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Effects of environmental variables on Oligochaeta (Annelida) assemblages in Çardak Lagoon (Turkish Straits System)

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ABSTRACT

This study aimed to investigate the relationships between the abundance of the Oligochaeta assemblages in Çardak Lagoon, an area impacted by domestic pollutants. A total of 3 oligochaeta species [(*Thalassodrilides gurwitschi* (Hrabě, 1971), *Thalassodrilides* sp., and *Oligochaeta* sp.] were recorded. The peak abundance periods for these communities were determined to be spring and summer. Analysis of the environmental variables across the sampling seasons revealed that the anionic detergent level in the water and the percentage of gravel in the sediment exhibited the highest correlation with overall oligochaete abundance. At the sampling points, the maximum correlation value was recorded specifically between the percentage of organic matter (OM%) in the sediment and the abundance of *Thalassodrilides gurwitschi*.

Keywords: Oligochaeta, Sewage pollution, Çardak lagoon, Turkish straits system

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Introduction

Oligochaetes constitute one of the major macrozoobenthos groups and play a significant ecological role in aquatic ecosystems. Although marine oligochaetes are frequently encountered in shallow waters, studies investigating the environmental factors influencing these populations remain relatively scarce (Pfannkuche, 1978; Thompson & Shin, 1983; Diaz et al., 1987; Diaz & Erseus, 1994; Gierre, 2006; Lafont & Vivier, 2006; Gamito, 2008; Coelho et al., 2015; Guimarães et al., 2024). The structure of oligochaete communities, which is indicative of aquatic ecosystem health, can be significantly influenced by environmental factors across diverse water bodies, including marine, freshwater, and brackish environments (Guimarães et al., 2024). These ecological variables encompass the availability and quality of food resources, contaminants in the water and sediment, and physicochemical characteristics (Behrend et al., 2012).

Most Oligochaeta species typically inhabit areas where the sediment is rich in organic material. Furthermore, they often displace other macrozoobenthos communities that exhibit a lower tolerance for elevated organic content (Rosa et al., 2014).

Aquatic oligochaetes fulfil a significant ecological function within the food web and in sediment mixing. They also serve as a critical food source for various fish and crustacean species (Guimarães et al., 2024). The particle composition and the level of organic matter in the sediment are primary factors influencing the structure of marine ecosystems. Crucially, the burrowing activity of oligochaetes facilitates the release of accumulated biogenic compounds and pollutants from the sediment into the surrounding water column.

The distribution of marine oligochaetes is significantly influenced by key water quality parameters, including oxygen and salinity concentrations, as well as the presence of hydrogen sulfide (Giere, 2006). Oligochaetes can thrive in sediments rich in organic matter, provided there is sufficient oxygen availability. However, these assemblages are particularly vulnerable to heavy metal contamination (Rodriguez & Reynoldson, 2011). Species recognised as indicators of nutrient-rich environments often exhibit strong tolerance to silty substrates heavily loaded with organic material. Consequently, analysing current oligochaete populations plays a crucial role in assessing the trophic status of water bodies (Chapman et al., 1982).

Anthropogenic pollution has significantly escalated worldwide in marine environments, leading to severe detrimental effects on benthic communities, encompassing both meiofauna and macrofauna. Oligochaetes, a key macrozoobenthic group, are widely recognised as effective indicators of pollution (Chapman et al., 1982; Abubakr et al., 2018).

These organisms are frequently encountered in surface sediments and thrive in areas characterised by low oxygen levels (Lafont & Vivier, 2006). Marine oligochaetes, notable for their high numbers and large biomass, particularly in nutrient-rich coastal areas, are primarily regarded as indicators of both water quality and sediment contamination (Pfannkuche, 1978).

Sewage pollution constitutes a major challenge for coastal regions. The sludge from household waste, often containing carbon levels between 50% and 70%, serves as a significant nutrient source for oligochaetes. Furthermore, they play a crucial role in the formation of sea floor sediment and substantially influence the mineralisation process within aquatic sediments (Ratsak & Verkuijlen, 2006).

This study investigates the relationships between oligochaete abundance in a contaminated lagoon and various temporal and spatial environmental variables.

Materials and Methods

Samplings

The sampling area was established across seven distinct points (GPS Coordinates: 40 ∘ 23 ′ 14 ″ N, 26 ∘ 43 ′ 30 ″ E) within the Çardak Lagoon, located in the northeastern part of the Çanakkale Strait. The sampled depths ranged from 1 to 1.8 meters (Figure 1).

Faunistic Analysis

Oligochaete samples were collected by a SCUBA diver using a 30x30 cm metal-framed quadrat during October 2018, and subsequently in February, April, and June 2019. The samples were preserved in 5 L plastic containers using a 4% neutralized formaldehyde solution. In the laboratory, the sediment was processed by rinsing with pressurised water and passing it through a three-tiered sieve system with mesh sizes of 0.5, 1, and 2 mm. Individuals retained on the sieves were collected (both macro- and micro-levels) and preserved in 70% ethanol in 50 cc glass tubes. All identified oligochaetes were examined and counted under a trinocular stereomicroscope based on classifications from previous studies. Identification relied specifically on the definitions provided by Brinkhurst (1971, 1980, 1982). The relationships between environmental variables and oligochaete populations across the seven distinct sampling sites and four seasonal periods were statistically evaluated using the Pearson correlation coefficient (r) via the PAST software.

