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Original article (Orijinal araştırma)

Determination of arthropod biodiversity and some ecological parameters of Erdal Şekeroğlu (Isparta, Turkey) and Kadıini (Antalya, Turkey) cave ecosystems with evaluation of usability of insects in cave mapping[1]

Erdal Şekeroğlu (Isparta-Türkiye) ve Kadıini (Antalya-Türkiye) mağara ekosistemlerinde arthropod biyolojik çeşitliliği ile bazı ekolojik parametrelerin belirlenmesi ve böceklerin mağara haritalamasında kullanım olanaklarının araştırılması

Gökhan AYDIN[2*] **İsmail ŞEN[3]**

Abstract

The aim of the study was to determine the species composition, diversity, similarity and completeness of cave-dwelling arthropods in cave zones (entrance, twilight and dark zones) in Erdal Şekeroğlu Cave (ESC) (Atabey-Isparta Province) and Kadıini Cave (KIC) (Alanya-Antalya Province) ecosystems in Turkey. The study also aimed to investigate whether these species can be used for mapping cave zones. The samplings were conducted by using aspirator and pitfall trap methods in ESC among 2010-2020 and in KIC in 2017. Hence statistical analyses were performed with the data gathered from the field studies conducted in the same year (2017) in order to evaluate ecological data in the two cave ecosystems homogeneously. During the study, a total of 51 arthropod species, mostly hexapods, belonging to five classes were collected. Biodiversity parameters, similarity index, indicator species analyses, and species richness estimators were calculated for each cave and cave zones. In addition to reporting the distributions of hexapods in cave ecosystems, this paper discusses for the first time if such ecological data can inform cave mapping and exploration.

Keywords: Cave zones, indicator species, similarity, species richness estimators

Öz

Çalışmada, Erdal Şekeroğlu (ESC) (Isparta, Türkiye) ve Kadıini (KIC) (Antalya, Türkiye) Mağaralarının farklı (giriş, alacakaranlık ve karanlık) zonlarında yaşayan arthropod türlerinin çeşitliliğinin, benzerliğinin ve tahmini tür sayılarının belirlenmesi amaçlanmıştır. Ayrıca, çalışmada belirlenen türlerin mağara bölgelerinin haritalanmasında kullanılabilirlikleri araştırılmıştır. Örneklemeler, ESC'de 2010-2020 yılları arasında, KIC'da ise 2017 yılında, aspiratör ve çukur tuzak yöntemleri kullanılarak gerçekleştirilmiştir. İstatistiksel analizler, iki mağara ekosistemindeki ekolojik verileri homojen olarak değerlendirmek amacıyla, aynı yıl (2017) yapılan saha çalışmalarından elde edilen verilerle yapılmıştır. Çalışmada, çoğu hexapod olmak üzere beş sınıfa ait toplam 51 eklem bacaklı türü tespit edilmiştir. Her iki mağara ve mağara zonları için biyolojik çeşitlilik, benzerlik, biyolojik gösterge ve tür tahminleyici analizleri yapılmıştır. Ayrıca, böceklerin mağara haritalaması ve keşiflerinde kullanılabilirliği de dünyada ilk kez tartışılmıştır.

Anahtar sözcükler: Mağara zonları, biyolojik gösterge türleri, benzerlik, tür zenginliği tahminleyicileri

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[2] Isparta University of Applied Sciences, Atabey Vocational School, 32670, Atabey, Isparta, Turkey
[3] Isparta University of Applied Sciences, Faculty of Technology, Department of Biomedical Engineering, 32260, Isparta, Turkey
* Corresponding author (Sorumlu yazar) e-mail: gokhanaydin@isparta.edu.tr
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Introduction

Caves are formed over millions of years and contain unusual ecosystems. In general, underground areas, large enough to be entered by a person are considered a cave. Cave depths and lengths range can be from a few meters to thousands of meters (Palmer, 1991; Northup & Lavoie, 2001; Gunn, 2004) and cave ecosystems have a relatively stable temperature, humid and limited supply of nutrients (Barton & Jurado, 2007; Weliange, 2016).

Caves have been used throughout human history for many purposes including scientific studies, recreation and tourism, natural cold storage, maturation and preservation of animal products (e.g., cheese and oil), mushroom cultivation, treatment of respiratory diseases, liquefied gas, natural gas and fuel oil storage, shelter and protection for military purposes, guano collection, mineral extraction, groundwater extraction and protection of spring waters (Tolan-Smith & Bonsall, 1997).

The science of studying the structure, formation, biology and physical features of caves is called speleology. Speleology is a broad interdisciplinary field incorporating archaeology, biology, chemistry, geology, physics, meteorology, hydrology, scientific exploration and cartography in the subterranean environment to better understand the cave ecosystems (Gunn, 2004; Kowalczk, 2009; Lee et al., 2012). While speleology is the branch of science that investigates cave exploration, the structure, physical properties, history and life forms of the caves, biospeleology examines the cave species and their roles of the food chain in cave ecosystems (Latella & Stoch, 2002; Veni, 2019). Biospeleology came into being in the mid-nineteenth century (Vandell, 1964; Camacho, 1992). Remarkable progress was achieved in the biospeleology of the European and American caves in the mid 20th century (Camacho, 1992). These studies revealed that caves have taxonomically diverse fauna (Hobbs, 2012).

Biodiversity can be defined as the diversity of genes, species, and ecosystems (Feest et al., 2010, Cramer et al., 2017, Tydecks et al., 2018). Cave ecosystems often support high diversity and can contain species found in no other terrestrial and aquatic ecosystems (Howarth, 1983; Tercafs, 1988; Culver & Sket, 2000; Culver et al., 2004; Culver & White, 2005; Fernandes et al., 2016). However, the biological diversity of caves remains incompletely documented (Culver et al., 2006). This is particularly the case in Turkey, despite it being a cave rich country. One approach that can be useful in filling this knowledge gap is the use of indicator species, i.e., species that are indicators of the condition of a habitat, community or ecosystem (McGeoch & Chown, 1998; Zacharias & Roff, 2001; Carignan & Villard, 2002; Niemi & McDonald, 2004; Latella et al., 2012; Kurniawan et al., 2018). In the cave ecosystems, indicator species have been used to determine microhabitat, cave area or season and to monitor organic pollution and the effects of cave tourism (Eberhard, 1992; Moulds, 2006; Village et al., 2019).

Cave-dwelling organisms can be classified into three groups according to the degree of adaptation to the subterranean environments. Their classification is typically as follows (Barr, 1968).

Trogloxenes: these species inhabit caves temporarily for particular physiological needs that are linked to seasonal variation and are characterized by a prolonged decrease in their activity. Trogloxenes only enter caves during periods of reduced activity (hibernation, estivation or diapause). Their reproduction is aboveground, and no morphological differences are apparent between subterranean and aboveground individuals.

Troglophiles: these species can be defined as facultative subterranean dwellers in the sense that they are suitable to live in subterranean biotopes because of behavioral and physiological (principally linked to diet) predispositions. They have no typical morphological adaptations to cave ecosystems.

Troglobites: these are permanent, obligatory occupants of the subterranean environment, and cannot live elsewhere. Cave-dwelling species (troglobites) are adapted only to cave conditions. As they

are confined to a very particular biotope, have a restricted range and small populations therefore these species are very sensitive to environmental changes (Samways, 1994, 2007).

Light is one of the main factors affecting evolutionary development in cave ecosystems. As a result of the effect of the light, the cave is divided into three zones: entrance, twilight and dark zones. The distribution of arthropods in the cave zones can use to assign these zones.

Turkey with about 40 000 caves is considered a cave heaven when compared to other countries of the world (Anonymous, 2019). However, biospeleological studies have been very limited in Turkey up to date (Kunt et al., 2010) with only limited scientific studies on the life cycles of the cave arthropods, their roles in the food chain, their use in zone identification and cave mapping, biological indicator values, and biological diversity (Eberhard, 1992; Moulds, 2006; Village et al., 2019).

Based on these facts, the aims of the study were (1) to determine the biodiversity of the arthropod assemblages of the Erdal Şekeroğlu Cave (ESC) (Atabey District, Isparta Province, Turkey) and Kadıini Cave (KIC) (Alanya District, Antalya Province, Turkey), (2) to compare the arthropod assemblages inhabiting in the three cave zones in each cave, (3) to evaluate the usability of insects in cave mapping with indicator species analyses (ISA) performed to test whether the species can be used as an indicator of that of cave zones, and (4) to calculate the completeness of the inventory by using species richness estimators.

Materials and Methods

This study was conducted in ESC and KIC to determine the biodiversity of the arthropod assemblages, compare the arthropod assemblages inhabiting in the three cave zones in each cave, calculate the completeness of the inventory by using species richness estimators, and evaluate the usability of insects in cave mapping.

