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Research Article

The non-native copepod *Oithona davisae* (Ferrari F.D. and Orsi, 1984) in the Western Black Sea: seasonal and annual abundance variability

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Abstract

A new cyclopoid copepod species, *Oithona davisae* was discovered during regular monitoring along the western coast of the Black Sea in 2009–2012. In the short period since its discovery off the Bulgarian Coast, *O. davisae* populations have increased to become one of the dominant zooplankters, contributing up to 63.5–70.5 % of total mesozooplankton numbers in the Varna Bay and adjacent open sea waters. This species thrived in early autumn with a maximum density of 43818 ind.m^{-3} in the eutrophic Varna Bay, but seasonal and annual abundance fluctuated widely during the investigation period. Temperature variability, changes in the phytoplankton community composition, and decreased abundance of gelatinous plankton were investigated as possible drivers for rapid increase in the new established population *O. davisae* in the Black Sea.

Key words: alien species; abundance fluctuations; zooplankton; Varna Bay

Introduction

Small copepods, such as those of the cyclopoid family *Oithonidae*, are among the most ubiquitous and abundant metazoans in the oceans of the world (Gallienne and Robin 2001; Turner, 2004). Oithonids contribute significantly to secondary production and are an important component of marine trophic chains, presenting a food source for planktivorous fish and many predatory fish larvae (Calbert and Agusti 1999; Saiz et al. 2003; Turner 2004).

Two representatives of *Oithonidae*, namely *Oithona similis* (Claus, 1866) and *Oithona nana* (Giesbrecht, 1893), are thought to be native to the Black Sea. *O. similis* is a deepwater inhabitant that can perform large vertical migrations and is common in the plankton community (Vinogradov 1989). *O. nana*, is an eurythermic copepod that was widely distributed in the region in the 1970's and 1980's, where it was present at high densities in the surface layer. Since the beginning of the 1990's, however, *O. nana* has totally disappeared from the zooplankton community, apparently due to predation by the invasive ctenophore *Mnemiopsis leidyi* (Agassiz, 1865), which became established at this time (Pereladov 1988; Shushkina et al. 1990). Since then, the zooplankton community has been characterized as ctenophore-dominated with devastating consequences on the ecosystem, most notably a major decline of mesozooplankton numbers and fish stocks (Shiganova 1997; Zaitsev and Mamaev 1997). In 1997, the carnivorous ctenophore *Beroe ovata* (Mayer, 1912) was introduced into the Black Sea. It feeds on other ctenophores and has caused a reduction in the concentration of *M. leidyi* (Konsulov and Kamburska 1998; Kideys and Romanova 2001).

Since 2001, a new species of *Oithonidae* initially described as *Oithona brevicornis,* has been collected in Sevastopol Bay, Crimea, Black Sea (Zagorodnyaya 2002; Gubanova and Altukhov 2007). Temnykh and Nishida (2012) recently reassessed the species' identification and concluded that the species' was actually *Oithona davisae* (Ferrari and Orsi, 1984). *O. davisae* inhabits eutrophic embayments (Uye and Sano 1995; Almeda et al. 2010) and is indigenous to Japan and the China Seas, and other coastal areas (Razouls et al. 2012). It is an invasive species along the west coast of the US (Ferrari and Orsi 1984) and the Spanish Mediterranean (Saiz et al. 2003). Most likely the vector of introduction to the Black Sea is from the ballast waters of ships (Selifonova 2009).

The aim of this study was to examine the seasonal and inter-annual variation in abundance of *O. davisae* in the western part of the Black Sea. Variation in abundance and possible controlling environmental factors were examined in both native and introduced parts of its range. Recent plankton community changes in the Black Sea were assessed to gain insight about possible driving factors for the success of this newly established invasive species.

Material and methods

Zooplankton samples were collected at 31 stations in the Western Black Sea, between March 2009 and March 2012, including Varna and Bourgas Bays and open sea waters (Figure 1). Information about the collected samples, including sampling localities, number of stations and time intervals is presented at Table 1. In 2009 the sampling took part in March, June, September and November, while in 2010 the monitoring program encompassed March, April, July, August, September and December. During 2011 the sampling occurred in April, May, July, August, September and October. A minimum of four common stations in each sampling area were visited during the monitoring, while duplicate tows were performed at each 2^{nd} or 3^{rd} station, depending on the total station number.

