Turkish Journal of Zoology

http://journals.tubitak.gov.tr/zoology/

Research Article

Turk J Zool
(2019) 43: 367-378
© TÜBİTAK
doi:10.3906/zoo-1902-24

Ecological surveys on the parthenogenetic *Artemia* populations in the hypersaline lakes of Anatolia, Turkey

Armin ESKANDARİ[1], **Yasemin SAYGI**[2,*]

[1]Department of Education, SETT Group, Çankaya, Ankara, Turkey

[2]Department of Biology, Faculty of Science, Hacettepe University, Ankara, Turkey

Received: 20.02.2019 • **Accepted/Published Online:** 19.06.2019 • **Final Version:** 01.07.2019

Abstract: The objective of this study is to provide information on the parthenogenetic *Artemia* populations in some hypersaline lakes of Anatolia (Tuz, Bolluk, Tersakan, and Acıgöl). Sampling studies were performed for abiotic factors and population parameters between November 2009 and October 2010. During the survey we focused on the local *Artemia* populations to investigate population dynamics, reproduction, brood size, and cyst and naupliar biometrics. Generally, the *Artemia* habitats in Anatolia were relatively shallow, and thus they were subject to major seasonal fluctuations. Dramatic declines in population size in Tuz and Acıgöl Lakes were found during this study. All *Artemia* populations were parthenogenetic and brood sizes of females showed significant differences among the populations ($P < 0.05$). The largest brood size was observed in the Acıgöl population and it may be concluded that local conditions for reproductive success were more adequate in this population. Substantial differences among populations were revealed during the studies on cyst and naupliar biometry. Cyst diameter mean values ranged from 231.8 to 266.9 µm. The cyst diameters for the Acıgöl population are determined as the smallest in these populations and among the smallest values recorded in parthenogenetic populations. The total length of newly hatched nauplii ranged from 484 to 512 µm for these populations.

Key words: *Artemia*, population fluctuations, brood size, cysts biometry, Turkey

1. Introduction

Hypersaline habitats are abundant worldwide, and these habitats are shelters for migratory birds and also the home of unique native fauna well adapted to extremely harsh conditions. The brine shrimp *Artemia* is a specialized organism able to live under harsh conditions such as extreme salinity, temperature, frequent desiccation, anoxia, and predation. *Artemia* is a dominant inhabitant organism of hypersaline lakes and it produces diapausing eggs to overcome extreme conditions (Torrentera and Dodson, 2004).

The brine shrimp *Artemia* is an anostracan crustacean, existing on all continents with the exception of Antarctica (Triantaphyllidis et al., 1998). It is able to resist the severe physiological stress created by habitats with various adaptations. The best known way of adaptation is based on an interchangeable life cycle. The life cycle of *Artemia* begins as an embryo within a dormant cyst. Depending on environmental conditions, embryos can go into diapause and the development of embryos can be arrested for many years; thus, they can escape from harsh environmental conditions (Clegg and Trotman, 2002). Diapausing embryos are specialized for surviving during adverse environmental conditions and hatching when the environmental conditions are improved. *Artemia* females produce free-living nauplii (ovoviviparous) when environmental conditions are favorable and produce dormant encysted embryos or diapausing cysts (oviparous) under severe conditions (high salinity and temperature, low oxygen and food supply, or short photoperiods) (Clegg and Trotman, 2002; Criel and Macrae, 2002; Nambu et al., 2004).

Artemia is among the most intensely studied aquatic organisms due to its importance in aquaculture. Its cysts can be stored for several years; its larvae are a convenient substance as a natural diet for fish and shrimp larvae and indispensable live food in marine finfish and shellfish hatchery operations worldwide. Furthermore, they have broad use as a model organism in ecotoxicology, developmental biology, ecology, and evolutionary biology. As extreme halophilic organisms, they have existed in hypersaline environments such as salt pans, inland salt lakes, and coastal salty lagoons worldwide. Since the initial recording of 80 *Artemia* sites, the site number has steadily

* Correspondence: basbug@hacettepe.edu.tr

increased. For example, Van Stappen (2002) reported more than 500 *Artemia* locations. The search for new *Artemia* populations is relevant to solve fundamental questions on population differentiation in stressful habitats and is also important for detecting new commercial populations, which are highly demanded for aquaculture. Hence, studies of alternative *Artemia* resources have intensified in recent years, especially in large and productive inland lakes that are suitable for commercial utilization.

In this study we investigated several ecological factors to characterize the hypersaline ecosystems of the Konya Closed Basin (Tuz Lake, Bolluk Lake, Tersakan Lake) and Burdur Basin (Acıgöl Lake). We also describe here *Artemia* population dynamics (distribution, structure, and abundance) in the field and environmental factors affecting brine shrimp development and reproductive strategy.

2. Materials and methods

2.1. Site description

An ecological study was conducted to investigate the current status of parthenogenetic *Artemia* populations and some habitat characteristics in Tuz, Bolluk, Tersakan, and Acıgöl Lakes in Anatolia, Turkey. The locations of the lakes are given Figure 1.

2.1.1. Tuz Lake

Tuz Lake, the second largest lake of Turkey, is located within the boundaries of the provinces of Ankara, Konya, and Aksaray. Tuz Lake has the highest salinity values in Turkey, and geologically it has a tectonic structure. At the largest part, the distance between the coasts is 48 km, the south-north length is 80 km, and the surface area is approximately 1600 km^2. The lake is 905 m in altitude from sea level and its depth is very shallow. Tuz Lake is located in a closed basin in Central Anatolia. Tuz Lake is fed by streams as well as groundwater and surface waters. Small streams feeding the lake (Peçeneközü Stream, İnsuyu Stream) are mostly dry in summer. Tuz Lake was designated as a conservation area in 1992 and a special environmental protection area in 2000. Salt production in the lake is done by the pooling system and evaporation method. In recent years, Tuz Lake faces various environmental problems, especially drought. In this respect, the lake is one of the ecologically sensitive regions in the country (Yarar and Magnin, 1997).

2.1.2. Bolluk Lake

Bolluk Lake is located on the east of the Cihanbeyli–Konya highway and it is 20 km away from the town. It is a lake with 1150 ha of surface area, located to the southwest of Tuz Lake. The lake and its surroundings are situated within

Figure 1. Geographical location of study areas.

the boundaries of a special environmental protection area. Bolluk Lake's surroundings are covered with lime hills and steppes. The main water resources feeding the lake are the surface waters and a sulfur source on the northern side. An artificial water source, which is the main evacuation channel of Konya's canalization, is separated from the lake by a bank. There is no direct flow of the channel into the lake, but occasionally some water is discharged into the lake to prevent the lake from drying out. Since 1963, the Alkim Company has been producing sodium sulfate and sodium chloride in two salterns covering a total area of 200 ha (Yarar and Magnin, 1997).

