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Ecological studies on marine fouling invertebrates in Eastern Harbor, Alexandria, Egypt

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ABSTRACT

This study aimed to study the settlement of fouling organisms in the Eastern Harbor of Alexandria during the period from 2019 to 2020. Seasonal samples of marine fouling invertebrate species had been collected using white roughened wood test panels. Some environmental parameters (temperature, transparency, salinity, pH, and dissolved oxygen) were studied. The fouling invertebrate species and taxa were identified and classified. Statistical analysis was conducted using primer and paste software. The results of this study showed that some environmental parameters such as dissolved oxygen and water temperature of marine water in Eastern Harbor, Alexandria can significantly affect the settlement of fouling organisms. The results showed also that the fouling was composed of 37 invertebrate species, belonging to 23 families, within 12 orders, 7 classes, and 6 phyla. The highest diversity phyla were Crustacea (20 species from 11 families), followed by Bryozoa (7 species from 7 families) and Annelida (6 species from 2 families). The biomass of fouling invertebrate families and their species varied in different depths. The most heavy families were Serpulidae and Balanidae. At 0.5 m depth, *Hydroides elegans* had the mostly heavy biomass (2720.2±1716.3 g/m^2); followed by *Balanus amphitrite* (889.3±687.4 g/m^2). At 1.5 m depth, also *Hydroides elegans* had the heavy biomass (2264.6±2506.7 g/m^2); followed by *Balanus perforates* (1691.3±3198.3 g/m^2). Seasonal variation in fouling invertebrate biomass showed that *Hydroides eleganes* represented the heaviest recorded biomass during spring, summer and autumn, while *Balanus amphitrite* was the heaviest biomass observed during winter.

INTRODUCTION

Biofouling is a fast, dynamic and cumulative process and constitutes a complex problem with several forefronts in the shipping industry **(Detty *et al.*, 2015)**. The increases in friction drag and hydrodynamic weight by fouling layers reduce shipping speed and maneuverability **(Selim *et al.*, 2017)**. Thus, high fuel consumption is necessary to maintain the required speed and navigation setting; as a result, financial costs are increased, and harmful compounds emitted into the environment **(Yang *et al.*, 2014)**. Biofouling is a natural process in the marine environment which refers to the colonization of microorganisms and macro-organisms on animate or inanimate surfaces **(Dobretsov *et al.*, 2015)**. Biofouling is the settlement and subsequent growth of marine organisms on submerged artificial surfaces, e.g., boat hulls, oil platforms, aquaculture cages and enclosures. Fouling organisms present a significant problem to human activities in the marine environment. The formation of fouling organisms on boats increases drag; reducing ships speed while increasing fuel costs and dry dock time **(Champ, 2000)**. Biofouling on a submerged surface consists of the formation of a conditioning layer **(Satheesh & Wesley, 2010)** possibly by the dissolved materials from the surrounding waters **(Wesley & Satheesh, 2009)**, colonization of the surface by microorganisms, phytoplankton communities and settlement of larval forms of higher organisms and macro-algal spores **(Satheesh & Wesley, 2010)**.

The Eastern Harbor of Alexandria is a semi-closed small shallow basin, lying at the central part of Alexandria coast and exposed to different stresses due to commercial, touristic, transport activities and anthropogenic stress of fishing activities (either direct or indirect discharged wastes). The harbor's bottom is covered by three types of sediments **(Hamouda *et al*., 2016; Hamdy & Dorgham, 2018)**. The Eastern Harbor, due to the water circulation, is subjected to an amount of municipal wastewater from the main sewer of Alexandria (Kayet Bey), located at its western vicinity **(Labib, 2002)**.

The present study aimed to study the settlement of fouling organisms in Eastern Harbor of Alexandria (a location with diverse environmental variations). It was directed toward the species composition and numerical abundance and biomass of fouling communities on a wood panel in the Eastern Harbor of Alexandria during the period from 2019 to 2020.

MATERIALS AND METHODS

1. Study area:

This study was conducted during the period from 2019 to 2020, in front of the building of National Institute of Oceanography and Fisheries (NIOF) and Oceanography Department, Faculty of Science, Alexandria University (situated from longitudes 29º 53´ to 29º 54´ 40” E and latitudes 31º 12´ to 31º 13´ N; **Fig. 1**). This area located at the Eastern Harbor of Alexandria, it is relatively shallow semi-circular bay, surrounded by the city except its northern side which opened to the sea through two outlets.

2. Environmental condition measurements

Water samples were collected from two depths of 0.5 and 1.5 m through this study area. Water temperatures were measured by a mercuric thermometer, while water transparency was determined using a Secchi disc, meanwhile salinity was measured using Beckman induction salinometer (Model RS-7B), also levels of pH were taken by a digital portable pH-meter, at the same time dissolved oxygen was determined by titration according to the Winkler method explained in **APHA (1989).**

Fig. (1): Location map. Geographical location of Alexandria at the Egyptian Mediterranean Sea coast and enlarged map showing the sampling area (the jetty of the National Institute of Oceanography and Fisheries).

3. Fouling substrate

Six roughened wood panels (each 15 x 20 cm) were used as a substrate to be fouling individuals to grow on. Three of them were fixed at 0.5 m depth and the other three at 1.5 m. All panels were regularly replaced every season.

4. Fouling preservation and panel examination

The panels were preserved immediately in buffered 10% formalin in separate 2 L plastic sacs and brought to the laboratory for examination. In the laboratory, fouling organisms were isolated manually from the panels with take care to avoid damage of these organisms. These isolated organisms were initially sorted out into their relative groups. The sorted organisms were individually examined under a binocular zoom stereomicroscope (NOVEL, model no. NTB-2B).

5. Fouling identification

In the present work, fouling organisms were identified according to relevant literatures **(Balavoine, 1959; Ryland, 1959)**; and consultant with some experts was made for more identification of these groups.

