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SEASONAL AND DIEL CYCLES OF ACTIVITY IN THE RUIN LIZARD, *PODARCIS SICULA*

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ABSTRACT

Adult ruin lizards, *Podarcis sicula*, at a study site near Pisa, Italy, were seen during all months of 1988, but in significantly reduced numbers in January, February, November and December. The length of the diel period during which individuals were observed varied from 2-3 h in mid-winter to 14 h in July and August. High activity, defined as any one-hour period of the day during which the total number of lizards observed over three days of observation in any month was greater than the 95% confidence limits for the overall mean, was bimodal from April to October inclusive. Bimodality in the activity pattern was particularly pronounced in the hottest months, as low activity, when numbers observed were lower than the C.L. for the overall mean, occurred during the central hours of the day (1200-1400 h) in July and August. Low activity was also recorded at the beginning and end of the active period in all months from February to November. The diel cycles of juveniles (lizards less than 6 months old) appeared to be less structured than those of adults.

INTRODUCTION

Investigations of the inter-relationships between climate, habitat and activity pattern are of crucial importance in understanding the ecology and behaviour of many ectotherms; this is especially true of diurnal lizards (Porter, Mitchell, Beckman & DeWitt, 1973; Avery, 1976; Porter & Tracy, 1983). The activity component requires that the study animals should be relatively easy to observe, unless there is some indirect means for determining their movements. In many Mediterranean regions the presence of man over many millenia has resulted in a substantial reduction in vegetation cover. This has created environments which are apparently particularly favourable for lizards, and the animals often occur at high densities. The combination of open environments and large numbers makes the lizards fairly easy to observe, and they are thus very suitable for studies of activity patterns and other behaviour. Observations of activity patterns in the field not only help to disclose important aspects of the ecology, ecophysiology and spatio-temporal organisation of behaviour, but can also greatly contribute to our understanding of the adaptive significance of circadian and other rhythms in natural environments (e.g. Janik, 1987; Underwood, 1990).

This paper describes the seasonal and diel cycles of activity in a population of ruin lizards, *Podarcis sicula*, inhabiting the coastal plains at Pisa, Italy. It is planned that this is to be one of a series of papers, which will include both field and laboratory studies, on the physiology and ecology of rhythmic behaviour in the species.

MATERIALS AND METHODS

The work was carried out during the period January-December 1988 at the field station of the Dipartimento di Scienze del Comportamento Animale e dell'Uomo of Pisa University, located 1.5 km from the Ligurian sea in an area of reclaimed marshland with well-drained, sandy soils. The 150 m^2 study site is in a flat meadow and incorporates the foundations of a dismantled poultry pen. The surrounding vegetation is mostly mown grass, but isolated plants of mullein, *Verbascum sinuatum* L., and a few trees and shrubs, provide shade and refuge. The activities of many of the individual lizards in the study population centred on the foundations, in which perforated bricks and other debris provided abundant shelter.

The term activity is used in this paper in a broad sense (see Discussion). We measured as an index of lizard activity the total number of lizards which could be observed in a specified unit of time. We defined as "active" all those lizards whose presence could be visually detected within the study area. This included (i) moving lizards (ii) immobile lizards which were basking (iii) other immobile lizards which could be detected, e.g. hidden beneath vegetation. The data were obtained as follows: one observer walked through the study area along standard paths, counted the number of lizards, and attributed each sighting to one of the categories adult male, adult female, subadult, juvenile. This was repeated every hour, from sunrise to sunset, for three days every month for a total of twelve months (N=468). The units in which the data were compiled were total number of lizards observed within a specified hour over three days. The soil temperature was measured at the point at which each lizard was first observed. Times were always recorded as European Standard Time; this is one hour ahead of Greenwich Mean Time (GMT).

RESULTS

Adult *P. sicula* were observed in all months of the year, but activity in January and December was sporadic and only very few individuals were seen (Table 1). Numbers were also significantly reduced during February and November (based on the null hypothesis of equal numbers in all months from February to November, χ^2=149, P<0.001). Adult males and adult females showed similar monthly cycles of activity (G-test with STP analysis, P<0.05) and the sexes have been combined for further analysis.

Month	Total number of adults	Total number of juveniles	Maximum soil temperature (°C)
January	2	-	-
February	40	-	25.6
March	127	-	28.3
April	213	-	33.4
May	187	-	39.1
June	186	-	36.6
July	139	30	42.8
August	148	100	40.9
September	160	72	40.0
October	174	33	32.5
November	42	4	22.9
December	3	0	-

TABLE 1. Monthly values for total number of lizards observed and maximum recorded soil temperatures.

