KSÜ Tarım ve Doğa Derg 24 (4): 824-833, 2021
KSU J. Agric Nat 24 (4): 824-833, 2021
DOI:10.18016/ksutarimdoga.vi.825506

Diversification of Sexual Size Dimorphism in *Cyclops vicinus*

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ABSTRACT
The aim of this study was to qualify the sexual size dimorphism at the both inter and intra-population levels of a copepod species, *Cyclops vicinus*, populations living in a small-scale geographical range. Sexual size dimorphism is evaluated by the ratio of female to male total length. But, to deep insight into sexual size dimorphism we assumed that the more difference between same measurements on the body from different sexes lead to more sexual dimorphism rate. The samples were taken from four water sources locating east and south-east part of Turkey. The significant inter and intra population differences were detected. The thorax width related measurements (mostly) and abdomen length had the most effective ones with changing order in the different populations on the sexual size dimorphism. Pearson correlation coefficients (r) showed that there were strong positive relationships between sexual dimorphism rate and predator presence (r = 0.88) and water volume of lake (r=0.72), while a moderate negative relationship both with water depth (r= -0.50) and with lake area (r= -0.45).

Research Article

Article History
Received : 13.11.2020
Accepted : 29.12.2020

Keywords
Dimorphism
Copepod
Cyclops vicinus

Cyclops vicinus'ta Cinsel Büyüklük Farklılaşması

ÖZET
Bu çalışmanın amacı, bir kopepod türü olan *Cyclops vicinus*'un, küçük ölçekli bir coğrafi aralıkta yaşayan popülasyonların hem popülasyon içi hem de popülasyonlar arası düzeylerinde eşeysel boyut dimorfizmini nitelendirmektir. Cinsel büyüklük dimorfizmi, dişi / erkek toplam uzunluğunun oranı ile değerlendirilir. Ancak, cinsel boyut dimorfizmi hakkında derinlemesine bir kavrayışa sahip olmak için, farklı cinsiyetlerden vücutta aynı ölçümler arasındaki daha fazla farkın daha fazla cinsel dimorfizm oranına yol açtığını varsaydık. Örnekler, Türkiye'nin doğu ve güneydoğusundaki dört su kaynağından alınmıştır. Popülasyon içi ve popülasyonlar arası önemli farklılıklar tespit edildi. Göğüs genişliği ile ilgili ölçümler (çoğunlukla) ve karın uzunluğu, cinsel boyut dimorfizminde farklı popülasyonlarda değişen sıra ile en etkili olanlara sahipti. Pearson korelasyon katsayıları (r), eşeysel dimorfizm oranı ile avcı varlığı (r = 0.88) ve gölün su hacmi (r = 0.72) arasında güçlü pozitif ilişkiler olduğunu gösterirken, hem su derinliği (r = -0.50) hem de göl alanıyla (r = -0.45) orta derecede negatif bir ilişki olduğunu göstermiştir.

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 13.11.2020
Kabul Tarihi : 2.12.2020

Anahtar Kelimeler
Dimorphism
Copepod
Cyclops vicinus

To Cite : Bozkurt A, Can MF 2021. Diversification of Sexual Size Dimorphism in *Cyclops vicinus*. KSU J. Agric Nat 24 (4): 824-833. DOI: 10.18016/ksutarimdoga.vi.825506.

INTRODUCTION

Sexual size dimorphism (SSD) is a widespread phenomenon among animal groups (Fairbairn 1997; Blanckenhorn 2005) including the Copepoda, which are the most abundant metazoans on Earth (Humes 1994), and play an important role in aquatic food webs. Planktonic copepods show sexually dimorphic traits, inthat their males are generally smaller than females (Gilbert and Williamson 1983; Ohtsuka and Huys 2001; van Someren Gréve et al. 2017).

The higher relative size of female copepods may reflect their greater role in reproduction and posterity, especially in species that carry eggs during their development (Gilbert and Williamson 1983). Large females are more fertile (Corkett and McLaren 1969; Maly 1983), but may mature more slowly than small

females or males (Gilbert and Williamson 1983; Nishikawa and Maly 1996). Some females stock most of the energy for breeding during their development, so the adult female final size represents the maximum potential resource base that can be invested in reproduction (Gilbert and Williamson 1983). Mate location and recognition are essentially asymmetrical processes in the reproductive biology of copepods. The male is the active partner during these phases and its primary role is to locate and catch alargely passive female partner. Consequently, males are adapted for its locating role and its success can be enhanced through signals provided by the female. This behavioural asymmetry may have led to the evolution of sexual dimorphism in copepods. Sexually dimorphic appendages and structures are engaged in (1) mate recognition by males; (2) capture of the female by the male; (3) transfer and attachment of a spermatophore to the female by the male; (4) removal of discharged spermatophore(s) by the female; and (5) fertilization and release of the eggs by the female (Blades 1977; Blades and Youngbluth 1979; Jacoby and Youngbluth 1983; Vaupel Klein 1998).

