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COMPARATIVE STUDY OF THE DORSAL PATTERN IN *SALAMANDRA SALAMANDRA BEJARAE* (WOLTERSTORFF, 1934) AND *S. S. ALMANZORIS* (MÜLLER & HELLMICH, 1935)

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The dorsal pattern of six populations of *Salamandra salamandra* was studied. Several quantitative characters of the dorsal spots (number, area, perimeter, axes length, co-ordinates of the centre of gravity, etc.) were analysed using computer assisted technology. The study of these characters results in unexpected clustering of the populations. The population of Macizo de Peñalara, which is considered within *S. s. bejarae* seems to be closely related to the *S. s. almanzoris* populations.

INTRODUCTION

Salamandra salamandra is a remarkably polymorphic species in terms of the dorsal pattern. Until now, in the Iberian Peninsula the presence of seven subspecies has been recognized, though not by all researchers (Barbadillo, 1987): *S. s. bejarae*, *S. s. almanzoris*, *S. s. gallaica*, *S. s. bernardezi*, *S. s. fastuosa*, *S. s. crespoi* and *S. s. terrestris*. The subspecies were described on the basis of both the position and the extension of the dorsal spots. *S. s. bejarae* is characterized by yellow or red spots scattered on the black dorsum. These spots are very variable in size, pattern and abundance. This subspecies is distributed throughout the Iberian Peninsula, except in the areas of distribution of the other subspecies (García-París, 1985). *S. s. almanzoris* shows a lower number of yellow spots, which are smaller and more dispersed. Its distribution is restricted to glacial lakes in Sierra de Gredos (García-París, 1985). *S. s. terrestris* shows yellow stripes arranged in two lines along the black back. It appears in France, although some authors are of the opinion that this subspecies is distributed across the Oriental Eastern Pyrineos Mountains and that it is present in some parts of Catalonia (Barbadillo, 1987). Eiselt (1958) studied the geographic variation of *S. salamandra* in Europe and the Middle East. He considered that the populations of *S. salamandra* of Montseny (Barcelona) belonged to *S. s. bejarae*.

The dorsal pattern of the family Salamandridae has been studied for many years in terms of their supposedly aposematic colouration (e.g. Howard & Brodie, 1973; Hensel & Brodie, 1976). In *S. salamandra* the dorsal pattern has been used in subspecific characterizations (Wolterstorff, 1934; Müller & Hellmich, 1935), and perhaps too frequently, authors have used only this character to assign local populations to a subspecies (Veith, 1992); Malkmus (1991) studied the geographic variation of the dorsal pattern in a large number of individuals of *S. s. gallaica* but he only analysed qualitative variables.

The dorsal pattern of *S. salamandra* has hardly been studied in a quantitative way. Degani (1986) only studied the number of yellow spots and determined the ratio between yellow and black areas. Here we determine if the affinities of several quantitative variables of the dorsal pattern of *S. s. bejarae* and *S. s. almanzoris* conform to the taxonomic classification traditionally accepted for the populations studied. Only quantitative variables were studied to eliminate any kind of subjectivity in the study of the dorsal pattern and to find if the pattern can be used to characterize these subspecies.

MATERIAL AND METHODS

The dorsal pattern of fifty adult individuals was analysed. The following populations were studied: Facinas (Cadiz) (n=9), Sierra Bermeja (Málaga) (n=10), Macizo de Peñalara (Sierra de Guadarrama, Madrid) (n=10), and Santa Fe del Montseny (Barcelona) (n=10), considered traditionally belonging to *S. s. bejarae* subspecies; Laguna Grande and Cinco Lagunas (Macizo Central de la Sierra de Gredos) (n=10, n=11, respectively) considered traditionally to belong to *S. s. almanzoris* . The individuals of Facinas, Montseny and Laguna Grande populations belong to the herpetological collection of the National Museum of Natural Sciences of Madrid (MNCN), and the sample from Sierra Bermeja belongs to a private collection. All preserved individuals were filmed with a video camera Sony V7AF 8 mm. Live animals were photographed in the field with the camera situated perpendicularly to the dorsal surface of the animal. A scale in cm was filmed with it. Films and photographs were digitized using a

Digi View Gold Digitalizator and a Commodore Amiga 500 computer. The images were analysed on a Macintosh IIsi using the Image 1.41 and Photoshop 2.0 software.

For each individual the following variables were measured: number of dorsal spots (ND), total yellow area (YA) and for each spot, the area (A) and perimeter (P). Total dorsal surface (yellow and black area), major axis length, minor axis length and co-ordinates of the centre of gravity of each spot were measured in order to calculate three new variables: the percentage of yellow area (%Y), axes ratio (M/m) and minimum distance across the centre of each dot (Dist). An arcsin linear transformation was applied to the variable percentage (ASIN%Y) and a square root transformation to the area variable (SQRA). The M/m variable gives us an idea of the shape of the spots.

To remove the effect of the size of the animal in the variables which were correlated with it, we used the residuals of the regression between each variable and the size of the animal (square root of the total surface). The analyses were performed using Statview II 1.03 program and the NTSYS statistical package (Rohlf, 1992). Classical statistical techniques were performed. A standardized matrix was used to calculate the "average taxonomic distance" between each pair of species and the clusters were generated through the application of an unweighted average (UPGMA) on the previously calculated matrix.

