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**ABSTRACT.**—West European Rock Lizards within the *Iberolacerta* group have a restricted distribution, with small, widely separated ranges in highland areas. The aim of this study was to identify possible habitat requirements (including habitat structure, type of vegetation, and refuge availability) and topographic factors (altitude and orientation) that may determine variations in the abundance of *Iberolacerta cyreni* on a 300-km<sup>2</sup> mountain range and to discuss the implications of our results for the conservation of this endangered endemism. Both a stepwise regression and a best model selection approach showed that lizard abundance was positively correlated with only two predictors: altitude and cover of large rocks. Thus, the successful exploitation of alpine habitats by *I. cyreni* seemed to depend on the abundance of large rocks that may provide suitable basking substrates while minimizing predation risk. The positive association between altitude and lizard abundance predicts a fragmented distribution with isolated populations in the mountain peaks.

Mediterranean mountain ranges are unique ecological systems, where complex topography and historical climate changes have promoted high levels of diversity and endemism (Taberlet et al., 1998; Hewitt 1999; García-Barros et al., 2002). Moreover, their ecosystems are expected to be particularly sensitive to global change (Nogués-Bravo et al., 2007; Thuiller et al., 2005), which emphasizes the need to obtain reliable information on the altitudinal distribution of the organisms that are confined to these environments. For that purpose, a good starting point is to explore the correlations with both biotic and abiotic factors (Hoffmann and Blows, 1994; Holt, 2003; Fortin et al., 2005). This approach has been widely used in a variety of species including lizards (Díaz and Carrascal, 1991; Díaz, 1997; Fisher et al., 2002).

The aim of this study was to identify possible habitat requirements (including habitat structure, type of vegetation, and refuge availability) and topographic factors (altitude and orientation) that may determine the range limits of an alpine Rock Lizard in a 300-km<sup>2</sup> area in Central Spain. West European Rock Lizards within the *Iberolacerta* group have a restricted distribution, with small, widely separated ranges in highland areas, but the causes of their confinement remain largely unexplored. *Iberolacerta cyreni* is endemic to the Sistema Central mountains (Sierras de Guadarrama, Gredos, and Béjar), Spain. It was formerly considered a subspecies of *Iberolacerta monticola* but has recently achieved full species status based on morphological and molecular evidence (Arribas, 1996; Carranza et al., 2004; Crochet et al., 2004). This taxon is listed as Endangered in IUCN Red Lists because of its reduced extent of occurrence and acute fragmentation, with habitat loss and habitat degradation (e.g., development of infrastructure such as roads and ski resorts) being the major causes of its

declining population trend (Pérez-Mellado and Cheylan, 2005; Amo et al., 2007). Habitat preferences of this species have been previously analyzed by Martín and Salvador (1997), but only at a particular site at 1,900-m altitude. Therefore, it is of interest to explore the variations of lizard abundance at a larger, regional scale, covering the whole area of one of the three mountain ranges in which the species is known to be present. Moreover, the Sierra de Guadarrama, where our study was conducted, has been proposed to be declared a National Park, which emphasizes the concern about the degradation of this relevant natural site. Therefore, the results of this study may give helpful insights into management and conservation strategies that should help to preserve the vulnerable populations of this species and the welfare of its alpine habitat.

### MATERIALS AND METHODS

**Study Area.**—The Sierra de Guadarrama is a mountain range located in Central Spain that extends over 80 km in a southwest to northeast direction, reaching its highest peak (Peñalara) at 2,428 m above sea level (a.s.l.). Its continental climate is characterized by contrasting seasonal conditions, with cold wet winters and marked summer droughts. Average minimum (February) and maximum (July) monthly temperatures are  $-3.3^{\circ}\text{C}$  and  $20.8^{\circ}\text{C}$  (Puerto de Navacerrada meteorological station, 1,860 m a.s.l.), respectively. Average annual precipitation is 1,409 mm (Montero and González, 1984). Mountain bases (1,200–1,700 m a.s.l.) are covered with monospecific oakwoods of *Quercus pyrenaica*, which are progressively replaced by Scots Pine (*Pinus sylvestris*) forests at higher altitudes. These forested areas, that spread from 1,500–2,100 m a.s.l., gradually become sparse patches, until vegetation is dominated by a mosaic of dense mixed-shrub formations (of perennial *Juniperus communis* and *Cytisus oromediterraneus*) interspersed with small meadows (of *Festuca* and other grasses).

