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Uso de hábitat, distribución y abundancia del conejo zacatuche (*Romerolagus diazi*) en la Sierra del Chichinautzin

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Foto: Areli Rizo Aguilar

A esta enigmática criatura

DECLARACIÓN

Excepto cuando es explícitamente indicado en el texto, el trabajo de investigación contenido en esta tesis fue efectuado por la M. en C. Areli Rizo Aguilar como estudiante de la carrera de Doctor en Ciencias entre septiembre de 2009 y septiembre del 2013, bajo la supervisión del Dr. Alberto González Romero y Dr. Enrique Martínez Meyer.

Las investigaciones reportadas en esta tesis no han sido utilizadas anteriormente para obtener otros grados académicos, ni serán utilizadas para tales fines en el futuro.

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Resumen

El conejo zacatuche (*Romerolagus diazi*), es endémico de la Faja Volcánica Transmexicana, con distribución restringida a los volcanes Pelado, Tláloc, Popocatépetl e Iztaccíhuatl. Es una especie con requerimientos especializados de hábitat, el principal de estos es la presencia de pastos del género *Muhlenbergia* y la especie *Jarava ichu*. El área en la que se distribuye está sujeta a fuertes presiones antropogénicas que han repercutido en la cantidad y calidad del hábitat disponible para el conejo de zacatuche, por lo que se ha catalogado como especie en peligro de extinción en la NOM-059-SEMARNAT-2010 y como Amenazada en la lista de la IUCN.

Los pastizales de la Sierra del Chichinautzin representan una zona importante de pastizal en la región central de México, por lo que estudiamos la distribución de *R. diazi* en el Área Natural Protegida Corredor Biológico Chichinautzin (COBIOCH). Además, analizamos las variables descriptoras del hábitat en la Sierra Chichinautzin y su relación con la abundancia de las poblaciones del conejo zacatuche, para generar un índice de calidad de hábitat. Los resultados sugieren que el COBIOCH representa un área de distribución importante para la conservación de la especie, donde ocupa una superficie de 166 km^2, con densidades de 6.2 conejos/ha que son incluso mayores que las reportados para el Volcán Pelado, que históricamente se ha considerado una zona núcleo de distribución de la especie. En lo que respecta al índice de calidad de hábitat, el mejor modelo sugiere que las variables del hábitat que explican que las abundancias de los zacatuches sean mayores son una cobertura de pastos altos, árboles más altos y alturas homogéneas de arbustos.

Capítulo I

Introducción

En el manejo y conservación de la fauna se considera fundamental estudiar los factores que influyen en el uso y la selección del hábitat por una determinada especie, y por lo tanto es necesario realizar el estudio a diferentes escalas (Henske *et al*., 2001). La selección de hábitat es un proceso complejo con niveles de discriminación y una serie de factores que interactúan. El individuo debe elegir sitios específicos dentro del hábitat, es decir el microhábitat, lo cual puede estar influenciado por varios factores. El proceso de selección de hábitat también conlleva una jerarquía espacial, de forma que los procesos que lo determinan son distintos a diferentes escalas (Graf *et al*., 2005), y las interacciones entre los patrones espaciales, la distribución y dinámica de las poblaciones influyen en la abundancia y distribución de los organismos.

En la distribución, abundancia y dinámica de una población influyen las características de la especie, tales como la capacidad de dispersión, patrones de movimiento, especialización de hábitat, demografía; así como también las características del hábitat, como pueden ser calidad, tamaño, disponibilidad de alimento, agua y otros factores, como son las condiciones ambientales y climáticas, competencia, entre otras causas (Van Dyke, 2007).

El conocimiento de los requerimientos de una especie acerca del hábitat es fundamental para entender e incluso poder predecir su distribución y abundancia, en el caso de especies altamente especializadas en usar características particulares de ciertos recursos. En el caso de especies endémicas con un rango de distribución restringido, son especialmente vulnerables a la extinción debido a que los cambios en los patrones de uso de suelo o cambios climáticos, afectan a todos los individuos de esa población. Por lo que especies con tales características deberían recibir atención prioritaria para su conservación (Pimm, 1998, Van Dyke, 2007).

La fragmentación del hábitat inducida directa o indirectamente por el hombre es uno de los factores que más contribuyen a la pérdida de diversidad biológica (Wilcox y Murphy, 1985), también es causante de modificaciones en la estructura espacial de las poblaciones afectadas, que en caso de ser suficientemente acentuada puede producir la división de la población original en pequeñas subpoblaciones conectadas únicamente por eventos puntuales de inmigración-emigración a través de una matriz de hábitat desfavorable (Levins 1970; Hanski y Gilpin, 1991). Estos aportes de individuos entre subpoblaciones se convierten en elemento clave para mantener la estabilidad de la metapoblación, que de otro modo se verá conducida al declive (Doncaster et al., 1997; Hanski y Simberloff, 1997).

La especie *Romerolagus diazi*, conocida popularmente como conejo de los volcanes, zacatuche o teporingo, es endémica de México, con distribución restringida y es el lagomorfo más pequeño del país. Actualmente el Orden Lagomorpha incluye 78 especies, clasificadas en 2 familias: Ochotonidae y Leporidae (Fig. 1). Este Orden tiene una amplia distribución geográfica, reportada desde el ecuador hasta los 80° latitud Norte, y desde el nivel del mar hasta los 5,000 m.s.n.m., ocupando una amplia diversidad de hábitats (Chapman y Flux, 1990). Los miembros de este grupo desempeñan un rol ecológico importante, por su tamaño y abundancia, forman parte de la dieta alimenticia de mamíferos carnívoros, aves de presa y reptiles. Es una especie gregaria, suele vérsele en grupos de dos a cinco individuos lo que indica una organización social bien definida (Cervantes-Reza y Martínez, 1996). Su periodo reproductivo comprende todo el año, aunque se intensifica durante el verano y disminuye en el invierno. La distribución reportada del teporingo la componen 16 zonas: cuatro consideradas zonas núcleo y 12 zonas periféricas (Velázquez et al., 1996). Estas últimas se encuentran aisladas dado que presentan barreras infranqueables para el teporingo, tales como autopistas y carreteras, grandes campos de cultivo y asentamientos humanos. Las cuatro zonas núcleo se ubican en los volcanes Pelado, Tláloc, Popocatépetl e Iztaccíhuatl y las restantes zonas, se encuentran en la periferia de los volcanes mencionados (Velázquez et al., 1996).