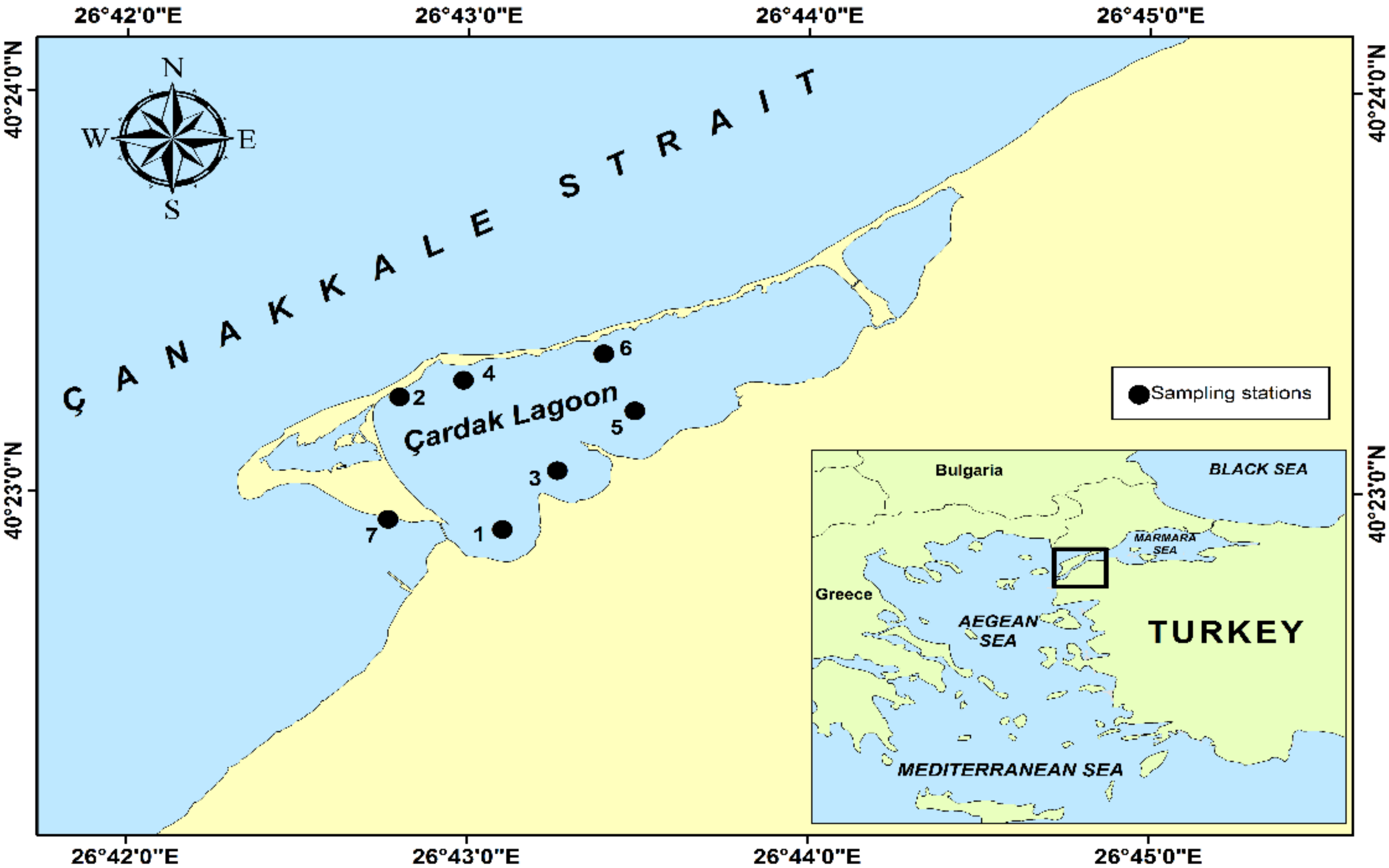


Figure 1. Map of the study area showing the sampling points

Water and Sediment Analyses

Water quality variables of the lagoon water were measured in situ using a YSI 650 MDS multi-parameter device. Nutrient levels (NO^-_2, NO^-_3, NH^+_4, PO_4-P, SiO_2) and total suspended solids (TSS) in the lagoon water were determined in the laboratory following the analytical methods established by Strickland and Parsons (1972). These measurements utilised various wavelengths on a Jasco Brand UV spectrophotometer located at the Faculty of Marine Sciences and Technology laboratory. The determination of percentage organic matter and particle content in the sediment was performed at the Central Laboratory of Çanakkale Onsekiz Mart University. Sediment particle size analyses were carried out according to the standards established by Allen (1997).

Results and Discussion

Water and Sediment Variables Data

Environmental conditions in the lagoon varied seasonally. Water temperature ranged from 7.57 to 27.34 ◦C, peaking at 27.34 ◦C in June 2019. Surface water salinity fluctuated between 20.17‰ and 24.40‰. The pH levels, spanning 7.78 to 8.56, remained within the typical range for seawater. Dissolved oxygen concentrations in the water varied from 5.90 to 9.51 mg L^{-1}.

