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A Comparative Study on Temperature and Relative Humidity Data of Three Caves in Different Climatic Regions of Turkey, with Notes on the Distribution of Anatolian Cave Crickets (Insecta, Orthoptera, Rhaphidophoridae)

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ABSTRACT

The diversity of cave crickets (Orthoptera, Rhaphidophoridae) remarkably differs between geographic regions in Anatolia. While only 4 species are distributed in northern Anatolia where Black Sea climate prevails, 14 species are found throughout southern and western Anatolia where the Mediterranean climate is dominant. However, no cave crickets were reported from the middle and eastern Anatolia where the continental climate is present. There is no data-based study on the distribution pattern of cave cricket species in Anatolia. This study aimed to reveal any possible relation between climatic conditions and distribution of cave crickets in three caves selected as representatives for three climate types present in Anatolia. Temperature and relative humidity in the ecological zones of the given caves and the surface were periodically measured by using data loggers. Our data show within cave variations in temperature and relative humidity among all three caves: (i) variations in temperature and relative humidity decreased from the entrance zone to the dark zone, (ii) over the winter period, temperature increased from the entrance zone to the dark zone, (iii) over the summer period, temperature decreased from the entrance zone to the dark zone, (iv) the most distinct temperature variation was measured in continental climate, and (v) the major similarity of climatic conditions between cave and climate type was observed in the Black Sea region which cave crickets species have widened distribution and limited speciation.

Key words: Rhaphidophoridae, cave crickets, cave zones, climatic factors, distribution, Anatolia.

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INTRODUCTION

Caves, naturally occurring underground spaces, range in size from single small rooms to interconnecting passages which can become minor caves in time, and host many unique biota that are highly interconnected and interdependent, and that fall into three different groups based on the amount of time they spend in the cave: Troglobites or cave dwellers, troglophiles or cave lovers, and trogloxenes or cave guests. Although cave ecosystems in which a diversity of habitats lies are often thought of as constant, they directly depend upon the surrounding surface environment that is very changeable. While cave ecosystems differ in terms of environmental conditions such as temperature, relative humidity, and light intensity, these conditions can change even in the entrance, twilight and dark zones of a cave (Cropley, 1965; Culver, 1982; De Freitas & Littlejohn, 1987; Gample, Dogwiler, & Mylroie, 2000; Culver & Pipan, 2009; Romero, 2009).

Caves are valued as natural underground laboratories by scientists since they can provide insight into evolutionary and ecological processes because of their geographical and hydrological isolation, by allowing rapid colonization (Vandel, 1964; Poulson & White, 1969; Sbordoni, 1980). Ecological studies on caves began with simple experimental observations towards the end of the 19th century (Crump, 1886; Leonard, 1889; Crump, 1890) and continued with increasing momentum (Di Russo, Carchini, & Sbordoni, 1994; Carchini, Rampini, & Sbordoni, 1994; Di Russo & Sbordoni 1998; Di Russo, Carchini, Rampini, Lucarelli, & Sbordoni, 1999, Yoder, Hobbs, & Hazelton, 2002; Weckerly, 2012). Especially in recent years methodological advances in speleology have enabled the development of biospeleology involving more detailed ecological studies in which temperature, RH, pressure, radon and CO_2 gas measurements of a given cave were taken, and air currents in the vertical and horizontal caves and the connection between surface and cave climate were examined (Cropley, 1965; De Freitas, Littlejohn, Clarkson, & Kristament, 1982; Ek & Gewelt, 1985; De Freitas & Littlejohn, 1987; Nepstad & Pisarowicz, 1989; Smithson, 1991; Forbes, 1998; Gample et al, 2000; Sanderson & Bourne, 2002; Gunn, 2004; Stoeva & Stoev, 2005; De Freitas, 2010; Gregoric, Zidansek, & Vaupotic, 2011). Surprisingly, despite the approximate presence of 40,000 caves in Turkey (Ozansoy & Mengi, 2006) there are few studies on cave biology. The majority of the studies carried out to date are faunistic rather than ecological (Kunt, Yağmur, Özkütük, Durmuş, & Anlaş, 2010).

So far, studies on relationships between ecological factors and the biology (reproduction, nutrition, physiology, etc.) of cave crickets have been restricted to North America and Europe. However, there are not any studies on the ecology of cave crickets in Anatolia. The distribution of cave crickets (Orthoptera, Rhaphidophoridae) remarkably differs among geographic regions in Anatolia. While only four species are distributed along northern Anatolia where the Black Sea climate prevails (Bey-Bienko, 1969; Di Russo, Rampini, & Landeck, 2007; Taylan, Mol, & Şirin, 2015), 14 species are found throughout southern and western Anatolia where the Mediterranean climate is dominant (Bolivar, 1899; Taylan, Di Russo, Rampini, & Cobolli, 2011; Rampini, Di Russo, Taylan, Gelosa, & Cobolli, 2012; Taylan, Di Russo, Cobolli, & Rampini, 2012; Gorochov & Ünal, 2015). However, cave crickets may not exist in the middle and eastern Anatolia where the Continental climate is present (Taylan et al, 2011) (Table 2, Fig. 1). Although some previous studies assumed that ancient central Anatolian lake systems (Taylan & Şirin, 2016), and climatic factors including temperature and RH in the cave ecological zones and the surface may affect the distribution of cave crickets (Taylan et al, 2011), there is no data-based explanation of the distribution pattern of different species of cave crickets in Anatolia. Therefore, this study aimed to reveal any possible relation between climatic conditions and distribution of cave crickets as model organisms in three caves selected to represent three climate types seen in Anatolia (Fig. 1), (i) by comparing the annual data of temperature and RH for each cave, cave zone and climate type, (ii) comparing the relationship between surface and cave climate in different climate regions, and (iii) evaluating possible effects on the biogeographic distribution of cave crickets.

Table 1. The data of surface and ecological zones of the study caves.

