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Rapid Communication

First record of the calanoid copepod *Pseudodiaptomus marinus* Sato, 1913 in the North Aegean Sea, in Thessaloniki Bay, Greece

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Abstract

The presence of the non-indigenous calanoid copepod *Pseudodiaptomus marinus* is reported for the first time in the North Aegean Sea, in Thessaloniki Bay, a semi-enclosed basin in the inner part of Thermaikos Gulf. Both female and male specimens were collected during monitoring sampling in the study area. The pathway of arrival of the species most probably is via ballast water, since the sampling site is next to the port of Thessaloniki, which experiences high traffic of commercial maritime transport. Continuous monitoring of the area is needed to reveal the establishment status of the species and its impacts on the zooplankton community.

Key words: invasive species, ship-transferred copepoda, biological invasion, Thermaikos Gulf, Eastern Mediterranean

Introduction

Marine non-indigenous species' (NIS) introductions are of global growing concern, affecting mostly coastal areas, estuaries and harbors while globalization of maritime activities that increased during the last decades further intensify this phenomenon (Geburzi and McCarthy 2018). Ballast water is an important vector for marine invasive species, especially invertebrates such as planktonic copepods, facilitating their dispersal into new regions away from their indigenous environments (Bailey 2015).

The calanoid copepod *Pseudodiaptomus marinus* Sato, 1913, is indigenous to the Northwestern Pacific region (Brylinski et al. 2012). It is a herbivorous and detritivorous species (Uye and Kasahara 1983), with wide ranges of temperature and salinity tolerance, inhabiting shallow and eutrophic waters (Sabia et al. 2015). Moreover, it is a serial invasive species with well documented invasion history, introduced in increasingly numerous sites worldwide, arriving through human related vectors (ballast water, transcoastal currents, aquaculture) (Brylinski et al. 2012). Apart from Japanese, Chinese, Russian, Australian and American coastal regions (Deschutter et al. 2018) the species has already invaded numerous sites of Northern Europe (Figure 1). These include the French coasts of the North Sea (Brylinski et al. 2012), the

Figure 1. Location of the sampling station in Thessaloniki Bay (inset: Thermaikos Gulf, Greece) as well as the reported worldwide distribution of *Pseudodiaptomus marinus*. (Google Earth, modified). Triangle symbols indicate: Black, native distribution; yellow, distribution to the introduced regions; red: present study. Numbers indicate:1, Sato 1913; 2, Tanaka 1966; 3, Chen and Zhang 1965; 4, Jiang et al. 2008; 5, Soh et al. 2001; 6, Chang and Fang 2004; 7, Greenwood 1977; 8, Grindley and Grice 1969; 9, Lawrence and Cordell 2010; 10, Fleminger and Kramer 1988; 11, Jiménez-Pérez and Castro-Longoria 2006; 12, De Olazabal and Tirelli 2011; 13, Sabia et al. 2015; 14, Vidjak et al. 2019; 15, Brylinski et al. 2012; 16, Delpy et al. 2012; 17, Jha et al. 2013; 18, Fernandez de Puelles et al. 2003; 19, Albaina et al. 2016; 20, Reyes-Martínez and González-Gordillo 2019; 21, Erdoğan and Ertan 2015; 22, Garbazey et al. 2016; 23, Present study (Geo-referenced species record information: Supplementary material Table S1).

German Bight (Jha et al. 2013) and the Belgian coasts of the North Sea (Deschutter et al. 2018). It is now spreading fast also in the Mediterranean region and has been reported in Italy (Sabia et al. 2014), the Adriatic Sea (De Olazabal and Tirelli 2011), Spain (Albaina et al. 2016, Reyes-Martínez and González-Gordillo 2019) and Turkey (Erdoğan and Ertan 2015) as well as the Black Sea (Garbazey et al. 2016). The increasing number of records in the European region resulted in the establishment of EUROBUS (Towards a EURopean OBservatory of the non-indigenous calanoid copepod *Pseudodiaptomus marinUS*) Working Group (WG), which aims to provide a guideline framework regarding the spreading process of this invader (Uttieri et al. 2020).

Here we report its discovery in Thermaikos Gulf, being the first record for Greek Seas, further expanding the species' known invasion distribution.