Some authors have found that low food availability can reduce the length of males, which may enhance food availability for females (Maly 1978; Gilbert and Williamson 1983). The strongest dimorphism is found in species that occur exclusively in temporary waters, in which harsh environmental conditions limit species richness and thus interspecific competition (Bayly 1978). In such conditions, prominent sexual dimorphism may improve resource use by allowing access to an exceptionally wide range of particle sizes (Garcia et al. 2013).

This research was mainly focused to qualify the different measurements taken from the body on the sexual size dimorphism at the both inter and intra-population levels of a copepod species, *Cyclops vicinus*, populations living in a small scale geographical range. Eventually, this approach would be highlighted the major distance/distances on the body that contribute the diversification of sexual size dimorphism of that species. Also, we wanted to evaluate the relationships of some properties of water resources and overall sexual size dimorphisms.

MATERIALS AND METHODS:

Sampling

C. vicinus specimens were sampled from four water sources located in the east and south-east part of Turkey: Keban Dam Lake (38° 49/ 44.63// N – 39° 17/ 24.22// E), Mehmetli Dam Lake (37° 30/ 28.25// N-36° 01/ 12.57// E), Tahtaköprü Dam Lake (36° 52/ 03.51// N – 36° 41/ 16.84// E), and Yalintaş Dam Lake (38° 40/ 21.83// N 34° 20/ 07.03// E) with horizontal and vertical draws by using 60 µm mesh sized plankton net, during the 12 months of 2005 and 2006.

All specimens were placed into glass jars, fixed with 4% formaldehyde, then transferred into ethanol. Sampled specimens were examined, counted and measured using an Olympus CH40 microscope and a micrometric ocular. Borutski (1963), Scourfield and Harding (1966), Dussart (1969), and Kiefer and Fryer (1978) were used to identify the zooplankton specimens. Temperature (°C) was measured in the field with a thermometer and a YSI 52 model oxygen meter. Some features of sampling locations were given in Table 1.

Table 1. Some features of studied locations
Çizelge 1. Çalışılan lokasyonların bazı özellikleri

Features	Keban Dam Lake	Tahtaköprü Dam Lake	Mehmetli Dam Lake	Yalıntaş Dam Lake
Altitude	822 m	398 m	186 m	1079 m
Water depth	160 m	35 m	40 m	13 m
Surface Area	675 km²	23.40 km²	2.75 km²	0.80 km²
Volume	31 000 hm³	200,00 hm³	53 hm3	10 hm³
Temperature (mean ± Sd, in Celsius)	15.9 ±4.77	18.08 ±4.25	18.8± 4.47	15.25 ±4.27

Assumption on sexual size dimorphism rate

Generally, level of sexual dimorphism is evaluated by the ratio of female to male length (Anufriieva and Shadrin 2014). But in this study, instead of ratio, we used difference between female and male for both each measurements and overall body size. Therefore, mathematically we can assume that the more difference between male and female measurements lead to more sexual dimorphism rate.

Morphological measurements

Fifteen measurements or distances on Copepod body were taken using a binocular microscope to the nearest 0.01 mm at a magnification of 10x and 40x according to the Böttger-Schnack (1989) (Figure 1: Table 2). For each location 20 female and 10 male specimen were considered to measure.

Data Analysis

Before starting main data analysis, every measurement was checked for outliers and missing values by simply plotting the data as xy pairs. To reduce size effects in morphological analyses, the model proposed by Elliott et al. (1995) was used to