6. Statistical analysis

Data were coded and entered using the statistical package SPSS V.22. Data were tested for satisfying assumptions of parametric tests, continuous variables were subjected to Shapiro- Wilk, and Kolmogorov-Smirnov test for normality. Probability and percentile data were standardized for normality using Arcsine Square Root. Data were presented as mean, and stander deviation. ANOVA analyses were done for experimental groups, analysis evaluated using replicates; post-hoc analysis evaluated using Tukey pairwise comparison; P-value were considered significant at<0.05 analysis became available using MiniTab V 14. Data were visualized when possible, using R studio V 2022.02.4.

RESULTS

1. Environmental parameters

The results showed that the highest average of water temperature in Eastern Harbor, Alexandria was recorded during summer being 30.16 ± 0.6 ºC but the lowest one was noticed in winter being 16.43 ± 2.9 ºC. Also, the water transparency measurements was mostly high all over the year exept spring, where the lowest transperancy (145.16 ± 23.38 cm) was recorded; then it reached its maximum value (199.33 ± 17.33 cm) during winter. In addition, the water salinity varied slowly from 36.13 ± 0.31‰ in autumn to 37.23 ± 0.53‰ in summer. At the same time, the pH measurements fluctuated from 7.82 ± 0.31 to 8.3 ± 0.05 through autumn and spring respectively. Meanwhile, the highest average of dissolved oxygen was recorded in summer being 5.76 ± 1.92 mg l^{-1}; while the lowest value was noticed in winter being, 4.46 ± 0.82 mg l^{-1} **(Table 1)**.

During different season the variations observed in pH, DO, salinity and transparency were not statistically significant (P> 0.05). On the other hand, Temperature showed a significant difference (P<0.05) during autumn and winter in comparison to spring and summer.

At 0.5 meter depth, dissolved oxygen (r= 0.985) was the most powerful correlated parameters with fouling species observed during the present study; followed by water temperature (r=0.667) and salinity (r= 0.663), while pH was the negatively highest correlated parameter (r= -0.348).

At 1.5-meter depth, water temperature (r= 0.624) was the most powerful correlated parameters with fouling species observed followed by pH (r=0.501) and salinity (r= 0.030), while Transparency (r= -0.914) and DO (r= -0.017) were the negatively highest correlated parameter.

Table (1): Descriptive statistics of environmental parameters (Mean ± SD) in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)

Seasons	Temperature (ºC)	Transparency (cm)	Salinity (‰)	pH	DO (mg l^{-1})
Winter	16.43 ± 2.9^b	199.3 ± 17.3^a	37.5 ± 0.32^a	8.27 ± 0.06^a	4.46 ± 0.8^a
Spring	26.6 ± 1.14^a	145.5 ± 23.4^a	36.5 ± 0.49^a	8.3 ± 0.05^a	4.5 ± 1.4^a
Summer	30.5 ± 0.6^a	191.3 ± 19.9^a	37.2 ± 0.53^a	7.89 ± 0.2^a	5.8 ± 1.9^a
Autumn	20.7 ± 1.9^b	181.3 ± 20.7^a	36.1 ± 0.31^a	7.8 ± 0.31^a	4.5 ± 0.4^a

**Means in column that share the same letter are no significantly different (P> 0.05)

2. Fouling composition

During the present work, 37 species and taxa of fouling organisms were recorded belonging to 23 families, within 12 orders, 7 calsses and 6 phyla. Crustacea, Bryozoa and Annelida were the most diversified phyla in the fouling communities, where they contained 33 species belonging to 20 families from 9 orders **(Table 2)**.

Crustacea represented the highest diversity phylum in the fouling structure; it comprised most of the collected species (20 species of the total fouling species and 11 families). It followed by Bryozoa which comprised 7 species from 7 families; then phylum Annelida which comprised only 6 species in 2 families. Phylum Chordata contained 2 species belonging to one family, one order and one class. While, each of Phylum Cnidaria and Phylum Mollusca constituted one class; one orders; one family and one species **(Table 2)**.

Only four families had the most fouling diversity, containing 16 species (43.2% of the total number of species). Family Balanidae (Phylum: Crustacea) and family Serpulidae (Phylum: Annelida) were the most diversified fouling families; where each comprised of 5 species. They followed by family Sphaeromatidae (Phylum: Crustacea), containing 4 species. Then, each of family Corophiidae (Phylum: Crustacea) and family Ascidiidae (Phylum: Chordata) comprising 2 species. While, most of the fouling families (19 families, 82.6% of the total number of families) containing only one species **(Table 2)**.

Table (2): List of the fouling invertebrate species collected from experimental panels in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)

