

## Contribution and acclimatization of the swarming tropical copepod *Dioithona oculata* (Farran, 1913) in a Mediterranean coastal ecosystem

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**Abstract:** In this study, tropical oithonid copepod *Dioithona oculata* was recorded for the first time in the Mediterranean Sea. This species is distinguished easily by its large ocular lenses and by the number of setae on the endopod of the maxillule. The study was conducted seasonally in the coastal area of İskenderun Bay between April 2013 and December 2016. *D. oculata* was first observed in October 2013 in the study area (Station 4; 3.1 ind. m<sup>-3</sup>); after this period, this species became an important contributor to zooplankton assemblages in October with the highest level seen in 2016 (Station 4, 834.5 ind. m<sup>-3</sup>). The proportion of this species in the copepod community varied from 0.14% (2014) to 29.4% (2016), and the highest proportions, observed in October 2016, were at Stations 3 and 4 (51.1% and 65.3%, respectively). Females dominated the *D. oculata* population and the ratio of female to male was 5.6 ± 7 on average. Copepodit stages were also observed in the population.

Altogether, these data indicate that the *D. oculata* population increased year after year. In addition, the presence of copepodits in the population suggests that this species was established and successfully acclimatized to the conditions, becoming an important component of the zooplankton community in the İskenderun Bay ecosystem.

**Key words:** alien species, *Dioithona oculata*, İskenderun Bay, Mediterranean Sea

### 1. Introduction

The eastern Mediterranean is sensitive to alien invasions due to its geographic position (i.e., its connection with Atlantic Ocean, Black Sea, and Erythrean regions), crowded maritime traffic, fisheries, and tourism activities in the coastal regions (Galil and Zenetos, 2002). Alien species increased after the opening of the Suez Canal in 1869 and construction of the Aswan Dam (Galil, 2000); hundreds of alien species passed through the Suez Canal to the Mediterranean Sea, forming thriving populations along the Levantine coast (Galil and Zenetos, 2002). To our knowledge, an average of 821 alien species have been reported in the Mediterranean Sea, of which approximately 75% were established in these ecosystems (Zenetos et al., 2017).

The species belonging to Oithonidae are widely distributed in different ecosystems and are the most successful free-living cyclopoids in the marine ecosystems (Uye and Sano, 1998). This family is one of the most abundant taxa in estuarine, coastal, and oceanic regions (Paffenhöfer, 1993; Gallienne and Robins, 2001). The importance of the small copepods, such as Oithona, has been recently recognized in pelagic ecosystems

(Gallienne and Robins, 2001). Moreover, Oithonidae species are important contributors to ecosystems of the Mediterranean Sea (Siokou-Frangou et al., 1997; Andersen et al., 2001; Fernandez de Puelles et al., 2003; Gaudy et al., 2003; Mazzocchi et al., 2003; Saiz et al., 2003; Licandro and Icardi, 2009; Siokou et al., 2010; Terbiyik Kurt and Polat, 2013; Mazzocchi et al., 2014) and dominate zooplankton with other cyclopoid families such as Oncaeidae and Corycaeidae, as well as small calanoids including *Clausocalanus* and *Paracalanus* in eastern Mediterranean ecosystems (Siokou et al., 2010). These small copepods play an important role in the pelagic food web by transferring matter and energy from phytoplankton to larger zooplankton and several pelagic ichthyoplankton (Castro et al., 2010; Spinelli et al., 2012; Wang et al., 2017). Overall, 47 species belong to Oithonidae (Walter and Boxshall, 2018a; Walter and Boxshall, 2018b). Six species are included in *Dioithona* (Walter and Boxshall, 2018b); the rest of the species are in *Oithona*. A total of 23 *Oithona* and 2 *Dioithona* species are distributed across the Mediterranean Sea. Only 18 of these species inhabit the Levantine Sea. Except for *Dioithona rigida*, all of these species are oithonid copepods (Razouls et al., 2005–

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2017). The Indo-Pacific species *D. oculata* (Farran, 1913) is widely distributed in subtropical and tropical areas of the Indian, Pacific, and Atlantic oceans (Razouls et al., 2005–2017). This swarm-forming copepod is especially common in tropical marine environments near coral reefs and mangroves (Hamner and Carlton, 1979; Ambler et al., 1991; McKinnon, 2000), as well as in upper sandy bottoms and algal beds (Ueda et al., 1983).

In this study, we observed the first occurrence of Indo-Pacific *D. oculata* in a coastal ecosystem of the Mediterranean Sea and have focused on the temporal abundance distribution of its population in İskenderun Bay. In addition, we discuss morphological characters that are useful for species identification.