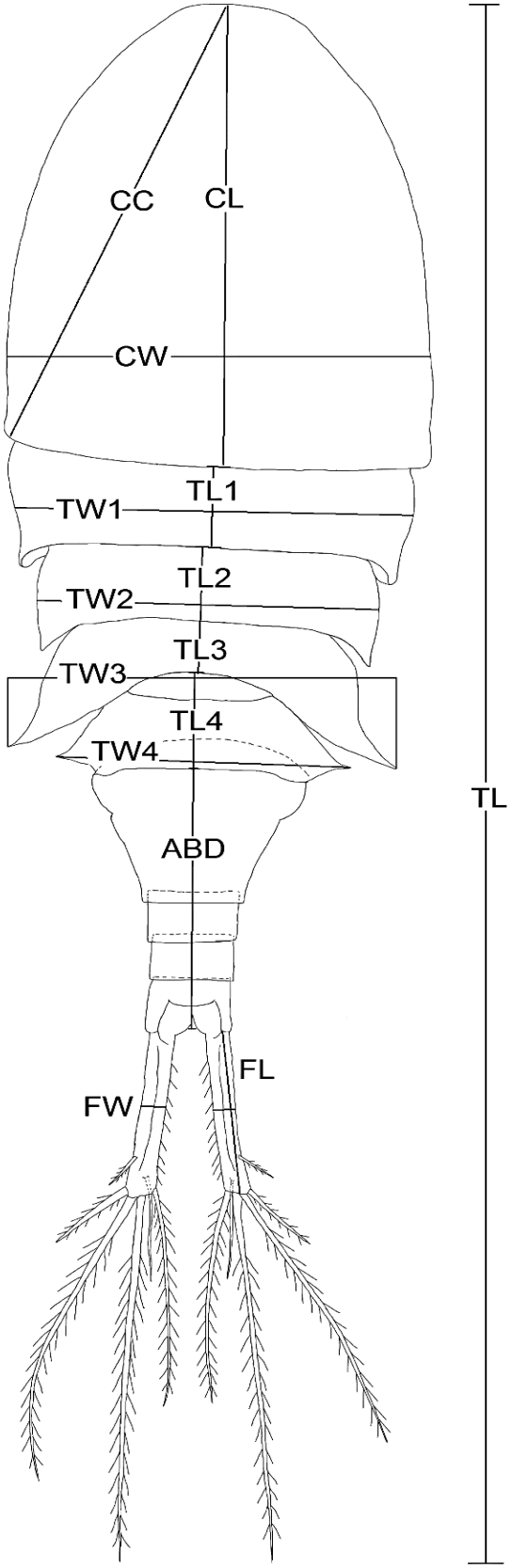

Figure 1. Measurement applications on the body of *Cyclops vicinus*

Şekil 1. Cyclops vicinus'un gövdesindeki ölçüm uygulamaları

Table 2. Measured distances (measurements) on the body with their corresponding abbreviations.

Çizelge 2. Vücut üzerinde ölçülen mesafelere (ölçümler) karşılık gelen kısaltmalarıyla birlikte.

Measured Distance (measurement)	Abbreviation
Cephalozom Length	CL
Cephalozom-Cross	CC
Cephalozom- Width	CW
Thorax-1- Width	TW1
Thorax-1- Length	TL1
Thorax-2- Width	TW2
Thorax-2- Length	TL2
Thorax-3- Width	TW3
Thorax-3- Length	TL3
Thorax-4- Width	TW4
Thorax-4- Length	TL4
Abdomen	ABD
Furca- Width	FW
Furca- Length	FL
Total Length	TL

removes the size component from the shape measurements (allometry). Due to sexual dimorphism, standardization was applied for both sexes separately. The model is defined by the following equation:

$$Ms = Mo\left[\frac{Ls}{Lo}\right]^{b}$$

Where Ms = standardized measurement, Mo = measured character length (mm), Ls = overall (arithmetic) mean standard length (mm) for all individuals from all populations of each sex, Lo = standard length (mm) of specimen, and "b" was estimated for each character from the observed data using the non-linear equation, M = a Lb.

Forest plot, t-test, hierarchical clustering routine, correlation analysis and SIMPER (Similarity Percentage) analysis were used to evaluate the inter and intra-population diversity in the sexual size dimorphisms of both each measurements and overall size. Forest plots and Student t-test were used to display and to compare the differences of each measurements and overall size of sexes in every populations, respectively.

Pearson correlation coefficient (r) was used to asses relationships between sexual dimorphism versus other factors such as altitude, depth, volume, surface area, mean temperature, and predator presence of each locations. Cosine similarity distance indices was used for assessing similarity/dissimilarity among the populations (Clarke 1993).

All calculations and statistical analysis were conducting using MS Excel and PAST software (PAleontologicalSTatistics, Version 3.20) (Hammer et al. 2001).

RESULTS

The mean (±SD) of the standardized measurements to total length of *C. vicinus* specimen by sexes from different sampling locations and the differences in mean standardized measurement between sexes (female-male) with their significance level (based on t-test for 5 % significance level) were given in Figure 2 and Table 3.