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Mountain tops are also characterized by extensive patches of large granite rocks and scree with scattered shrub formations (Rivas-Martínez et al., 1987; Costa et al., 2005).

*Lizard Abundance and Habitat Characterization.*—From May to July 2006, we carried out surveys to relate the abundance of *I. cyreni* with potentially important habitat variables in different sites of the Sierra de Guadarrama. Study sites ( $N = 31$ ) were spread throughout the mountain range, across an altitudinal gradient between 1,800 and 2,300 m a.s.l. The sampled surface covered an area of approximately 300 km<sup>2</sup> including all the major alpine and subalpine habitat types. Thus, our range of habitats encompassed those in which this lizard is abundant (rock outcrops with mixed-shrub formations), together with those in which it is rare or practically absent (i.e., transition and pure pinewoods, respectively). Our sample of sites allowed different combinations of altitude, cardinal orientation, slope, and habitat structure.

At each study site, one of us (CM) walked a 200-m transect counting the number of lizards seen within a 5-m wide belt (2.5 m each side of the progression line). This census belt width allowed us to detect all active lizards, either directly by sight or by hearing their escape movement in vegetated areas before identifying them. Censuses were done between 0900 and 1300 h (Mean European Time), only on sunny and windless days. All transects were repeated twice, and the maximum number of lizards observed was used as a relative abundance index. This simple index does not provide a measure of the actual density of lizards but allows between-habitat comparison of abundances, facilitating the detection of underlying biogeographical patterns (Díaz and Carrascal, 1991; Fisher et al., 2002; Martín and López, 2002).

Habitat structure, vegetation type, and distance to the nearest refuge (rock or shrub that could be a feasible shelter for lizards) were measured every 20 m along the transects (10 sampling points per transect). Four 5-m lines were laid out radiating from the sampling location into the four cardinal directions. At 1-m intervals along these lines, we registered the presence or absence of small rocks (<25-cm diameter), medium-sized rocks (25–100 cm), large rocks (>100 cm), grass, leaf litter, *Cytisus oromediterraneus* and *Juniperus communis* shrubs, and *Pinus sylvestris* saplings. This procedure resulted in 20 habitat measures per sampling point, which allowed calculation of the percent cover value for each habitat variable. These cover values were then averaged for each transect (Díaz and Carrascal, 1991; Martín and Salvador, 1997; Díaz et al., 2006). Variables related to the geographical position of the census sites were recorded using a GPS GARMIN® (UTM coordinates, altitude) or obtained from 1 : 25,000 maps from the Servicio Cartográfico Regional de España (slope and cardinal orientation). To adequately quantify the orientation of transects giving higher values to more southerly orientations (Huertas and Díaz, 2001), we used the negative cosine of the cardinal orientation of the transect slopes.

*Data Analyses.*—Because of the exploratory and correlational nature of our data set, we were particularly careful in applying several statistical techniques to identify the most relevant predictors of lizard