## 2. Materials and methods

### 2.1. Study area

İskenderun Bay is located in the northeastern part of the Mediterranean Sea (Figure 1). The surface area of the bay is approximately 2275 km<sup>2</sup> with a maximum depth of approximately 100 m at the opening of the bay (Avşar, 1999). İskenderun and Mersin bays comprise one of the largest continental shelf regions. Local winds and current systems prevailing in the eastern Mediterranean are affected by the hydrographic structure of the bay (Yilmaz et al., 1992). In addition, there are many industrial factories surrounding the bay (e.g., petroleum pipelines, iron-steel, fertilizer industries, ports, energy plants), and industrialization is increasing intensely. Ceyhan River is a major freshwater source for the bay (180 m<sup>3</sup> s<sup>-1</sup>) (Yilmaz et al., 1992). Primary production level is higher 2–4 times than in most of the other ultraoligotrophic regions of the Levant Sea. However, chlorophyll-a values and nutrients have not reached high levels equivalent to those in eutrophic environments (Polat and Terbiyik Kurt, 2013).

### 2.2. Sampling and laboratory studies

The investigation was conducted seasonally between 2013–2016 at an inshore area of İskenderun Bay (Table 1). Zooplankton samples were collected vertically using a WP-2 net with 200- $\mu$ m mesh at 5 stations in April (spring), July (summer), October (autumn), and December (winter) of each year. Sampling depth ranged from 5 m to 15 m. After collection, samples were immediately preserved with a seawater-formalin solution. In the laboratory, subsamples were taken from all samples using a Folsom splitter (1/2–1/32), then identified and counted using the Olympus SZX16 stereomicroscope and Leica CME light microscope. When the number of individuals of *D. oculata* was low, entire samples were taken into consideration. Pictures of the specimens were taken with an Olympus BX50 attached to a Nikon D7200 camera. Morphological measurements were taken from 50 individuals (both females and males). The abbreviations of the body parts are as follows: P (prosoma), U (urosoma), Mx1 Ri (endopod of maxillule), Cr (caudal rami), P1 (1<sup>st</sup> leg), P2 (2<sup>nd</sup> leg), P3 (3<sup>rd</sup> leg), P4 (4<sup>th</sup> leg), P5 (5<sup>th</sup> leg). Bradford-Grieve et al. (1999) and Razouls et al. (2005–2017) were used for taxonomic identification. Abundance values were determined as individuals per metercube (ind. m<sup>-3</sup>). The volume of the filtered sea water was calculated using the frame diameter of the zooplankton net and hauling depth. Temperature and salinity were measured in situ with a YSI 6600 CTD probe. Temperature and salinity values for the 2013–2015 period of the study were obtained from Terbiyik Kurt and Polat (2017). The relationship between the abundance of *D. oculata* and physical variables were evaluated using the Spearman correlation.

## 3. Results

### 3.1. Hydrography

Clear seasonal cycles were observed using temperature values in the study area. The lowest and highest values

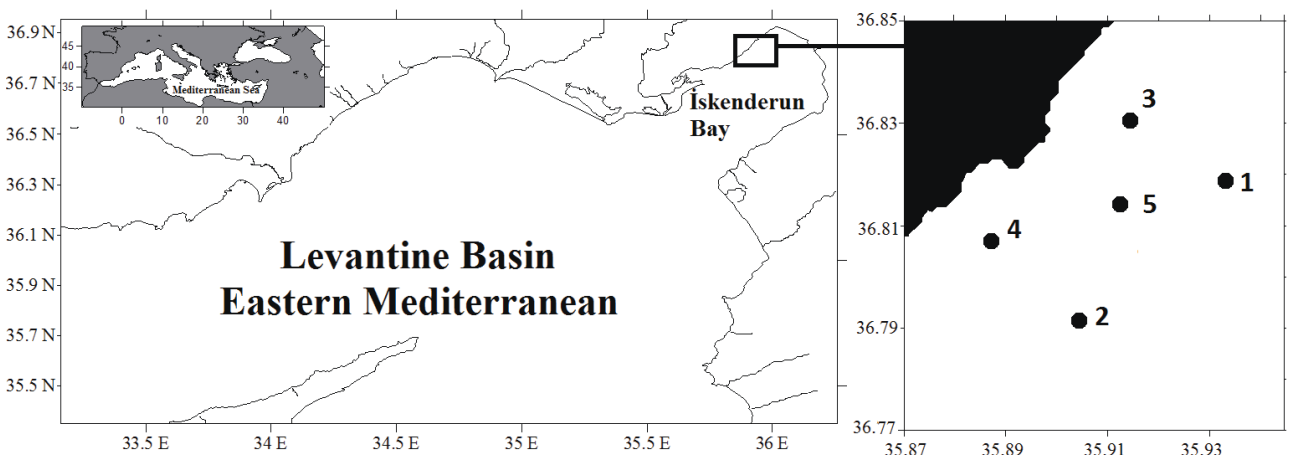


Figure 1. Sampling stations.

