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HABITAT SELECTION AND CONSERVATION OF AN ENDEMIC SPANISH LIZARD *Algyroides marchi* (REPTILIA, LACERTIDAE)

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Abstract

We study the habitat selection of Algyroides marchi, *a small lizard endemic to the southeastern mountains of the Iberian Peninsula whose populations are concentrated in a few small localities. Three spatial scales of study were used to analyse the different factors affecting the species distribution patterns: regional scale, local scale and within-habitat use of different substrates. The results obtained at these different spatial scales showed a high consistency, suggesting that the same ecological pressures probably acted at different scales. Localities occupied by* A. marchi *were characterized by high altitude, high geomorphological complexity, northern aspect, high cover of large rocks, and presence of water. Density of* A. marchi *in a favourable locality was 213 adult–subadult lizards/ha. Abundance and use of space of* A. marchi *(at local and individual levels) were directly associated with extent of water (streams and small pools) and the presence of large rocks, and inversely with hours of direct solar radiation and cover of small stones and vegetation. Considering the habitat selection of* A. marchi *and the management practices within its geographical range, potential risks for the conservation of the species are identified.*

Keywords: lizard, habitat selection, spatial scales, *Algyroides marchi*, Spain.

INTRODUCTION

Morris (1987) and Wiens (1989*a*) stress the importance of different spatial scales in the analysis of habitat preferences. If only one scale is used, some important determinants of distribution may be hidden (Hutto, 1985). This important issue has received little attention in the studies of habitat selection of reptiles (Heatwole, 1977; Heatwole & Taylor, 1987). The utilization of large geographical scales may lead to ignorance of the proximal factors that determine habitat selection, and similarly habitat patterns obtained at reduced scales may vanish at broader ones (Wiens, 1989*b*). In the case of small animals with small home ranges and reduced possibilities for dispersion (e.g. lacertid lizards), a knowledge of the factors affecting habitat preferences at different spatial scales is necessary to conserve their endangered populations and to manage their habitats within the whole geographical range.

The geographic range of *Algyroides marchi* Valverde 1958 is restricted to the Alcaraz, Cazorla and Segura ranges (SE Spain) and constitutes one of the narrowest among continental European lacertids (Arnold, 1973, 1987). Moreover, populations are not uniformly distributed in the area, being concentrated in certain limited localities (Palacios *et al.*, 1974). This suggests that this species is vulnerable and a thorough knowledge of its habitat selection and distribution patterns is necessary for its conservation (Blanco & González, 1992). However, the patterns of habitat selection and the factors affecting the distribution of this species remain nearly unknown (see reviews by Arnold & Burton, 1978; Salvador & Palacios, 1981; Salvador, 1985; Barbadillo, 1987). Observations on the habitat of *A. marchi* that have been reported in the few papers on this species are anecdotal (Klemmer, 1960; Buchholz, 1964; Eikhorst *et al.*, 1979) or constitute rough descriptions (Palacios *et al.*, 1974; Arnold, 1987). In this paper we therefore study the patterns of habitat selection of *A. marchi* at three spatial scales: regional, local and habitat use by individuals. At each scale, we analyse different ecological pressures affecting habitat selection and abundance, and test the consistency of environmental factors determining distribution patterns. We also point out some of the main problems for the conservation of this restricted species, and provide some recommendations for maintaining its populations.

STUDY AREA

The study was carried out in the Sierra de Alcaraz (Albacete, Spain, 38° 30' N, 2° 30' E), a group of rugged mountains 700–1700 m in height, mainly oriented SW–NE. A great part of the area is occupied by karst systems. The climate is Mediterranean subhumid, characterized by an average annual precipitation of 685–837 mm and an average annual temperature of 12–16°C (frosts in November–April). The vegetation is dominated by evergreen oak and gall-oak forests with accompanying deciduous trees (*Quercus rotundifolia, Q. faginea, Acer granatensis, Taxus baccata*, etc.) and native pine *Pinus nigra salzmani* forests. Dry shrublands,

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pine reafforestations (*P. halepensis, P. pinaster*) and cultivated fields replace the potential vegetation in many areas (Valle *et al.*, 1989).

