

Research Article



Spatial distribution and structure of benthic polychaete communities in shallow waters of the south Caspian Sea, Iran

Rowshan O.¹; Sakhaei N.^{1*}; Zolgharnein Z.¹; Paknezhad H.²;
Taheri M.³

Received: July 2022

Accepted: December 2022

Abstract

Polychaetes are the most abundant taxon in benthic communities. The polychaete assemblages on the Iranian Caspian Sea coast were studied during the summer of 2016 and winter of 2017 to examine the spatial-temporal variability in diversity and community structure, as well as their relationships with the main environmental variables. As a representative of the study area, fifteen stations at 1, 3, and 5 m depths were chosen. *Capitella capitata* was reported for the first time in the Caspian Sea. Four species were found: *Streblospio gynobranchiata*, *Alitta succinea*, *Hypania invalida*, and *Capitella capitata*. The eastern transect (Gorgan Bay) had the highest total abundance of polychaetes (15146 ind.m²) with increasing in the abundance of *S. gynobranchiata*. Furthermore, *S. gynobranchiata* appears to be well-distributed in this sea and plays the most prominent role in the community structure. *A. succinea*, *S. gynobranchiata*, and *C. capitata* showed an increasing trend from the western to the eastern parts of the shoreline. Changes in polychaetes abundance can be attributed to changes in the sediment type, with western transects containing more sand and eastern transects comprising silt-loam. Total polychaete abundance was correlated with salinity, water temperature, depth, dissolved oxygen, Total Organic Matter and sediment characteristics in the summer and winter seasons, according to the Canonical correlation analysis. *S. gynobranchiata* and *C. capitata*, as invasive species, may have altered the current polychaete community distribution, structure, and diversity in the southeast Caspian Sea. The disappearance of some species and the decrease in species richness could be due to the success of *S. gynobranchiata* in the competition for resources and space. Other conditions such as environmental factors and pollutants can also affect the presence of sensitive and tolerant organisms.

Keywords: *Capitella capitata*, Community diversity, Environmental parameters, Sediment analysis, *Streblospio gynobranchiata*

1-Department of Marine Biology, Faculty of Marine Science and Oceanography, Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran

2- Department of Fisheries, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

3-Hormoz Strait Oceanography Center, Iranian National Institute for Oceanography and Atmospheric Science, Iran

*Corresponding author. Email: sakhaei@kmsu.ac.ir

Introduction

Polychaetes are segmented worms that live in all ocean environments, from abyssal depths to shallow estuaries and rocky shores, and even free swimming in open water. According to the World Register of Marine Species (WoRMS), approximately 12299 accepted species of polychaetes have been identified worldwide (Read and Fauchald, 2022).

In many aquatic ecosystems, they account for 30–80% of all macrobenthic species (Manokaran *et al.*, 2013). Because of their diverse ecological adaptations, polychaetes can live in a wide range of habitats and play an important role in transferring energy to small plants and invertebrates in marine ecosystems (Gozler, 2009). These worms are among the taxa that include organisms that are both sensitive and tolerant to environmental changes, and they are excellent indicators of environmental disturbances. Polychaetes may be used as sensitive monitors of water quality especially in terms of the effects of pollutants on life history characteristics (Dean, 2008). Researchers are particularly interested in the Caspian Sea due to its geographical location, unique plant, and animal species (such as sturgeons), and specific ecological changes that influence its biota. Macrofauna is the original food item for sturgeons, especially when they are juvenile, and grazing pressure caused by them is the most critical factor in controlling the biomass and diversity of macrofauna in this Sea (Haddadi

Moghaddam *et al.*, 2005; Karpinsky, 2010). Benthic marine organisms play an important role in global nitrogen, sulfur, and carbon cycles (Snelgrove *et al.*, 1996). Furthermore, benthic invertebrates play an important role in feeding benthic fish directly and a group of pelagic fish indirectly. Macrofauna is the primary food source for sturgeons, the extremely valuable and ancient Caspian Sea species from which caviar is derived (Haddadi Moghaddam *et al.*, 2005, Aliakbarian *et al.*, 2020). In comparison to the Black Sea, which has 238 valid polychaetes species (Kurt and Cinar, 2012), the Caspian Sea has only a few polychaete species. Until 2003, *Nereis (Hediste) diversicolor* and *Ficopomatus enigmatic* were reported as Caspian Sea non-indigenous polychaetes (Grigorovich *et al.*, 2003).

Benthic fauna and species composition in this enclosed sea have changed over the last decade as a result of biological invasions caused by human activities and global climate change (Katsanevakis *et al.*, 2013). In addition, in the last decade, at least two new invasive polychaetes (from two families) have been introduced into the Caspian Sea (Rowshan *et al.*, 2018). As a result, study the biodiversity of polychaetes and the impact of environmental factors on these animals are critical for understanding the function of the ecosystem and the biota structure of the Caspian Sea.

The objectives of this study are: (1) the description of polychaete worms using

electron microscopy. (2) the determination of changes in the composition and structure of polychaetes populations as a result of their location, and (3) the identification of the relationships between these assemblages and the major environmental parameters.

Materials and methods

Study sites

Sampling (sediments and macrobenthos) was conducted along five separate transects at the depths of 1, 3, and 5 m perpendicular to the southern coastline of the Caspian Sea during the summer of 2016 and winter of 2017 (Fig. 1 and Table 1).

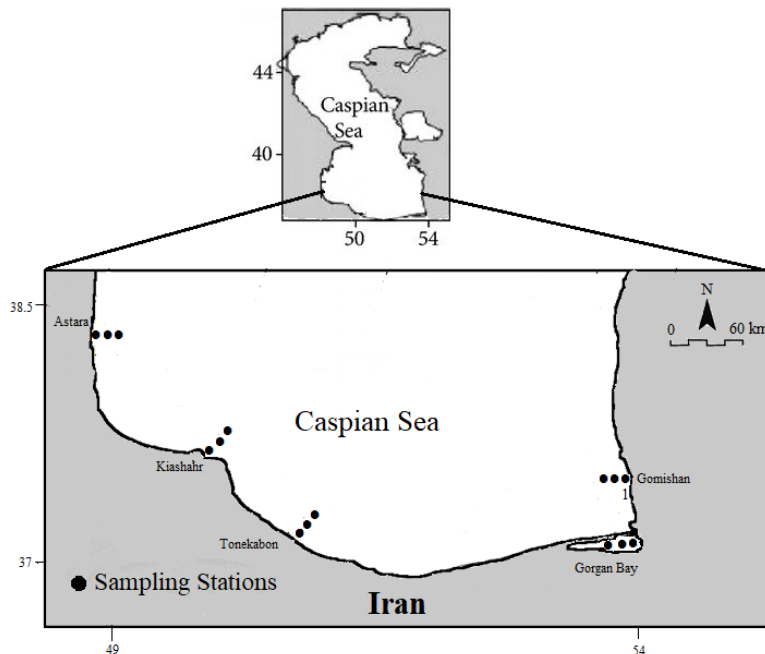


Figure 1: Sampling stations along the southern shoreline of the Caspian Sea, Iran.

Transects include Astará (western side of the mouth of Astarachai River), Kiashahr (near mouth of the Sefidrud River), Tonekabon (in the middle of the coastline where at least 9 rivers flow into the Caspian Sea), Gorgan Bay (in the southeastern corner of the sea), and Gomishan (in the easternmost part of the coastline adjacent to Gomishan International Wetland, mouth of the Atrak River).

Sampling and laboratory surveys

Triplicate sediment samples were collected at each station using a Van Veen grab of (0.025 m²). The retained material on the latest sieve was relaxed in 8% dentol solution (containing 10% carvacrol anesthetic or cymophenol; Sigma-Aldrich) for 20 min (Bonyadi Naeini *et al.*, 2016), then fixed in 70% alcohol (Wetzel *et al.*, 2005). Separately, for more detailed morphological examination and Scanning Electron Microscope (SEM) imaging, a series of

additional specimens were taken at the same stations. In addition, at each station, three sediment samples were collected in polyethylene terephthalate

(PET) glass to evaluate sediment grading and total organic matter content.

Table 1: Longitude and latitude of sampling stations along the southern shore of the Caspian Sea.

