DISTRIBUTION AND POPULATION SIZE OF
ROMEROLAGUS DIAZI ON EL PELADO
VOLCANO, MEXICO

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Distribution and population size of the volcano rabbit or zacatuche (Romerolagus diazi) were investigated at El Pelado volcano, one of the four remaining core distribution areas left in Mexico. Latrines or fecal pellets were counted at 342 randomly selected sampling sites between 1986 and 1989. Rabbits also were censused directly from horseback along 29 line transects in October 1988. There was a significant correlation between the mean number of latrines and mean number of rabbits sighted within each of four categories of abundance. Spatial distribution was mapped based on these categories of abundance. Mean size of populations of volcano rabbit was estimated at 6,488 individuals (range of 2,478–12,120). The lower value (2,478) should be used for conservation efforts. Most volcano rabbits occurred at 3,150–3,400 m elev., mainly in the upper and middle southern slopes.

Key words: volcano rabbit, Romerolagus, density, Mexico

The volcano rabbit (Romerolagus diazi) is an endangered (Thornback and Jenkinings, 1984), endemic (Hoth et al., 1987), and relictual species (Barrera, 1966). Its known geographic distribution covers 386 km² mainly on four volcanoes south of Mexico City (Fa and Bell, 1990; Hoth et al., 1987; Velázquez, 1993). These volcanoes exhibit a mosaic of different soils types and zonal, azonal, and man-made plant communities (sensu Walter, 1954), and are exposed to fluctuating climatic conditions. This mosaic represents a complex of types of habitat for Romerolagus (Velázquez, 1993) and makes estimates of population size problematic.

Size of populations within the geographic range of Romerolagus are unknown. Durrell and Mallinson (1970), gathering information from local people and personal observations, estimated populations of 150–200 volcano rabbits/colony and suggested a total population size of 1,200 rabbits over the entire range. This apparent small size of population called for urgent steps to protect the species (Granados, 1981).

Attempts by H. Granados (pers. comm.) and J. E. Fa (in litt.) to estimate size of populations of Romerolagus by mark-recapture techniques were unsuccessful due to vandalism. Other attempts (e.g., roadside counts by car and counts made while walking) usually scared the rabbits away before they were recorded (pers. obser.). The habitat was characterized by a thick layer of Muhlenbergia, Festuca, Calamagrostis, and Stipa bunchgrass (Velázquez, 1993), which makes sightings more difficult than in open areas. Unlike direct methods, fecal pellets of volcano rabbits are conspicuous and their identification in the field is reliable (Hoth et al., 1987). If Romerolagus is present, pellets usually are numerous and clumped into latrines. A reliable population census can be based upon the number of latrines.

Although estimates of population size and distribution are essential for conserva-
tion and management of endangered species (Brown, 1984; Krebs, 1978; Soule, 1986), such information is not available for many species, especially in developing countries (Myers, 1988; Thornback and Jenkins, 1984). *Romerolagus* has been considered an endangered species for 26 years by the International Union for Conservation of Nature and Natural Resources (Simon, 1966); yet, no reliable estimates of its abundance are available. Such estimates are urgently required to support decisions to insure the long-term conservation of the volcano rabbit due to the rapid growth of Mexico City (Velázquez, 1988). This paper provides a more reliable estimate of the density of the volcano rabbit than that previously suggested by Durrell and Mallinson (1970). Additionally, the spatial distribution of *Romerolagus* on El Pelado volcano and surrounding volcanoes is presented.

**MATERIALS AND METHODS**

El Pelado volcano (Fig. 1) was located ca. 10 km from the southern boundary of Mexico City (19°07′-19°11′N and 99°11′-99°16′W). The study area covered ca. 83 km², 48 km² of which has been described as *Romerolagus* habitat by Fa and Bell (1990). El Pelado volcano was of Recent geologic formation, irregular relief, and was between 2,850 and 3,160 m elev. Lithosol and Andosol soils predominate (Gonzáles, 1982). Thirteen plant communities clustered in five main physiognomic vegetation types were present: 1) pine woodland, which was most widely distributed in the upper slopes; 2) mixed coniferous-alder forest throughout the middle slopes; 3) dense fir forest, which was restricted to the cone of the volcano; 4) bunchgrassland; 5) mega-rosette vegetation. Velázquez (1992) gives a thorough description of the habitat types present in the study area.