Mesozooplankton was collected by vertical hauls using a "Juday" plankton net, (provided with a flowmeter), with a 36 cm diameter opening and mesh size of 150 µm. Sampling was carried out from the whole water column. Samples were preserved in 4% formaldehyde and processed by the methodology for zooplankton studies in the Black Sea of Korshenko and Aleksandrov (2006, draft, pers.com.) and HELCOM Annex C 7: Mesozooplankton. According to the methodology the sample was homogenized, and a calibrated Stempel-pipette with a 1-ml sampling chamber was used for the first sub-sampling, and quantitative and qualitative processing was performed in a Bogorov's chamber. A minimum one additional sub-sample was treated, with a volume of 5–10 ml to obtain information on the species composition and abundance. In the subsample(s) all plankters were counted until each of the three dominant taxonomic groups reached 100 individuals. For estimation of large animals' numbers, the whole sample was observed under the microscope. All species were identified taxonomically to the species level except of the meroplankton larvae and rotifers. The species abundance was expressed as a number per cubic meter.

Mainly adult and copepodid stages of *Oithona* were found in the samples as the net mesh size was not appropriate for quantitative collection of nauplia stages.

Results and discussion

O. davisae specimens were first found along the Bulgarian coast in September 2009 (Table 1). Specimens were collected in several stations including the Bay of Varna and in the central west coastal waters. Abundance ranged between 128–1985 ind.m^{-3} with a mean value of 931 ind.m^{-3} for the whole investigated area. Average abundance of *O. davisae* during November 2009 was 1.8 times that of September in both localities – Varna Bay and open sea. During the next year, the species was detected from July to December with surface water temperatures ranging from 24.5 to 12.8°C, respectively. In 2011, *O. davisae* was present when sampling commenced in April at surface water temperatures of 14.9 to 16.4°C. Unlike 2009 and 2010, specimens of *O. davisae* were detected during March 2012 in the Bay of Bourgas, at a water temperature of 7.3°C. Sample collection was not, however, sufficient to assess the full tolerance of this species to low water temperatures, which might lead to almost all-year-round presence in the embayments.

O. davisae comprised up to 17.7% ± 5.1 (SE) of the total mesozooplankton abundance for the studied period, with highest percentages of

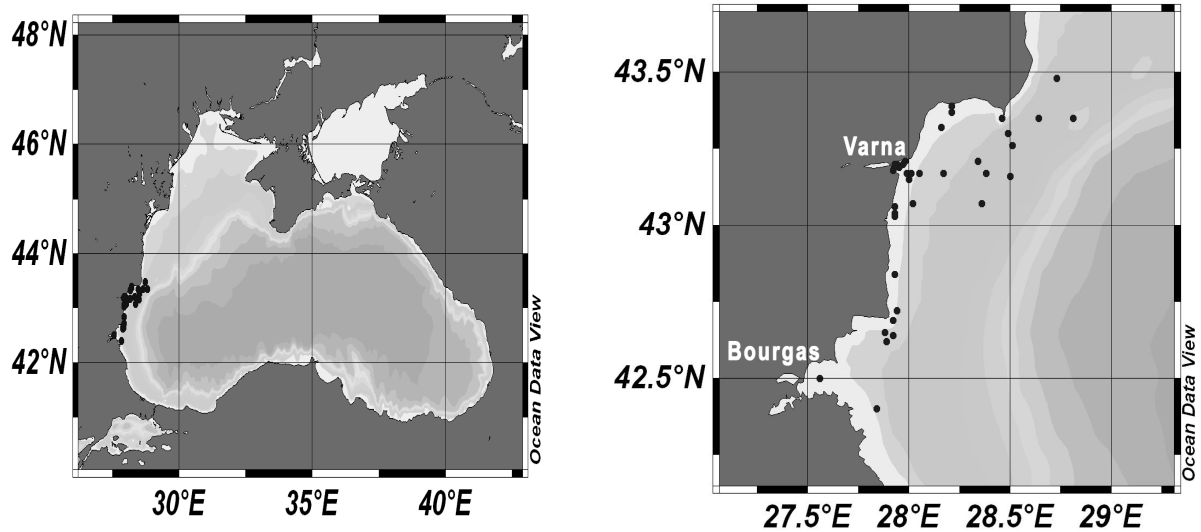

Figure 1. Investigated areas along the western coast of the Black Sea (A) and (B) close-up. The Figure was prepared using Ocean Viewer (Schlitzer 2011).

Table 1. Sampling frequency, range of abundance (minimal – maximal values; ind.m^{-3}) of *Oithona davisae* (OD) and total mesozooplankton (MZP), and percentage OD of total MZP abundance.