**Table 1.** Station coordinates.

Stations	Longitude	Latitude
1	35.93267333 E	36.81907683 N
2	35.90415583 E	36.79085412 N
3	35.9144805 E	36.82999083 N
4	35.88773383 E	36.80658751 N
5	35.91251417 E	36.81425733 N

were seen in 2016, 15.64 °C (Station 4, winter 2016) and 29.60 °C (Station 3, summer 2016), respectively (Figure 2). Salinity values fluctuated irregularly, ranging from 36.99 psu (Station 4, spring 2015) to 39.36 psu (Station 5, winter 2016). Highest values were observed in October and December 2016 (Figure 2).

**3.2. Description of *Dioithona oculata***

**Female**

Distinguishing characteristics of *D. oculata* are presented in Table 2. The mean body length was approximately 0.65 mm, ranging from 0.59 mm and 0.68 mm. The body is robust and egg-shaped (Figure 3A). The anterior part of the prosome is rounded in the dorsal view and the rostrum is blunt (Figure 3B). Two big eyes with a blue pigmentation are clearly seen (Figures 3A and 3B). The endopod of Mx1 has 2 setae (Figure 3C) and a mandible with 2 spinulose spines in the basis (Figure 3D). Exopodite setae formula is 1,1,3 in P1 (Figure 3E), P2 (Figure 3F), and P3 (Figure 3G), and 1,1,2 in P4 (Figure 3H). Terminal spine of third exopodite segment of P1-

P4 is longer than itself (Figures 3E–3H). P5 has 2 setae (Figure 3I).

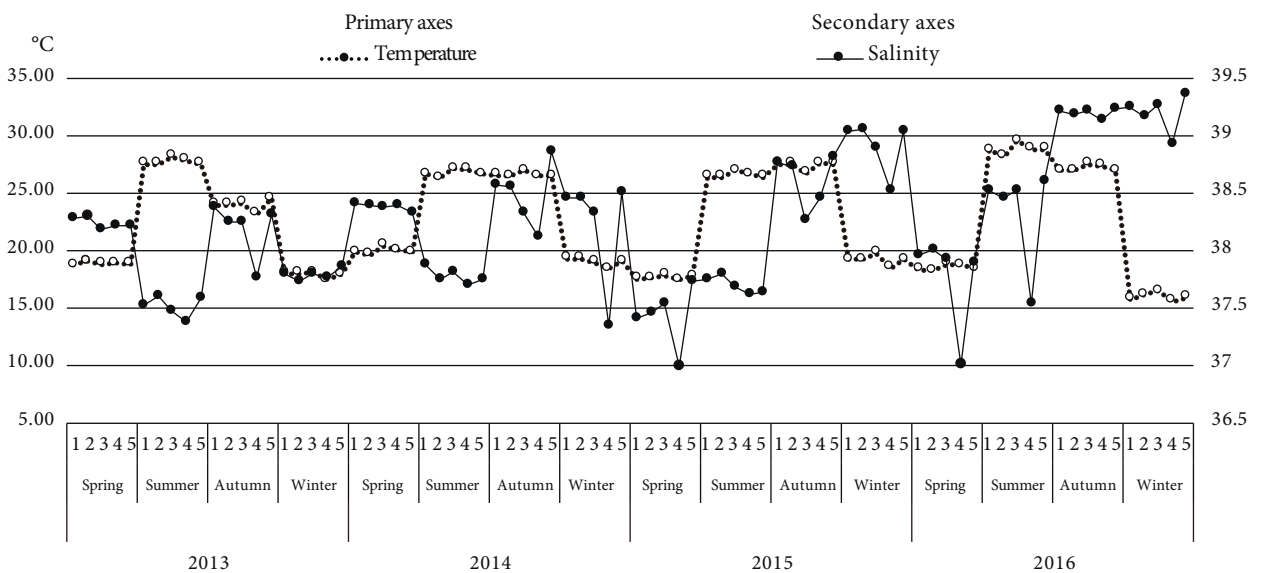
**Male**

Morphological characteristics for males are presented in Table 2. The mean body length was approximately 0.62 mm, ranging from 0.59 to 0.66 mm. The body is elliptical and robust (Figure 4A). The rostrum cannot be seen in the dorsal view (Figure 4B) and frontal part of prosome is relatively square (Figure 4A). The eyes are big and with blue pigmentation (Figures 4A and 4B). Setae formulae of exopodite for swimming legs (Figures 4C–4G), setae of Mx1 (Figure 4H), and spine of mandible (Figure 4I) are similar to that of females.