Studied caves

Erdal Şekeroğlu Cave

ESC is located in Atabey District, Isparta Province of Turkey (37°56’51.97" N, 30°34’38.16" E). The cave is 88 m long and 26 m deep. The main axis starting from the entrance of the cave was formed as a result of collapses and divided the cave into two layers. At the end of the cave, after a vertical climb of about 8 m, even the lower chamber can be reached. The upper floor, which extends towards the end of the cave, runs parallel to the main axis and ends about 5 m above the main axis. Immediately after the cave entrance zone, the twilight zone starts and extends for about 15 m. After the twilight zone, the dark zone continues until the end of the cave. Accordingly, the entrance zone of the ESC is 0-9 m, twilight zone 9-23 m and the dark zone 23-88 m (for more information, see www.magara.org). Sampling in ESC was performed at different times between 2010 and 2020.

Kadıini Cave

KIC is located in Alanya District, Antalya Province of Turkey (36°35’08.2" N, 32°04’39.5" E). The cave is 2027 m long and 45 m deep. The entrance zone consists of a large gallery. The twilight zone starts almost immediately after entering a sharp and narrow gallery from the entrance zone and takes about 50 m. The dark zone extends to the end of the cave. Accordingly, the entrance zone of KIC is 0-25 m, twilight zone, 25-50 m and the dark zone 50-2027 m (for more information, see www.magara.org). Sampling in KIC was conducted at different times during 2017.

Sampling methods

Samplings were conducted in the ESC at different times between 2010 and 2020 (November 2010; June 2011; 03-04 March, 07-08 July and 17-18 November 2012; 9-10 February, 15-16 June, and 23-24

November 2013; 14-15 June and 27-28 December 2014; 2-3 May, 11-12 July and 14-15 November 2015; July 2016; 22-26 February and 19-22 October 2017; 19-20 May, 18-19 August and 3-4 November 2018; 4-5 May and 6-7 July 2019; and 15-16 February 2020) and also in the KIC during 2017 (15-19 February and 12-15 October) for determination of arthropod fauna.

Homogeneous collecting procedures were applied and data from ESC between 22-26 February 2017, 19-22 October 2017, and from KIC between 15-19 February 2017 and 12-15 October 2017 were used for comparison of biodiversity and the other ecological parameters in both caves.

Samples were collected using an aspirator by eye and by pitfall traps inside both caves. In each zone within the caves, the arthropod samples were collected by aspirator from cave surfaces (such as wall and ceiling) for 5 min. Also, five pitfall traps were placed in each zone. Specimens were brought to the laboratory and then they sorted by family and labeled. Specimen identification was made with the support of specialists detailed in the Acknowledgments. The collected specimens are deposited in the special collection of the first author.

Data analysis

The arthropod assemblages of both caves were evaluated by the following diversity indices: Shannon-Wiener (H′), Simpson diversity index (S), Simpson dominance (Sd), Shannon evenness (*EH*), and Sörensen index (Bs).

Shannon-Wiener diversity index (H′) $$H' = -\sum p_i \ln(p_i)$$

where H' is the index of diversity, p_i is the importance value of a species as a proportion of all species, and ln is the natural logarithm.

Simpson's diversity index (S) $$S = 1 - \sum n_i(n_i - 1) / N(N-1)$$

where S is the index of diversity, n_i is the importance value of a species as a proportion of all species, and N is the sum of the number of individuals.

Simpson's dominance index (Sd) $$Sd = \sum n_i(n_i - 1) / N(N-1)$$

where Sd is the index of dominancy, i is number of species, n_i is the importance value of a species as a proportion of all species, and N is the sum of the number of individuals.

Shannon evenness index (EH) $$EH = H' / \ln(N))$$

where EH is Evenness index, H' is the index of Shannon-Wiener diversity, ln is the natural logarithm, and N is the sum of the number of individuals.

Sörensen index (Bs) was used to determine the compositional similarity between the arthropod assemblages of the cave zones of each cave (Southwood, 1971; Magurran, 1988; Krebs, 1999; Magurran, 2004).

Sörensen index $$Bs = 2C / A + B$$

where Bs is the similarity index, A is the number of species in A, B is the number of species in B, and C is the number of common species in A and B.

ISA are used to test the usage of the collected arthropod species to identify a cave zone. Percentage dominance of each sampled species was calculated according to Heydemann (1953) with the following formula;

$$D(\%) = 100N_i / N$$

where D is percent dominance, N_i is the number of captured individuals of a species, N is the sum of the number of individuals.

ISA gives indicator values (IV) for each species in each group and these values are tested for significance using the Monte Carlo test (Heydemann, 1953; Dufrêne & Legendre 1997) as follows:

(1) The proportional abundance of a particular species in a group was calculated relative to the abundance of that species in all groups.

Let A is sample unit x species matrix, a_{ijk} is the abundance of species j in sample unit (SU) i of group k, n_k is the number of sample units in group k, g is the total number of the groups.

Firstly, the mean abundance X_{kj} of species j in group k was calculated:

$$x_{kj} = \sum_{i=1}^{nk} a_{ijk} / n_k$$

Then the relative abundance *RAkj* of species j in group k was calculated:

$$RA_{jk} = x_{kj} / \sum_{k=1}^{g} x_{kj}$$

(2) The proportional frequency of species in each group was calculated:

Firstly, A is transformed into a matrix of presence-absence (*b*),

$$b_{ij} = a_{ij}^0$$

then relative frequency RF_{kj} of species j in group k was calculated:

$$RF_{kj} = \sum_{i=1}^{n_k} b_{ijk} / n_k$$

(3) The product of the two proportions calculated in steps 1 and 2 is then determined. The result is expressed as a percentage, yielding an indicator value IV_{kj} for each species *j* in each group *k*.

$$IV_{kj} = 100(RA_{kj} X RF_{kj})$$

(4) The highest indicator value (IV_{max}) for a given species across groups is saved as a summary of the overall indicator value for that species.

(5) The statistical significance of IV_{max} by using the Monte Carlo method is evaluated. The SUs are randomly reassigned to the groups a large number of times (default = 1000). Each time, IV_{max} is calculated. The probability of type I error is based on the proportion of times that the IV_{max} from the randomized data set equals to or exceeds the IV_{max} from the actual data set. The null hypothesis is that IV_{max} is no larger than it would have been expected by chance (i.e., the species has no indicator value).

In addition to these, to assess the completeness of the inventory, species richness estimators (Chao 1, Chao 2, Jacknife 1, Jacknife 2, Bootstrap, ACE, ICE) were used (Burnham & Overton, 1978, 1979; Heltshe

& Forrester, 1983; Chao, 1984; Smith & van Belle, 1984; Chao & Lee, 1992; Chao et al., 1993; Colwell & Coddington, 1994; Lee & Chao, 1994; Colwell, 1997; Chazdon et al., 1998). These methods provide a lower estimate of total species richness.

Following formulas of species richness estimators are given:

Chao 1 type estimators (for abundance data) (Chao, 1984; Colwell & Coddington, 1994)

$$S_{Chao\,1} = S_{obs} + F_1^2/2F_2$$

where S_{obs} is the observed number of species, F_1 is singletons (species with only one individual), and F_2 is doubletons (species with only two individuals) (Chao, 1984; Chazdon et al., 1998).

Chao 2 type estimators (for replicated incidence data) (Chao, 1987; Colwell & Coddington, 1994)

$$S_{Chao\,2} = S_{obs} + Q_1^2/2Q_2$$

where Q_1 is the frequency of uniques and Q_2 is the frequency of duplicates.

Jackknife 1 type estimators (for abundance data) (Burnham & Overton, 1978, 1979; Heltshe & Forrester, 1983)

$$S_{Jack\,1} = S_{obs} + Q_1\,(m - 1/m)$$

where m is the total number of samples.

Jackknife 2 type estimators (for incidence data) (Smith & van Belle, 1984)

$$S_{Jack\,2} = S_{obs} + \left(\frac{Q_1(2m-3)}{m} - \frac{Q_2\,(m-2)^2}{m(m-1)}\right)$$

Bootstrap type estimators (based on repetition) (Smith & van Belle, 1984)

$$S_{boot} = S_{obs} + \sum_{k=1}^{S_{obs}} (1 - p_k)^2$$

where p_k is the proportion of samples that contain species k.