abundance. For that purpose, we combined the traditional null hypothesis testing approach with inferences based on model selection (Johnson and Omland, 2004). We performed a preliminary Principal Component Analysis (PCA) to explore the structure of the correlation matrix among the microhabitat variables involved (Table 1), and we noted which variables had the greatest loadings on each principal component. These variables, together with the topographic ones (i.e., altitude and orientation) and the mean distance to the nearest refuge (which was excluded by design from the PCA to keep refuge availability as a separate variable), were introduced as predictors in a Stepwise Multiple Regression analysis. Normality of regression residuals was examined using normal probability plots. To corroborate the adequacy of our predictive model, we used the Akaike Information Criterion (AIC), which is the most widely used computational approach to model selection. Prior to these analyses, variables were checked for normality using Shapiro-Wilk's tests, and logarithmic transformations were applied when necessary. Because spatial autocorrelation could affect our results (because two closely located sampling sites are likely to be more similar to each other than two distantly located sites), we simultaneously tested for spatial effects (Legendre's polynomial; Borcard et al., 1992), topography, and habitat factors as determinants of lizard abundance.

	Mean ± SD
Leaf litter cover	14.4 ± 13.3
Grass cover	24.7 ± 9.1
Small rock cover (<25 cm diameter)	6.4 ± 6.9
Medium sized rock cover (25–100 cm diameter)	10.6 ± 8.2
Large rock cover (>100 cm diameter)	8.1 ± 7.9
<i>Cytisus oromediterraneus</i> shrub cover	22.6 ± 15.1
<i>Juniperus communis</i> shrub cover	21.1 ± 15.2
<i>Pinus sylvestris</i> saplings cover	3.4 ± 4.3
Distance to nearest refuge (cm)	52 ± 44
Altitude (m a.s.l.)	1978 ± 118
Orientation (negative cosine of cardinal orientation)	0.157 ± 0.682

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## RESULTS

The exploratory PCA with habitat variables yielded four factors that accounted for 76% of the variance (Table 2). The following variables presented the highest loadings for each factor: leaf litter cover (PC1, a component giving high scores to cleared pine-forests with a high cover of pines and leaf litter), large rocks (PC2, a component contrasting meadows without rocks to sites with a high cover of large rocks), *J. communis* shrub cover (PC3), and *C. oromediterraneus* shrub cover (PC4, a component contrasting rock scree areas to sites with a high *Cytisus* shrub cover). These four variables were used, together with the topographic ones (altitude and orientation) and the mean

TABLE 2. Principal components analysis with the microhabitat variables shown in Table 1. Factor loadings greater than 0.6 ( $P = 0.00036$ ) are shown in **bold** type.

	PC1	PC2	PC3	PC4
Leaf litter cover	<b>0.885</b>	-0.147	-0.121	-0.112
Grass cover	0.162	<b>-0.679</b>	0.404	-0.240
Small rock cover (<25 cm diameter)	-0.498	-0.470	-0.517	-0.024
Medium sized rock cover (25–100 cm diameter)	-0.546	0.123	-0.198	<b>-0.627</b>
Large rock cover (>100 cm diameter)	-0.167	<b>0.846</b>	0.076	-0.183
<i>Cytisus oromediterraneus</i> shrub cover	-0.241	0.039	-0.254	<b>0.804</b>
<i>Juniperus communis</i> shrub cover	-0.196	0.087	<b>0.837</b>	0.190
<i>Pinus sylvestris</i> saplings cover	<b>0.753</b>	0.321	-0.277	-0.021
Eigenvalue	2.046	1.547	1.333	1.180
Proportion of explained variance	0.256	0.193	0.167	0.147

distance to the nearest refuge, in the subsequent analyses, after having checked that all tolerance values were higher than 0.5 to avoid inconsistent results generated by stepwise procedures when explanatory variables are highly collinear.