METHODS

Habitat preferences at regional scale

Habitat preferences at the regional level were studied in an area of 30 × 30 km, in June–July 1988. This area had been extensively searched during the three previous years for populations of *A. marchi* using the available network of roads and forest tracks, and knowing the general habitat preferences of the species (Palacios *et al.*, 1974; Eikhorst *et al.*, 1979; Arnold, 1987). Populations were found in 19 localities, defined as areas of variable size (100–400 m diameter). In each locality a plot of 50 m in radius was centred in the area with the highest number of observed individuals.

Thirteen variables were measured within each sampling plot: altitude, north aspect of the main slope of the locality, geomorphological enclosure, water, percentage of area occupied by rocks and/or stones of three different sizes (diameter > 70 cm, 30–70 cm, and < 30 cm) and percentage cover of trees, bushes, grasses/forbs, moss and bare ground. Altitude and north aspect were measured by means of an altimeter and a compass respectively. The degree of enclosure of the locality was scored as (1) flat terrain, (2) moderate slope (5–30°) on one side of the plot, (3) open gully (5–30° on both sides of the plot), (4) closed gully with steep slopes (>30° on both sides of the plot), and (5) within a deep karst crevice. An index of water volume was calculated from measurements of the length, average width and average depth of streams and pools present in the plots (multiplication of these variables).

Vegetation cover was measured in four subplots of 25 m radius within each plot. Cover was visually estimated (after previous training) from the centre of each subplot (Prodon, 1976) using eight continuous categories (0, 1–5, 6–12, 13–25, 26–50, 51–75, 76–90 and 91–100%). Four categories were established under 25% because relationships between vertebrates and vegetation structure are not linear, and small differences in this range may be important (Willson, 1974; Prodon & Lebreton, 1981). By careful measurements on some samples we found that the errors involved in these estimations were < 3% between 0% and 25%, and < 5% between 26% and 100%.

The physical structure of the landscape available in the study area was also estimated at 15 sites located systematically by the intersections of the UTM coordinates of 5 × 5 km. The exact location of the sampling sites was determined on 1:50000 topographical maps, and we again measured the structural variables using the methods described above.

Population density

The population density of *A. marchi* was estimated in El Nacimiento del Rio Mundo (Riopar, Albacete province, 950 m altitude), an area regarded as representative of a typical locality favourable for the species (Palacios *et al.*, 1974). A plot of 50 × 56·25 m^2 was established in the bottom of a gully (the sector with the highest density of *A. marchi*; Palacios *et al.*, 1974).

The estimation of population density was carried out by an intensive capture–recapture programme during eight consecutive days 25 July–4 August 1989. Lizards were marked by toe clipping, and by a unique code with Humbrol paint on the shoulder to ease long-distance identification and to reduce the necessity for recapture. The entire surface of the plot was systematically surveyed every day during the period of maximum activity of the species (0830–1730 h GMT), capturing all individuals observed or noting the colour codes. A total number of 51 adult and subadult specimens (snout–vent length: 30–45 mm) were marked. Given the short duration of the capture–recapture period, and the reproductive phenology of the species (Rubio & Palacios, 1986). the population may be considered demographically 'stable and closed' during the intensive marking period. The population density was therefore estimated by the Hayne method for closed populations (Tellería, 1986).

Habitat preferences at local scale

The habitat selection of *A. marchi* was also studied in the Rio Mundo plot. The plot was subdivided into 72 (8 × 9) squares of 6·25 × 6·25 m^2 using white ropes for easier visibility and location. Ten habitat variables were measured in July 1990: percentage cover of rocks (by three size classes: diameter > 70 cm, 70–30 cm, and < 30 cm), mean rock size (weighted average), number of tree trunks, canopy cover, vegetation cover at 150 cm, at 50 cm and at the ground level, and litter, moss, and area of water (pools and stream; we did not consider water volume due to the constancy of water depth throughout the plot). Cover variables were estimated by eye after previous training using the same categories described in the previous section. To measure the number of hours of direct sun radiation on the 72 plot-squares, we noted the time of beginning and end of sun incidence over each square on 2 July 1990.

Presence of,individuals in every square was recorded in 12 sampling visits in July 1990. All visits were carried out on sunny days between 0830 and 1600 h GMT, which is within the peak of the daily period of summer activity for *A marchi* (unpublished data). Recording took 1·5 h, and covered all the squares at an average walking speed of 0·3 km/h.

