $\chi^2 = 8.38$ ,  $df = 1$ ,  $p = 0.003$ ) and livestock grazing ( $\chi^2 = 2.85$ ,  $df = 1$ ,  $p = 0.001$ ). Rocky outcrops that favored the presence of pellets traditionally attributable to the volcano rabbit were

recorded in 70.73% of the SU with pellets. Grazing was recorded in only one SU with pellets, showing the negative influence of livestock herding on pellets attributable to the volcano rabbit.

We obtained a total of 23 independent photographic records (IR) out of 8,601 records from a sampling effort of 165 camera trap days. The specific richness was five species of three orders (Passeriformes, Lagomorpha and Rodentia; table 3).

Table 1. Variables associated with the presence/absence of *Romerolagus diazi*.

Tabla 1. Variables asociadas a la presencia y ausencia de *Romerolagus diazi*.

Variable	Other studies	Present study
Rocky outcrop	Presence of <i>R. diazi</i>	Presence of <i>R. diazi</i>
Altitude (m a.s.l.)	3,400–4,000	3,500–3,700
DAS	<i>Pinus hartwegii</i>	<i>Pinus hartwegii</i>
DHS	<i>Festuca toluensis</i>	<i>Festuca</i> spp.
DSS	–	<i>Senecio cinerarioides</i>
Recent fire	Presence of <i>R. diazi</i>	Absence of <i>R. diazi</i>
Livestock grazing	Presence of <i>R. diazi</i>	Absence of <i>R. diazi</i>
Aspect	–	Northeast hillside
Slope (°)	–	19 (5–38)
PSC (%)	–	16 (0–70)
PHC (%)	70	> 70

## Discussion

The presence of the volcano rabbit in the Nevado de Toluca has not been confirmed in any scientific study although pellets considered attributable to the species have been reported (Ceballos et al., 1998). In our study, pellets attributable to the volcano rabbit were mostly associated with rocky outcrops, where *P. hartwegii* was the dominant arboreal species, *F. toluensis* was the dominant herbaceous species and the percentage of herbaceous cover was > 70%. These characteristics are similar to those reported in the Pelado volcano, Mountain Tlaloc and Iztaccíhuatl, where the species is known to exist (Velázquez et al., 1996a, 1996b; Hunter and Cresswell, 2015).

The PAFFNT is a relatively small area. It is subject to anthropogenic pressure such as agriculture, livestock grazing, logging and feral species (dogs and cats; CONANP, 2016). However, in our study, SUs with pellets were found in habitat considered optimal for the species since they show environmental characteristics similar to other sites of confirmed distribution (Velázquez, 1996).

The presence of the volcano rabbit is related to several factors. The most positive factor is the herbaceous stratum (Fa et al., 1992; Velázquez et al., 1996b) that not only provides protection and refuge from predators (Trigo et al., 2003) but also contributes to diet. Several negative factors have also been described, particularly livestock grazing, controlled burning, and feral dogs (Weber, 2010; García-Aguilar, 2012). In a study conducted in the Iztaccíhuatl volcano, the species was most abundant in the habitat with the highest percentage of grassland and least abundant in areas with more hunting and grazing (Hunter and Cresswell, 2015). This coincides with our results, since the sites with pellets attributed to *R. diazi* were found in areas with over 70% of herbaceous cover, mainly *Festuca*.

The incidence of forest fires within the area is another threat to their ecosystems. In the APFFNT 80% of fires are intentional (PROBOSQUE, 2012). The main type of fire during the last ten years was the superficial or creeping type (CONANP, 2016), whose most severe damage is reflected on the herbaceous

cover. In other distribution sites of *R. diazi*, however, it has been reported that controlled burning has a significant positive effect on the appearance of the rabbit (Hunter and Cresswell, 2015). In the PAFFNT, however, the incidence of recent fires is not related to the presence of pellets.

Table 2. Frequencies in sampling units (F) of dominant species/genus for the arboreal, herbaceous and shrub cover.

*Tabla 2. Frecuencia de las especies o géneros dominantes (F) de la cobertura arbórea, herbácea y arbustiva en las unidades de muestreo.*

Cover	
Dominant species/genus	F
<b>Arboreal</b>	
<i>P. hartwegii</i>	36
<i>A. jorullensis</i>	3
<i>C. lusitanica</i>	1
<i>P. pseudostrubus</i>	1
<b>Herbaceous</b>	
<i>Festuca</i>	23
<i>Muhlenbergia</i>	16
<i>Calamagrostis</i>	2
<b>Shrub</b>	
<i>S. cinerarioides</i>	11
<i>Lupinus montanus</i>	10
<i>B. salicifolius</i>	9
<i>S. microphyllus</i>	1
<i>A. elongata</i>	1
<i>B. conferta</i>	1
Not shrub cover	8

Table 3. Species registered by camera traps in the sampling units with pellets attributable to *R. diazi*: IR, independent records; IAR, relative abundance index.

*Tabla 3. Especies registradas con cámaras en las unidades de muestreo que presentaban excrementos atribuibles a R. diazi: IR, registros independientes; IAR, índice de abundancia relativa.*

Order	Family	Species	IR	IAR
Passeriformes	Troglodytidae	<i>Troglodytes aedon</i>	3	0.36
	Emberizidae	<i>Oriturus superciliosus</i>	8	0.97
Lagomorpha	Leporidae	<i>Sylvilagus floridanus</i>	1	0.12
		<i>Sylvilagus cunicularius</i>	7	0.85
Rodentia	Cricetidae	<i>Neotoma</i> sp.	4	0.48

*Pinus hartwegii* grows between 3,000 and 4,000 m on high mountain forests in Mexico (Rzedowski, 2006; Endara et al., 2013). Forests of *P. hartwegii* are closely related to the presence of pellets attributable to *R. diazi*. Endara et al. (2013) state that the areas with the greatest deterioration dynamics are *Pinus* spp. High mountain ecosystems are among the most threatened and impacted ecosystems worldwide due to climate change, which is transforming their landscape, substantially changing environmental conditions, and affecting the viability of biodiversity in these areas (Astudillo-Sánchez et al., 2017).

Camera trapping is a common technique to study medium and large mammals. In rabbits, it has been used to record their presence and calculate their relative abundance (Monroy-Vilchis et al., 2011; Hernández-Hernández et al., 2018). Although we were unable to confirm the presence of *R. diazi* in the Nevado de Toluca, pellet data suggest it is present there in the PAFNT. Because the evidence is indirect we consider the occurrence of the species should be verified using direct methods such as photographic records. Further photo-trapping should also be carried out in the other sites with ideal habitat characteristics for the species. Ecological and social studies are needed in these sites to gain further knowledge on how to extend the distribution of the species to the Nevado de Toluca.

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