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Species composition of Black Sea marine planktonic copepods

A. Gubanova [a,*], D. Altukhov [a], K. Stefanova [b], E. Arashkevich [c], L. Kamburska [d], I. Prusova [a], L. Svetlichny [a], F. Timofte [e], Z. Uysal [f]

[a] Institute of Biology of the Southern Seas National Academy of Sciences of Ukraine, Sevastopol, Ukraine
[b] Institute of Oceanology, Bulgarian Academy of Sciences, Varna, Bulgaria
[c] P.P. Shirshov Institute of Oceanology Russian Academy of Sciences, Moscow, Russia
[d] Institute for Ecosystem Study, National Research Council, Verbania, Italy
[e] National Institute for Marine Research and Development "Grigore Antipa," Romania
[f] Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey

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ABSTRACT

This paper reviews the changes in the marine planktonic copepods of the Black Sea species' list from the beginning of taxonomic research to the present day. The study was based on the SESAME biological database, unpublished data, literature and data obtained during the course of the SESAME project. Comparisons were made with the Guidebook for Marine Fauna of the Black Sea and the Sea of Azov, which revealed changes both in the taxonomic status of some species and in the structure of the copepod community. The taxonomic status of two species (*Acartia clausi* small form and *Centropages kroyeri pontica*) and the nomenclature of two species (*Oihona minuta* and *Calanus helgolandicus*) have been changed. Three native species (*Acartia margalefi*, *Oithona nana*, and *Paracartia latisetosa*) have disappeared. Two non-indigenous copepods (*Acartia tonsa* and *Oithona davisae*) became established in the Black Sea ecosystem in the 1970s and 2000s, respectively. The success of their establishment was determined by biological features of the species and vulnerability of the native copepod community to invasions. It is highly probable that both species were introduced to the Black Sea by vessel ballast water. The hypothesis of "mediterranization" of the Black Sea fauna does not appear to hold true for zooplankton. Numerous claims of alien copepod species in the Black Sea remain largely unverified due to insufficient information. Data on newly discovered species of the *Acartia* genus are not authenticated. An updated list of marine planktonic copepods of the Black Sea is hereby presented.

1. Introduction

The detailed taxonomic analysis of species composition is crucial for any ecological study, including community dynamics and variability, the influence of external factors, extinctions and invasions, as well as for biogeography and comparison with similar communities throughout the world.

Studies of the Black Sea zooplankton started in the mid-nineteenth century. The first researchers focused their efforts on the species composition of zooplankton, specifically pelagic copepods. A number of publications resulting from these studies were produced at the end of the nineteenth and beginning of the twentieth centuries by renowned scientists of the age (e.g. Chichkoff, 1912; Dolgopolskaya, 1940; Galadzhiev, 1948; Karavaev, 1894; Klyucharev, 1952; Krichagin, 1873; Potemkina, 1940; Ulomskiy, 1940). By the late 1950s investigations into the species composition of Black Sea fauna were considered to be complete. The results were summarized in the "Guidebook for Marine Fauna of the Black Sea and the Sea of Azov" (Dolgopolskaya et al., 1969), which listed all copepod species of the Black Sea and the Sea of Azov known at that time. Further detailed studies of Copepoda taxonomy resulted in species name modifications and clarification of the taxonomic status of some native species (Belmonte and Mazzocchi, 1997; Hulsemann, 1991; Sazhina and Kovalev, 1971).

During the 1960s, about fifteen Mediterranean species were recorded in the Black Sea, mostly near the Bosphorus (Kovalev et al., 1976; Pavlova, 1965). These findings were one of the outcomes of intensive investigation of the water exchange between the Sea of Marmara and the Black Sea through the Bosphorus. The Mediterranean species which were occasionally found in the Bosphorus were included in several lists of the Black Sea copepod species (Shmeleva et al., 2009).

During the second half of the twentieth century, research revealed serious changes in the copepod community caused by intensive human activities in the Black Sea (Belmonte et al., 1994; Gubanova et al., 2002). The occasional introduction of alien species into the Black Sea can be deemed as the most serious anthropogenic impact. The invasion of the predatory ctenophore *Mnemiopsis leidyi* in the Black Sea is consequently considered one of the most catastrophic invasions known to date (Boxshall, 2007; Oğuz and Öztürk, 2011). It has led to dramatic changes in plankton biodiversity, both in general as well as

* Corresponding author. Tel.: +380 692 54 24 84; fax: +380 692 55 78 13.
E-mail address: adgubanova@gmail.com (A. Gubanova).

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in the copepod community (Altukhov and Gubanova, 2006; Kamburska et al., 2003).

Recent reports on new findings of alien copepod species have appeared rather frequently (Selifonova et al., 2008; Shmeleva et al., 2008, 2009). Finally, eight species of *Acartia* new for science were found in the Black Sea: *A. eremeevi*, *A. hasanii*, *A. ioannae*, *A. janetae* *A. lamasii*, *A. mollicula*, *A. vivesei* and *A. zaitsevi* (Pavlova and Shmeleva, 2010).

For the above reasons the list of copepod species presented in the "Guidebook for Marine Fauna of the Black Sea and the Sea of Azov" (Dolgopolskaya et al., 1969) does not correspond to the present day species composition of copepods.

In this paper we (i) discuss changes in the species composition of copepods from the 1970s to the present; (ii) review the list of native copepod species; and (iii) finally present the updated list of the Black Sea marine planktonic copepods.

2. Materials and methods

The present study is based on historical data, data obtained during the SESAME scientific cruises and current literature.

The historical data include detailed taxonomic analysis of zooplankton samples carried out by scientists from Bulgaria, Romania, Russia, Turkey and the Ukraine within the framework of national monitoring and research programs and a number of international research projects (such as the NATO Hydroblack program, GEF projects, the NATO TU-Black Sea project and TUBITAK). The historical data were mainly obtained from the SESAME biological database (http://isramar.ocean.org.il/sesamemeta/).

Data gathered during the SESAME cruises (spring and autumn of 2008) were issued from the detailed taxonomic analysis of 211 samples collected in the Bulgarian, Romanian and Russian regions of the Black Sea.

In total, data obtained from over 3500 samples acquired at 942 geographical locations and which cover the entire Black Sea for the period from1954 to 2009 are used in this study (Fig. 1).

Samples were collected by vertical hauls using plankton nets of different types (mesh sizes 100–180 μm). A Nansen net (mesh size 300 μm) was used by the Institute of Marine Sciences (Turkey). All nets allowed the capture of adult individuals of all copepod species in the Black Sea. Samples were fixed with a 4% formaldehyde solution and zooplankton counts were made under stereomicroscopes. The copepods were identified up to species level.

Only the marine pelagic Black Sea copepod species are considered in the study. Freshwater species recorded in the river estuaries and coastal lagoons have not been taken into account.

3. Results and discussion

3.1. Inventory of the Black Sea copepods list. Native species

Despite the fact that the Black Sea fauna is mainly of Mediterranean origin, it is much less diverse. It has been found that the overall species biodiversity of the Black Sea is 3.5–4 fold less than in the Mediterranean (Mordukhay-Boltovskoy, 1972; Zaika, 2000), which can be explained by specific features of the Black Sea basin. This is because the low salinity (17–18 versus 37–39 in the Mediterranean Sea), low winter water temperature and hydrogen sulfide below 200 m depth form ecological barriers for the penetration of zooplanktonic Mediterranean species. In the mid-twentieth century, 13 species and 1 form of copepods were included in the Guidebook for Marine Fauna of the Black Sea and the Sea of Azov (Dolgopolskaya et al., 1969) (Table 1).

The names and status of some species in the taxonomic classification system have been revised. It is important to note these changes to avoid confusion in taxonomy and to routinely monitor ongoing changes within the copepod community.

