Turkish Journal of Zoology

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

Research Article

Turk J Zool
(2014) 38: 222-228

doi:10.3906/zoo-1007-7

Seasonal variations in body length and fecundity of 2 copepod species: *Thermocyclops crassus* (Fischer, 1853) and *Eudiaptomus drieschi* (Poppe & Mrázek, 1895)

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Received: 06.07.2010 • **Accepted:** 29.11.2013 • **Published Online:** 17.01.2014 • **Printed:** 14.02.2014

Abstract: The effects of temperature, dissolved oxygen, nitrate, phosphate, and chlorophyll-*a* concentration on the body length and egg production of a cyclopoid copepod, *Thermocyclops crassus*, and a calanoid, *Eudiaptomus drieschi*, were evaluated. Sampling was conducted in Yenişehir Lake (Hatay, Turkey) on a monthly basis between May 2003 and April 2004. The results of the present study showed that, among the parameters considered, temperature and chlorophyll-*a* concentration were the main parameters influencing the body length of *T. crassus* and *E. drieschi* in Yenişehir Lake. For *E. drieschi*, egg production was also affected by chlorophyll-*a* levels.

Key words: Copepod, body length, egg production, water quality parameters, Yenişehir Lake

1. Introduction

Several studies have shown that copepods have a higher nutritional value than other live food sources for many fish larvae, because their broad size range, high digestibility, and high food value allow better growth and development than other live diets (Treece and Davis, 2000). In addition, cyclopoids and calanoids are planktonic and have a discontinuous swimming behavior, which is an important visual stimulus for fish larvae (Puello-Cruz et al., 2009).

In marine and in freshwater zooplankton ecology, one of the main issues is the determination of factors that influence copepod production. Laboratory studies have shown that food availability, temperature, and salinity are major factors controlling the growth, reproduction, and survival rates of copepods (Smith and Lane, 1985; Ban, 1994). In oceans and in fresh waters, these variables also control the growth and dynamics of copepod populations. Nevertheless, natural environments are more complex than most laboratory situations, and the relationships might not be straightforward. For instance, variables such as food availability can be difficult to quantify or even define in the field (Saiz et al., 1999).

Egg production of copepods has been shown to be correlated with phytoplankton standing stock, which is measured as chlorophyll-*a* concentration (Runge, 1985; Kiørboe and Nielsen, 1994; Uye and Murase, 1997) in situ, but not necessarily observed in other systems (Durbin et al., 1992; Kleppel, 1992).

On the other hand, laboratory studies have shown that body size and ambient temperatures affect egg production rates of some copepod species (Gislason et al., 2008). This discrepancy may suggest that chlorophyll-*a* concentration alone is not a good indicator for body length and egg production of copepods. Recently, Kleppel et al. (1991) found that microzooplankton was an important component of the copepod gut, and they found that biomass of microzooplankton was correlated with egg production of the copepods tested.

In this study, we tried to examine the monthly variations in body size and egg production of *Thermocyclops crassus* (Fischer, 1853) and *Eudiaptomus drieschi* (Poppe & Mrázek 1895) in relation to nitrate, phosphate, chlorophyll-*a*, dissolved oxygen, and temperature in the warm Yenişehir Lake, to assess the relative importance of these variables as potential determinants of body size and egg production.

2. Materials and methods

Yenişehir Lake, located in the northeastern Mediterranean region of Turkey (36°14′13″N, 36°34′07″E), is a natural lake with a surface area of 105,340 m^2 (Altunlu, 2002). The lake was shallow and its depth changed between 1 and 4 m. Two sampling stations were selected with a depth of 2 and 4 m, respectively (Figure 1). Yenişehir Lake is used for generally recreational purposes by the local residents. The first station was selected close to the source of water feeding the lake, and second station was selected close to the discharge channel.

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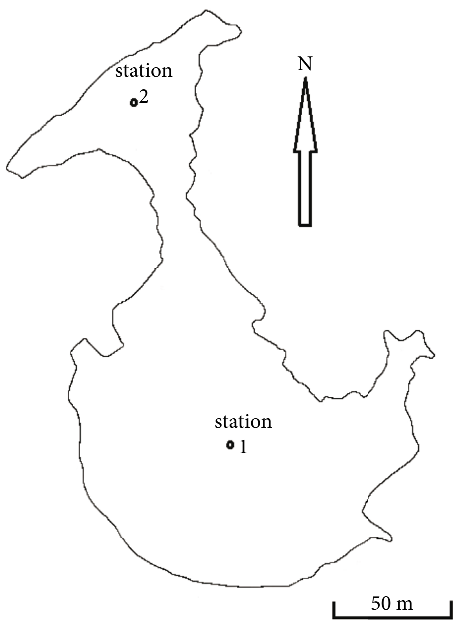

Figure 1. Study area and sampling stations.