**3.3. Distribution of *Dioithona oculata***

*D. oculata* was first observed at Station 4 in October 2013 (3.1 ind. m<sup>-3</sup>). Its abundance and frequency increased in the following years (Figure 5). *D. oculata* was observed only in October of each year. In 2014 and 2015, the species was found in all sampling stations and reached relatively high abundance levels (40 and 12.4 ind. m<sup>-3</sup>, respectively). The mean abundance values (367.5 ind. m<sup>-3</sup>) reached their highest level in 2016 (Figure 5). The lowest abundance value was observed at Station 1 in 2015, while the highest values were observed at Stations 3 and 4 (709 and 834.5 ind. m<sup>-3</sup>, respectively) in 2016 (Figure 6). Spearman correlation analysis revealed that the abundance of *D. oculata* had a positive correlation with salinity (P < 0.01). No association was found with temperature (Table 3).

The proportional contribution of *D. oculata* to the zooplankton and copepod communities was low when we first observed it in 2013. Although they increased in 2014 (2.5% and 5.5%, respectively) and 2015 (0.9% and



**Figure 2.** Seasonal changes of the sea water temperature and salinity values in the study area.

**Table 2.** Some morphological characteristics of female and male individuals of *D. oculata*.

	Female	Male
Total length	0.65 mm	0.62 mm
P:U	1.62–1.65	1.6–1.7
Rostrum	Blunt	Blunt
Mx1 Ri	4 setae	4 setae
P1 outer spine	1,1,3	1,1,3
P2 outer spine	1,1,3	1,1,3
P3 outer spine	1,1,3	1,1,3
P4 outer spine	1,1,2	1,1,2
P5 free segment setation	2 setae	2 setae
CR length/width	2–2.1	1.4–1.6

2.5%, respectively), their proportional contribution was limited during that time. It increased considerably in 2016, contributing to a high proportion of the zooplankton and copepod communities (21% and 29.4%, respectively). *D. oculata* also predominated among copepods at Stations 3 and 4, which were located near the shore, in October 2016 (51.1% and 65.3%, respectively) (Figure 7).

The dominance of female individuals was observed in the population of *D. oculata*. The ratio of female to male varied from 1 to 18.7 (mean, 5.67). Moreover, copepodites were observed in populations as well as mature individuals. Most copepodite of *D. oculata* were at stage 5, however a few of the copepodites were at stage 3. The copepodite ratio was quite low, since the mesh size of zooplankton net was not suitable for the nauplii and the former stages of copepodites (Figure 8).