Lizards were detected in 21 of 31 transects, and their numbers ranged from zero to nine individuals per transect. A stepwise multiple regression ( $R^2 = 0.67$ ,  $F_{2,28} = 28.5$ ,  $P < 0.0001$ ) showed that lizard abundance was positively correlated with altitude ( $\beta = 0.57$ ,  $P < 0.0001$ ) and cover of large rocks ( $\beta = 0.52$ ,  $P < 0.0001$ ); these two variables were largely independent, with a tolerance value  $>0.98$ . Thus, Rock Lizards reached high population densities at high-altitude sites where large rocks were abundant (Fig. 1). We found no sign of spatial autocorrelation, because a multiple regression with spatial (Legendre's polynomial), topographic, and habitat variables did not alter our results: altitude and large rock cover were the only variables with significant partial correlations. These variables also provided the best predictive model following the AIC model selection approach, either with or without a correction term for small sample size. Altitude was the first variable to enter all the best models obtained, and cover of large rocks was the second variable in five of the six best models, including the three first ones (Table 3).

#### DISCUSSION

Our main result is that the abundance of *I. cyreni* was positively correlated with only two predictors: altitude and cover of large rocks. Although the ecological mechanisms involved in this distribution pattern remain to be clarified, our data suggest that the ability of lizards to thrive in high-altitude environments was greater at those sites where large rocks were more abundant. This can be partially explained by their morphological adaptations, with a dorsoventrally compressed skull, which illustrates their specialization as scansorial, rock-dwelling lizards that usually seek shelter in narrow crevices (Arnold, 1973). However, there are other behavioral and ecological considerations that should also be addressed. West European Rock Lizards within the *Iberolacerta* group have a restricted distribution, with small, widely separated ranges in highland areas (Carranza et al., 2004), and these and other high-altitude lacertids seem to be adapted to the challenging thermal conditions of alpine environments (Van

Damme, 1989; Bauwens et al., 1990). Prior research at a smaller microhabitat scale showed that *I. cyreni* selected large rocks and avoided grass cover (Martín and Salvador, 1997), which can be attributed to the suitability of open rocky habitats as basking and refuge sites. Attaining optimal body temperatures without overexposure to predators must be particularly difficult in high-altitude environments, where these heliothermic lizards thermoregulate by means of long basking periods (Carrascal et al., 1992) and adjust

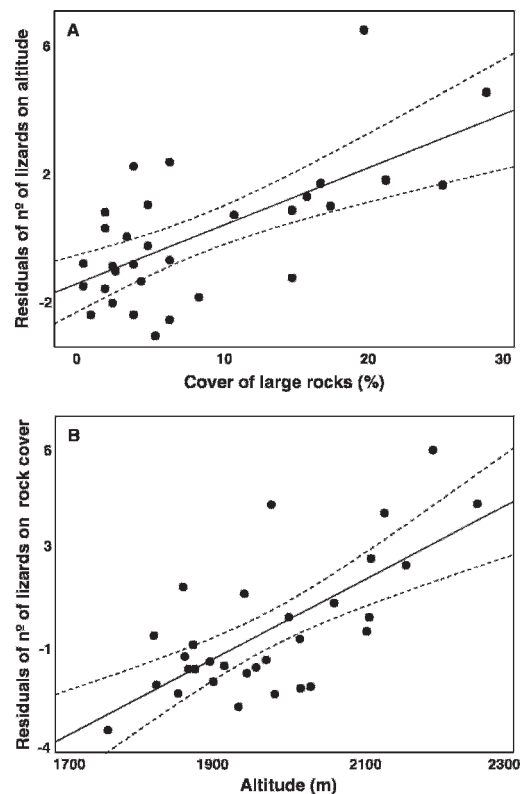


FIG. 1. Scatterplots of (A) the residuals of the regression of lizard abundance on altitude versus rock cover; and (B) the residuals of the regression of lizard abundance on rock cover versus altitude.

TABLE 3. Best model selection approach to predict the abundance of rock lizards as a function of the microhabitat and topographic variables shown in Table 1. The best six models, with Akaike Information Criteria (AIC) smaller than minimum AIC + 2, are shown. AIC<sub>c</sub> = Akaike Information Criterion corrected for small sample size.

