ACTA ZOOLOGICA BULGARICA

Acta Zool. Bulg. 72 (4), December 2020: 517-524

http://www.acta-zoologica-bulgarica.eu/00SIO_1_05

Special Issue:
ESENIAS and DIAS Scientific Reports 4
Research Article

Spatial and Seasonal Variation of the New Invader *Oithona davisae* (Ferrari F. D. & Orsi, 1984) (Cyclopoida: Oithonidae) in the Southeast Black Sea

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Abstract: *Oithona davisae* is one of the top 10 invaders in the ESENIAS area, widely distributed in the Black Sea. According to published data, *O. davisae* has replaced the other cyclopoid copepod *O. nana* in the Black Sea. The aim of the present study was to determine the population structure and abundance of *O. davisae* in the coastal and offshore zones of the Southeast Black Sea Anatolian Continental Shelf Area in the period from May 2015 to February 2016. Our results showed that the abundance of *O. davisae* was higher in the coastal area compared to the offshore area. The mean abundance of *O. davisae* population changed with season and it was the highest in November 2015 (7,344 ind. m^{-3}). In contrast, the mean lowest population abundance was estimated for coastal stations (170 ind. m^{-3}) and for offshore stations (17 ind. m^{-3}) in February 2016 and May 2015, respectively. Therefore, it can be concluded that autumn is the most productive period for *O. davisae*.

Key words: Black Sea, Copepoda, abundance, invasive alien species.

Introduction

The Black Sea is one of the enclosed sea basins of the European continent, as well as the largest anoxic basin in the world (Mee 1992, Turgut et al. 1992, Zaitsev et al. 2002). The Black Sea is virtually isolated, connected with the Mediterranean Sea by a small and narrow channel system called Turkish Straits System, which includes Istanbul and Canakkale Straits. This system separates the continents Europe and Asia (Basar 2010). Because of its location the Black Sea is a very delicate ecosystem, which can be easily affected by invasive species. Well-known introduction pathway is ships' ballast water (Selifonova 2009, 2011). Ship transit traffic has increased in the last two decades because of the goods imported and exported by the Black Sea countries (Basar 2010). Consequently, the ballast water operation frequency has also increased. This has enabled the introduction of new invaders into the Black Sea, coming from different parts of the world (Shalovenkov 2019).

The cyclopoid copepod *Oithona davisae* (Ferrari F. D. & Orsi, 1984) (Oithonidae), one of the recently introduced species in the Black Sea, has been classified among the top 10 invaders in the ESENIAS area (Trichkova et al. 2017). It originates in East Asia: Japan and the China Seas, and many coastal areas (Mihneva & Stefanova 2013). It is also a cyclically abundant member of the planktonic fauna in many remote marine and estuary ecosystems. This species is considered a small-size copepod, its size ranging between 0.47–0.55 mm and 0.41–0.51 mm for females and males, respectively (Ferrari & Orsi 1984). Minimum and maximum lengths of the specimens range from

0.43 to 0.50 mm, while the average total length (± SE) is 0.46±0.021 mm in the Black Sea population (Yildiz et al. 2017). Body shape is oval and can be easily distinguished from other cyclopoid copepods by a strongly pointed rostrum (Temnykh & Nishida 2012, Shiganova et al. 2015). *Oithona davisae* mostly prefers eutrophic embayment (Uye & Sano 1995, Almeda et al. 2010).