Materials and methods

Study site

Samplings were conducted in Thessaloniki Bay (40°37′52.7″N; 22°56′06.1″E) (Figure 1), a semi enclosed basin adjacent to Thermaikos Gulf, in the Northern Aegean Sea, Eastern Mediterranean. The bay is characterized by restricted water circulation and shallowness as well as by fluctuations in salinity and nutrient inputs, caused by three rivers which flow in the western part of the Gulf (Krestenitis et al. 2012). An influx of low-salinity surface waters from the Black Sea, contributes, through the Dardanelles Straits, to the surface layer of waters in the Thermaikos Gulf, also influencing its northern section, Thessaloniki Bay (Hyder et al. 2002). Various urban and industrial activities take place in Thessaloniki Bay, resulting in anthropogenic eutrophication pressure (Genitsaris et al. 2019). In addition, the study site is next to the port of Thessaloniki, one of the main Mediterranean ports, receiving a significant amount of commercial maritime transport that discharge their ballast tanks in the bay (Angelidis 2013), making this complex marine environment even more susceptible to biological invasions (Crooks et al. 2011). Another well-known copepod invader, the cyclopoid *Oithona davisae,* has already been recorded as having established a successful population in the study area (Dragičević et al. 2019).

Methods

Samplings were conducted in Thermaikos Bay on a weekly basis from July 2021 to November 2021, during monitoring of the urban sea front of Thessaloniki Bay. Samplings were carried out in a shore-based fixed station (maximum depth 3.5 m), between 8:00–10:00 am. Quantitative samples were collected by vertical hauls through the whole water column (from bottom to surface), while qualitative samples were collected by oblique tows, using a 50 μm mesh size plankton net in both cases. Collected zooplankton samples were preserved in 4% formaldehyde-seawater solution for further microscopic analysis. Quantitative samples were analyzed according to Harris et al. (2000). During all samplings, in situ measurements of water transparency (m), using a Secchi disk, and pH, using a HI-98100 Checker Plus pH Tester, were carried out. Also, surface water temperature (°C) and conductivity (μS/cm) were measured using the YSI Pro 1030 instrument (YSI Inc., Ohio, USA). Conductivity was transformed to salinity (PSU) based on the equation in Weyl (1964).

Samples were analysed and zooplankton individuals were identified under a microscope (Leica, Leitz Laborlux S). The taxonomic identification of *Pseudodiaptomus marinus* individuals followed the classification system proposed by Razouls et al. (2005–2022).

Results

The presence of *Pseudodiaptomus marinus* was recorded in August, September and October 2021 (Table 1). During morphological examination both female and male adult specimens were identified as *P. marinus* based on the sharp posterior corner spines on the last thoracic segment and the morphology of the fifth pair of legs (P5). More specifically:

Male (Figure 2A–C): Mean total length 1.190 μm, urosome 5-segmented, right geniculated antenna (A1), P5 biramous, asymmetrical with a 3-segmented

Table 1. Sampling dates, environmental parameters and characteristics of *Pseudodiaptomus marinus* specimens collected from Thessaloniki Bay (NF = Not Found).

Date	Secchi (m)	Temperature (°C)	Salinity (PSU)	Qualitative analysis		Quantitative analysis
				Gender	Total length (mm)	
30.07.2021	3.5	30.0	35.8		NF	
04.08.2021	3.5	31.0	35.6	Adult male	1.228	NF
18.08.2021	2.5	29.1	36.2	Adult male	1.068	NF
25.08.2021	3.0	28.6	36.4	Adult female	1.421	NF
04.09.2021	2.0	27.1	37.1		NF	
10.09.2021	1.5	25.8	35.7	Adult male	1.276	204 ind/m^3
18.09.2021	3.0	26.5	37.2		NF	
25.09.2021	3.5	23.4	36.4		NF	
01.10.2021	1.5	23.1	34.8	Ovigerous female, copepodites	1.363 0.912	340 ind/m^3
8.10.2021	1.7	20.7	36.2		NF	
16.10.2021	2.8	19.4	36.2		NF	
22.10.2021	3	18.8	37.0		NF	
29.10.2021	3	18.0	36.6		NF	
05.11.2021	3	18.0	36.6		NF	
12.11.2021	3.5	17.2	38.5		NF	