Habitat use by focal individuals

The use of space by adult and subadult individuals was studied in the Rio Mundo plot during July–August of 1991 in the area of highest density of *A. marchi* (the bottom of the gully; see Results). The activity of 45 individually recognizable 'focal' lizards that did not react to the presence of the observer was sampled by dictating their behaviour into a portable tape-recorder (after Martin & Bateson, 1986). The average sampling time was 343 seconds per individual (range: 100–1000 s).

Table 1. Structural characteristics of localities systematically selected and those with *A. marchi* in the Alcaraz mountains
See Material and Methods for details. All one-way ANOVAs were with 1,32 d.f. Within-function correlations between variables and the canonical discriminant function are also shown.

	Systematically selected localities		Localities with *A. marchi*		One-way ANOVA	Correlation with discriminant function
	$\bar{x}$	SD	$\bar{x}$	SD	*p*	
Altitude (m)	982·7	224·0	1182·1	198·8	0·008	0·29
Enclosure index	2·0	1·8	3·3	1·6	0·013	0·27
Rock cover (%)						
Rocks >70 cm in diameter	3·0	4·0	11·4	10·1	0·001	0·39
Rocks 30–70 cm in diameter	5·7	6·7	11·7	8·9	0·004	0·32
Rocks <30 cm in diameter	13·0	14·0	10·0	7·7	0·808	0·02
Water volume index	4·7	12·3	56·8	84·1	0·003	0·33
Canopy cover (%)	27·7	25·7	21·9	17·5	0·577	0·06
Bush cover (%)	42·4	28·8	20·0	17·0	0·058	−0·20
Grass cover (%)	21·0	25·8	7·5	9·0	0·112	−0·17
Moss cover (%)	1·2	3·3	1·3	1·8	0·290	0·11
Bare ground cover (%)	17·2	19·6	8·0	7·3	0·213	−0·13
Sample size	15		19			

Lizards were observed from a distance of 3–6 m using binoculars. We recorded the time lizards spent moving or making short stops while food searching or territory patrolling on the following five substrates: rocks > 70 cm, 30–70 cm and < 30 cm in diameter, moss, and litter. We excluded basking times in the analyses. Substrate use by lizards was expressed in percentages. The percentage availability of these substrates was estimated by recording the presence of each substrate every 2 m along three ropes 100 m long running parallel within the sampling area (n = 150 sampling points).

Data analysis

Habitat variables describing the localities systematically selected and where *A. marchi* was present were compared using multivariate and univariate analyses of variance. To find the best linear combination of environmental variables for distinguishing between the two types of localities, we employed discriminant analysis.

The 72 squares in the Rio Mundo plot were ordered by Principal Components Analysis (PCA) using the correlation matrix of the 10 variables of habitat structure. Due to the spatial contiguity of the squares, they cannot be considered as independent samples. Therefore the relationship between the number of individuals per square and independent variables can only be studied after the site component effect is partialled out (Legendre, 1993). The site component is viewed as a geographical-location factor defined by the geographic coordinates of each square (x: 1–8, y: 1–9). These coordinates were regressed onto each environmental variable in turn, and only the regression residuals were retained. The residuals of each environmental variable were then used as independent variables to model the target dependent variable (number of lizards per square) (Legendre, 1993). Stepwise multiple regression analysis was used to analyse the relationship between number of observed individuals per square (considering all sampling days), and the residuals of the environmental factors (structural components of the PCA, and number of hours of direct sun radiation).

In the analysis of the use of space by focal individuals, Hotelling's T^2 test (MANOVA one-sample test) with Wilks' lambda estimation, and t-tests were used to compare a series of values obtained for each variable (percentage of time lizards were observed on each substrate) with an expected mean (percentage of sampling points contacting with each substrate; contacts were obtained by random sampling).

All tests were performed with variables log- or arcsin-transformed (in the case of percentages) to attain equal variance and normality. All data analyses were performed using Windows-SPSS package.