Species used in the study were selected because of their abundance and their constant presence in the lake. Specimens were collected monthly from Yenişehir Lake between May 2003 and April 2004. Sampling was conducted with an open net with 30-cm mouth diameter and 100-µm mesh size. Three vertical tows were carried out from the bottom to the surface of both stations.

Sampling could not be done due to the shallow depth observed in August and heavy rain in January. As a result of the sampling periods, adult specimens of *T. crassus* in May and adult specimens of *E. drieschi* in September, October, and November could not be found.

Dissolved oxygen levels and temperature were measured directly on site with a digital oxygen meter (YSI-52) from the surface and different depths (2 m and 4 m).

Water samples for nitrate and phosphate measurement were collected using a Nansen bottle from the surface and from 2 m and 4 m depths. To estimate the value of chlorophyll-*a* in the lake, water samples of 1 L from the surface and from 2 m and 4 m depths were collected. The water was filtered using a filter membrane (0.45 µm), and the concentration of chlorophyll-*a* was measured using the acetone method (APHA, 1985). Zooplankton samples were fixed and preserved immediately after collection in 4% formaldehyde. Copepods were identified, counted, and measured under an inverted microscope.

Water quality parameters such as nitrate and phosphate were measured on the same day in the Mustafa Kemal University Faculty of Fisheries laboratories. Nitrate (NO_3) and phosphate (PO_4) measurements, which require photometric measurements, were performed according to standard procedures (APHA, 1985) using a Shimadzu brand UV-1601PC model spectrophotometer.

Thermocyclops crassus and *Eudiaptomus drieschi* samples were separated by sex under an inverted microscope. Males and females of both species were selected randomly each month. Total body length, between the top of the cephalosome and the end of the furca, of all copepod specimens was measured. The total body length of 70 adults (35 males + 35 females) of each species was measured monthly for each sample with an ocular micrometer (100 subdivisions) at a magnification of 10×. Taxonomic literature used to identify the zooplankton groups included the studies of Borutsky (1964), Scourfield and Harding (1966), Dussart (1969), and Kiefer and Fryer (1978).

All computations, correlation tests, and statistical analyses were performed in Microsoft Excel.

3. Results

The monthly variations in temperature, dissolved oxygen, nitrate, phosphate and chlorophyll-*a* concentration are shown in Figure 2. Annual mean values of these parameters are given, as well. Temperature varied from 15.15 °C (December) to 25.80 °C (July) with a mean value of 20.96 ± 4.05 °C. Mean chlorophyll-*a* concentration was 24.20 ± 7.09 mg m^{-3} with a range from 16.62 mg m^{-3} in December to 35.51 mg m^{-3} in June. Nitrate nitrogen (4.25 ± 3.10 mg L^{-1}) varied from 0.13 mg L^{-1} (February) to 8.46 mg L^{-1} (July), and phosphate (0.09 ± 0.07 mg L^{-1}) varied from 0.033 mg L^{-1} (September) to 0.240 mg L^{-1} (July). Dissolved oxygen varied from 4.65 mg L^{-1} in July to a peak of 10.16 mg L^{-1} in November with a mean value of 7.81 ± 1.53 mg L^{-1}.

Monthly variations in the body length of males and females of the 2 copepod species are illustrated in Figure 3. During the study, body lengths of a total of 1400 specimens belonging to *Thermocyclops crassus* (770 ind.) and *Eudiaptomus drieschi* (630 ind.) were measured.

Mean lengths for *T. crassus*, both females and males, were highest in February (1458 µm and 1163 µm, respectively) and lowest in June (1320 µm and 1039 µm, respectively). Mean length of *E. drieschi* females was greatest in December and February (2527 µm) and was smallest in April (1996 µm). Mean length of *E. drieschi* males was greatest in December (2273 µm) and was smallest in April (1911 µm).