The Black Sea ecosystem provides an important habitat for many commercial fish species and supports a large-scale fishery for adjacent countries (Kideys 2002, Agirbas et al. 2010). Copepoda is an important zooplanktonic group providing food for such commercial fish populations as *Engraulis encrasicolus* Linnaeus, 1758 (anchovy) and *Trachurus trachurus* Linnaeus, 1758 (horse mackerel) (Saglam & Yildiz 2019). Gubanova et al. (2014) reported that three native zooplankton species (*Acartia margalefi* Alcaraz, 1976, *Oithona nana* Giesbrecht, 1893, and *Paracartia latisetosa* Krichagin, 1873) have disappeared, while two non-indigenous copepods (*Acartia tonsa* Dana, 1849 and *O. davisae*) have occurred in the Black Sea ecosystem in the 1970s and 2000s, respectively. The change in *O. nana* population may have been caused by a large-scale change in the meteorological and oceanographic conditions (Bilio & Niermann 2004). Changes in the zooplankton composition have led to changes in the food chain of fish. Because of its small size *O. nana* has been an important food source, especially for fish larvae (Kideys et al. 2000). After its sudden disappearance in 2000, fish larvae faced difficulties finding bait, and at the same time fisheries was affected (Gubanova et al. 2014). For example, after 1985, a change in the stomach content of anchovy larvae has been observed (Kideys et al. 2000). This change in gut content has correlated with major changes in the zooplankton composition – decrease in *O. nana* and its gradual replacement by *O. davisae* after 2000 (Gubanova & Altukhov 2007).

Oithona davisae was first recorded as single individuals in the Sevastopol Bay in 2001 (Zagorodnyaya 2002, Altukhov et al. 2014), but since 2005, this species has been routinely observed and even dominated in the Black Sea (Svetlichny et al. 2018). Its current distribution in the ESENIAS area is summarised by Karachle et al. (2017). Although *O. davisae* was first recorded in the northwestern Black Sea in 2001, the first observations of the species in the western and eastern parts of the Anatolian coast were in 2009 and 2010, respectively (Üstün & Terbiyik Kurt 2016, Yildiz et al. 2017, Svetlichny et al. 2018). Since 2012, the species has become more abundant and distributed in the entire Black Sea (Yildiz et al. 2017). Based on the reproduction and population structure, since 2014, *O. davisae* has been considered naturalised in the Black Sea (Yildiz et al. 2017). This species has also been reported as an important edible planktonic organism for fish larvae, which fills the gap caused by the disappearance of *O. nana* in the Black Sea ecosystem (Vdodovich et al. 2017).

Because of its prey-predator relations, *O. davisae* has become one of the key species in the Black Sea ecosystem. The reproductive biology and population dynamics of important species in the ecosystem has to be explored in order to understand the trophic relations in the ecosystem with the emphasis on fisheries management. From this point, several ecological studies have been conducted in the eastern Black Sea pelagic ecosystem (Besiktepe et al. 1998, Besiktepe 2001). The aim of the present study was to investigate the spatial and seasonal dynamics of the invasive alien copepod *O. davisae* in the Southeast Black Sea.

Materials and Methods

The samples were taken from the Southeast Black Sea on a quarterly basis from May 2015 to February 2016 from eight stations, some of which are coastal (2 miles) and others are offshore (20 miles and 50 miles), by KTU DENAR-1 Research Vessel (Table 1, Fig. 1). WP2 Hydro-Bios plankton net (57 cm diameter stainless steel ring, with a 2.6 m long net bag, and 100 µm mesh size) was used for sampling.

The water volumes were measured by using a Hydro-bios digital flow meter, which was attached to the mouth of the plankton net. A vertical tow was applied during the sampling. The samples were taken from 3 m above the bottom and OMZ (Oxygen Minimum Zone, Sigma–t 16.2) to sea surface in

Table 1. Geographic location and depths (m) of sampling stations.

Station Codes	Geographic Location	Depth (m)
S1	40°57’20”N – 40°11’34”E	90
S2	41°12’58”N – 40°09’33”E	1396
S3	41°38’42”N – 40°03’59”E	1840
RC1	41°07’11”N – 40°42’57”E	125
RC2	41°21’32”N – 40°33’53”E	1786
RC3	41°46’56”N – 40°36’39”E	1830
H1	41°24’39”N – 41°22’11”E	65
H1	41°33’20”N – 41°04’22”E	1275