Caves	Measured data	Surface	Entrance zone	Twilight zone	Dark zone
Geyikbayırı cave	Annual mean temperature	18.98	15.06	15.65	16.64
	Annual mean relative humidity	50.64	98.53	98.91	98.94
	Weekly maximum mean temperature	32.99	20.83	17.2	17.61
	Weekly minimum mean temperature	5.06	7.78	14.22	15.06
	Weekly maximum mean relative humidity	77.8	99.0	99.0	99.0
	Weekly minimum mean relative humidity	18.37	97.0	97.0	98.0
Sipahiler cave	Annual mean temperature	11.10	9.79	10.08	9.76
	Annual mean relative humidity	78.65	78.61	99.85	98.98
	Weekly maximum mean temperature	23.6	15.14	12.1	10.72
	Weekly minimum mean temperature	-0.98	6.25	8.74	8.89
	Weekly maximum mean relative humidity	91.75	88.61	99.99	99.0
	Weekly minimum mean relative humidity	60.79	68.71	96.61	97.8
Tuluntaş cave	Annual mean temperature	11.81	11.02	9.43	10.09
	Annual mean relative humidity	57.12	98.60	98.92	98.99
	Weekly maximum mean temperature	30.23	16.98	10.6	10.56
	Weekly minimum mean temperature	-7.83	5.1	7.35	9.56
	Weekly maximum mean relative humidity	87.25	99.0	99.0	99.0
	Weekly minimum mean relative humidity	27.29	97.0	97.08	98.99

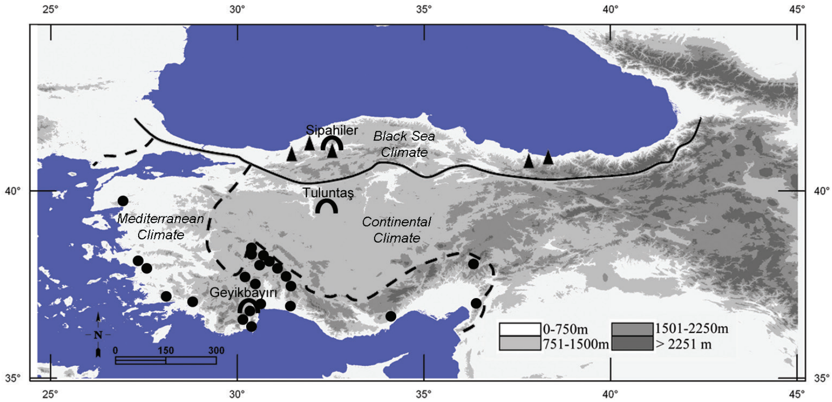

Fig. 1. Localities of the study caves and climatic regions in Turkey. The spots indicate the locations of the cave crickets.

MATERIAL AND METHODS

The climate characteristics in Turkey with reference to the locations of the studied caves

The climate mainly determined by the topography and other geographical factors such as landscape and altitude, along with atmospheric circulation patterns. Three different types of climate are found in the country; (i) Mediterranean climate with hot, moderately dry summers and mild to cool, wet winters, (ii) Black Sea climate with warm, wet summers and cool to cold, wet winters, and (iii) Continental climate with sharply contrasting seasons in that summers are extremely hot and dry and winters are especially severe. Mediterranean climate prevails in the coastal areas of Turkey bordering the Aegean Sea and the Mediterranean Sea, having both winter and late spring precipitation peaks which vary from 580 to 1.300 mm. Black Sea climate is seen in the coastal areas of the country which border the Black Sea and receive high precipitation (2000-2500 mm) throughout the year. About half of Turkey, which lies between the North Anatolian Mountains with 3942 m elevation and the South Anatolian Mountains (Taurus) with an elevation of 3000 m, is dominated by Continental climate with a precipitation peak in late spring or early summer, being between 295 and 770 mm for the central Anatolia, 321 and 1230 mm for the East Anatolia, and 331 and 821 mm for the south-eastern Anatolia (Atalay, 2000; Sensoy, Demircan, Ulupinar, & Balta, 2008; Deniz, Toros, & Incecik, 2011). Depending on location and elevation, the annual mean temperature (AMT) in Turkey varies from 3.6°C to 20.1°C, reaching a maximum in July (the Southern parts of Anatolia and the Mediterranean coasts) and a minimum in January (the East Anatolia). The annual mean precipitation in the country is around 648 mm, ranging from 295 (the central Anatolia) to 2220 mm (the eastern Black Sea coasts), and the precipitation occurs mostly during the winter months (Deniz et al, 2011). Three natural non-tourist caves, each from three different climatic regions and having horizontal structure and similar entrance size, were selected as the study caves: Geyikbayırı cave, Sipahiler cave and Tuluntaş cave which are located in the Mediterranean, the Black Sea and the Continental climate regions, respectively (Fig. 1).

The characteristics of the studied caves

Geyikbayırı cave is located in the village of Geyikbayırı about 26 km away from Antalya Province (N 36°52’ 37’’- E 30°28’ 21’’, entrance elevation is 550 m). The cave with a total length of 120 m is 7 m deep. It has completely developed in massive gray Permian limestone, with Triassic conglomeratic limestone and sandstone in its base, and has many travertine formations. This cave, which has almost completed its development process, was researched and mapped by General Directorate of Mineral Research and Exploration of Turkey (MTA) in 1982 (Gürcan, Yamaç, Tanındı, & Uygun, 2006). *Dolichopoda lycia* (Galvagni, 2006) is known to occur in this cave (Taylan & Şirin, 2016).

Sipahiler cave having dimensions of 338 m length and 32 m depth is situated (N 21°38’ 15’’- E 32°29’ 42’’, entrance elevation is 204 m), in Kayadibi, a village in the central district of Bartın Province (Gürcan et al, 2006). Although a detailed geological investigation of the cave has not yet been carried out, the cave is famous for its large-scale stalactites, stalagmites, and columns that form a wonderful spectacle. The Society of Anatolian Speleology Group (ASPEG) researched and mapped the cave in 2009. *Troglophilus aspegi* Taylan & Şirin, 2015 was reported from this cave (Taylan et al, 2015).

Tuluntaş cave, 15 km away from Ankara, is located in the village of İncek in Gölbaşı district of Ankara Province (N 39°46’ 26’’- E 32°40’ 59’’, entrance elevation is 1251 m), and is 549 m long and 10 m deep. The cave with stalagmites and stalactites has developed in Permo-Triassic limestone blocks which spread about 5-7.5 square km and have a thickness of 30-40 m. This cave has almost completed its development process, and consists of a horizontal gallery and interconnecting passages. It was explored and mapped in a joint work of MTA and Cave Research Association of Turkey (MAD) in 1992 (Gürcan et al, 2006). No cave crickets were found in this cave.

