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Exotic Polychaetes of a Sewage Pollution Influenced Lagoon (Çardak Lagoon, Turkish Straits)

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Abstract: This paper includes three exotic polychaeta species, *Hydroides dianthus* (Verrill, 1873), *Polydora cornuta* Bosc, 1802, and *Pseudopolydora paucibranchiata* (Okuda, 1937), found during benthic samplings in Çardak Lagoon (Turkish Straits). The sampling was collected from the sandy and silty bottoms known to be polluted by sewage discharges. A total of 45 specimens of exotic polychaetes (*H. dianthus*: 1; *P. cornuta*: 4; *P. paucibranchiata*: 40) were found. The correlation values between the annual average values of the nutrients and the polychaeta abundance showed that the highest positive relationships with the abundance were between sand content, total phosphate, and pH. *P. cornuta* was the most observed species with a frequency index value of 75%, while *H. dianthus* was represented with a single species in the study area. Albeit the previous studies, *P. paucibranchiata* was observed most abundantly in the sampling station having low organic matter amounts. The study showed that opportunistic polychaetes observed in Çardak Lagoon mostly preferred organically poor sediments.

Keywords: polychaeta; exotic; environmental variables; sewage pollution; Çardak Lagoon; Turkish Straits

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1. Introduction

Lagoons in coastal areas have a number of different characteristics affecting the biota as well as the physical conditions [1]. Coastal lagoons are areas mainly exposed to environmental and anthropogenic effects [2]. Therefore, it can be confusing to consider physico–chemical variables alone to investigate the impacts of pollution observed in these sensitive areas. Thus, the common use of both the biological and the environmental variables is effective, and the dominant factors can be distinguished [3]. Domestic wastes discharged into lagoons contain mainly organic biomass and nutrients (such as ammonium, nitrate, and phosphate). Accordingly, organic matter and nutrients in water may change the biotic diversity and density [4].

Studies on benthic fauna in coastal lagoons can determine the ecological impact of stressors at community and ecosystem levels. Assemblages of benthic communities play an important role in coastal lagoon ecosystems [1]. Polychaeta is one of the most important benthic groups and can be used as indicators for levels of domestic pollution due to their tolerance to organic enrichment in seawater and sediment [5]. High volumes of untreated domestic wastes entering lagoon environments can cause an increase in the abundance of capitellid, dorvilleid, and spionid polychaeta species that rapidly react to eutrophication [6,7]. These opportunistic species can quickly colonize habitats and positively characterize the degree of organic matter-sourced pollution [7–9]. The relationships between Polychaeta species abundance and environmental variables of the lagoon areas were investigated in many studies [10,11]. In addition, several spionid polychaeta, defined as invasive species, can be found on partially polluted bottoms of harbors, estuaries, and lagoons [12–14]. Invasive spionids can penetrate the Mediterranean Ecosystem by ballast waters of ships, especially via the Suez Canal, or associated with bivalves transported for aquaculture [13]. Çardak Lagoon on the Northeast Coast of the Çanakkale Strait (Anatolian Part) is one of the 12 lagoon areas in the Turkish Straits System. It is a leaky type lagoon with a coastline of 4.3 km, a surface area of 1.2 km^2, and an average depth of 1.3 m, having a rich natural habitat. The commercial marine bivalves harvested in Çardak Lagoon are the venerid clam *Chamelea gallina* (Linnaeus, 1758), scallop *Flexopecten glaber* (Linnaeus, 1758), Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819), carpet shell clam *Ruditapes decussatus* (Linnaeus, 1758), Manila clam *Ruditapes philippinarum* (Adams, 1850), and oyster, *Ostrea edulis* (Linnaeus 1758) [15].

Çardak Lagoon was declared a first-degree natural site by the Council for the Protection of Cultural and Natural Assets in Türkiye (Decree No. 3298, 6 August 1992). Knowledge of macrozoobenthic assemblages and exotic species in Çardak Lagoon is quite limited. As the three exotic invaders, *Hydroides dianthus*, *Polydora cornuta*, and Pseudopolydora paucibranchiata, are good indicators of sediment pollution, we tried to present the relationships between the abundance of exotic polychaeta in the study area and environmental variables. Thus, this study could be an important contribution to evaluating their condition and help maintain their status as well as their rich natural habitat.

2. Material and Methods

2.1. Sediment Samplings

Samplings were collected at the depths between 1 and 1.8 m of 7 stations in order to determine the effects of domestic pollution and environmental variables on macrozoobenthic assemblages found in the shallow waters of Çardak Lagoon located in the Northeast of the Çanakkale Strait in October 2018, and February, April, and June 2019 (Figure 1).

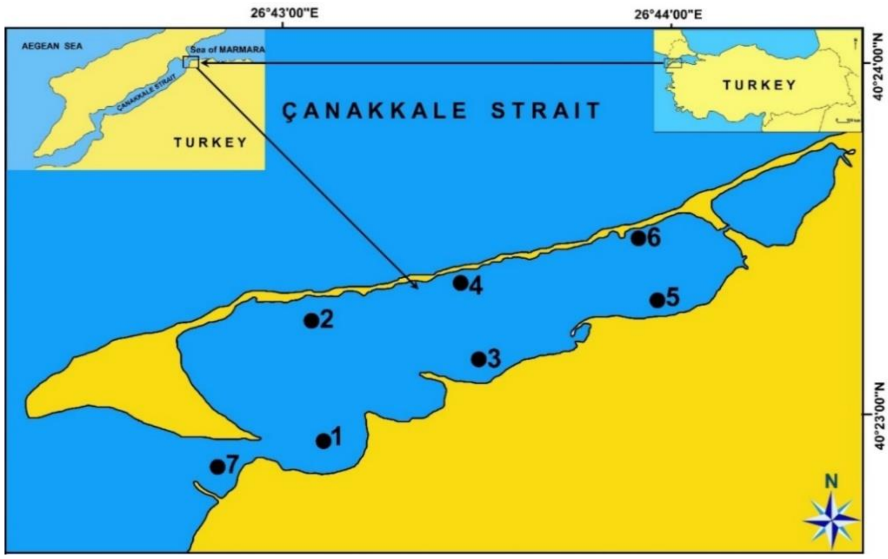

Figure 1. Map of the study area.

Three random replicates were taken at each station using a quadrate of 30 × 30 cm in dimension, and all materials within each quadrate were carefully scraped by a spatula and immediately put in jars with 4% seawater formalin solution by SCUBA diver.

2.2. Faunistic Analyses

Fixed samples were washed and passed through a triple sieve system with mesh sizes of 0.5, 1, and 2 mm in the laboratory. Once the faunal species were extracted, they were preserved in 70% ethanol in 50 cc glass tubes on a group basis. Polychaeta species were identified using a trinocular stereomicroscope according to definitions based on previous studies, and all specimens were counted. In the diagnoses, the definitions of [13,16–24] were used.

2.3. Statistical Analysis

The correlations between environmental variables and the polychaeta abundance at the stations were calculated according to the Pearson coefficients (r) using the SPSS 20.0 program.

2.4. Water Quality Measurements

In the sampling studies, water quality variables (temperature, salinity, pH, oxygen solubility) of lagoon water were measured in situ by means of a YSI 650 MDS Multiparameter Display System [YSI (Yellow Springs, OH) USA]. Concentrations of nutrients, such as NO_2, NO_3, NH_4, PO_4–P, SiO_2, and total suspended solids (TSS), were measured in a spectrophotometer according to chemical and biological analysis techniques [25]. Jasco Brand UV Spectrophotometer in the Faculty of Marine Sciences and Technology Laboratory was used for analysis. Measurements were made at different wavelengths. The gravimetric method was used to determine the amount of TSS in lagoon water [26].