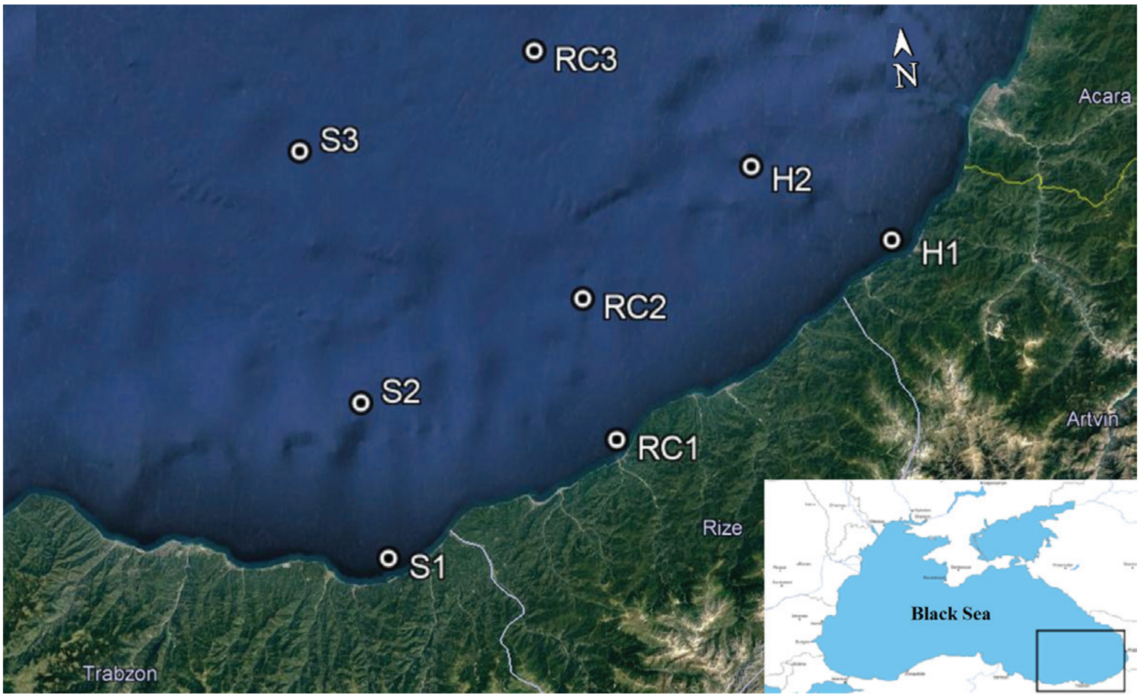

Fig. 1. Map of sampling locations in the Southeast Black Sea. For station codes see Table 1.