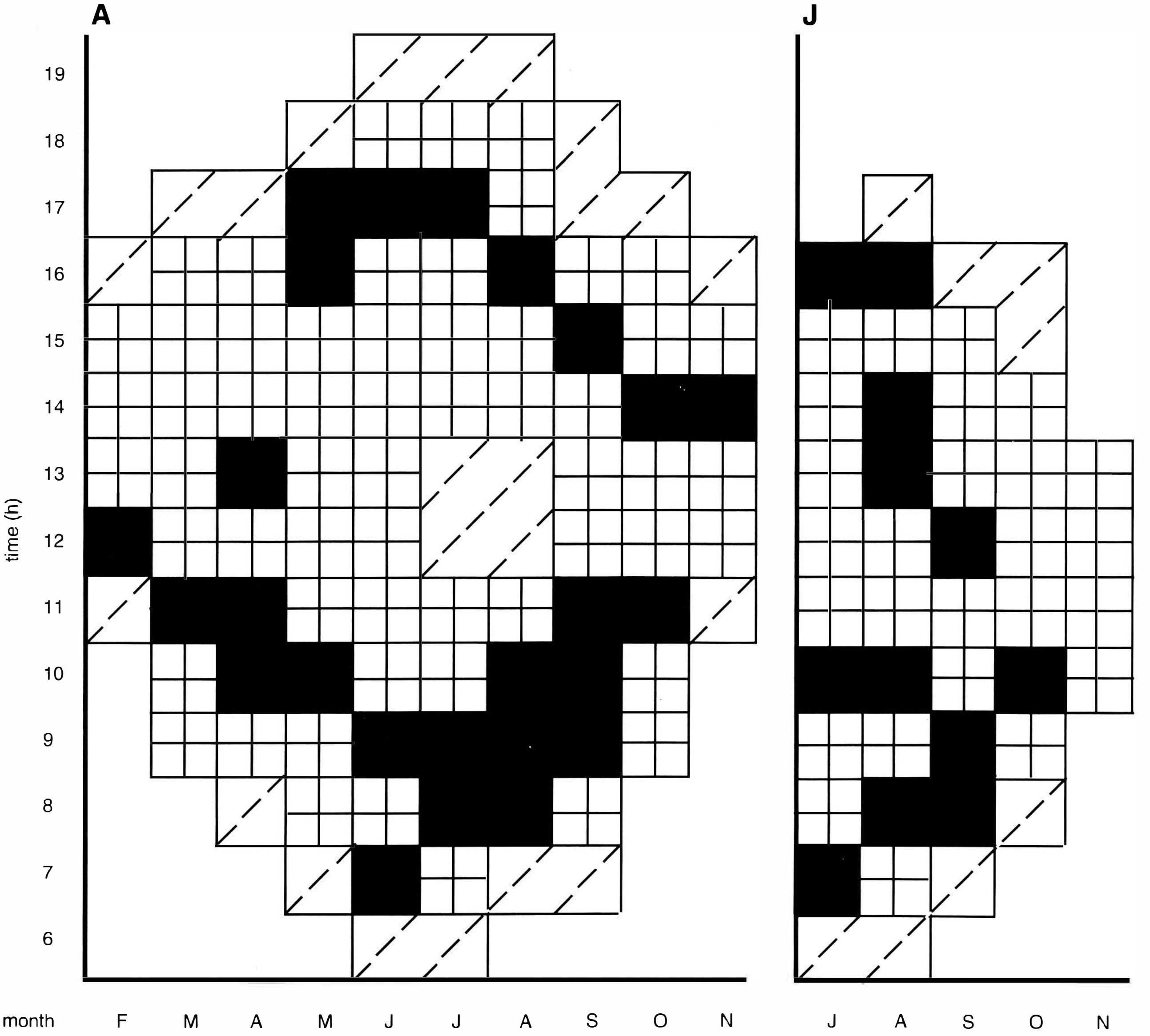

Fig. 1. Seasonal (monthly) and diel activity of *P. sicula*: adults (A) on the left, juveniles (J) on the right. January and December are not shown because of very small sample sizes. Black squares represent high activity, diagonal hatching low activity and cross-hatching intermediate levels of activity (see text for definitions).

The length of the period during which adults were observed varied seasonally, from 2-3 h in January and December to 14 h in June and July (Fig. 1). Activity during the latter months occupied most of the period from sunrise to sunset; during January and December less than one half of this period was utilised, with intermediate proportions in intervening months (Fig. 1). There was considerable variation in the number of lizards actually observed from hour to hour, much probably due to sampling error. In order to remove this error to demonstrate any underlying trends, the mean and 95% confidence limits for the overall hourly totals within each month were calculated. Any individual total which lay outside the 95% confidence limits of the mean was designated "high activity" if above the mean, "low activity" if below it. Fig. 1 demonstrates a clear seasonal pattern in the distribution of both high and low activity.