ACE (abundance coverage estimator) type estimators (for abundance data) (Chao & Lee, 1992; Chao, et al., 1993)

$$S_{ace} = S_{abund} + \frac{S_{rare}}{C_{ace}} + \frac{F_1}{C_{ace}} Y_{ace}^2$$

where S_{abound} is the number of abundant species (each with more than 10 individuals) when all samples are pooled, S_{rare} is the number of rare species (each with 10 or fewer individuals) when all samples are pooled, C_{ace} is the sample abundance coverage estimator and Y^2_{ace} is the estimated coefficient of variation of the F_i for rare species

ICE (incidence coverage-based estimator**)** type estimators (for incidence data) (Lee & Chao, 1994)

$$S_{ice} = S_{freq} + \frac{S_{\inf r}}{C_{ice}} + \frac{Q_1}{C_{ice}} Y_{ice}^2$$

where S_{freq} is the number of frequent species (each found in more than 10 samples), $S_{inf\ r}$ is the number of infrequent species (each found in 10 or fewer samples), C_{ice} is the sample incidence coverage estimator and Y^2_{ice} is the estimated coefficient of variation of the Q_i for infrequent species.

The type estimators calculated from the data obtained from ESC and KIC were graphed and computer simulations made. The all type estimators results were compared with each other. Diversity indices were analyzed with EvenDiv 1.1 (Heimann, 2004) and similarity indices were analyzed using the MultiVariate Statistical Package (MVSP 3.11c) for Windows (Kovach, 1999). PC-Ord (Version 4.14) was used for Biological Indicator Analysis (McCune & Mefford, 2016) and species estimations were calculated with EstimateS v8.2 (Colwell, 2019). Statistical analyses were performed with the data gathered from the field studies conducted in the same years.

Results

Arthropoda fauna of Erdal Şekeroğlu and Kadıini Caves

A total of 25 arthropod species were caught in the ESC with 622 individuals belonging to five classes, nine orders, 15 families between 2010 and 2020 (see description of the Table 1 for details) while 26 arthropod species were sampled in KIC with 160 individuals belonging to three classes, six orders, 18 families during 15-19 February 2017 and 12-15 October 2017 (Tables 1 & 2).

It was determined that the frequency of sampling did not increase significantly in species richness in ESC. Taxa that could be identified to species in situ, such as some of the carabid, chrysomelid, coccinellid, curculionid, scarabaeid (Coleoptera), erebid (Lepidoptera), gryllid and rhaphidophorid (Orthoptera) were counted and released in the zone where captured.

According to homogeneous collecting procedures (ESC, 22-26 February 2017 and 19-22 October 2017, and KIC, 15-19 February and 12-15 October 2017), 47 arthropod species (21 species from ESC and 26 species from KIC) were determined (Table 3). Among these, 36 species (7 Arachnida, 1 Diplopoda and 28 Hexapoda) were identified to species while eight species (6 Arachnida, 1 Diplopoda and 1 Hexapoda) were identified at the genus level. Two arachnids could be identified as family level however one chilopod species could be identified as a morphospecies (Tables 4 & 5).

Most of the hexapods *Stigmatomma denticulatum* Roger, 1859 (Hymenoptera: Formicidae), *Camponotus aethiops* (Latreille, 1798) (Hymenoptera: Formicidae), *Messor semirufus* (André, 1883) (Hymenoptera: Formicidae), *Tomicus minor* (Hartig, 1834) (Coleoptera: Curculionidae), *Ips sexdentatus* (Boerner, 1776) (Coleoptera: Curculionidae), *Carabus glabratus* Paykull, 1790 (Coleoptera: Carabidae), *Carabus graecus* Dejean, 1826 (Coleoptera: Carabidae), *Anoxia asiatica* Desbrochers, 1871 (Coleoptera: Scarabaeidae), *Oxythyrea cinctella* (Schaum, 1841) (Coleoptera: Scarabaeidae), *Cetonia aurata* (L., 1758) (Coleoptera: Scarabaeidae), *Chrysomela populi* L., 1758 (Coleoptera: Chrysomelidae), *Rhynchaenus asellus* Gravenhorst, 1807 *Gymnetron asellus* Scopoli, 1763 (Coleoptera: Curculionidae), *Larinus curtus* Hochhut, 1851 (Coleoptera: Curculionidae), *Scoliopteryx libatrix* L., 1758 (Lepidoptera: Erebidae), and one callipodid, *Eurygyrus* sp. (Callipodida: Schizopetalidae) were sampled from entrance zone of ESC. One centipede, described as morphospecies, was found with two individuals from twilight zone of ESC. One carabid beetle which is a troglobite species only occurs in cave ecosystems, *Ophonus (Hesperophonus) azureus* (F., 1775) and the other species *Laemostenus (Antisphodrus) longicornis* Casale, 1988 (Coleoptera: Carabidae) a typical troglophiles to troglobite species were found only dark zone of ESC with six and 12 individuals, respectively. Three arachnids; *Carios* sp. *(*Ixodoidea: Argasidae) and one from the family Linyphiidae, and one from Dysderidae, identified as morpho species were sampled on the dark zone of ESC (Table 4).

Table 1. Number of individuals and sampling dates of the species in ESC

Class	Order	Family	Species	Individuals and sampling date codes*
Arachnida	Ixodoidea	Argasidae	*Carios* sp. ?	1 (A); 2 (B); 1 (E 2); 1 (F2); 2 (H1); 1 (J1)
	Araneae	Dysderidae	?	1 (A); 1 (B); 1 (C2); 1 (C3); 1 (D1); 1 (E1); 1 (F3); 1 (G); 1 (H1); 3 (H2); 1 (I1); 1 (I3); 2 (J2)
		Linyphiidae	?	4 (C1); 2 (D3); 2 (E 2); 11 (F2); 3 (H1); 5 (H2); 7 (I2); 3 (J2); 1 (K)
		?	?	1 (A); 3 (C1); 1 (C3); 2 (D3); 1 (E2); 2 (I2); 1 (K)
		?	?	2 (B); 1 (C1); 1 (C3); 2 (D1); 1 (D3); 1 (E1); 1 (E2); 1 (F2); 1 (F3); 1 (I3)
Chilopoda	Scolopendromorpha	?	?	1 (C3); 2 (D1); 2 (D2); 1 (D3); 1 (E2); 1 (F1); 1 (I2); 1 (I3); 1 (J1); 1 (K)
	?	?	?	1 (C2); 2 (D2); 1 (E1); 2 (F1); 1 (F3); 1 (G); 1 (H1); 1 (H2); 1 (I1); 1 (J2)
Collembola	?	?	?	12 (A); 38 (C1); 15 (C3); 17 (D3) 11 (E2); 8 (F3); 6 (I1)
Diplopoda	Callipodida	Schizopetalidae	*Eurygyrus* sp.	2 (A); 1 (C1); 1 (C2); 2 (C3); 1 (D1); 1 (D2); 2 (D3); 4 (E1); 3 (E2); 2 (F1); 1 (F3); 1 (G); 4 (H1); 5 (H2); 4 (I1); 7 (I2); 1 (I3); 3 (J1); 4 (J2); 2 (K)
Hexapoda	Coleoptera	Carabidae	*Carabus glabratus* Paykull, 1790	1 (A); 2 (C1); 1 (C2); 1 (C3); 1 (D1); 2 (D3); 3 (E1); 1 (F1); 2 (F2); 2 (F3); 1 (G); 1 (H1); 2 (I1); 1 (I2); 1 (I3); 1 (J1); 2 (J2); 1 (K)
			Carabus graecus Dejean, 1826	1 (A); 1 (B); 2 (C1); 1 (C3); 1 (D1); 3 (D2); 1 (D3); 2 (E1); 1 (E2); 3; (F1); 1 (F3); 1 (G); 1 (H2); 3 (I1); 1 (I3); 1 (J2); 1 (K)
			Laemostenus (Antisphodrus) longicornis Casale, 1988	2 (A); 1 (B); 1 (C1); 3 (C2); 2 (C3); 4 (D1); 1 (D3); 4 (E1); 3 (E2); 2 (F1); 7 (F2); 2 (F3); 2 (G); 7 (H1); 5 (H2); 2 (I1); 1 (I2); 1 (I3); 2 (J1); 3 (J2); 3 (K)
			Ophonus (Hesperophonus) azureus (F., 1775)	1 (A); 2 (B); 1 (C1); 1 (C2); 3 (C3); 3 (D1); 2 (D2); 1 (D3); 3 (E2); 2 (F1); 1 (F2); 3 (F3); 2 (G); 3 (H1); 3 (H2); 1 (I1); 2 (I2); 1 (I3); 1 (J1); 2 (J2); 2 (K)
		Chrysomelidae	*Chrysomela populi* L., 1758	1 (B); 1 (C); 1 (D2); 1 (F1); 1 (F2); 1 (G); 1 (H1); 1 (I1); 1 (I2); 1 (I3); 2 (J1); 1(K)
		Curculionidae	*Rhynchaenus asellus* Gravenhorst, 1807	1 (A); 1 (C2); 2 (D2); 3 (E1); 1 (F1); 1 (H2); 1 (I2); 2 (K)
			Ips sexdentatus (Boerner, 1776)	1 (B); 1 (C1); 1 (D1); 2 (D2); 1 (E1); 1 (F2); 1 (H1); 1 (I3); 1 (J2)
			Larinus curtus Hochhuth, 1851	1 (C1); 1 (D2); 1 (F2); 1 (H1); 1 (J1)
			Tomicus minor (Hartig, 1834)	2 (B); 2 (C2); 1 (D2); 1 (F1); 1 (G); 1 (H2); 1 (J1)
		Scarabaeidae	*Anoxia asiatica* Desbrochers, 1871	1 (B); 2 (C2); 2 (D2); 2 (F1); 1 (F2); 1 (G); 1 (H2); 1 (I1); 2 (I2); 1 (I3); 1 (J1); 1 (J2)
			Cetonia aurata (L., 1758)	1 (A); 2 (B); 3 (C2); 2 (D2); 2 (E1); 3 (F2); 1 (G); 1 (H2); 1 (I1); 1 (I2); 1 (J1); 1 (J2)
			Oxythyrea cinctella (Schaum, 1841)	1 (B); 1 (C1); 1 (C2); 1 (D1); 1 (E1); 1 (F2); 1 (H1); 2 (I2); 1 (I3); 2 (J2); 1 (K)
	Hymenoptera	Formicidae	*Camponotus aethiops* (Latreille, 1798)	2 (B); 1 (C2); 4 (D2); 1 (E1); 1 (F1); 1 (F2); 1 (H1); 1 (I2); 2 J2)
			Messor semirufus (André, 1883)	1 (B); 2 (F2); 2 (H2); 4 (I2); 1 (J2)
			Stigmatomma denticulatum Roger, 1859	1 (A); 9 (B); 4 (C2); 6 (D2); 4 (E1); 8 (F1); 4 (F2); 6 (G); 1 (H1); 4 (I1); 4 (I2); 3 (J1); 6 (J2)
	Lepidoptera	Erebidae	*Scoliopteryx libatrix* L., 1758	1 (A); 1 (C1); 1 (C2); 1 (C3); 2 (D1); 1 (D2); 2 (D3); 1 (E1); 1 (E2); 1 (F1); 1 (F3); 1 (G); 2 (H1); 1 (H2); 2 (I1); 1 (I2); 1 (I3); 1 (J1); 3 (K)