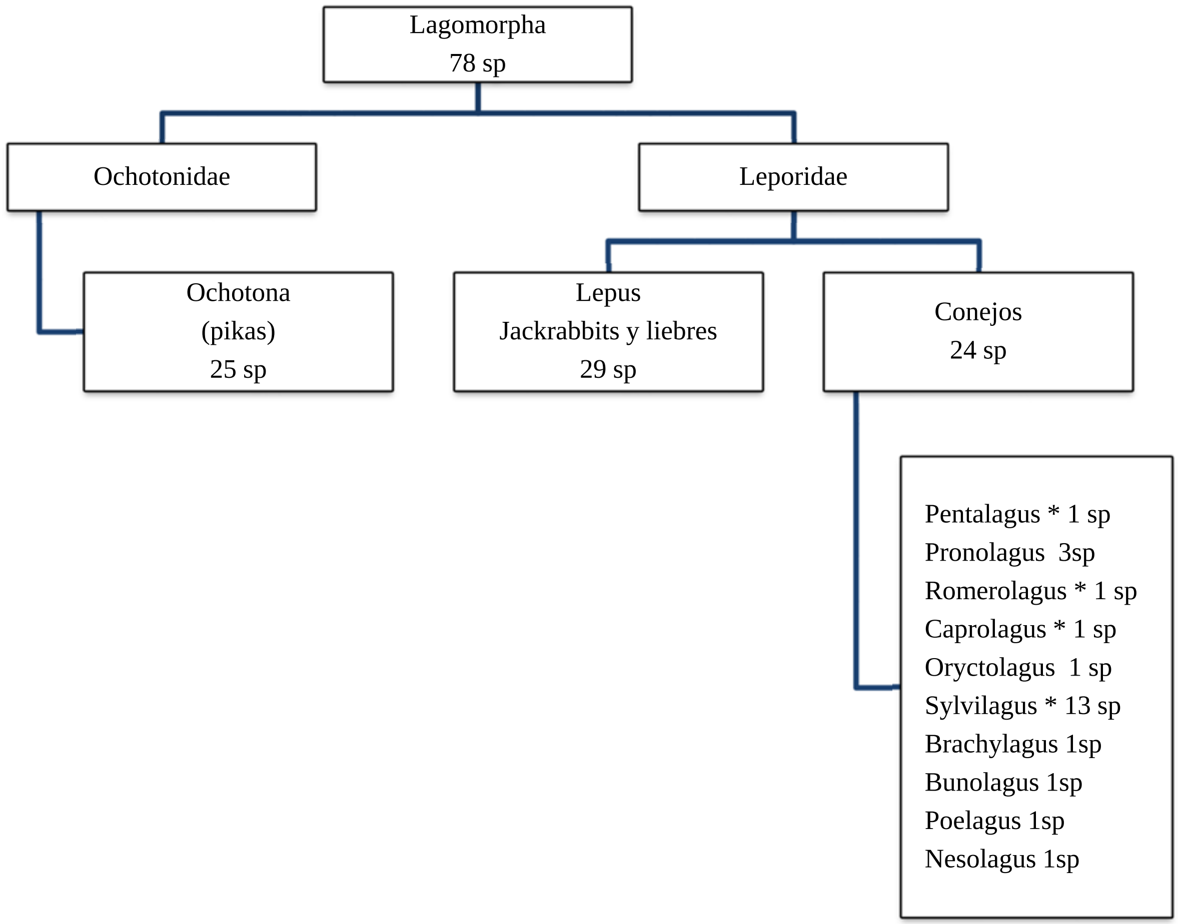

Figura 1. Familias y géneros del Orden Lagomorpha. Modificado de Chapman y Flux (1990).

* Indica que al menos una de la especie del Género está Amenazada.

Como consecuencia del aumento de las áreas en las que se realizan actividades agrícolas y pecuarias, extracción de madera e incendios forestales, el hábitat de esta especie ha sido fragmentado de manera gradual y en algunas zonas de su área de distribución ha desaparecido (Velázquez et al., 1996), éstas son las principales razones por las que se encuentra en la categoría de especie en peligro de extinción en la Norma Oficial Mexicana-059-SEMARNAT-2010. A nivel internacional se encuentra incluida en el Apéndice I, del CITES (Comercio Internacional de Especies Amenazadas de Flora y Fauna Silvestres) desde 1991 y como Amenazada en la lista da la IUCN (Unión Internacional para la Conservación de la Naturaleza y Recursos Naturales).

Los estudios realizados sobre la ecología de *Romerolagus diazi* indican que es una especie con requerimientos especializados de hábitat y un área de distribución geográfica limitada, sobre la que actualmente se ejerce una fuerte presión por actividades antropogénicas, en consecuencia la calidad y disponibilidad del hábitat se ve afectada por la fragmentación y la escasez de corredores que conecten los parches, así como también por la destrucción de su hábitat.

Pese a la situación de conservación del zacatuche la información sobre aspectos ecológicos se ha limitado a dos de las zonas núcleo de su distribución, La Sierra Nevada (Volcanes Iztaccíhuatl y Popocatépetl) y el Volcán Pelado. Además, dichos estudios fueron realizados durante el periodo de 1987 a 1996 (Hoth *et al.*, 1987, Velázquez *et al*., 1996) y desde entonces no se han hecho investigaciones/estudios que aporten información sobre el estado actual de las poblaciones y el hábitat del zacatuche.

En este trabajo nos planteamos como objetivo general realizar un estudio de las relaciones entre el conejo zacatuche y su hábitat, así como de la distribución de esta especie en un paisaje altamente fragmentado como es la Sierra Chichinautzin. Diseñamos una investigación buscando evaluar las variables descriptoras de la estructura del hábitat a una escala local y su relación con la abundancia de las poblaciones del conejo *R. diazi*, con el propósito de generar un índice de calidad del hábitat.

Capítulo II

THE RELEVANCE OF THE CORREDOR BIOLÓGICO CHICHINAUTZIN PROTECTED NATURAL AREA TO THE CONSERVATION OF THE ENDEMIC VOLCANO RABBIT (*Romerolagus diazi*)

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Abstract

The Corredor Biológico Chichinautzin (COBIOCH) Protected Natural Area (PNA) is one of the largest areas of bunch grassland on the Trans-Mexican Volcanic Belt, a habitat which is necessary for the survival of the volcano rabbit. As part of a monitoring program to evaluate the status of the volcano rabbit's populations within this PNA, we estimated its distribution using direct (sightings) and indirect methods (latrines) during visits to all available habitats. Additionally, we estimated the annual density of the volcano rabbit using the line transect method, sampling eight, one-kilometer-long transects monthly in 2008. Based on 101 latrine records and 48 sightings, a distribution map was prepared for the region using the convex polygon method in ArcView (ESRI). Most of this distribution (166.43 km^2) represents an area that had not been previously reported in the literature for the volcano rabbit. Using the half-normal model that best fit the data, we estimate a density of 4.2 rabbits/ha. Our results suggest that the COBIOCH has the meets the criteria necessary to be cataloged as a core distribution area for the volcano rabbit. As such, we think that the management and conservation of this habitat should become a priority.

Keywords: *Romerolagus diazi*, Chichinautzin, density, distribution, IUCN.

The volcano rabbit (*Romerolagus diazi*) is endemic to the Trans-Mexican Volcanic Belt that crosses central Mexico. Previous studies have indicated that the volcano rabbit has a strong preference for subalpine habitats (2,800 - 4,200 m a.s.l.), with higher abundances found in open pine forests (*Pinus* spp.) that have abundant bunch grasses (*Festuca tolucensis*, *Muhlenbergia* spp., *Jarava ichu*) in their understory (Velazquez and Heil 1996; Rizo-Aguilar et al. in press). Based on this, the volcano rabbit is considered a habitat specialist. Its habitat has been severely fragmented by urbanization, agricultural conversion, illegal logging, and wildfires (Velázquez et al. 1996). Additionally, volcano rabbit populations are decreasing because they are regularly hunted for food by the local inhabitants and preyed upon by feral dogs (Cervantes-Reza and Martinez-Vazquez 1996; Portales et al. 1997). More recently, there has been severe habitat transformation in the range of the species, resulting in habitat loss. As a result, the species is classified as critically endangered on the IUCN Red List (IUCN 2012), and as endangered by Mexican Legislation (SEMARNAT 2010).

Reliable estimates of the presence of a species can provide substantial information for addressing conservation questions related to its distribution and habitat use. With such information, conservation biologists can predict how a species distribution and abundance will respond to changes to the landscape and environmental change. Until the late 1980s the precise area of distribution of *R. diazi* was unknown. Lopez-Forment and Cervantes-Reza (1979) estimated that it covered a total area of 150 km^2, while De Poorter and Van der Loo (1981) reported an area of 1,500 km^2. In contrast, Hoth et al. (1987) only found volcano rabbits in three isolated areas in the central Trans-Mexican Volcanic Belt: the Sierra Nevada mountain, and the Tlaloc and Pelado volcanoes. The total area of distribution estimated by Hoth et al. (1987) was 280 km^2. Motivated by these contrasting findings, Velazquez et al. (1996) conducted a survey throughout the proposed geographic range of *R. diazi* to document its historical and current distribution. Based on collection records, sightings, traces (pellets) and interviews with farmers, their estimate was 386 km^2. Within this area, three core and 12 peripheral areas were recognized. This information was used to prepare the distributions maps for the volcano rabbit that are now in the literature and on web pages (Velazquez et al. 1996; IUCN, 2012). Studies conducted on the Pelado Volcano (Sierra del Ajusco mountain range) and the Iztaccihuatl Volcano (Sierra Nevada mountains) based on fecal pellet counts have shown that the abundance of this species is highly variable throughout its range: 0.1 to 1.2 latrines/m^2 (Velázquez 1994; Velázquez et al. 1996). These studies have documented the distribution and described the habitat requirements of the volcano rabbit, but they were conducted more than 10 years ago, and most were done in a single locality, the Pelado Volcano. Consequently, concerns have arisen regarding the identification of current landscape patterns in volcano rabbit distribution and abundance as this information is used to make decisions on species management and conservation.