Regarding nutrients, ammonium (NH^+_4) concentrations were consistently minimal (<0,01 mg L^{-1}) across all sampling sites throughout the study period. Phosphate (PO_4-P) levels ranged from 0.01 to 0.03 mg L^{-1}. Furthermore, total phosphate concentrations varied between 0.02 and 0.17 mg L^{-1}, with the maximum total nitrogen measurement recorded at 0.99 mg L.

The maximum NO^-_2 +NO^-_3 concentration (0.195 mg L^{-1}) was recorded during the autumn of 2018. The peak chlorophyll-*a* (Chl-*a*) level observed in the lagoon water (12.85 µg L^{-1}) occurred in the summer of 2019, while the highest total suspended solids (TSS level (71.33 mg L^{-1}) was recorded in the winter of 2019. A significant negative linear relationship (p <0.001) was found between Chl-*a* and TSS values. This finding suggests that the suspended load in the lagoon was predominantly of terrestrial rather than phytoplanktonic origin.

Chemical Oxygen Demand (COD) values were higher in autumn and winter compared to other seasons. Conversely, the concentrations of anionic detergents were lower during autumn and winter. Table 1 presents the average values for all environmental variables throughout the sampling periods.

Table 1. Spatiotemporal variability in water chemistry, nutrients, chlorophyll-*a* (chl-*a*), total suspended solids (TSS), chemical oxygen demand (COD), and anionic surfactant (AS) values measured in the study

Variable	Station	Mean±SD	Min.	Max.	Variable	Station	Mean±SD	Min.	Max.
	St. 1	15.59±6.77	8.46	24.75		St. 1	7.97±0.19	7.78	8.20
	St. 2	16.74±8.07	7.86	27.34		St. 2	8.29±0.08	8.18	8.37
	St. 3	15.61±7.21	7.69	25.20		St. 3	8.18±0.09	8.05	8.26
T (°C)	St. 4	15.53±6.61	7.96	24.07	pH	St. 4	8.32±0.09	8.23	8.43
	St. 5	15.89±7.85	7.57	26.31		St. 5	8.25±0.15	8.07	8.40
	St. 6	16.33±7.88	7.68	26.54		St. 6	8.34±0.20	8.14	8.56
	St. 7, ref.	16.19±7.03	8.72	25.46		St. 7, ref.	8.25±0.09	8.12	8.35
	St. 1	21.91±1.69	20.29	23.92		St. 1	8.18±1.49	6.11	9.51
	St. 2	22.01±1.37	20.78	23.92		St. 2	7.76±1.19	6.85	9.50
	St. 3	21.79±1.20	20.76	23.00		St. 3	7.21±1.08	6.15	8.17
S (‰)	St. 4	22.04±1.37	20.77	23.69	O_2 (mg L^{-1})	St. 4	7.07±1.01	5.99	8.27
	St. 5	22.04±0.88	20.80	22.85		St. 5	7.18±1.12	6.16	8.47
	St. 6	21.87±0.84	20.74	22.74		St. 6	7.08±0.81	5.90	7.69
	St. 7, ref.	22.04±1.93	20.17	24.40		St. 7, ref.	7.76±0.37	7.41	8.20
	St. 1	0.02±0.012	0.01	0.03		St. 1	0.01±0.00	0.01	0.01
	St. 2	0.015±0.006	0.01	0.02		St. 2	0.01±0.00	0.01	0.01
	St. 3	0.013±0.005	0.01	0.02		St. 3	0.01±0.00	0.01	0.01
PO^-_4 (mg L^{-1})	St. 4	0.015±0.006	0.01	0.02	NH^+_4 (mg L^{-1})	St. 4	0.01±0.00	0.01	0.01
	St. 5	0.01±0.00	0.01	0.01		St. 5	0.01±0.00	0.01	0.01
	St. 6	0.015±0.01	0.01	0.03		St. 6	0.01±0.00	0.01	0.01
	St. 7, ref.	0.01±0.00	0.01	0.01		St. 7, ref.	0.01±0.00	0.01	0.01
	St. 1	0.048±0.026	0.02	0.07		St. 1	0.480±0.206	0.30	0.74
	St. 2	0.029±0.013	0.02	0.04		St. 2	0.230±0.126	0.10	0.37
	St. 3	0.026±0.009	0.02	0.04		St. 3	0.427±0.170	0.25	0.66
TP (mg L^{-1})	St. 4	0.035±0.018	0.02	0.05	TN (mg L^{-1})	St. 4	0.162±0.047	0.10	0.20
	St. 5	0.051±0.066	0.02	0.15		St. 5	0.498±0.379	0.20	0.99
	St. 6	0.065±0.073	0.02	0.17		St. 6	0.498±0.379	0.20	0.99
	St. 7, ref.	0.052±0.072	0.02	0.16		St. 7, ref.	0.262±0.075	0.20	0.35
	St. 1	0.083±0.04	0.04	0.13		St. 1	0.367±0.241	0.15	0.60
	St. 2	0.071±0.059	0.04	0.13		St. 2	0.563±0.442	0.20	1.20
	St. 3	0.071±0.059	0.02	0.13		St. 3	0.292±0.225	0.05	0.55
NO_2+NO_3 (mg L^{-1})	St. 4	0.036±0.02	0.01	0.06	SiO_2 (mg L^{-1})	St. 4	0.575±0.561	0.20	1.40
	St. 5	0.088±0.074	0.03	0.20		St. 5	0.555±0.632	0.17	1.50
	St. 6	0.088±0.063	0.03	0.18		St. 6	0.186±0.156	0.02	0.40
	St. 7, ref.	0.094±0.041	0.05	0.14		St. 7, ref.	0.487±0.477	0.20	1.20
	St. 1	3.64±3.84	1.61	9.39		St. 1	11.00±4.62	6.80	17.60
	St. 2	2.64±1.52	1.06	3.96		St. 2	8.07±2.74	4.30	10.20
	St. 3	3.39±2.27	1.09	5.75		St. 3	22.1±22.5	3.80	54.40
Chl-*a* (µg L^{-1})	St. 4	2.96±2.26	0.97	6.19	TSS (mg L^{-1})	St. 4	9.35±4.85	4.00	15.60
	St. 5	2.59±2.13	1.31	5.76		St. 5	19.1±24.8	3.20	56.00
	St. 6	4.47±5.61	1.07	12.85		St. 6	28.4±29.7	7.20	71.30
	St. 7, ref.	1.49±0.44	1.05	1.98		St. 7, ref.	15.98±8.36	7.70	24.40
	St. 1	127.9±52	76.00	198		St. 1	0.045±0.022	0.02	0.07
	St. 2	152.1±102.8	76.00	295		St. 2	0.027±0.016	0.02	0.05
	St. 3	105.0±55.2	40.00	158		St. 3	0.032±0.014	0.02	0.05
COD (mg L^{-1})	St. 4	87.5±64.1	40.00	181	AS (mg L^{-1})	St. 4	0.040±0.014	0.02	0.05
	St. 5	120.5±111.8	40.00	277		St. 5	0.034±0.011	0.02	0.05
	St. 7, ref.	101.5±79.6	40.00	207		St. 7, ref.	0.032±0.016	0.02	0.05

