HABITAT-STRUCTURAL AND METEOROLOGICAL PARAMETERS INFLUENCING THE ACTIVITY AND LOCAL DISTRIBUTION OF THE GOLDEN-STRIPED SALAMANDER, CHIOGLOSSA LUSITANICA

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We studied the activity pattern and small-scale spatial distribution of the golden-striped salamander, *Chioglossa lusitanica*, in a forest plot in northwestern Portugal. A large proportion of the local population inhabited an underground watercourse and foraged in the woodland, leaving and entering the underground shelter through three holes. Surface activity – measured as the number of salamanders out in the open and their distance from the inferred shelter– was positively associated with relative humidity and precipitation. A negative relationship between dispersion distance and temperature was found in females. Distances moved were higher for adult salamanders than for juveniles. Spatial models indicated that males, females and juveniles differed in habitat utilization. The frequency of occurrence of salamanders at the surface was highest in the area of the stream (adults and juveniles), near dry-stone walls (males and juveniles), in areas with a higher than average density of trees (adults) and in areas of dense undergrowth (females). The results suggested that (1) the underground watercourse served as a retreat from which the salamanders would visit the surface, (2) dry stone walls functioned as retreats rather than as foraging grounds, and (3) trees and dense vegetation served as shelter for foraging salamanders. The results are compared with those for phylogenetically related and morphologically similar species.

Key words: Chioglossa lusitanica, distribution, habitat, spatial model, Portugal

INTRODUCTION

The distribution of the golden-striped salamander, Chioglossa lusitanica, is restricted to the northwestern part of the Iberian Peninsula. Its range corresponds to areas of low and medium altitude (< 1200 m) with high annual precipitation (> 1000 mm; Arntzen, 1981; Vences, 1997). The species lives alongside mountain brooks with well-vegetated margins and has nocturnal habits. Secluded places such as mine galleries are used for reproduction. In habitats like these the natural history of the species is well documented (Goux, 1957; Gonçalves, 1962; Arntzen, 1981, 1994a, 1995; Faria et al., 1996; Vences, 1990, 1993; Teixeira et al., 1999). A picture has emerged in which the ecological requirements and habits of C. lustitanica are similar not only to those of its sister-species Mertensiella caucasica from the Caucasus, but also to some Nearctic streamside salamanders to which it is phylogenetically unrelated (Hairston, 1987; Tarkhnishvili & Serbinova, 1993; Tarkhnishvili, 1994; Titus & Larson, 1995; Veith et al., 1998). The understanding of this apparent ecological (and etho-morphological) evolutionary convergence would be advanced by the description for all of these species of ecological profiles under a wide range of environmental conditions. Here we contribute to this growing data set with observations on C. *lusitanica* in an atypical habitat – a woodland plot with an underground watercourse – by analysing the effects of structural habitat characteristics and weather conditions on the activity and micro-distribution of the species.

MATERIALS AND METHODS

Observations were made in a 0.5 ha area near Alfena (12 km NE of Porto, Portugal) covered with Pinus pinaster, Quercus robur and Eucalyptus globulus, some Q. suber, Salix sp. and Alnus glutinosa, and with an undergrowth dominated by Osmunda regalis, Ulex europaeus, Hedera helix, Lonicera periclymenum, Rubus sp. and various graminaea. The site is crossed in a north-south direction by two low, dry-stone walls about 50 cm high, and diagonally by an underground stream that discharges into a man-made reservoir (Fig. 1). The watercourse is open to the outside world at the pond edge (Fig. 1: point W) and at three further sites (Fig. 1: X, Y and Z). The holes X and Y are narrow (ca. 30 cm), washed-out crevices along tree roots. Holes W and Z are wide, derelict, man-made entrances. The study area was divided into 72 quadrangular areas (8 m x 8 m), for each of which we counted the number of trees (N_{tree}) and measured the shortest distance from the centre of the grid cell to the dry stone wall (D_{wall}) , to the water (pond or position of the watercourse in a straight line, D_{unter}), and to the holes (D_{holes}) . The undergrowth was classified as vegetation type A - low, grassy vegetation providing

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poor cover, type B - medium-height Osmunda regalis and grassy vegetation providing medium cover, or type C - high and dense grassy and herbaceous vegetation with tree shoots, providing good cover. The places where salamanders were found were classified as (1) at an exit hole, (2) at the base of – or within – a dry-stone wall, (3) at the base of a tree, or (4) out in the open.