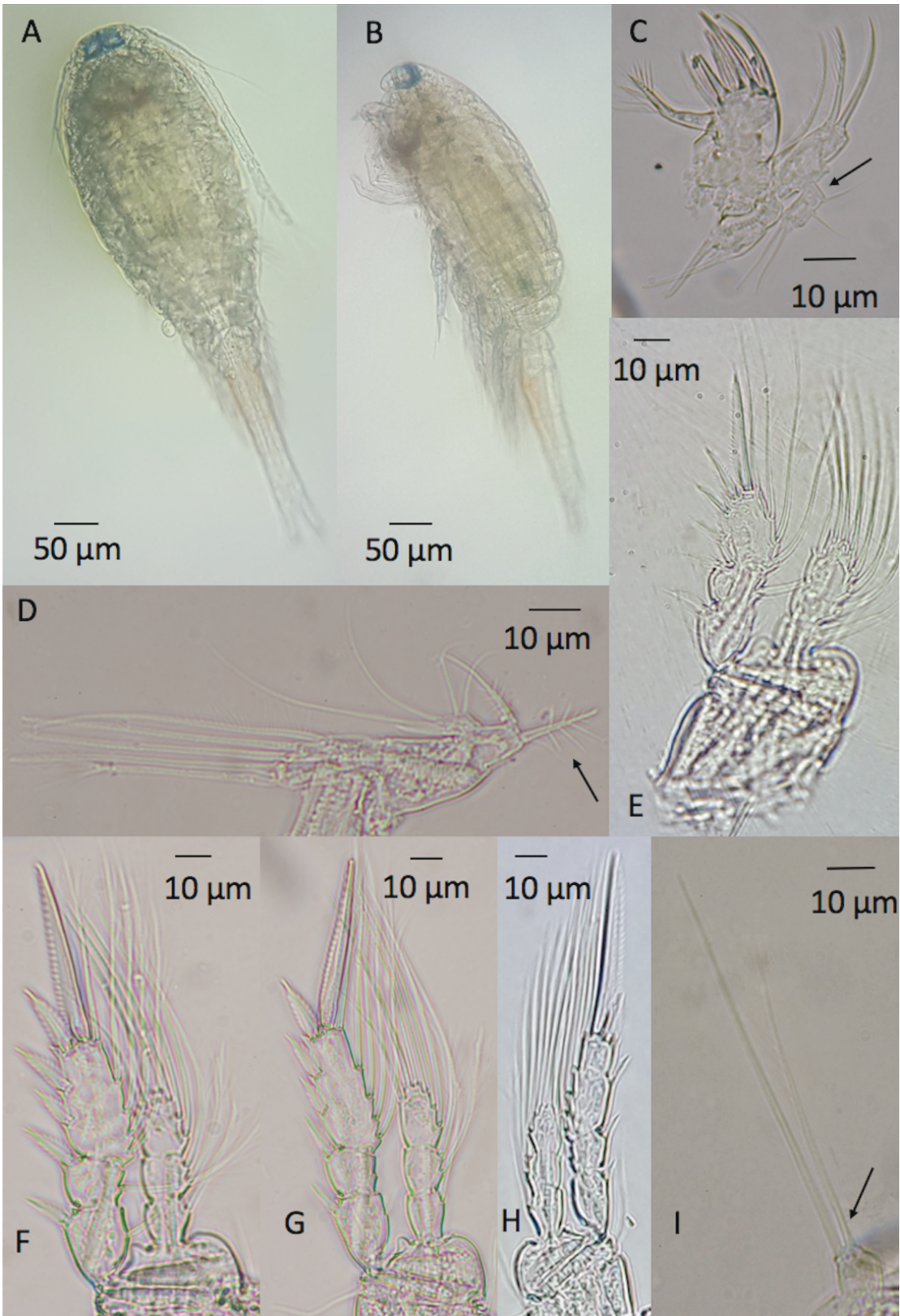
### 3. Discussion

This is the first report to observe *D. oculata* in a coastal ecosystem of the Mediterranean Sea, providing information on morphological characteristics that can be used for identification. It also includes seasonal and interannual abundance variations of *D. oculata* and its contribution to zooplanktonic assemblages.

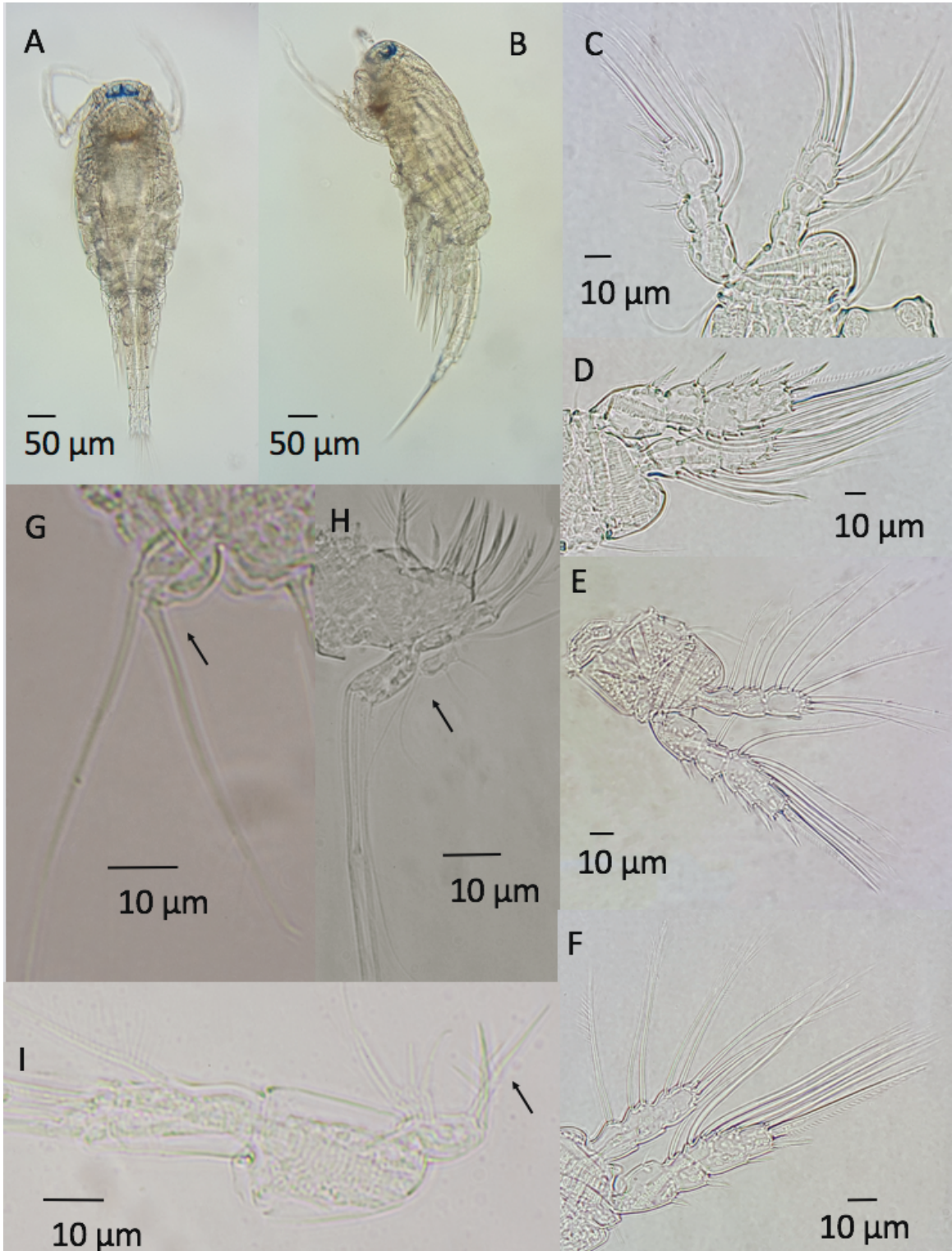
*D. oculata* is clearly different from other copepods belonging to Oithonidae inhabiting the Mediterranean Sea in terms of body structure and morphological characters. Dioithonian copepods are easily distinguished from oithonids, because they have 2 setae on the free segment of leg 5 (McKinnon, 2000). Two dioithonid copepods inhabit the Mediterranean Sea: *Dioithona minuta* and *Dioithona rigida* (Razouls et al., 2005–2017). The forehead is triangular with a blunt tip in dorsal view and the base of the mandible has 2 thick, blunt curved spines in *D. minuta*. However, *D. rigida* and *D. oculata* differ from *D.*