2.1.3. Tersakan Lake

Tersakan Lake is a hypersaline lake located in the Cihanbeyli District of Konya Province and has a surface area of 6400 ha. When the water level in the lake is very high, some of its water is discharged into Tuz Lake through an artificial channel. In the north, salt is produced in the salterns of the Alkim Company. A saltern with 500 ha of surface area opened in 1963. There are very large mud plains between the artificial channel and the lake. Apart from the small fresh water marshes in the southwest, there is no coastal vegetation anywhere in the lake. Tersakan Lake was declared a conservation area in 1992 (Yarar and Magnin, 1997).

2.1.4. Acıgöl Lake

Acıgöl Lake, located between Afyon and Denizli Provinces, is a tectonic lake with a surface area of 16,500 ha. The lake is fed with surface water from the surrounding mountains, with spring waters in the south and with the waters of the Kocaçay in the east. In summer the lake is very dry. Salt production is carried out by Alkim, Sodaş, and Otuzbir Kimya, which have been operating since the 1950s on an area of 450 ha to the west and north of the lake. Sodium sulfate is extracted from the lake as the main production area in Turkey (Yarar and Magnin, 1997).

2.2. Climate of *Artemia* sites

Tuz Lake, Tersakan, and Bolluk Lakes are located in the Konya Closed Basin. This region has a typical continental climate; the winters are cold and rainy and the summers are very hot and dry. The annual rainfall in the basin is 347 mm, and the driest and the rainiest months are August (5.2 mm) and December (53.8 mm), respectively, while the average air temperature is between –0.4 and 23.0 °C. Tuz Lake, Tersakan Lake, and Bolluk Lake reach their maximum depths in winter. These lakes become mostly dry in summer and salt marsh areas appear around the lakes. Acıgöl Lake, which is located within the boundaries of the Burdur Basin, is under the influence of continental climate conditions and the average air temperature is between 2.5 and 24.5 °C. The annual precipitation is 425.9 mm, the driest month is August (7.9 mm), and the rainiest period is December (58.7 mm).

2.3. Field sampling and laboratory analyses

Depending on the logistics and meteorological and topographical conditions, different sampling strategies were applied in the study regions. Monthly studies were conducted between March 2010 and October 2010 in Tuz, Bolluk, and Tersakan Lakes and between November 2009 and October 2010 in Acıgöl Lake. All four lakes are natural salt lakes and open to commercial salt production companies. The salt production area in Tuz Lake is located far away from the *Artemia* habitat; therefore, the *Artemia* population is not affected by salt production activities. Since the Tuz Lake population was found only between the Devekonağı and Çalören Districts on the eastern side of the lake, the studies were conducted in an isolated area for this lake. However, the situation is completely different for Tersakan, Bolluk, and Acıgöl Lakes. The salt production is managed in the same area of the *Artemia* population. During the studies, it was observed that the main body of the lakes remains dry or very shallow (<20 cm) because the water is pumped into the salt production ponds. Therefore, the natural habitat for *Artemia* populations is usually limited to these ponds. Considering the heterogeneous distribution of *Artemia* and topographical conditions, two sampling stations were defined in each lake and samples were taken along three different transects at each sampling station. A list of sampling sites and their geographical characteristics is given in Table 1.

Artemia sampling was performed using with a Apstein plankton net (opening diameter: 25 cm, mesh size: 55 μm). A plankton net was hauled 10 m horizontally along the bottom at each transect. The samples were preserved in 4% formalin. The *Artemia* samples collected for population composition analyses were subdivided into nauplii, metanauplii, juveniles, and adults. Nauplii and metanauplii counts were performed in 3 replicates by using Bogorow's chamber. In addition, adults and juveniles were counted under a binocular microscope in petri containers. Brood size was examined on a monthly basis with at least 30 female individuals (or in all samples if there were fewer individuals than 30) for each population. The cyst diameter (non-decapsulated and decapsulated), chorion thickness, and first instar nauplius length were determined using the method given by Lavens and Sorgeloos (1996).

During the field studies, the depth was recorded at each sampling station. The temperature, salinity, dissolved oxygen, and pH were measured in situ at the surface and at the bottom by using a YSI 556 MPS (measurement range for salinity: 0–70 ppt, with ±0.1 ppt accuracy) and an Atago PAL-ES3 refractometer (measurement range for salinity: 0–33 g/100 mL, with ±0.6 g accuracy). Conductivity, dissolved oxygen, and pH calibration of the YSI instrument was carried out prior to each field study. Water samples for anion-cation analysis were taken monthly and concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, Li^+, SO_4^{2-}, HCO_3^-, and CO_3^{2-} were measured by using BIONEX high performance ion chromatography.

3. Results

3.1. Ion composition, salinity, pH, oxygen, and temperature

The minimum, maximum, and average values of anions and cations analyzed monthly in the study regions are summarized in Table 2. In all studied areas, the most dominant anions and cations were chlorine, sodium, sulfate, and magnesium. Fluorine, lithium, bicarbonate, and carbonate were generally detected in small amounts. The predominant anion-cation concentration distributions were found as Cl > Na > SO_4 > Mg in Tuz Lake, SO_4 > Cl > Na > Mg in Tersakan and Acıgöl Lakes, and Cl > SO_4 > Na > Mg in Bolluk Lake. The highest concentrations of chlorine and sodium were measured in Tuz Lake, the highest sulfate concentration was determined in Acıgöl Lake, and the highest magnesium concentration was found in Bolluk Lake (Table 2).

Principal component analysis (PCA) was applied to the environmental data in order to determine which of the anions and cations showed differences in the investigated lakes. In PCA, 10 variables were included in the analysis. These variables were sodium, chlorine, magnesium, potassium, lithium, fluorine, bicarbonate, carbonate, sulfate, and calcium. In this analysis, Factor 1, Factor 2, and Factor 3 explained 37.4%, 27.8%, and 14.2% of the variance, respectively. In PCA, close correlation was observed between potassium, carbonate, and magnesium and axis 1 and between sodium, chlorine, and axis 2 (Figure 2).

In this study, the lowest salinity was measured as 41 g L^{-1} in Tersakan Lake, while the highest salinity was found as 217 g L^{-1} in Tuz Lake. It was found that seasonal salinity changes were significant due to environmental factors such as evaporation or precipitation and salt production processes in the lakes (Table 3).

During the study, pH was generally close to neutral (pH 7.30–7.91), but it was slightly alkaline (pH 8.00–8.77) in some months. Slightly alkaline values are generally

Table 1. List of sampling sites with their geographic characteristics.