Twenty-eight rounds of observations at regular intervals of about two weeks were made from 16 March 1995 to 28 March 1996. Temperature and relative humidity were measured locally at the start of each visit, three hours after sunset. Precipitation data (rainfall in mm over 48 hours, measured at 0900 hrs prior to the study night) were obtained from the meteorological station at Matosinhos, 15 km west of Alfena. One search took from two to four hours to complete, depending on time of year, weather conditions, and catch. Orientation was done by visual triangulation with 220 mapped trees as reference points. Accessible parts of the underground watercourse were inspected five times in autumn. Salamanders with snout-vent length of 38 mm or more were considered to be adults and their sex was determined from the expression of secondary sexual characteristics (cf. Arntzen, 1981).

The distribution of the salamanders was analyzed by stepwise linear regression, with relative density (number per square averaged over visits, N_s) as the dependent variable and D_{hole} , D_{wall} , D_{water} , N_{tree} , and vegetation type (VT) as independent variables. The resulting models were visualized with the help of a Geographic Information System (ILWIS 2.0). The activity of the salamanders was estimated through the parameters 'catch' and 'dispersion'. Catch was the total number of salamanders caught during each visit (N_v). Dispersion (m) was the mean shortest distance between each salamander and the structural feature(s) (i.e. exithole, dry-stone wall, and watercourse) selected in the distribution models.

The normality of data distribution was tested by Shapiro-Wilk's *W*-test. Parametric and non-parametric statistical tests followed Sokal & Rohlf (1981) and Siegel & Castellan (1988).

RESULTS

Out of 1550 observations of salamanders above ground, 217 (14%) were juveniles and 1333 (86%) were adults. Excluding salamanders for which gender could not be determined unequivocally, 674 were males (60%) and 454 were females (40%). The observed sex-ratio was male-biased during summer, autumn and winter (*G*-test of goodness of fit, 15.6 < G < 28.1, df=1, P < 0.001), but not significantly different from unity during spring (G=0.5, df=1, P > 0.05). From 130 to 180 salamanders were observed in the underground watercourse in autumn. We observed six pairs in amplexus, and 11 eggs that were deposited just above the water surface.

Fig. 2 shows how N_v (i.e. the no. individuals observed) varied seasonally and in relation to meteorological conditions. A significant relationship



FIG. 1. Map of the area in which *Chioglossa lusitanica* was studied. For a description of the vegetation types see text.



FIG. 2. Numbers of adult and juvenile *Chioglossa lusitanica* observed. Temperature and relative humidity were recorded locally; precipitation was recorded at the 'Estação de Avisos Agrícolas de Entre Douro e Minho' at Matosinhos, 15 km west of the study area. Three sampling periods were conducted in August.

	Precipitation in preceding 2 days		Relative humidity	
	No(<i>n</i> =13)	Yes(n=15)	<95%(<i>n</i> =13)	>95%(n=15)
Number				
Juveniles	1.9	12.8	2.6	13.7
Males	5.2	40.5	8.0	42.6
Females	2.8	27.8	6.4	27.5
Dispersion (m)				
Juveniles	0.4	1.9	0.3	2.3
Males	1.2	5.2	1.4	5.5
Females	2.4	6.7	2.3	7.5

TABLE 1. Average number and dispersion of Chioglossa lusitanica observed under dry and moist weather conditions.