2.5. Analyses of Organic Matter and Particle Size in Sediment

For organic matter and particle size analyses in the soft bottoms of the lagoon, a sediment core made of 393 cm^3 volume acrylic transparent material was used during the sampling period. A total of 14 core samples for both organic matter and sediment particle analysis were collected from soft sediments as two replicates at each sampling point in each sampling period. Particle size analyses in the sediment were performed according to [27]. The work of [28] was used in the analysis of organic matter in sediment. All analyses of sediment were carried out in the Central Laboratory of Çanakkale Onsekiz Mart University.

3. Results and Discussion

3.1. Faunistic Data of *Polydora cornuta* Bosc, 1802

Genus Polydora Bosc, 1802
Polydora cornuta Bosc, 1802
(Figures 2 and 5B)

Polydora cornuta: [17]: 12–14, Figure 1A–F; [29]: 32–35, Figure 3; [30]: 205–208, Figure 3; [31]: 824–825, Figures 3, 4; [20]: 6–10, Figures 1A–G and 2A–F; 10–12; [21]: 232, Figure 3; [32]: 47–50, Figure 2A–F; [33]: 263–264; [34]: 81, Figure 2.

Polydora ligni: [35]: 119, pl. 5, Figures 45–47; [36]: 175–178, Figure 176A–I; [37]: 5–6, Figures 1–2.

3.1.1. Material Examined

28 June 2019; Station 6, depth 1.5 m, 93% sand bottom, 1 specimen; 7 February 2019, station 7, depth 1 m, 69% sand +29% coarse sand bottom, 3 specimens.

3.1.2. Description

The largest specimen is complete at 10.22 mm long and 0.84 mm wide, with 59 chaetigers. The body is slightly dorsoventrally flattened, stouter in the anterior part, gradually decreasing in width toward the posterior end, and is pale yellow. The prostomium is anteriorly incised to a bifid, low narrow caruncle extending to the end of chaetiger 3 (Figure 2A). Two pairs of small black eyes and a prominent occipital antenna are present on the prostomium (Figure 2A). Palps elongate, extending back to chaetiger 12, with a distinct ciliated groove; brownish lines are sometimes present along both sides of the groove.

Chaetiger 1 is without notochaetae, only with a short-winged neurochaetae; notopodial lamella digitiform (Figure 2A) is shifted dorsally with respect to the subsequent segments; neuropodial lamella is similar in shape and aligned with the following notopodial lamellae. Except for chaetiger 5, the notopodium of subsequent chaetigers is with capillaries only, those on anterior chaetigers numbering 9–10. Chaetiger 5 is with heavy five falcate spines, and companion chaetae are arranged in a slightly curved oblique row; falcate spines are each with a lateral tooth and a narrow thin subdistal longitudinal flange; companion chaetae are each with a broom-like distal tip closely adhering to the convex side of the falcate spine; dorsal superior and ventral capillaries are absent (Figure 2C). After chaetiger 6, neuropodia are with hooded hooks only; hooks bidentate (Figure 2D) are without accompanying capillaries and with a distinct manubrium on the shaft, numbering five on chaetiger 7, eight middle chaetigers and seven on posterior chaetigers; notopodial postchaetal lamellae are well developed and are gradually smaller in size from about chaetiger 18. Branchiae from chaetiger 7 are almost to the end of the body. Bidentate hooded hooks in neuropodia start from chaetiger 7; companion capillary chaetae are absent. The psygidium is an enlarged disc with a broad dorsal notch (Figure 2B).

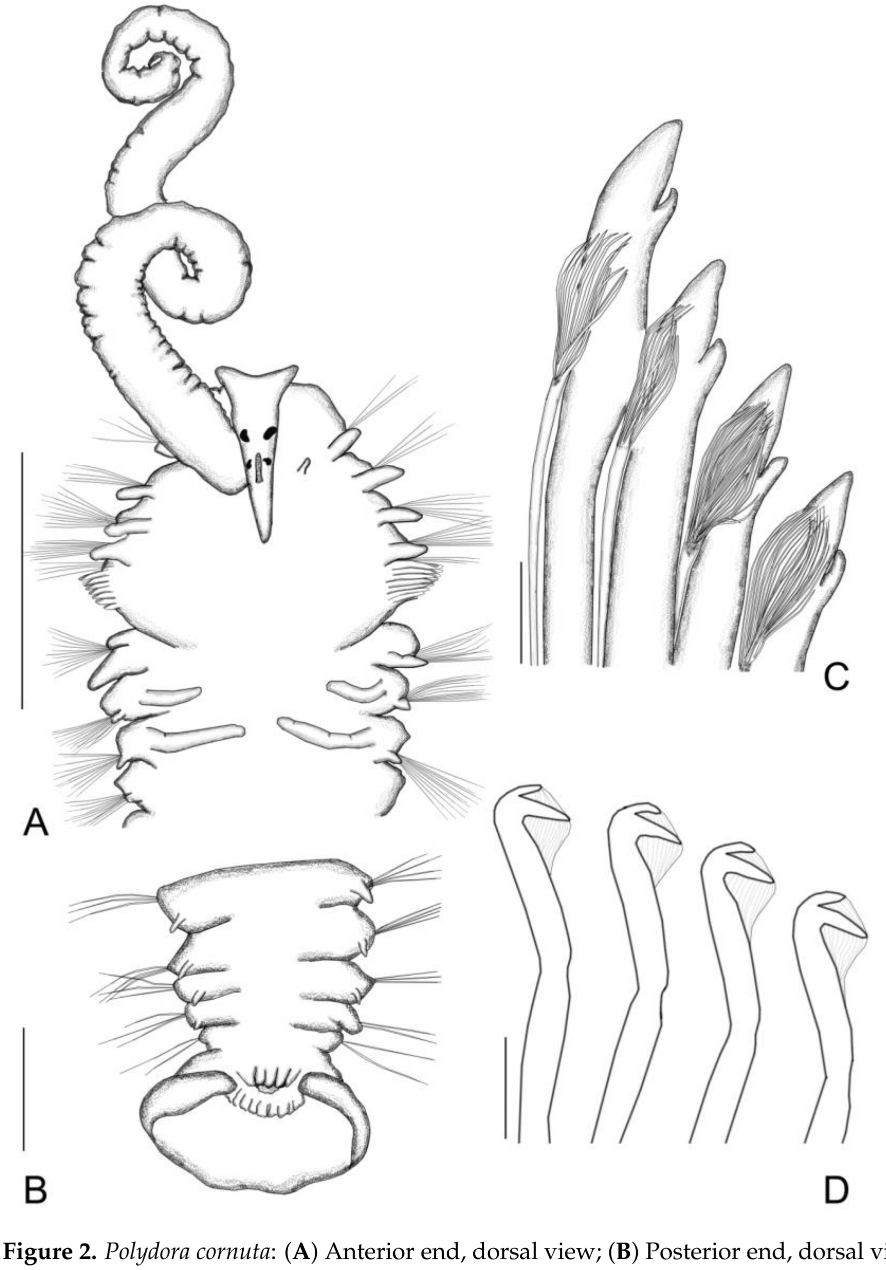

Figure 2. *Polydora cornuta*: (**A**) Anterior end, dorsal view; (**B**) Posterior end, dorsal view (Pygidium); (**C**) Major spines with companion chaeta; (**D**) Hooded hooks on middle chaetigers. Scale bars: (**A**): 1 mm; (**B**): 0.5 mm; (**C**,**D**): 10 µm.