Data loggers: their technical features and applications

Tt-Technic Ds 100 data loggers (Templog Electronic, Istanbul) were employed to continuously monitor air temperature and relative humidity (RH) at one-hour intervals. Battery-powered, these waterproof devices are small enough to be placed in environments such as caves and cold storages/rooms. They measure the temperature in the range of -20 ºC to +85 ºC with a standard error of ± 0.05 ºC and high measurement accuracy of 0.05 ºC, and RH in the range of zero to 100% with a standard error of ± 0.05% and a high measurement accuracy of 0.05%. A total of 12 data loggers were used in the present study, four data loggers in each cave. One device was placed in outside of cave as 10 m average distance among entrance zone to the cave to measure the surface temperature and RH, while the others were placed in the ecological zones (to entrance zone, twilight zone, and dark zone) (Culver & Pipan, 2009), with distance from entrance of cave; 10 m, 40 m, and 100 m, respectively to measure the temperature and RH of the cave atmosphere. The caves were visited on a three-monthly basis for data collection and battery replacement between the dates of January 15, 2012 and January 14, 2013.

Statistical analysis

With descriptive statistics, the maximum, minimum, average and standard deviations of temperature and humidity values on a weekly and annual basis were determined. Whether there is a difference in the humidity and temperature values of caves compared to climate characteristics was tested by one-way ANOVA. For multiple comparisons, Post-Hoc (Scheffe) test was used to find out from which caves the difference found resulted. The Pearson product-moment correlation coefficient test was used to refer to the correlation between surface and cave zones in terms of temperature and humidity values of each cave. Besides, descriptive statistical methods were used for comparison between each cave's zones. IBM SPSS Statistics 22.0 software was employed for all statistical analysis.

RESULTS

Daily air temperature and RH data were obtained from Geyikbayırı, Sipahiler and Tuluntaş caves over one year-study period. These data were analyzed based on weekly mean data. In order to make the data more understandable, atmospheric and ecological zones of the study caves were compared with each other for each study cave.

Comparison of temperature in surface and ecological zones among the caves

Whether there is a difference in temperature values among the caves (or among the climate types as each cave is in a separate climate) compared to climatic characteristics was tested by one-way ANOVA, and it was found that there was a statistically significant difference in all zones of the cave in each climate (Table 3). Scheffe's multiple comparison test was employed to determine which caves resulted in this difference. Accordingly, if the zones are evaluated separately:

Surface: Statistical analysis showed that in terms of surface zone temperature values Geyikbayırı cave was different from Sipahiler and Tuluntaş caves, but Sipahiler and Tuluntaş caves did not have a significant difference in terms of these parameters (Table 4). As the most southern cave, Geyikbayırı cave had the highest value of 18.98°C in terms of AMT. The AMT of Sipahiler cave, which is covered with temperate rain forests in the north, was 11.1 °C, while it was 11.81 °C in Tuluntaş cave, which is nearly located at the middle of Anatolia where the Continental climate is dominant (Table 1). The annual mean temperatures (AMTs) were negative in Tuluntaş cave for 12 weeks (minimum weekly mean -7.83 °C), negative temperatures lasted one week in Sipahiler cave (minimum weekly mean -0.98 °C), however negative values were never found in Geyikbayırı cave during the study year (minimum weekly mean 5.06°C) (Fig. 2A). The AMTs increased in the first 26-28 weeks of the year in three study caves, reaching maximum weekly values which were 32.99 °C for Geyikbayırı cave, 30.23 °C for Tuluntaş cave, and 23.6 °C for Sipahiler cave, while it decreased in the remainder of the year (Table 1, Fig. 2A).

Table 3. One-way ANOVA results of temperature (°C) values of cave zones compared to caves/climate characteristics.

		Sum of Squares	df	Mean Square	F	p
Surface	Between Groups	1972,862	2	986,431	12,980	,000
	Within Groups	11627,119	153	75,994		
	Total	13599,980	155			
Entrance zone	Between Groups	793,314	2	396,657	28,810	,000
	Within Groups	2106,494	153	13,768		
	Total	2899,808	155			
Twilight zone	Between Groups	1218,735	2	609,367	686,338	,000
	Within Groups	135,841	153	,888		
	Total	1354,576	155			
Dark zone	Between Groups	1564,857	2	782,428	2066,285	,000
	Within Groups	57,936	153	,379		
	Total	1622,792	155			

Entrance zone: Statistical analysis revealed that Geyikbayırı cave was different from Sipahiler and Tuluntaş caves in terms of entrance zone temperature values, but Sipahiler and Tuluntaş caves having no significant difference in terms of these parameters (Table 4). The AMT of this zone was determined as 15.06 °C in Geyikbayırı cave, 11.02 °C in Tuluntaş cave, and 9.79 °C in Sipahiler cave (Table 1). Although being the closest to the outside, negative temperatures were not observed in the entrance zone of all three study caves. Minimum values of 7.78 °C, 5.1 °C, and 6.25°C were observed in the 6th week for Geyikbayırı cave and the first week for Tuluntaş and Sipahiler caves, respectively (Table 1, Fig. 2B). The WMTs gradually increased in the first 30-38 weeks of the year, followed by a faster decline, reaching the value of the first week (Fig. 2B). Maximum values were measured in the 38th, 33rd and 30th week of the year as 20.83 °C, 15.14 °C, and 16.98 °C for Geyikbayırı, Sipahiler, and Tuluntaş caves, respectively (Table 1, Fig. 2B).

Twilight zone: It was found from statistical analysis that the three caves differed in terms of twilight zone temperature values (Table 4). The AMT of this zone was observed to be 15.65 °C in Geyikbayırı cave, 9.43 °C in Tuluntaş cave, and 10.08 °C in Sipahiler cave (Table 1). In this zone, the minimum weekly mean temperatures (WMTs) were higher than those of the entrance zone, in that they were 14.22 °C in Geyikbayırı cave in the 7th week, 7.35 °C in Tuluntaş cave in the 3rd week, and 8.74°C in Sipahiler cave in the 15th week (Table 1, Fig. 2C). These zonal temperatures exhibited a gradual increase during the first 39-41 weeks of the year and a rapid decrease after a shorter period (Fig. 2C). The WMTs reached a maximum of 17.20 °C in the 41st week, 12.10 °C in the 40th week, and 10.60 °C in the 39th week in Geyikbayırı, Sipahiler, and Tuluntaş caves, respectively (Table 1, Fig. 2C). There was a variation in the WMTs in this zone of all three caves from 2.98 °C to 3.36 °C (Fig. 2C).