A significant functional relationship was found between temperature and length of *T. crassus* females (R^2 = 0.67). This relationship, however, was not detected between temperature and length of *T. crassus* males (R^2 = 0.03). The lengths of *E. drieschi* females and males were correlated with temperature (R^2 = 0.58 and R^2 = 0.64, respectively).

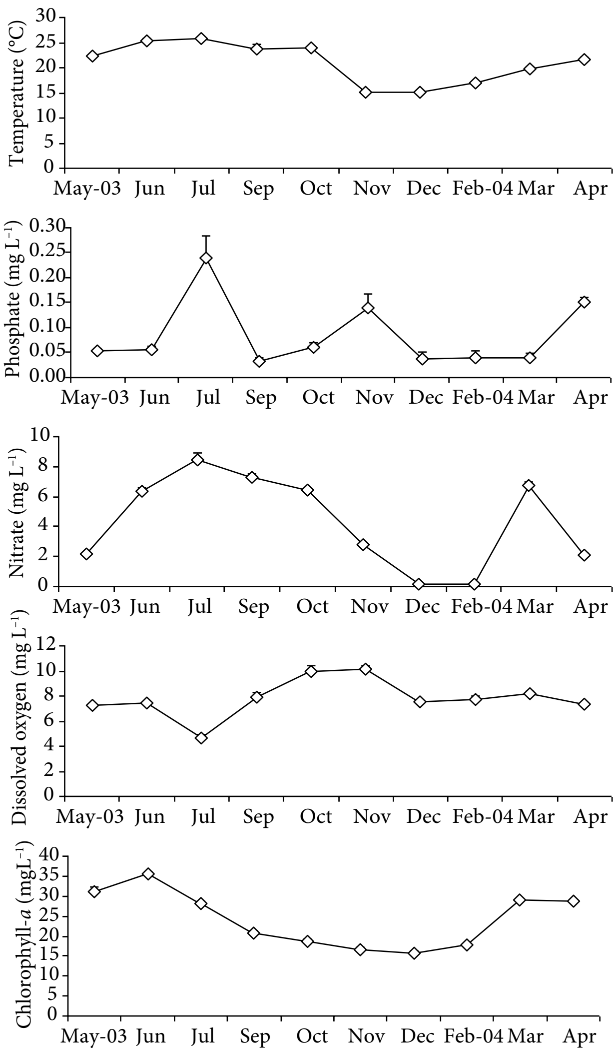

Figure 2. Monthly variations of temperature, phosphate, nitrate, dissolved oxygen, and chlorophyll-*a* during the study in Lake Yenişehir, from May 2003 to June 2004 (±SD).

Egg production was correlated with the length of *E. drieschi* females (R^2 = 0.82). However, a weak relationship was detected between length and egg production of *T. crassus* females (R^2 = 0.43). A significant relationship was found between temperature and egg production of *E. drieschi* females (R^2 = 0.71), but low correlation was found for *T. crassus* females (R^2 = 0.28).

A significant relationship was detected between egg production and chlorophyll-*a* for *T. crassus* and *E. drieschi* (R^2 = 0.61 and R^2 = 0.79, respectively). Chlorophyll-*a* level was also correlated with temperature (R^2 = 0.70).

The maximum and minimum egg production, length of the 2 copepod species, average temperature, and chlorophyll-*a* concentrations of each month are given in Table 1. For the whole data set, mean length and egg production are shown in Table 2. The greatest lengths of *T. crassus* and *E. drieschi* were observed at colder temperatures, during winter (December and February), and the lowest lengths were observed at warmer temperatures, during spring and summer (April and June). Maximum egg production of *T. crassus* was seen in summer (June) and minimum egg production was seen in winter (December and February). The maximum egg production of *E. drieschi*, however, was observed in winter (December and February), and minimum egg production was observed in spring (April).

4. Discussion

Seasonal variations in body size and fecundity are typical properties of many copepods found in temperate, subtropical, and boreal waters (Crawford and Daborn, 1986). In our study, *Thermocyclops crassus* and *Eudiaptomus drieschi* showed the same pattern in length. The greatest lengths of both copepod species were observed at colder temperatures during colder months, and the lowest lengths were observed at warmer temperatures. The same trend, with larger specimens seen in the cold season, was also observed in egg production for *E. drieschi*. The maximum egg production of *E. drieschi* was observed in winter and minimum egg production was observed in spring. In contrast to this, egg production of *T. crassus* was maximum in summer and minimum in winter. In the literature, there are different proposals on the relationship between temperature and body length or fecundity of copepods. Copepod body lengths are generally larger in winter and smaller in summer (Ara, 2002). According to Vijverberg (1989), zooplankton body length is connected with temperature. According to Gaudy and Verriopoulos (2004), copepod body length is inversely related to temperature. Some scientists suggest that temperature is the primary determinant of body size at maturity (Coker, 1933; Deevey, 1960; McLaren, 1963, 1965) and that it is a key abiotic factor regulating the growth and reproductive potential of copepods in marine and freshwater systems. Additionally, temperature is a key variable in the development of production regimes (Rhyne et al., 2009).

