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Rapid Communication

First record of mass occurrence of the tubeworm *Ficopomatus enigmaticus* (Fauvel, 1923) (Serpulidae: Polychaeta) in coastal waters of the Baltic Sea

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Abstract

The first mass occurrence of the alien, tube building polychaete *Ficopomatus enigmaticus* (Fauvel, 1923) was found in the Baltic Sea in 2020. Detailed surveys of private marinas, yacht clubs and boats as well as visual inspections, scratch sampling and a camera assisted remotely operated vehicle revealed its occurrence along a 12 km stretch of the lower saline section (7.12–11.67 PSU) of the Warnow River Estuary, Germany in the western Baltic Sea. The species was found mostly in sheltered areas in 1.0–4.5 m water depth, but it was not found in the higher saline areas (14.10–15.31 PSU) of the estuary or along the coast. Colony densities up to 28,800 ind. m^{-2} were detected. The occurrence of the invasive *F. enigmaticus* has the potential to alter the ecosystem significantly, suggesting that the colony be monitored closely for signs of expansion, establishment and possible alterations to these ecosystems.

Key words: bioinvasion, colonization, Warnow River Estuary, Mecklenburg-Western Pomerania

Introduction

Ficopomatus enigmaticus (Fauvel, 1923), also known as the Australian tubeworm, is a serpulid polychaete with mouth diameters up to 2 mm and lengths of up to 100 mm that forms and inhabits calcareous tubes (Bianchi and Morri 2001). A multitude of single tubes can form bigger aggregations and build reef-like structures in waters up to 3 m deep from meso- (8–18 PSU) to hypersaline (> 40 PSU) conditions (Dittmann et al. 2009). These reefs can cover tens of m^2 and reach thicknesses of more than 1 m (Bianchi and Morri 1996; Fornós et al. 1997). Bianchi and Morri (2001) reported population densities of 150,000 ind. m^{-2} from Tuscany, Italy (Mediterranean Sea). *Ficopomatus enigmaticus* is a suspension feeder and feeds on phytoplankton, zooplankton and detritus particles, which it filters from water using cilia on their radioles. Hence, through removal of suspended particulate matter, the Australian tubeworm can significantly contribute to water purification (Davies et al. 1989). However, the opposite may also be the case when *F. enigmaticus* displaces other species due to its higher filtration capacity, such as mussels. *Ficopomatus enigmaticus* not only has

the potential to change water quality conditions, but it can also significantly change habitat structure, which can lead to changes in indigenous communities (Katsanevakis et al. 2014).

Ficopomatus enigmaticus is a worldwide alien invasive species of unknown origin (Ten Hove and Weerdenburg 1978), but it most likely originated from the Indian Ocean and the coastal waters of Australia in the Southern Hemisphere (Dittmann et al. 2009). *Ficopomatus enigmaticus* is, in fact, a complex of several cryptic species (Styan et al. 2017). In European waters, it was first reported from northern France in 1921 and the London Docks in 1922 (Eno et al. 1997). It has also been recorded from Denmark (Jensen and Knudsen 2005), the Mediterranean Sea (Bianchi and Morri 1996; Despalatović et al. 2013; Çinar et al. 2014), the Sea of Marmara (Çinar et al. 2014), the Black Sea (Kurt Şahin and Çinar, 2012), the Caspian Sea (Read and Gordon 1991) and the Baltic Sea (Lübeck-Schlutup 2015 from Bock and Lieberum 2016). Several reports appeared in the local German media in September and October 2020 about a mass local occurrence of *F. enigmaticus* in the coastal waters of the German North Sea (Brockmann 2020). However no mass occurrence was reported before 2020 in the colder northern waters of the Baltic Sea, which is probably due to the observations of Dittmann et al. (2009) that reproduction of the species requires temperatures above 18 °C. Therefore, we took the opportunity to perform a baseline study straight after we received the first reports about a mass occurrence of *F. enigmaticus* in the Warnow Eastuary. Our main goal was to cover the geographical distribution along with site characteristics for the occurrence of the tubeworm.