*minuta* in having different spinulose spines originating in the mandible and the forehead being truncated broadly in the dorsal view (Bradford-Grieve et al., 1999). *D. oculata* is also closely related to *D. rigida*, which inhabits the Egyptian coast of the Mediterranean (Zakaria et al., 2016), but it can easily be recognized by its large eye lenses (Björnberg, 1963) and differing morphological characters. *D. oculata* has large terminal spines of swimming legs, whereas in *D. rigida*, the terminal spines of the exopod are shorter than the last segments of the swimming legs. The endopod of Mx1 has 2 setae in *D. rigida* and 4 setae in *D. oculata* (Farran, 1913; Bradford-Grieve et al., 1999).

Oithonid copepods are very common in zooplankton communities in İskenderun Bay (Terbiyik Kurt and Polat, 2013). Until recently, a total of 5 oithonid species (*Oithona plumifera*, *Oithona nana*, *Oithona similis*, *Oithona tenuis*, and *Oithona setigera*) were observed in İskenderun Bay (Toklu and Sarihan, 2003; Terbiyik Kurt and Polat, 2013; Toklu-Aliçlı and Sarihan, 2016). *O. plumifera* was one of the most abundant copepod species in summer and autumn in our study region (Terbiyik Kurt and Polat, 2013), and dominant among oithonids. However, its dominance clearly changed at the stations closest to the coast. *D. oculata* became dominant at these stations in autumn 2016, after its entrance into the coastal area of İskenderun Bay. *D. oculata* is a swarm-forming tropical copepod species that prefers epipelagic and coastal regions. In particular, it forms swarms in coral reefs and mangroves (Emery, 1968; Hamer and Carlton, 1979), and above sandy bottom (Ueda et al., 1983). Ueda et al. (1983) observed continuous flattened swarms of *D. oculata* over sandy flat bottom approximately 6–14 m in depth, and an abundance of this species in Tanabe Bay. The bottom structure of Stations 3 and 4 is sandy and suitable for the establishment and growth of this species. The abundance of these species was reported to be 5755 ind. m<sup>-3</sup> (Lo et al., 2004) and 1953 ind. m<sup>-3</sup> (Hsu et al., 2008) in Tapong Bay, 4000 ind. m<sup>-3</sup> in Tanabe Bay (Ueda, 1983), and sometimes reaching 1,500,000 ind. m<sup>-3</sup> on the Palau coast (Hanner and Carleton, 1979). However, abundance of *D. oculata* remained low in some areas, with a mean of 27.14 ind. m<sup>-3</sup> in Espírito Santo Bay (Oliveira Dias and Bonecker, 2008), 1.90 ind. m<sup>-3</sup> in the epipelagic coastal waters of Bracui (Araujo et al., 2017), 82 ind. m<sup>-3</sup> in the Straits of Malacca (Rezai et al., 2004), and 175 ind. m<sup>-3</sup> in the Vitória Bay estuarine system (Sterza and Fernandes, 2006). In this study, mean values reached 367.5 ind. m<sup>-3</sup> in October 2016. Although it was the dominant species of copepod, abundance values were lower than in the area where swarms of these species occurred. This species is widespread in tropical and subtropical waters of the Atlantic, Pacific, and Indian oceans (Bradford-Grieve et al., 1999). It is also widely distributed in the southern hemisphere (Farran,



**Figure 3.** Some morphological characters of *D. oculata*, adult female: (A) dorsal view, (B) lateral view, (C) maxillule, (D) mandible, (E) P1, (F) P2, (G) P3, (H) P4, (I) P5.