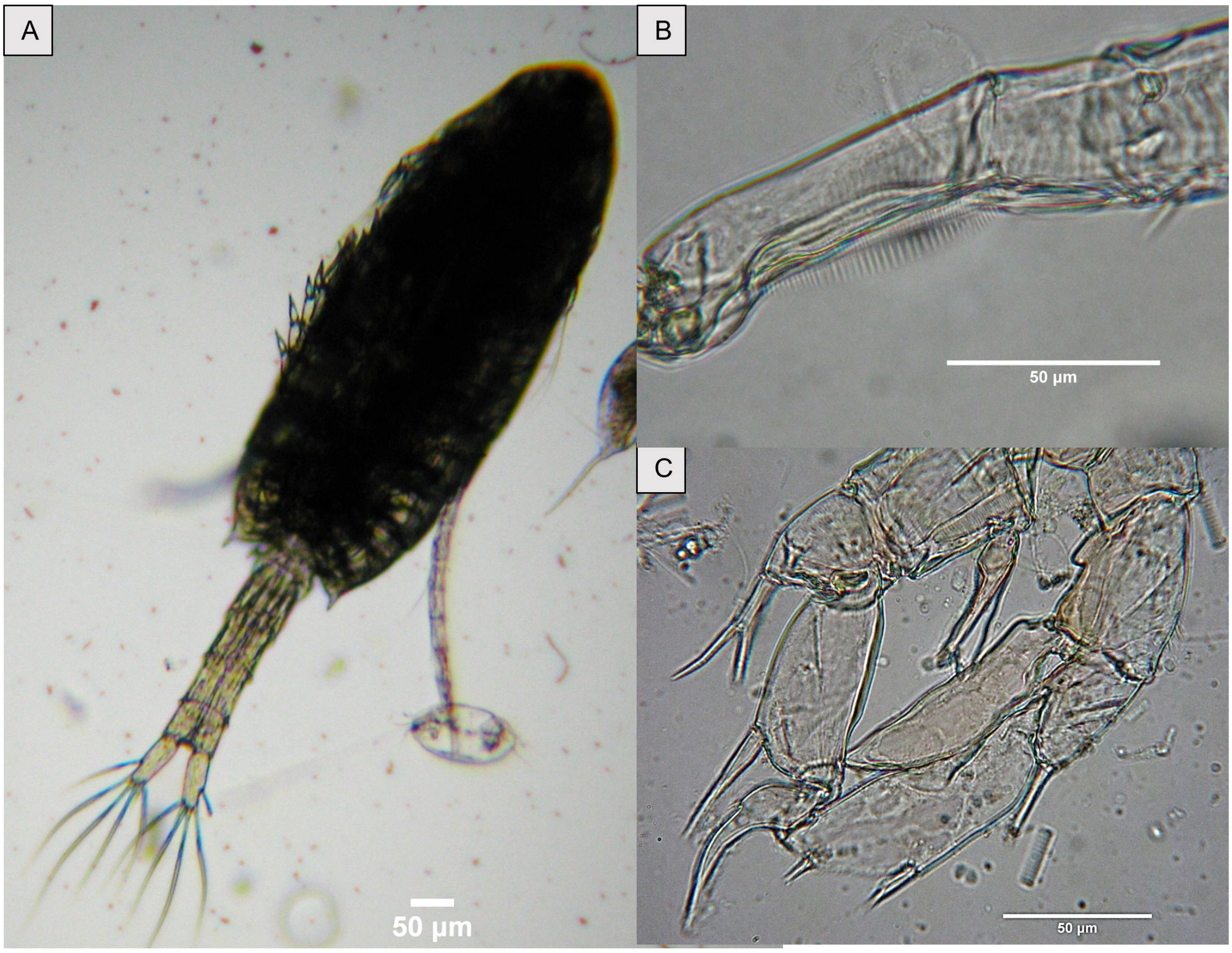

Figure 2. Male specimen of *Pseudodiaptomus marinus* Sato, 1913, found in Thessaloniki Bay, A) habitus, dorsal view, B) serrated margin of 18th segment in the right antenna A1, C) P5 pair of legs.

right exopod, a 2-segmented left exopod and uni-segmented endopods. Right exopod 1 with a characteristic forked spine, exopod 2 with a long spine and exopod 3 shaped like a hook. Left exopod 2 with three spinules on