Phylun	Class	Order	Family	Scientific name of species
Cnidaria	**Hydrozoa**	**Leptothecata**	**1. Campanulariidae**	**1.** *Obelia geniculate* (Linnaeus, 1758)
Bryozoa	**Gymnolaemata**	**Ctenostomatida**	**2. Vesiculariidae**	**2.** *Bowerbankia gracilis* Leidy, 1855
		Cheilostomatida	**3. Bugulidae**	**3.** *Bugula neritina* (Linnaeus, 1758)
			4. Lepraliellidae	**4.** *Celleporaria sp.*
			5. Schizoporellidae	**5.** *Schizoporella sp.*
			6. Cryptosulidae	**6.** *Cryptosula pallasiana* (Moll, 1803)
			7. Watersiporidae	**7.** *Watersipor subovoidea* (d'Orbigny, 1852)
			8. Electridae	**8.** *Conopeum reticulum* (Linnaeus, 1767)
Annelida	**Polychaeta**	**Phyllodocida**	**9. Nereididae**	**9.** *Nereis diversicolor* Müller, 1776
		Sabellida	**10. Serpulidae**	**10.** *Hydroides elegans* (Haswell, 1883)
				11. *Spirobranchus tetraceros* (Schmarda, 1861)
				12. *Spirorbis spirorbis* (Linnaeus, 1758)
				13. *Pomatoceros triqueter* (Linnaeus, 1758)
				14. *Pomatostegus polytrema* (Philippi, 1844)
Mollusca	**Bivalvia**	**Mytilida**	**11. Mytilidae**	**15.** *Modiolus barbatus* (Linnaeus, 1758)
Crustacea	**Thecostraca**	**Balanomorpha**	**12. Balanidae**	**16.** *Balanus amphitrite* Darwin, 1854
				17. *Balanus eburneus* Gould, 1841
				18. *Balanus perforates* Bruguière, 1789
				19. *Balanus trigonus* Darwin, 1854
				20. *Balanus sp.*
	Malacostraca	**Tanaidacea**	**13. Tanaididae**	**21.** *Tanais dulongii* (Audouin, 1826)
			14. Leptocheliidae	**22.** *Leptochelia savignyi* (Krøyer, 1842)
		Isopoda	**15. Cirolanidae**	**23.** *Cirolana bovina* Barnard, 1940
			16. Sphaeromatidae	**24.** *Sphaeroma walkeri* Stebbing, 1905
				25. *Sphaeroma serratum*
				26. *Paradella dianae* (Menzies, 1962)
				27. *Cymodoce truncata* Leach, 1814
		Amphipoda	**17. Corophiidae**	**28.** *Corophium acutum* Chevreux, 1908
				29. *Corophium sextonae* Crawford, 1937
			18. Maeridae	**30.** *Elasmopus pectenicrus* (Spence Bate, 1862)
			19. Podoceridae	**31.** *Podocerus variegatus* Leach, 1814
			20. Stenothoidae	**32.** *Stenothoe gallensis* Walker, 1904
			21. Ischyroceridae	**33.** *Ericthonius brasiliensis* (Dana, 1853)
				34. Amphipoda tubes
		Decapoda	**22. Polybiidae**	**35.** *Liocarcinus depurator* (Linnaeus, 1758)
Chordata	**Ascidiacea**	**Phlebobranchia**	**23. Ascidiidae**	**36.** *Ascidia sp.* Linnaeus, 1767
				37. *Alacoma atra*

3- Biomass of fouling invertebrates at different depths:

The results showed that, the biomass of fouling invertebrate species in different depths were greatly varied. At 0.5 m depth, Family Serpulidae had the mostly heavy biomass 2800.4 g/m^2), followed by Family Balanidae (2082.2 g/m^2), then Family Nereididae (251.7 g/m^2) and Family Ascidiidae (180.4 g/m^2). While, At 0.5 m depth, Family Balanidae had the mostly heavy biomass (3236.8 g/m^2), followed by Family Serpulidae (2082.2 g/m^2), then Family Polybiidae (106.2 g/m^2) and Family Mytilidae (99.3 g/m^2).

Firstly, at 0.5 m depth, the fouling structure composed of 33 species with a total biomass of 5693.7±2820.1 g/m^2. The more effective species was *Hydroides elegans* (2720.2±1716.3 g/m^2) representing 47.8% of the total biomass; followed by *Balanus amphitrite* (889.3±687.4 g/m^2) representing 15.6% of the total biomass; then *Balanus eburneus* (651.7±883.29 g/m^2) representing 11.4% of the total biomass and *Balanus perforates* (540.6±720.54 g/m^2) representing 9.5% of the total biomass **(Table 3)**.

Also, at the depth 1.5 m, the fouling structure composed of 33 invertebrate species of fouling invertebrates with a total biomass of 5996.2±5120.3 g/m^2. The more effective species was *Hydroides elegans* (2264.6±2506.7 g/m^2) representing 37.8% of the total biomass; followed by *Balanus perforates* (1691.3±3198.3 g/m^2) representing 28.2 % of the total biomass; then *Balanus amphitrite* (1030.1±693.5 g/m^2) representing 17.2% of the total biomass and *Balanus eburneus* (512.5±746.2 g/m^2) representing 8.5 of the total biomass **(Table 3)**.

In case of the whole depths, the fouling was composed of 37 species with a total biomass of 5844.9±213.9 g/m^2. The more effective species was *Hydroides elegans* (2492.4±322.18 g/m^2), representing 42.6% of the total biomass; followed by *Balanus perforates* (1116±813.71 g/m^2) representing 19.1% of the total biomass; then *Balanus amphitrite* (959.7±99.53 g/m^2) representing 16.4% of the total biomass and *Balanus eburneus* (582.1±98.41 g/m^2) representing 10% of the total biomass **(Table 3).**

Only two families (Balanidae and Serpulidae) comprised 85.8% and 93.9% of the total fouling invertebrate biomass in the depths 0.5 m and 1.5 m, respectively. Family Serpulidae had the highest biomass followed by Family Balanidae, representing 49.2% and 36.6% of the total fouling biomass at 0.5 m depth. But at 1.5 m depth, Family Balanidae increased in biomass than Family Serpulidae, representing 54.0% and 39.9% of the total fouling biomass at this depth for the above two families respectively. As whole fouling structure, the family Balanidae had the highest biomass, representing 45.5% of the total biomass value; followed by the family Serpulidae which represented 44.4% of the total biomass **(Fig. 2)**.

Seasonal variation in biomass of fouling invertebrates

The results showed that there were differences in biomass (g/m^2) of fouling invertebrate species and their relative biomass ratios (%) of the total biomass during the different seasons. The more effective invertebrate species were greatly varied from season to another. *Hydroides eleganes* represented the heaviest recorded biomass during spring, summer and autumn by 41.6%, 50.4% and 41% of the total biomass of these seasons, respectively. While *Balanus amphitrite* was the heaviest biomass observed during winter, representing 40.9% of the total biomass of this season **(Table 4** and **Fig. 3)**.