Sediment analysis in the sampling area revealed a composition dominated by sand (71.59%), followed by gravel and shell content (20.16%), and mud (encompassing both clay and silt) at 8.19%. The highest proportion of sand (92%) was recorded at Station 6. Conversely, Station 5 exhibited the maximum levels of mud (16.71%) and gravel/shell content (25.64%) (Table 2).

Regarding the organic matter content in the sediment, the peak measurement (16.88%) occurred at Station 3 during both the spring and summer sampling periods. The reference station consistently showed the lowest average organic matter content, recording 1.79% (Table 3). Seasonal variations were also observed in the water column: the maximum organic matter concentration in water (14.6 mg L^{-1}) was recorded in winter at Station 2. Conversely, the minimum concentration (9.6 mg L^{-1}) was noted in spring at Stations 2, 5, and 7. (Seasonal variations in sediment organic matter are further detailed in Table 3).

Faunistic Data

A total of 937 oligochaete specimens, encompassing three species (*Thalassodrilides gurwitschi* (Hrabě, 1971), *Thalassodrilides* sp., and *Oligochaeta* sp.), were recorded in Çardak Lagoon between autumn 2018 and summer 2019. *Oligochaeta* sp. was identified as the most dominant species in the study area, exhibiting a density of 886 ind. 0.09 m^{-2}. This was followed by *Thalassodrilides* sp., from which 42 specimens were recorded (Table 4). The highest abundance of *Oligochaeta* sp. (616 ind. 0.09 m^{-2}) was recorded at the reference site, which was characterised by the lowest sediment organic matter content (1.73%). Temporally, spring exhibited the maximum number of *Oligochaeta* sp. individuals (448 ind. 0.09 m^{-2}). Conversely, the marine oligochaete species *T. gurwitschi* was the least frequently encountered throughout the entire study, with only 9 individuals sampled across all periods.

Table 2. Mean seasonal percent granulometry ratios recorded at stations

	Particle type %							
Factor	**Clay+silt**	**Very fine sand**	**Fine sand**	**Medium sand**	**Coarse sand**	**Very coarse sand**	**Gravel and shell**	**Coarse gravel and shell**
Stn, 1	14.16	13.89	18.04	9.43	8.91	11.46	14.74	9.3
Stn, 2	3.17	10.96	15.93	19.57	**16.49**	15.72	10.47	7.65
Stn, 3	13.24	7.25	7.92	9.85	12.82	**17.3**	**19.72**	11.83
Stn, 4	5.27	20.08	**43.68**	7.1	8.91	6.42	4.12	4.36
Stn, 5	**16.71**	**23.66**	9.27	7.17	7.75	9.76	11.85	**13.79**
Stn, 6	3.29	13.67	43.94	**25.06**	6.16	3.91	2.59	1.38
Stn, 7, ref,	1.49	3.1	15.26	17.55	15.88	**17.3**	16.11	13.25
Mean	8.19±6.27	13.23±7.06	22.00±15.32	13.67±4.04	10.98±4.08	11.69±5.34	11.37±6.24	8.79±4.65

Table 3. Seasonal values of organic matter content in water and sediment. WOM: Organic matter in water, SOM: Organic matter in sediment