Station	Site coordinates	Depth (cm)	Total lake area (ha)
Tuz Lake S1	38°48′264″N, 33°34′419″E	25–70	160,000
Tuz Lake S2	38°49′490″N, 33°36′450″E	<10–70	
Tersakan Lake S1	38°38′270″N, 33°02′070″E	25–100	6400
Tersakan Lake S2	38°37′340″N, 33°02′400″E	50–60	
Bolluk Lake S1	38°33′070″N, 32°56′040″E	80–100	1150
Bolluk Lake S2	38°32′270″N ,32°56′370″E	40–60	
Acıgöl Lake S1	37°50′210″N, 29°47′060″E	40–120	16,500
Acıgöl Lake S2	37°51′170″N ,29°50′010″E	60–200	

Table 2. Ion concentrations (g L^{-1}) of *Artemia* sites. Chemical analyses were performed monthly on a single sample for each lake (n = number of samples analyzed).

	n	Na	Cl	SO_4	CO_3	HCO_3	K	Ca	Mg	F	Li
Tuz Lake	7	93.8	150.5	8.88	0.027	0.131	2.13	1.57	3.46	0.121	0.017
		(70.2–110.2)	(113.9–184.9)	(3.2–5.25)	(0–0.147)	(0–0.226)	(0.95–3.7)	(0.99–3.25)	(2.20–6.14)	(0–0.426)	(0–0.036)
Tersakan Lake	7	29.5	32.35	37.53	0.242	0.147	3.71	0.83	6.35	0.166	0.026
		(13–35.7)	(12.20–44.40)	(22–44.3)	(0.20–0.33)	(0–0.404)	(0.92–4.5)	(0.63–1.21)	(2.71–8.20)	(0–0.606)	(0–0.041)
Bolluk Lake	7	33.5	61.94	39.9	0.553	0.103	5.52	0.77	13.64	0.09	0.028
		(10–71.2)	(19.34–152.2)	(13–80.5)	(0.28–1.59)	(0–0.261)	(1.42–15)	(0.32–1.15)	(0.84–36.73)	(0–0.266)	(0–0.047)
Acıgöl Lake	11	37.5	38.11	40.14	0.110	0.220	1.35	0.91	2.75	0.07	0.00023
		(20–56.3)	(6.41–95.6)	(12–79.3)	(0–0.33)	(0–0.405)	(0.48–3.1)	(0.64–1.30)	(0.74–7.47)	(0–0.284)	(0–0.001)

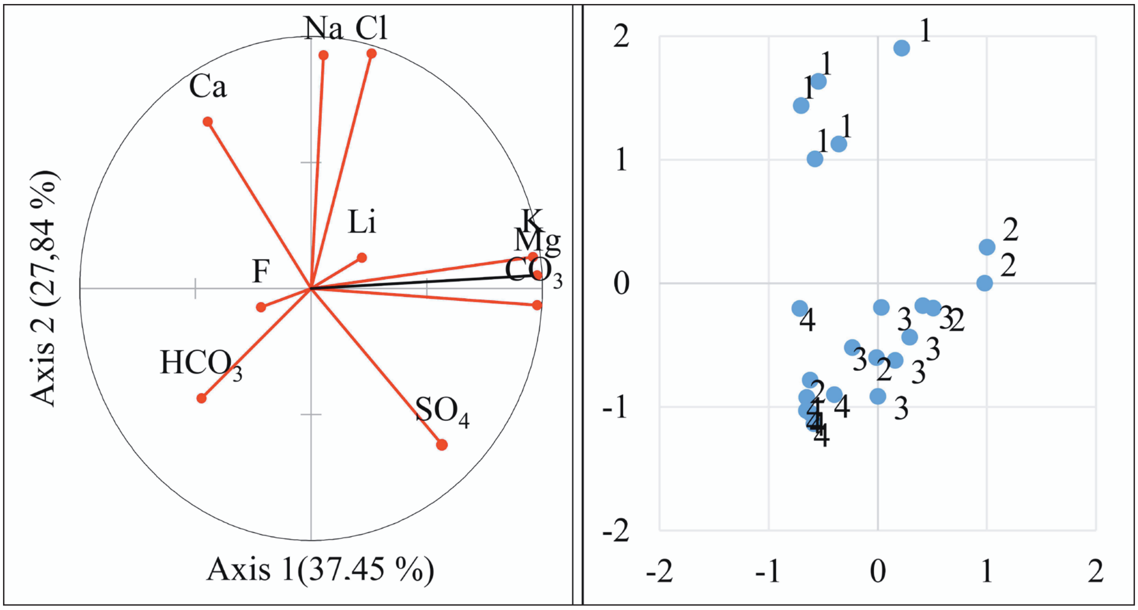

Figure 2. Left: PCA components projection on Axis 1 and Axis 2. Right: PCA stations projection on Axis 1 and Axis 2 (1- Tuz Lake, 2- Bolluk Lake, 3- Tersakan Lake, 4- Acıgöl Lake).

Table 3. Ratios of main ions, salinity, pH, water temperature, and dissolved oxygen ranges of *Artemia* sites (n = number of measurements in situ at each sampled lake).

	n	Cl/SO_4	Cl/Na+K	Mg/Ca	Na+K/ Mg+Ca	Salinity range (g L^{-1})	pH range	Temperature range (°C)	Oxygen range (mg L^{-1})
Tuz Lake	32	10.56	1.56	2.20	19.07	173–217	7.30–7.91	2.5–32	0.98–5.75
Tersakan Lake	32	0.86	0.97	7.65	4.62	41–103	8.03–8.74	4.0–30	3.55–8.89
Bolluk Lake	32	1.55	1.58	17.71	2.71	78–130	7.27–8.47	3.5–32	0.71–8.10
Acıgöl Lake	44	0.94	0.98	3.02	10.61	58–131	7.81–8.77	8.0–29	1.58–10.37

recorded in Acıgöl Lake. The lowest pH value was determined as 7.30 in Tuz Lake and the highest pH value was recorded as 8.77 in Acıgöl Lake (Table 3).

Being located in an explicit continental climate zone, considerable seasonal temperature fluctuations have been recorded for the lakes. In all the lakes water temperature values optimal for the reproduction and growth of *Artemia* were generally recorded between April and August. These months were the evident periods in which *Artemia* showed optimum development and the average monthly temperature was recorded between 14 and 32 °C. The lowest winter temperatures were measured between 2.5 and 4 °C in the lakes of the Konya Closed Basin. In Acıgöl Lake where *Artemia* even develops during winter months, water temperature was determined between 7 and 12 °C in winter (Table 3). The lowest water temperature was measured as 2.5 °C in Tuz Lake, and the highest water temperatures were 32 °C in Tuz and Bolluk Lakes (Table 3).

During the study, the lowest and highest dissolved oxygen was measured in Tuz Lake (0.98 mg L^{-1}) and in Acıgöl Lake (10.37 mg L^{-1}), respectively. The dissolved oxygen concentration showed significant changes during the year; the lowest values were recorded in July and August when the water temperature was maximum, and the highest values were recorded in autumn and winter months (Table 3).