3.1.3. Remarks

Polydora cornuta was originally described from Charleston Harbor, South Carolina, Atlantic USA by [38] and later reported from all over the world (see [20]) and the Mediterranean Sea [29]. This species was first reported to be found on the polluted muddy bottom of Valencia Harbor in the Mediterranean Sea by [29] and, subsequently, in İzmir Bay by [31], the Sea of Marmara by [21], Turkish Mediterranean coast by [39], and Turkish coast of Black Sea by [40] in Türkiye. Re-examination of old material from İzmir Bay by [31] exposed that *P. cornuta* was present in the region in 1986; sampling in this area in 2003 found a dense population of the species, up to 3170 ind·m^{-2} [31]. In the Sea of Marmara, *P. cornuta* was reported from in İzmit Bay (up to 170 ind·m^{-2}) [21], Kalamış Bay [41], the Golden Horn Estuary in the Bosporus Straight (up to 4340 ind·m^{-2}) [12]), and Sinop Harbor (up to 10 ind·m^{-2}) [40]. Populations of *P. cornuta* up to 50 ind·m^{-2} were reported from Mersin Bay [39].

The Dardanos specimen agrees with the original and subsequent descriptions of the species [17,20,21,29,31,33]. However, the number of anterior capillaries chaeta is 9–10 in the Dardanos specimen and 11 in the İzmir Bay specimens. The number of spines of chaetiger 5 is six İzmir Bay's specimens [31], whereas our specimens have five falcate spines.

Polydora cornuta is an opportunistic species tolerant of wide ranges of salinity and temperature characterized by early maturation, high larval production, the ability to colonize disturbed and polluted substrata, and to establish high-density populations in a short time [20]. It is widely distributed by shipping and aquaculture. Planktotrophic larvae of the species survive transportation in ballast water, and adults may form dense settlements through the fouling of ship hulls [33]. These could be the reasons why the records of the species have been given from all the Turkish seas.

3.1.4. Distribution

Polydora cornuta is distributed in temperate and subtropical zones worldwide [20]. This species has been reported in the Atlantic, Pacific, and Indian Oceans, the Western and Eastern Mediterranean Seas [29,31,42], the Sea of Marmara [21,41,43], and the Black Sea [32,33,40].

3.2. Faunistic Data of Pseudopolydora paucibranchiata (Okuda, 1937)

Genus Pseudopolydora Czerniavsky, 1881

Pseudopolydora paucibranchiata (Okuda, 1937)

(Figures 3 and 5C)

Polydora (Carazzia) paucibranchiata [16]: 231–233, Figures 11 and 12.

Pseudopolydora paucibranchiata [44]: 110–118, Figures 1–11; [36]: 161–163, Figures 162–163; [45]: 244–246, Figure 8; [46]: 17, Figure 7; [47]: 50–53, Figure 27; [13]: 90–95, Figures 2,3,5; [48]: 3629–3635, Figures 4,5; [22]: Figures 7.4.1.41 D–F, I–K; [24]: 582–583, Figure 3C.

3.2.1. Material Examined

28 October 2018, station 2, depth 1 m, 79% sand bottom, 3 specimens; 28 October 2018, station 4, depth 1 m, 86% sand bottom, 1 specimen; 28 October 2018, station 6, depth 1.5 m, 92% sand bottom, 11 specimens; 7 February 2018, station 6, depth 1.5 m, 92% sand bottom, 5 specimens; 26 April 2019, station 2, depth 1 m, 79% sand bottom, 2 specimens; 26 April 2019, station 4 depth 1 m, 86% sand bottom, 2 specimens; 26 April 2019, station 6, depth 1.5 m, 92% sand bottom, 5 specimens; 28 June 2018, station 2, depth 1 m, 79% sand bottom, 1 specimen; 28 June 2018, station 4, depth 1 m, 86% sand bottom, 3 specimens; 28 June 2018, station 6, depth 1.5 m, 92% sand bottom, 3 specimens; 28 June 2018, station 7, station 7, 28 June 2019, depth 1 m, 69% sand + 29% coarse sand bottom, 4 specimens.

3.2.2. Description

The largest specimens are complete at 12 mm long and 0.67 mm wide for 65 chaetigers. The body is slightly dorsoventrally flattened, enlarged in the anterior part, gradually decreasing in width towards the posterior end, and is pale yellow. The body is without pigmentation.

The prostomium is anteriorly rounded, caruncle reaching to the posterior of chaetiger 3. A short occipital antenna is present (Figure 3A). Two pairs of black eyes are usually present. Palps elongate, extending the back to chaetiger 10–12, with a distinct ciliated groove; brownish lines are sometimes present along both sides of the groove.

Chaetiger 1 has short capillaries in neuropodia and postchaetal lamellae in both rami; notochaetae are absent on distinct notopodial lobes (Figure 3A). Chaetigers 2–4 and 6–7 have both noto- and neuropodial capillary setae. From chaetiger 8 to the posterior end of the body, parapodia have both capillary chaetae and hooded hooks. Notochaetae in anterior segments has 10–12 capillaries. Neurochaetae on chaetigers 2–7 is with about 7–9 capillaries per fascicle. Neuropodial hooded hook is first present on chaetiger 8, reaching up to 9 per fascicle in posterior parapodia. Hooks are bidentate, with small distal teeth; a well-defined constriction is present on the shaft, not accompanied by capillary chaetae (Figure 3C).

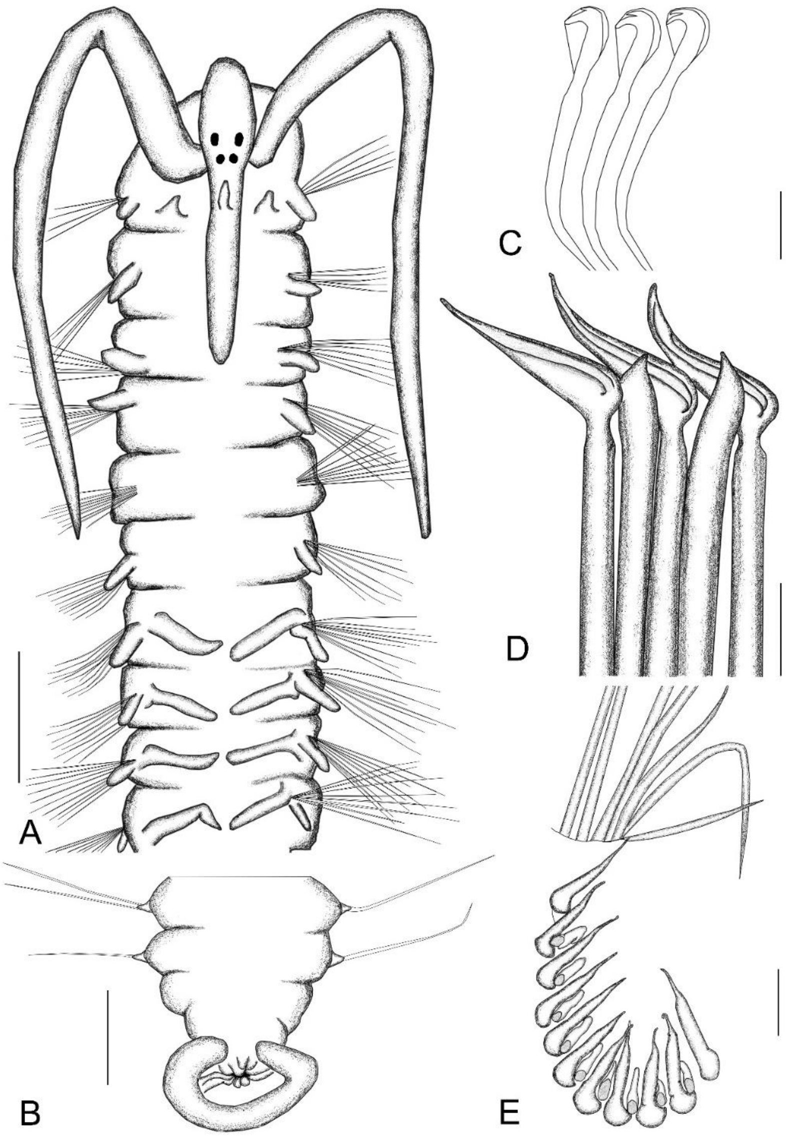

Figure 3. Pseudopolydora paucibranchiata. (**A**) Anterior end, dorsal view. (**B**) Disc-like pygidium with dorsal gap. (**C**) Hooded hooks on middle chaetigers. (**D**) Lateral view of chaetiger 5 with two types of specialized spines. (**E**) Lateral view of chaetiger 5, showing J-shaped double row of heavy spines and capillaries. Scale bars: (**A**): 0.5 mm; (**B**): 0.2 mm; (**C**,**D**): 20 μm; (**E**): 10 μm.