	Sampling period							
	Autumn 18		**Winter 19**		**Spring 19**		**Summer 19**	
Sampling point	WOM (mg L^{-1})	SOM (%)	WOM (mg L^{-1})	SOM (%)	WOM (mg L^{-1})	SOM (%)	WOM (mg L^{-1})	SOM (%)
St. 1	11	11,43	11,6	8,9	10,6	10,14	11,2	12,14
St. 2	10,8	2,73	**14,6**	3,99	9,6	3,6	11,6	1,82
St. 3	11,1	**14,21**	12,8	**14,13**	**11,4**	**16,88**	11,2	**16,88**
St. 4	**11,2**	4,38	10,6	2,97	10	4,08	11,6	2,56
St. 5	11	7,76	12,2	7,53	9,6	6,76	**12**	9,6
St. 6	10,9	2,69	12,4	2,94	10	2,73	11,4	2,64
St. Ref.	**11,2**	1,76	11,2	1,4	9,6	2,1	11,4	1,69

Table 4. The number of individuals of oligochaeta species by sampling periods and stations. Σ: Total abundance, Di%: Dominance.

OLIGOCHAETA	St. 1	St.2	St.3	St. 4	St. 5	St. 6	Ref.	Aut. 18	Win. 19	Spr. 19	Sum. 19	∑	Di%
Thalassodrilides gurwitschi	0	0	8	0	0	1	0	0	0	9	0	9	0,96
Thalassodrilides sp.	17	0	0	0	0	15	10	13	5	24	0	42	4,48
Oligochaeta sp.	0	171	39	15	6	39	616	41	151	448	246	886	94,55
Total	17	171	47	15	6	55	**626**	54	156	**481**	246	**937**	

Temporal and Spatial Correlations Between Environmental Factors and Oligochaeta Abundance in the Study Area

Correlation analysis revealed several strong and statistically significant relationships between oligochaete abundance and environmental parameters. *Thalassodrilides gurwitschi* abundance exhibited the most robust seasonal positive correlation (r=0.98; p <0.05) among all variables examined, specifically with the anionic detergent level in the water. Across all sampling periods, its abundance also demonstrated a significant positive correlation (r=0.75; p <0.05) with the percentage of organic matter in the sediment. Similarly, the abundance of Oligochaeta sp., the most dominant species in the study area, showed strong and statistically significant positive correlations with both the anionic detergent concentration in water (r=0.95; p <0.05) and the percentage of gravel in the sediment (r=0.96; p <0.05) (Fig. 2, 3).

Correlations With Environmental Variables for Abundance

The Principal Component Analysis (PCA) of the oligochaete data visualises stations as blue dots and environmental and biological variables as red arrows. Together, PC1 and PC2 account for 50.5% of the total variance. The Oligochaeta sp. vector extends towards high organic matter (OM%, WOM) and fine-grained sediment (Mud%), reflecting its tolerance to organic pollution; conversely, *Thalassodrilides gurwitschi* and *Thalassodrilides* sp. exhibit sensitivity to more oxygenated habitats with lower organic content. PC1 (28.3%) represents the sediment and trophic conditions, while PC2 (22.2%) reflects temperature and oxygen dynamics. The distribution of the stations along these two axes indicates the segregation of species according to the environmental stress gradient (Figure 4).

This table clearly demonstrates that the species occupy distinct ecological niches within the lagoon environment; *Thalassodrilides gurwitschi:* Indicator of organically rich but low-stress habitats, *Thalassodrilides* sp.: Adapted to nutrient-rich and well-oxygenated environments, *Oligochaeta* sp.: Tolerant species, resilient to increased organic load and salinity. These relationships quantitatively support the species–environment segregation observed in the PCA analysis and confirm that gradients of organic matter, salinity, and nutrients are the primary drivers shaping the benthic community composition within the lagoon system.

Considering the sampling stations, *T. gurwitschi* preferentially inhabits sediments rich in organic matter but moderately oxygenated. *Thalassodrilides* sp. thrives in areas characterised by high nutrient enrichment (verging on eutrophication). Conversely, *Oligochaeta* sp. is capable of tolerating very high levels of organic matter, yet its optimum density is observed under intermediate organic conditions. As for the sampling seasons, *T. gurwitschi* preferentially inhabits coarse-grained, oxygenated, and detritus-rich sediments, whereas *Thalassodrilides* sp. is tolerant of habitats that are organically rich, highly nutrient-loaded, and characterised by temperate temperatures. Conversely, *Oligochaeta* sp. is adapted to coarse-grained, low-oxygen, and organic matter-rich environments.

The most recent literature concerning the ecology and biology of marine oligochaetes was extensively analysed by Giere (2006). In lagoon and estuarine environments subjected to pollution, the increase in oligochaete abundance coupled with the decline in pollution-sensitive polychaete species has become increasingly pronounced (Díaz, 1980). However, oligochaetes are not universal indicators; therefore, other taxa must be concurrently considered to obtain comprehensive information on the ecological quality of aquatic environments (Lafont & Vivier, 2006). Oligochaetes significantly influence sediment properties—biologically, chemically, and physically—through bioturbation, which facilitates mineralisation and organic matter decomposition (Ito et al., 2016).

Although the organic matter content in the sediment is a crucial environmental variable, it is important to note that oligochaetes exhibit a stronger correlation with the organic matter in polluted sediments. Elevated organic matter in aquatic environments often leads to anoxic conditions. This restriction inhibits the growth of filter-feeding species, such as mussels, resulting in a shift in species composition where bivalves are typically replaced by polychaetes and oligochaetes (Coelho et al., 2015).