Indirect (number of latrines) and direct (number of rabbits sighted from transects) techniques were used to estimate the population size of *R. diazi*. Number of latrines also was used to delineate the spatial distributional pattern of the volcano rabbit.

Number of latrines was used as an index of relative abundance. Direct and indirect methods have been used extensively to estimate size of animal populations (Anderson et al., 1979; Caughley, 1977; Cochran, 1977; Krebs, 1989; Seber, 1982). Both methods have been applied to lagomorphs (Foran, 1986; Frame and Wagner, 1981; Krebs et al., 1986a; Ranwell, 1960); many studies have relied on indices of abundance obtained by number of pellets (Clark, 1972; Gross et al., 1974; Oosterveld, 1983; Taylor and Williams, 1956; Wagner and Stoddart, 1971). Gibb (1970) tested the estimation of population size of domestic rabbits by pellet counts with an enclosed population. Krebs et al. (1986a) estimated population density of snowshoe hares (*Lepus americanus*). Using pellet counts and mark-recapture techniques to compare the reliability of both methods, Gibb (1970) and Krebs et al., (1986a) found significant correlations between the population estimates and the pellet counts ($r = 0.96$ and $r = 0.94$, respectively) demonstrating that pellet counts were an accurate way to census rabbits on an extensive geographic scale.

In the present study, I selected randomly and surveyed 342 sites from 1986 to 1989. I chose size and shape of the sites (2.5 by 2.5 m) on the basis of the physiognomy of the herbaceous layer, insuring at least three bunches of grass in each sample and counted all latrines at every site. Counts of latrines ranged from zero to six per site. Because of large variability in the number of latrines observed per site, I assigned ev-
ery site to one of four categories of rabbit abundance, following Cochran (1977) and Krebs (1989). El Pelado volcano was then divided into 251 mapping units of 500 by 500 m (25 ha) each. Based on the mean number of latrines counted per site within the mapping unit, I assigned each mapping unit to one of four abundance classes. Of 251 mapping units, 197 (78%) actually were sampled, and the rest (22%) were classified according to the value of the adjacent mapping units. When adjacent mapping units differed as to mean number of latrines counted, I calculated an overall mean value. If no sampled mapping unit was adjacent, further sampling in the field was conducted. I identified broad areas of the four categories of rabbit abundance by clustering all mapping units of the same class value, which in turn were correlated with complexes of plant communities and their distributions delineated from aerial photographs (Kitichler and Zonneveld, 1988). A final map was prepared by using a geographical information system (Integrated Land and Watershed Information System—Valenzuela, 1988). A statistical program was used to test significance between means and dispersion among categories of rabbit abundance (NEGBINOM—Krebs, 1989). The degree of aggregation was compared using the chi-square test for goodness of fit (Zar, 1984). A level of P < 0.05 was considered as significant throughout the analyses.

To translate values of relative abundance (obtained by the number of latrines) into actual estimates of density, I counted rabbits in 29 transects that were in a line 1 km long. Nine transects were conducted in category II of rabbit abundance, 10 in category III, and 10 in category IV. Category I, where Romerolagus was absent, was thoroughly surveyed by walking. Transect lines were chosen randomly within each category of abundance. Counts of rabbits along the transects were conducted in October 1988 from 0600 to 1000 h, on horseback to increase probability of sighting rabbits and to avoid disturbing the rabbits. Distance from observer and angle from the line transect was measured for all animals sighted. The actual estimation of density was calculated using the modified Hayne estimate (Krebs, 1989). This method assumes that there is a fixed distance from the observer for flushing and detecting the animal, but there are no restrictions in the mean.
TABLE 1.—Habitat characteristics and abundance of Romerolagus diazi in four categories of abundance on El Pelado volcano, Mexico.