Date	Locality	Number of stations	OD Range	OD Average density	MZP Range	MZP Average density	OD (%) of Total MZP
03.2009	Varna Bay	8	-	-	10387-458430	70261	-
	Open Sea	5	-	-	4189-13206	8698	-
05.2009	Open sea	12	-	-	1514-26394	8542	-
06.2009	Varna Bay	5	-	-	20061-64433	47950	-
	Open Sea	12	-	-	4494-20851	10473	-
09.2009	Varna Bay	10	128-1985	1056	2008-11456	5263	20.1
	Open Sea	4	205-1405	806	4487-11216	7852	10.3
11.2009	Varna Bay	10	248-4492	1899	954-13289	6841	27.8
	Open Sea	4	368-1789	1016	1012-5962	3138	32.4
03.2010	Varna Bay	8	-	-	2913-25021	11040	-
	Open Sea	5	-	-	5910-7126	6518	-
04.2010	Varna Bay	10	-	-	7343-33730	16516	-
	Open Sea	5	-	-	5263-9462	7363	-
07.2010	Varna Bay	7	192-797	495	8133-18788	13461	3.7
	Open Sea	7	137-242	190	3850-9742	6796	2.8
08.2010	Varna Bay	7	1299-4921	2942	10091-31022	20557	14.3
09.2010	Varna Bay	7	6666-43818	19127	12399-53039	30111	63.5
	Open Sea	6	2321-11135	5988	4770-18249	11549	51.8
12.2010	Open Sea	5	19-549	203	112-3288	2079	9.8
04.2011	Varna Bay	7	87-93	90	5636-58571	34131	0.3
05.2011	Varna Bay	8	83-265	174	2152-13953	7892	2.2
	Open Sea	4	52-97	75	2342-13191	7139	1.1
07.2011	Varna Bay	6	141-304	223	6689-21272	16004	1.4
	Open Sea	11	59-341	151	2925-6856	5188	2.9
08.2011	Varna Bay	6	93-988	482	3536-9231	6322	7.6
	Open Sea	11	86-2172	691	652-21561	9980	6.9
09.2011	Open Sea	6	17-95	63	2411-7902	5202	1.2
10.2011	Varna Bay	6	2479-5918	3857	4121-17461	8714	44.3
	Open Sea	5	2065-3408	2737	2924-4842	3883	70.5
03.2012	Bourgas Bay	5	12-61	15	3708-23136	12576	0.1

63.5% and 70.5% recorded in September 2010 and October 2011 respectively (Table 1). Maximum density of *O. davisae* was documented in the Varna Bay in 2010, when only a month after the species' first appearance its abundance had increased 9-fold and reached ~ 3000 ind.m^{-3} in August. Later in September, the average abundance increased 6 fold with a maximum single-station estimate in the central part of the Bay of Varna of 43818 ind.m^{-3} (Table 1). The latter is slightly greater than a maximum density of 42667 ind.m^{-3} previously measured in Bay of Sevastopol (Gubanova and Altukhov 2007) and indicates comparable density ranges in different bay areas of the Black Sea.

For the two years (2010–2011) when there was consistent summer sampling, the abundance of *O. davisae* increased in August and sustained high levels in September 2010, but crashed to very low levels in September 2011 and then increased again in October 2011. In Crimea region, Gubanova and Altukhov (2007) observed an abundance increase of *Oithona* in September - October 2005. Obviously, in the Black Sea, the species proliferates in early autumn, but its abundance fluctuates widely from year to year and between the different months. The collected data show some differences with monthly pattern of population abundance of *O. davisae* in the native habitats. In the Japanese Sea for example, species' abundance begins increasing in spring, attains maximum levels by the middle of June, with quantities ranging from 50000 to 1×10^6 ind.m^{-3} (Hirota and Tanaka 1985; Uye and Sano 1998). The abundance remains high until mid July, then it declines to a mid-summer minimum, increases again in early September to form a fall peak, and finally declines until late winter (Uye and Sano 1998). Thus *O. davisae* could contribute to 99.8% of overall copepod abundance in Japanese waters (Hirota and Tanaka 1985; Uye and Sano 1998) while maximum contribution of *O. davisae* in the Black Sea is 92.6% of copepod abundance. However, direct comparison of abundance ranges between native habitats and the Black Sea is problematic because smaller mesh sizes were used for sample collection by Hirota and Tanaka (1985), and Uye and Sano (1998) provided a better estimation of the early, and more abundant, stages of the small oithonids. Temperature variation is comparable between the two localities, with a slightly higher temperature range in the Japanese Sea, 8.9–28.2°C (Uye and Sano 1998), while the Western Black Sea (WBS) ranged between 5.6–24.8°C. Salinity is considerably higher in the Japanese Sea, 28.6 – 32.2 (Uye and Sano 1998) compared to the WBS at 15.8–17.2. Ferrari and Orsi (1984) described the presence of *O. davisae* in the Sacramento-San Joaquin Estuary (California, USA) in waters of salinities down to 12; hence, it is worth noting that *O. davisae* could well adjust to the brackish conditions in the Black Sea.