The Corredor Biológico Chichinautzin (hereafter COBIOCH) is a Protected Natural Area located in the northern part of the state of Morelos (Figure 1). Its elevation ranges from 1,250 to 3,450 m a.s.l., and spans three types of climate: 1) semi-cold sub-humid with rains in summer and an average temperature of 5 to 12 °C, 2) warm-humid with summer rains, and an average temperature in the warmest month of 6.5 to 22 °C, and 3) warm (the coolest of the warm category), with an average annual temperature below 22 °C and the most humid of the subhumid category. This variety of climates, together with topographic heterogeneity, produces a range of ecological conditions resulting in a remarkable diversity of habitats and species richness. The area of the COBIOCH (657.2 km^2) includes Fractions I and II, covering the zone between the Lagunas de Zempoala and El Tepozteco National Parks, and creating a biological corridor that ensures the continuity of ecological processes of the biota in the area (Figure 1). The COBIOCH represents a barrier against the rapid urban growth of Mexico City and Cuernavaca. And, because of its highly permeable soil, it recharges the aquifers that supply the

Valley of Cuernavaca. It may be the most important area of grasslands in central Mexico (Cabrera-García et al. 2006), and likely acts as corridor connecting the volcano rabbit populations of the Tlaloc Volcano with those of the Pelado Volcano, two core areas of its distribution (Velázquez et al. 1996). Paradoxically, very little is known about the current status of *R. diazi* in the area, and there are only a few historical records dating from 1996.

As part of an ongoing program to monitor the volcano rabbit in the COBIOCH, to determine its current status and to collect baseline information for the area to make decisions about species management and conservation, we conducted a survey using direct (sighting the rabbits in the field) and indirect (fecal pellet counts, number of latrines) techniques, and estimated its density within the area of the biological corridor. To document the distribution of the volcano rabbit, from June to November 2008, and from June to December 2011 we randomly selected 174 points from all of the suitable habitats in the COBIOCH. Each point consisted of an area of 50 x 50 m within which exhaustive searches were conducted and latrines counted by at least 4 people. The latrine counting method had been used previously to document the abundance and distribution of the volcano rabbit (Fa et al. 1992; Velázquez 1994). In addition, we recorded all rabbits sighted along the roads and in the grasslands while driving or walking between sampling sites. Each sampling point and rabbit sighting was recorded using the Universal Transverse Mercator (UTM) geographic coordinate system, and uploaded to Geographical Positioning System software using a Garmin GPS device (coordinate output to WGS84). Using these records, we estimated the area of distribution for the species within the COBIOCH, and compared it to the distribution area estimated using all of the records reported by Velazquez et al. (1996). In both cases and using ArcView 3.2 (ESRI), we first generated a buffer area, 500 m in radius, around the location of each record, to determine the area where the species might be located. We then estimated its probable distribution area using the Minimum Convex Polygon method, and the Fixed Kernel Isopleths method, both at the 95% confidence level (Harris et al. 1990; White and Garrott 1990; Worton 1989). The output models for each method were combined spatially (MCP + Kernel model), and were subsequently cut with contours above 2,800 m a.s.l., and finally intersected with the polygon of the COBIOCH to measure the area that lies within the protected natural area. The process was done using the "Animal Movement Analyst" extension for ArcView 3.2.

The annual density of the volcano rabbit was estimated using the line transect method (Buckland et al. 1993). For this, eight reasonably straight, permanent 1000-m-long walking line transects were established, at least 1 km apart, to cover different habitats. Monthly volcano rabbit surveys were conducted from March 2008 to February 2009. Two experienced observers conducted the survey, both searching ahead and to each side of the transect while walking at a relatively constant speed of 0.5 km/h. All surveys were conducted between 0700 and 0900 h, which is when the volcano rabbit is most active (Cervantes-Reza and Martinez-Vazquez 1996). The position of rabbits observed on the center line was recorded as a distance of zero, and for those observed to either side of the transect the perpendicular distance (m) was recorded from the rabbit to the center line (Buckland et al. 1993) using a Multi Measure Combo Pro (Sonin Inc.) electronic distance measuring tool. The data were analyzed using the Distance 5.0 program (Thomas et al. 2010) to estimate rabbit density per hectare. To model the detection function of the perpendicular distances, data were pooled across all transects. Three models were considered for the detection function: half-normal, uniform and hazard rate. In each case the need for cosine adjustment terms was assessed using likelihood ratio tests. In all analyses 5% of the longest distances were truncated to avoid bias introduced by outlier distance sightings. The final model was chosen based on a combination of a low value for Akaike's information criterion (AIC) and low variance.

The presence of the volcano rabbit was documented at 149 points in the northernmost part of the COBIOCH. It was absent from 25 points with suitable habitat. The records include 48 sightings and 101 pellet records. Based on all the records, the estimated area occupied by this species in the Protected Natural Area and the zone of influence was 166.43 km^2 (Table 1). Interestingly, most of this area was not included in the distribution map proposed by Velazquez et al. (1996), which is the basis for the IUCN map (IUCN, 2012). Thus, our results represent an increase in the range of the known distribution for *R. diazi* (Figure 2). Before our field survey, there were only 49 historical records based on collecting, the literature and field surveys conducted in the study area (see Appendices 2 and 3 in Velazquez et al. 1996). Based on that information, coupled with an analysis of climate, elevation and vegetation maps along the Trans-Mexican Volcanic Belt, six peripheral areas—isolated from each other—were recognized for the volcano rabbit within the area inside the COBIOCH (Velazquez et al. 1996). Our direct and indirect records point to a different scenario. First, the proximity of all the records indicates that the populations of the volcano rabbit might not be isolated from each other and that the rabbits are likely moving between landscapes. The only barrier to dispersal is the highway, built in 1952, that crosses the COBIOCH and has prevented connectivity between populations on either side of the highway, as indicated by genetic data (Campos-Chavez 2005). Second, Velazquez et al. (1996) recognized as core distribution areas of *R. diazi* those with suitable habitat where rabbits were sighted, and traces (pellets) were found. The results presented here clearly meet these criteria, therefore indicating that the COBIOCH must be also considered a core area of distribution of the volcano rabbit.

During the 12 months of the density survey, a total of 97 volcano rabbits were sighted along 96 km of transect. The analysis of these data using the Distance 5.0 software indicates that the half-normal + 1cosine model provided the best fit to our distance data according to the AIC and variance values (Table 2). This model estimates a density of 6.2 volcano rabbits/ha. This is higher than the only previous report of 1.22 rabbits/ha for the area of the Pelado Volcano using similar methodology (Velázquez 1994), and provides evidence that the COBIOCH is one of the most important habitats for volcano rabbit populations.

These results make an important contribution to our knowledge of the distribution of *R. diazi*, and the evidence regarding its occurrence and density obtained during this study allow us to assert that the COBIOCH provides a suitable habitat with conditions that are appropriate for *R. diazi* to establish and maintain populations with high abundances. It is therefore necessary to implement conservation actions that focus on habitat management in order to avoid the habitat loss and fragmentation that result from grazing, crop cultivation and road construction. Further studies should be conducted to investigate the movement patterns of individual volcano rabbits, and their genetic variability in the COBIOCH, as well as their relationship with the volcano rabbits inhabiting other core distribution areas.

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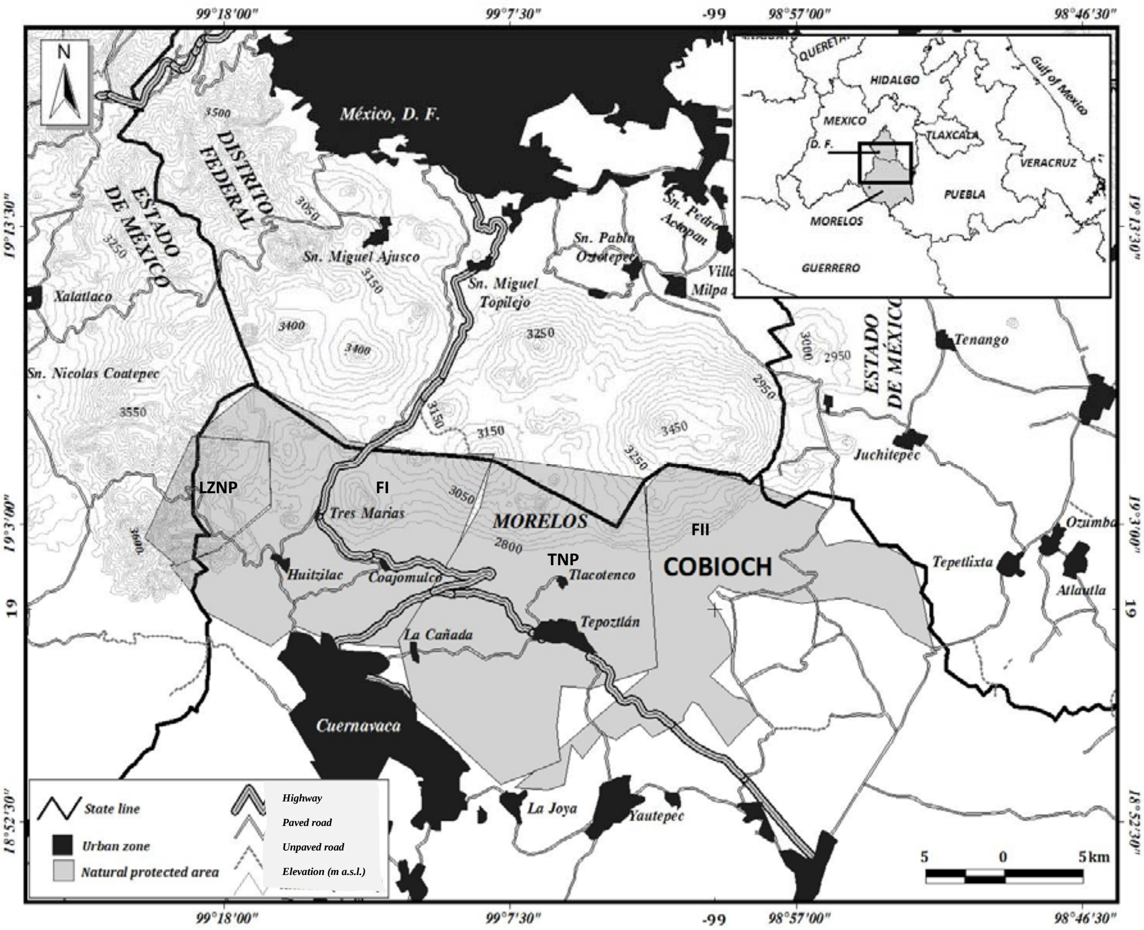
Table 1. Estimated area occupied by *R. diazi* (km^2) based on the historical and current records for the *Corredor Biológico Chichinautzin* (COBIOCH) Protected Natural Area.