RESULTS

Regional level

Table 1 shows values of the variables in the localities where the species was present and in those systematically selected. The Bartlett test of sphericity indicates that the 11 environmental variables were highly correlated (parameter estimate = 101·5, 66 d.f, p = 0·003). The two types of localities were significantly different when all these variables were considered together (Hotelling's T^2 test: $F_{11,22}$ = 6·01, p < 0·001). Analysis of variance (Table 1) showed that altitude, degree of enclosure, ground cover by large and medium rocks, and water volume were all significantly greater, while bush cover was lower, in the localities with *A. marchi* than in those systematically selected. No significant differences were found among the remaining variables.

The discriminant analysis provided a significant function (Wilk's lambda = 0·250, 11 d.f., χ^2 = 36·765, p = 0·0001) that correctly classified all the localities (100% of cases). About 75% of the variability in the discriminant scores is attributable to between-locality differences considering the 11 variables (canonical correlation = 0·87). The discriminant component that distinguishes between the two types of localities shows that those where *A. marchi* was present had a significantly higher cover of cliffs and large rocks, higher altitude, enclosure and water volume, and a lower shrub cover.

The localities occupied by the species faced predominantly north (NW–NE; 80%), this frequency differing marginally from that expected by chance (50%; $\chi^2 = 3{\cdot}6$, 1 d.f., $p = 0{\cdot}058$).

Habitat preferences at local level

In the Rio Mundo plot the percentage cover of large rocks (>70 cm) was 17%, tree canopy cover (*Pinus nigra, Quercus rotundifolia, Fraxinus angustifolia, Salix eleagnos*) 35%, cover of bushes (*Thymus* sp., *Cistus* sp., *Rubus* sp., etc.) 45%, and grass cover 19%. The average number of hours of direct solar radiation in the first fortnight of July was 8·4 h/day. In the study period (June–July), water bodies were reduced to a small shallow stream and dispersed pools. The location in a deep gully with dense tree cover produced a shady and humid environment.

The estimated size of the population living in the Rio Mundo plot (0·28 ha) was 59·6 ± 19·6 adults and subadults individuals ($\bar{x}$ ± 95% interval about the mean), i.e. a density of 213 lizards/ha.

Table 2 shows the results of the Principal Components Analysis performed with the 72 squares of the Rio Mundo plot. The first factor (PCl) is a gradient from higher tree density and canopy, grass, and litter cover, to lower values of these variables and high cover of large rocks and water. The second factor (PC2) is directly associated with bush cover, and PC3 is related to the moss cover and size of rocks. These three components account for 71·3% of the original variance.

The step-wise multiple regression analysis with the residuals of these factors and the residuals of the number of hours of direct sun radiation (residuals of the regression of each variable and the square coordinates; see Material and Methods) shows that the variation in the number of lizards observed per square was significantly and negatively associated with PCl ($p < 0{\cdot}001$), and with the number of hours of sun incidence per square ($p = 0{\cdot}013$). The other two components (residuals of PC2 and PC3) were not significantly correlated with number of lizards ($p > 0{\cdot}5$). The within-area variation of *A. marchi* density was therefore directly associated with large rock cover and presence of streams and water pools, and inversely related to tree cover and total sun radiation (see Fig. 1 for simple correlations). These two variables explained the 59·0% ($F_{2,69} = 49{\cdot}604$, $p << 0{\cdot}001$) of the observed variation in the distribution of *A. marchi* at the within-locality level.