Materials and methods

The brackish Warnow River Estuary in the German Baltic Sea stretches approximately 15 km from a weir in the south to the river mouth in the north (Figure 1). The hydrodynamic regime of this non-tidal and highly eutrophic system is rather complex, and the salinity varies depending on wind direction, sea water level and freshwater discharge from the river. Modelling studies of Lange et al. (2020) revealed that the average salinity ranges between 6 PSU in the southern parts to 15 PSU at the river mouth to the Baltic Sea. To confirm the reported observations and scout possible new locations, the field studies of the present work were carried out from November 2020 to January 2021 using a camera assisted remotely operated vehicle (ROV) and scratch sampling (i.e., using a pole scraper for sampling; Hydro-Bios; Germany). A small size ROV (Blue ROV 2; Blue Robotics; USA) was used for the underwater surveys. This vehicle allowed studies of the occurrence of *F. enigmaticus* not only on underwater ship hulls but also on natural substrates and artificial structures within the ecosystem.

Salinities were obtained from surface water samples using a calibrated portable conductivity meter (SevenGo SG3; Mettler Toledo; Switzerland).

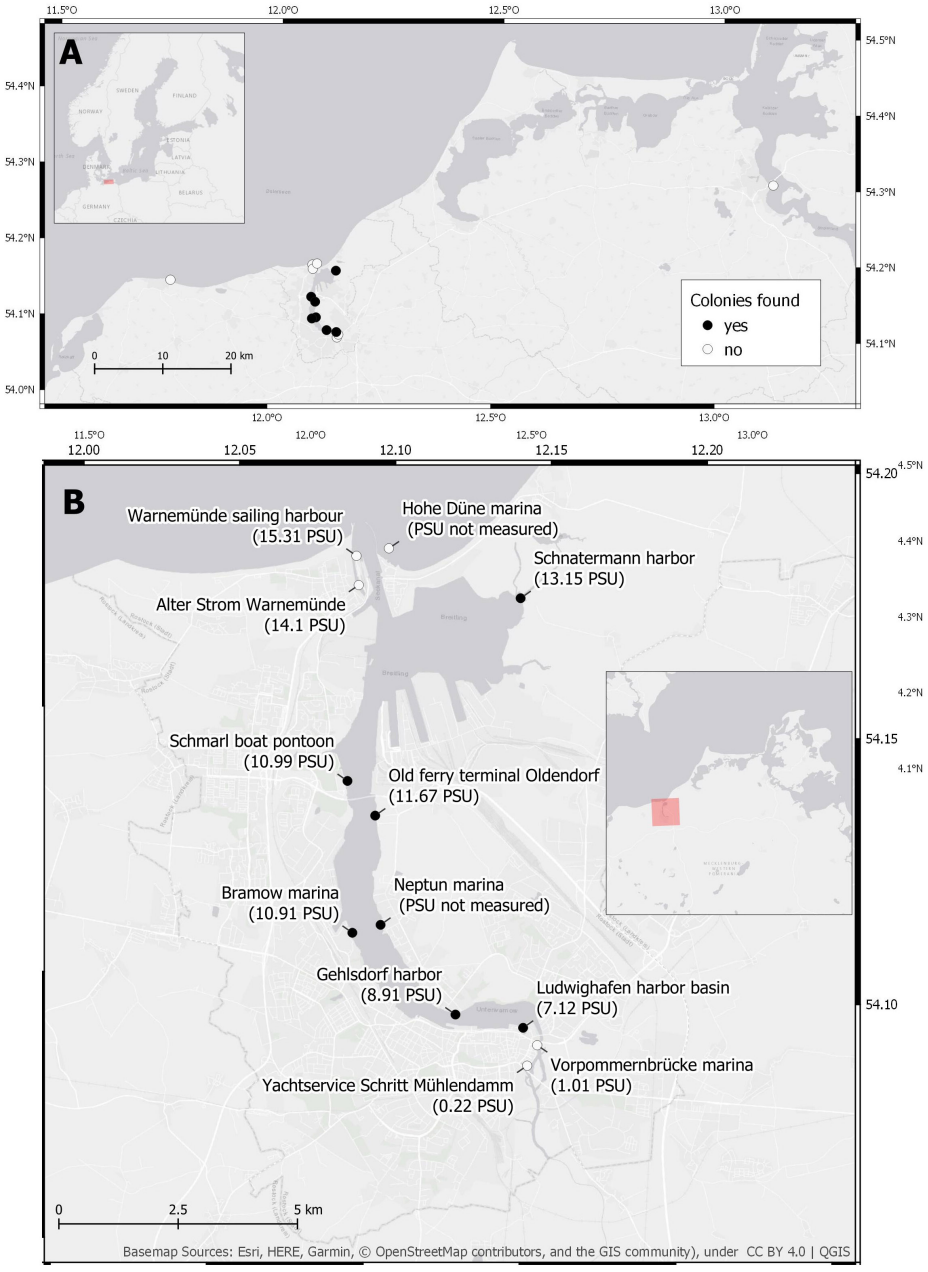

Figure 1. Geographical location of the study area (A) and mapping of *F. enigmaticus* colonies in the Warnow River Estuary and location of temperature monitoring station (B). For details see Supplementary material Table S1. Basemap sources: Esri, HERE, Garmin, ©OpenStreetMap contributors, and the GIS community, under CC BY 4.0.

Monthly mean surface water temperature data for the central part of the estuary were derived from the monitoring station UW3 run by the regional environmental agency.

Results

The first mass occurrence of the alien polychaete *Ficopomatus enigmaticus* was reported in the Warnow River Estuary (Germany) in the south-western Baltic Sea. The measured salinities ranged from 0.22–15.31 PSU in the study area (Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg). The observed temperature range, as derived from monitoring

Figure 2. Z-Drive of a motor yacht moored in Ludwighafen harbor basin site #3 almost completely covered by *F. enigmaticus.* Photo credit: D. Neue.

station UW3, was from a minimum of 2.49 °C in January 2020 to a maximum of 19.35 °C in August 2020.