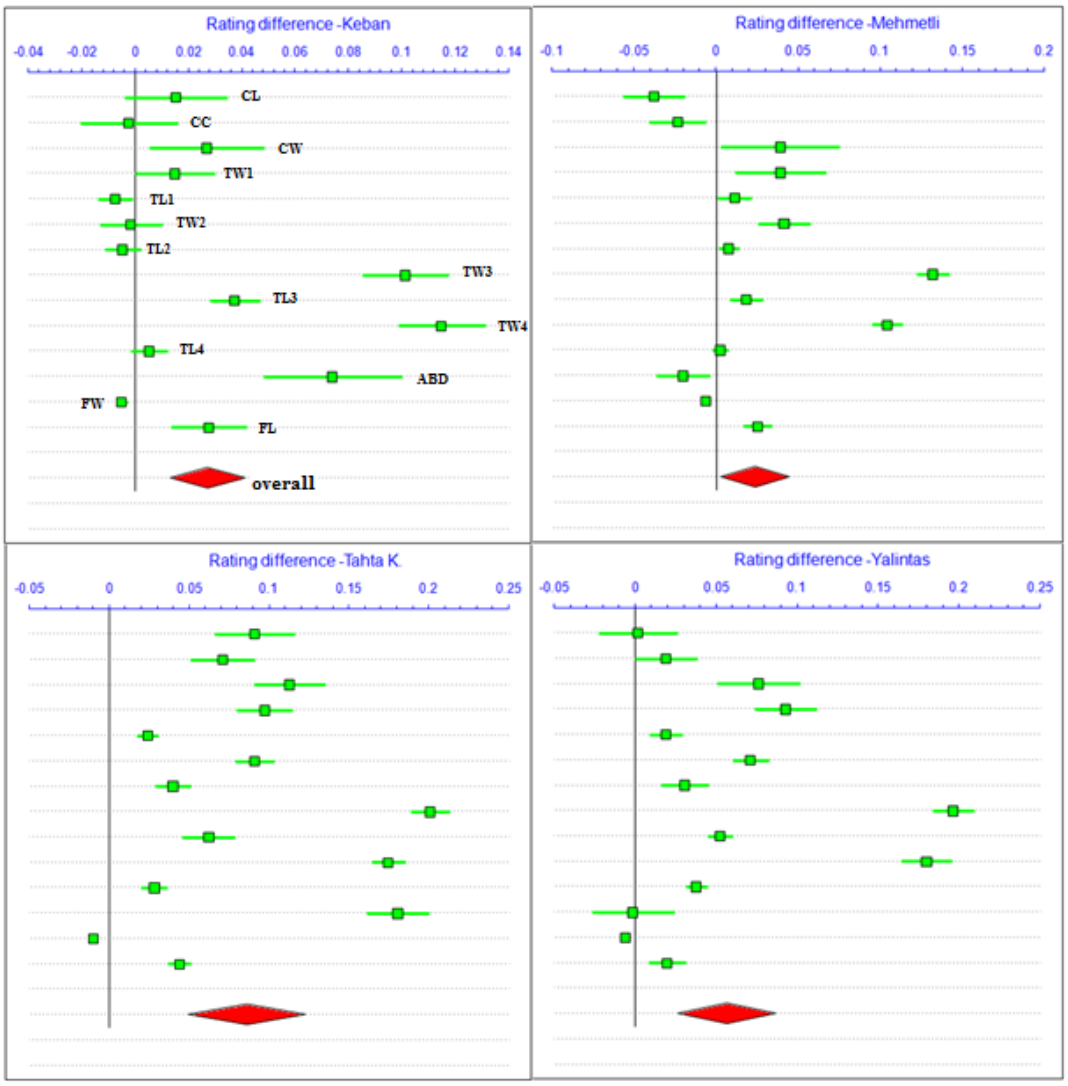

Figure 2. Difference in mean standardized measurement between sexes (female-male) for each measurements from sampling locations. Squares with horizontal bars show mean difference and their confidant limits for each measurements, respectively (Top one shows CL, and bottom one shows FL measurement in accordance with Table 2). Diamonds show overall differences with confidant limits between female and male. Zero point on the top horizontal exes shows testing of Null hypothesis against the μ = 0 at 5 % significance level.

Şekil 2. Örnekleme yerlerinden alınan her ölçüm için cinsiyetler (dişi-erkek) arasındaki ortalama standartlaştırılmış ölçümdeki fark. Yatay çubuklu kareler, sırasıyla her ölçüm için ortalama farkı ve bunların sırdaşlık limitlerini gösterir (Üstteki CL'yi ve alttaki Tablo 2'ye göre FL ölçümünü gösterir). Elmaslar, dişi ve erkek arasındaki sırdaşlık sınırlarıyla genel farklılıkları gösterir. En üst yatay ekse üzerindeki sıfır noktası, %5 anlamlılık düzeyinde μ = 0'a karşı Sıfır hipotezinin test edildiğini gösterir.

Intra-population level: In Keban Dam Lake population, 6 out of 14 measurements (in descending order: TW4>TW3>ABD> and so on) were represented very strong significant (***, $p<0.05$) sexual dimorphism on behalf of female specimen. Three (CW>TW1>TL1) were suggestive significance (*), and five (CL, CC, TW2 and so on) were non-significant ($p>0.05$). In Mehmetli Dam Lake population, 7 measurements (TW3>TW4>TW2 and so on) were very strong (***), 2 (CC>TW1) were moderate (**), 4 (CW>TL1>TL2>ABD> and so on) were suggestive (*), and one (TL4) was non-significance ($p<0.05$).

Table 3. The mean (±SD) of the standardized measurements to total length of *C. vicinus* specimen by sexes from different sampling locations and the differences in mean standardized measurement between sexes (female-male) with their significance level (based on t-test for 5 % significance level).

Çizelge 3. Farklı örnekleme yerlerinden cinsiyetlere göre C. vicinus numunesinin toplam uzunluğuna standartlaştırılmış ölçümlerin ortalaması (± SD) ve cinsiyetler (dişi-erkek) arasındaki ortalama standartlaştırılmış ölçümdeki farklılıklar (t- % 5 anlamlılık düzeyi için test).