3.1.1. Species whose names have been changed

Centropages kroyeri was first described as being from the Mediterranean Sea (Giesbrecht, 1892). Karavaev (1895) found differences in the morphology of the fifth pair of legs in specimens from the Black Sea and designated these to be the variety *C. kroyeri* var. *pontica* (Sazhina and Kovalev, 1971). He supposed that these differences were distinctive for the Black Sea community of *C. kroyeri*. Gurney (1927) found specimens similar to *C. kroyeri* var. *pontica* in the Suez Canal and deduced that this was not the Black Sea variety but a separate species. Later Kovalev (1967), based on materials collected from different seas of the Mediterranean basin (including the Black Sea), proved *C. ponticus* Karavaev, 1895 to be a species separate from *C. kroyeri*.

Oithona minuta was firstly found in the Black Sea by Krichagin (1873). Giesbrecht (1892), having no knowledge of Krichagin's paper, described the same species from the Mediterranean Sea as *O. nana*. The latter name was used in copepod publications throughout the world. Nevertheless, this species continues to be cited as *O. minuta* in several publications on the Black Sea zooplankton (Koval, 1984). Sazhina and Kovalev (1971) noted that such nomenclature inconsistency has led to some confusion in taxonomic publications. Moreover, in

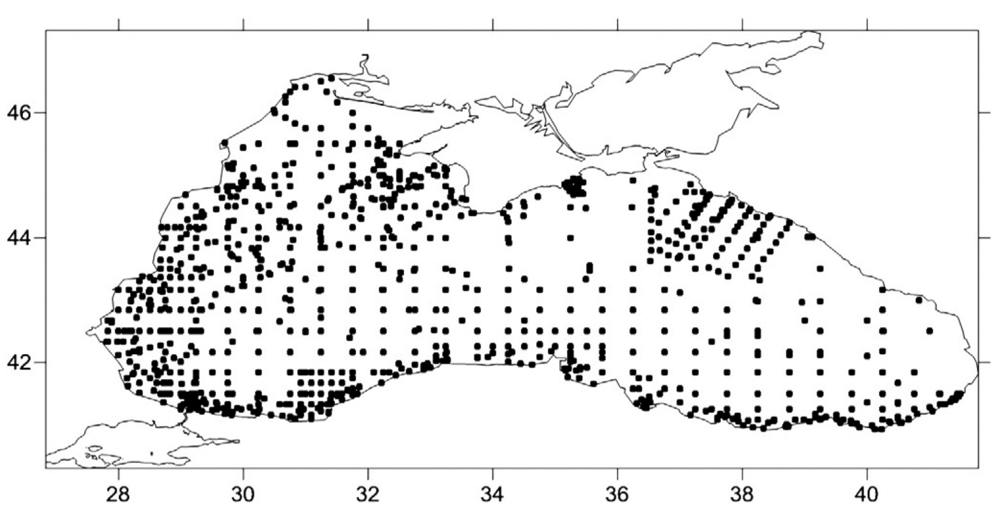

Fig. 1. Map of mesozooplankton stations sampled in the Black Sea during 1954–2009.

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Table 1
Marine planktonic copepod species recorded in the Black Sea until 1969.

Valid species name	Species name according to the guidebook (Dolgopolskaya et al., 1969)
Acartia (*Acartiura*) *margalefi* Alcaraz, 1976	*Acartia clausi* (small form) Potemkina, 1940
Acartia (*Acartiura*) *clausi* Giesbrecht, 1892	*Acartia* (*Acartiura*) *clausi* Giesbrecht, 1892
Anomalocera patersoni Templeton, 1837	*Anomalocera patersoni* Templeton, 1837
Calanus euxinus Hulsemann, 1991	*Calanus helgolandicus* Claus, 1863
Centropages ponticus Karavaev, 1894	*Centropages kroyeri pontica*, Karavaev, 1894
Labidocera brunescens (Czerniavsky, 1868)	*Labidocera brunescens* Czernjavsky, 1868
Oithona nana Giesbrecht, 1892	*Oithona minuta* (Krichagin, 1873)
Oithona similis Claus, 1866	*Oithona similis* Claus, 1866
Paracartia latisetosa (Krichagin, 1873)	*Paracartia latisetosa* (Krichagin, 1873)
Paracalanus parvus (Claus, 1863)	*Paracalanus parvus* (Claus, 1863)
Pontella mediterranea (Claus, 1863)	*Pontella mediterranea* Claus, 1863
Pseudocalanus elongatus (Boeck, 1865)	*Pseudocalanus elongatus* (Boeck, 1865)
Acartia (*Acanthacartia*) *italica* Steuer, 1910	*Acartia* (*Acanthacartia*) *italica* Steuer, 1910
Centropages spinosus (Krichagin, 1873)	*Centropages spinosus* (Krichagin, 1873)

1894 the name *Oithona* (*Dioithona*) *minuta* was given by Scott (1894b) to a species with a different morphology and natural habitat than that of *O. nana* (Shuvalov, 1980). Thus, despite Krichagin (1873) discovered this species, the valid common name for this Black Sea copepod species *O. nana* (Giesbrecht, 1892) should be accepted and used.

Specimens morphologically identical to *Acartia clausi* but 1.5 fold smaller were firstly reported in the Black Sea by Potemkina (1940). This species was classified as a small form of *A. clausi* until Belmonte and Mazzocchi (1997) revealed morphological differences with *A. clausi* and identified it as *Acartia margalefi* (Alcaraz, 1976). Apparently, this smaller species existed in the Black Sea prior to 1940 but had not been identified as a separate species due to its morphological similarities with *A. clausi* (Fig. 2).

There is only one species of the genus *Calanus* in the Black Sea. A detailed history of its study is presented by Unal et al. (2006). Until recently it was known in the Black Sea as *Calanus helgolandicus*, whose geographical range extended from the temperate North Atlantic Ocean to the Mediterranean Sea. Based on some morphometric characteristics (the prosome:urosome ratio) and the different distribution of supernumerary pores overlying the integumental glands of the female urosome, Fleminger and Hulsemann (1987) recognized the Black Sea population as a distinct species —*Calanus ponticus*. In 1991 a new name —*Calanus euxinus* —was given to this species by Hulsemann (1991). According to these authors, *C. euxinus* is an endemic Black Sea species. Papadopoulos et al. (2005) and Unal et al. (2006) further highlighted the problem following genetic analysis of *C. euxinus* (from the Black Sea) and *C. helgolandicus* (from the NE Atlantic and Adriatic Sea). They showed both species to be closely related, with genetic deviation between 0.22% and 0.57%, typical for conspecific communities. For this reason, the morphological and genetic similarities between *C. euxinus* and *C. helgolandicus* raised new questions about the status of *C. euxinus* as a different species. Therefore, Isinibilir et al. (2011) have suggested that var. *euxinus* be added to the species name of *C. helgolandicus* from the Black Sea population. Thus the issue of the Black Sea *Calanus* population remains open (Yebra et al., 2011).

3.1.2. Species from the Guidebook for Marine Fauna of the Black Sea and the Sea of Azov (1969) with insufficient information

Acartia italica has only once been reported in the Black Sea. A few adult specimens were found in samples collected near the Crimean coast in 1940 (Potemkina, 1940). This species has neither been reported before or since 1940. Probably, it was an alien species with occasional occurrence.

Centropages spinosus was described by Krichagin (1873) for the Kerchenskiy Strait of the Black Sea as a scientifically new species. The basic features of the species coincide with those of *C. kroyeri*. Some differences in the prosome length:width ratio of the male were considered a specific indication by Krichagin but later these differences were attributed to allometric changes (Sazhina and Kovalev, 1971). Krichagin did not again mention *C. spinosus* in any subsequent publications and for 130 years no other author has reported this species. Nevertheless, a female specimen of *C. spinosus* was recently described and male specimens redescribed (Shmeleva, 2005), both found in Sevastopol Bay. The author claimed that the species was recorded in all areas of the Black Sea according to her own unpublished data. However, no other researchers have yet confirmed these findings —*C. spinosus* has not been reported in Sevastopol Bay in a number of papers (e.g. Greze et al., 1971; Gubanova, 2003b; Gubanova et al., 2002; Hubareva et al., 2004; Kovalev, 1980; Pavlova et al., 1999; Prusova and Shadrin, 1983). The species is also notably absent from the SESAME database on biological data (http://isramar.ocean.org.il/sesamemeta/). There is therefore insufficient information to confirm the existence of *C. spinosus* communities in the Black Sea.