In October 2020, a yacht service company (https://bootswerft-schritt.de/) reported the fouling of several pleasure boats with unknown organisms to the Leibniz Institute for Baltic Sea Research. Each of the boats had moored in the Warnow River Estuary. On November 18, 2020 a boat owner collected specimens from their hull, which we have identified taxonomically as *F. enigmaticus*. In order to describe the distribution of *F. enigmaticus* in the Warnow River Estuary, a telephone survey was conducted with all of the major yacht service companies that serviced, in total, well over 500 boats every season. All respondents had found the tubeworm on several serviced boats in different densities. Most often, the species was found only in smaller amounts on parts which are not protected properly by efficient antifouling paint like on engine shafts and drives (see Figure 2). Additionally, harbor masters from marinas located closer to the sea were approached for their observations. As yet, none have reported tubeworms from their harbors.

All observations were summarized in the supplementary material (see Supplementary material Table S1) and mapped in Figure 1. The ROV studies and scratch sampling confirmed all observations reported from yacht service companies, harbor masters and the Institute for Applied Ecosystem Research (IfAÖ 2020) except for sites #2 and #14. The tubeworm was found at three other sites, including one on the north-easternmost edge of the estuary (site #9, visual inspection) and two on the eastern shore (sites #5 and #8, ROV). The observed extensions and densities of tubeworm colonies differed greatly across the examined underwater hulls and other structures from sporadic occurrence of single tubeworms through to dense colonies covering 2–3 m^2.

Table 1. Summary of depths of first occurrence of *F. enigmaticus* and maximum water depths as derived from ROV studies along with salinities and substrates on the investigated sites.

site #	depth of first occurrence [m]	max. water depth [m]	salinity [PSU]	substrate
3	1.5	3.0	7.12	steel sheet piling, metal drive of a sailing yacht
4	1.0	1.0	8.91	wooden pile
5	2.3	2.5	–	steel sheet piling
6	2.0	4.5	10.91	metal pile, wooden pile, mooring lines
8	2.0	3.2	11.67	metal pile

Figure 3. *Ficopomatus enigmaticus,* grown on top of *Amphibalanus improvisus* (Darwin, 1854) at site #6. Photo credit: S. Hille.