Transects	Stations no.	Depth (m)	The geographical position
Astara	1	1	38° 24' 56" N, 48° 52' 58" E
	2	3	38° 24' 57" N, 48° 53' 31" E
	3	5	38° 25' 00" N, 48° 54' 01" E
Kiashahr	4	1	37° 25' 32" N, 49° 58' 42" E
	5	3	37° 25' 59" N, 49° 58' 51" E
	6	5	37° 26' 08" N, 49° 59' 05" E
Tonekabon	7	1	36° 48' 09" N, 50° 54' 41" E
	8	3	36° 48' 15" N, 50° 54' 47" E
	9	5	36° 48' 23" N, 50° 54' 53" E
Gorgan Bay	10	1	36° 54' 26" N, 54° 02' 19" E
	11	1.2	36° 54' 35" N, 54° 01' 58" E
	12	2.5	36° 51' 23" N, 59° 59' 42" E
Gomishan	13	1	37° 10' 52" N, 53° 56' 57" E
	14	3	37° 15' 21" N, 53° 53' 45" E
	15	5	37° 14' 47" N, 53° 51' 27" E

Environmental parameters such as temperature, Dissolved oxygen (DO) and salinity were measured at the sampling stations by a water measurement portable device (TOA-DKK WQC). The sediment total organic matter (TOM) content was determined as a percent of the weight on ignition at 550°C for 8 h after drying at 70°C for 24 h (Buchanan, 1984). The sediment gradation was determined using the hydrometric method. The United States Department of Agriculture Soil Taxonomy, the particle sizes were classified into three grades, clay (<2 µm), silt (2–50 µm), and sand (50–2000 µm) (Bai *et al.*, 2020). The polychaetes samples were identified and photographed using an A dissecting

stereomicroscope (Nikon SMZ 800 ED Plan 2X WD 32.5) and AIS-2100 scanning electron microscope (SEM). Specimens chosen for SEM were fixed in the 3% glutaraldehyde solution for 48 hours after relaxation in the solutions of 8% mgcl₂. The specimens were dehydrated within an increasing ethanol concentration series for an hour in each concentration. Specimens in hexamethyldisilazane (HMDS) were allowed to air dry (Shively and Miller, 2009), then mounted on aluminum stubs and coated with gold-palladium (Merz, 2015). Finally, Specimens were photographed by AIS-2100 scanning electron microscopes at the Amirkabir University of Technology. The identification of the polychaetes was

done by available keys of Birstein *et al.* (1968), Day (1973), Fauchald (1977), Bakken *et al.* (2009), Blake (2009), Jirkov (2011), Garcia and De Leon (2011), Ghasemi *et al.* (2013), and Silva *et al.* (2017).

Data analysis

The total number of species, the Shannon- Weaver diversity index was calculated for each station by using MVSP (Multi-Variate Statistical Package) software (Shannon and Weaver, 1963). Differences between stations were tested with one-way ANOVA. A multivariate PERMANOVA test with three factors based on the Bray-Curtis dissimilarity was used to examine possible relationships between the Polychaeta community structures. In addition, the relationships between environmental properties (TOM, sand, silt and clay, temperature, salinity, and DO) and Polychaeta density were investigated using a Canonical Correspondence Analysis (CCA). CCA was carried out using the software PAST 2.17b (Hammer *et al.*, 2001).

Results

Morphological features

A total of 1125 polychaete were identified, including 410 Nereids, 370 Capitellids, 35 Ampharetids, and 310 Spionids. Some specimens were photographed by SEM. All obtained specimens belonged to 4 species, 4 genera, and 4 families as follow:

Alitta succinea (Leuckart, 1847)

The maximum body length was 100 mm. Prostomium is pyriform and includes two pairs of large bean-shaped eyes, a pair of antennae, a pair of thick spindle-shaped palps and 4 pairs of lateral tentacular cirri (Fig. 2A). The posterior tentacular cirri are longer than the others, extends posteriorly to chaetigers 4-8. The paragnaths on the proboscis are distributed in 8 distinct areas as follows, I: 2-4 in an arch, II: 20-30 in 2-3 arched rows, III: 32-45 in 4-5 transverse rows, IV: 25-37 in diagonal rows, V: 0-4 in a longitudinal line, VI: 6-12 in circular arrangement surrounding a central tooth, VII and VIII: 40-60 teeth in the form of a continuous abdominal band (Fig. 2 B).

The parapodia are divided into two branches, which are in turn divided into smaller lobes, called ligules. Notopodial dorsal ligules are triangular, long and wide with a dorsal cirri located near of the tip that often extends beyond the ligule (Fig.2C). The lower middle ligule is conical and atrophied accompanied by a bunch of elegant setae.

Hypania invalida (Grube, 1860)

The maximum body length is 1.2 mm. Thorax with 16-18 chaetigers and abdomen with 20-23 chaetigers. Parapodia are not developed well and appeared as short protrusions. Two rod-shaped appendages close together are upon the prostomium. Eight branchiae are located on prostomium in two distinct common-based bouquets. Neuropodium is distinguished from notopodium.

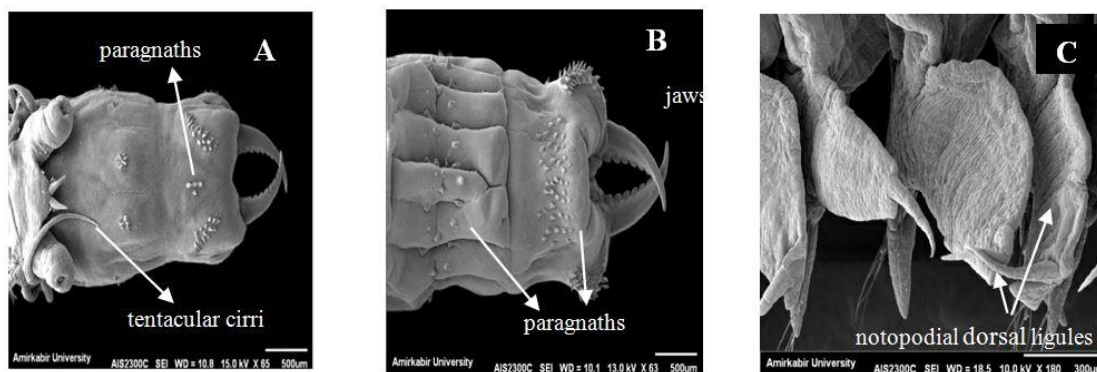


Figure 2: Scanning electron images of *Alitta succinea* from the Iranian shallow waters of the Caspian Sea. A) Dorsal view of prostomium, everted pharynx and paragnaths of the regions I, II and VI (Scale bar=500 μm); B) Ventral view of prostomium, everted pharynx and paragnaths of the regions III, IV and VII-VIII (Scale bar=500 μm); C) Notopodial dorsal ligules and their dorsal cirri (Scale bar=300 μm).

In all thoracic segments, notopodium is equipped with long capillary setae. Neuropodium with hooded hooks. Abdominal chaetigers are only equipped with ventral hooded hooks without

notopodial setae. Abdominal hooded hooks are different in shape compared to thoracic ones. Pygidium was not visible (Fig. 3 A-D).

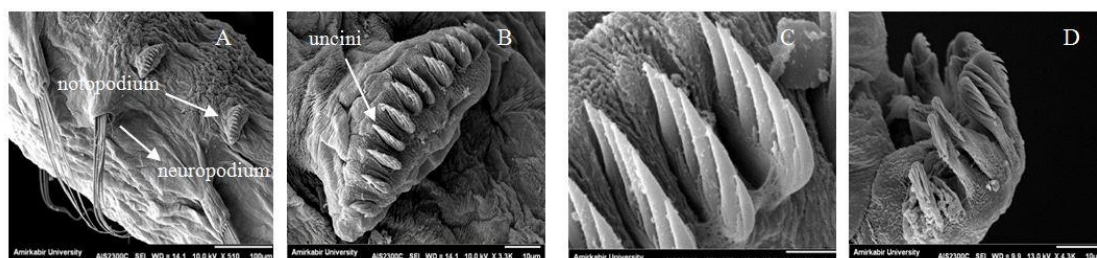


Figure 3: Scanning electron images of *Hypania invalida* from the Iranian shallow waters of the Caspian Sea. A) Thoracic neuropodium and notopodium (Scale bar=100 μm); B) Thoracic neuropodium and uncini (Scale bar=10 μm); C) Thoracic uncini (Scale=3 μm); D) Uncini in abdominal neuropodium (Scale bar=10 μm)

Streblospio gynobranchiata (Rice and Levin, 1998)

The maximum body length is up to 10 mm including 53 chaetigers. The surface of the branchiae looks like an accordion with a large number of transverse walls in a scanning electron micrograph (Fig. 4A). At the first chaetiger, notopodium with 4 capillary setae without postchaetal lobe whereas neuropodium with postchaetal lobe with 7 thick capillary setae. Whereas at the second chaetiger, notopodium and neuropodium

with a broad postchaetal lobe with 12 and 13 broad capillary setae respectively. In the fourth chaetiger, notopodium with 13 capillary setae and neuropodium with 14 capillary setae (Fig. 4B). In most chaetigers, one sabre setae is present at the ventral side of neuropodium except in the first six and the last three chaetigers. Hooded hooks like sabre setae first appeared on chaetiger 7 (Fig. 4C).