Table 4. Post-Hoc (Scheffe) test results of temperature (°C) values of cave zones compared to caves/climate characteristics. (1. Geyik Bayırı Cave, 2. Sipahiler Cave, 3. Tuluntaş Cave)

Dependent Variable		(I) caves	(J) caves	Mean Difference (I-J)	p	Dependent Variable		(I) caves	(J) caves	Mean Difference (I-J)	p
Surface	Scheffe	1,00	2,00	,000	,000	Twilight zone	Scheffe	1,00	2,00	,000	,000
			3,00	,000	,000				3,00	,000	,000
		2,00	1,00	,000	,000			2,00	1,00	,000	,000
			3,00	,917	,917				3,00	,003	,003
		3,00	1,00	,000	,000			3,00	1,00	,000	,000
			2,00	,917	,917				2,00	,003	,003
Entrance zone	Scheffe	1,00	2,00	,000	,000	Dark zone	Scheffe	1,00	2,00	,000	,000
			3,00	,000	,000				3,00	,000	,000
		2,00	1,00	,000	,000			1,00	1,00	,000	,000
			3,00	,245	,245				3,00	,025	,025
		3,00	1,00	,000	,000			3,00	1,00	,000	,000
			2,00	,245	,245				2,00	,025	,025

*The mean difference is significant at the 0.05 level.

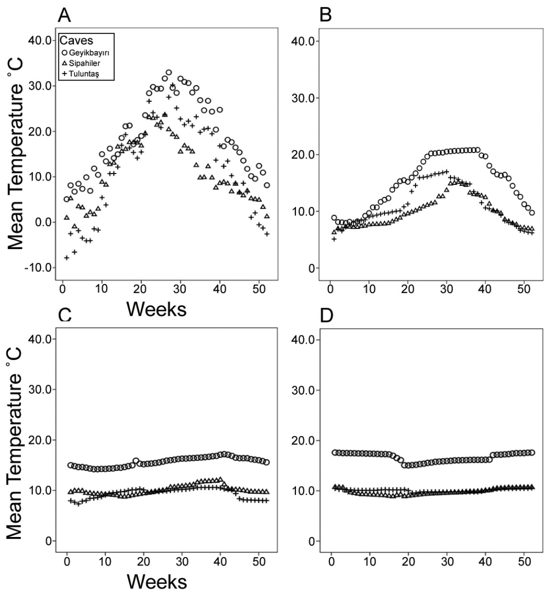

Fig. 2. Comparison of weekly mean temperatures of surface and ecological zones of the study caves (A: Surface, B: Entrance zone, C: Twilight zone, D: Dark zone).

Dark zone: Based on statistical analysis, Geyikbayırı, Sipahiler, and Tuluntaş caves were found to be different from each other in terms of temperature values of the dark zone (Table 4). The AMT of this zone was quite similar to that of the twilight zone, being 16.64 °C, 10.09 °C, and 9.76 °C in Geyikbayırı, Tuluntaş, and Sipahiler caves, respectively (Table 1). This zone exhibited a different pattern of temperature variation, such that the WMT decreased gradually in Geyikbayırı and Tuluntaş caves until the 15th and the 20th week, respectively, then showing a rapid decline in the former for 5 weeks and in the latter for 2 weeks, following a gradual increase in Geyikbayırı cave until the 41st week and in Tuluntaş cave until the 38th week, and a high increase during the following two weeks, and a gradual increase until the end of the year. In Sipahiler cave, the temperature of this zone decreased until the 16th week, and gradually increased until the end of the year (Fig. 2D). In this zone, the minimum WMTs were higher than in the entrance zone and recorded as 15.06 °C in Geyikbayırı cave in the 20th week, 9.56°C in Tuluntaş cave in the 21st week, and 8.89 °C in Sipahiler cave in the 16th week (Table 1, Fig. 2D). Yet, the maximum WMTs reached 17.61°C in Geyikbayırı cave and 10.72 °C in Sipahiler cave in the first week, while 10.56 °C in Tuluntaş cave in the 52nd week of the year (Table 1, Fig. 2D). Variation in WMT was found to be in the range of 1.00°C to 2.55°C in all three study caves (Fig. 2D).

Temperature variations in surface and ecological zones of each study cave

Geyikbayırı cave: Pearson correlation analysis revealed a significant positive correlation between surface temperature values and entrance and twilight zone temperature values in this cave, whereas a significant but negative correlation was found between surface and dark zone. On the other hand, it was determined that entrance zone temperature values showed a significant and positive relationship with twilight zone temperature values, but a significant but negative correlation with dark zone temperature values. Furthermore, a significant negative correlation was found between twilight and dark zones temperature values, whereas a negative correlation was found between dark zone temperature values and other ecological zones (Table 7). In this cave, the temperature followed a very similar pattern in the atmospheric and entrance zones. The WMTs increased from 5.06 °C to 32.99 °C from the first week until the 27th week of the year in the surface, while from 7.78 °C to 20.83 °C from the 6th week through the 38th week in the entrance zone, followed by a gradual decrease reaching the initial temperatures in both zones. The WMTs of the twilight zone continued to fall from the first week through the 7th week (from 15.00°C to 14.22°C), reached 17.2 °C by gradually increasing from the 8th week to the 42nd week, and then dropped to 15.58 °C in the last week of the year (Fig. 3A). The WMTs of the dark zone were quite different from other zones during the study year, in that a WMT variation of only 0.36 °C occurred from the first week to the 15th week of the year (a drop from 17.61 °C to 17.25 °C), and subsequently another temperature drop of only 2.15 °C (15.15 °C from 17.25 °C) over the next 4 weeks was observed, followed by a gradual increase from the 20th week through the 41st week, and about a 1 °C increase (from 16.2 °C to 17.12 °C) between the 41st and 42nd weeks, and then a gradual increase until the end of the year (Fig. 3A).