Our data support an inverse interaction between body length and temperature.

A significant relationship (R^2 = 0.82) was detected between body length and egg production for female adult *E. drieschi* specimens. However, a weak relationship (R^2 = 0.43) was found between the same variables for *T. crassus*. Such variations are typically attributed to temperature and varying food concentrations and food quality (Huntley and Boyd, 1984). Gaudy and Verriopoulos (2004) declared that egg production was inversely related to temperature. Female size is believed to affect egg production by influencing clutch size (Runge and Plourde, 1996), while temperature affects egg production by influencing the

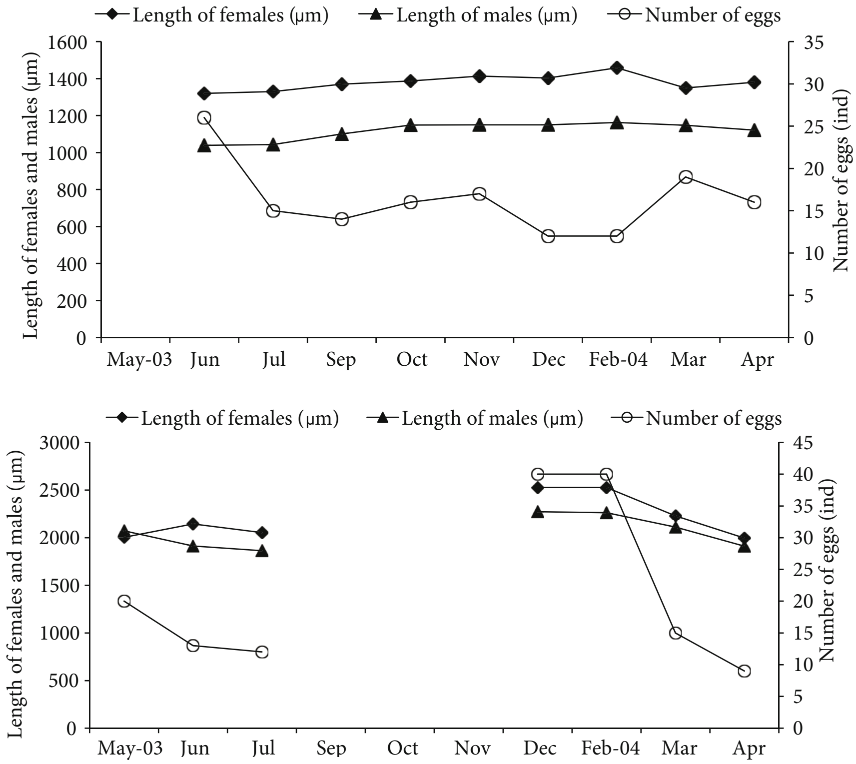

Figure 3. Monthly variations in mean egg numbers and lengths of females and males of 2 copepod species in Lake Yenişehir during the study period (broken lines show that no *E. drieschi* was found in this period).

Table 1. Mean egg numbers and lengths of *Thermocyclops crassus* and *Eudiaptomus drieschi* in Yenişehir Lake.