	KEBAN DAM LAKE			MEHMETLI DAM LAKE			TAHTAKÖPRÜ DAM LAKE			YALINTAS DAM LAKE		
	Female (mean±SD)	Male (mean±SD)	Sig.	Female (mean±SD)	Male (mean±SD)	Sig.	Female (mean±SD)	Male (mean±SD)	Sig.	Female (mean±SD)	Male (mean±SD)	Sig.
CL	0.747±0.027	0.732±0.015	ns	0.718±0.027	0.756±0.011	***	0.766±0.030	0.675±0.032	***	0.739±0.027	0.737±0.036	ns
CC	0.769±0.026	0.771±0.010	ns	0.747±0.025	0.771±0.011	**	0.786±0.025	0.715±0.025	***	0.782±0.024	0.763±0.025	ns
CW	0.564±0.028	0.537±0.023	*	0.539±0.047	0.500±0.040	*	0.589±0.025	0.476±0.032	***	0.615±0.030	0.539±0.036	***
TW1	0.507±0.021	0.492±0.009	*	0.511±0.034	0.472±0.037	**	0.554±0.022	0.457±0.021	***	0.583±0.026	0.490±0.016	***
TL1	0.145±0.008	0.153±0.008	*	0.175±0.015	0.164±0.007	*	0.182±0.009	0.158±0.005	***	0.190±0.014	0.171±0.009	***
TW2	0.422±0.017	0.424±0.008	ns	0.437±0.016	0.395±0.027	***	0.465±0.014	0.374±0.015	***	0.496±0.014	0.424±0.012	***
TL2	0.151±0.008	0.156±0.006	ns	0.163±0.007	0.155±0.009	*	0.189±0.012	0.149±0.015	***	0.208±0.022	0.177±0.005	***
TW3	0.432±0.017	0.331±0.025	***	0.450±0.012	0.318±0.013	***	0.502±0.015	0.301±0.013	***	0.522±0.018	0.325±0.011	***
TL3	0.195±0.011	0.157±0.013	***	0.186±0.012	0.168±0.013	***	0.219±0.024	0.157±0.011	***	0.235±0.009	0.182±0.009	***
TW4	0.361±0.023	0.246±0.011	***	0.338±0.011	0.234±0.012	***	0.409±0.015	0.235±0.007	***	0.443±0.023	0.263±0.008	***
TL4	0.095±0.005	0.089±0.013	ns	0.090±0.006	0.087±0.006	ns	0.109±0.011	0.081±0.009	***	0.118±0.007	0.080±0.010	***
ABD	0.754±0.037	0.680±0.021	***	0.712±0.021	0.733±0.019	*	0.723±0.027	0.543±0.016	***	0.715±0.031	0.716±0.034	ns
FW	0.034±0.002	0.039±0.002	***	0.038±0.002	0.044±0.001	***	0.037±0.002	0.047±0.001	***	0.037±0.002	0.043±0.002	***
FL	0.278±0.019	0.250±0.014	***	0.280±0.012	0.255±0.007	***	0.283±0.009	0.239±0.007	***	0.285±0.012	0.265±0.018	**
Overall: 0.027 (CL: 0.013-0.041)			***	0.023 (CL: 0.003-0.045)		*	0.086 (CL: 0.049-0.122)		***	0.056 (CL: 0.026-0.086)		***

ns: non- significant, *: suggestive significant, **: moderate sig., ***: very-strong sig., CL: Confidant limits at 5 % sig. level

In Tahtaköprü Dam Lake population all measurements were very strong significance (***), but the most ones were TW3>ABD>TW4. In Yalıntas Dam Lake, 10 measurements (TW4>TW3>TW1> and so on) were very strong significance (***), one (FL) was moderate (**), and 3 were non significance (CL, CC, ABD) (Table 3). The intra-population variability on sexual size dimorphism of populations in descending order was Tahtaköprü>Yalintas>Mehmetli>Keban (Figure 3). Mostly thorax width related (TW4, TW3, TW1) measurements, and secondly Abdomen length (ABD) had the most effective measurements with changing order in the different populations on the sexual size dimorphism (Table 3).

Inter-Population Level

The mean sexual size dimorphism rate of populations in descending order was Tahtaköprü>Yalintas>>Keban> Mehmetli (Figure 3). The overall sexual dimorphism rate in Keban, Tahtaköprü and Yalıntaş were very significant (***, $p<0.05$), whereas in Mehmetli was suggestive (*, $p<0.05$). In addition, considering the overall difference between the measurements of female and male among the populations; only Tahtaköprü Dam Lake population was significantly difference ($p<0.05$) both from Keban and Mehmetli populations. Whereas, there were not significant differences among other populations ($p>0.05$) (Figure 3, Figure 4). The similarity among the populations were Keban-Mehmetli: 0.73, Keban-Tahtaköprü: 0.78, Keban-Yalıntas: 0.76, Mehmetli-Tahtaköprü: 0.89, and Mehmetli-Yalıntas: 0.88. (Table 4).

Sexual Size Dimorphism Versus Some Variables:

The relationship of sexual size dimorphism with some variables (surface area, volume, depth, altitude, predator presence of lake) were evaluated. Pearson correlation coefficient showed that there were strong positive relationships between sexual dimorphism rate and predator presence ($r = 0.88$) and water volume of lake ($r=0.72$), and moderate negative relationship with water depth ($r= -0.50$) and with lake area ($r= -0.45$) (Figure 5).