<table>
<thead>
<tr>
<th>Rabbit abundance category</th>
<th>Dominant habitat types (percentage of occupied area)</th>
<th>Number of pellets (X ± SE)</th>
<th>Number of transects (X ± SE)</th>
<th>Number of rabbits sighted per ha (X ± SE)</th>
<th>Surface (ha)</th>
<th>Total number of rabbits</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Fir forest (60%); man-induced vegetation by grazing, burning and crops (40%)</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>83</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>Bunchgrassland (40%); megarosette vegetation (20%); mixed coniferous-alder forest (40%)</td>
<td>0.6 ± 0.2</td>
<td>9</td>
<td>0.11 ± 0.05</td>
<td>913</td>
<td>100 (54–146)</td>
</tr>
<tr>
<td>III</td>
<td>Mixed coniferous-alder forest (100%)</td>
<td>1.6 ± 0.4</td>
<td>10</td>
<td>0.24 ± 0.07</td>
<td>2,573</td>
<td>617 (437–2,418)</td>
</tr>
<tr>
<td>IV</td>
<td>Pine woodland (50%); bunchgrassland (20%); mixed coniferous-alder forest (30%)</td>
<td>3.4 ± 0.5</td>
<td>10</td>
<td>1.22 ± 0.8</td>
<td>4,731</td>
<td>5,771 (1,987–9,556)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>83,000</td>
<td>6,488 (2,478–12,120)</td>
</tr>
</tbody>
</table>

sighting angle (Burnham and Andersen, 1976; Burnham et al., 1980). Calculations were made with the aid of the computer program HAYNE (Krebs, 1989). Significance of the relationship between number of latrines and counts of rabbits on the transects was tested by correlation analysis (Zar, 1984).

RESULTS

Categories of rabbit abundance mapped in Fig. 2 were significantly different from each other in both mean and degree of aggregation of latrines (P < 0.001; Fig. 3). In category III of rabbit abundance, an aggregated pattern was found (SMID = 0.5032, P < 0.05). A similar pattern was obtained for category IV of rabbit abundance (SMID = 0.5010, P < 0.05), suggesting similar use of habitat in categories III and IV. The value from the index of dispersion in category II of rabbit abundance does not suggest a clumped pattern (SMID = −0.1188, P > 0.05).

Number of rabbits sighted per transect and total area surveyed were used to estimate the population size of Romerolagus per category of rabbit abundance (Table 1). Population size in the entire study area was estimated to be 6,488 individuals (range = 2,478–12,120). Despite the small samples and high variability, both the direct and indirect methods show similar trends (Fig. 3). These results reach an accuracy of 30% for category III and 50% for category IV. The mean number of latrines and mean number of rabbits sighted are significantly correlated (P < 0.05; Fig. 4).

DISCUSSION

The random index of dispersion found in category II seems unlikely considering the

![Fig. 4. — Correlation between mean number of latrines and mean number of rabbits sighted per category of rabbit density. See Table 1 of text for explanation of categories.](image-url)
sociability of *Romerolagus*. It may mean that habitat conditions are unsuitable to support aggregated colonies or that, at low densities, a random pattern is more advantageous for survival. However, the apparently random dispersion may be an artifact of small sample size (C. J. Krebs, pers. comm.). Similar values of dispersion (SMID) for categories II and IV suggest similar use of habitat by *Romerolagus*. Conclusions based upon values of dispersion (SMID) seem to be more reliable than values of aggregation, which are dependent on sample size and density (Myers, 1978).

Groups of five to seven volcano rabbits have been reported to inhabit dense patches of bunchgrassland, which provide food and protection (Cervantes, 1980; Vélazquez, 1993). In category III of rabbit abundance, fewer patches would be expected than in category IV, but those present should provide the same ecological conditions. This may be a possible biological explanation of the differences in the abundance of rabbits in categories III and IV (Table 1). Actual suitability of habitats might be determined by disturbance factors (e.g., grazing or burning) or by interspecific competition with other lagomorphs (Fa et al., 1992).