3.1.3. Species which have disappeared

Changes in the composition of copepod assemblages from the beginning of the twentieth century until the present are illustrated in Fig. 2. Three species disappeared in the1980s and 1990s.

Paracartia latisetosa was a thermophilic species which inhabited coastal areas of the Black Sea. It was an abundant species occurring in bays from the months of July to October (Petipa, 1959). *P. latisetosa* produced resting eggs in response to low temperatures during the cold seasons of the year which resulted in a state of dormancy throughout the *P. latisetosa* community. The changes in the copepod community of the Black Sea have been recorded since the 1970s when strong eutrophication and pollution in the coastal areas were firstly observed (Gubanov et al., 1996). At this period the abundance of *P. latisetosa*

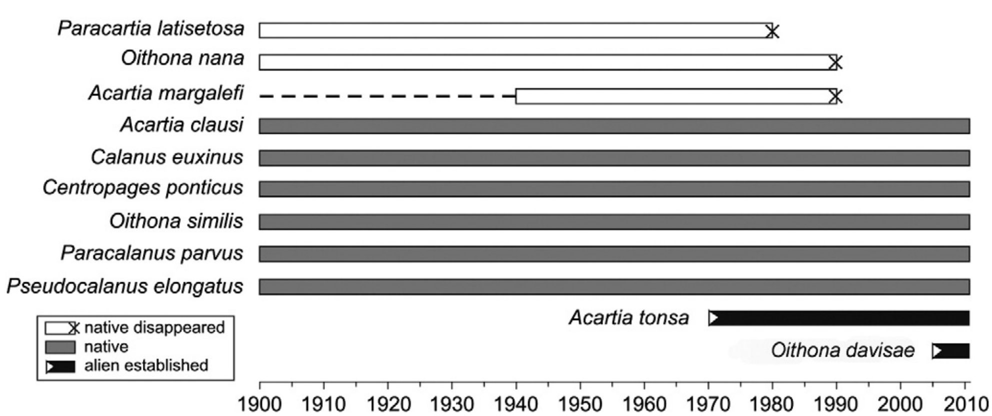

Fig. 2. Changes in the species composition of common species of the Black Sea from the beginning of the twentieth century to the present day.

Table 2
Questionable alien species recorded in Sevastopol Bay (1); Chernaya river estuary, Sevastopol Bay (2); Western Black Sea (3); and Novorossiysk Bay (4).

Name of species according to cited source	Area	Source
Acartia danae	3	Selifonova et al., 2008
Acartia negligens	4	Selifonova and Shmeleva, 2007
Acrocalanus gibber	3	Selifonova et al., 2008
Acrocalanus monachus	3	Selifonova et al., 2008
Calocalanus sp.	1	Murina et al., 2002
Calocalanus gracilis	3	Selifonova et al., 2008
Calocalanus grezei	3	Selifonova et al., 2008
Calocalanus pavo	2	Shmeleva et al., 2008
Calocalanus pavoninus	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Calocalanus sp. (small form)	3	Selifonova et al., 2008
Calocalanus tenuis	2	Shmeleva et al., 2008
Candacia sp.	3	Selifonova et al., 2008
Canthocalanus pauper	3	Selifonova et al., 2008
Centropages bradyi	3	Selifonova et al., 2008
Centropages furcatus	3	Selifonova et al., 2008
Centropages kroyeri	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Centropages ponticus	3	Selifonova et al., 2008
Centropages sp.	3	Selifonova et al., 2008
Centropages violaceus	3; 4	Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Clausocalanus parapergens	2	Shmeleva et al., 2008
Clausocalanus furcatus	4	Selifonova and Shmeleva, 2007
Clausocalanus sp.	1	Murina et al., 2002
Copilia sp.	3	Selifonova et al., 2008
Corycaeus sp. (small form)	3	Selifonova et al., 2008
Corycaeus speciosus	3	Selifonova et al., 2008
Corycaeus furcifer	4	Selifonova and Shmeleva, 2007
Corycella rostrata[1]	4	Selifonova and Shmeleva, 2007
Corycella sp.[2]	1	Murina et al., 2002
Ctenocalanus sp.	3	Selifonova et al., 2008
Cyclopina gracilis	2	Shmeleva et al., 2008
Cyclopoida	3	Selifonova et al., 2008
Delius nudus[3]	3	Selifonova et al., 2008
Euchirella sp.	3	Selifonova et al., 2008
Euterpina acutifrons	4	Selifonova and Shmeleva, 2007
Heterorhabdus sp.	3	Selifonova et al., 2008
Lucicutia sp.	1	Murina et al., 2002
Mecynocera clausi	2	Shmeleva et al., 2008
Metridia sp.	3	Selifonova et al., 2008
Microsetella rosea	4	Selifonova and Shmeleva, 2007
Microsetella sp.	1	Murina et al., 2002
Oithona brevicornis	2; 3; 4	Shmeleva et al., 2008; Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Oithona decipiens	2	Shmeleva et al., 2008
Oithona nana	3	Selifonova et al., 2008
Oithona plumifera	4	Selifonova and Shmeleva, 2007
Oithona similis	3	Selifonova et al., 2008
Oithona simplex	3; 4	Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Oncaea clevei	4	Selifonova and Shmeleva, 2007
Oncaea conifera[4]	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Oncaea dentipes[5]	1; 4	Murina et al., 2002; Selifonova and Shmeleva, 2007
Oncaea ivlevi[6]	3	Selifonova et al., 2008
Oncaea mediterranea	1; 4	Murina et al., 2002; Selifonova and Shmeleva, 2007
Oncaea media	4	Selifonova and Shmeleva, 2007
Oncaea minuta[7]	4	Selifonova and Shmeleva, 2007
Oncaea sp.	3	Selifonova et al., 2008
Oncaea subtilis[8]	1; 4	Murina et al., 2002; Selifonova and Shmeleva, 2007
Oncaea venella	2; 3; 4	Shmeleva et al., 2008; Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Oncaea venusta	4	Selifonova and Shmeleva, 2007
Oncaea venusta var. *venella*	1	Murina et al., 2002
Oncaea vodjanitskii	4	Selifonova and Shmeleva, 2007
Oncaea zernovi	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Oncaea zernovi	3; 4	Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Paracalanus aculeatus	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Paracalanus dendatus	4	Selifonova and Shmeleva, 2007
Paracalanus indicus	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Paracalanus indicus	3	Selifonova et al., 2008
Paracalanus nanus	3; 4	Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Paracalanus pygmaeus	2; 4	Shmeleva et al., 2008; Selifonova and Shmeleva, 2007
Paracalanus quasimodo	2	Shmeleva et al., 2008
Paracalanus sp. (small form)	3	Selifonova et al., 2008
Paracartia grani	3	Selifonova et al., 2008
Parvocalanus crassirostris	3; 4	Selifonova et al., 2008; Selifonova and Shmeleva, 2007
Pleuromamma gracilis	4	Selifonova and Shmeleva, 2007
Pleuromamma indica	3	Selifonova et al., 2008
Pontellina sp.	3	Selifonova et al., 2008
Sapphirella sp.	3	Selifonova et al., 2008
Scolecithricella sp.	3	Selifonova et al., 2008
Scolecithrix bradyi	3	Selifonova et al., 2008
Temora discaudata	3	Selifonova et al., 2008
Temora turbinata	3	Selifonova et al., 2008
Temora stylifera	4	Selifonova and Shmeleva, 2007

Current valid names of species as follows: 1 — *Farranula rostrata*; 2 — *Farranula* sp.; 3 — *Delibus nudus*; 4 — *Triconia conifera*; 5 — *Triconia dentipes*; 6 — *Spinoncaea ivlevi*;, 7 — *Triconia minuta*; 8 — *Monothula subtilis*.

decreased sharply. Later on this species disappeared completely from the Black Sea (Gubanova, 2003a).