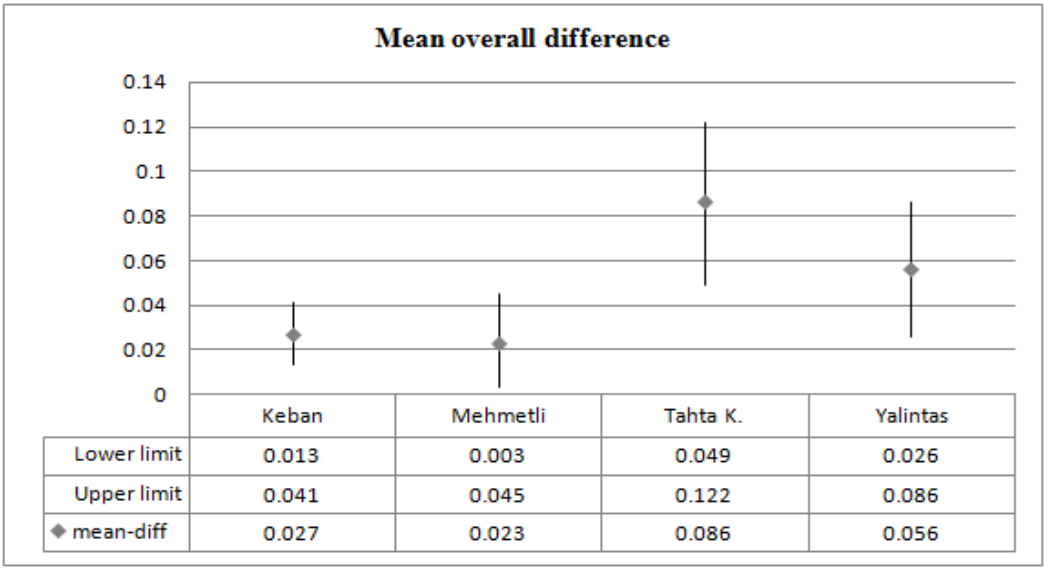

Figure 3. Mean overall difference between female and male specimen with their confidence limits by locations.
Şekil 3. Konumlara göre güven sınırları ile dişi ve erkek örnek arasındaki ortalama genel fark.

Table 4. The cosine similarity among the populations
Çizelge 4. Popülasyonlar arasındaki kosinüs benzerliği

Location	Keban Dam Lake	Mehmetli Dam Lake	Tahtaköprü Dam Lake	Yalıntas Dam Lake
Keban Dam Lake	1.00	0.74	0.79	0.76
Mehmetli Dam Lake	0.74	1.00	0.89	0.79
Tahtaköprü Dam Lake	0.79	0.89	1.00	0.88
Yalıntas Dam Lake	0.76	0.79	0.88	1.00

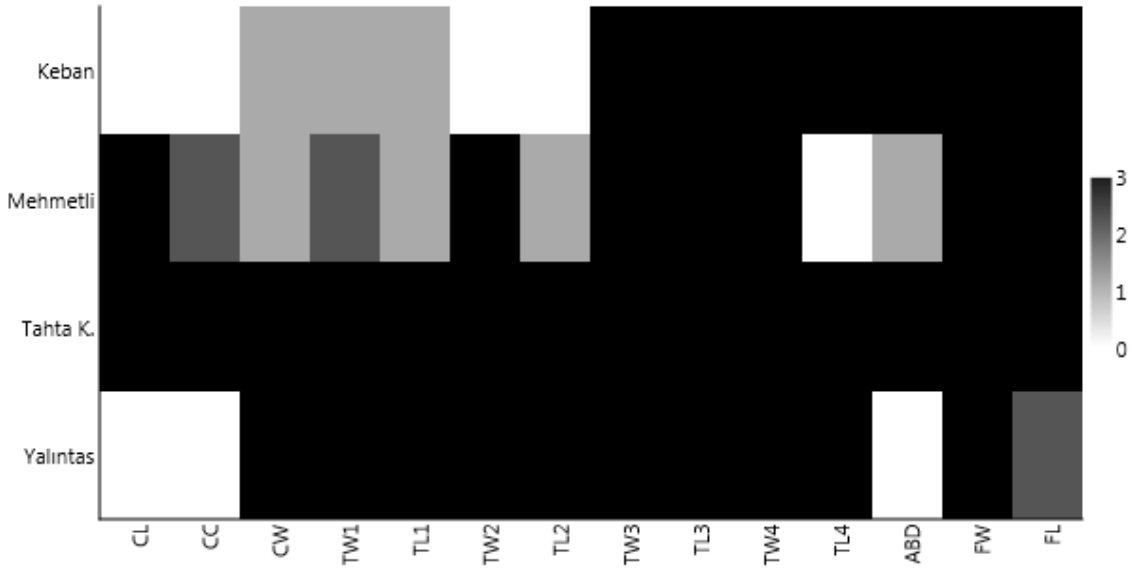

Figure 4. Significance level (3: very strong, 2: moderate, 1: suggestive, 0: non-significance, at α=0.05) for difference between each of the measurements of female and male by the populations.