**Figure 4.** Some morphological characters of *D. oculata*, adult male: (A) dorsal view, (B) lateral view, (C) P1, (D) P2, (E) P3, (F) P4, (G) P5, (H) maxillule, (I) mandible.

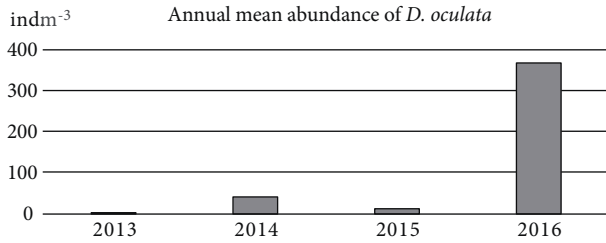


Figure 5. Annual mean abundance of *D. oculata* in autumn.

1913; Rosendorn, 1917; Dakin and Colefax, 1933; Tanaka, 1960; Björnberg, 1963; Vervoort, 1964; Smith et al., 1979; Hamner and Carketon, 1979; Sterza and Fernandes, 2006) and in the northern hemisphere (Sewell, 1947; González and Bowman, 1965; Yeatman, 1976; Sander and Moore, 1978, 1979; Ara et al., 2017). However, the Californian shores, Japan Sea, the Mexican Gulf (Razouls et al., 2005–2017), and Turkish coast (this study) are the highest latitudes at which this species have been observed.

The majority of the zooplankton species inhabiting the Mediterranean Sea are of Atlantic origin. However, species from the Indo-Pacific region have begun to be observed more frequently in the Mediterranean ecosystem in recent years (Galil and Zenetos, 2002). It has been observed that some species have dominated the communities from time

to time (Terbiyik et al., 2007, Terbiyik Kurt and Polat, 2013). The opening of the Suez Canal in 1869 made it possible for these species to enter the Mediterranean ecosystem (Por, 1971, 2012). The barrier effect of Nile River decreased after the building of the Aswan Dam, and the entry of alien species into the Mediterranean ecosystem increased (Galil, 2000). It is known that the majority of alien species passed into the Mediterranean Sea through the Suez Canal as Lessepsian migrators. However, there are several different ways of entering this ecosystem, such as maritime traffic, the pet trade, and mariculture (Galil and Zenetos, 2002). It has been suggested that the transport of this species to the study area with ballast water has had greater impact than Lessepsian migration due to the absence of *D. oculata* on the southeastern coasts of the Levantine Sea and Red Sea. Indeed, shipping is the second most important route for the introduction of alien species into the Mediterranean Sea. The eastern Mediterranean is fringed with major ports and marinas, and shipping may serve to transport invading Erythrean species into Mediterranean fouling or ballast waters (Galil and Zenetos, 2002). Moreover, İskenderun Bay is a very important area and one of the largest international ports is located in the bay (Matyar and Dinçer, 2010).

İskenderun Bay is one of the sites where alien species are most frequently observed; new records have increased over the past decade (Çeviker and Albayrak, 2006; Çevik

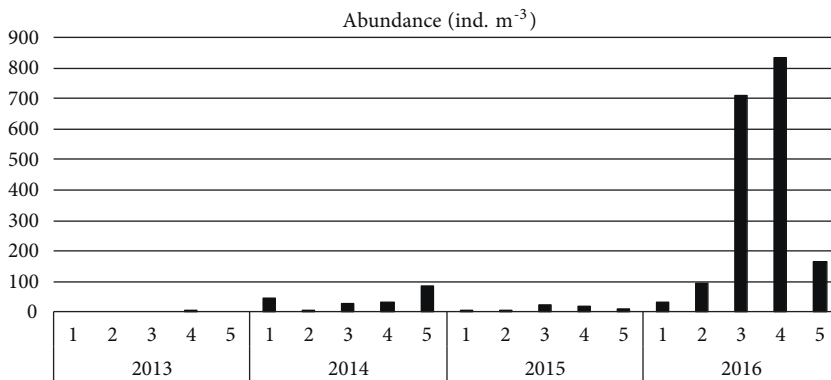


Figure 6. Abundance distribution of *D. oculata* in the study area in autumn.

Table 3. Spearman correlation results.

Variables	Salinity	Temperature
<i>D. oculata</i>	.443	.660 (**)
Proportion of <i>D. oculata</i> in zooplankton	.111	.459
Proportion of <i>D. oculata</i> in Copepoda	.120	.419

\*\* Correlation is significant at the 0.01 level (2-tailed).