Considering the aquatic oxygen level, oligochaete species are highly tolerant to low dissolved oxygen levels, enabling them to inhabit polluted sediments where they can constitute nearly 100% of the macrozoobenthos in terms of both number and biomass (Sowa & Krodkiewska, 2020). While most aquatic oligochaetes are highly sensitive to oxygen depletion and consequently inhabit cleaner and/or colder water bodies, certain observations indicate their presence in deeper, anoxic sections of muddy bottoms, where they engage in feeding and predator avoidance. The distribution of oligochaetes is therefore primarily dictated by the availability of dissolved oxygen in and on the sediment. Consistent with this tolerance, our study also revealed weak and negative relationships between water oxygen levels and overall oligochaete abundance.

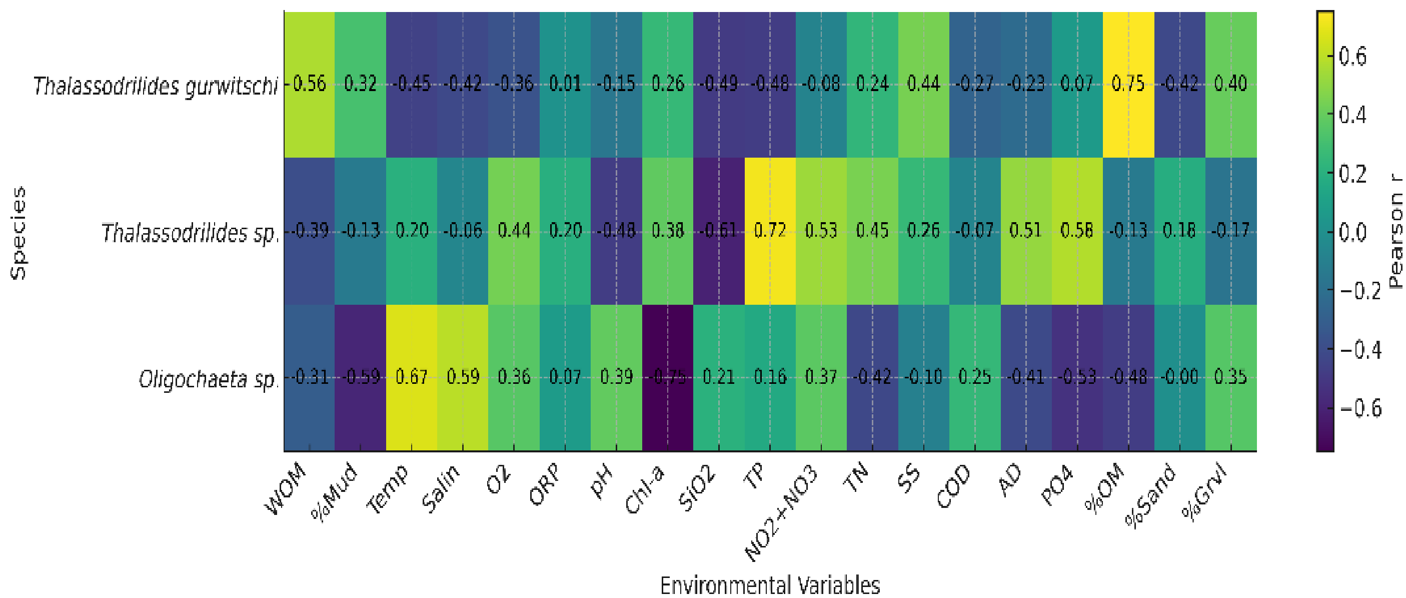
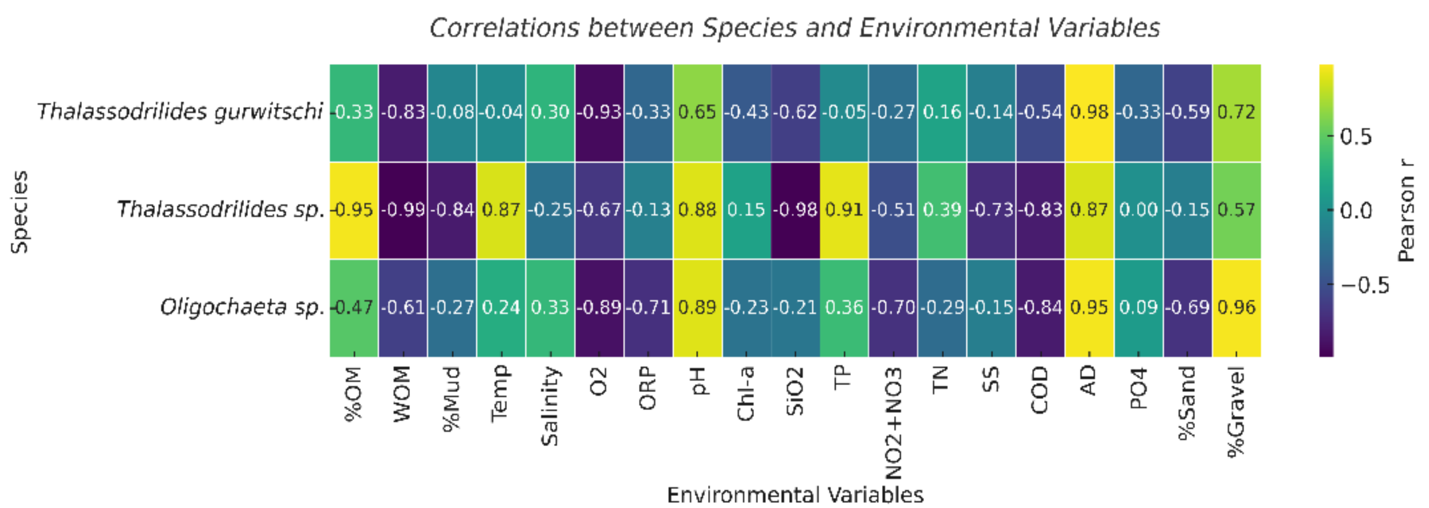