Table 2. Estimates of annual volcano rabbit density (D) using Akaike's information criterion (AIC) and the percent coefficient of variation (%CV) for each model.

Figure 1. Location of the Corredor Biológico Chichinautzin Protected Natural Area in Mexico. LZNP, Lagunas de Zempoala National Park. FI, Fraction I. FII, Fraction II. TNP, El Tepozteco National Park.

Figure 2. Estimated area of the volcano rabbit distribution in the Corredor Biológico Chichinautzin, based on historical and current records.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México, D. F.
DISTRITO FEDERAL
ESTADO DE MÉXICO
Sn. Miguel Ajusco
Sn. Miguel Topilejo
Sn. Pablo Oztotepec
Sn. Pedro Actopan
Villa Milpa
Xalatlaco
Sn. Nicolas Coatepec
Tenango
Juchitepec
Ozumba
Tepetlixta
Atlautla
LZNP
FI
FII
TNP
COBIOCH
MORELOS
Tres Marias
Huitzilac
Coajomulco
Tlacotenco
Tepoztlán
La Cañada
Cuernavaca
La Joya
Yautepec
3500
3050
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3400
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3600
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QUERETARO
HIDALGO
MEXICO
D. F.
TLAXCALA
VERACRUZ
PUEBLA
MORELOS
GUERRERO
Gulf of Mexico
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Urban zone
Natural protected area
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Paved road
Unpaved road
Elevation (m a.s.l.)
5
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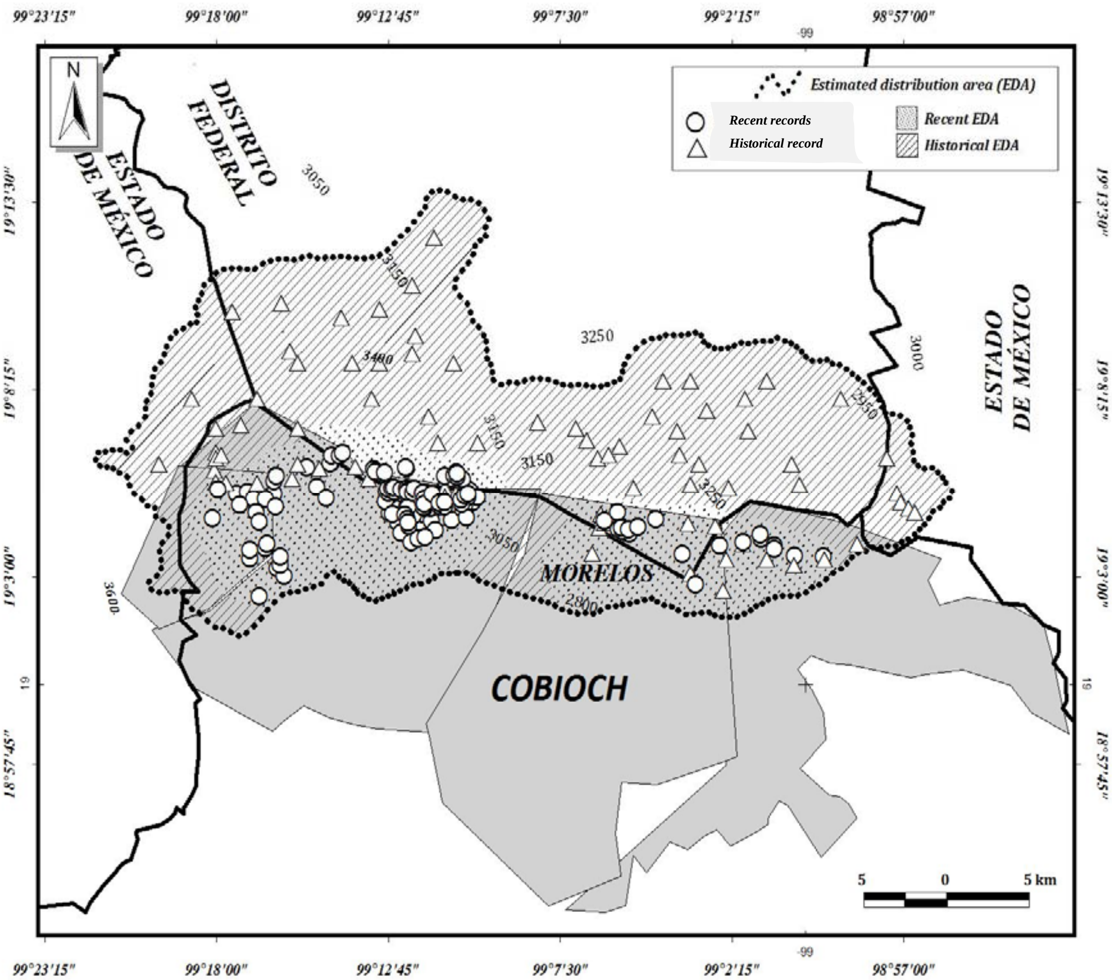
5 km


Estimated distribution area (EDA)
Recent records
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Recent EDA
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ESTADO DE MÉXICO
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5 0 5 km
99°23'15"
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99°2'15"
98°57'00"
19°13'30"
19°8'15"
19°3'00"
18°57'45"

Table 1. Estimated area (Km^2) based on the historical and present records in the COBIOCH

	Estimated Area (Km^2)	
	Historical Records	Present Records
Fraction I and II	32.09	98.96
El Tepozteco	8.64	46.88
Lagunas de Zempoala	16.12	20.59
Total Area	56.85	166.43

Table 2. Estimates of volcano rabbit annual density (D) with Akaike's information criterion (AIC) and percentage coefficient of variation (%CV) for each model.

Models	AIC	D	%CV
Half-normal + 1 cosine	614.24	6.2	10.1
Unifrom + 1 cosine	675.68	7.7	14.7
Hazard rate + 1 cosine	668.13	8.1	12.5

Capítulo III

Aceptado en Oryx, The International Journal of Conservation

Relationship between the abundance of the Endangered volcano rabbit *Romerolagus diazi* and vegetation structure in the Sierra Chichinautzin mountain range, Mexico

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Abstract The volcano rabbit *Romerolagus diazi* is endemic to the mountains of central Mexico, where its habitat has been gradually destroyed to make way for agriculture, ranching and logging, and by forest fires. The volcano rabbit is categorized as Endangered on the IUCN Red List. We evaluated the relationship between the abundance of the volcano rabbit and vegetation structure at a small scale (0.25 ha). Using a general linear model we generated a set of 21 predictive models and proposed the best model as a habitat quality index. Our results suggest that greater grass height and cover and the presence of a shrub layer offer the volcano rabbit the best refuge from predators. The habitat quality index and the limited available habitat documented in our survey indicate that the populations of volcano rabbits in the study area are more threatened than previously thought. As *R. diazi* is a habitat specialist it does not have the option of moving to another habitat type.