	Month									
	May	Jun	Jul	Sep	Oct	Nov	Dec	Feb	Mar	Apr
Mean temp (°C)	22 ± 0.22	25 ± 0.45	29 ± 0.20	24 ± 0.76	24 ± 0.27	15 ± 0.29	15 ± 0.26	19 ± 0.15	20 ± 0.50	21 ± 0.54
Mean chlorophyll-a ($mg\ m^{-3}$)	31.2 ± 1.01	35.5 ± 0.50	28.1 ± 0.65	20.6 ± 0.76	18.6 ± 0.59	16.5 ± 0.50	15.6 ± 0.52	17.7 ± 0.30	28.9 ± 0.43	28.7 ± 0.29
T. crassus										
Egg numbers (individual)	-	26 ± 3.66	15 ± 1.85	14 ± 2.07	16 ± 2.45	17 ± 2.93	12 ± 2.71	12 ± 2.71	19 ± 3.02	16 ± 3.21
Females (μm)	-	1320 ± 57	1330 ± 50	1370 ± 40	1387 ± 40	1414 ± 70	1403 ± 60	1458 ± 62	1349 ± 60	1380 ± 50
Males (μm)	-	1039 ± 41	1044 ± 56	1101 ± 36	1149 ± 42	1150 ± 38	1150 ± 70	1163 ± 70	1148 ± 71	1121 ± 60
E. drieschi										
Egg numbers (individual)	20 ± 4.39	13 ± 2.13	12 ± 3.04	-	-	-	40 ± 3.62	40 ± 3.62	15 ± 4.07	9 ± 2.00
Females (μm)	2003 ± 100	2145 ± 50	2054 ± 60	-	-	-	2527 ± 60	2527 ± 62	2230 ± 120	1996 ± 60
Males (μm)	2072 ± 120	1912 ± 72	1863 ± 78	-	-	-	2273 ± 49	2263 ± 49	2111 ± 112	1911 ± 61

Table 2. Mean length (µm) and mean egg numbers (individual) of 2 copepod species in Yenişehir Lake.

Species	Sex	Mean length	SD	Mean eggs	SD
Thermocyclops crassus	F	1399	57	16.43	4.28
	M	1131	36		
Eudiaptomus drieschi	F	2237	234	21.38	13.03
	M	2075	177		

frequency of spawning (Hirche, 1990; Hirche et al., 1997). There is the apparent inverse relationship between temperature and egg production. However, as discussed by Halsband and Hirche (2001), it may be difficult to discern the effects of these factors independently in the field, where the effects of one factor may be overridden by others.

Our findings showed that there was a weak relationship between egg production and temperature for *T. crassus* (R^2 = 0.28), but there was significant negative correlation for *E. drieschi* (R^2 = –0.71). Some of the previous studies showed that egg production was significantly correlated with female body size in both fresh water and sea water. Egg number increased with increasing copepod body length almost all year (Smyly, 1973; Crawford and Daborn, 1986). According to Crawford and Daborn (1986), egg production did not show significant correlations with water temperature at any time. Among the factors affecting copepod body size and fecundity, food concentration seems highly important, at least in some environments (Deevey, 1960; Durbin et al., 1983; Razouls and Razouls, 1988; Viitasalo et al., 1995).

A negative correlation (R^2 = –0.78) was found between chlorophyll-*a* concentration and adult body length for *E. drieschi*. A significant correlation between chlorophyll-*a* concentration and egg production was found for both *T. crassus* and *E. drieschi* (R^2 = 0.61 and R^2 = 0.79, respectively). Some authors have reported a negative relationship (Moraitou-Apostolopoulou et al., 1986), while others have reported a positive relationship (Klein Breteler and Gonzales, 1982; Sander and Moore, 1983; Ban, 1994) between chlorophyll-*a* concentration and copepod body length. Confusion about the effect of chlorophyll-*a* concentration on copepod body length continues.

It was emphasized that total chlorophyll-*a* does not appear to be a good estimator of food availability, because most copepods feed inefficiently on particles of smaller than 5 µm (Berggreen et al., 1988; Dam and Peterson, 1991).

The concentration of algal cells of >5 µm seems to be one of the main factors controlling egg production rates. However, it appears that chlorophyll-*a* concentration is not always sufficient to explain the observed egg production (Saiz et al., 1999). Furthermore, adults of *T. crassus* consume not only algae (Moriarty et al., 1973; Infante, 1978; González, 1998) but also nauplii, rotifers, and cladocerans (Gras et al., 1971). In this study, however, chlorophyll-*a* concentration affected egg production of both species.

Therefore, the expected increase in fecundity due to increasing temperatures may be overridden by the decrease in female size. Thus, interactions between food, ingestion rates, ambient temperatures, and body size on one hand and egg production rates on the other hand may prove to be complex.

The results of the present study suggest that temperature and chlorophyll-*a* concentration were the main parameters influencing the body lengths of *T. crassus* and *E. drieschi* in Yenişehir Lake. Egg production was also affected by chlorophyll-*a* and the body length of *E. drieschi* (R^2 = 0.79 and R^2 = 0.82, respectively).

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