Chaetiger 5, with two kinds of notopodial spines, is arranged in a double J-shaped (Figure 3E), comprising up to 11 rows with pennoned spines with a curved tip and weak constriction between tip and shaft (Figure 3D) and 9 simple falcate spines (Figure 3D). Bidentate hooded hooks are located in neuropodia from chaetiger 8, up to 11 per fascicle (Figure 3C). Branchiae are from chaetiger 7, up to 6–8 pairs.

The pygidium is cup-shaped to disc-like with a dorsal gap (Figure 3B).

3.2.3. Remarks

Pseudopolydora paucibranchiata was first described by [16] from Japan, and it has been widely reported all over the world. Çardak Lagoon specimens of *Pseudopolydora paucibranchiata* agree with the original description of the species from the coast of Japan [16] and the subsequent description from the coast of Türkiye [13]. We also compared our specimens of *P. paucibranchiata* with the [13] species and observed some slight differences. These differences include the following: (1) number of neuropodial hooded hooks per fascicle (up to 12 in the) [13]'s specimens vs. up to 9 in our specimens); (2) number of branchiae (usually 6–8 pairs in Çardak Lagoon specimens vs. 7–11 pairs in the Aegean Sea specimens); (3) number of specialized spins on chaetiger 5 (inner row up to 10 spines in Dagli and Çinar specimens vs. 9 spines in our specimens). Moreover, the number of notochaeta in anterior segments on specimens of *P. paucibranchiata* collected in İzmir, İskenderun, and Mersin Bay [13]) reached up to 14–16 per fascicle, whereas our specimens have up to 10–12 per fascicle.

Radashevsky et al. (2020) [48] carried out genetic analyses in individuals of the species collected from the North Pacific, Northeast Atlantic, Mediterranean, and Australia. This analysis distinguished four clades which were considered four pseudocryptic species; they formed a monophyletic *Pseudopolydora paucibranchiata* complex [48]. Then, the specimens found from Pacific Canada (British Columbia), Russia (Sea of Japan), South Korea (the East Sea), Italy (Tyrrhenian and Ionian Seas), Australia (Victoria), Netherlands, and Japan coasts were also analyzed, and *P. paucibranchiata* complex was confirmed. This analysis showed that the Northwest Pacific individuals were endemic to this species. This species is probably carried here by ship transportation or oyster cultivation to distant parts of the world. This transportation was first observed in the Mediterranean Sea (Lago di Sabaudia, Tyrrhenian Sea) in 1978, followed by reports in the 1980s both in Atlantic and Mediterranean Spain and in the 1990s in Portugal and Türkiye [48].

Therefore, genetic analysis of individuals belonging to *Pseudopolydora paucibranchiata*, found in both Çardak Lagoon and Turkish Seas, should be carried out. Thus, the origin of this species of individuals penetrating Turkish coasts can be determined. The genus of Pseudopolydora may represent three species (*P. antennata*, *P. paucibranchiata*, and *P. pulchra*) on the coast of Türkiye; however, further population genetic studies are needed to examine the invasion history.

3.2.4. Distribution

Pseudopolydora paucibranchiata was originally described in Japan (Onomichi, Hiroshima Prefecture) and was subsequently reported from the Northeast Pacific, Southwest Pacific, Northeast Atlantic, Mediterranean Sea, and Black Sea Atlantic [13,43,44,47,48]. To date, this species has not been reported from Çardak Lagoon. This species was previously reported to have been introduced to the Turkish waters from Japan by fouling and ballast water [13].

3.2.5. The Population Density

The population density of *Pseudopolydora paucibranchiata* varied in İzmir, İskenderun, and Mersin Bay [13]. Its density ranged from 11,750 ind·m^{-2} (station 6) to 10 ind·m^{-2} (stations 3, 7) in İzmir Bay. On the Levantine coast of Türkiye, the maximum density (625 ind·m^{-2}) of this species was found at station K12, which is located near the Mersin Harbor. This species seems to form a scarce population (maximum 125 ind·m^{-2} at K7, near İskenderun Harbor) in İskenderun Bay. The maximum density of *P. paucibranchiata* was reported to be 810 ind·m^{-2} in İzmir Bay [39]. Çinar et al. (2017) [49] reported the maximum density of this species as 25 ind·m^{-2} in the Brachidontes pharaonis facies in Antalya Bay.

Habitat

Pseudopolydora paucibranchiata was previously reported to form dense populations on rock, sand, and in Padina pavonica Brachiodontes pharaonis facies in Türkiye [13] or worms were found inside their tubes in soft sediments [39]. We collected it on the sandy and silty sandy bottom between 1 and 1.5 m depths.

3.3. Faunistic Data of Hydroides dianthus (Verrill, 1873)

Genus Hydroides Gunnerus, 1768.
Hydroides dianthus (Verrill, 1873)
(Figures 4 and 5A)

Hydroides dianthus; [50]: 549, plate xx, Figure 10; [51], 694, 497–498, Figures 1–5; [52]: 845, Figure 1m–u; [18]: 143–146; Figures 23A–M, 24A–K, 28; [53]: 2–3; Figure 1; [19]: 25–28, Figure 4B.

3.3.1. Material Examined

26 April 2019, station 4, 1 m, depth, 86% sandy bottom, 1 specimen.

3.3.2. Description

The tube is opaque white, with an internal diameter of 1.1 mm and an external diameter of 1.4 mm; the tube is covered by epibionts, and transverse ridges are inconspicuous and lack peristomes. The body is colorless in preserved specimens; the total length is 12.6 mm. Branchial lobes are arranged in semi-circles, with 15 radioles on the left lobe and 14 on the right lobe. Radioles are 3.62 mm long, the peduncle is cylindrical, smooth, and not separated from the opercular funnel by a constriction, and the length is 2.8 mm. Radiolar eyes are absent. Pseudoperculum is present. The operculum length is 0.59 mm, and the opercular diameter is 0.51 mm. A funnel with 26 radii has pointed tips (Figure 4A). Verticil has ten amber-colored spines, all curving more or less in a ventral direction, without external and lateral spinules or wings (Figure 4A). Dorsal spines are larger than ventral ones. Tips of spines are pointed. Spines have one basal internal spinule without external and lateral ones and/or wings (Figure 4A). Collar chaetae is a bayonet type, with two blunt rounded teeth, a distal blade smooth (Figure 4E), and hooded (capillary) chaetae are present (Figure 4D(a,b)). The length of the thorax is 2.01 mm, and the width is 0.85 mm. Thoracic membranes are well-developed. Six chaetigers have hooded (limbate) chaetae of two sizes (Figure 4D(c–e)), and saw-shaped uncini have eight teeth (Figure 4C). Abdomen has 37 chaetigers. Anterior and middle abdominal chaetigers have flat-trumpet chaetae. Posterior chaetigers have “capillary” chaetae (Figure 4D). Anterior abdominal chaetigers have saw-shaped uncini with five–six teeth arranged in one row on notopodia (Figure 4B).