was observed between N_v for males, females and juveniles with relative humidity (Spearman rank-correlation test, 0.72 < r < 0.77, P < 0.001) and with precipitation (0.60 < r < 0.72, P < 0.001), but not with temperature (-0.35) <r < 0.29, P>0.05). The average catch was higher during visits preceded by precipitation than during dry periods and higher when relative humidity was high (> 95%) than when it was not high (Table 1). It should be noted that rainfall and humidity data were correlated (r=0.71, P<0.001). Dispersion did not differ significantly between males and females (Mann-Whitney U-test, Z=0.81; P>0.05) but was higher for adults than for juveniles (Z=2.44, P<0.05). A significant association was observed between dispersion of both adults and juveniles with precipitation (0.52 < r < 0.64, P < 0.01) and relative humidity (0.65<r < 0.76, P< 0.001). Dispersion was higher during visits preceded by precipitation than during dry periods and higher when relative humidity was high than when it was not high (Table 1). A significant negative relationship of dispersion with temperature was observed for females (r_s =-0.51, P<0.05), but not for males or juveniles (-0.21 $\leq r \leq$ -0.25, $P \geq$ 0.05). The two sexes were not found in equal proportions in different microhabitats: males were found more frequently at the bases of trees than females (G-test for independence,

G=8.4, df=3, P<0.05); similarly, adults were found at the bases of trees more frequently than juveniles (18.1<G<36.6, df=3, P<0.001; Table 2). During wet conditions, adults and juveniles were found relatively often at the bases of trees, while during dry conditions they were found more frequently at the exit holes (G-test for independence, 25.8<G<123.0, df=3, P<0.001; Table 2).

A preliminary analysis showed a poor fit of spatial models based on linear regression $(0.15 < r^2 < 0.30)$. However, our observations indicated that hole W was rarely used, and excluding that hole from the analyses markedly improved the fit of the models – for juveniles: $log(N_s+1)=0.781-0.010xD_{wali}-0.022xD_{water}$ (P<0.01, $r^2=0.35$); for males: $log(N_s+1)=1.190-0.010xD_{wall}-0.032xD_{hole}+0.091xN_{tree}$ (P<0.01, $r^2=0.64$); for females: $log(N_s+1)=0.443-0.022xD_{water}+0.079xN_{tree}+0.123xTV$ (P<0.01, $r^2=0.28$).

The spatial distribution of salamanders as described by these models is presented in Fig. 3.

DISCUSSION

Large and stockily-built salamander species are better able to cope with conditions of drought than small and slender ones (Spight, 1968). For example, the stocky Salamandra salamandra may survive dehydration to

TABLE 2. Number of *Chioglossa lusitanica* observed in particular micro-habitats under moist and dry weather conditions. Moist conditions are those of high humidity or rain or both (for definitions see Table 1).

	Microhabitat				
Weather conditions	Hole	Dry-stone wall	Base of tree	Out in the open	
Juveniles					
Moist (<i>n</i> =16)	22(11%)	19(10%)	140 (73%)	12(6%)	
Dry (<i>n</i> =12)	5(21%)	9 (38%)	5 (21%)	5(21%)	
Males					
Moist (<i>n</i> =16)	71(11%)	14(2%)	514 (82%)	26(4%)	
Dry (<i>n</i> =12)	31(63%)	3 (6%)	13 (27%)	2(4%)	
Females					
Moist (<i>n</i> =16)	64(15%)	20 (5%)	322 (76%)	19(5%)	
Dry (<i>n</i> =12)	21 (72%)	3 (10%)	4(14%)	1 (3%)	



FIG. 3. Spatial models describing the density distribution of male (A), female (B) and juvenile (C) *Chioglossa lusitanica* (for formulae see text). The shading represents the number of salamanders predicted to be found per unit of space and time (grid cells and visits respectively).