RESULTS

The average of the non-transformed variables studied for each population are shown in Table 1. The individuals of Sierra Bermeja were the largest, followed by the population of Facinas, while the smallest individuals were those collected in Cinco Lagunas and Laguna Grande. The number of dorsal spots is highest in Facinas (t=3.13; P<0.01), while the individuals of the Montseny population showed the lowest number of spots (t=4.36; P<0.001); spots in the latter population were larger than the ones of Facinas (t=3.08; P<0.01), the percentage of yellow area being very similar

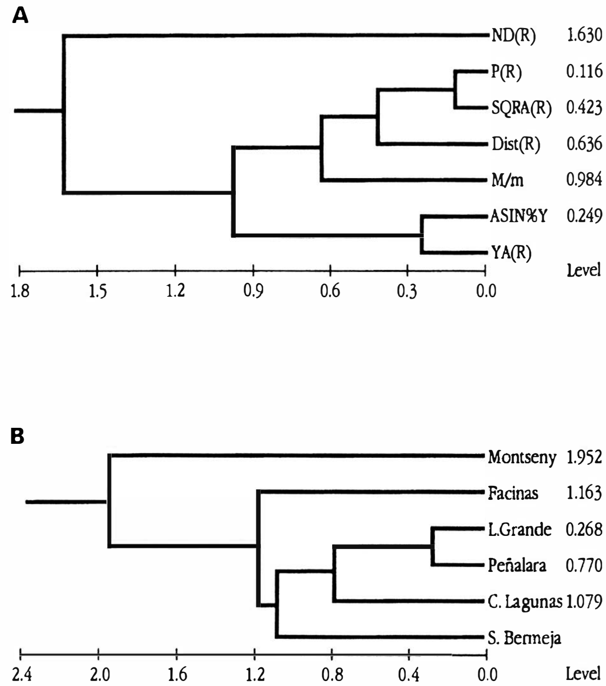

FIG. 1. A, Cluster of the variables analysed; B, Cluster of the populations studied.

(χ^2=1.02; NS). The M/m ratio is highest in the striped Montseny population (U'=82; P<0.01) and lowest for the dotted Cinco Lagunas population (U'=100; P<0.01). The individuals of Laguna Grande show the minimum percentage of yellow, being significantly lower than the other population of *S. s. almanzoris*, Cinco Lagunas (χ^2=20.82; P<0.001).

The ND, SQRA, P, SQRYA and Dist variables show a meaningful correlation with the size of the animal (F=10.2, P<0.01; F=29.6, P<0.001; F=22.8, P<0.001; F=136.3, P<0.001; F=27.0, P<0.001, respectively); while M/m and ASIN%Y show a non-significant correlation.

The average values of the residuals of the variables correlated with the size of the body and the average values of the rest of variables were standardized in order to calculate the cluster analysis. First we performed a cluster of the variables (Fig. 1A) to analyse the proxim-

Population	n	Total Surface (mm²)	ND	A (mm²)	P (mm)	M/m	Dist (mm)	%Y
Montseny	10	2795.8 (319.6)	22.1(4.4)	41.5(6.6)	20.0(2.3)	2.4(0.2)	8.5(1.0)	32.7(6.6)
Laguna Grande	10	2352.9 (363.5)	33.0(6.5)	18.1(3.5)	10.8(1.6)	1.9(0.2)	5.8(0.9)	25.2(4.9)
Cinco Lagunas	11	2258.3 (176.6)	34.8(4.5)	20.4(4.7)	11.1(2.1)	1.6(0.1)	5.9(0.7)	31.2(6.7)
Peñalara	10	3322.2 (821.8)	36.0(4.9)	24.8(6.3)	13.3(2.7)	1.9(0.1)	6.6(1.3)	27.5(8.5)
Facinas	9	4615.7(1379.4)	43.5(7.1)	33.3(4.8)	17.0(1.9)	2.0(0.2)	6.9(0.6)	32.5(4.5)
S. Bermeja	10	4924.8 (680.0)	33.0(7.6)	44.1(12.1)	19.6(4.1)	1.9(0.2)	9.5(1.7)	28.6(6.3)

TABLE 1. Mean and standard deviation of the variables analysed

ity among them. The variable ND seems to be far from the rest of variables. In a second group we find the two variables YA and ASIN%Y. The perimeter, SQRA and the minimum distance are together in another group. The SQRA and the perimeter are logically the most related variables. Considering the results of this cluster analysis another cluster was performed using the average values of the populations after removing the SA and P variables (Fig. 1B). The Montseny population appears far from the other populations, this is the expected result because of its different dorsal pattern. The rest of the populations are less differentiated and the most striking result is that the most closely related populations are Laguna Grande and Peñalara.

DISCUSSION

The quantitative analysis of the dorsal pattern seems to be more useful for defining the subspecies of *S. salamandra* than simple qualitative descriptions.

The population of Montseny is different from the other populations, with a striped dorsal pattern very similar to that of *S. s. terrestris*. This could be explained by assigning this population to *S. s. terrestris* , and not to *S. s. bejarae*, in contrast to Eiselt (1958).

The striking resemblance of the dorsal pattern in the populations of Peñalara and Laguna Grande can be interpreted in two different ways. It could be that the dorsal pattern in *S. salamandra* reflects different "ecomorphs". This hypothesis is supported by the fact that Peñalara and Laguna Grande are very similar habitats (high mountain).

On the other hand, it could be explained by the existence of high genetic proximity between both populations. This hypothesis is supported by genetic studies performed by Alcobendas, Dopazo & Alberch, (1993) where several Iberian Peninsula populations were analysed, and the idea of *S. s. almanzoris* occurring as relict populations was rejected.

A way of studying the validity of the dorsal pattern in the characterization of subspecies would be to check whether populations which are ecotypically different but geographically close show similar patterns.

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