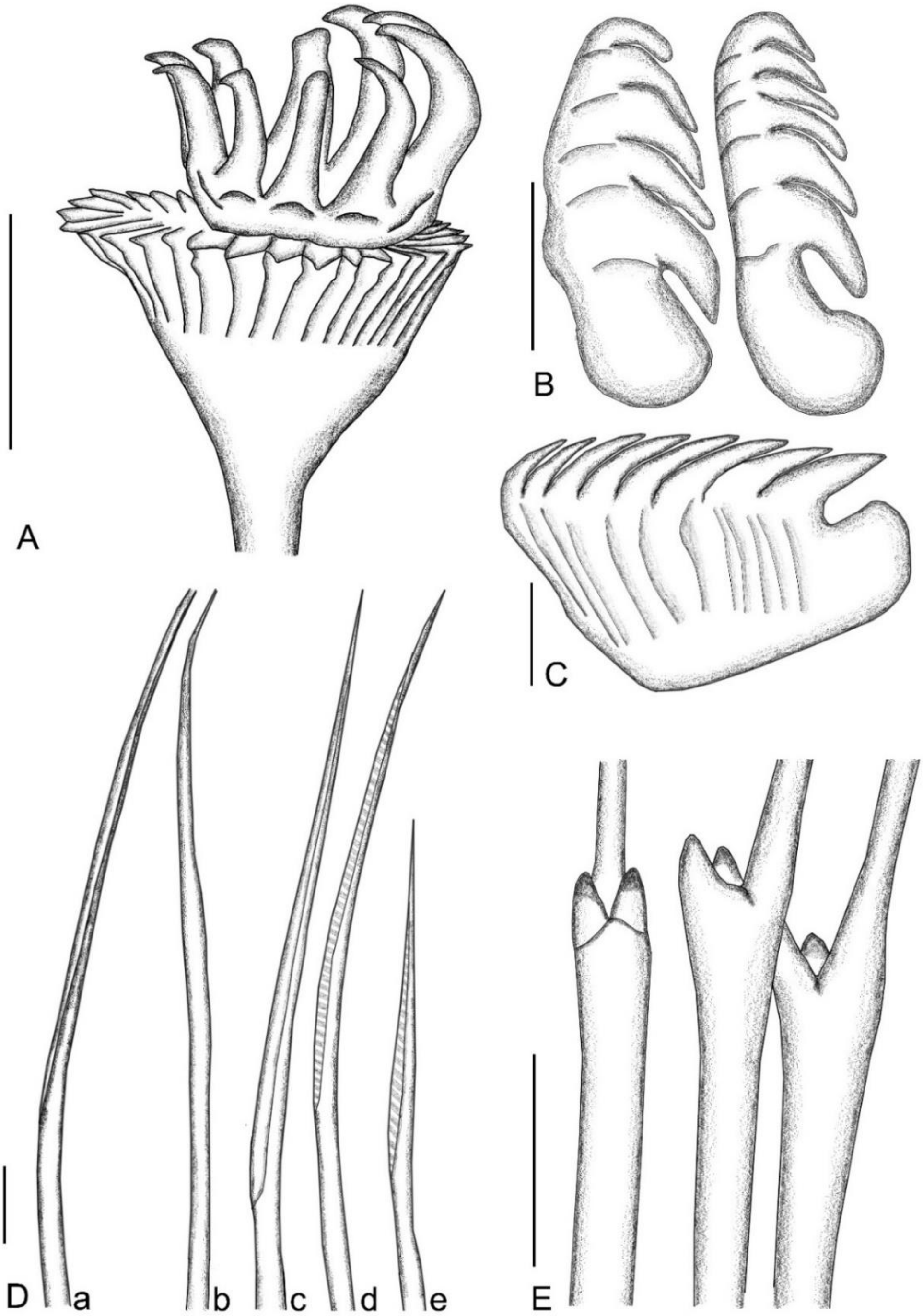

Figure 4. *Hydroides dianthus*. (**A**) Operculum, lateral view. (**B**) Abdominal uncinus on neuropodium. (**C**) Thoracic uncinus on neuropodium. (**D**) a,b: Capillary chaeta; c–e: Thoracic limbate chaeta. (**E**) Collar chaeta lateral and frontal view. Scale bars: (**A**): 0.5 mm; (**B**,**C**): 10 µm; (**D**(a,b)) 20 µm; (c–e) 38 µm, (**E**): 50 µm.

3.3.3. Remarks

Hydroides dianthus was described in New Jersey to Massachusetts, the East Coast of the United States. The specimens examined in the present study agree with the original and subsequent descriptions of the species [18,19,52,53]. As reported by [18], the operculum of *H. dianthus* showed a remarkable morphological variation. These morphological variations did not exist in our individuals.

3.3.4. Distribution

Hydroides dianthus was originally described in New Jersey to Massachusetts (East Coast of the United States) and was subsequently reported from the Pacific, Atlantic, and Indian Oceans, the Mediterranean Sea, and the Black Sea [18,19]). This species was known to be introduced to the Mediterranean Sea from the North American Atlantic by shipping [54].

Hydroides dianthus is a cryptogenic serpulid polychaeta in Turkish seas and is a fouling organism on ship hulls worldwide. *H. dianthus* was described for the first time as Serpula dianthus from New England by [55] and is known from Amphi–Atlantic, West Africa, the Mediterranean Sea, and Japan [53,56]. *Hydroides dianthus* has been known from the area for more than a century [57]), and [58] first reported H. elegans from the polluted part of İzmir Bay [7]. This species is being newly reported from the Sea of Marmara.

3.3.5. The Population Density

The population density of *Hydroides dianthus* varied in İzmir Bay [7,9]. Its density ranged from 33,050 ind·m^{-2} (station 3, spring) to 1550 ind·m^{-2} (stations 4, fall) [9] and 830 ind·m^{-2} (station 7) to 10 ind·m^{-2} (stations 5 [7] in İzmir Bay. Furthermore, Koçak et al. (1999) [59] reported the maximum density of this species as 160 ind·m^{-2} in the same area (İzmir Bay). This species was only found in İzmir Bay in the studies performed to date.

3.3.6. Habitat

Hydroides dianthus is the dominant serpulid species of hard bottom communities of harbor environments in other parts of the Mediterranean [59]. Çinar et al. (2006) [7] and Çinar et al. (2008) [9] recorded this species both on concrete, stone, and tires in the harbor area and on Mytilus galloprovincialis shells on soft bottoms. We collected it on the sandy mud bottom at 1-m depth.