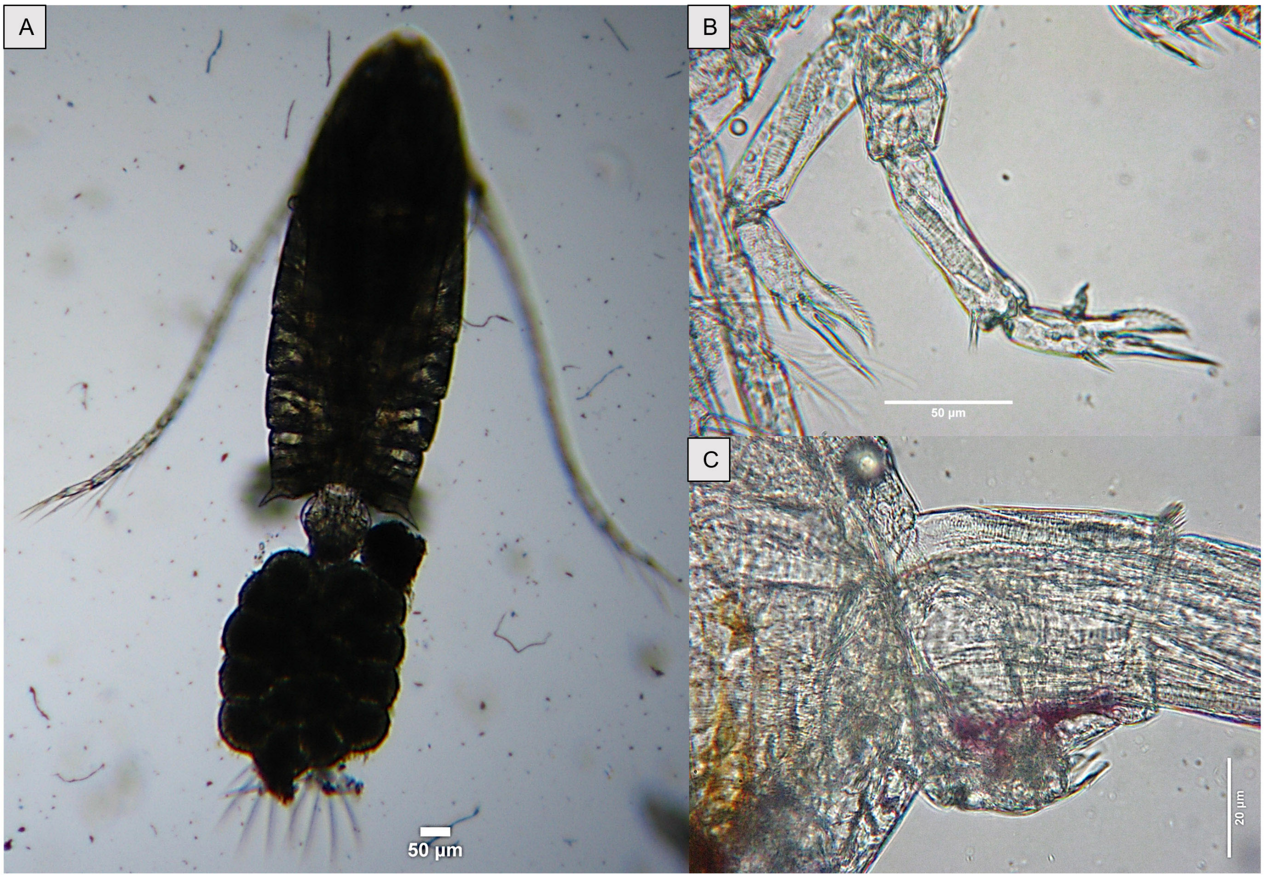

Figure 3. Female specimen of *Pseudodiaptomus marinus* Sato, 1913, found in Thessaloniki Bay, A) habitus, dorsal view, B) P5 pair of legs, C) genital segment.

distal half of inner margin. Right endopod with two rami (a characteristic forked endopod), left endopod characteristically lob-shaped.

Female (Figure 3A–C): Mean total length 1.392, urosome 4-segmented, genital somite slightly asymmetrical with a curved row of spines, P5 symmetrical, uniramous, 4-segmented with an inner serrated distal spine and an outer spine and a spiniform process near the base.