Acartia margalefi was a eurythermic species. This species mainly inhabited bays, where it was dominant during summer and was one of the most abundant copepods until the late 1980s (Gubanova et al., 2002; Prusova and Shadrin, 1983).

Oithona nana was also a eurythermic species, mostly abundant in the neritic areas of the Black Sea and revealed high abundance values in September (Greze et al., 1971; Gubanova et al., 2001). The unforeseen and highly destructive mass invasion of *M. leidyi* into the Black Sea in the early 1980s severely increased the grazing pressure on plankton in the late 1980s and early 1990s, especially during the summer and autumn months (Gubanova et al., 2002; Konsulov and Kamburska, 1997). As a result, the number of copepods, including the former dominant species *O. nana* and *A. margalefi*, fell drastically. These species later disappeared completely from the copepod community (Gubanova et al., 2001).

3.2. Alien species

Numerous information on alien species in the Black Sea has been accumulated over the past 20 years. The role and status of alien copepods in the Black Sea ecosystem vary: species established in the entire Black Sea, species found in the area surrounding the Bosphorus but not reproducing in the Black Sea, species recorded only once, and species with inaccurate information. At present we have yet to determine which of the alien species have become naturalized in the Black Sea and therefore integrated into the copepod community. Consequently such species may be included in an updated list of the Black Sea marine planktonic copepods.

3.2.1. Established species

Acartia tonsa appeared in the Black Sea in the early 1970s (Gubanova, 2000). It can be supposed that *A. tonsa* replaced the native *P. latisetosa* (see 3.1.3), because these species occupied the same ecological niche, but the alien *A. tonsa* was apparently more resistant to pollution and eutrophication than *P. latisetosa* (Gubanova, 2003a).

Some specimens of a cyclopoid copepod new to the Black Sea were first found in Sevastopol Bay in December 2001. The species was identified as *Oithona brevicornis* (Zagorodnyaya, 2002). The species also registered as *O. brevicornis* has been routinely observed in samples taken since the mid 2000s (Altukhov and Gubanova, 2006; Mihneva and Stefanova, 2011; Selifonova, 2009). Recently, the species was re-identified as *Oithona davisae* (Temnykh and Nishida, 2012). Consequently, *O. brevicornis* and *O. davisae* are two different names for the same Black Sea species, but *O. davisae* is accepted as the correct name.

After the first appearance of *O. davisae* in Sevastopol Bay, specimens were found again in 2005. In the period from 2006 to 2009, the average annual abundance of *O. davisae* increased considerably (Altukhov and Gubanova, unpublished data). The invader has been expanding along the Black Sea coast since 2009 (Altukhov, 2010; Mihneva and Stefanova, 2011; Selifonova, 2011).

One of the results of the destructive invasion of *M. leidyi* in the 1990s was the complete disappearance of *O. nana* (see Section 3.1.3). In the early 2000s, *Beroe ovata* reduced the grazing pressure of *M. leidyi* on zooplankton especially in the summer and autumn months (Gubanova, 2003b; Hubareva et al., 2004; Kideys, 2002). The absence of *O. nana* coupled with the reduced grazing pressure of *M. leidyi* played a significant role in the successful development of *O. davisae* in the Black Sea. *O. nana* and *O. davisae* are closely related species; they are of similar size and share, the same seasonal dynamics and habitat in the Black Sea (Gubanova and Altukhov, 2007). We can therefore conclude that these species are ecologically very similar within the planktonic community. *O. davisae* has most likely occupied the empty ecological niche.

Acartia tonsa and *O. davisae* have survived in their new Black Sea environment, reproduced there and established self-sustaining populations. Thus, they fit the term “established species”: introduced or feral community of species established in the wild with free-living, self-maintaining and self-perpetuating communities unsupported by and independent of humans (European commission, 2004).

To become established, these species have had to adapt to relatively low salinities and low winter temperatures. Both *A. tonsa* and *O. davisae* inhabit the upper layer and are distributed along the coastal areas of their native basins (Paffenhofer and Stearns, 1988; Temnykh and Nishida, 2012; Uye and Sano, 1995). *O. davisae* are abundant all year round being more plentiful in autumn. *A. tonsa* is a thermophilic species and produces resting eggs. Therefore, the community of *A. tonsa* is in a dormant state during the cold season in the Black Sea. The hatching of the resting eggs is triggered by an increase in temperature in the spring and summer (Gubanova, 2000; Lee and McAlice, 1979). Both species are tolerant to changes in salinity, and *A. tonsa* is tolerant to a wide salinity range of 2–33 psu (Calliari et al., 2006). According to an experimental study, the salinity tolerance of *O. davisae* ranges within 3–40 psu (Svetlichny and Hubareva, unpublished data).

The successful introduction and later establishment of a species depend not only on the biology of the alien species but also on the recipient community conditions. Usually, the invasion of a new species follows a number of changes to the ecosystem (Alimov et al., 2004).The low resilience of the native zooplankton community to invasions of new copepods in the Black Sea has been preconditioned by changes in the ecosystem caused by eutrophication, pollution, overfishing (1970s–1980s) and invasions of the predatory ctenophores (1990s; 2000s).

3.2.2. Non-established species

Comprehensive research of the dynamics and water exchange between the Sea of Marmara and the Black Sea via the Bosphorus was launched in the 1960s. The adjacent regions of the Black Sea and the Sea of Marmara are of particular interest since these areas could be considered as natural laboratories for the survival of organisms inhabiting water bodies with sharp gradients in the physical and chemical characteristics (Svetlichny et al., 2006).

Approximately fifteen Mediterranean copepod species were recorded in the Black Sea in the 1960s near the Bosphorus (Pavlova, 1965). The salinity at the depths where these species were recorded was higher than typical for the Black Sea and the number of the Mediterranean copepods in this area depended on the intensity of the water inflow from the Mediterranean into the Black Sea. Therefore, the occurrence of Mediterranean species may be considered a bio-indication of Mediterranean water inflow to the Black Sea through the lower Bosphorus current (Kovalev et al., 1976).

At the same time a number of species of Mediterranean mollusks, fish and amphipods were found in the Black Sea. These findings triggered the hypothesis termed the mediterranization of Black Sea fauna (Puzanov, 1967). Mediterranization currently means the enrichment of Black Sea fauna with Mediterranean species via the Bosphorus. I. Puzanov (1967) did not rule out that findings of new species might be a result of an intensification of research. However two scenarios of future mediterranization were supposed: a) an increase in the salinity of the Black Sea because of a reduction in river discharges will permit Mediterranean stenohaline species to spread into the Black Sea; b) the acclimatization and adaptation of Mediterranean species to the lower salinity and temperature in the Bosphorus area and the ensuing expansion into other areas of the Black Sea.

An attempt was made to consider the hypothesis of mediterranization also for the zooplankton species (Bogdanova and Shmeleva, 1967; Porumb, 1980; Selifonova et al., 2008). Kovalev et al. (1998) summarized data for all copepod species found in the Bosphorus area from the 1960s until 1996. About 60 copepod species were included in the list, but until now, this number remains unconfirmed. Species of copepods discovered in the area around the Bosphorus have not become established in the Black Sea. On the contrary, all established zooplankton species such as the copepods *A. tonsa*, *O. davisae* and the ctenophores *M. leidyi* and *B. ovata* are the euryhaline species of the epiplanktonic assemblage. They have been introduced to the Black Sea in ships' ballast waters, not via the lower Bosphorus current (Konsulov et al., 1998; Shiganova et al., 2008; Stefanova et al., 2010).

An example of successful invasion was the establishment of the pelagic copepod species *A. tonsa* in the Black Sea. This species was documented as an example of successful mediterranization (Kovalev et al., 1998; Oğuz and Öztürk, 2011). However detailed study has revealed that *A. tonsa* occurred in the Black Sea earlier than in the Mediterranean (Gubanova, 2000). Most probably *A. tonsa* was transferred to the Black Sea with ballast water from another oceanic region of the world.