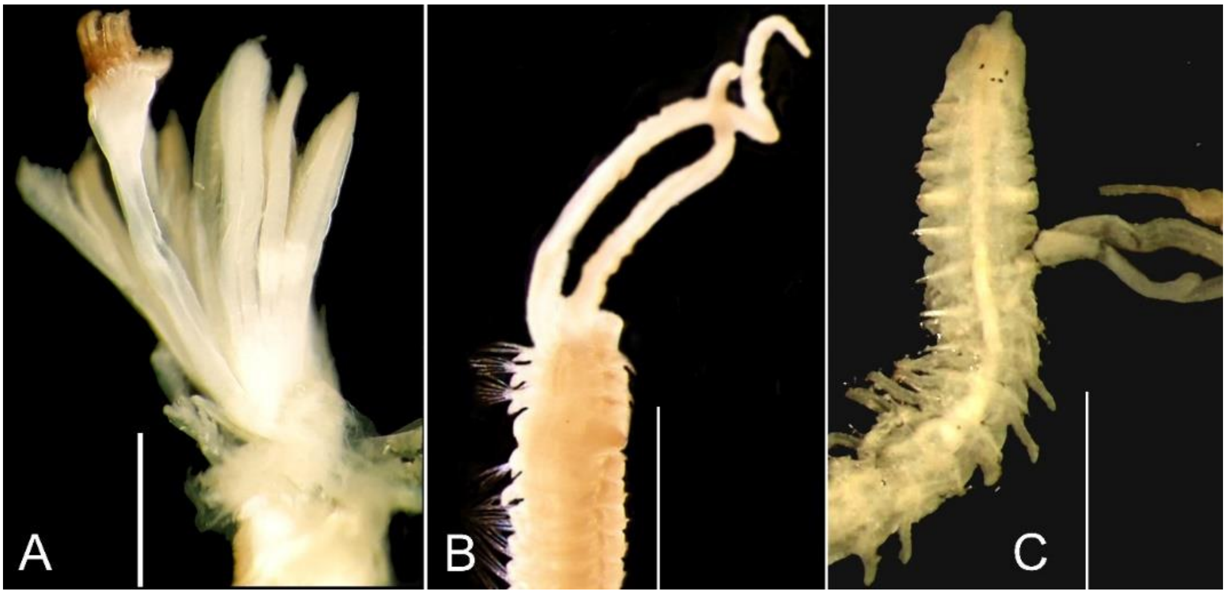

Figure 5. (**A**) Dorsolateral view of anterior part of *Hydroides dianthus* (Verrill, 1873). (**B**) Dorsolateral view of anterior part of *Polydora cornuta* Bosc, 1802. (**C**) Dorsal view of anterior part of *Pseudopolydora paucibranchiata* (Okuda, 1937). Scale bar: (**A**) 1 mm; (**B**) 0.8 mm; (**C**) 0.5 mm. (Photographed by E. Dagli).

In Çardak Lagoon, densities varied between 1 and 11 ind. 0.09 m^{-2} by stations and 5 and 15 ind. 0.09 m^{-2} by seasons (Table 1). The species was not abundant at station 6 (Figure 6).

Table 1. Distributions by sampling sites of 3 exotic polychaeta found in the study area (f%: Frequency; D: Dominance).

	Sampling Period																		
	18 October				19 February				19 April				19 June						
	Sampling Points																		
Species	**2**	**4**	**6**	**7**	**2**	**4**	**6**	**7**	**2**	**4**	**6**	**7**	**2**	**4**	**6**	**7**	**∑**	**f%**	**D**
Hydroides dianthus										1							1	6.25	2.22
Polydora cornuta								3							1		4	12.50	8.88
Pseudopolydora paucibranchiata	3	1	11				5		2	2	5		1	3	3	4	40	68.75	88.88

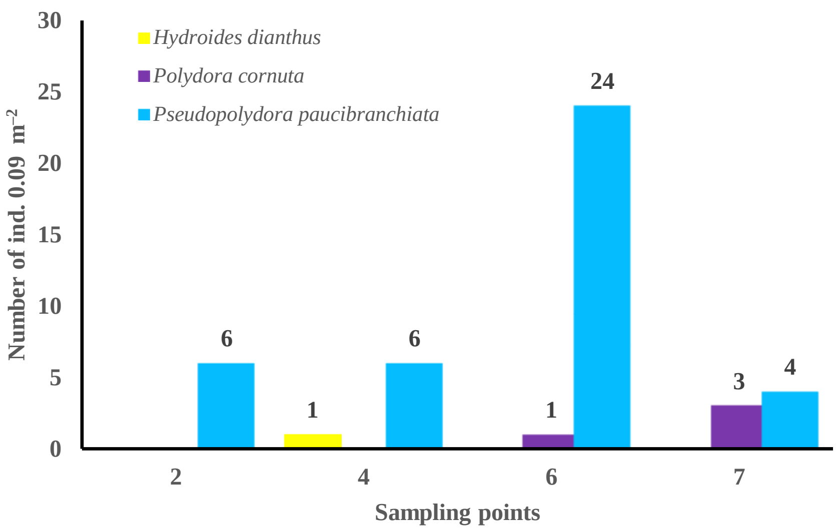

Figure 6. The abundance (ind. 0.09 m^{-2}) of 3 exotic polychaeta at sampling sites of Çardak Lagoon.

3.4. Physico–Chemical Data

The highest number of individuals (25 ind. 0.09 m^{-2}) was found at station 6 (Table 2), where the sand content was the highest (92.74%). However, no individual was observed at landside stations (stations 1, 3, 5), where the organic matter and mud contents in the sediments were the highest (Table 2).

Table 2. Annual average levels of environmental variables measured and total number of specimens at sampling points (Stn: Station, OM: Organic matter).

Sampling Points	Temperature (°C)	Salinity (‰)	pH	O_2 (mg L^{-1})	OM%	Clay + Silt %	Sand %	∑
Stn. 1	15.59 ± 6.77	21.91 ± 1.69	7.97 ± 0.19	8.18 ± 1.49	10.65 ± 1.24	14.16 ± 4.30	61.73 ± 4.31	0
Stn. 2	16.74 ± 8.07	22.01 ± 1.37	8.29 ± 0.08	7.76 ± 1.19	3.03 ± 0.84	3.17 ± 1.02	78.67 ± 7.32	6
Stn. 3	15.61 ± 7.21	21.79 ± 1.20	8.18 ± 0.09	7.21 ± 1.08	15.52 ± 1.36	13.24 ± 2.95	55.14 ± 5.37	0
Stn. 4	15.53 ± 6.61	22.04 ± 1.37	8.32 ± 0.09	7.07 ± 1.01	3.49 ± 0.75	5.27 ± 2.57	86.19 ± 5.56	7
Stn. 5	15.89 ± 7.85	22.04 ± 0.88	8.25 ± 0.15	7.18 ± 1.12	7.91 ± 1.04	16.71 ± 0.76	57.61 ± 5.06	0
Stn. 6	16.33 ± 7.88	21.87 ± 0.84	8.34 ± 0.20	7.08 ± 0.81	2.75 ± 0.11	3.29 ± 1.92	92.74 ± 2.73	25
Stn. 7 (Ref.)	16.19 ± 7.03	22.04 ± 1.93	8.25 ± 0.09	7.76 ± 0.37	1.73 ± 0.25	1.49 ± 1.86	69.09 ± 17.41	7

Considering the average nutrient amounts measured in lagoon water throughout the year, total suspended solids (TSS = 28.4 mg L^{-1}), total nitrogen (TN = 0.498 mg L^{-1}), and total phosphate (TP = 0.065 mg L^{-1}) at station 6 have the highest number of individuals. Although the amount of TSS had TN and the total TP were high on the land side stations (stations. 1, 3, 5) of the lagoon, no exotic polychaeta were found at these sites (Table 3).

Table 3. Annual average levels of nutrients and total suspended solids at sampling points of lagoon water (Stn: Station, TP: Total phosphate, TN: Total nitrogen, TSS: Total Suspended Solids).