My estimate of the population size of *Romerolagus* for El Pelado volcano is 2,478 (at the lowest value) and differs substantially from that of Durrell and Mallinson (1970), who estimated 1,200 rabbits. Durrell and Mallinson (1970) may have conducted their survey in habitats typified by categories I and II of rabbit abundance, which are the most accessible from roads and paths. Most suitable habitats for *Romerolagus* are characterized by dense undergrowth of bunchgrass (Cervantes and Martinez, 1993; Fa and Bell, 1990; Vélazquez, 1993). These dense habitats develop where activities of livestock and fire are less intensive. These man-made disturbances are most common along roads and paths. My results suggest that abundance and distribution of *Romerolagus* is influenced by ecological factors as well as anthropogenic activities. All types of habitat available within the entire distribution range should be surveyed to accurately estimate the size of populations of *Romerolagus*.

The lowest estimate of population size is recommended for planning any action in conservation and management, because of the broad confidence limits of the estimate. To achieve adequate statistical accuracy, 108 additional transects are needed. A further confounding issue is that cycles in the density of lagomorphs have been documented (Krebs et al., 1986b), although such cycles have not been observed in *Romerolagus*.

Number of latrines provides an adequate method to estimate both distribution and relative abundance of *Romerolagus*. Unlike direct methods (e.g., mark–recapture or line transects), indirect techniques can be conducted with minimal cost and easily can provide information necessary for long-term conservation plans in developing countries.

Patrolling transects from horseback is an adequate method to more directly estimate the size of populations of *Romerolagus*. The height on horseback provides easy detection and a good reference point for sighting. Further, because rabbits are not flushed easily while on horseback, the precision of the measurements from the animal to the transect line is increased.

Most grazing and burning activities take place in categories I and II of rabbit abundance. Implementation of an effective control of fire as well as a rotational system of grazing is needed to insure forage for livestock in winter. In the neighborhood of Parres (Fig. 2), environmental education is recommended because young adults and children often catch *Romerolagus* with the aid of dogs while tending herds of sheep and cattle. In habitats included in categories III and IV, it may be necessary to control logging, soil erosion, and destruction of bunchgrass by an effective system of patrolling. Category IV of rabbit abundance is recommended as the core area for protec-
tion because it contains the largest percentage (ca. 75%) of the total population of *Romerolagus* on El Pelado volcano. In contrast to Fa et al. (1992), who stated that *Romerolagus* was most predominant in pine-alder forest, category IV includes 50% of pine–woodland plant communities dominated by *Pinus hartwegii*, 20% of bunchgrassland plant communities dominated by *Festuca-Muhlenbergia*, and 40% of coniferous-alder forest plant communities dominated by *Pinus-Alnus*. The discrepancy may be caused by the subjective habitat classification of Fa et al. (1992; also see Velázquez, 1993).

Similar surveys are recommended throughout the distributional range of *Romerolagus*. These would increase the sample size and the subsequent precision of the estimates of the entire population. Detailed research on habitat characteristics and habitat use are necessary to support future conservation and management decisions. Preliminary studies suggest that habitat conditions differ enough among the four remaining areas of distribution (Velázquez, 1993) that direct observation rather than extrapolation are needed.

**Resumen**

Se investigó el patrón de la distribución y el tamaño de la población del conejo de los volcanes o zacatuche (*Romerolagus diazi*), en el volcán El Pelado, México (una de las cuatro áreas núcleo de distribución). Durante el período de 1986 a 1989 se realizaron conteos de grupos de excrementos (letrinas) en 342 unidades de muestreo elegidas al azar. Aunado a esto, se llevaron a cabo conteos de conejos avistados sobre 29 líneas de transecto durante octubre de 1988. Se obtuvo una correlación significativa entre el promedio de letrinas y el promedio de conejos avistados en cada categoría de abundancia de conejos. El área de estudio fue categorizada con base en la abundancia de conejos para definir el patrón espacial de la distribución. Se definieron cuatro categorías indicativas de diferentes valores de abundancia relativa de conejos. El tamaño de población promedio de zacatuches estimado para el área de estudio fue de 6,488 (rango = 2,478–12,120). Se recomienda utilizar el valor mínimo estimado para acciones de conservación (2,478). El porcentaje mayor de la población de zacatuches se restringió en su distribución a las laderas altas y medianas de la vertiente sur del volcán El Pelado, entre los 3,150 y los 3,400 m de elevación.

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