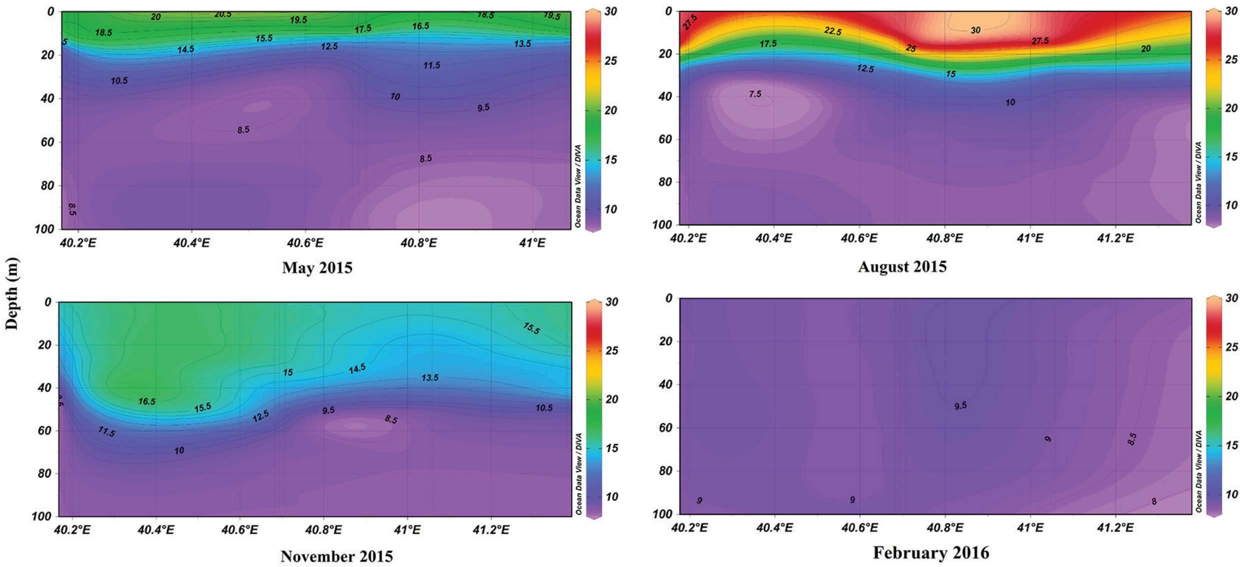

Fig. 2. Spatial and temporal distribution of temperature (ºC) along the Southeast Black Sea in the period May 2015 – February 2016.

the coastal and the offshore stations, respectively. After each haul, the nets were carefully rinsed. The contents of the cod-ends were fixed immediately after collection and preserved in a 4% formaldehyde seawater solution buffered with sodium borate. Then, the samples were concentrated in jars for quantitative analyses, depending on the density.

The organisms were counted under a Nikon SMZ 745 stereomicroscope and Nikon E 600, using 4x, 10x and 40x objectives and a Bogorov–Rass counting chamber. The quantitative analyses of the species were performed by using 9-mL subsamples. The counts were repeated for eight subsamples (Harris et al. 2000). The females with an egg sac were also counted in the samples under a Zeiss Stemi 508 stereomicroscope. The temperature and salinity data were obtained from Sea Bird SBE 37 ODO CTD prop.

Results

During February 2016, there were no temperature stratification and values of 7.5–8.5°C were recorded along the whole water body. The surface water temperature in May 2015 was determined to be 20°C. The thermocline was observed between 15 and 23 m. In August 2015, the surface water temperature increased up to 29°C on the coastal area. The surface mixture layer with warm water reached 27 m depth. The Cold Intermediate Layer (CIL) was formed between 30 and 80 m depth. In November 2015, the mixture layer went down to 50 m depth and its temperature varied between 14–16° C (Fig. 2).

The surface water salinity during the sampling period varied between 17.5 ppt and 18.5 ppt. Lower salinity values were mostly observed in coastal regions due to river run-off. The lowest salinity was determined in May 2015. The salinity values at the depth of 80 m were higher than 19 ppt in all sampling periods. After 100 m depth, the salinity gradually increased above 20 ppt (Fig. 3).

With regard to the sampling periods, it was determined that the average number of *O. davisae* reached a maximum at the coastal stations (Fig. 4). The most abundant samples were recorded at the coastal stations in November 2015. The lowest numbers of individuals at the coastal and offshore stations were observed in February 2016 and May 2015, respectively. During these periods, there were no *O. davisae* observed at certain stations, and the lowest average number of individuals was 17 ind. m^{-3} in the entire study area in February 2016, and 170 ind. m^{-3} at the coastal stations in May 2015 (Fig. 4).

The highest abundance of females and copepodite stages of *O. davisae* was observed at H1 station in May 2015 (Fig. 5A). During this period, at the coastal stations 35% of individuals were copepodites and 65% were females. Although the number of individuals at the offshore stations was low, the ratio of the copepodite stage and the females of *O. davisae* consisted respectively of 26% and 74% (Figs. 5A, 6A, and 7A).

In August 2015, all components of the *O. davisae* population (females, males, copepodite stages, and egg sac containing females) were present in the entire study area. Although the number of individuals at the coastal stations was 10 times higher than the offshore stations, the copepodites were observed with a dominance of 91% both in the coastal and offshore areas (Figs. 5B, 6B, and 7B).

Considering all the sampling periods, the highest abundance was recorded in November 2015. During this period, the number of individuals in the copepodite stage reached up to 2x10^4 ind. m^{-3} at the H1 station (Fig. 5C). The abundance at the offshore stations was determined as 6x10^3 ind. m^{-3}. The copepodite ratio was determined as 71% and 77% at the coastal and offshore stations, respectively, while the ratio of females was 21% at the coastal stations and 17% at the offshore stations. The proportions of female individuals carrying egg sacs at the stations varied between 3% and 5%.