Sampling Points	PO_4–P (mg L^{-1})	TP (mg L^{-1})	$NO_2 + NO_3$ (mg L^{-1})	NH_4 (mg L^{-1})	TN (mg L^{-1})	SiO_2 (mg L^{-1})	TSS (mg L^{-1})
Stn. 1	0.02 ± 0.012	0.048 ± 0.026	0.083 ± 0.04	0.01 ± 0.00	0.480 ± 0.206	0.367 ± 0.241	11.00 ± 4.62
Stn.2	0.015 ± 0.006	0.029 ± 0.013	0.071 ± 0.059	0.01 ± 0.00	0.230 ± 0.126	0.563 ± 0.442	8.07 ± 2.74
Stn. 3	0.013 ± 0.005	0.026 ± 0.009	0.071 ± 0.059	0.01 ± 0.00	0.427 ± 0.170	0.292 ± 0.225	22.1 ± 22.5
Stn. 4	0.015 ± 0.006	0.035 ± 0.018	0.036 ± 0.02	0.01 ± 0.00	0.162 ± 0.047	0.575 ± 0.561	9.35 ± 4.85
Stn. 5	0.01 ± 0.00	0.051 ± 0.066	0.088 ± 0.074	0.01 ± 0.00	0.498 ± 0.379	0.555 ± 0.632	19.1 ± 24.8
Stn. 6	0.015 ± 0.01	0.065 ± 0.073	0.088 ± 0.063	0.01 ± 0.00	0.498 ± 0.379	0.186 ± 0.156	28.4 ± 29.7
Stn. 7 (Ref.)	0.01 ± 0.00	0.052 ± 0.072	0.094 ± 0.041	0.01 ± 0.00	0.262 ± 0.075	0.487 ± 0.477	15.98 ± 8.36

3.5. Correlations between Environmental Variables and the Polychaeta Abundance

Considering the sampling data, Pearson's coefficient correlation values between several environmental variables, such as O_2 (mg L^{-1}), temperature (°C), salinity (‰), pH, and total abundance of exotic polychaeta showed that the highest positive correlation ($r = 0.58$; $p < 0.05$) was between pH level and the abundance. The lowest negative correlation with a value of $r = –0.14$ ($p < 0.05$) was found between salinity and abundance. The relationship between the number of individuals and the average value of the physico–chemical variables and nutrient quantities measured over the sampling period for all sampling points is given in Table 4. When the relationship between variables of the sediment characteristics and the abundance was examined, the highest positive relationship ($r = 0.83$; $p < 0.05$) was between sand content and abundance, while the lowest negative correlation ($r = -0.59$; $p < 0.05$) was found between organic matter amount (%) and abundance. The relationships between the annual average values of nutrients and TSS in the lagoon water and the number of individuals were also calculated. The highest positive relationships with the abundance were between TP ($r = 0.61$; $p < 0.05$) and TSS ($r = 0.53$; $p < 0.05$) (Table 4).

Table 4. Values of Pearson rank correlations ($p < 0.05$) between environmental variables and the abundance of polychaete (OM: Organic matter, TP: Total phosphate, TN: Total nitrogen, TSS: Total Suspended Solids).

	Abundance (ind. 0.09 m^{-2})	Temperature (°C)	Salinty (‰)	pH	O_2 (mg L^{-1})	OM (%)	Clay + silt (%)	Sand (%)	PO_4–P (mg L^{-1})	TP (mg L^{-1})	$NO_2 + NO_3$ (mg L^{-1})	NH_4 (mg L^{-1})	TN (mg L^{-1})	SiO_2 (mg L^{-1})	TSS (mg L^{-1})
Pearson Correlation	1	0.44	−0.14	**0.58**	−0.39	−0.59	−0.64	**0.83** *	−0.43	**0.61**	0.12	.[a]	0.07	−0.51	**0.53**
Sig. (2-tailed)		0.33	0.77	0.17	0.40	0.16	0.13	0.02	0.34	0.15	0.80		0.90	0.25	0.22

*. Correlation is significant at the 0.01 level (2-tailed). [a]. Cannot be computed because at least one of the variables is constant.

According to TUBI [60], opportunistic polychaete, *Pseudopolydora paucibranchiata*, which has an ecological quality group V, was the most dominant species with 40 ind. 0.09 m^{-2} in the area. *Pseudopolydora paucibranchiata* was found to be the most dominant (24 ind. 0.09 m^{-2}) at station 6, where the average amount of organic matter in sediment was 2.75% per year.

One of the main concerns in the lagoon areas is eutrophication (enrichment of nutrients in the environment), which has negative consequences for animal populations [2]. Macrozoobenthic communities respond relatively quickly to anthropogenic and natural stress, and due to eutrophication, low water quality leads to a reduction in the quantitative status and biodiversity of communities [6]. Depending on the dystrophic conditions in the discharge zones where domestic wastes are discharged to the coastal area, benthic species initially increase quantitatively and qualitatively, but then, sensitive species disappear [61].

Specifically, marine polychaete communities are the group living in the most stressful regions caused by anthropogenic pollution in lagoon environments [7]. Thus, their role as indicators in the assessment of organic pollution is well-known. Discharging wastewater into the marine environment at lower treatment levels has a greater impact on polychaeta when compared to biologically treated wastewater [62]. Spionid polychaeta could have been introduced to the Mediterranean Ecosystem via the ballast waters of vessels, especially by the Suez Canal [13]. Some 18 species of serpulid polychaeta are known to be alien or cryptogenic. Among these, *H. dianthus* lives in tube clusters in both temperate and subtropical regions. As a fouling species, it can attach to pier feet, ship ropes, and buoys [53]. It was previously recorded in the lagoon areas in the Po River Delta [10]. Otani and Yamanishi (2010) [63] reported that the maximum abundance of *H. dianthus* in Osaka Bay (Japan) occurred in periods with an average temperature of 19.1 ± 7.5 °C, an average salinity value of 29.9 ± 2.3‰, and an average oxygen value of 10.7 ± 3.4 mg L^{-1}. The density of *H. dianthus* showed a significant negative correlation with salinity ($r_s = -0.59$. $p < 0.01$) but showed no significant correlation with water temperature and dissolved oxygen. The species is able to tolerate low oxygen concentrations, and for the species' maturation, salinity levels of 25–35‰ are sufficient [53]). In this study, a single individual of *H. dianthus* was found where the oxygen level was 6.93 mg L^{-1}, and the salinity was 22.35‰ of the lagoon surface water. Our findings were similar to the oxygen and salinity levels tolerated by *H. dianthus* stated by [53].

Polydora cornuta lives both in fouling communities and muddy bottoms. Yet, it is not found in calcareous sediments [64]. The biotopes where it occurs are exposed to temperature and salinity extremes [31]. An opportunistic polychaeta, *P. cornuta* can tolerate hypoxic conditions and is abundant in organically enriched sediments [6,12,31]. It is known to colonies in distant geographic areas in ballast waters via ship transports and to be one of the worst alien species in the Mediterranean [34]. The first Mediterranean record of *P. cornuta* was from the organically polluted bottoms of Valencia Harbor, Spain [29]. Then, it was reported from İzmir Bay (eastern Aegean Sea) [31]. Its records in the Turkish Straits System were presented by [21,41], the Bosporus.

Bachelet et al. (2000) [11] reported that *P. cornuta* (7030 individuals) was one of the most dominant polychaeta species in the Prevost Lagoon (Southern France). *P. cornuta* was reported from the Romanian coast of the Black Sea as 6000–22,000 ind·m^{-2} (and approximately 95,000 ind·m^{-2} in extremely polluted sediments) [8]) and the Crimea [65]. Surugiu and Feunteun (2008) [5] reported that *P. cornuta* was one of the most dominant polychaeta species (444 ind·m^{-2}; di = 9.08%) on the Romanian coast of the Black Sea where domestic pollution was observed. In this study, *P. cornuta* was the most observed species according to the frequency index value (f = 75%). The environmental variable values measured in the seawater of the locality, where *P. cornuta* was the most dominant on the coast of Romania, are presented in ([5] Table 6). Additionally, *P. cornuta* was recorded as the highest (3 ind. 0.09 m^{-2}) at the reference site of the present study area. In another study performed on the Romanian coast, [66] *P. cornuta* was found to have a dominant value of 9.07% and 236 ind·m^{-2} in M. galloprovincialis beds at 1.5 m under the influence of domestic pollution.