During winter, the most effective species were eight invertebrate species; they represented 98.4% of the total fouling invertebrate biomass during this season. *Balanus amphitrite* was the most effective (1443.6±21.4 g/m^2, representing 40.9 % of the total biomass) in fouling structure; followed by *Hydroides eleganes* (989.3±444 g/m^2, representing

28.1 % of the total biomass); then *Balanus perforates* (793.5±1030.3 g/m^2, representing 22.5 % of the total biomass); and 5 species represented only 6.9% of the total biomass of fouling. While, 12 invertebrate species were very rare in the fouling and composed of less than 1.6% of the total fouling biomass during winter **(Table 4** and **Fig. 3)**.

Table (3): Biomass (g/m^2) of fouling invertebrate species in different in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)

Family	Species	Depth (m)				Total depths	
		0.5		1.5			
		Average	SD	Average	SD	Average	SD
Campanulariidae	**1.** *Obelia geniculate*	19.9	18.95	19.2	17.7	19.5	0.53
Vesiculariidae	**2.** *Bowerbankia gracilis*	0.3	0.52	1.6	3.1	0.9	0.92
Bugulidae	**3.** *Bugula neritina*	4.4	4.25	32.7	55.6	18.6	20.02
Lepraliellidae	**4.** *Celleporaria sp.*	0.3	0.54	0.3	0.4	0.3	0.03
Schizoporellidae	**5.** *Schizoporella sp.*	40.1	41.03	2.1	4.2	21.1	26.88
Cryptosulidae	**6.** *Cryptosula pallasiana*	20.6	23.37	9.9	10.6	15.3	7.55
Watersiporidae	**7.** *Watersipor subovoidea*	5.1	5.00	8.9	13.9	7.0	2.71
Electridae	**8.** *Conopeum reticulum*	9.0	8.69	9.4	11.0	9.2	0.28
Nereididae	**9.** *Nereis diversicolor*	251.7	449.14	0.0	0.0	125.8	177.95
Serpulidae	**10.** *Hydroides elegans*	2720.2	1716.31	2264.6	2506.7	2492.4	322.18
	11. *Spirobranchus tetraceros*	2.3	4.54	12.5	25.0	7.4	7.22
	12. *Spirorbis spirorbis*	74.1	52.50	64.9	48.0	69.5	6.48
	13. *Pomatoceros triqueter*	0.0	0.00	48.3	90.4	24.2	34.19
	14. *Pomatostegus polytrema*	3.8	7.51	1.3	2.5	2.5	1.77
	Total	**2800.4**	**1207.95**	**2391.6**	**998.90**	**2596**	**1103.37**
Mytilidae	**15.** *Modiolus barbatus*	87.4	113.46	99.3	168.3	93.3	8.43
Balanidae	**16.** *Balanus amphitrite*	889.3	687.40	1030.1	693.5	959.7	99.53
	17. *Balanus eburneus*	651.7	883.29	512.5	746.2	582.1	98.41
	18. *Balanus perforates*	540.6	720.54	1691.3	3198.3	1116.0	813.71
	19. *Balanus trigonus*	0.6	1.13	0.0	0.0	0.3	0.40
	20. *Balanus sp.*	0.0	0.00	2.9	5.8	1.5	2.05
	Total	**2082.2**	**400.22**	**3236.8**	**722.65**	**2659.6**	**522.17**
Tanaididae	**21.** *Tanais dulongii*	45.7	68.40	33.3	33.7	39.5	8.72
Leptocheliidae	**22.** *Leptochelia savignyi*	0.0	0.00	0.3	0.5	0.1	0.18
Cirolanidae	**23.** *Cirolana bovina*	1.3	1.66	0.1	0.1	0.7	0.87
Sphaeromatidae	**24.** *Sphaeroma walkeri*	4.5	5.46	2.7	4.3	3.6	1.29
	25. *Sphaeroma serratum*	0.0	0.10	0.8	0.9	0.4	0.52
	26. *Paradella dianae*	1.3	1.47	1.2	1.8	1.2	0.06
	27. *Cymodoce truncata*	0.1	0.16	0.9	1.9	0.5	0.61
	Total	**5.9**	**2.10**	**5.6**	**0.88**	**5.7**	**1.49**
Corophiidae	**28.** *Corophium acutum*	9.8	18.22	0.1	0.1	5.0	6.93
	29. *Corophium sextonae*	0.4	0.78	0.4	0.6	0.4	0.03
	Total	**10.2**	**6.65**	**0.5**	**0.21**	**5.4**	**3.25**
Maeridae	**30.** *Elasmopus pectenicrus*	4.0	7.11	0.4	0.6	2.2	2.49
Podoceridae	**31.** *Podocerus variegatus*	1.7	2.42	2.7	3.0	2.2	0.70
Stenothoidae	**32.** *Stenothoe gallensis*	5.8	11.59	23.4	46.8	14.6	12.44
Ischyroceridae	**33.** *Ericthonius brasiliensis*	0.4	0.51	0.2	0.4	0.3	0.18
	34. Amphipoda tubes	9.7	12.87	10.2	12.5	10.0	0.36
	Total	**10.1**	**6.58**	**10.4**	**7.07**	**10.3**	**6.86**
Polybiidae	**35.** *Liocarcinus depurator*	107.4	213.92	106.2	136.5	106.8	0.85
Ascidiidae	**36.** *Ascidia sp.*	107.9	215.79	0.0	0.0	53.9	76.29
	37. *Alacoma atra*	72.5	145.08	0.0	0.0	36.3	51.29
	Total	**180.4**	**25.03**	**0**	**0**	**90.2**	**12.45**
Total	**biomass**	**5693.7**	**2820.06**	**5996.2**	**5120.3**	**5844.9**	**213.85**
	No. of species	**33**		**33**		**37**	