In total, six specimens of *P. marinus* were found in the qualitative samples. During the quantitative analysis, the species was recorded in two samples with abundance of 204 and 340 ind/m^3 (Table 1).

Discussion

Since the first record of *Pseudodiaptomus marinus* in European waters (Adriatic Sea, 2007) (De Olazabal and Tirelli 2011), the species has successfully invaded numerous sites. It is identified as one of the most widespread non-indigenous copepods in Europe, following *Acartia tonsa* (Tsiamis et al. 2019). Its introduction and consequent spread are probably due to unintentional and/or passive transport of the species via ships' ballast water, aquaculture and water currents (Fleminger and Kramer 1988; Brylinski et al. 2012). The euryhaline and eurythermal traits of the species increases its invasive potential (Sabia et al. 2015), enabling its establishment even in marine environments with dynamic conditions, as the one in the present study. In its native range *P. marinus* is often a considerable component of zooplankton communities, i.e. in Japansese waters the species is recorded to contribute 2.7% (35270 ind/m^3) to total copepod abundance (Islam et al. 2006). In the introduced areas, abundance numbers are usually low and the population size of *P. marinus* differs among regions. Low abundance was noted when the species was first found in the Adriatic Sea (1.6–3.2 ind/m^3) (De Olazabal and Tirelli 2011). Similarly, In Germany's coastal waters, only a few specimens were found reaching densities of 0.05, 0.03 and 0.13 ind m^3 (Jha et al. 2013). In France numbers ranged from 0.2–4.0 ind/m^3 in 2010 when it was first found (Brylinski et al. 2012), although the following year, density reached 120 ind/m^3. Compared to the above, the density of *P. marinus* found in the present study was not quite as low (max: 340 ind/m^3). We assume that ballast water of ships is a possible vector of its introduction into Thessaloniki Bay, since the sampling site is next to Thessaloniki's port, where high traffic load of commercial maritime transport occurs. The specimens of *P. marinus* found during samplings included adults, copepodites and ovigerous females. Although all of them can be transported by ballast water, the presence of all three enhances the potential for establishment of a sustainable population. Furthermore, the species is known to be epibenthic during daytime (Fleminger and Kramer 1988) when the samplings were conducted. So, it is possible that the number of specimens found in the present study may not reflect the actual size of its population, therefore the time of sampling should be taken into consideration for future studies.

Previous monitoring surveys of the zooplankton community in the study area did not record the presence of *P. marinus* (*unpublished data*). We cannot exactly specify the time period that *P. marinus* might has entered Thessaloniki's Bay, but the fact that it was not recorded during the surveys conducted in 2019 and 2020, makes the recent introduction scenario more probable. Therefore, not much is known regarding its impact to zooplankton community. Fleminger and Kramer (1988) noted the disappearance of the indigenous *Pseudodiaptomus euryhalinus* from South California when *P. marinus* was present; however, no other species of the genus *Pseudodiaptomus* has been reported in Thessaloniki Bay. Nevertheless, the species may compete for food and space with other indigenous plankton species with similar physiological traits, like the herbivorous *Paracalanus parvus* or the detrivorous *Euterpina acutifrons* (Benedetti et al. 2016), resulting in changes in the trophic web (Islam and Tanaka 2009). This has been the case as reported in Lake Faro (Sicily) where after its introduction, *P. marinus* became the fourth most abundant copepod species (Sabia et al. 2014).

This paper reports the presence of *P. marinus* in Thessaloniki Bay, but long-term monitoring should be carried out in order to investigate whether it is a stable component of the zooplankton assemblage there, as well as its seasonal and interannual abundance variability. Furthermore, such a monitoring can shed light to potential impacts of *P. marinus* on the native zooplankton community and ecosystem structure of this enclosed bay.

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Authors' contribution

EM: research conceptualization; sample design and methodology; data analysis and interpretation; ethics approval; roles/writing – original draft; writing – review and editing; PK: investigation and data collection; data analysis and interpretation; roles/writing – original draft; writing – review and editing.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Geo-referenced species record information.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2022/Supplements/BIR_2022_Kourkoutmani_Michaloudi_SupplementaryMaterial.xlsx