Recently, Bertasi (2016) [34] conducted a study on the distribution of *P. cornuta* communities in Venice, Marinetta, and Barbamarco lagoons (Northern Adriatic). In this study, the highest abundance of *P. cornuta* with an average density of 2500 (±310.2 SE) ind·m^{-2} was recorded in Barbamarco Lagoon. This represented 3.8% of the macrofauna present and was recorded under conditions with an average water temperature of 8.7 °C and a salinity value of 31.2‰. Abundance values of *P. cornuta* (3170 ind·m^{-2}) in İzmir Bay (eastern Aegean Sea) [31] and the Sea of Marmara (3390 ind·m^{-2}) [41] were very similar. However, populations of the species along the Western Black Sea coasts of Romania have reached 150,000 ind·m^{-2} [8].

P. cornuta tolerates wide ranges of salinity and temperature [33]. Takata et al. (2011) [67] stated that *P. cornuta* was found to be the most abundant species (2412 individuals) in the eutrophic Fukuyama Harbor (Japan), where the sediment sludge content was 93%, the surface water salinity at a depth of 0.5 m was 25.7‰, and the oxygen saturation was 45.2%. The abundance (less than 10 individuals) was quite low in the waters with high oxygen saturation (above 100%). Colonies of *P. cornuta* prefer the sandy and silty mud soft bottoms in Italian Lagoons, and aquaculture activities in lagoons may have a role in the spreading dynamics of *P. cornuta* [34]. The presence of Manila clam, Ruditapes philippinarum, in the North Adriatic Lagoons supports a relationship between aquaculture activities and the occurrence of *P. cornuta*. Bertasi (2016) [34] states that *P. cornuta* has more abundance in the areas where Hediste diversicolor (O.F. Müller, 1776), Heteromastus filiformis (Claparède, 1864), and Capitella spp. (Blainville, 1828) are characteristic of polluted sediments. These species were observed on the soft bottoms of the Sea of Marmara as well [41]. Only four specimens of *P. cornuta* were recorded on the organically poor bottoms of the present study area. The average organic matter in sediment was 1.73 and 2.75% for the two stations of occurrence (Stations 6 and 7).

Exotic polychaeta, Pseudopolydora paucibranchiata, commonly prefers shallow muddy bottoms but also is known to be found in oyster beds. The species dwells in mud and mucus tubes in sediment [17]) and can create dense populations on soft bottoms and fouling communities. It was found previously in several polluted sediments of the Turkish coasts [13]. As new information, [23] stated that polychaete specimens described as *P. paucibranchiata* previously from Norway do not belong to this species. The abundance of *P. paucibranchiata* previously reached about 6180 ind·m^{-2} in İzmir Bay, the Eastern Aegean Sea. Sediments with organic matter and shallow water of 2–4 m also provide a proper biotope for this species. A maximum abundance (624 ind·m^{-2}) in İskenderun Bay (Eastern Mediterranean) was found on shallow (of 0.1 m) bottoms with the bivalve Brachiodontes pharaonis [13]. *P. paucibranchiata* can replace native species on the bottoms where environmental stress exists. However, it is not such a definitive indicator of pollution as the other exotic polychaete, *Polydora cornuta* [64]. It was first reported in 1997 from the polluted areas of the Mediterranean [68]. Spionid polychaeta, *P. cornuta*, and *P. paucibranchiata* have an important role in the cycle of organic matter in sediments of marine and lagoon environments and are excellent foods for predators, such as fish, birds, and crabs in the food chain [13]. No individuals of the exotic species were found at station 1 (OM% = 10.65) (OM = Organic matter) and station 3 (OM% = 15.52), where seasonal average organic matter was high in the sediment. However, *P. cornuta* and *P. paucibranchiata* were also abundant on organically rich bottoms in previous studies [13,67,68]. Contrarily, *P. paucibranchiata* was observed most abundantly (24 ind. 0.09 m^{-2}) in the station with low amounts (average 2.75%) of organic matter in Çardak Lagoon. In addition, the average seasonal salinity, temperature, and oxygen values were 21.87‰, 16.33 °C, and 7.08 mg $L^{-1,}$ respectively, at station 6, dominated by *P. paucibranchiata*.

Low concentrations of dissolved oxygen, salinity, and high nutrient levels in coastal areas are determinants of eutrophication. *Polydora cornuta* and *Pseudopolydora paucibranchiata* are known to be characteristic species of areas subjected to very high levels of pollution with organic matter. Conversely, the two exotic species indicated above were reported to be dominant on soft bottoms where the amount of organic matter was less than 2.75% in Çardak Lagoon. However, the highest amount of organic matter (16.88%) in the sediment was measured at station 3 in April 2019, and the lowest amount (1.4%) at the reference station (st.7) in February 2019. *Polydora cornuta* and *P. paucibranchiata* were not found at station 3, where the highest organic matter was determined in the sediment.

Ballast water of commercial vessels may cause the transport of alien species to different seas. Three polychaete species found in this study are exotics that are transported to the Mediterranean from distant areas. However, opportunistic polychaeta, *Polydora cornuta* and Pseudopolydora paucibranchiata, are known as both invasive alien species and new pollution indicator species in the Mediterranean Sea [60]. In this study, a few individuals belonging to *Hydroides dianthus* (single specimen) and *P. cornuta* (four specimens) were found on organic matter poor sediments (1.4–4.08%). *P. paucibranchiata*, another opportunistic polychaete found in the study, was recorded where the organic matter in sediment was between 1.69 and 4.38%. Contrarily, opportunistic polychaeta observed in Çardak Lagoon, which is under anthropogenic effect, mostly preferred organically poor sediments.

Coastal lagoons are complex transition environments between land and sea, which are usually shallow bodies of water separated from the sea by a barrier but connected to the sea via one or several channels [69]. These are extremely valuable parts of the coastal ecosystem as they are important elements for the sustainability of the aquatic ecosystems and provide great natural resources (fisheries, a gathering of algae, salt extraction, etc.), which have been exploited for many centuries. In order to provide the sustainability of such important coastal habitats, sustainability management studies should be carried out in lagoons. This management is necessary to ensure the continuity of the overall integrity of the ecosystem by minimizing negative impacts on aquatic life [70].

Biological invasion, which adversely affects fisheries, aquaculture, and biodiversity in aquatic ecosystems, is one of the serious threats to the lagoons, too. Invasive alien species are known to alter ecosystem functioning and even habitat structures [71]. Polluted or physically degraded environments are more prone to invasion than pristine sites [72]. As the Polychaeta is one of the groups with the most representatives in such regions, even with invasive ones, monitoring the status of exotics in a region is important for a sustainable ecosystem. As in the current study, the detection of alien polychaeta species in the region is important in terms of revealing the species with high invasion potential in the environment and determining possible risks in advance, thus contributing to the sustainable management of the lagoon. It is necessary to keep on monitoring studies in these important and vulnerable habitats in order to determine the threats, such as alien species invasions, as early as possible.

4. Conclusions

Three exotics polychaeta found in this study area are quite tolerant to sediment pollution (especially the amount of organic matter). *Polydora cornuta* and *Pseudopolydora paucibranchiata* were previously reported from the Turkish Straits. More than 100 commercial vessels pass through the Çanakkale Strait per day; because of that, the area is open to exotic species settlements. Exotics are currently not found in high abundance in the system. Since the study area is shallow water, it is possible that the excessive amount of organic matter that may occur in the sediment over time will increase the population of these pollution indicator species, which is important in terms of the degree of invasion to be observed in the area. Therefore, to keep on monitoring the study area is essential for the sustainable management of the lagoon because the increase in the amount of organic matter in the sediment will encourage the increase in opportunistic and invasive polychaete species, which may further adversely affect the ecosystem quality.

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