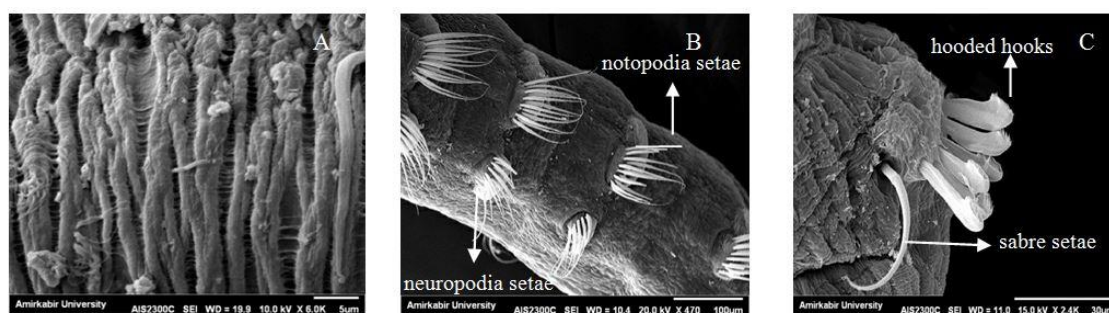


Figure 4: The scanning electron images of *Streblospio gynbranchiata* from the Iranian shallow waters of the Caspian Sea. A) Exterior surface of branchiae (Scale bar=5 μm); B) Neuropodia (neup) and notopodia setae (Scale bar=100 μm); C) Hooded hooks and sabre setae (Scale bar=30 μm)

Capitella capitata (Fabricius, 1780)

C. capitata was identified as a new record of the Caspian Sea. A collection of the species specimens was deposited (Code: INIOC-3-1-S-Poly) in the Iranian National Institute for Oceanography and Atmospheric Science (INIOAS) museum. The worm's body is cylindrical up to 2 mm in length. Eyespots are not visible. Prostomium is short, rounded and dorso-abdominally compressed with a dorsal groove (Figs. 5A and B). Thorax includes nine chaetigers with a peristomium ring without any appendages. Peristomium is smaller than the first chaetiger in diameter and width. Thoracic segments look swollen, clearly larger in diameter than the abdominal segments, has an increasing trend from segment 1 to 5, decreasing in the following segments. Therefore, thoracic chaetiger 5 is the thickest segment. Also, among the largest number of specimens, the thoracic chaetiger 9 is smaller than the first abdominal chaetiger. Thoracic chaetigers 1-7 (1-8 in some individuals) with capillary setae (Fig. 5C). Abdominal chaetigers have short hammer-shaped hooks (Fig. 5E). These hooks are equipped with several rows of

teeth on the apex and are covered in transparent hoods. Females have genital pores and males have 4-5 genital spines placed in a semi-dorsally position between the thoracic chaetigers 8 and 9 (Fig. 5F).

Physicochemical parameters

The environmental conditions are shown in Table 2. The highest salinity (16.1 ± 0.0 psu) was measured in Gorgan Bay at a maximum depth of 2.5 m during summer. The lowest salinity (7.4 ± 0.2 psu) was measured in Kiashahr transect at a depth of 1 m in winter (Table 2). The highest and the lowest temperatures of $30.7 \pm 0.0^\circ\text{C}$ (at a depth of 1 m in summer) and $5.7 \pm 0.0^\circ\text{C}$ (at a depth of 5 m in winter) were measured in Astara transect.

The maximum and minimum percentages of TOM (4.5 and 0.5, respectively) were obtained from Gorgan Bay during summer and Tonekabon transect during winter (Table 3). The sea sediments consisted of silt-loam in Gomishan transect and Gorgan Bay and sand in all other transects (Table 4). ANOVA results showed that the differences in temperature, salinity and

TOM among the stations were significant in both seasons ($p \leq 0.05$).

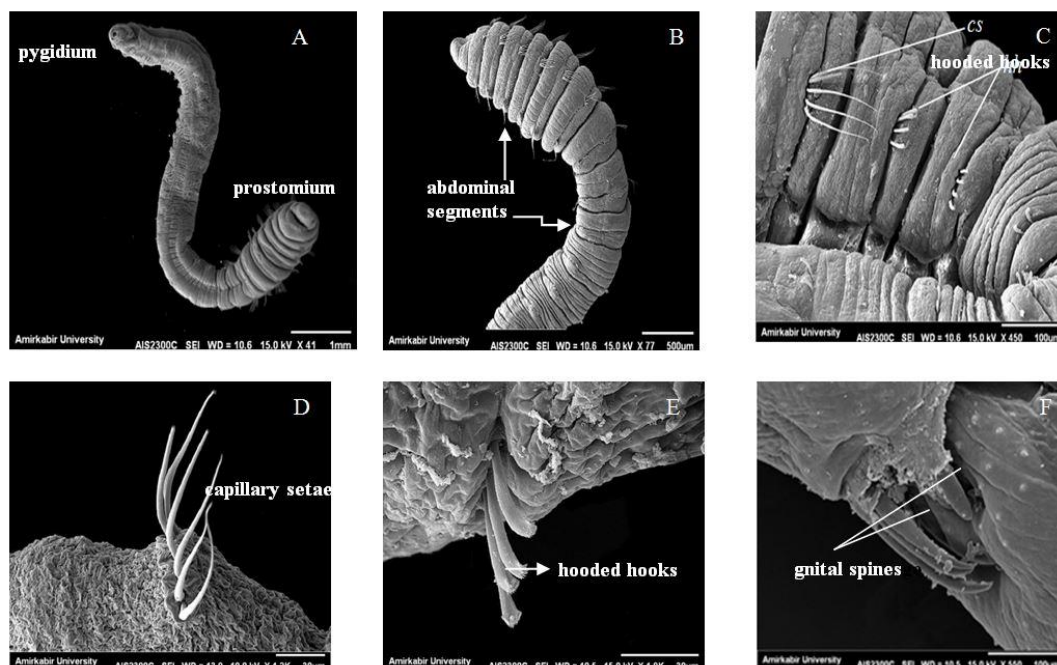


Figure 5: Scanning electron images of *Capitella capitata* from the Iranian shallow waters of the Caspian Sea. A) whole-body view: prostomium, thoracic segments, capillary setae, pygidium (Scales=1 mm); B) Thoracic bulging segments (Scales=500 μm); C) Capillary setae and hooded hooks of the segments 7-9 (Scales=100 μm); D) Capillary setae (Scale bar=30 μm); E) Hooded hooks (Scale bar=30 μm); F) Genital spines (Scale bar=100 μm)

Table 2: Physicochemical parameters of seawater surface of the southern shore of the Caspian Sea (summer 2016 and winter 2017).