Keywords Endemic, habitat quality index, habitat specialist, lagomorph, Mexico, pellet count, *Romerolagus diazi*, volcano rabbit

Introduction

The volcano rabbit *(Romerolagus diazi)* is endemic to central Mexico and its current distribution is one of the most restricted of the mammals in Mexico. It is limited to the Ajusco-Chichinautzin mountains, and to the Popocatépetl, Iztaccíhuatl, Pelado and Tláloc volcanoes. Known locally as the teporingo or zacatuche, this species is distributed over an approximate area of 386 km^2 (Velazquez et al., 1996) at elevations ranging from 2,800 to 4,250 m. (Fa & Bell, 1990). *R. diazi* is considered a habitat specialist and depends on wild subalpine bunch grassland communities (known locally as *zacatonales*) characterized mainly by *Muhlenbergia* spp., *Festuca* spp., and *Jarava ichu*, and associated with trees of the genus *Pinus*, *Alnus* and *Quercus* (Hoth et al., 1987; Velázquez, 1993). Due to the increase in the areas used for agriculture, ranching, logging and those consumed by forest fires, the habitat of the volcano rabbit has been gradually destroyed (Portales et al., 1996). Populations of the volcano rabbit are now at risk and this species is currently listed as endangered by the Mexican government (SEMARNAT, 2010), and as an endangered species on the Red List of the International Union for Conservation of Nature (IUCN, 2012).

The habitat of a species can be examined at various scales ranging from the local micro-scale (microhabitat) to the regional and global macro-scales (Partridge, 1978, Delcourt & Delcourt, 1988; Dunning et al., 1992; Morrison et al., 2006). Heterogeneous landscapes are a common feature in the geographical distribution ranges of most species of mammals, even those with a restricted distribution (Feldhammer et al., 2007). This mosaic of environmental conditions or habitat types is necessary to meet all of the requirements for the survival of the species (Hansson, 1979). At the local scale, habitat use can be studied by measuring the population density or abundance of focal species, assuming that the abundance of animals is higher in the habitats that are more suitable for sustaining populations (Partridge, 1978, Duncan et al., 1997). This suggests a unimodal distribution of population density along a gradient of habitat types (Velázquez, 1993). Although the current status of wild populations of *Romerolagus diazi* is critical, until now no information has been reported on their size, structure or demography, and knowledge of the ecological relationships between this species and its habitat is scant. The available information on habitat use is limited to the landscape scale (Velázquez, 1993, Velázquez & Heil, 1996). The only study carried out on the local scale was limited to the area of the Pelado Volcano (Fa et al., 1992). So, little is known about the habitat relationships of this species at local scales throughout its distribution or about its peripheral populations (Velázquez et al., 1996).

Here, we evaluate habitat characteristics and their relationship to the abundance of the volcano rabbit. To this end, we counted rabbit latrines as an indirect method of determining population abundance (Palomares, 2001), and we describe the structure of the habitat and analyze the relationship between these two parameters in order to generate a habitat quality index.

Methods

Study Area

We investigated volcano rabbit populations in the Sierra Chichinautzin mountain range (Figure 1). This is an important area within the distribution of *R. diazi* because the populations of this species throughout its habitats may be effectively isolated from other volcano rabbit populations that inhabit the Pelado, Tlalóc, Popocatépetl and Iztaccíhuatl volcanoes, which are considered to be its core distribution areas (Velazquez et al., 1996). Part of the study area includes a protected area—the Chichinautzin Biological Corridor—that is located in the north-western part of the state of Morelos, and on the southern edge of the Federal District (Mexico City).

Sample site selection

Using 1:20,000 aerial photographs from 1995 (National Institute of Statistics, Geography and Informatics, INEGI), 115 sampling points were selected randomly with the criterion that they be located above 2,800 m a.s.l. (Arc view 3.2), with reference to the contour lines at 1:50,000 scale (INEGI). Urban areas were excluded (Tres Marías, Huitzilac, Coajomulco, Fierro del Toro and Parres). During the study we visited all of the points selected in order to document habitat availability based on the presence of the grasses *Muhlenbergia* spp. and *J. ichu*. After the *in situ* evaluation, 64 points were found to have suitable habitat for *R. diazi*, and 51 points did not (i.e. sites with fir oak and pine forest, secondary vegetation, landform, and mostly deforested areas used mainly for growing oats and potatoes). None of the latter sites has suitable habitat for the establishment of volcano rabbit populations.

Estimating abundance

Between June and December 2008 we estimated the population abundance of the volcano rabbit at the sampling sites, using the indirect method of counting the number of latrines. Following the method of Velázquez (1994), a group of 30 or more pellets was defined as a latrine. This method is considered reliable for estimating the population abundance of lagomorphs (Palomares, 2001) and has been used to estimate the population size of the volcano rabbit elsewhere in its distribution area (Velázquez, 1994). Thus, at each of the 64 sites, we mapped one 50 by 50 m quadrat (2,500 m^2), which was carefully surveyed for fresh latrines.

Habitat description

After the survey of volcano rabbit abundance, we randomly selected 22 of the 64 points to describe the structure of the volcano rabbit habitat. Seven vegetation attributes were measured:

tree height, cover, and diameter at breast height, shrub height and cover, and grass height and cover. In addition, we calculated standard deviation for the height of the three strata, and for diameter at breast height as a proxy for habitat complexity.

Tree height was measured using a clinometer, and shrub height with a telescopic rod (vegetation height was always measured in metres to the nearest centimetre). To calculate tree and shrub cover, we measured the crown diameter of all trees and shrubs in the quadrat using Sonin® Electronic Distance Measurers. From the diameter, the circular area of cover was obtained for each individual, and individual cover values were added and later transformed into percentages of cover. Grass height was obtained by measuring 10 individuals of the two most abundant species (*M. macroura* and *J. ichu*), and the percentage of cover was estimated visually by the same person, thereby minimising inter-observer variation.

Data Analysis

Because the variables used to describe the habitat at the sites are typically dependent on each other, they cannot be separated and analysed individually (Cooley & Lohnes, 1971). Therefore, we conducted a principal components analysis (PCA), which generates new axes from the linear combination of the original variables. The resulting principal components also have the advantage of being orthogonal and are considered independent variables. For this analysis we used the correlation matrix because the habitat description variables differ in unit and scale (James & McCulloch, 1990). From the resulting principal components, we selected those with the highest eigenvalues, the sum of which explained 90% of the variance.

Finally, these principal components were used as new descriptive variables of the habitat for the construction of a habitat quality index. We formulated a set of predictive models (21 in total) using different combinations of the major components, which were analysed using generalized linear models (GLM) under a Poisson distribution. The independent variables were the principal components and the dependent variable was the population abundance of the volcano rabbit (i.e. the number of latrines recorded at each site). To select the best models we used the Akaike Information Criterion (Akaike, 1973). The PCA was run in Statistica 6.0 (StatSoft, 2001), and habitat analyses in R 2.14.1 software and using the Biodiversity R package (Kindt & Coe, 2005) developed by R software.

Results

Abundance records

The total area sampled was 160,000 m^2. We counted 3,330 latrines in the 64 quadrats in the study area previously found to have suitable habitat. At 27 (42%) of the sites, latrine concentration was 1 to 50 latrines, 12 (19%) had latrine concentration ranging from 51 to 150, and only 9 (14%) of the sites had 151 to 300 latrines. Only in 16 (25%) sites no latrines were found. The abundance of latrines also has a variation in the altitudinal range of 2760 to 3760, the category 1 to 50 latrines was more frequent in the range of 2960 to 3050, while the 151 to 300 category it was in the range of 3060 to 3150 (Figure 2). Based on this we can say that population abundance is not homogeneous in the study area, even when the conditions necessary for the establishment of a population are present.

Of the 22 sites selected for habitat characterization eight (36%) had 1-50 latrines, 6 (27%) had 51-150 latrines, 5 (23%) had 151-300 latrines and 3 (14%) had no latrines

Habitat analysis

Five principal components were retained, which together accounted for 90% of the total variance in the habitat data (Table 1). PC1 is negatively associated with the variables representing the characteristics of the tree layer (cover, DBH and height). PC2 was negatively associated with shrub coverage. PC3 was associated with a mixture of variables from different strata: it was positively associated with grass height and tree height and negatively associated with the standard deviation of the height of tall shrubs. The PC4 axis was explained by positively associated with shrub coverage, and PC5 was explained by the negative correlation between of the standard deviation of the height of grass and the positive correlation with grass height. Figure 3 graphically represents the original variables used to describe the habitat in the space of principal components.