Model	1st variable	2nd variable	3rd variable	4th variable	AIC	AIC <sub>c</sub>
1	Altitude	Cover of large rocks			121.38	122.27
2	Altitude	Cover of large rocks	Distance to refuge		121.85	125.39
3	Altitude	Cover of large rocks	Cover of <i>Cytisus</i>		123.13	126.67
4	Altitude	Orientation	Cover of large rocks	Distance to refuge	123.36	126.90
5	Altitude	Cover of large rocks	Cover of <i>Juniperus</i>		123.36	126.90
6	Altitude	Cover of large rocks	Cover of <i>Juniperus</i>		123.38	126.92

their proximity to refuges as a function of their ability to escape from a predator (Martín and López, 2001).

Altitude was the single independent variable that most accurately predicted variations in lizard abundance. Moreover, assuming a mean cover of large rocks of 8.1% (equivalent to the average value for the 31 transects examined; see Table 1), our regression model predicts that lizard populations should disappear below 1,650 m a.s.l., a value which is fairly close to the lower altitudinal limit of this alpine species. The question of what factors represent an ecological barrier to *I. cyreni* remains to be clarified. For instance, it would be useful to study the thermoregulatory effectiveness of populations living at different altitudes with contrasted environmental conditions (e.g., refuge availability or operative temperatures available). It has also been proposed that past competition with species of the *Podarcis* group may be responsible for the restriction of *I. cyreni* and other species of *Iberolacerta* (Carranza et al., 2004), but this hypothesis seems unlikely because other lacertid species (e.g., *Podarcis muralis*) were very scarce in the areas sampled, independent of the abundance of *I. cyreni*.

Our results could be useful to adequately manage the populations of this endangered species. The Sierra de Guadarrama has been suffering from varied anthropogenic disturbances that entail habitat deterioration, such as forest exploitation, the construction of ski resorts, and growing urbanization. The positive relationship between lizard abundance and large rock cover revealed in our study highlights the need to manage this mountain range adequately, without reducing the availability of the lizards' preferred habitat. The harmful effects of habitat degradation by rock disturbance have already been reported for other reptilian species (Schlesinger and Shine, 1994; Goldingay and Newell, 2000; Goode et al., 2005; Díaz et al., 2006), suggesting that avoiding the deterioration of rock outcrops is a basic priority to prevent their decline. Furthermore, it has been shown that the body condition of Rock Lizards inhabiting ski slopes is negatively affected by behavioral adjustments induced by increased predation risk (Amo et al., 2007). In the Sierra de Guadarrama, there are two main ski slopes coinciding with the preferred habitat of Rock Lizards, but they cover less than 5% of the area suitable for the species in this mountain range. However, our results should be taken into account either for expanding the skiable area (which would be detrimental for *I. cyreni*) or for restoring the current ski

resorts and adjacent areas. In fact, the restoration of habitat simulating natural retreat sites is a successful technique to manage reptile species inhabiting rocky outcrops (Cheylan et al., 1990; Webb and Shine, 2000).

In conclusion, *I. cyreni* shows a restricted distribution pattern along the Sierra de Guadarrama that seems to be mediated by large rock abundance in high-altitude habitats. The species is locally very abundant in alpine remnant patches of rock outcrops and mixed shrub in the mountain range peaks, but it is absent from the surrounding forested belt and from the urbanized areas located at lower altitudes. Our model, which should be corroborated by future studies in other mountain ranges inhabited by *I. cyreni* (Sierras de Gredos and Béjar), indicates that high-altitude rocky areas are crucial for the survival of this species. It should also be noted that the positive association between altitude and lizard abundance is expected to produce a fragmented distribution that could be affected by metapopulation dynamics. Thus, it would be of great interest to discern whether this apparently fragmented spatial pattern actually represents isolated populations in the mountain peaks. For that purpose, we encourage the use of molecular techniques (i.e., microsatellites, mitochondrial DNA) to assess genetic flow between populations and to discriminate between historical and recent fragmentation events (Berry and Gleeson, 2005; Huey et al., 2006).

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