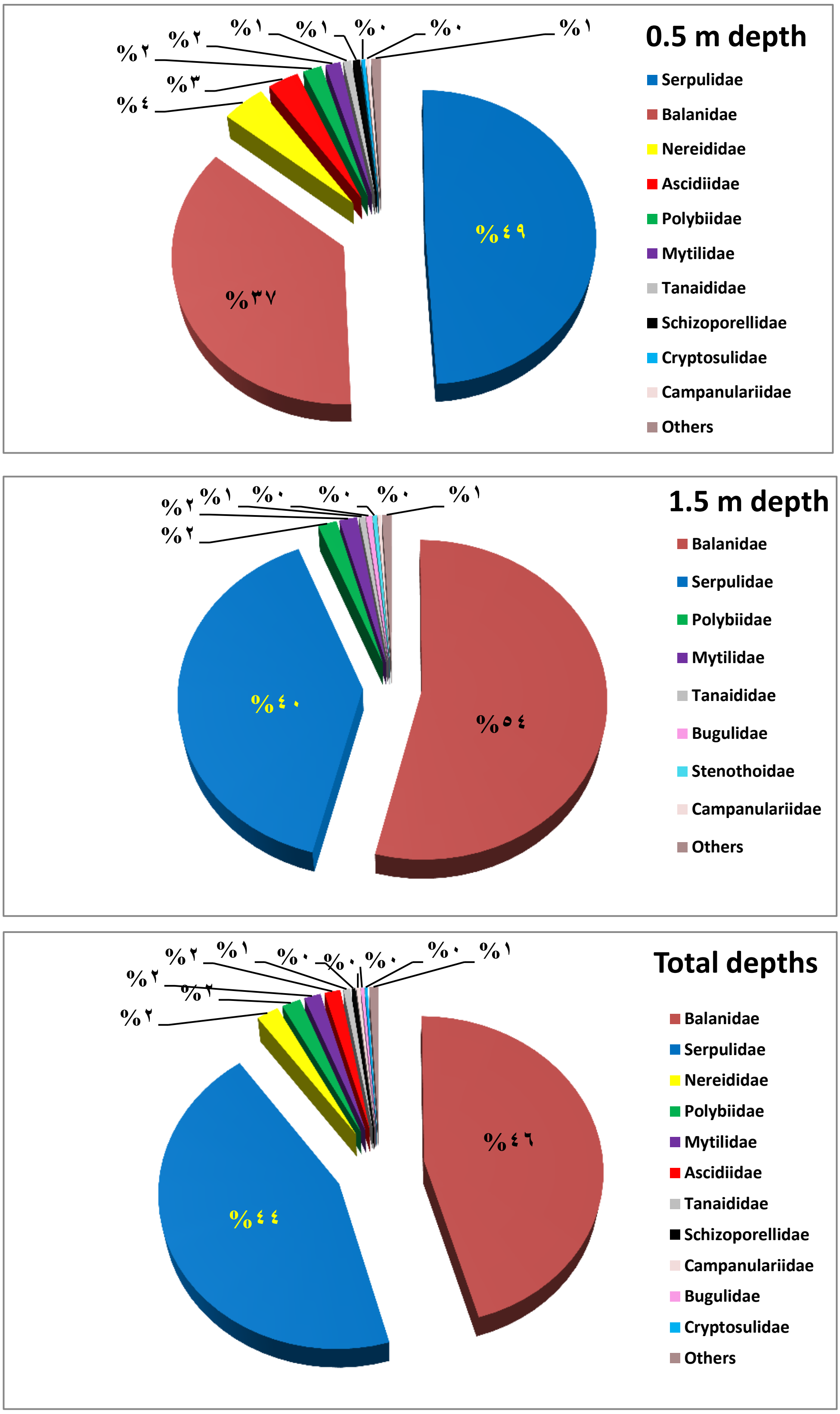


Fig. (2): Biomass (g/m^2) of more effective fouling invertebrate families in different depths in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)

During spring, seven species were the most effective invertebrate species; they represented 97.2% of the total fouling invertebrate biomass during spring. *Hydroides eleganes* was the most effective (3692.5±2726.2 g/m^2, representing 41.6 % of the total biomass) in fouling structure; followed by *Balanus perforates* (3563.6±4143.2 g/m^2, representing 40.2% of the total biomass); then *Balanus eburneus* (494.9±37.5 g/m^2, representing 5.6 % of the total biomass) and *Nereis diversicolor* (461.4±652.47 g/m^2, representing 5.2 % of the total biomass); and only 3 species represented only 4.7% of the total biomass of fouling. But, 21 invertebrate species were very rare in the fouling and composed of less than 2.8% of the total fouling biomass during spring **(Table 4** and **Fig. 3)**.

During summer, the most effective species were eight invertebrate species; they represented 97.3% of the total fouling invertebrate biomass during this season. While, 21 invertebrate species were very rare in the fouling and composed of less than 2.7% of the total fouling biomass during summer. *Hydroides eleganes* was the most effective (3928.4±1730.3 g/m^2, representing 50.4 % of the total biomass) in fouling structure; followed by *Balanus eburneus* (1758.5±249.9 g/m^2, representing 22.6 % of the total biomass); then *Balanus amphitrite* (1151.6±506.7 g/m^2, representing 14.8 % of the total biomass); and 5 species represented only 9.5% of the total biomass of fouling **(Table 4** and **Fig. 3)**.

During autumn, nine invertebrate species were the most effective species; they represented 98.4% of the total fouling invertebrate biomass during this season. *Hydroides eleganes* was the most effective (1359.2±1840.7g/m^2, representing 41.0 % of the total biomass) in fouling structure; followed by *Balanus amphitrite* (1015.5±1008.4 g/m^2, representing 30.6 % of the total biomass); then *Liocarcinus depurator* (357.1±100.7 g/m^2, representing 10.8 % of the total biomass) and *Modiolus barbatus* (230.4 ± 168.51 g/m^2, representing 6.9 % of the total biomass); and only 5 species represented only 9.1% of the total biomass of fouling. But, 11 invertebrate species were very rare in the fouling and composed of less than 1.6% of the total fouling biomass during spring **(Table 4** and **Fig. 3)**.