Contrary to the hypothesis of mediterranization of the Black Sea zooplankton, it has recently been shown that the Bosphorus plays the role of a natural ecological barrier (Oğuz and Öztürk, 2011). Zooplankton penetrates into the Black Sea via the Bosphorus through the bottom Mediterranean outflow and descends to the Black Sea cold intermediate layer where the temperature is 6–8 °C. In this layer, thermophilic and halophilic Mediterranean species experience low salinity and a temperature shock that results in extremely high mortality (Isinibilir et al., 2011). According to Zenetos et al. (2005, 2010) those species which have only periodically been found in the Bosphorus area are classified as casual (such species are determined as those having been recorded only once in scientific literature and are therefore presumed to be non-established in the Black Sea basin).

3.2.3. Alien species with insufficient information

A number of papers presenting the lists of species foreign to the Black Sea appeared in the 2000s (Murina et al., 2002; Selifonova et al., 2008; Shmeleva et al., 2008) with an unusually high number of alien species recorded (Table 2). Unfortunately, neither photos nor drawings of alien species were provided in these papers and any information on the species' frequency of occurrence and the number of examined samples was unavailable. Generally, no vectors of introduction were discussed and the proposed ideas were questionable. It was assumed (Selifonova et al., 2008) that these invaders had most likely been introduced by the lower Bosphorus flow. However, according to geographic distribution maps by Razouls et al. (2005–2012) only six species from the presented lists were found in the Aegean Sea, which is connected to the Sea of Marmara and the Black Sea by the Dardanelles and the Bosphorus. The remaining species are found in different regions —*Temora*

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Table 3
Species of *Acartia* genus new to science, which appeared in sources published in 2002–2010.

No.	Species, author(s)	Area of the species origin	Format of the source, in which the species is first described
1	*Acartia eremeevi* Shmeleva et al., 2008	No data	No data[a]
2	*A. eremeevi* Pavlova and Shmeleva, 2010	Black Sea	Article
3	*A. hasanii* Unal, Shmeleva & Kideys, 2002	Mediterranean Sea	Article
4	*A. hasanii* Shmeleva and Selifonova, 2005	Black Sea	Pre-symposium abstract
5	*A. ioannae* Unal, Shmeleva & Kideys, 2002	Mediterranean Sea	Article
6	*A. ioannaei* Shmeleva et al., 2008	No data	No data[a]
7	*A. janetae* Unal, Shmeleva & Kideys, 2002	Mediterranean Sea	Article
8	*A. jannetei* Shmeleva and Selifonova, 2005	Black Sea	Pre-symposium abstract
9	*A. lamasii* Shmeleva and Selifonova, 2005	Black Sea	Pre-symposium abstract
10	*A. mollicula* Shmeleva, 2007	No data	No data[b]
11	*A. mollicula* Shmeleva et al., 2008	No data	No data[a]
12	*A. mollicula* Pavlova and Shmeleva, 2010	Black Sea	Article
13	*A. vivesei* Shmeleva et al., 2008	No data	No data[a]
14	*A. zaitsevi* Shmeleva et al., 2008	No data	No data[a]

[a] Names of the species were indicated in the list of the Black Sea copepods (Shmeleva et al., 2009).
[b] Names of the species were indicated in the list of the Black Sea copepods (Shmeleva et al., 2008).

discaudata is common in the Levantine Sea (Eastern Mediterranean), whereas *Calocalanus gracilis*, *Paracalanus indicus*, *Acrocalanus gibber* inhabit the Alboran Sea (Western Mediterranean). *Canthocalanus pauper*, *Pleuromamma indica* and *Temora turbinata* are absent in the Mediterranean but present in the Red Sea as well as in different areas of the Atlantic, Indian and Pacific Oceans and in regions of the sub-Antarctic. Therefore, the high number of cited alien species in the Black Sea cannot be explained solely as a result of natural migration processes. It is also noteworthy that none of these species (Table 2) were found in more than 3500 samples examined in the present study (Fig. 1). According to Zenetos et al. (2005, 2010) categories of such species are questionable (species registered with insufficient background information are doubtful).

3.3. New species

Recently, the list of Black Sea copepods included some *Acartia* species new to science (Shmeleva et al., 2008, 2009) (Table 3). It is obvious that some of the names listed in Table 3 differ only slightly in spelling (no. 5–6 and no. 7–8), and can therefore be regarded as synonymous. Apparently, species cited in different sources (no. 1–2, no. 3–4 and no. 10–12) should be the same. As a result, the referred list can in fact be reduced to eight “correct original spellings” (Article 32 of the International Code of Zoological Nomenclature, hereinafter —ICZN) (Anonymous, 1999), namely, *A. eremeevi*, *A. hasanii*, *A. ioannae*, *A. janetae A. lamasii*, *A. mollicula*, *A. vivesei*, and *A. zaitsevi*. Two of the eight names (*A. vivesei* Shmeleva et al., 2008 and *A. zaitsevi* Shmeleva et al., 2008) have not been confirmed for the purposes of zoological nomenclature due to the complete lack of description. The references to the original descriptions of these species were, unfortunately, not given by Shmeleva et al. (2008, 2009) and it has not been possible to locate these papers in the body of world literature available. The description of *A. lamasii*, firstly reported in pre-symposium abstracts (Shmeleva and Selifonova, 2005), is also absent. Therefore, these three names do not satisfy the provisions of Art. 13 of the ICZN and they are not available for the purposes of zoological nomenclature, and thus should be classified as *Nomina nuda*.

The species *A. hasanii* Unal et al., 2002, *A. ioannae* Unal et al., 2002, *A. janetae* Unal et al., 2002, *A. eremeevi* Pavlova and Shmeleva, 2010, and *A. mollicula* Pavlova and Shmeleva, 2010 were reported in the articles (Pavlova and Shmeleva, 2010; Unal et al., 2002) corresponding to the publication criteria for the purposes of zoological nomenclature. However, the descriptions and drawings depicted in these articles were made without paying attention to details; the text in the species descriptions and their corresponding images include a number of contradictions, which rules out a positive identification. Differential diagnoses for *A. eremeevi* and *A. mollicula* are absent. In addition, fifth legs of *A. eremeevi*, *A. mollicula* (Pavlova and Shmeleva, 2010: Figs. 2-8; 5-5), *A. hasanii*, *A. ioannae* and *A. janetae* (Unal et al., 2002: Figs. 1F, 2D, 3E) correspond to fifth legs of immature specimens of Acartiidae. For this reason, the independent categorization of these five species is questionable.

As a consequence, it is not currently possible to add new species of the genus *Acartia* to the list of the Black Sea species.

3.4. Present state of copepod species composition

Despite the dramatic changes which have occurred in the Black Sea ecosystem during recent decades, the number of marine planktonic copepod species in the Black Sea remains almost the same as at the beginning of the twentieth century (Table 4). The native species *C. euxinus*, *Paracalanus parvus*, *Pseudocalanus elongatus*, *Centropages ponticus*, *A. clausi*, and *Oithona similis* are the most common in both offshore and onshore areas. The recently established copepods *A. tonsa* and *O. davisae* have enriched the assemblage of abundant copepod species of neritic zones. All species found in significant numbers were reported by experts from various areas of the Black Sea. The features of geographical and ecological distribution of copepods are shown in Table 4. The representatives of the copepods family Pontellidae are rare. In general only single individuals of pontellids (*Anomalocera patersoni*, *Labidocera brunescens*, and *Pontella mediterranea*) were found. It should be noted that these hyponeustonic copepods were found in high numbers in the uppermost 5 cm (Zaitsev Yu, 1962) and special nets and methods must be used in order to obtain significant numbers. Apparently,

Table 4
Native and established species of the Black Sea copepod community.