Sipahiler cave: It was revealed by Pearson correlation analysis that a significant positive correlation between surface and entrance zones temperature values was found in this cave, but the correlation between surface and dark zones was significant but negative, yet there was no significant correlation between surface and twilight zones temperature values. On the other hand, a significant positive correlation was determined between temperature values of entrance and twilight zones, while entrance zone temperature values did not show a significant correlation with dark zone temperature values. In addition, there was a significant positive correlation between twilight and dark zones temperature values (Table 7). Sipahiler cave followed a pattern very similar to that of Geyikbayırı cave for temperature in the surface and entrance zones. The WMTs showed an increase from -0.98°C to 23.6 °C from the first week to the 26th week of the year in the atmospheric zone, while an increase from 6.25 °C to 15.14 °C was observed from the first week to the 33rd week in the entrance zone; however, they gradually dropped up to the initial temperature values in both zones in the remainder of the year (Fig. 3B). Negative temperatures lasted a week at the beginning of the year on the surface. In the twilight zone, WMTs dropped to 8.74 °C from 9.66 °C until the 16th week of the year, followed by a gradual increase of 3.36 °C until the 40th week, reaching a maximum, and then a drop until the end of the year (Table 1, Fig. 3B). The WMTs of the dark zone showed a decrease of 1.83 °C in the first 16 weeks of the year, reaching the lowest temperature value of 8.89 °C, and then a gradual increase from this week to the end of the year (Fig. 3B).

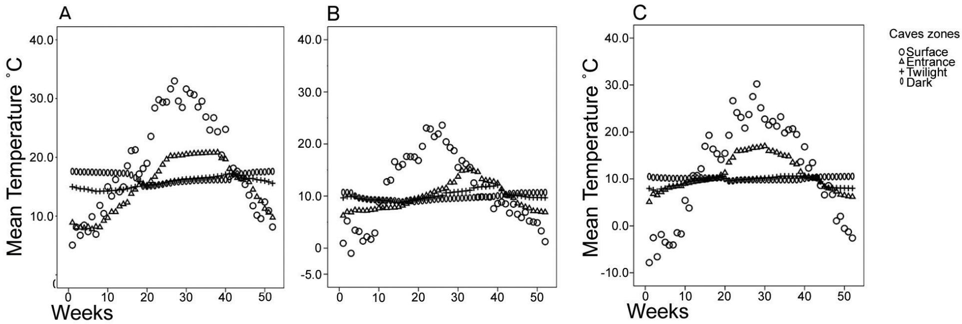

Fig. 3. Comparison of weekly mean temperature variations in surface and ecological zones of each study cave (A: Geyikbayırı Cave, B: Sipahiler Cave, C: Tuluntaş Cave)

Tuluntaş cave: With Pearson correlation analysis, it was revealed that there was a significant positive correlation between surface temperature values and entrance and twilight zones temperature values in this cave, whereas a significant but negative correlation was found between surface and dark zone temperature values. Also, it was determined that entrance zone temperature values showed a significant positive correlation with twilight zone temperature values, and a significant negative correlation with dark zone temperature values. Additionally, whereas a significant negative correlation was found between twilight and dark zones temperature values, a negative correlation was found between dark zone temperature values and other ecological zones (Table 7). The WMTs of the atmospheric and entrance zones of this cave showed a similar pattern to Geyikbayırı and Sipahiler caves (Fig. 3C), such that they increased from -7.83°C to 30.23°C within the first 26 weeks of the year in the atmospheric zone, whereas an increase from 5.1°C to 16.98°C was recorded from the first week to the 30th week of the year in the entrance zone (Fig. 3C). Negative temperatures lasted 12 weeks in the atmospheric zone. In both zones, the WMTs dropped during the remainder of the year, reaching the initial values (Fig. 3C). In the twilight zone, a drop of 0.61°C in the WMTs was observed in the first 3 weeks of the year and subsequently, they increased from 7.35°C to 10.6°C until the 36th week, followed by a constant temperature for next 4 weeks, and then a gradual drop (Table 1, Fig. 3C). In the dark zone, the first 21 weeks of the year exhibited a drop of 0.95°C in the WMTs, reaching a minimum value of 9.56°C. The WMTs gradually increased during the remainder of the year (Fig. 3C).

Comparison of surface and ecological zones of the study caves in terms of RH

Using one-way ANOVA, it was tested whether there is a difference in RH values among the caves (or among the climate types as each cave is in a separate climate) compared to climatic characteristics. This analysis found a statistically significant difference in all zones of the cave in each climate except for the dark zone (Table 5). Scheffe's multiple comparison test was employed to determine which caves resulted in this difference. Accordingly, if the zones are evaluated separately:

Table 5. One-way ANOVA results of relative humidity (%) values of cave zones compared to caves/climate characteristics.

		Sum of Squares	df	Mean Square	F	p
Surface	Between Groups	22367,091	2	11183,546	57,719	,000
	Within Groups	29644,926	153	193,758		
	Total	52012,018	155			
Entrance zone	Between Groups	13807,776	2	6903,888	925,015	,000
	Within Groups	1141,922	153	7,464		
	Total	14949,698	155			
Twilight zone	Between Groups	30,066	2	15,033	85,221	,000
	Within Groups	26,989	153	,176		
	Total	57,055	155			
Dark zone	Between Groups	,087	2	,044	1,573	,211
	Within Groups	4,239	153	,028		
	Total	4,326	155			

Surface: Statistical analysis showed that Sipahiler cave was different from Geyikbayırı and Tuluntaş caves in terms of surface RH values, while Geyikbayırı and Tuluntaş caves did not have a significant difference in terms of surface RH (Table 6). A wide range of RH was recorded in this zone of all three study caves. While

RH levels of 20-80% were measured in Geyikbayırı and Tuluntaş caves, it ranged between 60% and 80% in Sipahiler cave (Fig. 4A). The weekly mean relative humidity (WMRH) showed an irregular decrease in the first 32 weeks and 37 weeks of the year in Geyikbayırı (minimum value 18.37%) and Tuluntaş (minimum value 27.29%) caves, respectively, and then increased until the end of the year (Table 1, Fig. 4A). However, it did not fluctuate so much over the year in Sipahiler cave (Fig. 4A).

Entrance zone: It was shown by statistical analysis that Sipahiler cave differed from Geyikbayırı and Tuluntaş caves in terms of entrance zone RH values, but Geyikbayırı and Tuluntaş caves having no significant difference (Table 6). The WMRH of this zone was around 95-100% in Geyikbayırı and Tuluntaş caves throughout the year, while it was between 71-90% in Sipahiler cave, a similar value to that of the atmospheric zone (Fig. 4B). Besides, a minimum WMRH of 71.03% was seen in Sipahiler cave in the 25th week of the year (Fig. 4B).