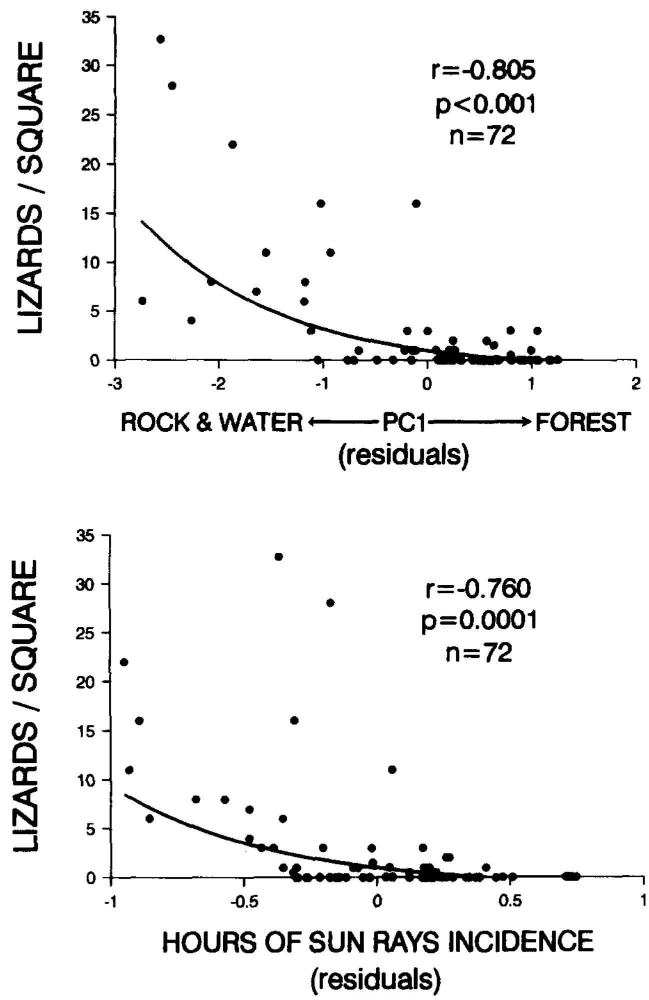

Fig. 1. Number of lizards observed per square in the Rio Mundo plot as a function of the number of hours of sun radiation received per day, and a gradient from high forest cover to high rock and water cover (PC1 scores; see Table 2). PC1 and hours of sun rays incidence are expressed as residuals of the regression of the geographic coordinates of each square onto each variable (see Materials and Methods). Lizards/square indicates the total number of lizards observed in the 12 itineraries made during July. Simple correlations are shown in the upper right corner of each scatter plot.

Table 2. Principal Components Analysis with environmental variables describing the habitat structure of squares of 6·25 × 6·25 m² of the Rio Mundo plot

Only variables significantly correlated with principal components are shown. The other principal components were not considered due to their low eigenvalues.

	PC1	PC2	PC3
Rock and strone cover	–0·74		
Rock size			0·82
Water cover	–0·81		
Moss cover			0·82
Litter cover	0·90		
Vegetation cover at 0 cm (ground)	0·76		
Vegetation cover at 50 cm in height		0·80	
Vegetation cover 150 cm in height		0·95	
Canopy cover	0·76		
Tree density	0·69		
Eigenvalue	3·85	1·70	1·58
% of variance	38·5	17·0	15·8

Substrate use by focal individuals

Table 3 shows the percentage of time focal individuals spent in the five main substrates within their home ranges in the Rio Mundo plot. The population means

Table 3. Percentage of time spent by individual lizards (n = 46) in five substrates (OBSERVED; without considering time devoted to basking), and availability of these substrates in the Rio Mundo plot (EXPECTED, expressed as percentage of presence in 150 regular distributed sampling points)

Results of t-tests comparing the observed means against the expected ones are also shown, using Bonferroni correction (ns: not significant).

	OBSERVED (%)		EXPECTED (%)		
	$\bar{x}$	SD		t	p
Rocks > 70 cm in diameter	64·2	32·0	36·8	5·74	<0·001
Rocks 30–70 in diameter	10·8	20·0	13·9	1·03	ns
Stones (rocks <30 cm in diameter)	7·2	17·8	28·8	8·15	<0·001
Litter	8·0	18·4	16·1	2·95	<0·001
Moss	9·7	20·1	4·4	1·76	ns

for the use of these five substrates significantly differed from expectation (availability; Hotelling's T^2 test: $F_{5,40} = 18{\cdot}03$, $p < 0{\cdot}001$). Active selection of these substrates by *A. marchi* explained the 69·3% of the variance observed in use of space Wilks' lambda = 0·307). The univariate t-tests comparing use of space with availability (both expressed in percentages; Table 3) showed that large rocks were actively preferred, while the remaining substrates were avoided or randomly used.

Large rocks also provide refugia and crevices where *A. marchi* spend up to 30% of the daily activity ($\bar{x}$ = 12·0%, SD = 24·2, n = 46 individuals). Within these crevices relative humidity was *c.* 10% higher, and operative temperature was 10–20°C lower, than on rock surfaces (unpublished data).