Species name	Comments
Acartia (*Acartiura*) *clausi* Giesbrecht, 1889	Common in neritic areas and offshore all year round
Acartia (*Acanthacartia*) *tonsa Dana, 1849*	Alien species. Established in early 1970s. Common in neritic areas and bays in warm season
Anomalocera patersoni Templeton, 1837	Rare
Calanus euxinus Hulsemann, 1991	Common offshore in all seasons; in neritic areas in cold season
Centropages ponticus Karavaev, 1894	Common in neritic areas in warm season
Labidocera brunescens (Czerniavsky, 1868)	Rare
Oithona davisae Ferrari F.D. & Orsi, 1984	Alien species. Established in early 2005–2006. Common in neritic areas all year round
Oithona similis Claus, 1866	Commson offshore in all seasons; in neritic areas in cold season
Paracalanus parvus (Claus, 1863)	Common in neritic areas and offshore all year round
Pontella mediterranea (Claus, 1863)	Rare
Pseudocalanus elongatus (Boeck, 1865)	Common offshore in all seasons; in neritic areas in cold season

Pontellidae abundance is underestimated when sampling by vertical hauls of a Juday net is performed.

4. Conclusion

Species composition of marine planktonic copepods in the Black Sea is rather poor. The community structure changes considerably by the appearance/disappearance of species. Time-series studies at all areas of the Black Sea are necessary for monitoring these changes. Coordination of efforts of plankton experts from the Black Sea countries is very important and the SESAME Project is a good example of such coordination.

Thus, based on the analysis of a large amount of data (historical, obtained during the SESAME cruises and unpublished) as well as on the available literature, the following conclusions can be drawn:

- Compared to the list from the Guidebook for Marine Fauna of the Black Sea and the Sea of Azov (Dolgopolskaya et al., 1969), the presence of two species (*A. italica* and *C. spinosus*) has not been confirmed, the taxonomic status of two species (*A. clausi* small form and *C. kroyeri pontica*) and the nomenclature of two species (*O. minuta* and *C. helgolandicus*) have been changed.
- Additionally, significant changes have occurred in the composition of the copepod community: three species have disappeared (*A. margalefi*, *O. nana* and *P. latisetosa*) and two species have become naturalized (*A. tonsa and O. davisae*).
- The hypothesis on the mediterranization of the Black Sea zooplankton has not been confirmed. Mediterranean species found occasionally in the Bosphorus area of the Black Sea do not form self-maintaining and self-perpetuating populations and do not expand into the Black Sea itself.
- New copepod species established in the Black Sea have in all likelihood been introduced from the ballast water of shipping vessels.
- A large number of alien species are reported in the Black Sea. However, the information in these reports is insufficient. Until now, none of these species were established and should therefore be removed in the checklists of the Black Sea copepods.
- The widespread application of genetic analysis for accurate taxonomic identification of copepods is still developing; thus the coupling of traditional taxonomic and genetic methods is essential for reliable clarification of copepod diversity in the Black Sea region.
- The updated list of the Black Sea marine planktonic copepods is composed of 11 species.
- The Black Sea is very sensitive to change and should be monitored in the long-term.

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References

Alcaraz, M., 1976. Descripción de *Acartia margalefi*, una especie nueva de Copépodo pelagico, y su relación con *A. clausi*. Investig. Pesq. 40 (1), 59–74.

Alimov, A.F., Bogutskaya, N.G., Orlova, M.I., Paevsky, V.A., Reznik, S.Ya., Kravchenko, O.E., 2004. Anthropogenic dispersal of species of animals and plants beyond the limits of the historical range: process and result. In: Alimov, A.F., Bogutskaya, N.G. (Eds.), Biological Invasions in Aquatic and Terrestrial Ecosystems. KMK Scientific Press Ltd, Moscow – St. Petersburg, pp. 16–83 (in Russian).

Altukhov, D.A., 2010. Distribution of *Oithona brevicornis* (Copepoda: Cyclopoida) community along the Crimean Coast. Mar. Ecol. J. 9 (1), 71 (in Russian).

Altukhov, D.A., Gubanova, A.D., 2006. *Oithona brevicornis* Giesbrecht in October, 2005–March, 2006. Mar. Ecol. J. 5 (2), 32 (in Russian).

(International Commission on Zoological Nomenclature)Anonymous, 1999. International Code of Zoological Nomenclature, Fourth ed. International Trust for Zoological Nomenclature, London 1–306.

Belmonte, G., Mazzocchi, M.G., 1997. Records of *Acartia* (*Acartiura*) *margalefi* (Copepoda, Calanoida, Acartiidae) from the Norwegian and Black seas. Crustaceana 70 (2), 252–256.

Belmonte, G., Mazzocchi, M.G., Prusova, I.Yu., Shadrin, N.V., 1994. *Acartia tonsa*: a species new for the Black Sea fauna. Hydrobiologia 292 (293), 9–15.

Bogdanova, T.K., Shmeleva, A.A., 1967. Hydrologic conditions of introduction of the Mediterranean species into the Black Sea. In: Vodyanitskiy, V.A. (Ed.), Water Dynamics and Issues on Hydrochemistry of the Black Sea. Naukova Dumka, Kiev, pp. 156–166 (in Russian).

Boxshall, G., 2007. Alien species in European coastal waters. Aquat. Invasions 2 (4), 279–280.

Calliari, D., Andersen, C.M., Thor, P., Gorokhova, E., Tiselius, P., 2006. Salinity modulates the energy balance and reproductive success of co-occurring copepods *Acartia tonsa* and *A. clausi* in different ways. Mar. Ecol. Prog. Ser. 312, 177–188.

Chichkoff, G., 1912. Contribution á l'étitude de la faune de la Mer Noire. Animaux écoltés sur les côtes bulgares. Arch. Zool. Exp. Gen. 10 (2), 29–39.

Dolgopolskaya, M.A., 1940. Zooplankton of the Black Sea at the Karadag area. Proc. Karadag Biol. Station. 6, 57–111 (in Russian).

Dolgopolskaya, M.A., Dukina, V.V., Griga, P.E., Sazhina, L.I., 1969. Subclass Copepoda. In: Vodyanitskiy, V.A. (Ed.), Guidebook for Marine Fauna of the Black Sea and the Sea of Azov. The Free-Swimming Crustaceans. 2. Naukova Dumka, Kiev, pp. 34–152 (in Russian).

European Commission, 2004. Environment Directorate-General LIFE Focus I Alien species and nature conservation in the EU. Office for Official Publications of the European Communities, The role of the LIFE program, Luxembourg (http://europa.eu.int/comm/environment/life/infoproducts/alienspecies_en.pdf).

Fleminger, A., Hulsemann, K., 1987. Geographical variation in *Calanus helgolandicus* s.l. (Copepoda, Calanoida) and evidence of recent speciation of the Black Sea community. Biol. Oceanogr. 5, 43–81.

Galadzhiev, M.A., 1948. Comparison of species composition, distribution and abundance of zooplankton in the Karkinitskiy Gulf and open sea at the South Crimea Coast area. Proc. Sevastopol Biol. Station. 6, 173–223 (in Russian).

Giesbrecht, W., 1892. Systematik und Faunistik der pelagischen Copepoden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. Fauna Flora Golf. Neapel, 19 1–831.

Greze, V.N., Baldina, E.P., Bileva, O.K., 1971. Dynamics of the abundance and production of the principal components of zooplankton in the neritic zone of the Black Sea. Mar. Biol. 24, 12–49 (In Russian).

Gubanov, V.I., Klimenko, N.P., Monina, T.L., et al., 1996. Modern state of the pollution of the Black Sea waters. In: Simonov, A.I., Ryabinin, A.I. (Eds.), The Black Sea. Marine Hydrometeorology and Hydrochemistry, ECOSI-Gidrofizika, Sevastopol, p. 230 (in Russian).

Gubanova, A.D., 2000. Occurrence of *Acartia tonsa* Dana in the Black Sea. Was it introduced from the Mediterranean? Mediterr. Mar. Sci. 1 (1), 105–109.

Gubanova, A.D., 2003a. Long-term changes in species composition and abundance of copepods of *Acartia* genus in Sevastopol Bay. In: Eremeev, V.N., Gaevskaya, A.V. (Eds.), Modern conditions of biological diversity in near-shore zone of Crimea (the Black Sea sector). EKOSI-Gidrofizika, Sevastopol, pp. 94–103 (in Russian).