the extent of losing 40% of body mass, while slender salamanders are likely to succumb if water loss exceeds 25% (Littleford et al., 1947; Warburg & Degani, 1979). Within a species, the small body size and correspondingly high surface area:volume ratio of juveniles renders them more sensitive to desiccation than adults (Bellis, 1962; Semlitsch, 1981) and gravid females tolerate greater water loss than males of corresponding size (Ray, 1958). In C. lusitanica juveniles were observed closer to the water than adults (Arntzen, 1981, 1995; Lima, 1995), and at breeding sites females were found at relatively dry places whereas most males were in or near the water (Arntzen, 1979), thus conforming to expectations from body shape and size. A strong moisture-dependence of C. lusitanica is also apparent from an analysis of its geographical range, of which precipitation appears to be the prime determinant (Arntzen, 1981; Teixeira, 1999).

In the present study, the above-ground density of C. lusitanica was highest in the vicinity of the stream, either on account of the exit-entry holes (males) or on account of the underground watercourse (juveniles and females). Density was also high near dry stone walls (juveniles and males), in areas with a higher than average density of trees (adults) and in areas of dense undergrowth (females). Interpretation of the results is, however, not entirely straightforward because they simultaneously describe retreat, surface activity and microhabitat. Moreover, the observed distances of salamanders to the holes and to the underground watercourse are correlated. Surface activity increased with high values of relative humidity and rain, and above-ground density decreased with increasing distance from the stream. Dispersion was higher in wet weather conditions than when it was dry. Together with the higher numbers at exit-entry holes in dry weather than in wet weather, the observations indicate that the underground watercourse served as a retreat from which the salamanders would visit the outside. The excursions presumably served for foraging and not for finding sexual partners, because mating (and egg-deposition) does not generally take place above ground, but in secluded places (Arntzen, 1981). The high number of salamanders observed at the bases of trees and in areas of dense vegetation may reflect the availability of food or shelter, or both. The association with dry-stone walls in dry weather conditions (when salamanders tend to be less active) indicates that walls function as retreats rather than as foraging grounds. Similar dependencies were described for Plethodon cinereus and P. richmondi that were found climbing the vegetation on wet nights, but did not leave their shelters under dry weather conditions (Jaeger, 1971).

The spatial models showed differences in habitat utilization for males, females and juveniles. The observations may well reflect different ecological and behavioural responses by the sexes. The low explanatory power of the spatial model derived for females may be influenced by the fact that we did not distinguish between gravid and non-gravid individuals. Similarly, the relatively low explanatory power of the spatial model derived for juveniles may be influenced by the classification of different life stages (e.g. newly-metamorphosed, near-adult) as a single group. A particular feature of the juvenile distribution was the high numbers in the stone wall adjacent to the pond. Since it is not uncommon for juvenile salamanders to stay close to their natalsite (Palis, 1997; Semlitsch, 1998), the metamorphosis of *C. lusitanica* from the local pond (where larvae have been observed) would help to explain this observation.

Moisture and precipitation have been related to foraging activity in Mertensiella caucasica (Tarkhnishvili & Serbinova, 1993), in plethodontids (Hairston, 1949; Heatwole, 1962; Salvidio, 1993; Cimmaruta et al., 1999) and other salamanders (Joly, 1968; Semlitsch, 1981, 1983; Degani & Mendelssohn, 1982; Beneski et al., 1986). Declines in salamander activity and foraging ranges with decreasing precipitation have also been observed in more typical C. lusitanica habitat, along fast-flowing mountain streams (Arntzen, 1981, 1995; Lima, 1995). It is unclear, however, whether this decrease is to be related to a change in shelter (closer to the brook) or to change in activity. In our study area, clearly, the shelter was fixed and the activity pattern changed. The similarity in response between C. lusitanica and some plethodontid salamanders to changing environmental parameters, the description of similar micro-distributions, and the extreme dependence on moist habitats support the hypothesis that these taxa are subject to evolutionary convergence (Wake & Özeti, 1969; Arntzen, 1994b).

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