The results illustrated in **Fig. (4)** showed that the seasonal variations in biomass (g/m^2) of different fouling invertebrate species or their biomass ratio (% of the total biomass in each season) were non-significant (P>0.05).

Table (4): Seasonal variation in biomass (g/m^2) of more effective fouling invertebrate species in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)

Species	Winter		Spring		Summer		Autumn	
	Mean ± SD	**Ratio %**	**Mean ± SD**	**Ratio %**	**Mean ± SD**	**Ratio %**	**Mean ± SD**	**Ratio %**
1. Obelia geniculate	33.1 ± 10.63	**0.9**	5.3 ± 7.44	0.1	34.6 ± 12.75	0.4	5.3 ± 7.44	0.2
2. Schizoporella sp.	46.5±65.7	**1.3**	4.2±5.97	0.0	8.4±11.94	0.1	25.3±35.8	**0.8**
3. Cryptosula pallasiana	30.9 ± 18.92	**0.9**	0.8 ± 1.09	0.0	28.8 ± 11.64	0.4	0.5 ± 0.72	0.0
4. Nereis diversicolor	0 ± 0	0.0	461.4 ± 652.47	**5.2**	0 ± 0	0.0	41.9 ± 59.31	**1.3**
5. Hydroides eleganes	989.3±444	**28.1**	3692.5±2726.2	**41.6**	3928.4±1730.3	**50.4**	1359.2±1840.7	**41.0**
6. Spirorbis sp.	105.8±21.9	**3**	56.4±75.8	0.6	52.2±73.8	0.7	63.5±5.98	**1.9**
7. Pomatoceros triqueter	4.8±6.8	0.1	0 ± 0	0.0	0 ± 0	0.0	91.9±129.9	**2.8**
8. Modiolus barbatus	0 ± 0	0.0	0 ± 0	0.0	143.0 ± 134.81	**1.8**	230.4 ± 168.51	**6.9**
9. Balanus amphitrite	1443.6±21.4	**40.9**	228.0±82.3	**2.6**	1151.6±506.7	**14.8**	1015.5±1008.4	**30.6**

10. Balanus eburneus		0 ± 0	0.0	494.9±37.5	**5.6**	1758.5±249.9	**22.6**	75.1±106.2	**2.3**
11. Balanus perforatus		793.5±1030.3	**22.5**	3563.6±4134.2	**40.2**	106.7±150.9	1.4	0 ± 0	0.0
12. Tanais dulongii		19.7±17.4	0.6	114.7±47.1	**1.3**	13.6 ± 5.23	0.2	9.9 ± 0	0.3
13. Amphipoda tubes		0.6 ± 0.17	0.0	0.1±0.17	0.0	121.8±35.8	1.6	0.3 ± 0.44	0.0
14. Liocarcinus depurator		26.5±1.7	**0.8**	69.4±98.1	**0.8**	29.0±41.03	0.4	357.1±100.7	**10.8**
15. Ascidia sp.		0 ± 0	0.0	0 ± 0	0.0	215.8±305.2	2.8	0 ± 0	0.0
16. Alacoma atra		0 ± 0	0.0	0 ± 0	0.0	145.1±205.2	1.9	0 ± 0	0.0
More effective species	**Biomass**	**3469.15**	**98.4**	**8624.47**	**97.2**	**7570.88**	**97.3**	**3259.9**	**98.4**
	No.	**8**		**7**		**8**		**9**	
Total species	**Biomass**	**3525.5**		**8869.2**		**7794.3**		**3317.4**	
	No.	**20**		**28**		**29**		**20**	