Gubanova, A.D., 2003b. Changes in mesozooplankton community in 2002, in comparison with 1990s. In: Eremeev, V.N., Gaevskaya, A.V. (Eds.), Modern Conditions of Biological Diversity in Near-Shore Zone of Crimea (the Black Sea Sector). EKOSI-Gidrofizika, Sevastopol, pp. 84–94 (in Russian).

Gubanova, A.D., Altukhov, D.A., 2007. Establishment of *Oithona brevicornis* Giesbrecht, 1892 (Copepoda: Cyclopoida) in the Black Sea. Aquat. Invasions 2 (4), 407–410.

Gubanova, A.D., Polikarpov, I.G., Saburova, M.A., Prusova, I.Yu., 2002. Long-term dynamics of mesozooplankton by the example of the Copepoda community in Sevastopol Bay (1976–1996). Oceanology 42 (4), 512–520.

Gubanova, A.D., Prusova, I.Yu., Niermann, U., Shadrin, N.V., Polikarpov, I.G., 2001. Dramatic change in the copepod community in Sevastopol Bay (Black Sea) during two decades (1976–1996). Senckenberg. Marit. 31 (1), 17–27.

Gurney, R., 1927. Zoological results of the Cambridge Expedition to the Suez Canal, 1924. Report on the Crustacea: Copepoda and Cladocera of the plankton. Trans. Zool. Soc. Lond. 2, 139–172.

Hubareva, E.S., Svetlichny, L.S., Romanova, Z.A., Abolmasova, G.I., Anninsky, B.E., Finenko, G.A., Bat, L., Kideys, A., 2004. Zooplankton community state in Sevastopol Bay after the invasion of ctenophore *Beroe ovata* into the Black Sea (1999–2003). Mar. Ecol. J. 3 (1), 39–46.

Hulsemann, K., 1991. *Calanus euxinus*, new name, a replacement name for *Calanus ponticus* Karavaev, 1894 (Copepoda: Calanoida). Proc. Biol. Soc. Wash. 104 (3), 620–621.

Isinibilir, M., Svetlichny, L., Hubareva, E., Yilmaz, I.N., Ustun, F., Belmonte, G., Toklu-Alicli, B., 2011. Adaptability and vulnerability of zooplankton species in the adjacent regions of the Black and Marmara Seas. J. Mar. Syst. 84, 18–27.

Kamburska, L., Doncheva, V., Stefanova, K., 2003. On the recent changes of zooplankton community structure along the Bulgarian Black Sea coast—a post-invasion effect of exotic ctenophores interactions. Proceeding of First Intern. Conf. on Environmental Research and Assessment (Bucharest, Romania, March 23–27, 2002). Docendi Publishing House, Bucharest, Romania, pp. 69–84.

Karavaev, V.A., 1894. Materials on fauna of Copepoda of the Black Sea. Zapiski Kievskogo obschestva Estestvoznateley. Proc. Kiev Soc. Nat. 13 (1), 15–31 (in Russian).

Karavaev, V.A., 1895. Materials on fauna of Copepoda of the Black Sea. Zapiski Kievskogo obschestva Estestvoznateley. Proc. Kiev Soc. Nat. 14, 117–174 (in Russian).

Kideys, A.E., 2002. Fall and rise of the Black Sea ecosystem. Science 297, 1482–1484.

Klyucharev, K.N., 1952. Materials for estimation of abundance of zooplankton at the Karadag Area of the Black Sea. Proc. Karadag Biol. Station. 12, 78–95 (in Russian).

Konsulov, A., Kamburska, L., 1997. Sensitivity to anthropogenic factors of the plankton fauna adjacent to the Bulgarian coast of the Black Sea. NATO ASI Series "Sensitivity to Change: Black Sea, Baltic Sea and North SeaEnvironment, Kluwer Academic publishers 95–104 (2/27).

Konsulov, A., Konsulova, Ts, Prodanov, K., Moncheva, S., Dencheva, K., Kamburska, L., Velikov, A., 1998. State of the art and tendencies for changes in the Black Sea biodiversity in front of the Bulgarian Black Sea coast. In: Kotlyakov, V., Uppenbrink, M., Metreveli, V. (Eds.), "Conservation of the Biological Diversity as a Prerequisite for Sustainable Development in the Black Sea Region" NATO, ASI Series 46. Kluwer Academic Publishers, pp. 101–129.

Koval, L.G., 1984. The zoo- and necrozooplankton of the Black Sea. 1–127 (in Russian).

Kovalev, A.V., 1967. On systematic status and distribution of *Centropages kroyeri* var. *pontica* Karavaev (Crustacea, Copepoda). In: Greze, V.N. (Ed.), Biology and distribution of plankton in southern seas. Nauka, Moscow, pp. 94–99 (in Russian).

Kovalev, A.V., 1980. Seasonal variations in zooplankton of Sevastopol Bay. Hydrobiol. J. 16 (6), 9–14 (in Russian).

Kovalev, A.V., Georgieva, L.V., Baldina, E.P., 1976. Influence of water mass exchange from Bosphorus on the content and distribution of the plankton in the nearest seas. In: Belyaev, V.I. (Ed.), Investigation of water mass exchange from Tunis Channel and Bosporus. Naukova dumka, Kiev, pp. 68–73 (in Russian).

Kovalev, A., Besiktepe, S., Zagorodnyaya, J., Kideys, A., 1998. Mediterranization of the Black Sea zooplankton is continuing. In: Ivanov, L., Oguz, T. (Eds.), Ecosystem Modeling as a Management Tool for the Black Sea. NATO ASI Ser 1, Global Environ Change, Dordrecht; Boston. Kluwer Acad. Publ, London, pp. 199–207.

Krichagin, N., 1873. Report on the faunal studies made at the eastern shores of the Black Sea in summer 1872 on behalf of the Kiev Society of Naturalists. Zapiski Kievskogo Obschestva Estestvoznateley. Proc. Kiev Soc. Nat. 3 (3), 10–15 (in Russian).

Lee, W.Y., McAlice, B.J., 1979. Seasonal succession and breeding cycles of three species of *Acartia* (Copepoda: Calanoida) in a marine estuary. Estuaries 2, 228–235.

Mihneva, V., Stefanova, K., 2011. Zooplankton abundance and biomass dynamics along the Bulgarian Black Sea coast during the period 2008–2010. Proceedings of the Union of Scientist – Varna, pp. 97–104.

Mordukhay-Boltovskoy, F.D., 1972. General characteristics of the fauna of the Black and Azov Seas. In: Vodyanitskiy, V.A. (Ed.), Guidebook for Marine Fauna of the Black Sea and the Sea of Azov. , 3. Naukova Dumka, Kiev, pp. 316–324 (in Russian).

Murina, G.-V., Shmeleva, A.A., Licitskaya, E.V., 2002. Annual monitoring mero- and holoplankton in Sevastopol Bay oceanarium. Hydrobiol. J. 38 (3), 3–11 (in Russian).

Oğuz, T., Öztürk, B., 2011. Mechanisms impeding natural mediterranization process of Black Sea fauna. J. Black Sea Mediterr. Environ. 17 (3), 234–253.

Paffenhofer, G., Stearns, D.E., 1988. Why is *Acartia tonsa* (Copepoda: Calanoida) restricted to nearshore environments? Mar. Ecol. Prog. Ser. 42, 33–38.

Papadopoulos, L.N., Peijnenburg, K.T.C.A., Luttikhuizen, P.C., 2005. Phylogeography of the calanoid copepods *Calanus helgolandicus* and *C. euxinus* suggests pleistocene divergences between Atlantic, Mediterranean, and Black Sea communities. Mar. Biol. 147, 1353–1365.

Pavlova, E.V., 1965. Penetration of the Mediterranean planktonic organisms into the Black Sea. Basic Features of Geological Structure, Hydrological Conditions and Biology of the Mediterranean Sea, pp. 171–174 (in Russian).

Pavlova, E.V., Ovsyanyi, E.I., Gordina, A.D., Romanov, A.S., Kemp, R.B., 1999. Modern state and trends of ecosystem of Sevastopol Bay. In: Pavlova, E.V., Shadrin, N.V. (Eds.), The Water Area and the Coast of Sevastopol: Ecosystem Processes and Services to the Public. Akvavita, Sevastopol, pp. 70–95 (in Russian).