3.2. *Artemia* population dynamics

In Tuz Lake *Artemia* cyst hatching was observed in the period beginning in the second half of March when the temperature reached 19 °C and salinity was 172 g L^{-1}. The growth and reproduction period for Tuz Lake's *Artemia* population was found to be between March and July. The largest peak in the population occurred in June. The population consisted only of metanauplius-nauplius larvae and the mean density reached 90 ind. m^{-3} in that period (Figure 3). Adult individuals in Tuz Lake were found in

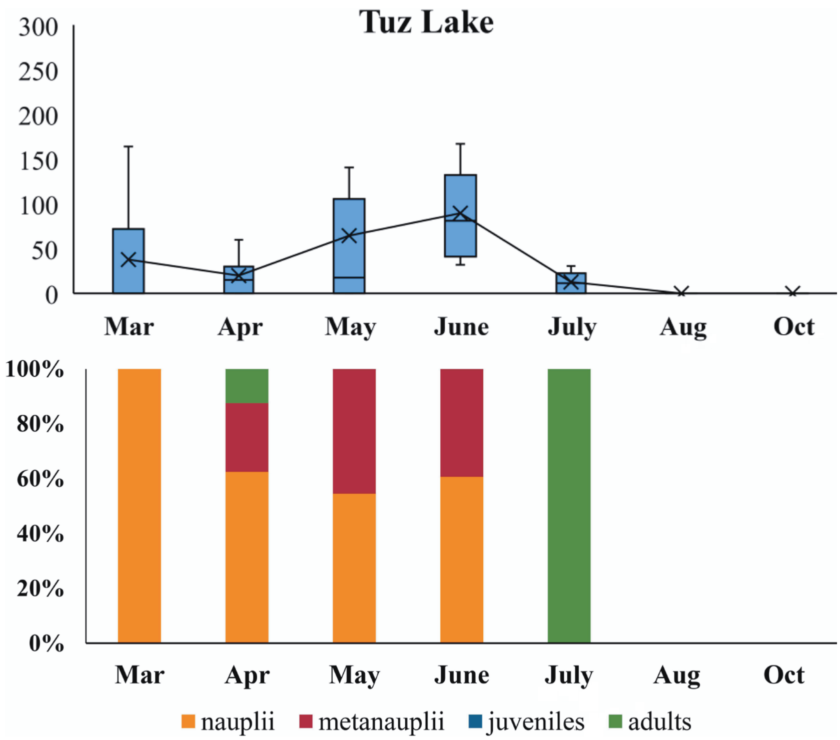

Figure 3. Seasonal fluctuations in densities (ind. m^{-3}) of *Artemia* and percentage of individuals subdivided in different age classes from Tuz Lake.

April and July and the mean density was recorded as 2 ind. m^{-3} and 13 ind. m^{-3}, respectively. In Tuz Lake, only cysts were detected after July. The salinity reached 212 g L^{-1} in July when the living individuals were recorded lastly in the active period.

The growth and reproduction period of the *Artemia* population in Bolluk Lake was determined between March and October and cysts started hatching in March, when salinity was 78 g L^{-1} and temperature was 16 °C. The maximum mean density in Bolluk Lake was determined as 14,701 ind. m^{-3} in June and it was observed that the population consisted mostly of metanauplius individuals (12,773 ind. m^{-3}) (Figure 4). The salinity in Bolluk Lake increased to 180 g L^{-1} in July, while the number of live individuals decreased significantly and only nauplius larvae were found in the population. Except in March and July, the adult population was found in Bolluk Lake in all periods, the mean adult density being lowest in August (5 ind. m^{-3}) and highest in June (1205 ind. m^{-3}).

In Tersakan Lake, the active growth period of the *Artemia* population was found to be between March and October. The highest mean population density in this lake was found as 6579 ind. m^{-3} in March and the lowest mean density was found as 223 ind. m^{-3} in May (Figure 5). When the population density was highest in March in Tersakan Lake, the water temperature was 14 °C and salinity was 102 g L^{-1}. Throughout the whole sampling period metanauplius individuals were dominant in the population. The mean number of adults in the population was found between 94 ind. m^{-3} (October) and 570 ind. m^{-3} (June).

Despite numerical fluctuations, nauplii, metanauplii, juveniles, or adult individuals were determined in Acıgöl Lake during the year. Even in winter, when population density was minimal, adult individuals were found in the population. It were two evident peaks in the Acıgöl population, the first peak registered in April and second one in August. In addition, between April and October, the density of individuals was generally over 20,000 ind. m^{-3} (Figure 6). The minimum mean population density in Acıgöl Lake was 205 ind. m^{-3} in November and the maximum mean population density was 54,993 ind. m^{-3} in August. In Acıgöl Lake nauplius/metanauplius individuals were mostly found dominant in the population. In addition, varying proportions of adult individuals were found in all sampling months. The adults were detected at the highest in August (mean: 1831 ind. m^{-3}) and the lowest in December (mean: 86 ind. m^{-3}). When the number of alive individuals in the population was very low in winter, the temperatures were 8–9 °C and the salinities were 112–131 g L^{-1}. During the highest densities, the water temperatures were recorded as 19–29 °C and salinities were recorded as 62–102 g L^{-1}.

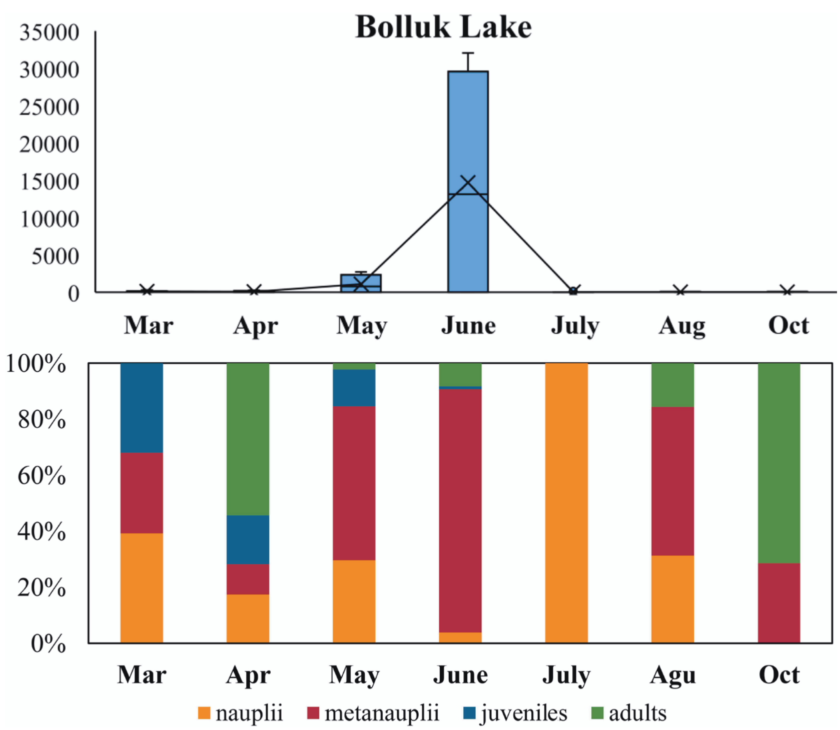

Figure 4. Seasonal fluctuations in densities (ind. m^{-3}) of *Artemia* and percentage of individuals subdivided in different age classes from Bolluk Lake.