High activity occurred during the middle period of the day in February, March and November. From April to October there were two peaks of high activity, separated by progressively increasing periods of time until June and decreasing periods of time from August to October. Low activity was concentrated at the beginning and end of the active period throughout the year (except in January and December, when sample sizes were too small to detect any hourly differences). There was also a period of low activity from 1200-1400 h in July and August; these are the months when maximum recorded soil temperatures reached their highest levels (Table 1). The presence of such low midday activity shows that the bimodal pattern was more pronounced in the hottest months of the year.

Juvenile lizards first appeared in July. They gave the impression of a less structured diel cycle, with comparatively high levels of activity maintained for long periods. This is partially borne out by the data (Fig. 1). Juveniles did not show a period of significantly reduced activity at midday in July and August.

DISCUSSION

The data presented in this paper show that adult *P. sicula* at Pisa conform to the patterns of diel and seasonal activity which have been recorded in a wide range of generalised lacertid lizards from southern Europe, including other populations of the species from elsewhere within its geographical range (for *P. sicula* : Avery, 1978; Ouboter, 1981; Henle, 1988; Van Damme, Bauwens, Castilla & Verheyen, 1990; for other lacertid species, examples include Gruber & Schutze-Westrum, 1971; Busack, 1976; Pough & Busack, 1978; Perez-Mellado & Salvador, 1981; Perez-Mellado, 1983; Bowker, 1986; Pollo Mateos & Perez-Mellado, 1989). This pattern is characterised by sporadic activity during the cool winter months, long periods of activity with peaks during the mid-morning and late afternoon during the hottest months of the summer.

Juvenile *P. sicula*, however, do not appear to conform so clearly to this pattern. Subadults (i.e. sexually immature lizards between six and eighteen months of age) probably have diel activity patterns similar to those of juveniles, but the data were too limited for detailed analysis. There was some evidence that subadult numbers decreased during March-June due to competition for territorial space with adults (*P. sicula* is a territorial species, see Verbeek, 1971 and review of literature in Henle & Klaver, 1986).

An important limitation of this, as of almost all of the studies of activity cycles of lacertid lizards cited above, is that "activity" is only partially defined. An "active" lizard is one which can be observed (see Materials and Methods). It is not in any kind of retreat or burrow, but may actually be engaged in a variety of behaviours. These include hunting for food, sexual and competitive interactions, sentinel predation, basking and periods immobile in shade during the hotter parts of the day. Only the first two involve a high portion of movement; in the last three, the "active" lizard may actually be immobile, sometimes for quite long periods. Different behaviours are associated with different probabilities that a lizard will be observed. Basking lizards are exposed to direct solar radiation and so the probability that they will be observed is high. Shade-seeking lizards, on the other hand, undoubtedly have a lower probability of being observed. This difference in observability is the likely explanation for the asymmetry in "high activity" seen in most months of the year and illustrated in Fig. 1. It is associated with basking, which occupies longer periods during the early morning, when both solar radiation and air/substrate temperatures are low, shorter periods during the late afternoon when solar radiation is low but air/substrate temperatures comparatively high, and very short periods (which can include zero) during the middle of the day when both solar radiation and air/substrate temperatures are high. This problem of differences in observability is probably unavoidable in any study based on scan samples (Altmann, 1974). For a more detailed interpretation it is necessary at the least to know the behaviour of an individual lizard during the period immediately prior to recording. This can be achieved by continuous observation of focal animals, but is inevitably a great deal more time-consuming.

The seasonal differences in activity patterns recorded here have been interpreted as responses to environmental conditions. There is some experimental evidence, however, that they may have an endogenous component. When, for example, *P. sicula* captured during the hottest months (July-August) were tested under constant temperature (29°C) and darkness in the laboratory, 71% of the individuals (10 out of 14) continued to display a bimodality in spontaneous locomotor activity; in a cooler period of the year, i.e. when *P. sicula* were captured between end of September and beginning of October, only 13% of the lizards (2 out of 15) tested under the same laboratory conditions was still bimodal (Foà, in preparation). This makes the species a particularly suitable model animal to study and test hypotheses relating to the internal or external coincidence of photoperiod and other environmental variables (e.g. Pittendrigh & Daan, 1976) in the induction, maintenance and experimental manipulation of rhythmic behaviour and seasonal activity patterns.

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