Şekil 4. Popülasyonlar tarafından dişi ve erkek ölçümlerinin her biri arasındaki fark için anlamlılık seviyesi (3: çok güçlü, 2: orta, 1: anlamlı, 0: anlamlı olmayan, α = 0,05).

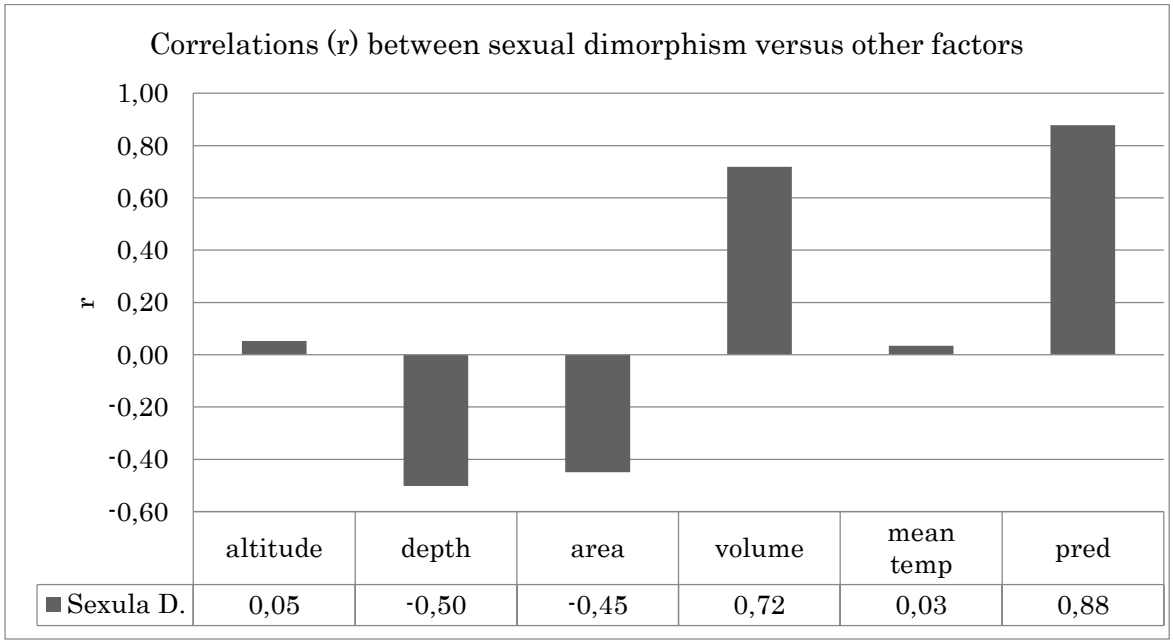

Figure 5. Correlations between sexual dimorphism versus altitude, mean water depth, surface area, volume, temperature, and presence of predator.

Şekil 5. Eşeysel dimorfizm ile yükseklik, ortalama su derinliği, yüzey alanı, hacim, sıcaklık ve yırtıcı hayvan varlığı arasındaki ilişkiler.

DISCUSSION

Cyclops vicinus is a common planktonic species in littoral regions in all kinds of water environments such as lakes, rivers, marshes, small water bodies and prefer hot water (Dussart 1969). It has huge body size (female: length 1.4-2.3 mm, male: Length 1.3-1.7 mm) (Chang 2013). Temperature and food quality seem are the primary factors influencing *C. vicinus* body lengths (Riccardi and Mariotta 2000; McLaren 1963; Miller et al. 1977; and Klein Breteler and Gonzales 1982. Planktonic copepods have sexually dimorphic properties and males and females often differ in body size and motile behavior (Gilbert and Williamson 1983; Ohtsuka and Huys 2001; van Someren Gréve et al.

2017).

It was clearly observed that the thorax width related (TW4, TW3, TW1) had the most effective measurements with changing order in the different populations on the sexual size dimorphism. There were strong positive relationships between sexual dimorphism rate and predator presence (r = 0.88) and of lake water volume (r=0.72), and moderate negative relationship with water depth (r= -0.50) and with lake area (r= -0.45).

There are different opinions about the sexual dimorphism of copepods. These; nutrition and food sources, females carry eggs, males spend more energy on mating (Gilbert and Williamson 1983). However, there are not enough studies investigating the relationship between the water surface area, water volume, water depth and altitude and sexual dimorphism in the waters where copepods live. We think that detailed studies on this subject are very important for solving some problems.

It has been reported that there are 34 fish species in Keban Dam Lake which is quite large and deep (Celayir et al. 2006; Yıldırım et al. 2015) and most of the fish that have a wide feeding network have omnivorous feeding feature, followed by herbivore and carnivore feeding feature. In this regard, we think that excessive feeding pressure is applied to all food sources, especially on zooplankton. It is possible to say that fish species are not generally very selective in nutrition, which creates a general pressure on zooplankton groups. In this case, *Cyclops vicinus* is thought to have similar predator pressure on males and females.