Figure 2. Diagram of heat correlation between oligochaeta abundance and environmental variables based on sampling points



WOM: Organic matter in water, OM: Organic matter in sediment, O_2: Oxygen, ORP: Oxygen reduction potential, Chl.-*a*: Chlorophyll-*a*, TP: total phosphate, TN: Total nitrogen, SS: Suspend solids, SiO_2: Silicate, COD: Chemical oxygen demand, AD: Anionic detergent, PO_4: Fosfat, Grvl%: Gravel.

Figure 3. Diagram of heat correlation between oligochaeta abundance and environmental variables based on sampling seasons

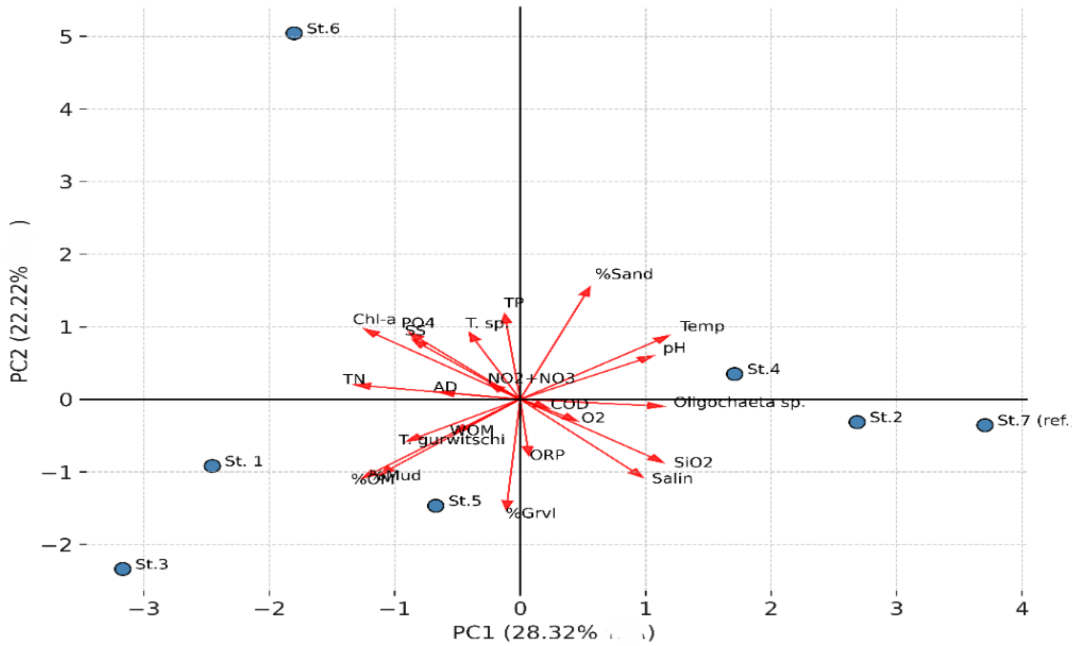


Figure 4. PCA ordination diagram for spatial mean environmental variables and abundance

The average abundance of several freshwater oligochaetes is positively correlated with the concentrations of various pollutants in the water column, including dissolved organic matter, ammonium, and phosphate (Rashid & Pandit, 2014). Specifically, freshwater *Limnodrilus* species are recognised as the most tolerant oligochaetes to organic pollution (Abubakr et al., 2018). Among these, *Limnodrilus hoffmeisteri* is known as an indicator of severe organic matter pollution in freshwater environments (Brinkhurst, 1980; Uzunov et al., 1988).

In this study, strong correlations were observed between the abundance of the marine oligochaete, *Thalassodrilides* species and sedimentary organic matter levels, which varied with station and season. Conversely, the abundance of *Oligochaeta* sp., which was the most abundant species recorded, demonstrated weak and negative correlations with the organic matter content. Based on these findings regarding organic matter, the *Thalassodrilides* species can be proposed as an effective indicator of organic matter pollution in this study area. In our study, the marine oligochaete *Thalassodrilides gurwitschi* was recorded in low numbers, which is consistent with its generally low prevalence in marine and brackish water environments (Torii et al., 2016). However, *T. gurwitschi* was previously identified by Thompson and Shin (1983) as one of the most dominant opportunistic species in Victoria Harbour (Hong Kong), particularly in bottoms where silt content exceeded 70%. Similarly, in the study area, the maximum number of *T. gurwitschi* individuals was encountered in bottom sediments characterised by a high silt and clay content (13.24%). Stoner and Acevedo (1990) also documented *T. gurwitschi* as the most dominant (2916 ind.m^{-2}) species in Joyuda Lagoon (western Puerto Rico).