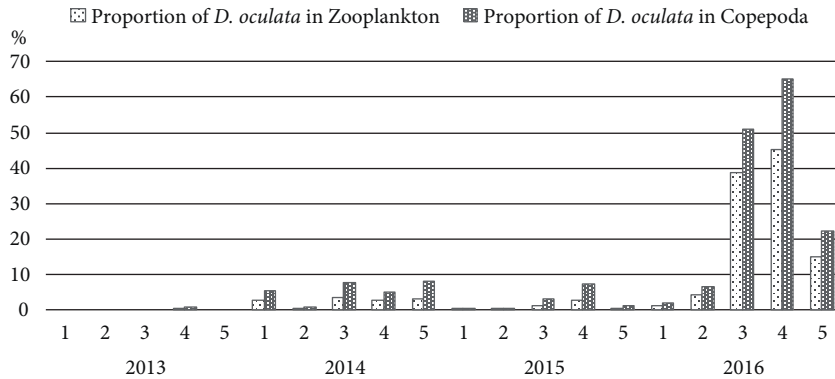


Figure 7. The proportion of *D. oculata* in Copepoda and zooplankton in autumn.

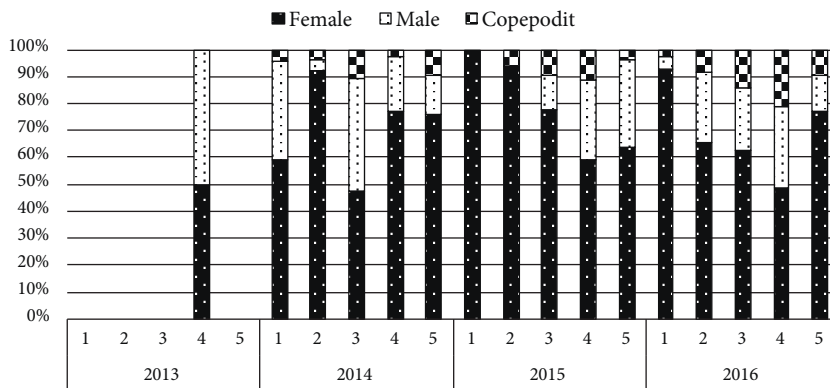


Figure 8. Interannual variations of proportional ratio in female, male, and copepodites in autumn.

et al., 2006; Terbiyik et al., 2007; Şahin and Çınar, 2009; Terbiyik Kurt and Polat, 2017). It is known that the sea surface temperature throughout the Levantine Sea has increased in recent years by an average of approximately 0.065 °C annually (Samuel-Rhoads et al., 2013). In İskenderun Bay, the temperature has been reported to have increased by approximately 2 °C since 1970 (Turan et al., 2016). These temperature increases in the Mediterranean Sea are thought to contribute to the formation of more favorable conditions for the majority of the Indo-Pacific species (Turan et al., 2016). Temperature values of the study area in October in the present study and previous studies conducted since 2008 (Terbiyik Kurt and Polat, 2013, 2014, 2015) were generally above 25 °C (except for 2014, with temperature values of about 24 °C). Although *D. oculata* is commonly observed in tropical regions where the temperature is higher and varies little (Rezai et al., 2004), it can also easily survive and inhabit subtropical areas where the temperature changes seasonally and the temperature drops to 17 °C in winter (Lo et al., 2004). Additionally, this species is estuarine (Lopes et al., 1998); in previously reported regions, salinity decreased to

14 psu (Lo et al., 2004). However, we found a positive correlation between abundance of *D. oculata* and salinity, and highest abundance values were observed during high salinity conditions. Temperature and salinity ranges in the study area seem to be suitable for this species to survive and inhabit. Moreover, along with environmental and anthropogenic factors, ecological and biological properties of alien species play an important role in the success of establishment and acclimatization. The swarm-forming nature of *D. oculata* could be an advantage for surviving and breeding in foreign habitats. Swarming allows for more mating encounters and avoidance of predators (Hamner and Carleton, 1979; Hebert et al., 1980). In particular, swarms during the day allow the species to save itself from predators; after sunset, individuals disperse throughout the water column. Therefore, this is a feeding advantage that reduces interspecific food competition.

In conclusion, *D. oculata* has easily adapted to the ecological and biological characteristics of İskenderun coastal waters, successfully acclimatized, and has become a prominent component of the autumn zooplankton community in the coastal waters of İskenderun Bay. A

monitoring study is needed to detect potential changes in ecosystem function and services by creating a bottom-up effect in this region. Anthropogenic factors such as industry, tourism, agriculture, and fisheries activity, as well as domestic input, intensely affect the İskenderun Bay ecosystem. Altogether, 500,000 people inhabit the İskenderun Bay area, and the population increases during the warmer seasons (Terbiyik Kurt and Polat, 2015). These anthropogenic factors, together with environmental

factors and alien bioecological properties of this species, could mean that the species could synergistically become dominant among indigenous species in these regions.

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