Six fish species were reported from Tahtaköprü Dam Lake as *Atherina boyeri* Risso 1810 (Ekmekçi et al. 2013), *Barbus luteus* (Heckel, 1843), *Squalius kottelati* Turan, Yilmaz and Kaya, 2009, *Cyprinus carpio* Linnaeus, 1758 (Sağat and Erdem, 1997), *Gambusia holbrooki* Girard, 1859 (Kurtul and Sari, 2019) and *Carassius gibelio* (Bloch, 1782). Among them, *B. luteus, Sq. kottelati, C. gibelio* and *C. carpio* are omnivorous and usually fed phytoplankton, zooplankton and benthic organisms (Maktoof 2013). But, mostly *A. boyeri* and *G. holbrooki,* secondly *C. gibelio* in general fed on zooplankton (Cladocera, Copepoda and Rotifera etc.). *G. holbrooki* mostly fed on zooplankton, snails, larval chironomids, molluscs, crusustaceans, insects, and algae, floating terrestrial insects and certain benthic insects and a variety of zoobenthos in pond ecosystems (Hurlbert et al. 1972; Hurlbert and Mulla 1981; Sokolav and Chavaliova 1936; Balık et al. 2003). *A. boyeri* is reported to be fed with large-sized zooplanktonic organisms. It was reported that there was a significant decrease in the zooplankton structure of the Eğridir lake after *A. boyeri* formed a population in the lake. Ekmekçi et al. (2013) reported that *A. boyeri* may have negative effects on biodiversity and ecosystem if it competes with predation pressure on zooplankton, endemic species living in the environment and fish species of economic importance. Therefore, it can be concluded that in Tahtaköprü Dam Lake, there was quite high predator pressure on the zooplankton. Male copepods typically exhibit mate-seeking behavior and swim more frequently and faster than females (Katona 1973; Ohtsuka and Huys 2001; Kiørboe et al. 2005; Bagøien and Kiørboe 2005). In that way, we were of the opinion that especially fish fed with zooplankton often eat moving forms more easily, thus creating greater predator pressure on mobile males.

Only the *Barbus rajanorum* (Heckel, 1843) has been reported in the Mehmetli Dam Lake, where there are a limited number of studies (Başusta and Erdem, 1994) and the feeding habit of this species is omnivorous (Erdogrul et al. 2004). It was detected that insect larvae, crustaceans, annelids, plants, molluscs, Chironomus, *Keratella* and *Polyarthra* were found from the digestive system of *B. rajanorum*.

It is thought that there is no predator pressure on the zooplankton due to the low variety of fish in the dam lake and in this case, there is a minimum size difference between the *Cyclops vicinus* males and females in the Mehmetli Dam Lake. *C. gibelio*, *Carassius auratus* (Linnaeus, 1758), *C. carpio*, *Squalius cephalus* (Linnaeus, 1758) were found in Yalıntaş Dam Lake and they were fed omnivore charecter (Yalçın Özdilek and Jones 2014; Specziáret al. 1997), Although they prefer different food groups at different stages of their lives, their food are mostly composed of algae, insects and macrophytes, mosquito larvae and chironomid larvae Gastropoda, Diptera, Cladocera, Copepoda, Ostracoda, Rotatoria, detritus, and benthic and planktonic invertebrates (Balıket al. 2003; Yalçın Özdilek and Jones 2014; Rogozin et al. 2011; Specziáret al. 1997).

CONCLUSION

The major findings for this study were given in summary as following.

The intra-population variability on sexual size dimorphism of populations in descending order was Tahta>Yalintas>Mehmetli>Keban. The overall sexual dimorphism rate in Keban, Tahta K. and Yalıntaş were very significant (***, $p<0.05$), whereas in Mehmetli was suggestive (*, $p<0.05$). Mostly thorax width related (TW4, TW3, TW1) measurements, and secondly Abdomen (ABD) length had the most effective measurements with changing order in the different populations on the sexual size dimorphism. Pearson correlation coefficient showed that there were strong positive relationships between sexual dimorphism rate and predator presence (r = 0.88) and water volume of lake (r=0.72), and moderate negative relationship with water depth (r= -0.50) and with lake area (r= -0.45)

The intra-population variability in sexual dimorphism

was occurred mostly in Tahtaköprü Dam Lake population followed by Yalintas Dam Lake>MehmetliDam Lake>Keban Dam Lake. In terms of inter-population variability, Tahtaköprü Dam Lake population was significantly difference ($p<0.05$) both from Keban and Mehmetli and populations, except from Yalintas. Whereas, there were not significant differences in overall sexual dimorphism among Keban, Mehmetli and Yalintas populations ($p>0.05$). According to the hierarchical clustering routine, a similarity pattern for the populations from the most close to the farthest was [(Yalintaş) ↔ (Keban↔Mehmetli)] ↔(TahtaKöprü). Among the considered factors that may effecting on sexual dimorphism (altitude, mean water depth, surface area, volume, temperature, and presence of predator), there was only a significantly positive relationship ($r = 0.86$) between sexual dimorphism rate and predator presence.

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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