The ROV studies further proved that *F. enigmaticus* was widely spread in the Warnow River Estuary. *Ficopomatus enigmaticus*was found at 1–4 m water depth and seemed to prefer more sheltered and shallower waters (Table 1 and Figure 4). Typically, the number of worms increased with depth, similar to what we observed at station # 6 (see Figure 4A). Colonies were found on different artificial structures mainly made of wood and metal. It was also often found on structures already covered completely by the non-native bivalve *Mytilopsis leucophaeata* or the non-native cirriped *Amphibalanus improvisus* (Figure 3). The measured salinities of the

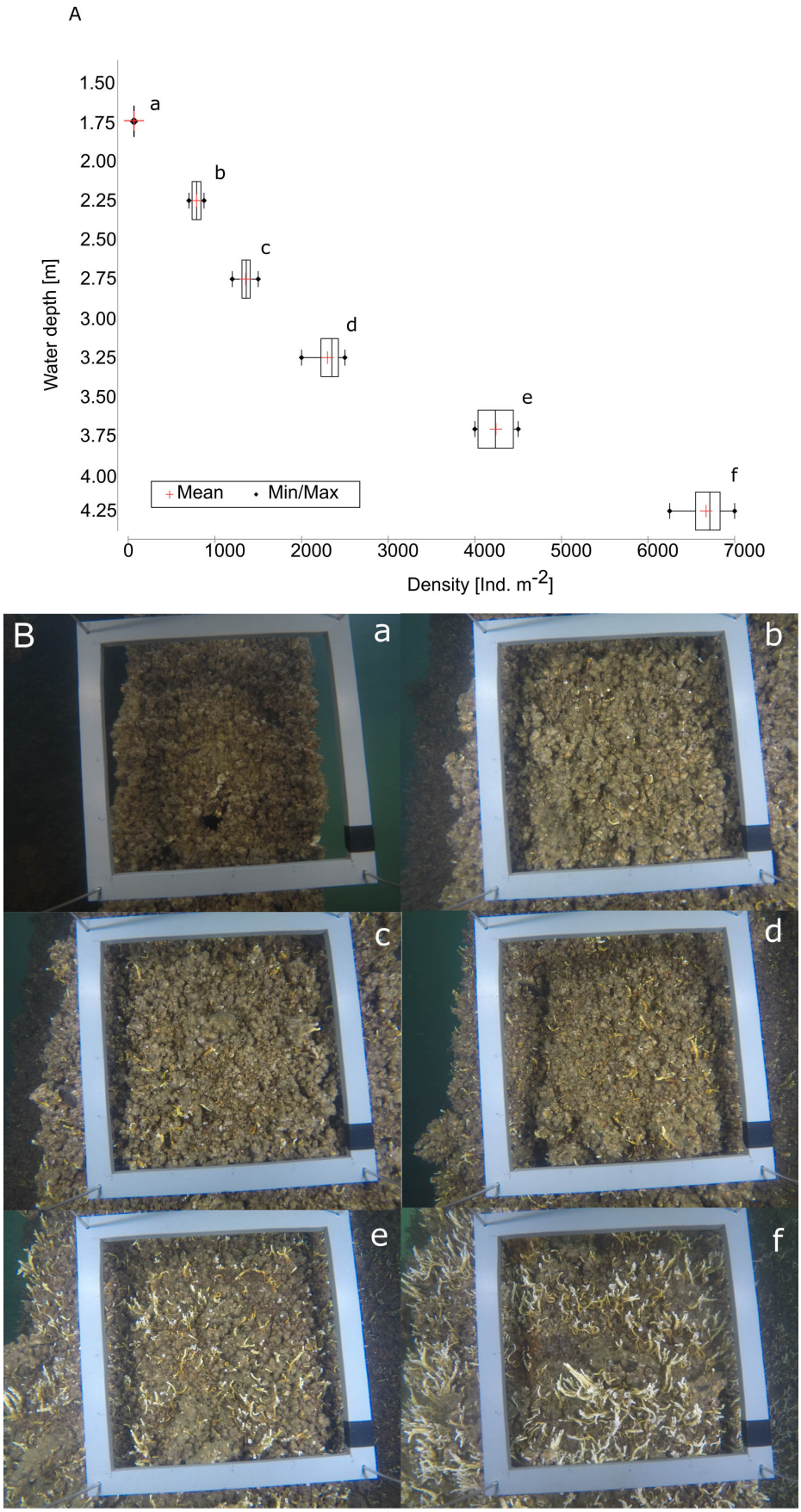

Figure 4. Vertical distribution of *F. enigmaticus* on a metal pile in Bramow marina at site #6 (A) and photographs as captured by a ROV used for estimations of colony densities with dimensions of sampling frame: 20 × 20 cm (B).

investigated sites ranged from 7.12 to 11.67 PSU (Table 1). The most extensive ROV studies were carried out in the Bramow Marina (Figure 1B), which also had the highest abundance of *F. enigmaticus* in the Warnow River Estuary with densities up to 6,633 ind. m^{-2}. In contrast to *A. improvisus*, *F. enigmaticus* did not occur on natural substrates in shallow water (< 2 m) exposed to waves (e.g., gravel and boulders), but was found on artificial hard substratum as harbor walls, pontoons, and mooring lines in these same locations.

Using pictures derived from the ROV, the vertical distribution of *F. enigmaticus* was quantified using four replicates from a steel pile overgrown almost exclusively by *A. improvisus*. The accurate quantification of colony densities was difficult because the colony consisted of different layers of individuals, which made it difficult to count the overgrown tubes. As observed at other locations, no tubeworms were found in the upper two meters of the water column. At a depth interval from 2.0–2.5 m to 4.0–4.5 m, the number of individuals increased gradually from 775 ind. m^{-2} to 6,633 ind. m^{-2}. A subsample (Figure 1B) taken from the underwater hull from a boat made of glass-reinforced fiber moored in the same marina (Figure 1, #6) revealed a density of 72 ind. on the sampled 25 cm^{-2}, which equals 28,800 ind. m^{-2}. This figure is 4 times more than the maximum found on the metal pile (Figure 4), indicating the huge potential of *F. enigmaticus* to grow in dense aggregations when it finds favorable growing conditions such as a clean boat hull. The longest tubes reached almost 10 centimeters in length. This particular boat had its hull cleaned in mid-September; when it was sampled on November 18, 2020, it had only been in the water for two months, showing the great growth capacity of *F. enigmaticus*.