Transect	St.	Depth	Temperature ($^{\circ}\text{C}$)		Dissolved Oxygen (mg L^{-1})		Salinity (psu)	
			Summer	Winter	Summer	Winter	Summer	Winter
Astara	1	1	30.7 \pm 0.0	6.2 \pm 0.2	7.4 \pm 0.0	10.0 \pm 0.1	10.9 \pm 0.2	9.1 \pm 0.3
	2	3	29.9 \pm 0.0	5.8 \pm 0.1	7.4 \pm 0.0	10.2 \pm 0.0	11.1 \pm 0.0	9.1 \pm 0.1
	3	5	29.8 \pm 0.0	5.7 \pm 0.0	7.7 \pm 0.0	9.5 \pm 0.0	11 \pm 0.0	9.1 \pm 0.0
Kiashahr	4	1	27.9 \pm 0.1	8.7 \pm 0.3	8.1 \pm 0.0	9.4 \pm 0.0	11 \pm 0.0	7.4 \pm 0.2
	5	3	28.5 \pm 0.2	8.5 \pm 0.3	7.3 \pm 0.1	9.5 \pm 0.0	10.7 \pm 0.0	7.5 \pm 0.1
	6	5	28.7 \pm 0.0	8.5 \pm 0.0	7.4 \pm 0.0	9.430.0	10.9 \pm 0.0	7.6 \pm 0.0
Tonekabon	7	1	29.2 \pm 0.0	9.1 \pm 0.1	7.1 \pm 0.0	9.1 \pm 0.0	8.4 \pm 0.0	8.6 \pm 0.1
	8	3	30.0 \pm 0.1	8.7 \pm 0.0	7.3 \pm 0.0	9.3 \pm 0.0	10.7 \pm 0.4	8.2 \pm 0.1
	9	5	30.2 \pm 0.0	7.6 \pm 0.0	7.5 \pm 0.0	8.49 \pm 0.0	11 \pm 0.0	7.6 \pm 0.0
Gorgan Bay	10	1	24.9 \pm 0.1	10.5 \pm 0.1	7.2 \pm 0.1	12.0 \pm 0.0	13.6 \pm 0.0	13.1 \pm 0.1
	11	1.2	24.7 \pm 0.1	8.1 \pm 0.0	6.7 \pm 0.0	12.1 \pm 0.0	13.6 \pm 0.0	12.2 \pm 0.0
	12	2.5	25.5 \pm 0.0	8.5 \pm 0.0	7.6 \pm 0.0	12.1 \pm 0.0	16.1 \pm 0.0	13.8 \pm 0.0
Gomishan	13	1	24.7 \pm 0.3	9.3 \pm 0.2	7.9 \pm 0.0	12.1 \pm 0.0	11.7 \pm 0.0	10.2 \pm 0.0
	14	3	25.7 \pm 0.0	7.6 \pm 0.0	6.7 \pm 0.0	11.9 \pm 0.0	11.3 \pm 0.0	10.4 \pm 0.0
	15	5	26.5 \pm 0.0	8.4 \pm 0.0	7.4 \pm 0.0	11.7 \pm 0.0	11.3 \pm 0.0	10.4 \pm 0.0
Average	-	-	27.8\pm2.2	8.08\pm1.3	7.4\pm0.4	10.5\pm1.4	11.5\pm1.7	9.6\pm2.1

Table 3: Sediment grading & total organic contents in the southern shore of the Caspian Sea (summer 2016 and winter 2017).

			Summer					Winter				
			Grain size (%)			Sediment type	TOM (%) Mean \pm SD	Grain size (%)			Sediment type	TOM (%) Mean \pm SD
			San	Sil	Cla			San	Sil	Cla		
Astara	1	1	96	2	2	Sand	1.1 \pm 0.	96	0	4	Sand	1.0 \pm 0.
	2	3	78	20	2	Sand-	0.8 \pm 0.	24	44	32	Clay-	2.0 \pm 0.
	3	5	88	8	4	Sand	0.7 \pm 0.	90	8	2	Sand	0.9 \pm 0.
Kiashahr	4	1	96	2	2	Sand	0.6 \pm 0.	98	0	2	Sand	0.5 \pm 0.
	5	3	96	2	2	Sand	0.6 \pm 0.	96	2	2	Sand	0.6 \pm 0.
	6	5	86	12	2	Sand	0.6 \pm 0.	82	16	2	Sand	0.7 \pm 0.
Tonekabon	7	1	98	0	2	Sand	0.7 \pm 0.	96	2	2	Sand	0.5 \pm 0.
	8	3	98	0	2	Sand	0.9 \pm 0.	96	0	4	Sand	0.6 \pm 0.
	9	5	84	14	2	Loam-	0.8 \pm 0.	92	6	2	Sand	0.9 \pm 0.
Gorgan Bay	10	1	30	62	8	Silt-loam	3.3 \pm 0.	22	66	12	Silt-loam	1.3 \pm 0.
	11	1.2	30	58	12	Silt-loam	3.0 \pm 0.	26	62	12	Silt-loam	2.0 \pm 0.
	12	2.5	22	62	16	Silt-loam	4.5 \pm 0.	22	60	18	Silt-loam	1.4 \pm 0.
Gomishan	13	1	10	75	12	Silt-loam	1.2 \pm 0.	6	76	18	Silt-loam	2.5 \pm 0.
	14	3	8	82	10	Silt	1.2 \pm 0.	4	70	26	Silt-loam	3.2 \pm 0.
	15	5	8	70	22	Silt-loam	2.1 \pm 0.	10	66	24	Silt-loam	3.5 \pm 0.

Table 4: One-way ANOVA analysis for differences in physicochemical parameters between stations (summer 2016 and winter 2017).

Season	Physicochemical parameters		Sum of Squares	df	Mean Square	F	Sig.
Summer	Temperature	Between Groups	66.343	4	16.586	49.264	0.000
		Within Groups	3.367	10	0.337		
		Total	69.709	14			
	Salinity	Between Groups	426.000	4	106.500	12.195	0.001
		Within Groups	87.333	10	8.733		
		Total	513.333	14			
	Dissolved Oxygen	Between Groups	6.487	4	1.622	3.018	0.071
		Within Groups	5.373	10	0.537		
		Total	11.860	14			
Tom	Between Groups	230.400	4	57.600	16.302	0.000	
	Within Groups	35.333	10	3.533			
	Total	265.733	14				
Winter	Temperature	Between Groups	18.517	4	4.629	7.556	0.005
		Within Groups	6.127	10	0.613		
		Total	24.644	14			

Table 4 (continued):

Season	Physicochemical parameters		Sum of Squares	df	Mean Square	F	Sig.
Winter	Salinity	Between Groups	57.404	4	14.351	77.995	0.000
		Within Groups	1.840	10	0.184		
		Total	59.244	14			
	Dissolved Oxygen	Between Groups	23.043	4	5.761	55.918	0.000
		Within Groups	1.030	10	0.103		
		Total	24.073	14			
	Tom	Between Groups	11.956	4	2.989	18.006	0.000
		Within Groups	1.660	10	0.166		
		Total	13.616	14			

Spatial distribution and structure of polychaete community

The highest total abundance of polychaetes was observed at station 11

(Gorgan Bay, depth of 1.2 m) in the summer and winter seasons (Fig. 6).

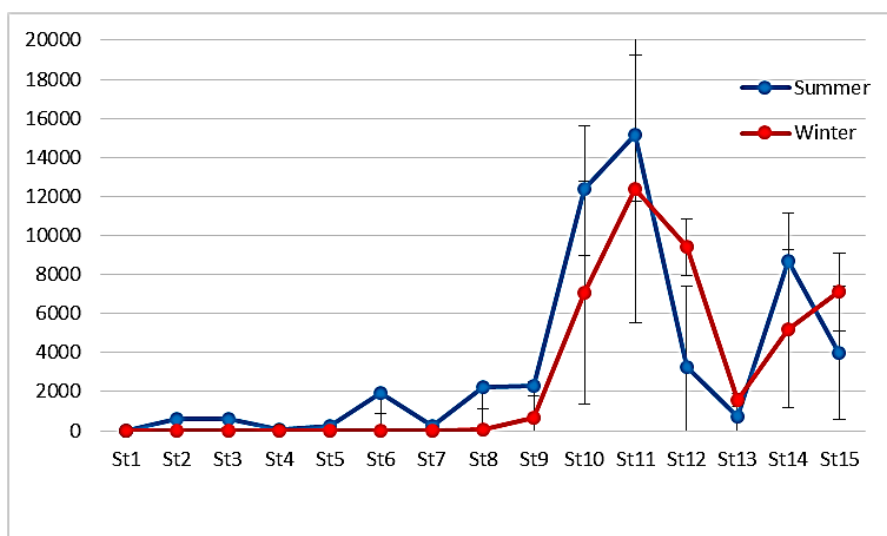


Figure 6: Mean (\pm SE) total abundance of the polychaetes in stations (summer 2016 and winter 2017).

Moreover, the highest population abundance was reported for *S. gynobranchiata*, *A. succinea* in Gorgan Bay during summer and winter at a depth of 1.2 m. Also, the highest abundance of *H. invalida* was observed in Astara and Kiashahr transects (st1 to st6). However, *C. capitata* was not reported on Astara and Kiashahr transects (Table 5). Significant differences in the abundance

S. gynobranchiata and *A. succinea* were observed among stations and seasons ($p \leq 0.05$) (Table 6). Moreover, significant differences were observed between the studied stations in terms of total densities of polychaetes depending on the season, transect, and depth.

Table 5: Population abundance of polychaetes (ind. m⁻²) in all station (summer 2016 and winter 2017).