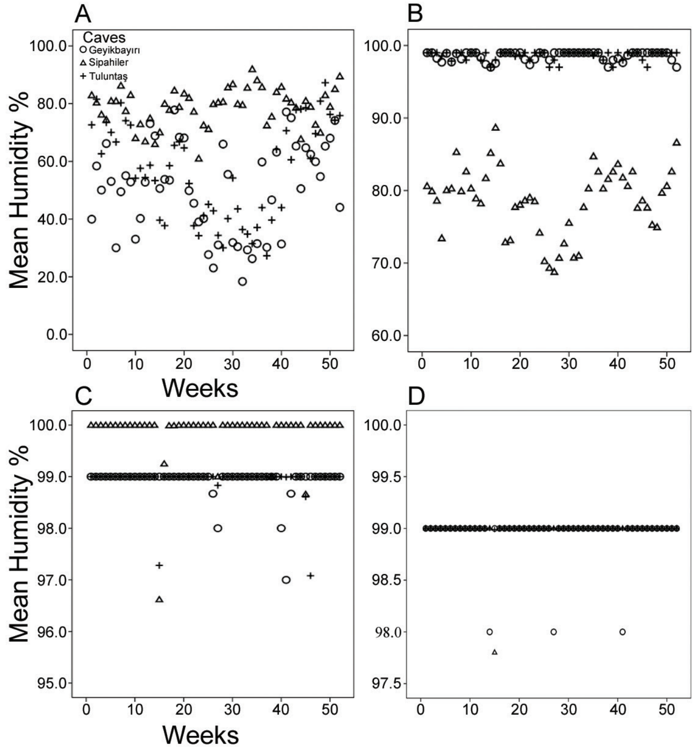

Fig. 4. Comparison of weekly mean RH of surface and ecological zones of the study caves (A: Surface, B: Entrance zone, C: Twilight zone, D: Dark zone).

Twilight zone: It was understood from statistical analysis that Sipahiler cave was different from Geyikbayırı and Tuluntaş caves in terms of twilight zone RH values, but Geyikbayırı and Tuluntaş caves did not have a significant difference (Table 6).

RH of this zone remained constant around 99.99% in Sipahiler cave throughout the year, while it was constantly 99% in Geyikbayırı (except for 26th and 42nd weeks) and Geyikbayırı caves (except for 15th, 27th, 41th, 45th and 46th weeks) (Fig. 4C).

Dark zone: Statistical analysis revealed no difference among three study caves in terms of dark zone RH values (Table 6). A constant RH of 99% prevailed in this zone of all three caves over the year except for a few extreme weeks (Fig. 4D).

RH variations in surface and ecological zones of each study cave

Geyikbayırı cave: Pearson correlation analysis revealed that there was no significant correlation between surface and ecological zones RH values in this cave. However, a significant positive correlation was found between twilight and dark zones RH values, while there was no significant correlation between other zones RH values (Table 8). The WMRH ranged between 18.37-77.8% in the surface, such that it was around 37.63% in the 25-40 weeks of the year, which cover the summer months, with a minimum WMRH of 18.37% in the 32nd week (Table 1, Fig. 5A), and the values of 30.03-77.8% were recorded in the other weeks. The WMRH of the other zones was nearly constant at a value of 97-99% throughout the year (Fig. 5A).

Sipahiler cave: With Pearson correlation analysis, no significant correlation was found between surface and ecological zones RH values in this cave. But, a significant negative correlation was seen between entrance and dark zones RH values, and there was a significant positive correlation between twilight and dark zones RH values (Table 8). The WMRH of 60-90% was observed in the surface and entrance zones over the year, a minimum WMRH of 18.37% is in the 32nd week (Table 1, Fig. 5B). However, it was constant in the other zones, are 99.99% and 99% in the twilight and dark zones, respectively (Fig. 5B).

Tuluntaş cave: Pearson correlation analysis revealed no significant correlation between surface and ecological zones RH values in this cave. However, it was found that there was a significant positive correlation between entrance and twilight zones RH values, and between twilight and dark zones RH values (Table 8). The WMRH of 80% in the first week gradually dropped to 27.29% in the 37th week, followed by an irregular increase to 80% until the end of the year (maximum 87.25%) on the surface (Fig. 5C). In the entrance and twilight zones, WMRH was around 97-99%, while it remained constant at a value of 99% in the dark zone (Fig. 5C).

Taken together, our data show within cave variations in temperature and RH among all three caves: (i) variations in temperature and RH decreased from the entrance zone to the dark zone, (ii) over winter period, temperature increased from the entrance to the dark zone, (iii) over summer period, temperature decreased from the entrance to the dark zone, (iv) the most distinct temperature variation was measured in Continental climate (Fig. 1), and (v) the greatest similarity of climatic conditions between cave and climate type was observed in the Black Sea region, therefore cave crickets species have widened distribution and limited speciation in this region.

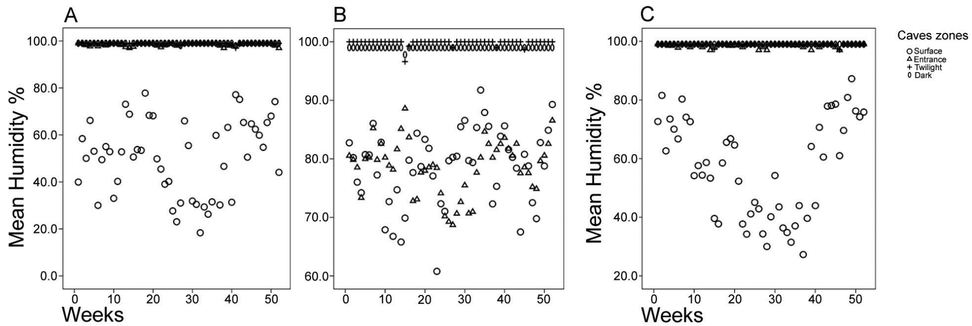

Fig. 5. Comparison of weekly mean RH variations in surface and ecological zones of each study cave (A: Geyikbayırı Cave, B: Sipahiler Cave, C: Tuluntaşş Cave).