DISCUSSION

The distribution pattern of *A. marchi* at the three spatial scales is shown to be a highly predictable phenomenon when considering a few habitat variables: nearly two-thirds of variance in regional distribution, local distribution and habitat use was explained by structural parameters that describe the habitat structure. *A. marchi* is clearly not a forest species living in densely vegetated habitats as previously thought (e.g., Arnold & Burton, 1978; Eikhorst *et al.*, 1979), but a species of rocky, shady areas. The presence of mature forests in many places where the species occurs is a reflection of the high conservation state of these localities (as a consequence of their inaccessibility) rather than a causal habitat selection relationship. The patterns of association between *A. marchi* and those structural parameters were highly consistent at the three spatial scales, showing that a few habitat variables are responsible for spatial variation of presence and abundance between and within localities for this species. This consistency and predictability may be of real value when deciding management plans for the conservation of *A. marchi* populations and habitats.

The equivalent patterns of habitat selection and habitat use at different scales in *A. marchi* contrasts with general results obtained for small birds and mammals (e.g. Morris, 1987; Wiens *et al.*, 1987; Steele, 1992; there is no available information on this topic for other lizard species). This different pattern of consistency in habitat preferences at different scales between birds and lizards could be related to differences in ecophysiological constraints. Ectothermy in lizards impedes their free distribution between and within habitats, as body temperature has to be maintained through behaviourial thermoregulation within a narrow range where performance levels are maximized. Behavioural thermoregulation is achieved by means of careful selection of habitat attributes within the thermal mosaic (Avery, 1982, Huey, 1982). Therefore, habitat use cannot be viewed as a phenomenon independent of thermoregulation. In this sense, distribution at larger scales may be the combined response to local conditions, with respect to the prominent role of factors influencing physiological tolerances.

The clear preference for higher altitudes, places with water, northern aspects, and localities (and patches within localities) with low exposure to solar radiation, casts light on the role of temperature and humidity in the distribution of this species. Small lizards attain a fast rate of heat exchange with the environment (e.g. Carrascal *et al.*, 1992) and a high relative evaporative water loss (Mautz, 1982) due to a high surface-to-volume ratio. The available data on the other three species of the genus with similar body size and localized distribution (*A. fitzingeri* in Corsica and Sardinia, *A. nigropunctatus* on the eastern coast of the Adriatic, and *A. moreoticus* in Greece) show a similar pattern of habitat selection in relation to temperature, insolation and humidity (Arnold, 1987; Keymar, 1988). This common pattern of habitat distribution clearly contrasts with the other, larger, Mediterranean lizards, which occupy warmer and drier habitats, and have broader distribution ranges (see, for example, Arnold & Burton, 1978; Arnold, 1987).

The selection of large rocks may be partly explained by considering escape from predators (Martín & Salvador, 1992; Schlesinger & Shine, 1994), and better opportunities for thermoregulation and water regulation than open surfaces on rocks (Huey *et al.*, 1989). The cool, humid conditions under these rocks also provide a better source of arthropod food (mainly small spiders and flies) than open rock surfaces (unpublished data).

The Alcaraz mountain range which *A. marchi* inhabits constitutes a continental 'island', surrounded by much warmer and drier lowlands. The absence of appropriate habitats in these lowlands determines the small dimensions of its distribution areas. In the recent past, when the autochtonous forests were more widespread and less intensively managed for wood and charcoal, localities with presence of *A. marchi* were probably more numerous, more extensive and less isolated. The extensive felling of trees, the practice of wood extraction through gullies and the construction of forestry tracks have dried up many potential areas for *A. marchi*, and have probably broken the continuity between favourable localities limiting the opportunities for dispersion and contact between different populations. Further study is therefore needed on the detailed distribution of localities where the species is present and on the degree of isolation between adjacent localities. These studies should be extended to the whole distribution range of the species (including the Segura and Cazorla mountains).

Conservation management should avoid forestry practices in known localities of this very local species. Gullies with streams and boulders should not be logged and used for wood extraction in order to provide an adequate habitat for the colonization or dispersion of the species between existing localities. When designing roads or tracks, special care should be taken when crossing gullies, avoiding the destruction of the particular habitat composed by large rocks, streams and mesophytic vegetation. The economic cost of these recommendations would be very low considering the small extent of suitable habitat for *A. marhci* in these sierras.

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