Discussion and outlook

According to IfAÖ (2020), single individuals or small colonies of *F. enigmaticus* were first detected in the Warnow River Estuary during a monitoring survey in 2016, was absent in 2017 and 2018, and then present again in 2019 but a mass occurrence was never reported. Therefore, the tubeworm had been present in the system for some years without being noticed by the public. Also in 2019, IfAÖ (2020) reported the first occurrence of the tubeworm in Stralsund, approximately 80 km east (# 14, see Figure 1A). Even though we could not prove the occurrence in Stralsund with our own ROV, the population of *F. enigmaticus* is likely to further spread and establish there as the environmental conditions (e.g. PSU, water depth, and trophic status) are similar to the Warnow River Estuary. All of the conditions in which *F. enigmaticus* were found were in line with the descriptions of Global Invasive Species Database (2021) for preferred site characteristics.

We had an additional opportunity to observe a privately owned boat (Figure 5A) to conduct a preliminary examination of the reproduction period

Figure 5. An underwater hull of a motorboat densely covered by *F. enigmaticus* after being in the water for only two months, left side is already cleaned (A) and subsample (B) taken for density estimations. Photo credit: F. Dautert.

of *F. enigmaticus*. Juvenile settlement peaked during the late summer to early autumn, when surface water temperatures were in excess of 18 °C. According to Dittmann et al. (2009), this temperature lies within the needed range for reproduction. A tight chronological period of larval production can be estimated because, according to Shanks (2009), the larvae have a planktonic duration of only 1–2 weeks. Temperature seems to be the key parameter controlling the expansion of the Australian tubeworm, particularly in more temperate regions, e.g as described for the invasion in Denmark. Despite being first recorded in the Danish part of the Baltic Sea in 1956 (Rasmussen 1958), the first small colonies in the Baltic Sea were documented in 1997 and 1998 in the harbor of Copenhagen (Denmark), near an outlet from a power plant (Jensen and Knudsen 2005). Further

monitoring is needed to conclude whether the first ever-recorded mass development in the Baltic Sea reported here was a one-off event triggered by extremely favorable climatic conditions or whether the expansion will gradually continue.