Season	Species	Group	Sum of Squares	df	Mean Square	F	Sig.
Summer	<i>Alitta succinea</i>	Between Groups	994312.183	4	248578.046	7.465	0.005
		Within Groups	333010.967	10	33301.097		
		Total	1327323.149	14			
	<i>Hypania invalida</i>	Between Groups	56742.523	4	14185.631	2.068	0.160
		Within Groups	68592.007	10	6859.201		
		Total	125334.529	14			
	<i>Streblospio gynobranchiata</i>	Between Groups	179578199.471	4	44894549.868	4.310	0.028
		Within Groups	104157714.967	10	10415771.497		
		Total	283735914.437	14			
	<i>Capitella capitata</i>	Between Groups	1893.931	4	473.483	1.080	0.41
		Within Groups	4384.593	10	438.459		
		Total	6278.524	14			
Winter	<i>Alitta succinea</i>	Between Groups	786275.404	4	196568.851	6.831	0.006
		Within Groups	287752.373	10	28775.237		
		Total	1074027.777	14			
	<i>Hypania invalida</i>	Between Groups	22088.416	4	5522.104	0.955	0.471
		Within Groups	57821.633	10	5782.163		
		Total	79910.049	14			
	<i>Streblospio gynobranchiata</i>	Between Groups	189480296.827	4	47370074.207	17.350	.000
		Within Groups	27303301.873	10	2730330.187		
		Total	216783598.700	14			
	<i>Capitella capitata</i>	Between Groups	17964.683	4	29671.550	7.541	0.392
		Within Groups	39346.967	10	3934.697		
		Total	57311.649	14			

Table 6: One-way ANOVA analysis for differences in abundance of polychaetes between all stations (summer 2016 and winter 2017).

Transect	St.	Depth (m)	<i>Alitta succinea</i> Mean ± SD		<i>Hypania invalida</i> Mean ± SD		<i>Streblospio gynobranchiata</i> Mean ± SD		<i>Capitella capitata</i> Mean ± SD	
			Summer	Winter	Summer	Winte	Summer	Winter	Summ	Winter
Astara	1	1	0	0	0	0	0	0	0	0
	2	3	40.0±69.2	0	186.6±128.5	0	400.0±280.1	0	0	0
	3	5	13.3±23.0	0	306.6±92.3	0	280.0±249.7	0	0	0
	4	1	0	0	0	0	53.3±61.1	0	0	0
Kiashahr	5	3	0	0	0	0	213.3±197.0	0	0	0
	6	5	0	0	173.3±83.2	26.6±23.0	1773.3±115.4	0	0	0
Tonekabon	7	1	0	0	0	0	253.3±61.1	26.6±23.0	0	0
	8	3	40.0±40.0	0	40.0±0.0	0	2133.3±1464.4	80.0±40.0	0	0
	9	5	0	13.3±23.0	26.6±46.1	293.3±122.2	2293.3±711.4	346.6±61.1	0	13.3±23.0
Gorgan Bay	10	1	653.3±128.5	160±40.0	0	0	11626.6±2461.3	6666.6±1254.9	80.0±40.0	240±105.8
	11	1.2	1066.6±201.3	773.3±189.0	0	0	14080±1862.9	11586.6±1147.0	0	0
	12	2.5	253.3±100.6	840±120	0	0	2986.6±1315.3	8573.3±2352.9	0	0
Gomishan	13	1	40±40	40±40	0	0	693.3±61.1	1506±580.1	13.3±23.0	40.0±40.0
	14	3	26.6±46.1	133.3±61.1	0	0	8626.6±2618.1	5000±1300.4	26.6±46.1	80.0±40.0
	15	5	13.3±23.0	146.6±83.2	0	0	3973.3±546.0	6893.3±1870.3	13.3±23.0	66.6±83.2
Average			152.4±307.9	140.4±277.1	48.8±94.6	277.0±75.5	3314±4670.9	2711.9±3935.0	8.88±21.17	29.32±63.0

In addition, *S. gynobranchiata* shows an effective contribution to the potential differences between stations. However,

there were fewer differences in community structure in summer compared to winter (Table 7).

Table 7: Permutational Multivariate Analysis of Variance of polychaete community Similarity in the southern shore of the Caspian Sea (summer 2016 and winter 2017).

Species	Average abundance %		Contrib, %	Cum, %
	Summer	Winter group		
<i>Streblospio gynobranchiata</i>	82.3	67.8	88.7	88.7
<i>Hypania invalida</i>	1.2	0.5	6.8	95.5

The highest Shannon-Wiener index was calculated (0.85) and (0.46) respectively at station 9 (depth of 5 m in Tonekabon transect) during winter (Fig.7).

The community structure of polychaetes differed significantly depending on the season, depth, and station (PERMANOVA, Pseudo-F=1.9174, $p=0.001$). The same can be said for the season, transect, and depth

for the *S. gynobranchiata* (Pseudo-F=10.016, $p=0.001$), *H. invalida* (Pseudo-F=12.217, $p=0.001$), and *C. capitata* (Pseudo-F=3.27, $p=0.004$), as well as the overall community of polychaetes (Pseudo-F=11.277, $p=0.001$). Changes in the population abundance of *A. succinea* were significantly related to transect and

depth (PERMANOVA, Pseudo-F=16.636, $p=0.001$) (Table 8).

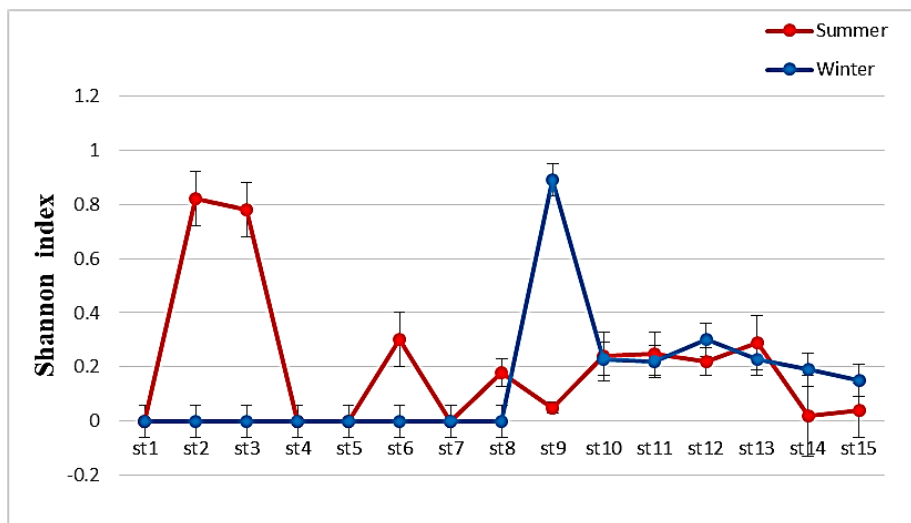


Figure 7: Mean values of Shannon-Wiener index of the polychaetes in stations (summer 2016 and winter 2017).

Table 8: Permutational Multivariate Analysis of Variance of polychaete community structure in the southern shore of the Caspian Sea (summer 2016 and winter 2017).

Source	Unique						
	df	SS	MS	Pseudo-F	P(perm)	perms	P(MC)
Tr	4	71937	17984	12.574	0.001	999	0.001
Se	1	13382	13382	9.3562	0.001	999	0.001
De	2	11818	5909.1	4.1314	0.001	999	0.001
TrxSe	4	22131	5532.9	3.8683	0.001	996	0.001
TrxDe	8	23203	2900.4	2.0278	0.001	999	0.001
SexDe	2	4531.4	2265.7	1.5841	0.002	997	0.027
TrxSexDe	8	21940	2742.5	1.9174	0.001	997	0.001
Res	60	85819	1430.3				
Total	89	2.5476E5					

The results of CCA showed that factors of Axis 1- Axis 3 contain more than 96 percent of the information. Salinity, depth and temperature factors are more important for the first main component in summer season, while salinity, DO and temperature factors are more important for the first main component in winter season (Fig. 8 and Table 9).