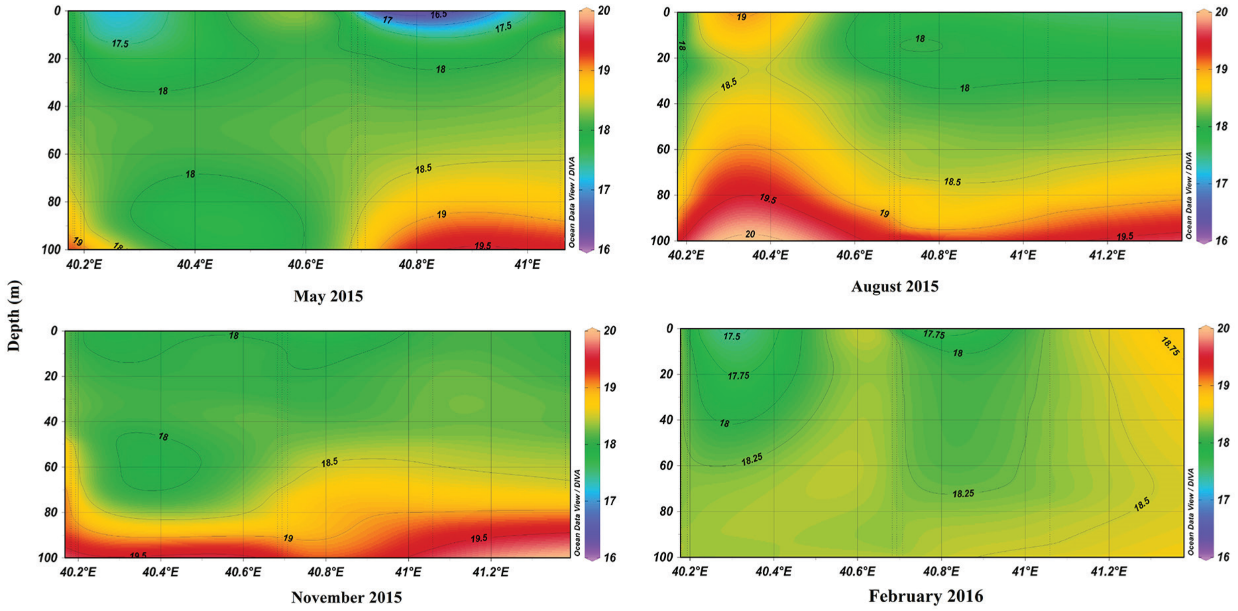

Fig. 3. Spatial and temporal distribution of salinity (ppt) along the Southeast Black Sea in the period May 2015 – February 2016.

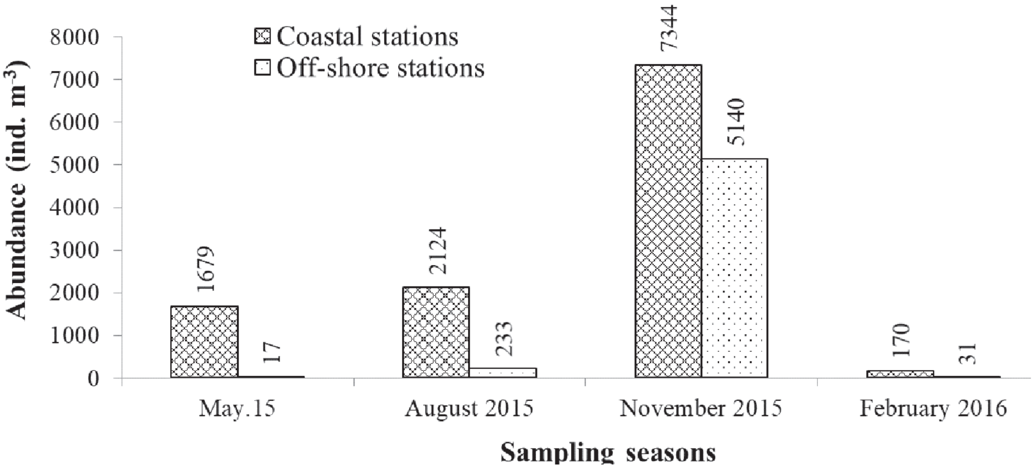

Fig. 4. Average abundance of *Oithona davisae* (ind. m^{-3}) at coastal and offshore stations during different sampling seasons.