Twenty-six different models were generated from different combinations of the five principal components used as descriptive variables for the abundance of the volcano rabbit. The model with the lowest value for the Akaike information criterion (AIC) held two major components (PC3 and PC5), both with a positive estimate (Table 2). This model represents the habitat quality index. Therefore, on analysing the correlations of the original variables and principal components (Figure 3), we note that *R. diazi* populations tend to be more abundant on sites with taller grasses, higher grass cover and taller trees, and where there is less variation in shrub and tree height.

Discussion

In this study we evaluated the vegetation structure characteristics that influence, on the small scale of habitat (0.25 ha), both the distribution and abundance of this species in the Sierra Chichinautzin mountains. These results broaden our understanding of the ecological relationships between the volcano rabbit and its habitat, provide evidence of habitat use, and about which aspects of the vegetation structure influence the establishment of *R. diazi* populations.

The only published study on the relationship between the occurrence of the volcano rabbit and its habitat (Velázquez & Heil, 1996) focused on the floristic composition of vegetation and found that greater rabbit abundance was recorded in *Festuca tolucensis* and *Trisetum altijugum* - *Festuca tolucensis* communities. Based on their analysis, Velázquez et al. (1996) concluded that *R. diazi* prefers a subalpine habitat. However, several authors have stated that it is the structure of the vegetation and habitat configuration, rather than a particular taxonomic composition, that determine patterns of habitat occupancy in several animal species (Pardini et al., 2005, Rotenberry, 1985, Rosenberg & McKelvey, 1999).

Since *R. diazi* is a prey species for several predatory animals, the availability of resources for feeding, breeding and shelter all are factors that determine its spatial distribution, habitat use and the shape of its home range (Gibb, 1993). It has also been shown that when populations live in contrasting environments their home range changes and that this response is directly related to habitat quality and resource distribution (Gibb, 1993; Hulbert et al., 1996; Lombardi et al., 2003; Stott, 2003; White et al., 2003).

Our results suggest that habitat features such as the height and cover of bunch grassland potentially represent a source of protection and food resources and that these, in turn, are the main factors that determine habitat selection by herbivorous species considered to be prey (Simonetti, 1989; Lagos et al., 1995). The greater height and cover provided by grasses, as well as the presence of a shrub layer may offer the volcano rabbit the best refuge from potential predators, including the carnivores *Lynx rufus*, *Canis latrans* and *Mustela frenata*, birds of prey such as *Buteo jamaicensis* and *Bubo virginianus*, and the rattlesnake *Crotalus triseriatus* (Cervantes-Reza, 1981).

The Sierra Chichinautzin may represent the last core area of bunch grassland in the central part of Mexico (Cabrera-García et al., 2006). However, the elimination of bunch grasses during the creation of new agricultural fields and their progressive elimination through excessive fires contribute to the degradation and disappearance of this habitat. This is evidenced by the limited available habitat documented in our field survey. Only 64 of the 115 points visited were found to have suitable habitat for *R. diazi*. This is particularly evident in the area covered by our survey of available habitat fragments between 2800 and 2900 m, because there are areas that have been converted by land owners to croplands and pastures, and others which are used for timber extraction, the main economic activities in the area.

The strong association of volcano rabbit abundance with the habitat quality index provided here together with the limited availability of suitable habitat documented in our field survey, suggests that populations of *R. diazi* in the area are at risk. The fact that *R. diazi* is a habitat specialist means it has no options for moving to another habitat type.

The information presented here, along with that previously reported for the landscape scale and other areas in the distribution of the volcano rabbit (Fa et al., 1992; Velázquez, 1993; Velázquez et al., 1996) can be used to generate strategies for habitat conservation; an important endeavour considering that habitat destruction is the most important driver of species extinction worldwide (Pimm & Raven, 2000). The continuous loss of volcano rabbit habitat warrants the implementation of an environmental education program and actions that bring together academia, government and nongovernmental organizations, so that the people of the region receive benefits for conserving their land, which is the only habitat of the volcano rabbit.

Acknowledgements

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Biographical sketches

A. Rizo-Aguilar is interested in the conservation biology of vertebrates, and for the last 6 years has been monitoring the populations and habitat of the volcano rabbit. José Antonio Guerrero is a researcher working on the molecular systematics of bats and rodents, and is also interested in the conservation and management of *R. diazi* and its habitat. Mircea Hidalgo-Mihart has worked on the conservation and management of tropical mammals, especially carnivores and rodents, in western and southeastern Mexico since 1998. A. González-Romero has been monitoring mammal populations in the Mapimi Biosphere Reserve in Durango, Mexico for the last 17 years and in recent years has also been studying the endemic ground squirrel of Perote, Veracruz, Mexico.

Figure and Table Legends

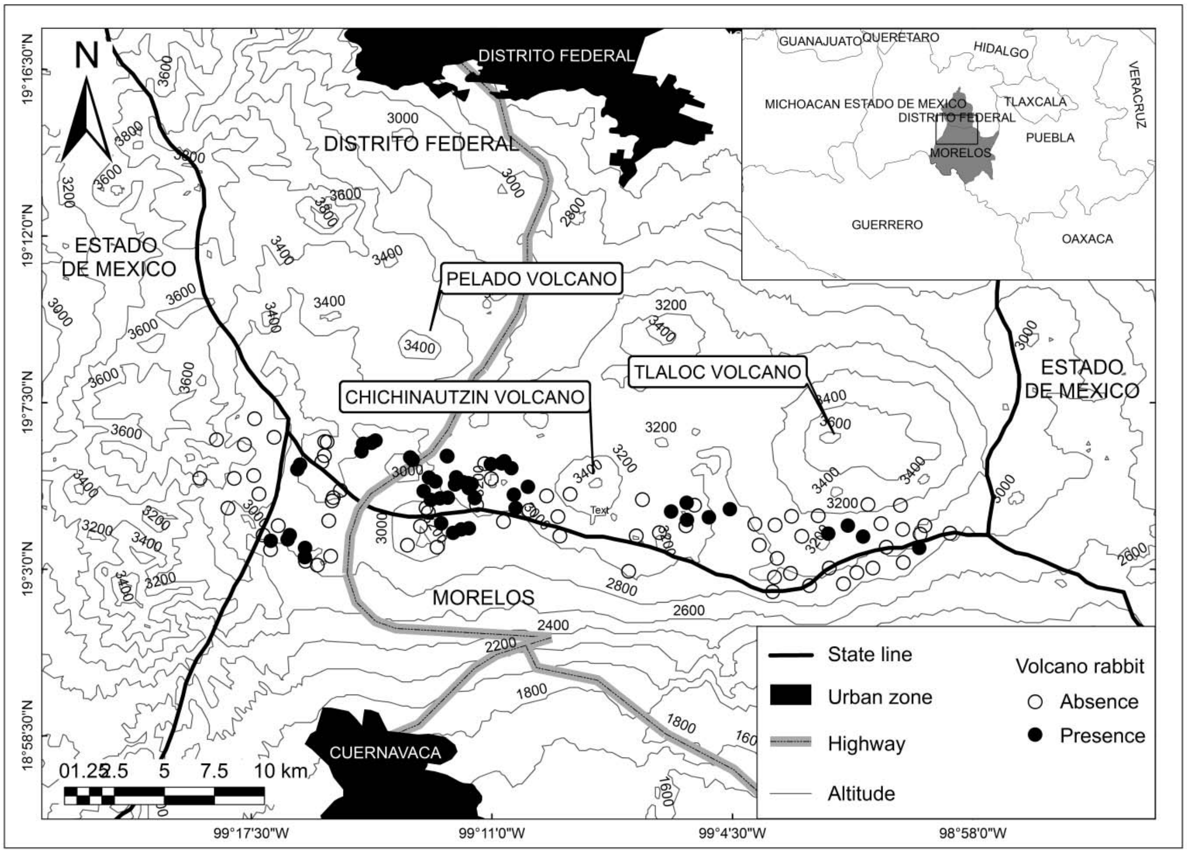
Figure 1. Location map of the Sierra de Chichinautzin mountain range, with the locations of the 115 sites sampled.

Figure 2. Frequency distribution of the categories of latrines abundance on the altitudinal range. The lowest record of latrines was at 2760 m and the upper at 3180 m.

Figure 3. The relative weights (correlations) of the original variables that describe the habitat with the four principal components. GC Grass cover, GH Grass height, SDGH SD of Grass height, SH Shrub height, SDSH SD of Shrub height, SC Shrub cover, TC Tree cover, HT Height tree, SDHT SD of height tree, DBH Diameter at breast height, SDDBH SD of DBH.