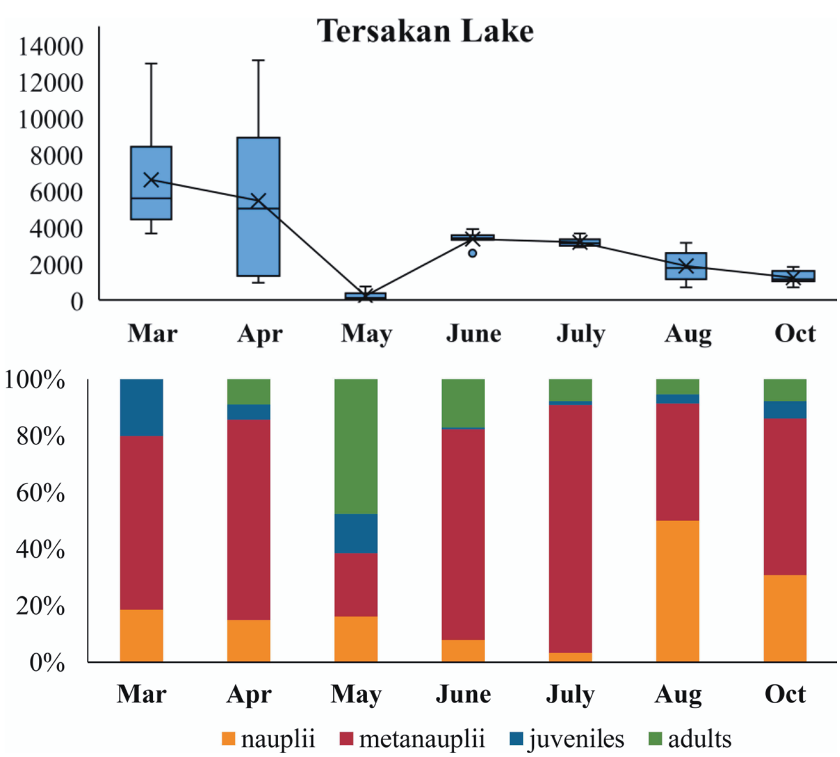

Figure 5. Seasonal fluctuations in densities (ind. m^{-3}) of *Artemia* and percentage of individuals subdivided in different age classes from Tersakan Lake.

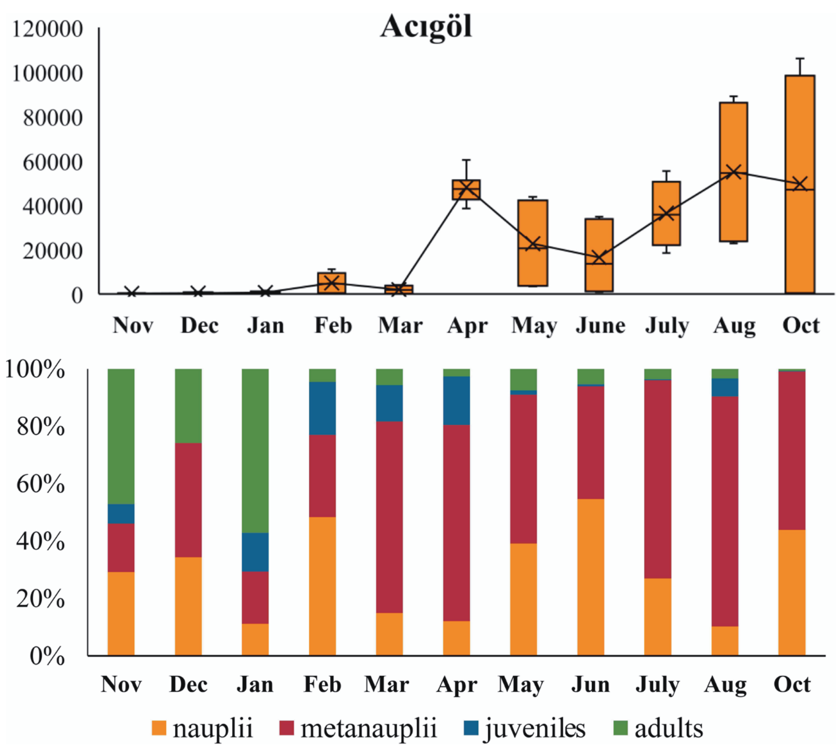

Figure 6. Seasonal fluctuations in densities (ind. m^{-3}) of *Artemia* and percentage of individuals subdivided in different age classes from Acıgöl Lake.

3.3. Reproductive characteristics and brood size

Adult individuals and female ovisacs were examined to determine the reproductive characteristics of the populations. In the analyses, no male individuals were found in any samples and it was concluded that all of the populations consisted exclusively of female individuals. The reproductive characteristics of all populations were determined as parthenogenetic via oviparous or ovoviviparous reproduction. Unfortunately, cysts or nauplius larvae were not detected in the ovisacs of the Tuz Lake population. However, it was concluded that the reproduction in Tuz Lake is also parthenogenetic because the adult individuals in this population consisted only of females.

In order to determine the proportional contribution of oviparous and ovoviviparous reproduction in the populations, cysts and nauplius larvae in the ovisac of the females were counted, and the findings are summarized in Figure 7. According to this, oviparous reproduction was dominant in the Bolluk and Acıgöl populations, while ovoviviparous reproduction was dominant in the Tersakan population. Contrary to other populations, it was observed that reproduction continued throughout the year and female ovisacs with cysts or embryos were observed in all months in the Acıgöl population. The average brood size was determined to be between 14 and 98 in the Acıgöl population. The female ovisacs were found to have cysts or embryos in April, June, and July and the average brood size was between 14 and 68 in Tersakan Lake. Ovisacs of female individuals in Bolluk Lake were observed to have cysts or embryos in May and June, and the average brood size varied between 20 and 23 (Figure 7).

3.4. Cyst and naupliar biometrics

Table 4 provides an overview of the non-decapsulated and decapsulated cyst diameters, the chorion thickness, and the naupliar size of the investigated *Artemia* populations. Cyst biometry data showed that significant differences between parthenogenetic populations occurred ($P < 0.05$). The average non-decapsulated cyst size was 266.9 µm in Tuz Lake, 250.5 µm in Tersakan Lake, 243.2 µm in Bolluk Lake, and 231.8 µm in Acıgöl Lake. Average decapsulated cyst size was found between 225 and 249.8 µm and chorion thickness was determined between 0.56 and 8.55 µm in the populations. It was found that the population with the highest chorion thickness was in Tuz Lake and the population with the lowest chorion thickness was in Bolluk Lake. In addition, the naupliar size varied from 484 (Acıgöl Lake) to 512 µm (Tersakan Lake) (Table 4).