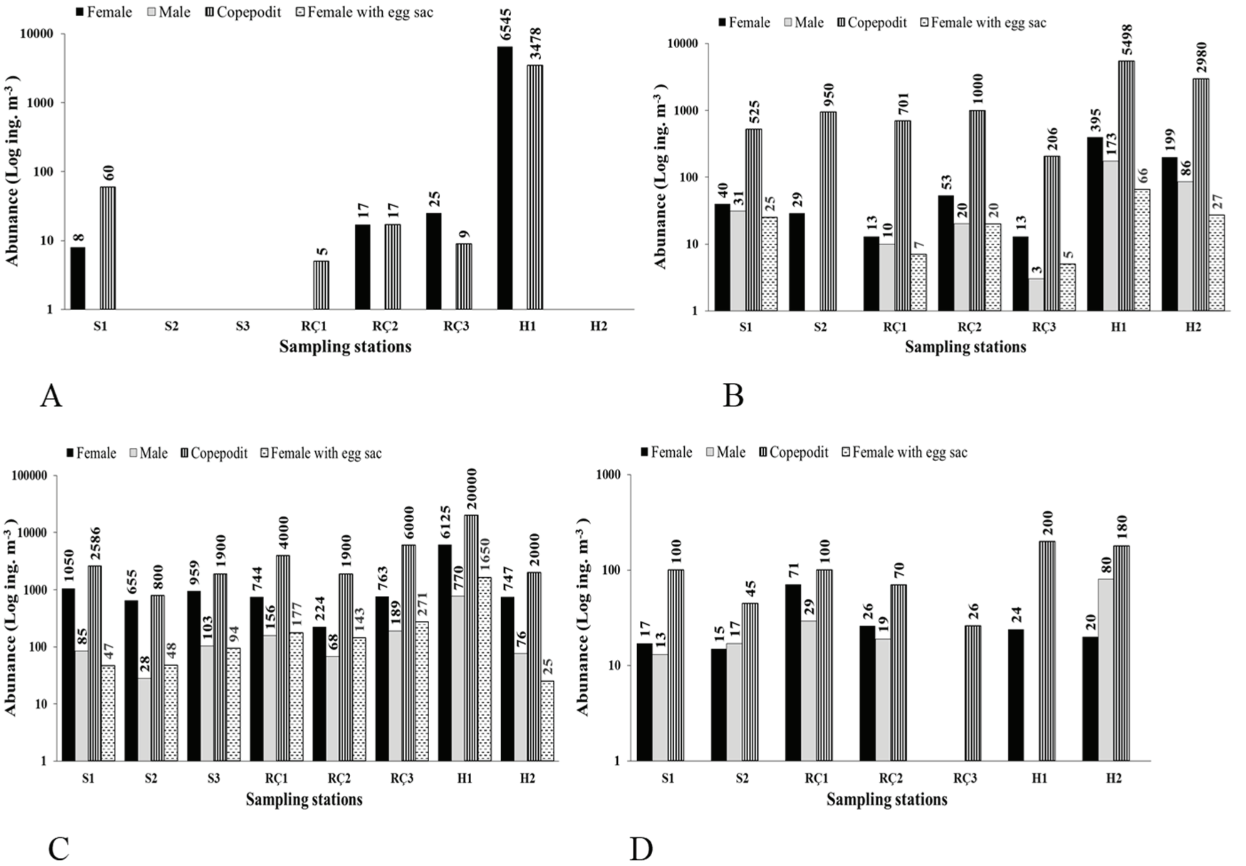

Fig. 5. Seasonal pattern of the *Oithona davisae* population (males, females, copepodites, and females with an egg sac) at different sampling stations. A: May 2015, B: August 2015, C: November 2015, and D: February 2016.

The ratio of males was determined to be 3% in the whole area (Figs. 6C and 7C).