Table 1. Weights of the variables describing the habitat on the main components and variance explained by these components. Significant correlations are marked in bold.

Table 2. Parameters of the best model selected on Akaike information criterion, with estimated value, standard error. Wald’s statistic, and P value.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HIDALGO
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GUERRERO
OAXACA
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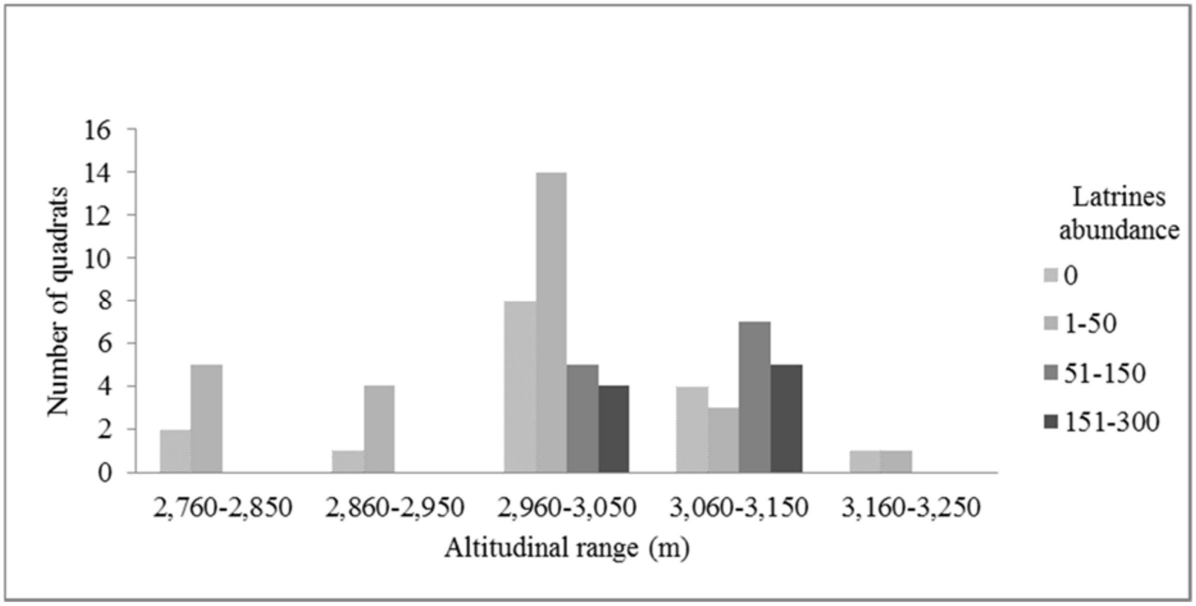
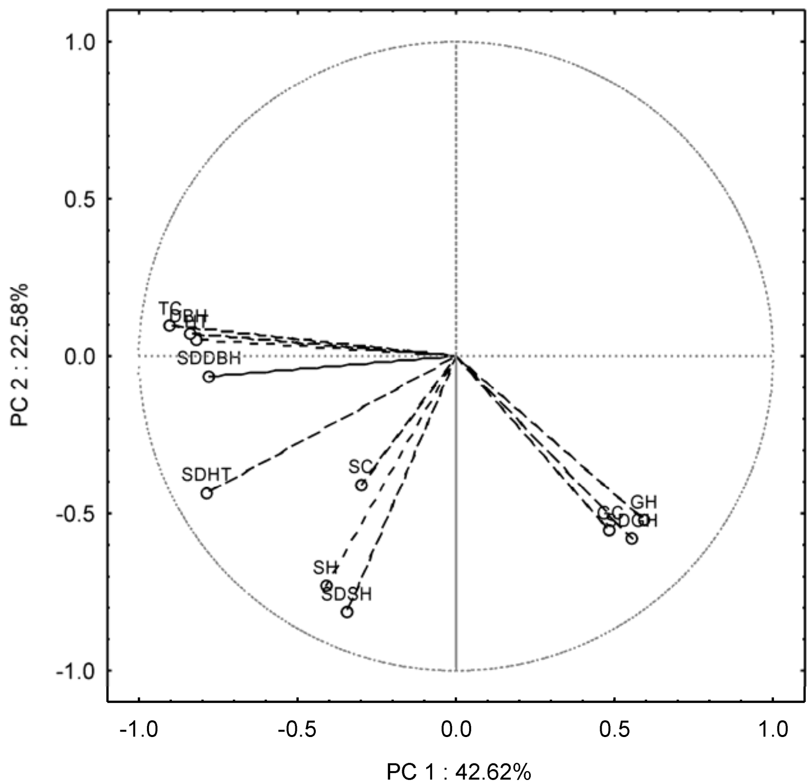
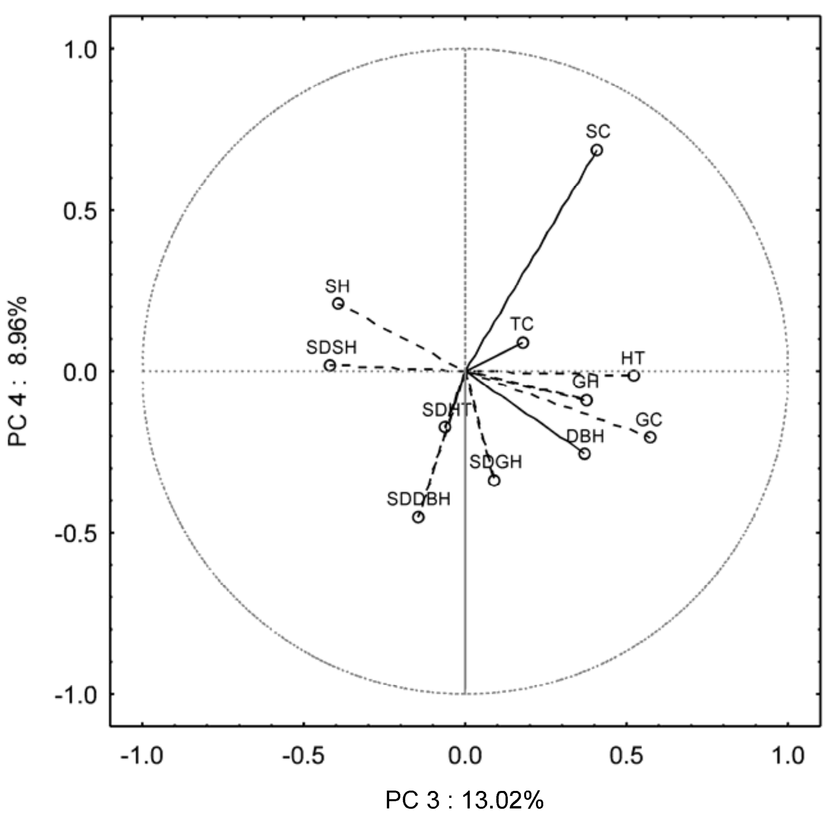
Highway
Altitude
Volcano rabbit
Absence
Presence
0 1.25 2.5 5 7.5 10 km
19°16'30"N
19°12'0"N
19°7'30"N
19°3'0"N
18°58'30"N
99°17'30"W
99°11'0"W
99°4'30"W
98°58'0"W



Number of quadrats
16
14
12
10
8
6
4
2
0
2,760-2,850
2,860-2,950
2,960-3,050
3,060-3,150
3,160-3,250
Altitudinal range (m)
Latrines abundance
0
1-50
51-150
151-300


1.0
0.5
0.0
-0.5
-1.0
PC 2 : 22.58%
PC 1 : 42.62%
TC
DBH
SDDBH
SDHT
SC
SH
SDSH
GH
GC
SDGH


1.0
0.5
0.0
-0.5
-1.0
PC 4 : 8.96%
PC 3 : 13.02%
SC
SH
TC
SDSH
HT
GH
SDHT
GC
DBH
SDGH
SDDBH

	PC 1	PC 2	PC 3	PC 4	PC5 5
Variance explained	42.61	22.57	13.02	8.96	4.86
Grass coverage	0.4816	-0.5555	**0.5712**	-0.2051	0.1736
Grass height	0.5939	-0.5216	0.3759	-0.0875	**0.3534**
SD of Grass height	0.5565	-0.5798	0.0908	-0.3352	**-0.4474**
Shrub height	-0.4102	**-0.7279**	-0.3936	0.2072	0.1810
SD of Shrub height	-0.3423	**-0.8132**	**-0.4183**	0.0191	0.0220
Shrub coverage	-0.2983	-0.4082	0.3068	**0.6882**	-0.2271
Tree coverage	**-0.9018**	0.0946	0.1760	0.0907	0.2403
Height tree	**-0.8189**	0.0528	**0.5189**	-0.0149	-0.0947
SD of height tree	**-0.7856**	-0.4333	-0.0613	-0.1744	-0.1535
DBH	**-0.8415**	0.0701	0.3685	-0.2559	-0.0358
SD of DBH	**-0.7807**	-0.0620	-0.1454	-0.4501	0.0538