Mostly abundant **Moderately abundant** **Less abundant** **Rarely abundant**

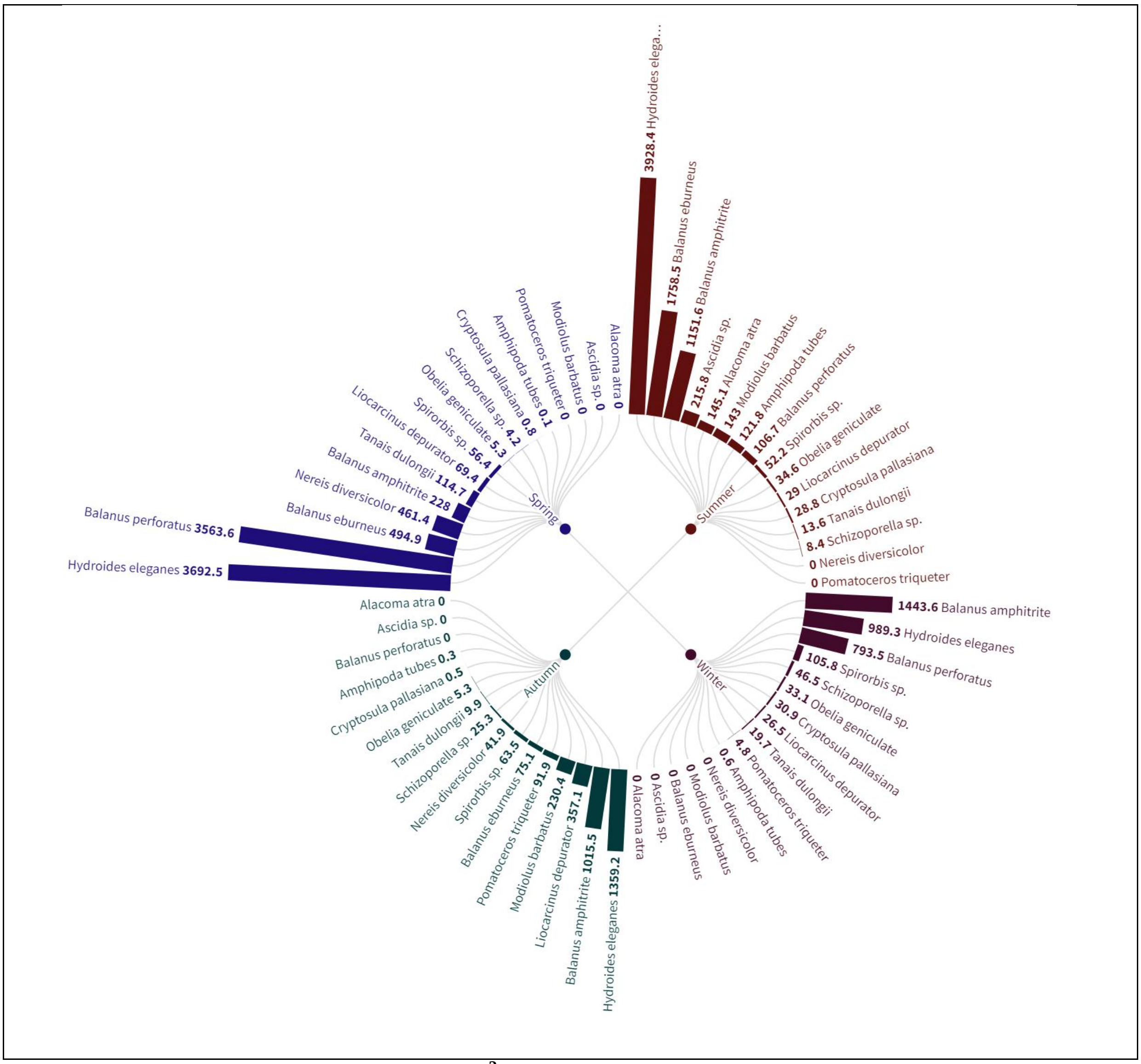
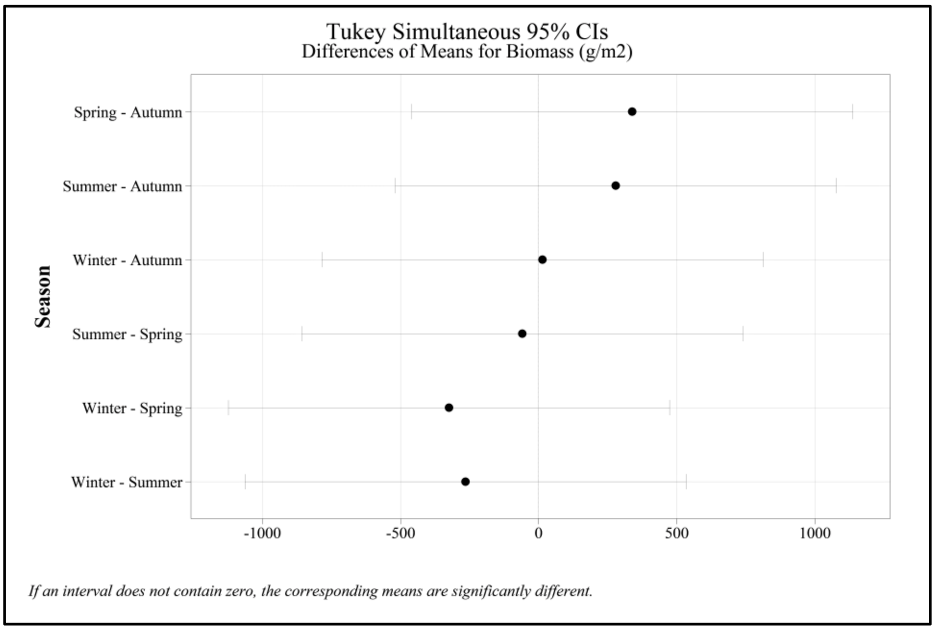


Fig. (3). Radial bar tree for biomass (g/m^2) of the observed fouling invertebrate species recorded during different seasons in Eastern Harbor, Alexandria, during the study period (winter 2019 to autumn 2020)



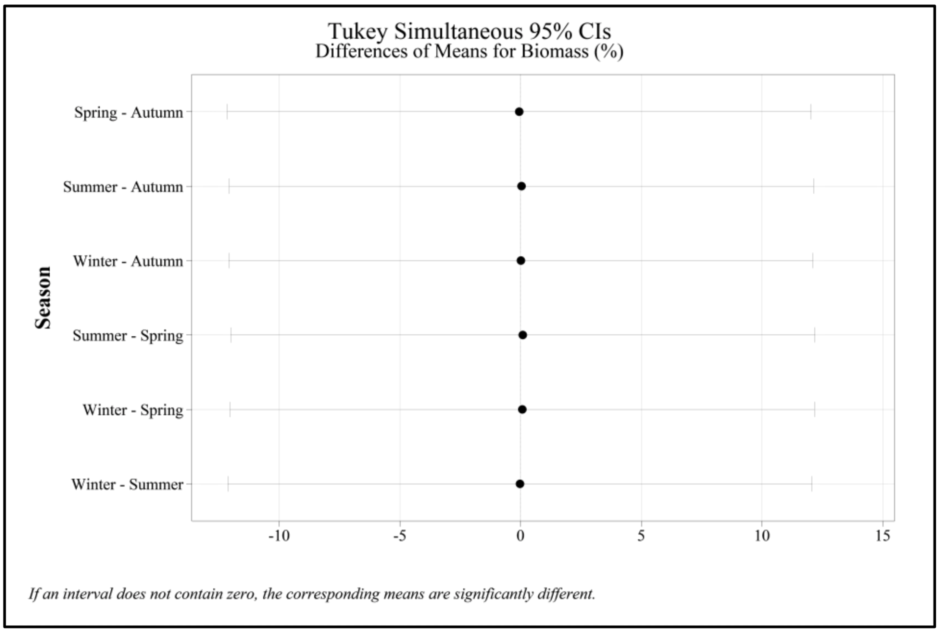


Fig. (4): Tukey simultaneous 95% CIs for the seasonal differences of means of biomass (g/m^2) or ratios of biomass regard studied seasons