Many oligochaete species exhibit wide thermal tolerance, surviving both low (around 0 °C) and high (above 20 °C) temperatures (Timm & Martin, 2015). Research on oligochaete population structure, particularly by Japanese scientists, including Kuniyasu et al. (1997) and Inamori et al. (1983), has examined the effects of water temperature, pH, and phosphate concentration on the population growth of freshwater species. Oligochaetes are typically found in environments characterized by elevated nutrient levels and chlorophyll-*a* content (Çelik et al., 2010). Furthermore, oligochaete abundance peaked during the spring and summer periods when the surface water temperature was elevated. In our study, although weak and negative correlations were observed between oligochaete abundance and the water variables of phosphate and temperature, strong seasonal positive correlations were recorded with pH levels.

Regarding oligochaete communities in the Mediterranean Sea, Casellato (1994) conducted a study on the oligochaete fauna, including *T. gurwitschi*, distributed across various lagoons and brackish water areas of the Po Delta (Northern

Adriatic). Furthermore, several studies have investigated oligochaete communities and their relationships with environmental variables in brackish and lagoon areas off the coast of Portugal (Gamito, 2008; Silva et al., 2012; Coelho et al., 2015). Among these studies, Gamito (2008) noted that the most heavily polluted bottoms of the Ria Formosa Lagoon (Southern Portugal, Western Mediterranean) were dominated by oligochaetes, particularly tubificids. In the Arade estuary, another aquatic area in Southern Portugal, Silva et al. (2012) documented high abundances of both *Capitella* spp. and oligochaetes associated with freshwater discharges. Furthermore, in the Salgado Lagoon (Southern Portugal), Coelho et al. (2015) established that oligochaete abundance exhibited a positive correlation with sediment phosphorus content, clay content, and chlorophyll a concentration. Conversely, despite the high concentration of chlorophyll-*a* in the water, particularly during the spring, we observed weak and negative correlations between Chl-*a* levels and oligochaete abundance recorded in the lagoon area.

While studies conducted in Türkiye on this subject have primarily focused on freshwater habitats, there remain limited investigations carried out in marine coastal areas such as lagoons and estuaries (Çınar et al., 2011; Aydın et al., 2022). Specifically, Çınar et al. (2011) reported five oligochaete species from depths ranging from 0 to 66 m in the Sea of Marmara; notably, *T. gurwitschi*, which was also recorded in the present study, was found at depths between 0 and 25 m. In another recent study within the Turkish Strait System, Aydın et al. (2022) documented oligochaetes exhibiting a dominance of 19.7% in Küçükçekmece Lagoon. More recently, Çınar et al. (2024) reported a total of 18 oligochaete species from Turkish seas and lagoons, noting that 11 of these species were distributed in the Aegean Sea. The same authors highlighted that no marine oligochaete species had been observed on the Turkish Mediterranean coast to date.

In the Enez Lagoon (northeastern Aegean Sea), which is in proximity to the present study area, Güher et al. (2005) examined the seasonal limnological characteristics. They analysed the faunal components in relation to environmental variables. As a result of their description of the benthic communities in Enez Lagoon, they concluded that the area exhibits a mesotrophic character.

While the organic matter content in the water was highly consistent across the study area, the percentage of organic matter in the sediment varied considerably. Sediment samples collected near domestic discharge points exhibited elevated organic matter levels. Specifically, Oligochaeta sp. was the most dominant species at Station 7, the site characterised by the lowest sediment organic matter and silt/clay content. Similarly, Oligochaeta sp. was dominant at Stations 2 and 6, where the combined organic matter and silt/clay content remained low (3%).

In the present study, the primary environmental variables determining oligochaete abundance across all sampling seasons were the anionic detergent level in the water and the percentage of sediment gravel. Furthermore, the percentage of organic matter, a well-established sediment variable influencing oligochaete distribution, was specifically found to affect the abundance of two Thalassodrilides species significantly.

Conclusion

The specific distribution and high abundance of *Oligochaeta* sp. in low-organic sediment, contrasted by the sensitivity of *Thalassodrilides* species to organic matter, highlight the need for species-specific analysis when assessing the ecological status of coastal lagoons. Future studies should focus on the chronic effects of anionic detergents and gravel content on benthic fauna in brackish water environments. The results of our study partially corroborate findings reported in various brackish, deltaic, and lagoon systems across the Mediterranean and global geographies concerning oligochaete distribution patterns and the relationships between their abundance and environmental variables. Çardak Lagoon, due to its semi-restricted nature (or slightly closed characteristic), appears to be less severely impacted by anthropogenic effects. However, the lagoon is subjected to multiple environmental stressors that influence the structure of the existing oligochaete community. The community's response to this stress is indicated by low densities, particularly at coastal sampling points where sediment pollution was observed. Therefore, further analysis of oligochaete communities in relation to environmental variables is crucial for gaining detailed insight into the ecosystem functioning of this lagoon area.

Compliance with Ethical Standards

Conflict of interest: The author(s) declare no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: This study was conducted in accordance with ethics committee procedures, with no animal experiments.

Data availability: The data will be made available upon request from the author.

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