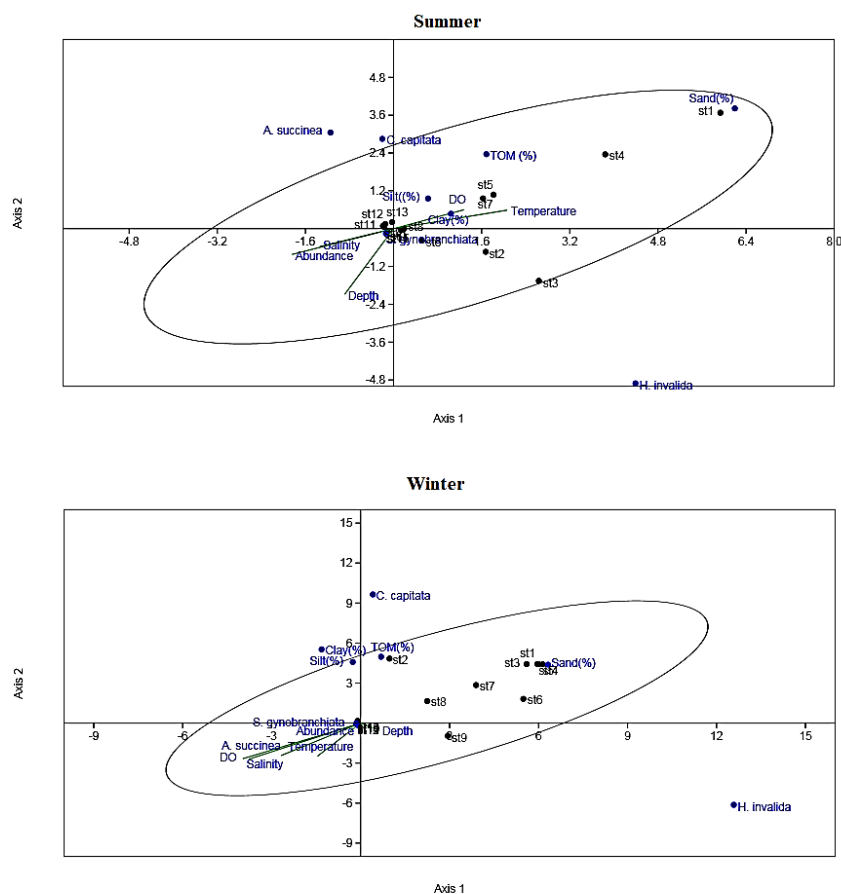


Figure 8: CCA of polychaete assemblages and environmental variables. (st= station)

Table 9: Correlation environmental factors and polychaets assemblages with the first three ordination axes of the CCA.

Parameters	Summer			Winter		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
TOM (%)	1.685	2.361	3.559	0.691	4.975	0.566
Sand (%)	6.195	3.815	-0.899	6.319	4.385	6.123
Silt (%)	0.625	0.955	8.778	-0.267	4.582	0.070
Clay (%)	1.039	0.471	8.979	-1.316	5.527	-2.959
Temperature	0.589	0.167	-0.565	0.029	-0.496	-0.256
Salinity	-0.038	-0.162	0.249	-0.753	-0.540	-0.528
DO	0.366	0.171	0.190	-0.794	-0.533	-0.537
Depth	-0.253	-0.595	0.023	0.121	-0.103	-0.166
Total Abundance	-0.526	-0.233	0.050	-0.075	-0.185	-0.024
<i>Alitta succinea</i>	-1.146	3.049	-0.833	-0.537	-0.487	-0.410
<i>Hypania invalida</i>	4.392	-4.910	-0.241	12.582	-6.129	-7.965
<i>Streblospio gynobranchiata</i>	0.140	-0.150	-0.065	-0.147	-0.028	0.062
<i>Capitella capitata</i>	-0.203	2.848	7.215	0.411	9.644	-8.579
st1	5.934	3.677	-0.464	5.961	4.436	5.708
st2	1.673	-0.735	0.0295	0.972	4.840	0.554
st3	2.637	-1.655	-0.105	5.595	4.428	5.413
st4	3.844	2.356	-0.339	6.139	4.410	5.914
st5	1.813	1.078	-0.200	6.003	4.415	5.789
st6	0.515	-0.378	-0.054	5.487	1.815	1.853
st7	1.624	0.956	-0.238	3.890	2.849	3.795
St8	0.1909	-0.007	-0.108	2.240	1.646	2.223

Table 9 (continued):

Parameters	Summer			Winter		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
st9	0.135	-0.057	-0.036	2.936	-0.954	-1.327
st10	-0.051	0.0529	-0.010	-0.093	0.091	-0.121
st11	-0.093	0.086	-0.079	-0.104	-0.089	0.023
st12	-0.052	0.145	0.082	-0.103	-0.083	0.021
st13	-0.026	0.206	0.921	-0.102	0.165	-0.091
st14	-0.128	-0.116	0.046	-0.108	0.015	-0.052
st15	-0.110	-0.098	0.154	-0.106	-0.026	-0.022

Discussion

A total of four polychaete species were identified in this study. Previously, 11 species had been reported (Taheri *et al.*, 2006, 2009, 2012; Taheri and Yazdani, 2011; Ghasemi *et al.*, 2014, 2016, 2017). This disparity could be attributed to different sampling locations over the years. The success of *S. gynobranchiata* opportunistic species in competing for essential resources and space may also be contributing to the declined numbers of the species (Bennett and Rakocinski, 2020). However, there may be other factors affecting communities, such as pollution resources and environmental factors.

Polychaetes were found in greater abundance in Gorgan Bay during the winter and summer due to the increased abundance of *S. gynobranchiata*. Species *S. gynobranchiata* had the highest participation in the station's dissimilarity in summer and winter, with 88.7%. This result is similar to Gorgan Bay's findings (Ghasemi *et al.*, 2014).

On the list of the worst invaders, *S. gynobranchiata* was introduced and is now spreading in the Mediterranean, Black, and Caspian Seas. This invasive species most likely entered Izmir Bay in the eastern Mediterranean via ship ballast water discharge (Cinar *et al.*,

2005) and then, entered the ports of Amirabad, Nowshahr, and Anzali in the southern Caspian Sea. According to our findings, this species is a dominant and invasive species in the southern Caspian Sea. Other researchers have confirmed our findings (Taheri and Yazdani, 2011; Taheri *et al.*, 2011). *S. gynobranchiata* has the highest density of polychaetes in 10 to 12 stations in Gorgan Bay, as well as the highest percentage of TOM in the sediment. Gorgan Bay is a major biological and fishery area. The Gorgan Bay ecosystem has been severely harmed in recent years as a result of the expansion of agricultural, industrial, and tourism activities, as well as the reduction in water resources (Aali and Shahryari, 2022).

According to the CCA, salinity and temperature were correlated with the total abundance of polychaetes and the abundance of *S. gynobranchiata* in 10, 11, and 13 Gorgan Bay stations. Gorgan Bay is a distinct ecosystem with higher salinity than other transects.

The salinity reduction trend observed in the southern shores of the Caspian Sea is from east to west. This decrease is caused by more rainfall and rivers with higher discharge in the west of the southern coast of the Caspian Sea. In general, the eastern part of the Caspian

Sea (Gorgan Bay) receives less rain and fresh water from small rivers and swamps than the western part, as a result, the water in this area has higher salinity (Taheri *et al.*, 2011). In addition, Gorgan Bay has the highest population abundance of *A. succinea*. However, *A. succinea* was not found in the western transects, which may be due to differences in salinity, temperature, and DO compared to the eastern regions (Tables 2 and 5; Fig. 8).

H. invalida was not reported at many stations and was only found in abundance at a few individual, such as the Tonekabon and Astara transects on the western shores. For this reason, *H. invalida* has not shown correlation with other species and environmental factors, which has caused the isolation of this species. Some data showed that the distribution of *H. invalida* was not affected by changes in depth or salinity (Pavel *et al.*, 2021), which is consistent with the current study's findings.

In this study, the species *C. capitata* was observed for the first time in Gorgan Bay and Gomishan stations. The *C. capitata* is a common opportunist polychaete that is especially associated with organically enriched and polluted sediments (Warren, 2009; Pearson and Rosenberg, 1978). The presence of the non-endogenous species *C. capitata* suggests that the southeast of the Caspian Sea has favorable conditions for opportunistic polychaetes.

As a result, they can alter the structure of the region's multidisciplinary community. *C. capitata* was highly correlated with the % TOM in CCA. *C.*

capitata is a polychaete that is frequently found in organic-enriched sediments (Grassle and Grassle, 1976; Blake, 2009; Riera *et al.*, 2011; Fernandez Rodriguez and Londono Mesa, 2015).

Finally, the results of this study revealed that the abundance of *A. succinea*, *S. gynobranchiata*, and *C. capitata* sp. was lower on the east coast of the Caspian Sea (Gorgan Bay and Gomishan transects) than on the west coast (Astara and Kiashahr transects), while the abundance of *H. invalida* was increased (Tables 5 and 9; Fig. 9).