4. Discussion

The brine shrimp *Artemia* is a cosmopolitan halophilic organism that continues its life in over 500 different

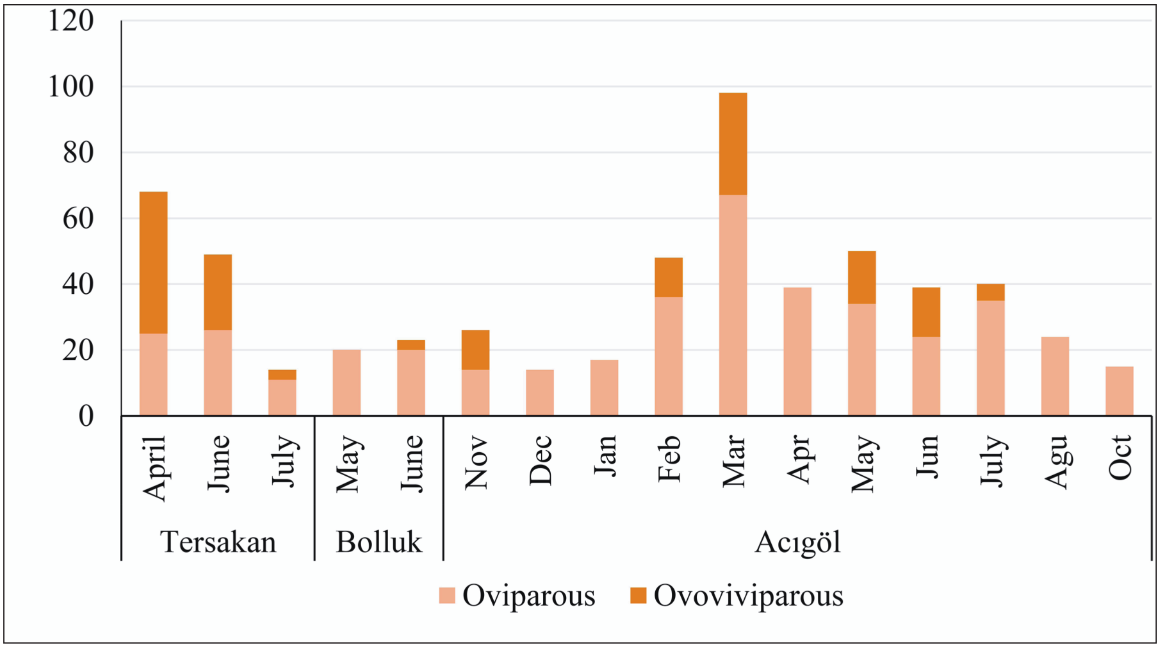

Figure 7. Average brood size fluctuations of *Artemia* populations in Tersakan, Bolluk, and Acıgöl Lakes.

Table 4. Cyst and naupliar biometrics of *Artemia* populations from salt lakes in Turkey. Populations sharing the same superscript are not significantly different (P = 0.05) (n=number of samples analyzed).

	Cyst diameter	(μm)		Diameter of decapsulated cyst (μm)			Chorion thickness	First instar nauplius length (μm)		
	Mean	Min–max	n	Mean	Min–max	n	(μm)	Mean	Min–max	n
Tuz Lake	266.9[a]	240–294	500	249.8[b]	243–295	500	8.55	486[a]	448–524	30
Tersakan	250.5[b]	231–270	500	239.2[a]	216–263	500	5.65	512[c]	482–542	50
Bolluk Lake	243.2[b]	227–260	500	242.2[a]	218–264	500	0.56	495[b]	447–522	50
Acıgöl Lake	231.8[c]	210–252	500	225.4[c]	215–246	500	2.80	484[ab]	463–505	50

hypersaline lakes, ponds, lagoons, and man-made salterns in the world (Triantaphyllidis et al., 1998; Van Stappen, 2002). There are seven bisexual species and a parthenogenetic strain with varying ploidy levels in the genus (Gajardo et al., 2002; Baxevanis et al., 2006). Asexual parthenogenetic populations have been classified in *Artemia parthenogenetica* in some studies (Browne and Bowen, 1991); however, this binomen is generally no longer accepted. Abatzopoulos et al. (2002) suggested that parthenogenetic populations at different levels of ploidy could not be included in a single species; rather, they should be named as parthenogenetic populations or parthenogenetic strains. During this study only parthenogenetic populations were identified in all studied areas and thus the populations in Anatolia have been considered as parthenogenetic *Artemia* populations.

In PCA, the basic anion-cations that affected the water quality of the lakes were determined as potassium, carbonate, magnesium, sodium, and chlorine (Figure 2, left). The PCA distinguished the sampling stations in the four different lakes very well; for example, Tuz Lake was clearly different in terms of sodium-chlorine (Figure 2, right). Cole and Brown (1967) studied the ions in lakes inhabited by *Artemia* and classified them as chloride, sulfate, or carbonate lakes. In our study, the proportional values of the main ions in the lakes are given in Table 3. According to the results of this table, Tuz Lake and Bolluk Lake have been classified as chlorine-dominant lakes, while Tersakan and Acıgöl Lakes have been classified as sulfate-dominant lakes.

Some notable differences and similarities in terms of life cycle have been found among the parthenogenetic *Artemia* populations in the sampled lakes of Turkey. The minimum threshold temperature at which cysts hatch and development begins in *Artemia* is in the range of 4–5 °C and the optimum growth/reproduction temperature varies between 20 and 30 °C (Lavens and Sorgeloos, 1996; Van Stappen, 2002). In our study, during winter no active life stages of *Artemia* were observed in the lakes of the Konya Closed Basin, while encysted embryos were found in the water in Tuz, Tersakan, and Bolluk Lakes. In March, when the water temperature increased above 5 °C (threshold temperature for cysts hatching), the first free-swimming larvae were detected in the water column. However, since water temperature is above those mentioned threshold values throughout the year in Acıgöl Lake, larvae, preadults (juveniles), or adult individuals are detected during the whole year. The Acıgöl population was consistently more productive per unit volume than the other lakes.

In this study, the *Artemia* population size and ontogenetic structure in all lakes showed monthly variations; this is quite typical for *Artemia* populations in the temperate zone, such as the Great Salt Lake (Wurtsbaugh and Gliwicz, 2001), Urmiah Lake (Van Stappen et al., 2001), and the Aral Sea (Marden et al., 2012). Survival and reproductive success of *Artemia* are influenced by multiple biological, physiological, chemical, and physical factors but the most important variables that control the life cycle of populations and affect the density are temperature and salinity (Vanhaecke et al., 1984; Lenz and Browne, 1991; Browne and Wanigasekara, 2000). Populations in Tuz, Bolluk, and Tersakan Lakes displayed very similar life cycles. However, larval or adult abundance in Tuz Lake is quite below the values recorded in Bolluk and Tersakan Lakes, which are located in the same basin. This may be related to salinity rather than temperature. While there were no significant differences in the water temperature of the lakes during the active population period ($P > 0.05$), the salinity fluctuations were quite characteristic ($P < 0.05$). Due to the extreme salinity of Tuz Lake, the population density is considered to be very limited. With contrast to other populations, larvae or adult individuals have been detected throughout the year in Acıgöl Lake. This situation is thought to be related to temperature. In Acıgöl Lake, the water temperature is always above the threshold value of 5 °C for the development of cysts in *Artemia* (Lavens and Sorgeloos, 1996; Van Stappen, 2002).