DISCUSSION

This study demonstrated that water temperature was a key environmental factor influencing the settlement patterns of fouling invertebrates in Eastern Harbor, Alexandria. This corroborated previous studies that have documented the effect of water temperature on the spatial and temporal variation of marine fouling assemblages in different regions **(Chan *et al*., 2016; van der Stap *et al*., 2016)**. Water temperature can modulate the physiological functions of fouling organisms, such as metabolism, growth, reproduction and larval development, as well as their ecological interactions, such as competition and predation **(Wisely, 1959, Floerl *et al*., 2004)**. The maximum water temperature recorded in this study was 30.16 ± 0.6 ºC during summer, which is near the upper thermal threshold for some fouling species **(Floerl *et al*., 2004)**. Hence, it is plausible that high water temperature may have impaired the survival or recruitment of some fouling organisms in Eastern Harbor, Alexandria, leading to lower species richness and biomass than other seasons.

The present study revealed that fouling composition in Eastern Harbor, Alexandria was dominated by three phyla (Crustacea, Bryozoa and Annelida) which comprised 89.2% of the total number of species. This is consistent with the results of other studies that have reported high diversity and abundance of these phyla in fouling communities from various marine habitats and regions **(e.g., Portas *et al*., 2022; Jewett *et al*., 2022)**. These phyla include many sessile or sedentary organisms that can adhere to hard substrates and create complex three-dimensional structures that offer refuge and food for other species **(Floerl *et al*., 2005)**. Furthermore, these phyla encompass several non-indigenous species that have been introduced by human-mediated vectors, such as ship hulls, aquaculture and marine debris, and have successfully established and spread in new environments **(Chan *et al*., 2016; Floerl *et al*., 2005)**. Therefore, the high diversity of these phyla in the fouling composition may reflect the impact of anthropogenic activities and biological invasions in Eastern Harbor, Alexandria.

In addition, the biomass of fouling invertebrate species differed significantly with depth. The maximum biomass was observed at 1.5 m depth, followed by 0.5 m depth, for both total and individual species. This indicated that depth is a crucial factor affecting the growth and accumulation of fouling organisms in this area. Depth can influence the availability of light, nutrients, oxygen and other environmental parameters that are vital for the survival and development of fouling organisms **(Schurmann *et al*., 2007; Portas *et al*., 2022)**. Furthermore, depth can also influence the exposure of fouling organisms to hydrodynamic forces, such as waves and currents that can dislodge or damage them **(Jewett *et al*., 2022; Floerl *et al*., 2005)**. Therefore, the intermediate depth of 1.5 m may provide optimal conditions for fouling organisms to flourish compared to the shallower or deeper depths.

At the same manner, the biomass of fouling invertebrates exhibited seasonal variation. The highest biomass was observed during spring and summer, followed by autumn and winter, for both total and individual species. This indicated that seasonal changes in environmental conditions, such as temperature, salinity, light and nutrient availability, affect the growth and development of fouling organisms in this area. Seasonal variation in fouling biomass has been reported in other studies from different marine habitats and regions **(Schurmann *et al*., 2007; Portas *et al*., 2022; Jewett *et al*., 2022)**. Therefore, the highest biomass during spring and summer may reflect the optimal conditions for fouling organisms to survive and accumulate compared to other seasons.

Also, the biomass of fouling invertebrates varied among different seasons; where the most effective species (i.e., those with the highest values biomass) changed from season to season. Seasonal variation in the biomass and composition of fouling invertebrates has been reported in some studies from various marine habitats and regions **(Schurmann *et al*., 2007; Portas *et al*., 2022; Jewett *et al*., 2022)**. The dominant species in all seasons was *Hydroids elegans*, a tube-building polychaeta that can form dense mats on hard substrates and facilitate the settlement of other fouling organisms **(Floerl *et al*., 2005)**. The second most abundant species in most seasons was *Balanus perforates*, an acorn barnacle that can withstand wide ranges of salinity and temperature **(Zabin *et al*., 2014)**. The third most present species in all seasons except autumn was *Balanus eburneus*, another acorn barnacle that can tolerate low salinities and high turbidities **(Zabin *et al*., 2014)**. These results indicated that these species have high ecological plasticity and competitive ability, which enable them to flourish in different environmental conditions and seasons.

CONCLUSION

This study investigated the effects of environmental factors on the composition and biomass of fouling invertebrates in Eastern Harbor, Alexandria. The results showed that water temperature was a key factor influencing the settlement patterns of fouling organisms, with lower species richness and biomass recorded during summer when the water temperature was near the upper thermal limit for some species. Also showed that depth was an important factor affecting the growth and accumulation of fouling organisms, with higher biomass observed at 1.5 m depth compared to the shallower depths. The results further showed that the biomass and composition of fouling organisms varied among different seasons, with *Hydroides elegans, Balanus perforatus* and *Balanus eburneus* being the most abundant species with their biomass in some seasons. These species exhibited high ecological plasticity and competitive ability, which enabled them to thrive in different environmental conditions and seasons. The results of this study suggested that fouling invertebrates in Eastern Harbor, Alexandria are influenced by a complex interplay of environmental factors, which can affect their distribution, abundance and diversity. In addition we suggest that fouling invertebrates in this area are dominated by several non-indigenous species that have been introduced by human-mediated vectors and have successfully established and spread in new environments. This study provided valuable information for understanding the ecology and management of fouling communities in Eastern Harbor, Alexandria and other similar marine habitats.

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