	Parameters of the model			
	Estimated value	Standard Error	Wald's Statistics	*P*
Intercept	1.545463	0.003697	737.7	0.04570
PC 3	0.040936	0.003542	133.6	0.00000
PC 5	0.03967	0.003671	3.6	0.01772

Capítulo IV

Conclusiones generales

El estudio se realizó en la Sierra del Chichinautzin, área de la Faja Volcánica Transmexicana donde se encuentra el Área de Protección de Flora y Fauna Corredor Biológico Chichinautzin (COBIOCH). Como parte de esta investigación se estimó el área que ocupa *Romerolagus diazi* dentro del polígono decretado por la Comisión Nacional para las Áreas Naturales Protegidas, y su zona de influencia, obteniendo un área de 166.43 km^2. Los resultados de este trabajo muestran un incremento en los registros del zacatuche, así como una mayor extensión del área de distribución conocida para *R. diazi* en el COBIOCH. Hasta el momento del estudio se habían documentado sólo 49 registros, mientras que el trabajo de campo aportó 149 registros. El área de ocupación estimada con los registros históricos era de 56.85 km^2, es decir que, con los muestreos detallados de la especie se estimó un área tres veces mayor de lo conocido. Además, se estimó una densidad de 6.2 conejos/ha, la cual representa una densidad incluso mayor a la reportada en el Volcán Pelado, considerada una zona núcleo. Por la distancia entre los registros de ocurrencia de la especie, es posible que exista intercambio de individuos entre los fragmentos de hábitat; la única barrera de dispersión es la autopista México-Acapulco. Los resultados de este trabajo muestran evidencia de la importancia de esta Área Natural Protegida para la conservación del conejo de los volcanes, al ofrecerle áreas de hábitat con la calidad necesaria para establecerse y mantener sus poblaciones.

El análisis de la estructura del microhábitat del conejo zacatuche es el primero reportado donde se relacionan las variables descriptoras del hábitat con las abundancias relativas del zacatuche. Los resultados de este análisis sugieren que el hábitat de mayor calidad es el que presenta mayor cobertura de pastos y árboles altos, y mayor homogeneidad en la altura de los arbustos.

Los resultados del análisis de calidad del hábitat mostraron que la cobertura y altura del zacatonal son variables de la estructura del hábitat que favorecen la abundancia del conejo zacatuche. Estos resultados, coinciden con los hallazgos de Rangel-Cordero (2008), sobre la recolonización de parches de pastizal incendiados. Las coberturas densas de pastizal que se desarrollan después de 2 años de ocurrido el incendio favorecen el establecimiento de poblaciones de zacatuche. Igualmente, coinciden en que la presencia de un estrato arbustivo, en este caso dominado por la especie *Lupinus montanus*, le ofrece una cobertura importante para visitar parches de pastizal en regeneración. En el caso de *R. diazi* el único estudio publicado sobre la relación entre la ocurrencia y su hábitat, se basó en estudiar la composición florística y relacionarla con la abundancia poblacional, registrando las mayores abundancias en comunidades compuestas por *Festuca tolucensis* and *Trisetum altijugum - Festuca tolucensis* (Velázquez y Heil, 1996).

Si bien no hay datos reportados del área de actividad del conejo zacatuche, Solorio (2013) documenta que los individuos no se alejan grandes distancias del fragmento de hábitat con cobertura densa para realizar sus actividades de forrajeo, cortejo y otras actividades interespecíficas, y que el tiempo que permanecen fuera del zacatonal, se mantienen en estado de alerta. Esto puede indicarnos la importancia de conservar la cobertura, no sólo dentro del fragmento de hábitat, sino también en los corredores que conecten los fragmentos de hábitat, para favorecer el desplazamiento de los individuos.

Otro aspecto importante que se ha estudiado recientemente en relación a la calidad del hábitat del zacatuche es la cuantificación de los niveles de cortisol metabólico entre individuos que habitan en sitios conservados (coberturas de zacatonal mayores al 70% y con poca influencia humana) *versus* sitios transformados (cobertura del zacatonal menores del 70% y con actividades humanas como pastoreo y extracción de tierra de monte). Los resultados mostraron mayores concentraciones de cortisol en excretas de individuos que habitan en sitios transformados (Montoya, 2012). El incremento de cortisol propiciado por la mala calidad del hábitat, puede tener consecuencias en el mediano y largo plazo en la salud de los individuos, ocasionando eventos de reproducción fallidos, alteraciones en la conducta e inmunosupresión (Munck *et* al, 1984; Sapolsky y Pulsinelli, 1985; Martínez-Mota *et al*, 2007).

Los pastizales de la Sierra del Chichinautzin representan la última área de pastizal en la región central de México (Cabrera-García et al., 2006). Esta área que se encuentra bajo fuertes presiones por la expansión urbana y agrícola, y actualmente es fragmentada por importantes vías de comunicación que conectan el Distrito Federal con los estados de Morelos y Guerrero. Estudios realizados simulando escenarios futuros muestran el efecto del cambio climático en la distribución de *R. diazi*, (Domínguez, 2007). La proyección para el año 2050 muestra una reducción del 58% del área de distribución que actualmente es hábitat potencial para *R. diazi*., principalmente en áreas por debajo de los 3000 m s.n.m. Algunos estudios reportan que el bosque templado es uno de los ecosistemas con mayor afectación por el cambio climático (Villers y Trejo, 2004)

La sustitución del pastizal por otro tipo de cobertura como campos agrícolas de avena o papa, y los incendios forestales, contribuyen a la degradación y reducción de este hábitat. De manera que, dada la fuerte asociación de *R. diazi* con las características del hábitat, sus poblaciones en esta área están seriamente amenazadas puesto que no tienen opciones viables para migrar.

Derivado de lo anterior, es necesario realizar acciones concretas en un corto plazo para conservar a la especie, por lo que presentamos algunas propuestas.

PROPUESTAS DE CONSERVACIÓN

- Reconocer al Área de Protección de Flora y Fauna Corredor Biológico Chichinautzin como una zona núcleo de distribución de la especie.

- Restaurar el hábitat del conejo zacatuche en la Sierra Chichinautzin, enfocar los esfuerzos para conservar los fragmentos de pastizal en altitudes mayores a 3000 m s.n.m., implementar acciones de conservación enfocadas al manejo del hábitat, para frenar su pérdida y degradación, y controlar las actividades de pastoreo, agrícolas y construcción tanto de vías de comunicación como de casas-habitación.

- Limitar la construcción de brechas, caminos y carreteras que favorecen la fragmentación del hábitat y dificultan la conectividad

- Regular la extracción de tierra de monte, ya que esta actividad destruye los sitios de refugio del conejo zacatuche y disminuye la cobertura del zacatonal al destruir los macoyos.

- Regular las actividades de pastoreo, que además de causar deterioro en el hábitat, fomentan los incendios forestales y de pastizales.

- Desarrollar un protocolo de estimación poblacional para implementarlo en toda el área de distribución de la especie, en el cual se unifique el método de estimación y la frecuencia de muestreo, lo que permitirá un monitoreo a largo plazo de la especie.

- Diseñar material de divulgación enfocado en la sensibilización/concientización de los pobladores y propietarios de las áreas que contienen hábitats y poblaciones del zacatuche

- Otro aspecto de gran importancia para la conservación de *R. diazi* corresponde a las políticas públicas en las que se involucren los tres niveles de gobierno y autoridades locales. Aquí es, necesario implementar un programa de educación ambiental en el que se involucren academia, gobierno y organizaciones no gubernamentales, buscando que los habitantes de la Sierra Chichinautzin que comparten el hábitat con el conejo de los volcanes, sean los principales actores y beneficiarios de las estrategias de conservación.

- Es necesario continuar realizando investigaciones sobre distintos aspectos del teporingo y su hábitat. Entre ellos se sugiere realizar estudios que analicen las posibilidades de conectar las poblaciones del conejo zacatuche, estimar la disponibilidad actual de hábitat, estudiar el ámbito hogareño, conocer la prevalencia de parásitos, analizar la variabilidad genética y realizar estudios experimentales de manejo de hábitat.

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