Mean adult densities were calculated as 8 ind. m^{-3} in Tuz Lake, 265 ind. m^{-3} in Bolluk Lake, 316 ind. m^{-3} in Tersakan Lake, and 715 ind. m^{-3} in Acıgöl Lake. These values are higher than the values recorded in the parthenogenetic population of Aral Lake (1–190 ind. m^{-3}) (Arashkevich et al., 2009; Marden et al., 2012) and quite lower than the values recorded in southwestern Siberia (100–10,000 ind. m^{-3}), Urmia (3000 ind. m^{-3}), and the Great Salt Lake (10,000–20,000 ind. m^{-3}) (Wurstbaugh and Smith Berry, 1990; Van Stappen et al., 2001).

Artemia population dynamics were not been investigated in Tersakan and Bolluk Lakes before this study; thus, the time-dependent changes of populations could not be evaluated. However, changes in the population characteristics and fluctuations of Tuz and Acıgöl Lakes have been monitored in detail and have been extensively documented in the academic literature (Başbuğ and Demirkalp, 1997; Başbuğ, 1999a, 1999b; Koru, 2002; Saygı and Demirkalp, 2002). The average highest abundance in Tuz Lake over the period of 1994–1995 was determined as 468 ind. m^{-3} and the adult density was 187 ind. m^{-3}. Our data indicate that the number of individuals significantly decreased in the lake. Besides, the ratio of the adult individuals remained very low, and adults in the reproductive stage could not be caught. Thus, the population is thought to be under the risk of extinction due to the fact that there is no reproduction detected in adult individuals. In an annual survey conducted by Koru (2002) in Acıgöl Lake in 2001, larval density of the *Artemia* population was determined in the range of 42,000-387,000 ind. m^{-3}. It was also stated that there were living individuals in all months of the year. Based on this comparison, it is evident that there was a dramatic decline of abundance in the Acıgöl population .

Within the scope of this study, male individuals could not be detected in any studied lakes; thus, the reproductive characteristics of all the populations were found to be parthenogenetic. Başbuğ (1999) reported ovoviviparous/oviparous parthenogenetic reproduction and mean brood size between 3 and 69 for the Tuz Lake population. In contrast to previous periods, eggs or larvae were not found in ovisacs of adult females caught in Tuz Lake. In our study, both ovoviviparous and oviparous breeding was determined in Tersakan, Bolluk, and Acıgöl Lakes. Oviparous breeding was clearly observed to be dominant in the Bolluk and Acıgöl populations. In Acıgöl Lake reproduction activity in adult females was determined to be continuous the whole year, while this activity took place in spring and summer in the Bolluk and Tersakan populations. Our brood size data for these three lakes in the range of 14–98 are not extremely low or high when compared to the field values of other populations. For example, in the *Artemia* populations from southwestern Siberia, brood size values fluctuated in the range of 10–35 (Van Stappen et al., 2009), while Marden et al. (2012) reported field values in the range of 20–45 for the Aral Sea. In other research on *A. franciscana* from the Great Salt Lake average brood sizes were recorded as 64–81, whereas Wurtsbaugh and Gliwicz (2001) reported a lower brood size of 15–30 for the Great Salt Lake population. Among the parthenogenetic populations, for a population in southern France, brood size was observed in the range of 12–100 (MacDonald and Browne, 1990). Brood size of *Artemia* females is influenced by genetic predisposition, food availability, and abiotic factors (temperature, salinity)

(Browne et al., 1984). In this study, the brood size of females showed significant differences among the populations ($P < 0.05$), and this situation could be related to those biotic and abiotic factors. The largest brood size is observed in the Acıgöl population and it may be concluded that local conditions for reproductive success were more adequate in this population.

In this study *Artemia* populations showed high variability in their cyst and naupliar biometrics ($P < 0.05$). Our cyst size values are generally larger than the values reported for other bisexual species (Vanhaecke and Sorgeloos, 1980; Van Ballaer et al., 1987). Compared to other parthenogenetic populations, such as Tuticorin in India (283.8 µm; Vanhaecke and Sorgeloos, 1980), various Chinese strains (282 µm; Pan et al., 1991), and Citros and Megalon Embolon in Greece (260.2–264.7 µm; Abatzopoulos et al., 1989), the diameters of the Turkish parthenogenetic cysts were found to be smaller. The cyst diameter of the Tersakan and Bolluk populations is very close to the parthenogenetic populations of Iran, such as Qom Salt Lake (243.7 µm), Houze Sultan (245.9 µm), and peripheral lagoons of Lake Urmia (243.1 µm) (Abatzapoulos et al., 2006).

In conclusion, in this study, some ecological characteristics of parthenogenetic *Artemia* populations were explored in four Anatolian Lakes, namely Tuz, Tersakan, Bolluk, Acıgöl Lakes. The Tuz Lake population is concluded to be under the risk of extinction although the natural life habitat of the population is located far away from the salt production area. Considering the other three lakes, Tersakan, Bolluk, and Acıgöl, the natural life habitats of the populations are limited to the pools of salt production. As sudden salinity changes may occur in their environmental conditions, populations are concluded to be negatively affected by salt production process in those lakes. That reproduction activities of the Acıgöl population continue throughout the year can be evaluated as an economic aspect. One of the important results of this study is that the chorion thickness is less than 1 µm in Bolluk population. This situation should be investigated in more detail. It is necessary to conduct further laboratory studies to determine the life span and reproductive characteristics for the Acıgöl, Bolluk, and Tersakan populations. A long-term sustainable management plan should be organized for these four populations.

Acknowledgments

This study was carried out with the financial support of the Hacettepe University Scientific Research and Development Office under Project BAP 0901601003. This research was a part of the PhD thesis "Hydrobiology of biotopes and ecological, cytogenetical, molecular and morphometrical analyses of *Artemia* populations in coastal and inland saline ecosystem in Turkey". The authors thank the reviewers for their valuable contributions.

References

Abatzopoulos TJ, Agh N, Van Stappen G, Razavi Rouhani SV, Sorgeloos P (2006). *Artemia* sites in Iran. Journal of Marine Biological Association of the UK 86: 299-307.

Abatzopoulos TJ, Karamanlidis G, Leger P, Sorgeloos P (1989). Further characterization of two *Artemia* populations from Northern Greece: biometry, hatching characteristics, caloric content and fatty acid profiles. Hydrobiologia 179: 211-222.

Arashkevich EG, Sapozhnikov PV, Soloviov KA, Kudyshkin TV, Zavialov PO (2009). *Artemia parthenogenetica* (Branchiopoda: Anostraca) from the Large Aral Sea: abundance, distribution, population structure and cyst production. Journal of Marine System 76: 359-366.