The Shannon-Wiener index was changed by the seasons, stations, and transects. In the Astara and Kiashahr transects, no polychaetes were found. Furthermore, none of the species were present at the same time at the majority of the stations, possibly due to their different habitat preferences and inter-species competition. In comparison to other studies, Aliakbarian *et al.* (2020) reported a species diversity of 1.36 in the southeast Caspian Sea, which was higher than our findings (0.91). However, at a depth of 5 m in the Tonekabon transect, the Shannon-Wiener index reached its maximum level, indicating the presence of all four species in this transect during the winter season. One of the reasons for the increase in Shannon biodiversity in the Tonekabon transect in winter and decrease in summer can be attributed to the inflow of river water to Tonekabon's coastal waters. Cheshmeh Kileh River is one of the main rivers of the Tonekabon transect. This river flows into the Caspian Sea from the Alborz mountain range. The water level in the Cheshmeh

Kileh River is usually low during the summer and dry weather. However, during the melting season, snow and torrential rains fill up with water, increasing the Shannon diversity index in the Tonekabon transect.

Total polychaete abundance was correlated with salinity, water temperature, depth, dissolved oxygen, TOM, and sediment characteristics in the summer and winter, according to the CCA graphic representation. In addition, changes in polychaete abundance can be attributed to changes in transect sediment types. The sediments of the western transects mainly included sand, while the sediments of the eastern transects were mostly silt-loam. As a result of its sediment-eating and suspension-eating diets, the grain size of sediments, particularly silty-clay, can play an important role in the density of this species (Afraei Bandpei *et al.*, 2022).

According to Simboursa *et al.* (2000), the most important factors controlling the spatial distribution of polychaete abundance in shallow waters are the type of substratum and water hydrodynamics.

Ecologically, changes in benthic animals (particularly polychaete communities) are controlled by a set of temperature, salinity, oxygen, and sediment texture parameters, and it is impossible to identify a single parameter as a controller (Vizakat *et al.*, 1990).

In conclusion, the opportunistic spionid polychaete, *S. gynobranchiata* was the dominant species in the study area. It plays the main role in forming polychaete community structures and

their spatial distribution of fewer than 5 m in the south Caspian Sea. The opportunistic species *C. capitata* was first observed in many stations of Gorgan and Gomishan bays. *S. gynobranchiata* and *C. capitata*, as invasive species, may change the current distribution, structure and diversity of the polychaete community in the southeast Caspian Sea. In this study, four species of polychaete were recorded. Previous studies recorded 11 species of Polychaeta in the south Caspian Sea. The endemic polychaetes such as *Hypniola kowalewskii* and *Manayunkia caspica*, which were previously reported in the southern Caspian Sea, were probably replaced by *S. gynobranchiata*. To ensure the disappearance of these species in the southern shores of the Caspian Sea, it seems necessary to carry out more monitoring. To investigate the relationship between species, it seems useful to investigate the tolerance and competition ability of *S. gynobranchiata* with other species under controlled conditions.

Acknowledgements

The authors are grateful to the Iranian Department of the Environment, Golestan Fisheries Department and Gorgan University of Agricultural Sciences and Natural Resources to facilitate this research. Also, special thanks to Abdolhalim Balash, Farzaneh Farab, Sahab Mira and Andishe Rowshan for their close cooperation. The present work was supported by Khorramshahr University of Marine Science and Technology, Iran.

References

- Aali, R. and Shahryari, A., 2022.** Ecological Problems of Gorgan Bay in the Southeast Corner of the Caspian Sea (Iran) and Ways of Improvement. *Journal of Environmental Health and Sustainable Development*, 7(1), 1522-4. DOI: 10.18502/jehsd.v7i1.8962
- Afraei Bandpei, M.A., Nasrolahzade Saravi, H., Salarvand, G., Naderi, M. and Roohi, A., 2022.** Effects of some physico-chemical parameters of water and substrate sediments on abundance and biomass of *Streblospio gynobranchiata* (Annelida, Spionidae) in the Southeast of Caspian Sea (Goharbaran). *Iranian Scientific Fisheries Journal*, 28(3). DOI: 10.22092/ISFJ.2019.119109
- Aliakbarian, A., Ghorbani, R., Fazli, H., Salman Mahini, A., Yelghi, A. and Naddafi, R., 2020.** Diversity and spatial distribution patterns of the benthic macrofauna communities in the southeast of the Caspian Sea (Golestan Province- Iran) in relation to environmental conditions. *Iranian Journal of Fisheries Sciences*, 19(2): 525-540. DOI: 10.22092/ijfs.2019.120647
- Bai, Y., Qin, Y., Lu, X., Zhang, J., Chen, G. and Li, X., 2020.** Fractal dimension of particle-size distribution and their relationships with alkalinity properties of soils in the western Songnen Plain China. *Scientific Reports*, 10(1), 1-11. DOI: 10.1002/9781118445112.stat07841
- Bakken, T., Glasby, C.J. and Wilson, R.S., 2009.** A review of paragnath morphology in Nereididae (Polychaeta). *Zoosymposia*, 2(1): 305-316. DOI: 10.11646/zoosymposia.2.1.21.
- Bennett, A.D. and Rakocinski, C.F., 2020.** Respiration by the opportunistic spionid polychaete *Streblospio gynobranchiata* during adjustment to and recovery from moderate hypoxia. *Diversity*, 12(2), 73. DOI: 10.3390/d12020073
- Birstein, Y.A., Vinogradov, L.G., Kondakov, N.N., Astakhova, M.S. and Romanova, N.N., 1968.** Atlas of invertebrates of the Caspian Sea. *Pishchevaia promyshlennost, Moscow, Russian*. 415 P.
- Blake, A.J., 2009.** Redescription of *Capitella capitata* (Fabricius) from west Greenland and designation of a neotype (Polychaeta, Capitellidae). *PLoS ONE*, 12(5), e0177760. DOI: 10.1371/journal.pone.0177760
- Bonyadi Naeini, A., Rahimian, H. and Glasby, C.J., 2016.** A new substance to relax polychaete worms (Annelida) prior to morphological study. *ZooKeys*, 594, 1-9. DOI: 0.3897/zookeys.594.8061
- Buchanan, J.B., 1984.** Sediment analysis. In: Holme, N.A. and McIntyre, A.D. (eds) *Methods for the study of marine benthos*. Blackwell Scientific Publications, Oxford United Kingdom. pp 41-65.
- Cinar, M., Ergen, Z., Dagli, E. and Petersen, M., 2005.** Alien

- species of spionid polychaetes (*Streblospio gynobranchiata* and *Polydora cornuta*) in Izmir Bay, eastern Mediterranean. *Journal of the Marine Biological Association of the United Kingdom*, 85(4), 821-824. DOI: 10.1017/S0025315405011768
- Day, J.H., 1973.** New Polychaeta from Beaufort, with a Key to All Species Recorded from North Carolina. NOAA Technical Report NMFS CIRC-375. US. *Department of Commerce. National Marine Fisheries Service.* Available at: <https://www.biodiversitylibrary.org>
- Dean, H.K., 2008.** The use of polychaetes (Annelida) as indicator species of marine pollution: a review. *Revista de Biología Tropical*, 56(11), 11–38. DOI: 10.15517/rbt.v56i4.27162
- Fauchald, K., 1977.** The Polychaete Worms Definition and Keys to the Orders, Families and Genera. Natural History Museum of Los Angeles County in Conjunction with the Alian Hancock Foundation University of Southern California. *Science Series*, 28, 31-36.
- Fernandez Rodriguez, V. and Londono Mesa, M.H., 2015.** Polychaetes (Annelida: Polychaeta) as biological indicators of marine pollution: Colombian cases. *Gestión y Ambiente*, 18, 189-204.
- Garcia, M. and De Leon, A., 2011.** Review of the Capitellidae (Annelida, Polychaeta) from the Eastern Tropical Pacific region, with notes on selected species. *ZooKeys*, 151(51), 17-52. DOI: 10.3897/zookeys.151.1964
- Ghasemi, A.F., Taheri, M. and Jam, A., 2013.** Does the introduced polychaete *Alitta succinea* establish in the Caspian Sea?. *Helgoland Marine Research*, 67 (4) 715–720. DOI: 10.1007/s10152-013-0356-1
- Ghasemi, A.F., Clements, J., Taheri, M. and Rostami, A., 2014.** Changes in the quantitative distribution of Caspian Sea polychaetes: Prolific fauna formed by non-indigenous species. *Journal of Great Lakes Research*, 40(3), 692-698. DOI: 10.1016/j.jglr.2014.05.004
- Ghasemi, A.F., Taheri, M. and Yazdani, M., 2016.** Gorgan Bay: a microcosm for study on macrobenthos species-environment relationships in the southeastern Caspian Sea. *Acta Oceanologica Sinica*, 35, 82-88. DOI: 10.1007/s13131-015-0728-2
- Ghasemi, A.F., Savari, A., Nabavi, M.B., Doustshenas, B., Taheri, M. and Yazdani, M., 2017.** Spatiotemporal variations in macrofauna community in the South Caspian Sea. Paper presented at the 1rd international Conference on Oceanography for West Asia, Iranian National Institute for Oceanography and Atmospheric Science, Tehran, Iran. 30 October 2017.
- Gozler, A.M., 2009.** Spatial and Temporal Distribution of Nereidae (Polychaeta: Annelida) along the Coast of the Turkish Eastern Black Sea in the Upper-Infralittoral Zone. *Journal of Animal and Veterinary*