*A, during November 2010; B, during June 2011; C1, 03-04 March 2012; C2, 07-08 July 2012; C3, 17-18 November 2012; D1, 9-10 February 2013; D2, 15-16 June 2013; D3, 23-24 November 2013; E1, 14-15 June 2014; E2, 27-28 December 2014; F1, 2-3 May 2015; F2, 11-12 July 2015; F3, 14-15 November 2015; G, during July 2016; H1, 22-26 February 2017, H2, 19-22 October 2017; I1, 19-20 May 2018; I2, 18-19 August 2018; I3, 3-4 November 2018; J1, 4-5 May 2019; J2, 6-7 July 2019; and K, 15-16 February 2020.

Table 2. Number of individuals and sampling dates of the species in KIC

Class	Order	Family	Species	Individuals and sampling date codes*
Arachnida	Araneae	Agelenidae	*Tegenaria percuriosa* Brignoli, 1972	1 (L2)
			Tegenaria sp.	1 (l1); 3 (L2)
		Dysderidae	*Dysderocrates* sp.	2 (L1); 5 (L2)
			Harpactea sp.	1 (L1)
		Filistatidae	*Pritha* sp.	1 (L2)
		Linyphiidae	*Centromerus* sp.	1 (L1)
			Lepthyphantes leprosus (Ohlert, 1865)	1 (L1)
			Troglohyphantes sp.	1 (L1)
		Pholcidae	*Hoplopholcus asiaeminoris* Brignoli, 1978	2 (L1); 4 (L2)
			Hoplopholcus sp.	3 (L1); 6 (L2)
		Sparassidae	*Heteropoda variegata* (Simon, 1874)	4 (L2)
	Scorpiones	Iuridae	*Protoiurus kadleci* (Kovarik Fet, Soleglad & Yağmur, 2010)	1 (L1); 3 (L2)
Diplopoda	Callipodida	Schizopetalidae	*Eurygyrus bilselii* (Verhoeff, 1940)	7 (L1); 9 (L2)
Hexapoda	Coleoptera	Carabidae	*Calathus syriacus* Chaudoir, 1863	1 (L2)
			Harpalus distinguendus (Duftschmid, 1812)	1 (L2)
			Laemostenus longicornis Casale, 1988	8 (L1); 10 (L2)
		Coccinellidae	*Coccinella septempunctata* L., 1758	1 (L1)
		Curculionidae	*Orthotomicus erosus* (Wollaston, 1857)	1 (L2)
			Tomicus destruens (Wollaston, 1865)	1 (L1)
		Meloidae	*Zonitis flava* F., 1775	1 (L2)
		Scarabaeidae	*Oryctes nasicornis* L., 1758	1 (L1)
	Hymenoptera	Formicidae	*Cataglyphis nodus* (Brullé, 1833)	1 (L1); 4 (L2)
			Messor oertzeni Forel, 1910	1 (L1); 1 (L2)
			Tapinoma erraticum (Latreille, 1798)	1 (L1)
	Orthoptera	Gryllidae	*Ovaliptila alanya* Gorochov & Ünal, 2012	25 (L1); 37 (L2)
		Rhaphidophoridae	*Troglophilus gajaci* Us, 1974	3 (L1); 5 (L2)

*L1, 15-19 February 2017; and L2, 12-15 October 2017.

Most of the Hexapods were sampled only from entrance zone of KIC; *Tomicus destruens* (Wollaston, 1865) (Coleoptera: Curculionidae), *Orthotomicus erosus* (Wollaston, 1857) (Coleoptera: Curculionidae), *Zonitis praeusta Zonitis flava* F., 1775 (Coleoptera: Meloidae), *Tapinoma erraticum* (Latreille, 1798) (Hymenoptera: Formicidae), *Cataglyphis nodus* (Brullé, 1833) (Hymenoptera: Formicidae), *Messor oertzeni* Forel, 1910 (Hymenoptera: Formicidae), *Oryctes nasicornis* L., 1758 (Coleoptera: Scarabaeidae), *Coccinella septempunctata* L., 1758 (Coleoptera: Coccinellidae), *Harpalus distinguendus* (Duftschmid, 1812) (Coleoptera: Carabidae), and *Calathus syriacus* Chaudoir, 1863 (Coleoptera: Carabidae) with fewer individuals. *Pritha* sp. (Araneae: Filistatidae) was only one species from the order Araneae caught in the entrance zone (Table 5).

A notable result, *Dysderocrates* sp. (Araneae: Dysderidae) was captured in both entrance and dark zones with two and five individuals, respectively. Species sampled in all three zones, entrance, twilight, and dark were *Hoplopholcus asiaeminoris* Brignoli, 1978 (Araneae: Pholcidae) and *Hoplopholcus* sp. (Araneae: Pholcidae). One arachnid, *Heteropoda variegata* (Simon, 1874) (Araneae: Sparassidae), one callipodid, *Eurygyrus bilselii* (Verhoeff, 1940) (Callipodida: Schizopetalidae) and two hexapod, *Laemostenus longicornis* Casale, 1988 (Coleoptera: Carabidae), and *Ovaliptila alanya* Gorochov & Ünal, 2012 (Orthoptera: Gryllidae) were captured from twilight and dark zones of KIC. Species only found in dark zone were *Tegenaria percuriosa* Brignoli, 1972 (Araneae: Agelenidae), *Tegenaria* sp. (Araneae:

Agelenidae), *Harpactea* sp. (Araneae: Dysderidae), *Lepthyphantes* p*leprosus* (Ohlert, 1865) (Araneae: Linyphiidae), *Centromerus* sp. (Araneae: Linyphiidae), *Troglohyphantes* sp. (Araneae: Linyphiidae), *Protoiurus kadleci* (Kovarik Fet, Soleglad & Yağmur, 2010) (Scorpiones: Iuridae), and *Troglophilus gajaci* Us, 1974 (Orthoptera: Rhaphidophoridae). Except *T. gajaci*, most of these were captured with few individuals (Table 5).

During the study, homogeneous collecting procedures were applied, 159 and 60 individuals were sampled from KIC and ESC, respectively.

Biological diversity of Erdal Şekeroğlu and Kadıini Caves

Results of the biodiversity indices, Shannon-Wiener, Simpson diversity and Shannon evenness, evaluated by the arthropod assemblages of both caves are given in Table 3.

Species richness was 21 and 26 in ESC and KIC, respectively. ESC was found to be more diverse (H' 2.597 and S 0.8961) than KIC (H' 2.307 and S 0.8112) according to both Shannon-Wiener and Simpson diversity indices. Shannon evenness results showed that the population density of the species was more uniformly distributed in ESC than KIC.