Pavlova, E.V., Shmeleva, A.A., 2010. Two new copepods of the genus *Acartia* (Copepoda, Calanoida, Acartiidae) from the coastal sea of the south-western Crimea (Black Sea). Vestn. Zool. 44 (2), 99–106.

Petipa, T.S., 1959. Feeding of *Acartia clausi* Giesbr. and *A. latisetosa* Kritcz. in the Black Sea. Proc. Sevastopol Biol. Station. 12, 130–152 (in Russian).

Porumb, F., 1980. Developpement du zooplancton dans les conditions d'eutrophisation des eaux du littoral Roumain de la Mer Noire. Journees Etud. Pollutions, Cagliari, CIESM, Cagliari. 881–886.

Potemkina, D.A., 1940. Age stages of some Copepoda of the Black Sea. Zool. Zh. 19 (1), 119–125 (in Russian).

Prusova, I. Yu, Shadrin, N.V., 1983. Seasonal changes in the number and size of the two forms of *Acartia clausi* Giesbr. Sevastopol Bay. Marine Ecology (Ecologiya Morya), 15, pp. 17–19 (in Russian).

Puzanov, I., 1967. Mediterranization of fauna of the Black Sea and prospect of its strengthening. Zool. Zh. 46 (9), 1287 (in Russian).

Razouls, C., de Bovée, F., Kouwenberg, J., et Desreumaux, N., 2005–2012. Diversity and geographic distribution of marine planktonic copepods. Available at http://copepodes.obs-banyuls.fr/en.

Sazhina, L.I., Kovalev, A.V., 1971. About synonymy of copepods of the Black Sea. Zool. Zh. 50, 1099–1101 (in Russian).

Scott, T., 1894. Report on Entomostra from the Gulf of Guinea, collected by John Rattrey, B.Sc. Trans. Linn. Soc. Lond. Zool. 2 (6), 90.

Selifonova, J.P., 2009. *Oithona brevicornis* Giesbrecht (Copepoda, Cyclopoida) in ports of north-eastern shelf of the Black Sea. Inland Water Biol. 2, 30–32 (in Russian).

Selifonova, J.P., 2011. Invader *Oithona brevicornis* Giesbrecht (Copepoda, Cyclopoida) in the Black and the Azov Seas. Russ. J. Biol. Invasion 2, 142–150 (in Russian).

Selifonova, J., Shmeleva, A., Kideys, A., 2008. Study of copepod species from the Western Black Sea in the cruise r/v Knorr during May–June 2001. Acta Zool. Bulg. 60 (3), 305–309.

Selifonova, J.P., Shmeleva, A.A., 2007. Study of Copepoda fauna in Novorossiysk Bay of the Black Sea and in the Sea of Azov. Gidrobiologicheskiy Zhurnal 43 (5), 27–35 (in Russian).

Shiganova, T., Musaeva, E., Araskievich, E., Kamburska, L., Stefanova, K., Michneva, V., Polishchuk, L., Timofte, F., Ustun, F., Oguz, T., Khalvashi, M., 2008. The State of zooplankton. In: Oguz, Temel (Ed.), State of the Environment of the Black Sea, Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC) 3. BSC (Black Sea Commission), Istanbul, Turkey, pp. 201–246.

Shmeleva, A.A., Selifonova, J.P., 2005. Three new species of *Acartia* (Copepoda, Calanoida, Acartiidae) from the Black Sea. 9 Inter. Conf. of Copepoda (Hammamet, Tunisia, July 11–15, 2005), p. 57.

Shmeleva, A.A., 2005. Description of the female and redescription of the male *Centropages spinosus* (Kriczagin, 1873) (Copepoda, Centropagidae). Vestn. Zool. 39 (6), 65–69 (in Russian).

Shmeleva, A., Murina, V., Grintsov, V., Sherban, S., Garlitskaja, A., 2008. Invertebrates of the Chernaya River estuary (Sevastopol, Black Sea). Bull. Mosc. Soc. Nat. 13 (5), 31–36 (in Russian).

Shmeleva, A., Pavlova, E., Shcherban', S., 2009. Main steps and results of researches of Copepoda (Crustacea) in the Black Sea: review. In: Akimov, I.A., Eremeev, V.N., Morozova, A.L., Zaitcev, Yu (Eds.), Karadag-2009, pp. 313–326 (in Russian).

Shuvalov, V.S., 1980. Cyclopoid copepods of Oithonidae family of the World Ocean. Nauka, Leningrad 1–197 (in Russian).

Stefanova, K., Kamburska, L., Gubanova, A., Altukhov, D., 2010. Temporal fluctuations of zooplankton communities in Varna Bay (western Black Sea) and Sevastopol Bay (northern Black Sea): a comparative study. In: Gislason, A., Gorsky, G. (Eds.), Proceedings of the "Joint ICES/CIESM Workshop to Compare Zooplankton Ecology and Methodologies between the Mediterranean and the North Atlantic (WKZEM)". ICES Cooperative Research Report, 300, pp. 70–75.

Svetlichny, L.S., Hubareva, E.S., Kideys, A.E., Isinibilir, M., Shmeleva, A.A., 2006. Zooplankton community state in the Northeastern Marmara Sea during early autumn with comments on mass mortality of the Black Sea species due to the salinity gradient. J. Black Sea Mediterr. Environ. 12, 213–231.

Temnykh, A., Nishida, S., 2012. New record of the planktonic copepod *Oithona davisae* Ferrari and Orsi in the Black Sea with notes on the identity of "*Oithona brevicornis*". Aquat. Invasions 7 (3), 425–431.

Ulomskiy, S.N., 1940. Guidebook of Calanoida and Cyclopoida of the Black Sea. Proc. Karadag Biol. Station. 6, 145–171 (in Ukrainian).

Unal, E., Frost, B., Armbrust, V., Kideys, A., 2006. Phylogeography of *Calanus helgolandicus* and the Black Sea copepod *Calanus euxinus*, with notes on *Pseudocalanus elongatus* (Copepoda, Calanoida). Deep-Sea Res. 2 (53), 1911–1922.

Unal, E., Shmeleva, A., Kideys, A., 2002. Three new species of *Acartia* (Copepoda, Calanoida) from the northeastern Levantine Basin. Proceedings of Workshop on Lessepsian Migration, 20–21 July 2002. Turkish Marine Research Foundation (TUDAV), Gokceada, Turkey, pp. 35–39.

Uye, S., Sano, K., 1995. Seasonal reproductive biology of the small cyclopoid copepod *Oithona davisae* in a temperate eutrophic inlet. Mar. Ecol. Prog. Ser. 118, 121–128.

Yebra, L., Bonnet, D., Roger, P., Harris, R.P., Lindequel, P.K., Peijnenburg, K.C.T.A., 2011. Barriers in the pelagic: population structuring of *Calanus helgolandicus* and *C. euxinus* in European waters. Mar. Ecol. Prog. Ser. 428, 135–149.

Zagorodnyaya, Yu.A., 2002. *Oithona brevicornis* in the Sevastopol Bay: a single event or a new invader in the Black Sea fauna? Mar. Ecol. J. 61, 43 (in Russian).

Zaika, V.E., 2000. Marine biodiversity of the Black Sea and Eastern Mediterranean. Ecol. Sea 51, 59–62 (in Russian).

Zaitsev Yu, P., 1962. Tools and methods to study hyponeuston. Vop. Ekol. 4, 107–109 (in Russian).

Zenetos, A., Cinar, M.E., Pancucci-Papadopoulou, M.A., Harmeli, J.G., Furnari, G., Andaloro, F., Bellou, N., Streftaris, N., Zibrowius, H., 2005. Annotated list of marine alien species in the Mediterranean with records of the worst invasive species. Mediterr. Mar. Sci. 6 (2), 63–118.

Zenetos, A., Gofas, S., Verlaque, M., Çinar, M.E., García Raso, J.E., et al., 2010. Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution. Mediterr. Mar. Sci. 11 (2), 381–493.

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