We see this observation as a new milestone in the spread of this invasive species into Nordic, temperate seas. Due to the expected further rise in sea temperature in the temperate seas caused by climate change, further spread of this species is likely on longer time scales. As an agreed objective of the Marine Strategy Framework Directive, the introduction of new species should be reduced to a minimum (Olenin et al. 2010). This also requires the detection and monitoring of new alien species in a timely manner. The presence of alien species should not have a negative impact on native species. Since *F. enigmaticus* has the potential to significantly change the structure and functioning of the ecosystem and cause ecological and economic problems, this species introduction is of interest not only to scientists, but also relevant to environmental authorities, port authorities and commercial and recreational users in the boating and fishing sectors.

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Authors' contribution

SH: research conceptualization, sample design and methodology, investigation and data collection, data analysis and interpretation, writing original draft; FK: data analysis and interpretation, writing review and editing; GM: investigation and data collection, data analysis and interpretation; LR: investigation and data collection, data analysis and interpretation; MLZ: research conceptualization, sample design and methodology, data analysis and interpretation, writing review.

References

Bianchi CN, Morri C (1996) *Ficopomatus* 'Reefs' in the Po River Delta (Northern Adriatic): Their Constructional Dynamics, Biology, and Influences on the Brackish-water Biota. *Marine Ecology* 17: 51–66, https://doi.org/10.1111/j.1439-0485.1996.tb00489.x

Bianchi CN, Morri C (2001) The battle is not to the strong: serpulid reefs in the lagoon of Orbetello (Tuscany, Italy). *Estuarine Coastal and Shelf Science* 53: 215–220, https://doi.org/10.1006/ecss.2001.0793

Bock G, Lieberum C (2016) Neobiota in schleswig-holsteinischen Ostsee-Häfen [LLUR AZ 0608.451614]. Zwischenbericht im Auftrag des Landesamts für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein (LLUR), 40 pp

Brockmann T (2020) Australischer Wurm breitet sich im Hafen aus. Online Magazin NORD|ERLESEN, https://www.norderlesen.de/Heute/Australischer-Problem-Wurm-breitet-sich-im-Hafen-aus-48547.html (accessed 25 November 2020)

Çinar ME, Dagli E, Kurt Şahin G (2014) Checklist of Annelida from the coasts of Turkey Marine Biodiversity of Turkey. *Turkish Journal of Zoology* 38: 734–764, https://doi.org/10.3906/zoo-1405-72

Davies BR, Stuart V, De Villiers M (1989) The filtration activity of a serpulid polychaete population (*Ficopomatus enigmaticus* (Fauvel)) and its effects on water quality in a coastal marina. *Estuarine Coastal and Shelf Science* 29: 613–620, https://doi.org/10.1016/0272-7714(89)90014-0

Despalatović M, Cukrov M, Cvitković I, Cucrov N, Žuljević A (2013) Occurrence of non-indigenous invasive bivalve *Arcuatula senhousia* in aggregations of non-indigenous invasive polychaete *Ficopomatus enigmaticus* in Neretva River Delta on the Eastern Adriatic coast. *Acta Adriatica* 54: 213–220

Dittmann S, Rolston A, Benger SN, Kupriyanova EK (2009) Habitat requirements, distribution and colonisation of the tubeworm *Ficopomatus enigmaticus* in the Lower Lakes and Coorong. Report for the South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide, 99 pp

Eno NC, Clark RA, Sanderson WG (1997) Non-native marine species in British waters: a review and directory. Joint Nature Conservation Committee, Peterborough, UK, 152 pp