Shannon-Wiener's and Simpson's diversity indices showed that the entrance zones of both caves were more diverse than the other zones (Table 3). In addition to that, the dark zone of the KIC was more diverse than the dark zone of the ESC.

Table 3. Results of biological diversity indices for caves and each zone of the caves

Caves & Cave Zones*	Sr[1]	Ni[2]	H'[3]	S[4]	Sd[5]	EH[6]
ESC	21	60	2.5940	0.8961	0.1040	0.8523
ESCE	15	26	2.3174	0.8432	0,1568	0.8557
ESCT	1	2	-	-	-	-
ESCD	5	32	1.4615	0.7422	0,2578	0.9081
KIC	26	158	2.3070	0.8112	0.1890	0.7081
KICE	14	23	2.4615	0.8960	0.1040	0.9327
KICT	6	71	1.0304	0.4797	0.5203	0.5751
KICD	15	64	2.3704	0.8857	0.1143	0.8753

* E, entrance zone; T, twilight zone; and D, dark zone (as appended to the habitat names, ESC, Erdal Şekeroğlu Cave and KIC, Kadıini Cave);
[1] species richness; [2] Sum of individuals; [3] Shannon-Wiener Diversity index; [4] Simpson Diversity index; [5] Simpson Dominance index, [6] Shannon evenness index.

Similarity of Erdal Şekeroğlu and Kadıini Caves and cave zones

The similarity dendrogram built on the base of the Sörensen index showed that there was no similarity between ESC and KIC, and also between the zones of each cave. It was revealed that there was the only similarity between the zones in KIC. The twilight and dark zones of the KIC were 48.5% similar to each other, and the entrance zone was found 13.3% similar to this group (Figure 1). These results show that the cave ecosystems have their unique species diversity and ecosystems. Also, these results show that all of the species collected from both caves have limited dispersal ability because they are adapted to caves. The cladograms for ESC indicate that all of the species have special habitat preferences, but the cladograms for KIC indicates that some species can inhabit both twilight zone and dark zone. Therefore, it can be concluded that all of the species in ESC have specific zone adaptation based on light.

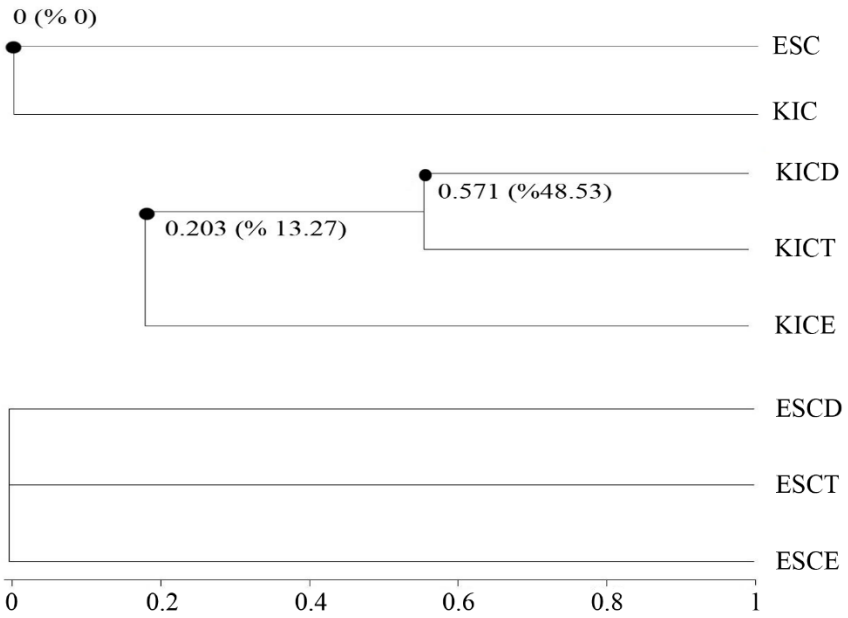

Figure 1. Similarity between arthropod assemblages inhabiting different caves and cave zones based on species composition (Sörensen index). ESC, Erdal Şekeroğlu Cave; KIC, Kadıini Cave; KICE, entrance zone of the Kadiini Cave; KICT, twilight zone of the Kadiini Cave; KICD, dark zone of the Kadiini Cave; ESCE, entrance zone of the Erdal Şekeroğlu Cave; ESCT, twilight zone of the Erdal Şekeroğlu Cave; ESCD, dark zone of the Erdal Şekeroğlu Cave (percentages given in parentheses are calculated separately from the percent similarity).

Indicator species of Erdal Şekeroğlu and Kadıini Caves

As a result of the inclusion of rare individuals in the analysis, all of these species were found statistically significant as indicators for zone description in ESC ($P < 0.001$). (Table 4). According to ISA, *O. alanya* was determined as an indicator species for the twilight zone of the KIC with 82% InV (Table 5), however, this species was also detected in the dark zone between 1700 and 1800 m ahead in the KIC (Figure 2). Photograph of the species is given Figure 3.

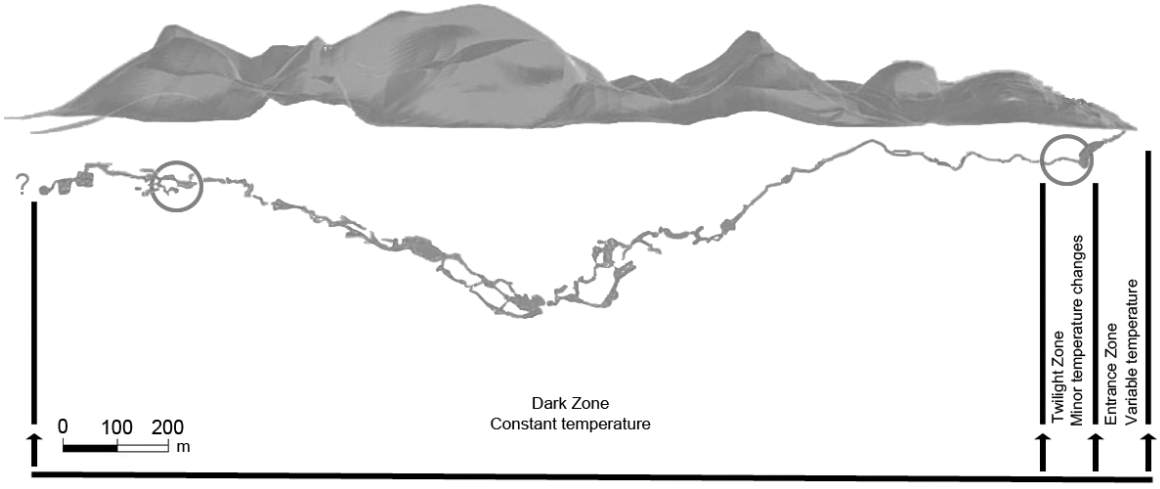

Figure 2. Map of the known part of the KIC (2027 m) showing the representation of the cave zones and the distribution of the *Ovaliptila alanya* in the cave (distribution of the species is indicated by two circles) (The base map prepared by members of Akdeniz University Caving Society-AKUMAK).

Figure 3. Photograph of *Ovaliptila alanya*, the first insect described from cave mapping (photo by the first author).

Table 4. Indicator species and their indicator values (Monte Carlo test, P < 0.05, 4999 permutations, random number seed of 699) in the zones of the ESC

Class	Order	Family	Species	Z	%InV	P*	E	T	D
Arachnida	Ixodoidea	Argasidae	*Carios* sp. ?	D	100	0.0324	-	-	2
	Araneae	Dysderidae	?	D	100	0.0324	-	-	4
		Linyphiidae	?	D	100	0.0324	-	-	8
Chilopoda	?	?	?	T	100	0.0354	-	2	-
Diplopoda	Callipodida	Schizopetalidae	*Eurygyrus* sp.	E	100	0.0382	9	-	-
Hexapoda	Coleoptera	Carabidae	*Carabus glabratus* Paykull, 1790	E	100	0.0382	1	-	-
			Carabus graecus Dejean, 1826	E	100	0.0382	1	-	-
			Laemostenus (Antisphodrus) longicornis Casale, 1988	D	100	0.0324	-	-	12
			Ophonus (Hesperophonus) azureus (F., 1775)	D	100	0.0324	-	-	6
		Chrysomelidae	*Chrysomela populi* L., 1758	E	100	0.0382	1	-	-
		Curculionidae	*Rhynchaenus asellus* Gravenhorst, 1807	E	100	0.0382	1	-	-
			Ips sexdentatus (Boerner, 1776)	E	100	0.0382	1	-	-
			Larinus curtus Hochhuth, 1851	E	100	0.0382	1	-	-
			Tomicus minor (Hartig, 1834)	E	100	0.0382	1	-	-
	Hymenoptera	Formicidae	*Camponotus aethiops* (Latreille, 1798)	E	100	0.0382	1	-	-
			Messor semirufus (André, 1883)	E	100	0.0382	2	-	-
			Stigmatomma denticulatum Roger, 1859	E	100	0.0382	1	-	-
	Coleoptera	Scarabaeidae	*Anoxia asiatica* Desbrochers des Loges, 1871	E	100	0.0382	1	-	-
			Cetonia aurata (L., 1758)	E	100	0.0382	1	-	-
			Oxythyrea cinctella (Schaum, 1841)	E	100	0.0382	1	-	-
	Lepidoptera	Erebidae	*Scoliopteryx libatrix* L., 1758	E	100	0.0382	3	-	-

*E, entrance zone; T, twilight zone; D, dark zone and Z, the zone where the species is the indicator
Maxgrp = group identifier for group with maximum observed IV
a Proportion of randomized trials with IV equal to or exceeding the observed IV.
p = (1 + number of runs ≥ observed) / (1 + number of randomized runs).