- Advances*, 8(2), 229-234. DOI: 10.4194/1303-2712-v16_1_07
- Grassle, J.P. and Grassle, J.F., 1976.** Sibling species in the marine pollution indicator *Capitella* (Polychaeta). *Science*, 192, 567–569.
- Grigorovich, I.A., Therriault, W.T. and MacIsaac, H.J., 2003.** History of invertebrate invasions in the Caspian Sea. *Biological Invasions*, 5, 111. DOI: 10.1023/A:1024050824073
- Haddadi Moghaddam, K., Paranaavar, H., Pazhand, Z. and Chobian, F., 2005.** Feeding habits of sturgeon fishes in shallow coastal waters of Guilan Province, southern Caspian Sea. *Iranian Journal of Fisheries Sciences*, 14(3), 37-48.
- Hammer, Q., Harper, D.A.T. and Ryan, P.D., 2001.** Paleontological Statistics software package for education and data analysis. *Palaeontol electron*, 4(1), 1-9.
- Jirkov, I.A., 2011.** Discussion of taxonomic characters and classification of Ampharetidae (Polychaeta). *Italian Journal of Zoology*, 78(1), 78-94. DOI: 0.1080/11250003.2011.617216.
- Karpinsky, M.G., 2010.** Review: The Caspian Sea benthos: Unique fauna and community formed under strong grazing pressure. *Marine Pollution Bulletin*, 61, 156-161. DOI: 10.1016/j.marpolbul.2010.02.009.
- Katsanevakis, S., Gatto, F., Zenetos, A. and Cardoso, A.C., 2013.** How many marine aliens in Europe? *Management of Biological Invasions*, 4(1), 37-42. DOI: 10.3391/mbi.2013.4.1.05.
- Kurt, G. and Cinar, M.E., 2012.** A check-list of polychaete species (Annelida: Polychaeta) from the Black Sea. *Journal of Black Sea/Mediterranean Environment*, 18(1), 10-48.
- Manokaran, S., Khan, S.A., Somasundaran, L., Raja, S. and Ansari, K.G.M., 2013.** Feeding guild composition of shelf macrobenthic polychaetes of the southeast coast of India. *Tropical Zoology*, 26(3). DOI: 10.1080/03946975.2013.825425
- Merz, R.A., 2015.** Textures and traction: how tube-dwelling polychaetes get a leg up. *Invertebrate Biology*, 134(1), 61-77. DOI: 10.1111/ivb.12079
- Pavel, A.B., Menabit, S., Cornel Pop, L., Stanescu I. and Naliana, L., 2021.** The spatio-temporal distribution of the Ponto-Caspian polychaete in the Lower Sector of the Danube River and in Danube Delta. *Global Ecology and Conservation*, 28, e01623. DOI: 10.1016/j.gecco.2021.e01623
- Pearson, T.H. and Rosenberg, R., 1978.** Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: an Annual Review*, 16, 229-311.
- Read, G. and Fauchald, K., 2022.** World polychaeta database. Accessed through: World Register of Marine Species at:

- <https://www.marinespecies.org/polychaeta> on 2022-09-21
- Rice, S.A. and Levin, L.A., 1998.** *Streblospio gynobranchiata*, a new spionid polychaete species (Annelida: Polychaeta) from Florida and the Gulf of Mexico with an analysis of phylogenetic relationships within the genus *Streblospio*. *Proceedings of the Biological Society of Washington*, 111(3), 694-707.
- Riera, R., Monterroso, O., Rodríguez, M. and Ramos, E., 2011.** Biotic indexes reveal the impact of harbor enlargement on the benthic fauna. *Journal of Chemical Ecology*, 27 (4), 311–326. DOI: 10.1080/02757540.2011.570753
- Rowshan, O., Sakhaei, N., Zolgharnein, H., Paknezhad, H. and Taheri, M., 2018.** First Report of *Capitella* sp. (Annelida: Polychaeta) from the south Caspian Sea. *Journal of Animal Environment*, 10(4), 531-536. [in Farsi]
- Shannon, G.E. and Weaver, W.W., 1963.** The Mathematical Theory of Communities. 1st Eds. University of Illinois Press, Urbana. pp. 111-125.
- Shively, S. and Miller, W.R., 2009.** The use of HMDS (hexamethyldisilazane) to replace critical point drying (CPD) in the preparation of tardigrades for SEM (Scanning Electron Microscope) imaging. *Transactions of the Kansas Academy of Science*, 112(4), 198-200. DOI: 10.1660/062.112.0407
- Simboura, N., Nicolaidou, A. and Thessalou-Legaki, M., 2000.** Polychaete communities of Greece: An ecological overview. *P.S.Z.N.I. Marine Ecology*, 21, 129-144.
- Silva, C.M., Seixas, V.C., Barroso, R., Domenico, M.D., Amaral, A.C.Z. and Paiva, C.P., 2017.** Demystifying the *Capitella capitata* complex (Annelida, Capitellidae) diversity by morphological and molecular data along the Brazilian coast. *PLoS One*, 31, 12(5):e0177760. DOI: 10.1371/journal.pone.0177760
- Snelgrove, P.V.R., Grassle, J.F. and Petrecca, R.F., 1996.** Experimental evidence for aging food patches as a factor contributing to high deep-sea macrofaunal diversity. *Limnology and oceanography*, 41, 605-614.
- Taheri, M., Seyfabadi, J. and Yazdani Foshtomi, M., 2006.** Ecological study and species identification of polychaetes of Gorgan Bay (Bandargaz Coast). *Iranian Journal of Biology*, 20(2), 286-294.
- Taheri, M., Seyfabadi, J., Abtahi, B. and Yazdani, M., 2009.** Population changes and reproduction of an alien spionid polychaete, *Streblospio gynobranchiata*, in shallow waters of the south Caspian Sea. *Marine Biodiversity Records*, 2, e40, 1-5. DOI: 10.1017/S1755267208000201
- Taheri, M. and Yazdani, M., 2011.** Community structure and biodiversity of shallow water macrobenthic fauna at Noor coast, South Caspian Sea, Iran. *Journal of the Marine Biological Association of the UK*, 91(3), 607-6013. DOI: 10.1017/S0025315410000378

- Taheri, M., Yazdani, M., Noranian, M. and Mira, S.S., 2011.** Annelida community structure in the Gorgan Bay, Southeast of Caspian Sea, Iran — a case study. *World Journal of Fish and Marine Sciences*, 3, 414-421.
- Taheri, M., Yazdani, M., Noranian, M. and Mira, S.S., 2012.** Spatial Distribution and Biodiversity of Macrofauna in the Southeast of the Caspian Sea, Gorgan Bay in Relation to Environmental Conditions. *Ocean Science Journal*, 47(2), 113-122. DOI: 10.1007/s12601-012-0012-8
- Vizakat, L., Harkantra, S.N. and Parulekar, A.H., 1990.** Population ecology and community structure of subtidal soft sediment dwelling macroinvertebrates of Konkan, west coast of India. *Indian Journal of Marine Science*, 20, 40-42. DOI: 10.1029/2004 GL020247
- Wetzel, M.A., Leuchs, H. and Koop, J.H.E., 2005.** Preservation effects on wet weight, dry weight, and ash-free dry weight biomass estimates of four common estuarine macroinvertebrates: no difference between ethanol and formalin. *Helgoland Marine Research*, 59, 206–213. DOI: 10.1007/s10152-005-0220-z
- Warren, L.M., 2009.** The ecology of *Capitella capitata* in British waters. *Journal of the Marine Biological Association of the United Kingdom*, 57, 151-159. DOI: 10.1017/S0025315400021305