Fauvel P (1923) Un nouveau serpulien d'eau saumâtre *Mercierella* n. g., *enigmatica* n. sp. *Bulletin de la Société Zoologique de France* 47: 424–430

Fornós JJ, Forteza V, Martínez-Taberner A (1997) Modern polychaete reefs in western Mediterranean lagoons: *Ficopomatus enigmaticus* (Fauvel) in the Albufera of Menorca, Balearic Islands. Palaeogeography, Palaeoclimatology and Palaeoecology 128: 175–186, https://doi.org/10.1016/S0031-0182(96)00045-4

Global Invasive Species Database (2021) Species profile *Ficopomatus enigmaticus*. http://www.iucngisd.org/gisd/species.php?sc=1382 (accessed 29 January 2021)

IfAÖ (2020) Erfassung und Bewertung nicht einheimischer Arten - Neobiota - in Küstengewässern Mecklenburg-Vorpommerns. Endbericht. Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern, 49 pp

Jensen KR, Knudsen J (2005) A summary of alien marine benthic invertebrates in Danish waters. *Oceanological and Hydrobiological Studies* 34: 137–162

Katsanevakis S, Wallentinus I, Zenetos A, Leppäkoski E, Çinar ME, Oztürk B, Grabowski M, Golani D, Cardoso AC (2014) Impacts of marine invasive alien species on ecosystem services and biodiversity: a pan-European review. *Aquatic Invasions* 9: 391–423, https://doi.org/10.3391/ai.2014.9.4.01

Kurt Şahin G, Çinar ME (2012) A Checklist of Polychaete Species Annelida Polychaeta from the Black Sea. *Journal of the Black Sea / Mediterranean Environment* 18(1): 10–48

Lange X, Klingbeil K, Burchard H (2020) Inversions of estuarine circulation are frequent in a weakly tidal estuary with variable wind forcing and seaward salinity fluctuations. *Journal of Geophysical Research: Oceans* 125, https://doi.org/10.1029/2019JC015789

Olenin S, Alemany F, Cardoso A, Gollasch S, Goulletquer P, Lehtiniemi M, McCollin T, Minchin D, Miossec L, Occhipinti Ambrog, A, Ojaveer H, Jensen KR, Stankiewicz M, Wallentinus I, Aleksandrov B (2010) Marine Strategy Framework Directive - Task Group 2 Report. Non-indigenous Species. Office for Official Publications of the European Communities, Luxembourg, 44 pp

Rasmussen (1958) Emigranter i Kobenhavs Sydhavn. *Verden* 8: 231–234

Read G, Gordon D (1991) Adventive occurrence of the fouling serpulid *Ficopomatus enigmaticus* (Polychaeta) in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 25: 269–273, https://doi.org/10.1080/00288330.1991.9516478

Shanks AL (2009) Pelagic larval duration and dispersal distance revisited. *Biological Bulletin* 216: 373–385, https://doi.org/10.1086/BBLv216n3p373

Styan CA, McCluskey CF, Sun Y, Kupriyanova EK (2017) Cryptic sympatric species across the Australian range of the global estuarine invader *Ficopomatus enigmaticus* (Fauvel, 1923) (Serpulidae, Annelida). *Aquatic Invasions* 12: 53–65, https://doi.org/10.3391/ai.2017.12.1.06

Ten Hove HA, Weerdenburg JCA (1978) A generic revision of the brackish-water serpulid *Ficopomatus* Southern 1921 (Polychaeta: Serpulinae), including *Mercierella* Fauvel 1923, *Sphaeropomatus* Treadwell 1934, *Mercierellopsis* Rioja 1945 and *Neopomatus* Pillai 1960. *The Biological Bulletin* 154: 96–120, https://doi.org/10.2307/1540777

Supplementary material

The following supplementary material is available for this article:

Table S1. Detailed information and geographical positions of mapping sites of *F. enigmaticus* occurrence in the Warnow River Estuary, Kühlungsborn and Stralsund.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2021/Supplements/BIR_2021_Hille_etal_SupplementaryMaterial.xlsx