Table 5. Indicator species and their indicator values (Monte Carlo test, P < 0.05, 4999 permutations, random number seed of 5733) in the zones of the KIC

Class	Order	Family	Species	Z	%InV	P*	E	T	D
Arachnida	Araneae	Agelenidae	*Tegenaria percuriosa* Brignoli, 1972	D	100	0.0336	-	-	1
			Tegenaria sp.	D	100	0.0336	-	-	4
		Dysderidae	*Dysderocrates* sp.	E	71	0.6689	2	-	5
			Harpactea sp.	D	100	0.0336	-	-	1
		Filistatidae	*Pritha* sp.	E	100	0.0348	1	-	-
		Linyphiidae	*Centromerus* sp.	D	100	0.0336	-	-	1
			Lepthyphantes leprosus (Ohlert, 1865)	D	100	0.0336	-	-	1
			Troglohyphantes sp.	D	100	0.0336	-	-	1
		Pholcidae	*Hoplopholcus asiaeminoris* Brignoli, 1978	-	33	-	2	2	2
			Hoplopholcus sp.	-	33	-	3	3	3
		Sparassidae	*Heteropoda variegata* (Simon, 1874)	T	50	0.6743	-	2	2
	Scorpiones	Iuridae	*Protoiurus kadleci* (Kovarik Fet, Soleglad & Yağmur, 2010)	D	100	0.0336	-	-	4
Diplopoda	Callipodida	Schizopetalidae	*Eurygyrus bilselii* (Verhoeff, 1940)	T	67	0.6743	-	5	11
Hexapoda	Coleoptera	Carabidae	*Calathus syriacus* Chaudoir, 1863	E	100	0.0348	1	-	-
			Harpalus distinguendus (Duftschmid, 1812)	E	100	0.0348	1	-	-
			Laemostenus longicornis Casale, 1988	T	50	0.6743	-	9	9
		Coccinellidae	*Coccinella septempunctata* L., 1758	E	100	0.0348	1	-	-
		Curculionidae	*Orthotomicus erosus* (Wollaston, 1857)	E	100	0.0348	1	-	-
			Tomicus destruens (Wollaston, 1865)	E	100	0.0348	1	-	-
		Meloidae	*Zonitis praeusta* F., 1792	E	100	0.0348	1	-	-
		Scarabaeidae	*Oryctes nasicornis* L., 1758	E	100	0.0348	1	-	-
	Hymenoptera	Formicidae	*Cataglyphis nodus* (Brullé, 1833)	E	100	0.0348	5	-	-
			Messor oertzeni Forel, 1910	E	100	0.0348	2	-	-
			Tapinoma erraticum (Latreille, 1798)	E	100	0.0348	1	-	-
	Orthoptera	Gryllidae	*Ovaliptila alanya* Gorochov & Ünal, 2012	T	81	0.6743	-	50	12
		Rhaphidophoridae	*Troglophilus gajaci* Us, 1974	D	100	0.0336	-	-	8

* E: entrance zone, T: twilight zone, D: dark zone, Z: the zone where the species is the indicator;
Maxgrp = group identifier for group with maximum observed IV;
a Proportion of randomized trials with IV equal to or exceeding the observed IV;
p = (1+number of runs ≥ observed) / (1+number of randomized runs).

Species richness estimations of Erdal Şekeroğlu and Kadıini Caves

The results of the species estimators for both caves showed that there were still some undetected species in each cave (Table 6, Figure 4). The percentage of the determined species falls between 20% (ACE) and 81% (Bootstrap) in KIC and between 13% (ICE and Chao 2) and 84% (MMRuns) in ESC (Table 6). Although the range of estimation percentages was similar for both caves, the estimation percentages of ESC were more similar, apart from ICE and Chao 2.

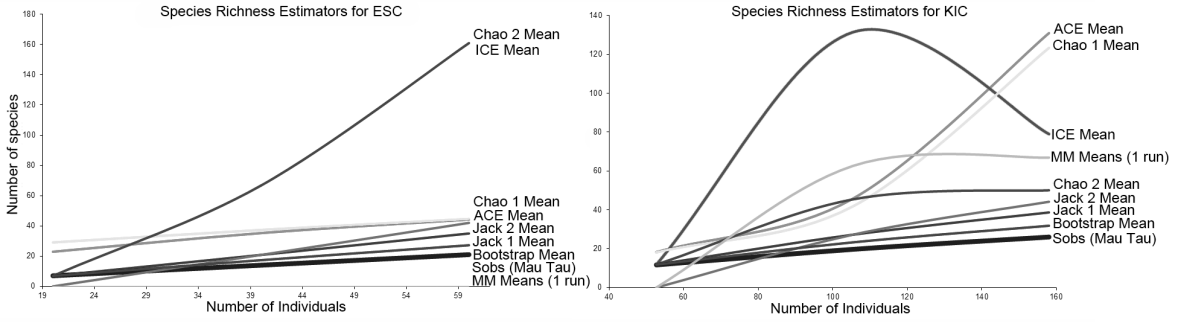

Figure 4. Species accumulation curves for ESC (left) and KIC (right).

Table 6. The number of the recorded and estimated species, and the percentage of the estimated species number recorded for each cave

	KIC	ESC
Observed species (S*obs*)	26	21
Number of samples	3	3
Number of individuals	158	60
Singletons	14	12
Doubletons	1	3
ACE	131	44
ACE %	20	48
ICE	79	161
ICE %	33	13
Chao 1	123	45
Chao 1 %	21	47
Chao 2	50	161
Chao 2 %	52	13
Jack 1	39	35
Jack 1 %	67	60
Jack 2	44	42
Jack 2 %	59	50
Bootstraps	32	27
Bootstraps %	81	78
MMRuns	42	25
MMRuns %	62	84
MMMeans	67	0
MMMeans %	39	0

Discussion

The arthropod biodiversity of KIC (Antalya, Alanya) and ESC (Isparta, Atabey) was determined. As a result of the study, 51 arthropod species were detected. These belonged to five classes: 29 Hexapoda, 17 Arachnida, two Chilopoda, two Diplopoda and one Collembola. The species richness and diversity of insects are similar in these two cave ecosystems as well as other ecosystems of the worldwide. Many scientific studies in cave ecosystems show that hexapods are more diverse than other arthropod classes. Additionally, a significant proportion of the arthropod species that are collected in the cave ecosystems are hexapods (Poulson & Culver, 1969; Schneider et al., 2010; Culver & Pipan, 2018; Niemiller & Taylor, 2019; Ledesma et al., 2020).

Biodiversity parameters can be measured differently, even in different regions in the same cave ecosystem. This is due to many ecological factors such as human activity, habitat degradation, nutrient and availability (Poulson & Culver, 1969). When the caves were evaluated for species diversity, Shannon-Wiener and Simpson diversity indices showed that the ESC was more diverse than KIC. For species diversity, results of the diversity indices revealed that the twilight zones in both caves are less diverse than the entrance zones and the dark zones. Our study thus agrees with similar studies conducted on species diversity of arthropods inhabiting different cave zones (Prous et al., 2004; Tobin et al., 2013; Kurniawan et al., 2018). However, most of these studies have revealed that the state of diversity varies between zones depending on the many biotic and abiotic factors (Tobin et al., 2013). Also, it is known that diversity increases with the increasing area because the larger area has more habitats and niches to be able to support a larger variety of species (MacArthur & Wilson, 1967). When considering the length of the caves, the results of the present study are inconsistent with this theory. There is some knowledge of human activities from the Chalcolithic Age-Early Bronze Age in the KIC (Yılmaz Usta, 2019). So, the lower species diversity in KIC may have been caused by anthropogenic activities (such as habitat destruction and modification) from nearly 5,000 BC to today in this cave. The abundance of the species living in the entrance zone and accidentally fall into the cave should also be considered.