CONCLUSIONS AND DISCUSSION

This study is the first report on a comparative evaluation of temperature and RH data obtained from three caves which represent three climate types, Mediterranean, Black Sea, and Continental climate, present in Anatolia. Results show that the temperature and RH data of the zones of the given caves are generally similar in the three caves located in different geographical regions (Fig. 2, Fig. 4). In spite of this similarity, however, it appears that there are some conspicuous differences among many parameters (the number of weeks with the negative temperature values, WMTs and RH, etc.) when considered in detail (Table 1, Fig. 2, Fig. 4). Ecological studies concerning annual temperature and RH on the existing caves in Turkey are limited. A study by Bekaroğlu & Yiğitbaşıoğlu (2010) provided annual temperature values for Karaca cave (Gümüşhane Province) in the Black Sea Region; however, in their study data loggers were not placed in the ecological zones, but in the rooms which are visited by people mostly, since it is a public cave which opens for eight months to tourists (through April to November). Additionally, although this cave with an altitude of 1550 m is geographically in the Black Sea Region, its location is closer to the Eastern Anatolia Region where typical Black Sea climate is not observed, as supported by the temperature values of the surface of this cave which were always negative from January to the end of March. When the temperature data are evaluated, it is seen that Karaca cave is more similar to Tuluntaş cave in the region with a Continental climate in our study, with some differences, such that AMT values of Karaca cave are 2-4 °C higher than Tuluntaş cave (Karaca cave's room I 13.38 °C vs. Tuluntaş cave's entrance zone 11.81 °C; Karaca cave's rooms II and III 13.47-13.39 °C vs. Tuluntaş cave's twilight zone 9.43 °C; Karaca cave's room IV 12.82 °C vs. Tuluntaş cave's dark zone 10.09 °C) (Bekaroğlu & Yiğitbaşıoğlu, 2010). Once again concerning Karaca cave, the highest temperatures were measured in the 35th-40th weeks for room I, 31st-38th weeks for room II, 32nd-37th weeks for room III, and 26th-30th weeks for room IV (Bekaroğlu & Yiğitbaşıoğlu, 2010), but the maximum values were observed in the 22nd-33rd weeks of the year in the zones of Tuluntaş cave. This situation in

Karaca cave may result from its structure as well as such anthropogenic conditions as lighting, electricity cabling, tourist paths, and open to visitors for 8 months of the year.

When the number of species and geographical distribution of cave crickets in Turkey is taken into account, a remarkable distribution is noted: There are four species (*Dolichopoda euxina* Semenov 1901, *Dolichopoda noctivaga* Di Russo & Rampini, 2007, *Troglophilus tatyanae* Di Russo & Rampini 2007, *Troglophilus aspegi* Taylan & Sirin 2015) spread throughout northern Anatolia where the Black Sea climate prevails, whereas 14 species (*Dolichopoda aranea* Bolivar 1899, *D. pusilla* Bolivar 1899, *D. sbordonii* Di Russo & Rampini, 2006, *D. lycia* (Galvagni, 2006), *D. sutini* Rampini & Taylan 2012, *D. fortuita* Gorochov & Ünal, 2015, *Troglophilus escalerai* Bolivar, 1899, *T. adamovici* Us 1974, *T. gajaci* Us 1974, *T. bicakcii* Rampini & Di Russo, 2003, *T. alanyaensis* Taylan, Di Russo, Cobolli & Rampini, 2012, *T. fethiyensis* Taylan, Di Russo, Cobolli & Rampini, 2012, *T. ferzenensis* Taylan, Di Russo, Cobolli & Rampini, 2012, *T. ozeli* Taylan, Di Russo, Cobolli & Rampini, 2012) were reported from southern and western Anatolia with a Mediterranean climate (Bolivar, 1899; Us, 1974; Rampini & Di Russo, 2003; Di Russo & Rampini, 2006; Galvagni, 2006; Di Russo et al, 2007; Rampini & Di Russo, 2008; Taylan, 2011; Taylan et al, 2011; Rampini et al, 2012; Taylan et al, 2012; Gorochov & Ünal, 2015; Taylan & Şirin, 2016) (Table 2).

Intriguingly, to date, no cave crickets have been found in Central Anatolia where Continental climate is dominant. Diversity and distribution patterns of species groups (Heller & Sevgili, 2005; Şirin, Helversen, & Çıplak, 2010; Şirin, Mol, & Çıplak, 2011; Mol & Zeybekoglu, 2013; Mol, Taylan, & Şirin, 2015), genera (Demirsoy, Salman, & Sevgili, 2002; Sevgili, 2004; Sevgili, Çağlar, & Sağlam, 2010; Taylan, Di Russo, Rampini, & Ketmaier, 2013; Taylan & Şirin, 2016; Ünal, 2017) or larger groups (Demirsoy, 1977; Şirin, Eren, & Çıplak, 2010; Taylan et al, 2011; Ünal, 2016) in Anatolian Orthoptera have been proposed regardless of annual climatic data until this study.

It can be seen from the obtained results that RH values of the twilight and dark zones are almost the same in the three study caves, while RH values (almost 100%) of the entrance zone of Geyikbayırı cave in the Mediterranean climate region are similar to those of Tuluntaş cave in the Continental climate region, but the entrance zone of Sipahiler cave in the Black Sea climate region has an RH of 60-90% (Fig. 5B). As to surface, RH is between 20% and 80% in Geyikbayırı and Tuluntaş caves, while it ranges from 60% to 90% in Sipahiler cave. Although RH values of Geyikbayırı and Tuluntaş caves seem to be similar, in fact, the values of Geyikbayırı are steady throughout the year, whereas Tuluntaş cave has fluctuating RH values, with a decline from 80% to 20% towards the middle of the year, and increase to 80% again at the end of the year. Hence, if RH values of the three cave zones supported cave cricket populations, they could be expected in Tuluntaş and other caves in the Continental climate region. In this case, one can say that surface-climatic conditions (annual distribution of negative temperature and RH values) significantly influence the distribution of cave crickets (Table 2).

Table 2. Cave crickets, their localities and climatic zones in Anatolia.