Extreme environmental conditions occurred in the Western Black Sea in summer 2010, before *O. davisae* reached maximal abundance. Higher than average air temperatures were observed in the spring and summer according to the meteorological data from the Varna weather station (Truhchev et al. 2010). Elevated temperatures were accompanied by low atmospheric dynamics, which reduced the water exchange between coastal and open-sea regions. In late August this led to the highest sea water temperatures (31.0°C and 31.5°C along the northern coasts) being registered in the history of meteorological investigations (Truhchev et al. 2010). In the bibliography it is well documented that the specific growth rate of the nauplia and copepodite stages of *O. davisae* increases exponentially with temperature (Uye and Sano 1998), and the period of egg development is also temperature-dependent (Uye and Sano 1995), thus contributing to enhanced concentrations of the species during warmer seasons. Calm weather could also play a role for swarms of *O. davisae* in early autumn of 2010, because the species appears sensitive to high and moderate turbulence intensities that might affect feeding capture success (Saiz et al. 2003).

Recent phytoplankton studies in the Black Sea have shown important structural changes and a prevalence of small flagellate species, explained mainly by climate-driven effects and reduced concentrations of nutrients (Nesterova et al. 2008; Mavrodieva 2012). *O. daviase* is a raptorial feeder, feeding on flagellates, dinoflagellates and ologotrichines (Uchima and Hirano 1986; Uchima 1988; Kiorboe and Viesser 1999; Saiz et al. 2003). Growth in the different developmental stages of the species could be restricted if the amount of food available becomes limited (Uchima and Hirano 1986; Almeda et al. 2010). *Oithona* nauplii, however, display lower metabolic rate and consequently lower food requirements than calanoid nauplii, which contributes to the ubiquity of the *Oithona* species in marine ecosystems (Almeda et al. 2010). Castellani et al. (2007) found that the biomass of *Oithona* spp. varies significantly with temperature and dinoflagellate biomass concentration. Therefore, the current plankton community shift in the Black Sea associated with small flagellate development may be a significant driving force contributing to the proliferation of the *O. davisae* population, especially in the eutrophic inlets.

A reduction in the biomass of *M. leidyi* to levels below 1 g.m^{-2} in September 2010 could also favor oithonid population growth. Since 2005, the quantity of *M. leidyi* in the Western Black Sea began to diminish notably due to an increased abundance of its introduced predator, the cteno-phore *Beroe ovata*; and abundance of its prey species simultaneously increased (Mihneva and Stefanova 2011). At present, the zooplankton in the eutrophic embayments has a low species diversity, dominated by the copepod *Acartia clausi*, the protozoa *Noctiluca scintillans* and meroplankton larvae (Mihneva and Stefanova 2011). It appears that *O. davisae* now occupies a niche in the shallow coastal waters during the warm months, where just a few years ago the zooplankton was heavily consumed by *M. leidyi*.

Plankton community evolution, under the increasing presence of *O. davisae,* may involve several "scenarios" (keeping in mind observa-tions from other oceanic regions of the world where oithonids are already present in huge abundances). Because of the specific features of *O. davisae,* feeding on flagellates and not on diatoms and detritus, their mass development could affect the abundance of flagellates and bacteria (Roff et al. 1995). It is known that per capita herbivory of microzooplankton exceeds that of copepods (Burkill et al. 1993). Nakamura and Turner (1997) described some oithonids as "retrievers" of primary production by feeding on micro-zooplankton. Another important, yet open question for the Black Sea is whether the mass development of *O. davisae* will support fish or jellyfish populations. Recent observations show an enhanced abundance of the medusae *Aurelia aurita* alongside diminishing populations of *M. leidyi* and an improved mesozooplankton food base. However, a stable increasing trend in fish species' abundances has not yet been observed in the region (Oguz et al. 2012).

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