The arthropod assemblages inhabiting in the three cave zones in each cave were compared. The similarity dendrograms built on the base of the Sörensen index showed that there was no similarity between ESC and KIC and between similar zones in both caves. However, the twilight zone and dark zone of the KIC had 48% similarity and these two zones had 13% similarity with the entrance zone of this cave. It should be taken into consideration that one of the factors that increased the similarity between the twilight zone and the dark zone may be caused by the unexpected distribution of *O. alanya*. Despite this eventuality it is clear that the arthropod assemblages of the twilight zones of both caves are more similar to the assemblages of the dark zones. The higher similarity among these arthropod assemblages is caused by the higher abiotic similarity among the twilight and dark zones. These results are found similar to those of other studies (Kurniawan et al., 2018).

When species compositions of both caves have taken into account at the species level, results showed that both caves have unique species composition. However, when the species compositions of both caves are considered at the family level, it was found that taxa in the twilight zone and the dark zone of both caves belong to the same families. These situations may be due to two reasons. Firstly, species-level differences can arise from the geographical distance between the caves. Secondly, family-level similarity can arise from the fauna of in each cave being descended from similar ancestral fauna. Considering similarities of cave zones, although KIC was longer than ESC, the similarity among the cave zones in KIC was higher than ESC. There may be two reasons for the zone similarity of KIC. Firstly, food may be carried into the dark zone by cavers and animals due to the structure of KIC. Secondly, the dark zone of the KIC could be connecting to the outside with small cracks. In other words, the zones of the ESC are better separated from each other. However, many arthropods seem to delimit that transition zone based on light penetration, salinity, supply of nutrients and other factors (Wittmann, 2004).

No study to date has examined insects as indicators in cave mapping. In present study we investigated whether there is a species that can be used as a biological indicator. ISA showed that *O. alanya* can be used as an indicator species for the twilight zone of the KIC with 81% InV. It is quite unlikely that this species would also be concurrently collected from the dark zone of the KIC. Under normal circumstances, the indicator value of the species must have been found 100% in the twilight zone (Taylan et al., 2020) This significant distribution pattern of the *O. alanya* could be due to another undiscovered entrance of the cave or small cracks connecting the dark zone (actually twilight zone if the light comes in) of the KIC with the external environment. In this context, this species appears to be potentially useful in cave mapping.

Completeness of the arthropod inventory was calculated by using species estimators. According to all of the species estimators, the species estimates for KIC ranged from 20 to 81% and the species estimates for ESC ranged from 13 to 84%. Similarly, Wynne (2014) stated that none of the accumulation curves neared an asymptote in the studied four caves. In the present study, the results show that species estimators are reasonably incomplete and all of the estimators agree in their values that there are still undetected species in each cave. The high amount of rare species and sampling limitations made species richness estimation more challenging in the both caves ESC and KIC. Due to the large number of rare species in cave ecosystems the number of species predicted by species richness estimators is large (Schneider & Culver, 2004; Chao & Chiu, 2016).

In conclusion, the present study (1) highlights the need for further studies to determine the complete fauna in both caves and (2) shows that each cave and its zones have a unique fauna, and warrant conservation on this basis. Also, the study highlights that there are limited studies of the biodiversity and ecological parameters of arthropod assemblages on the cave ecosystems (Prous et al., 2004; Tobin et al., 2013; Wynne, 2014; Kurniawan et al., 2018).

An additional conclusion is our results demonstrate how insects can be used in cave mapping, and in supporting caves protection and conservation. The study is a small, but crucial, step towards understanding biodiversity patterns in these important but poorly documented ecosystems. This is key given the role of these species have in the food chains and in light of their vulnerability to changing environmental conditions. We argue strongly that trogloxene and troglophile arthropods should be taken into consideration before any decision to open the cave for tourism. Follow up work is urgently needed in this area before known and unknown species become extinct.

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References

Anonymous, 2019. Mağara Turizmi. (Web page: http://yigm.kulturturizm.gov.tr/TR-10335/magara-turizmi.html) (Date accessed: 14.07.2020).

Barr, T. C., 1968. “Cave Ecology and the Evolution of Troglobites. 35-102”. In: Evolutionary Biology, Vol. 2 (Eds. T. Dobzhansky, M. K. Hecht & W. C. Steere) Springer, Boston, MA, USA, 452 pp.

Barton, H. A. & V. Jurado, 2007. What’s up down there? Microbial diversity in caves. Microbe, 2 (3): 132-138.

Burnham, K. P. & W. S. Overton, 1978. Estimation of the size of a closed population when capture probabilities vary among animals. Biometrika, 65 (3): 623-633.

Burnham, K. P. & W. S. Overton, 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology, 60 (5): 927-936.

Camacho, A. I., 1992. The Natural History of Biospeleology. Madrid: Museo Nacional De Ciencias Naturales, Spain, 701 pp.

Carignan, V. & M. Villard, 2002. Selecting indicator species to monitor ecological integrity: a review. Environmental Monitoring and Assessment, 78 (1): 45- 61.

Chao, A., 1987. Estimating the population size for capture data with unequal catchability. Biometrics, 43 (4): 783-791.

Chao, A., 1984. Non-parametric estimation of the number of classes in a population. Scandinavian Journal of Statistics, 11 (4): 265-270.

Chao, A. & C. H. Chiu, 2016. Species richness: Estimation and comparison. Wiley Stats. Ref: Statistics Reference Online, 1-26. (Web page: https://doi.org/10.1002/9781118445112.stat03432.pub2) (Date accessed: 01.07.2020).

Chao, A. & S. M. Lee, 1992 Estimating the number of classes via sample coverage. Journal of the American Statistical Association, 87 (417): 210-217.

Chao, A., M. C. Ma & M. C. K. Yang, 1993. Stopping rules and estimation for recapture debugging with unequal failure rates. Biometrika, 80 (1): 193-201.

Chazdon, R. L., R. K. Colwell, J. S. Denslow & M. R. Guariguata, 1998. "Statistical Methods for Estimating Species Richness of Woody Regeneration in Primary and Secondary Rain Forests of NE Costa Rica, 285-309". In: Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old-World Case Studies (Eds. F. Dallmeier & J. A. Comiskey). Unesco Paris & The Parthenon Publishing Group, Paris, 671 pp.

Colwell, R. K., 1997. EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples (Software and User´s Guide), Versión 7.01. (Web page: http://viceroy.eeb.uconn.edu/estimates) (Date accessed: 10.01.2020).

Colwell, R. K., 2019. EstimateS 8.2 User's Guide. (Web page: http://viceroy.eeb.uconn.edu/estimates) (Date accessed: 10.01.2020).

Colwell, R. K. & J. A. Coddington, 1994. Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society (Series B), 345 (1311): 101-118.

Cramer, W., E. Egea, J. Fischer, A. Lux, J. M. Salles, J. Settele & M. Tichit, 2017. Biodiversity and food security: from trade-offs to synergies. Regional Environmental Change, 17 (5): 1257-1259.

Culver, D. C., M. C. Christman, B. Sket & P. Trontelj, 2004. Sampling adequacy in an extreme environment: species richness patterns in Slovenian caves. Biodiversity & Conservation, 13 (6): 1209-1229.

Culver, D. C., L. Deharveng, A. Bedos, J. J. Lewis, M. Madden, J. R. Reddell, B. Sket, P. Trontelj & D. White, 2006. The mid-latitude biodiversity ridge in terrestrial cave fauna. Ecography, 29 (1): 120-128.

Culver, D. C. & T. Pipan, 2018. "Insect in Caves, 123-152". In: Insect Biodiversity: Science and Society Vol.: 2 (Eds. R. G. Foottit & P.H. Adler). Wiley Blackwell, UK, 1024 pp.

Culver, D. C. & B. Sket, 2000. Hotspots of subterranean biodiversity in caves and wells. Journal of Cave and Karst Studies, 62 (1): 11-17.

Culver, D. C. & W. B. White, 2005. Encyclopedia of Caves. Elsevier, Amsterdam, 1250 pp.

Dufrêne, M. & P. Legendre, 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecologial Monographs, 67 (3): 345-366.

Eberhard, S., 1992. The Invertebrate Cave Fauna of Tasmania: Ecology and Conservation Biology. University of Tasmania, (Unpublished) Research Master Thesis, 184 pp.

Feest, A., T. D. Aldred & K. Jedamzik, 2010. Biodiversity quality: a paradigm for biodiversity. Ecological Indicators, 10 (6): 1077-1082.

Fernandes, C. S., M. Batalha & M. E. Bichuette, 2016. Does the cave environment reduce functional diversity? Plos One, 11 (3): 1-14.

Gunn, J., 2004. Encyclopedia of Caves and Karst Science. Taylor & Francis, New York, 1940 pp.