The lowest temperature throughout the sampling period was observed in February 2016. The number of individuals was also the lowest during this period due to environmental conditions. The number of *O. davisae* individuals was approximately 10^2 ind. m^{-3}. While the females, males and copepodites were identified as 17%, 15% and 68%, respectively, no egg-sac-carrying females were found at the coastal stations. In contrast, at the offshore stations, the number of individuals was 26 ind. m^{-3} and they were represented only by copepodites (Figs. 5D, 6D, and 7D).

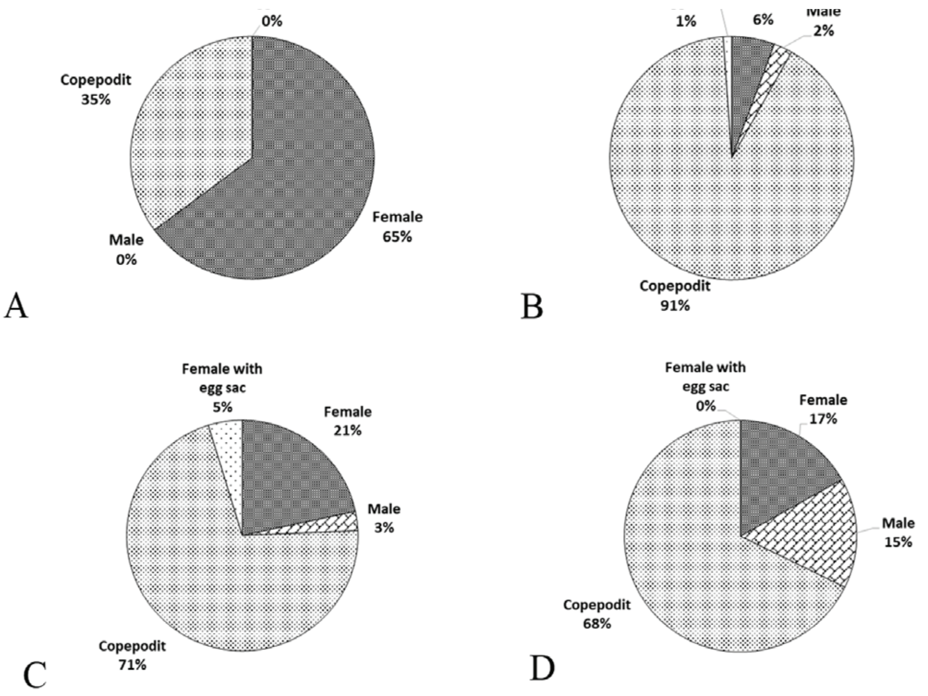

Fig. 6. Mean percentage distribution of *Oithona davisae* (males, females, copepodites, and females with an egg sac) at the coastal stations. A: May 2015, B: August 2015, C: November 2015, and D: February 2016.