Taxa	Localities	Climate type		
		Mediterranean	Black Sea	Continental
Dolichopoda aranea Bolivar, 1899	K.Maraş, Yenidje-kale	+	-	-
D. pusilla Bolivar, 1899	Hatay, Akbez Cave	+	-	-
D. euxina Semenov, 1901	Artvin, in forest zone	-	+	-
D. sbordonii Di Russo & Rampini, 2006	Antalya, Karaini cave, Kocain cave, Tabak cave	+	-	-
D. lycia (Galvagni, 2006)	Antalya, Kemer, Gedelma Cave, Geyikbayırı cave	+	-	-
D. noctivaga Di Russo & Rampini, 2007	Artvin, Erzurum, Bartın, Bolu, Karabük provinces	-	+	-
D. sutini Taylan & Sirin 2016	İzmir, Selçuk, Sutini Cave, Aydın, Aşıkali Cave	+	-	-
D. fortuita Gorochov & Ünal, 2015	Antalya, Göynük	+	-	-
Troglophilus escalerai Bolivar, 1899	K.Maraş, Yenidje-kale, Döngel Cave	+	-	-
T. gajaci Us, 1974	Mersin, Cennet Cave, Alanya Kadıini cave	+	-	-
T. adamovici Us, 1974	Isparta Zindan Cave	+	-	-
T. bicakcii Rampini & Di Russo, 2003	Konya Derebucak, Bıçakçıini cave, Balatini cave, Feyzullah Cave, Suluin cave	+	-	-
T. tatyanae Di Russo & Rampini 2007	Artvin province, forest zone	-	+	-
T. alanyaensis Taylan, Di Russo, Cobolli & Rampini, 2012	Alanya, Dim cave	+	-	-
T. ozeli Taylan, Di Russo, Cobolli & Rampini, 2012	Balıkesir, Havran cave	+	-	-
T. ferzenensis Taylan, Di Russo, Cobolli & Rampini, 2012	Konya, Seydişehir, Ferzene cave	+	-	-
T. fethiyensis Taylan, Di Russo, Cobolli & Rampini, 2012	Muğla Fethiye, Güroluk cave	+	-	-
T. aspegi Taylan & Sirin 2015	Bartın, Sipahiler cave	-	+	-

*Data from Bolivar 1899, Semenov 1901, Us 1974,Rampini and Di Russo 2003, Di Russo et al. 2007, Taylan 2011, Taylan et al. 2012, Gorochov and Ünal 2015, Taylan et al. 2015, Taylan and Şirin 2016.

Cave crickets are troglophiles, and spend most of their lives in caves; however, they are reported to go out the cave at night for feeding purposes when bat guano (bat droppings) as source of energy and nutrients is not found or occurs in small amounts in the cave (Di Russo, Vellei, Carchini, & Sbordoni, 1987; Di Russo & Sbordoni, 1998). Therefore, more realistic scenarios about the diversity and distribution of cave crickets can be produced by considering both in-cave conditions and surface climatic conditions together. Among the studied three caves, Geyikbayırı Cave contains one cave cricket species (*Dolichopoda lycia* (Galvagni, 2006) and Sipahiler Cave (*Troglophilus aspegi* Taylan & Şirin, 2015), while Tuluntaş cave does not contain any cave crickets species. The most species density of *D. lycia* observed in the twilight zone of Geyikbayırı cave. On the other hand, most species density of *T. aspegi* observed in the entrance zone (first room) and the twilight zone of Sipahiler Cave which has similarity to surface RH with Black Sea region. However, *T. aspegi* (Sipahiler Cave) species has a wider distribution zone than *D. lycia* (Galvagni, 2006) *species* (Geyikbayırı Cave) in the caves zones. The specimens of *T. aspegi* Taylan & Şirin, 2015 have distribution in all zones and *main galleries* of the cave while the specimens of *D. lycia* (Galvagni, 2006) have limited distribution in the *side galleries* of twilight zone.

From the data of this study, RH of the atmospheric zone of Sipahiler cave in the Black Sea climate region appears to be very close to that surface of the cave, especially of the entrance zone (Table 1, Fig. 5), being an expected situation for the Black Sea Region which has a temperate rainforest characteristic. As a predominately-forested region in Turkey (Doğanay & Doğanay, 2004), the Black Sea Region generally has a forest structure consisting of non-evergreen trees (*Fagus* sp., *Carpinus* sp., *Alnus* spp. etc) at altitudes of 200 m to 1200 m, and coniferous trees resistant to harsh climatic conditions above 1200 m (Atalay, Tetik, & Yılmaz, 1985). Dense and moist forests in this region allow cave crickets to move within the forests, thereby to expand their distribution areas and to exchange genes with individuals in different areas, explaining the presence of *Dolichopoda noctivaga* Di Russo & Rampini, 2007, almost the provinces on whole Black Sea Region (Bolu, Karabük, Bartın, Ordu, Artvin). RH of in-cave zones of Geyikbayırı cave in the Mediterranean climate region is higher than that of its atmospheric zone (Fig. 5, Table 1). Long periods with low or high temperatures outside the cave (Fig. 2A, Fig. 3A) may dissuade cave crickets from their visits to outside the cave (Poulson, Lavoie, & Helf, 1995; Helf, 2003; Taylor, Krejca, & Denight, 2005; Lavoie, Helf, & Poulson, 2007; Helf, Philippi, Moore, & Scoggins, 2015). Furthermore, the vegetation of the Mediterranean Region is maquis at lower altitudes, arid-climate-loving Calabrian pine (*Pinus brutia*) forests at altitudes of 250-300 m to 1200 m, followed by cedar (*Cedrus libani*) forests above 1200 m (Kürschner, Parolly, & Raab-Straube, 1982). It may be said that since the surface temperature values are very high at certain periods of the year, and RH remains at low levels from time to time, and the vegetation that will allow them to spread does not exist, cave crickets in this region are isolated to their caves, thus leading to restricted gene exchange among the populations, and correspondingly speciation.

Although it is necessary to examine more caves in a longer period, we can make some assumptions from this study based on data logging. Our study reveals that distinct variations in temperature and RH lead to minute changes in the dark zone in that a 50 ºC variation drops the temperature of the dark zone by 1-2 ºC, suggesting that the cave ecosystem tolerates considerable changes in the outdoor atmosphere. An assumption can be made from this important finding: As it is known, cold-loving (cryophilic) organisms tend to gradually move towards the higher parts of mountains as a result of global warming (Hewitt, 1996, 1999, 2000; Taberlet, Fumagalli, Wust-Saucy, & Cosson, 1998). Like this vertical translocation, cave crickets may be passing from the entrance zone to the dark zone within their caves in response to warming, as revealed by this study that temperature and RH gradually drop from the entrance zone towards the dark zone (horizontal translocation) which becomes almost a stable ecological zone (Fig. 3D, Fig. 5D). Concordantly, and the high tolerance of dark zone to temperature variations makes caves important shelters for many invertebrates, especially troglophiles that mostly inhabit entrance and twilight zones of a cave (Reddell, 2005; Romero, 2009), against the negative effects of global warming.

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