Başbuğ Y, Demirkalp FY (1997). A note on the brine shrimp *Artemia* in Tuz Lake (Turkey). Hydrobiologia 353: 45-51.

Başbuğ Y (1999a). Tuz Gölü'nde yaşayan *Artemia salina* (L., 1758)'nın bazı biyolojik özellikleri. Turkish Journal of Zoology 23 (2): 617-624 (in Turkish with an abstract in English).

Başbuğ Y (1999b). Tuz Gölü'nde yaşayan *Artemia salina* (L., 1758)'nın üreme özellikleri. Turkish Journal of Zoology 23 (2): 635-640 (in Turkish with an abstract in English).

Baxevanis AD, Kappas I, Abatzopoulos TJ (2006). Molecular phylogenetic and asexuality in the brine shrimp *Artemia*. Molecular Phylogenetics and Evolution 40: 724-738.

Browne RA, Sallee SE, Grosch DS, Segreti WO, Purser SM (1984). Partitioning genetic and environmental components of reproduction and life-span in *Artemia*. Ecology 65: 949-960.

Browne R, Wanigasekera G (2000). Combined effects of salinity and temperature on survival and reproduction of five species of *Artemia*. Journal of Experimental Marine Biology and Ecology 244: 29-44.

Clegg JS, Trotman C (2002). Physiological and biochemical aspects of *Artemia* ecology. In: Abatzopoulos TJ, Beardmore JA, Clegg JS, Sorgeloos P (editors). *Artemia* Basic and Applied Biology. Dordrecht, the Netherlands: Kluwer Academic Publishers, pp. 129-170.

Cole GA, Brown RJ (1967). The chemistry of *Artemia* habitats. Ecology 48: 858-861.

Criel GR, Macrae TH (2002). Reproductive biology of *Artemia*. In: Abatzopoulos TJ, Beardmore JA, Clegg JS, Sorgeloos P (editors). *Artemia* Basic and Applied Biology. Dordrecht, the Netherlands: Kluwer Academic Publishers, pp. 39-128.

Gajardo G, Abatzopoulos TJ, Kappas I, Beardmore JA (2002). Evolution and speciation. In: Abatzopoulos TJ, Beardmore JA, Clegg JS, Sorgeloos P (editors). *Artemia* Basic and Applied Biology. Dordrecht, the Netherlands: Kluwer Academic Publishers, pp. 225-250.

Koru E (2002). Türkiye tuzlaları ve iç sularındaki *Artemia* popülasyonlarının biyolojik özelliklerinin saptanması ve yetiştiricilikte kullanımı üzerine bir araştırma. PhD, Ege University, İzmir, Turkey (in Turkish).

Lavens P, Sorgeloos P (editors) (1996). Manual on the Production Use of Live Food for Aquaculture. Technical Paper. Rome, Italy: FAO.

Lenz P, Browne R (1991). *Artemia* ecology. In: Browne RA, Sorgeloos, P, Trotman CNT (editors). *Artemia* Biology. Boca Raton, FL, USA: CRC Press, pp. 237-254.

MacDonald GH, Browne RA (1990). Population dynamics of an asexual brine shrimp *Artemia* population. Journal of Experimental Marine Biology and Ecology 133 (3): 169-188.

Magnin G, Yarar M (1997). Turkiye'nin Önemli Kuş Alanları. İstanbul, Turkey: Türkiye Doğal Hayatı Koruma Derneği Yayınları (in Turkish).

Marden B, Van Stappen G, Musaev A, Mirabdullayev I, Joldasova I et al. (2012). Assessment of the production potential of an emerging *Artemia* population in the Aral Sea, Uzbekistan. Journal of Marine Systems 92: 42-52.

Nambu Z, Tanaka S, Nambu F (2004). Influence of photoperiod and temperature on reproductive mode in the brine shrimp, *Artemia franciscana*. Journal of Experimental Zoology Part A 301: 542-546.

Pan Z, Sun J, Bian B, Li M (1991). The biometrics of *Artemia parthenogenetica* from different localities in Shandong and Xinjiang. Transactions of Oceanology and Limnology 2: 62-69 (in Chinese).

Saygı YB, Demirkalp FY (2002). Effects of temperature on survival and growth of *Artemia* from Tuz Lake, Turkey. The Israeli Journal of Aquaculture-Bamidgeh 54 (3): 125-133.

Torrentera L, Dodson, SI (2004). Ecology of the brine shrimp *Artemia* in the Yucatan, Mexico, Salterns. Journal of Plankton Research 26 (6): 617-624.

Triantaphyllidis GV, Abatzopoulos TJ, Sorgeloos P (1998). Review of the biogeography of the genus *Artemia* (Crustacea: Anostraca). Journal of Biogeography 25: 213-226.

Van Ballaer E, Versichele D, Vanhaecke P, Leger P, Abdelkader NB et al. (1987). Characterization of *Artemia* from different localities in Tunisia with regards to their use in local aquaculture. In: Sorgeloos P, Bentson DA, Decleir W, Jaspers E (editors). *Artemia* Research and Its Applications. Vol. 1. Morphology, Genetics, Strain Characterization, Toxicology. Wetteren, Belgium: Universa Press, pp. 199-209.

Vanhaecke P, Siddal SE, Sorgeloos P (1984). International study on *Artemia* XXXII. Combined effects of temperature and salinity on the survival of *Artemia* of various geographical origin. Journal of Experimental Marine Biology and Ecology 80: 259-275.

Vanhaecke P, Sorgeloos P (1980). International study on *Artemia* IV. The biometrics of *Artemia* strains from different geographical origin. In: Persoone G, Sorgeloss P, Roels O, Jaspers E (editors). The Brine Shrimp *Artemia*. Vol. 3. Ecology, Culturing, Use in Aquaculture, Wetteren, Belgium: Universa Press, pp. 393-405.

Van Stappen G (2002). Zoogeography. In: Abatzopoulos TJ, Beardmore JA, Clegg JS, Sorgeloos P (editors). *Artemia* Basic and Applied Biology. Dordrecht, the Netherlands: Kluwer Academic Publishers, pp. 171-215.

Van Stappen G, Fayazi G, Sorgeloos P (2001). International study on *Artemia* LXIII. Field study of the *Artemia urmiana* (Günther, 1890) population in Lake Urmiah, Iran. Hydrobiologia 466: 133-143.

Van Stappen G, Litvinenko LI, Litvinenko AI, Boyko EG, Marden B et al. (2009). A survey of *Artemia* resources of Southwest Siberia (Russian Federation). Reviews in Fisheries Sciences 17 (1): 116-148.

Wurtsbaugh WA, Gliwicz MZ (2001). Limnological control of brine shrimp population dynamics and cyst production in the Great Salt Lake, Utah. Hydrobiologia 466: 119-132.

Wurtsbaugh WA, Smith Berry T (1990). Cascading effects of decreased salinity on the plankton, chemistry and physics of the Great Salt Lake (Utah). Canadian Journal of Fisheries and Aquatic Sciences 47: 100-109.