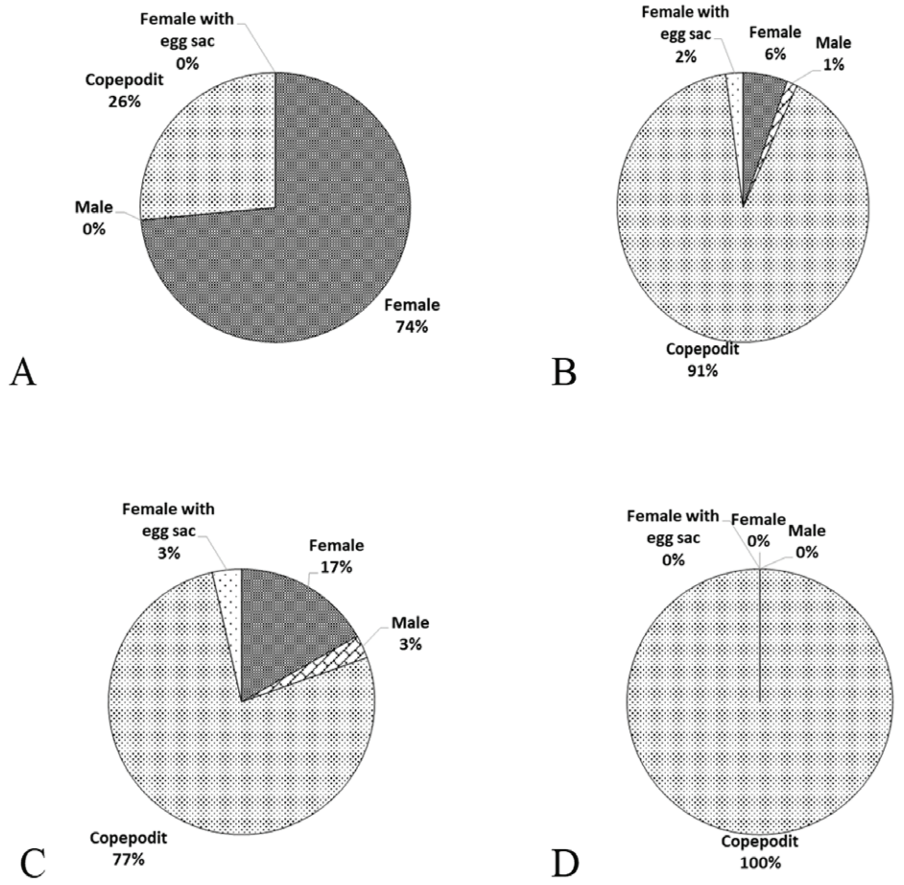

Fig. 7. Mean percentage distribution of *Oithona davisae* (males, females, copepodites, and females with an egg sac) at the offshore stations. A: May 2015, B: August 2015, C: November 2015, and D: February 2016.

Discussion

Most studies related to invasive species have focused on the direct negative impact of non-indigenous species on native biota (Shiganova & Bulgakova 2000, Oguz et al. 2008, Skolka & Preda 2010). But sometimes the invasive alien species can be beneficial to native community (Rodriguez 2006). Some species can be considered important for their new habitat as in the case of the small-sized copepods *O. davisae*. One of their ecological role is that they are an important prey source for the larval stages of some key fish species. Such kind of species facilitates energy transfer in complex trophic interactions between the protozoan and metazoan food webs (Zagami et al. 2018).

Because of the above mentioned ecological role of *O. davisae* in the Black Sea, research on this species has recently gained importance. The study of Üstün & Terbiyik Kurt (2016) shows that the species is found mostly at temperatures, ranging from 12.53 to 20.95ºC. This temperature range is observed in the Black Sea between September and December. Relatively high population values of *O. davisae* are observed in the same period, being the highest in November. The authors also report that the highest number of adults and copepodite stages of *O. davisae* are found between September and December. Yildiz et al. (2017) report that the highest abundance (49,761 ind. m^{-3}) has occurred at the coastal station at the end of autumn. In addition, the egg-carrying *O. davisae* is abundant in September (4,571 ind. m^{-3}) at the coastal station and in August (952 ind. m^{-3}) at the offshore station (Yildiz et al. 2017). The period from September to December is the productive season for *O. davisae* in the Black Sea. This is the season, in which *O. davisae* reaches its maximum abundance that corresponds to 15.9% of the total copepod abundance (Üstün & Terbiyik Kurt 2016). It is difficult to compare the results of various studies because of different methods used: different mesh size plankton nets, depth ranges and different kind of plankton collection direction, vertical and horizontal tow. However, in all studies conducted in the Black Sea it is a common conclusion that the abundance of *O. davisae* reaches the highest values during the autumn season.

The osmoregulatory abilities of *O. davisae* might have facilitated their successful adaptation to the brackish Black Sea (Svetlichny & Hubareva 2014, Svetlichny et al. 2016). This physiological adaptation ability causes the species to behave as a naturalised species in a short time.

Because of its role as an important food source for fish larvae, which fills the gap caused by the disappearance of *O. nana* in the Black Sea ecosystem, *O. davisae* should be studied not only with regard to the population structure but also with regard to the trophic relation in food consumption, ecological niche and the role in the energy transfer to upper level along the food chain.

Acknowledgements: This work was supported by the Republic of Turkey, Ministry of Agriculture and Forestry, Project No: TAGEM−14/AR-GE-12.

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