Heimann, D., 2004. EvenDiv 1.1. Based on a DBase Program Code Supplied by Jörg Perner and Martin Schnitter. Institute of Ecology, University of Jena.

Heltshe, J. & N. E. Forrester, 1983. Estimating species richness using the jackknife procedure. Biometrics, 39 (1): 1-11.

Heydemann, B., 1953. Agrarökologische Problematik dargetan an Untersuchungen über die Tierwelt der Bodenoberfläche der Kulturfelder. Dissertation, University of Kiel, 433 pp.

Hobbs III, H. H., 2012. "Diversity Patterns in the United States, 251-264". In: Encyclopedia of Caves (Eds. W. B. White & D. C. Culver). Academic Press, Amsterdam, 1250 pp.

Howarth, F. G., 1983. Ecology of cave arthropods. Annual Review of Entomology, 28 (1): 365-389.

Kovach, W. L., 1999. A Multi variate Statistical Package. United Kingdom: Kovach Computing Services.

Kowalczk, A., 2009. High Resolution Microclimate Study of Hollow Ridge Cave: Relationships Between Cave Meteorology, Air Chemistry, and Hydrology and the Impact on Speleothem Deposition. The Florida State University College of Arts and Sciences, (Unpublished) MSc Thesis, Florida, US, 238 pp.

Krebs, C. J., 1999. Ecological Methodology. An Imprint of Addison Wesley Longman Inc., 620 pp.

Kunt, K. B., E. A.Yağmur, S. Özkütük, H. Durmus & S. Anlas, 2010. Checklist of the cave dwelling invertebrates (Animalia) of Turkey. Biological Diversity and Conservation, 3 (2): 26-41.

Kurniawan, I. D., C. Rahmadi, R. E. Caraka, & T. E. Ardi, 2018. Cave-dwelling arthropod community of semedi show cave in Gunungsewu karst area, Pacitan, East Java, Indonesia. Biodiversitas Journal of Biological Diversity, 19 (3): 857-866.

Latella, L. & F. Stoch, 2002. "Biospeleology, 53-86". In: Caves and Karstic Phenomena: Life in the Subterranean World (Ed. F. Stoch). Italian Ministry of the Environment and Territory Protection, 159 pp.

Latella, L., N. Verdari, & M. Gobbi, 2012. Distribution of terrestrial cave-dwelling arthropods in two adjacent Prealpine Italian areas with different glacial histories. Zoological Studies, 51 (7): 1113-1121.

Ledesma, E., A. J. Valverde, E. Baquero, R. Jordana, A. Castro & V. M. Ortuño, 2020. Arthropod biodiversity patterns point to the Mesovoid Shallow Substratum (MSS) as a climate refugium. Zoology, 141: 125771.

Lee, S. M. & A. Chao, 1994. Estimating population size via sample coverage for closed capture-recapture models. Biometrics, 50 (1): 88-97.

Lee, M., D. B. Meisinger, R. Aubrecht, L. Kovacik, C. S. Jimenez, S. Baskar, R. Baskar, W. Liebl, M. Porter & A. S. Engel, 2012. "Caves and Karst Environments, 320-344". In: Life at Extremes: Environments, Organisms and Strategies for Survival (Ed. E. Bell). CAB International, UK, 576 pp.

MacArthur, R. H. & E. O. Wilson, 1967. The Theory of Island Biogeography. Princeton, NJ: Princeton University Press. 203 pp.

Magurran, A. E., 1988. Ecological Diversity and Its Measurement. Princeton University Press, 179 pp.

Magurran, A. E., 2004. Measuring Biological Diversity. Blackwell Science Ltd., 256 pp.

McCune, B. & M. J. Mefford, 2016. PC-ORD. Multivariate analysis of ecological data. Version 7. MjM Software Design, Gleneden Beach, Oregon, U.S.A.

McGeoch, M. A. & S. L. Chown, 1998. Scaling up the value of bioindicators. Trends in Ecology & Evolution, 13 (2): 46-47.

Moulds, T. A., 2006. The Seasonality, Diversity and Ecology of Cavernicolous Guano Dependent Arthropod Ecosystems in Southern Australia. The University of Adelaide, (Unpublished) Doctoral Dissertation, Australia, 260 pp.

Niemi, G. J. & M. E. McDonald, 2004. Application of ecological indicators. Annual Review of Ecology, Evolution and Systematics, 35 (1): 89-111.

Niemiller, M. L. & S. J. Taylor, 2019. "Protecting Cave Life, 822-829". In: Encyclopedia of Caves-3rd Edition (Eds. W. B. White, D. C. Culver & T. Pipan) Academic Press, Amsterdam, 1250 pp.

Northup, D. E. & K. H. Lavoie, 2001. Geomicrobiology of caves: A review. Geomicrobiol Journal, 18 (3): 199-222.

Palmer, A. N., 1991. Origin and morphology of limestone caves. Geological Society of America Bulletin, 103 (1): 1-21.

Poulson, T. L. & D. C. Culver, 1969. Diversity in terrestrial cave communities. Ecology, 50 (1): 153-158.

Prous, X., R. L. Ferreira & R. P. Martins, 2004. Ecotone delimitation: Epigean-hypogean transition in cave ecosystems. Austral Ecology, 29 (4): 374-382.

Samways, M. J., 1994. Insect conservation biology. Chapman & Hall, London, UK, 374 pp.

Samways, M. J., 2007. Insect conservation: A synthetic management approach. Annual Review of Entomology, 52: 465-487.

Schneider, K. & D. C. Culver, 2004. Estimating subterranean species richness using intensive sampling and rarefaction curves in a high-density cave region in West Virginia. Journal of Cave and Karst Studies the National Speleological Society Bulletin, 66 (2): 39-45.

Schneider, K., A. D. Kay & W. F. Fagan, 2010. Adaptation to a limiting environment: the phosphorus content of terrestrial cave arthropods. Ecological Research, 25 (3): 565-577.

Smith, E. P. & G. van Belle, 1984. Nonparametric estimation of species richness. Biometrics, 40 (1): 119-129.

Southwood, T. R. E., 1971. Ecological Methods with Particular Reference to the Study of Insect Populations. Chapman and Hall., 391 pp.

Taylan, M. S., M. Yılmazer & D. Şirin, 2020. 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). Journal of Entomological Research Society, 22 (1): 53-73.

Tercafs, R., 1988. Optimal management of karst sites with cave fauna protection. Environmental Conservation, 15 (2): 149-158.

Tobin, B. W., B. T. Hutchins & B. F. Schwartz, 2013. Spatial and temporal changes in invertebrate assemblage structure from the entrance to deep-cave zone of a temperate marble cave. International Journal of Speleology, 42 (3): 203-214.

Tolan-Smith, C. & C. Bonsall, 1997. "The Human Use of Caves, 217-218". In: The Human Use of Caves (Eds. C. Bonsall & C. Tolan-Smith). Oxford, British Arcaeological Reports, International Series No: 667, 218 pp.

Tydecks, L., J. M. Jeschke, M. Wolf, G. Singer & K. Tockner, 2018. Spatial and topical imbalances in biodiversity research. PLoS ONE, 13 (7): e0199327.

Vandel, A., 1964. Biospeleology-The Biology of Cavernicolous Animals (Translated by B. E. Freeman, 1965). Pergamon Press, Oxford, 524 pp.

Veni, G., 2019. Quiet preparation for the international year of caves and karst and other advances in speleology. International Union of Speleology Bulletin, 61 (1): 4-5.

Village, N. P., B. District, K, Province & P. D. R. Lao, 2019. Xe Bang Fai Cave Development and Management Strategy 2018-2020. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 20 pp.

Weliange, W. S., 2016. "Bio-Speleology and possible trophic networks in Sri Lankan caves, 12". 12. Proceedings of the International Forestry and Environment Symposium (2016, Sri Lanka), Department of Forestry and Environmental Science, University of Sri Jayewardenepura, Sri Lanka, 116 pp.

Wittmann, R., 2004. Retromysis nura new genus and species (Mysidacea, Mysidae, Heteromysini) from a superficial marine cave in Minorca (Balearic Islands, Mediterranean Sea). Crustaceana, 77 (7): 769-783.

Wynne, J. J., 2014. On Sampling, Habitat and Relict Species of Cave-Dwelling Arthropods in the American Southwest and Easter Island. Northern Arizona University, (Unpublished) Doctoral Dissertation, US, 211 pp.

Yılmaz Usta, N. D., 2019. Demographical analysis of the late Chalcolithic/Early Bronze Age skeletal population in Kadıini Cave. Antropoloji, 38: 65-78.

Zacharias, M. A. & J. C. Roff, 2001 Use of focal species in marine conservation and management: a review and critique. Aquatic Conservation: Marine and Freshwater Ecosystems, 11 (1): 59-76.