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Preliminary estimation of fouling organisms associated with the pearl oyster *Pinctada radiata* in the natural habitat of the Egyptian Mediterranean Sea

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Abstract

In the summer of 2021, marine fouling organisms associated with the pearl oyster *Pinctada radiata* in the natural habitat of Miyami area, Alexandria city, were surveyed, where samples were collected by scuba diving. Eighteen shells of variable sizes were collected to investigate the fouling community's biodiversity that settled on each shell. A total of 1674 organisms representing 106 fouling taxa were identified, weighing a cumulative wet weight of 147.98 g. The community composition consists of 52 taxa of Polychaeta, 19 species of Arthropods, 18 species of Mollusks, 5 species of Bryozoans, 4 species of Chordata, 2 species of Rhodophytes, Anthozoans, and Echinoderms, and one species for Sponge, and Platyhelminth. Species diversity, abundance, and total wet weight were variable among the eighteen studied shells, with higher recorded values on larger shells. The two barnacles (*Balanus trigonus* and *Perforatus perforatus*) were the most dominant species, followed by the Syllidae polychaete *Haplosyllis spongicola*, then the alien mytilid bivalve *Brachidontes pharaonis*, and the Dorvilleidae alien polychaete (*Dorvillea similis)*. A comparison with other similar studies in the Mediterranean Sea was conducted. Before performing manipulative studies on how biofouling communities might affect aquaculture productivity, it is first necessary to ascertain the composition of these organisms within the desired aquaculture locations.

Keywords: *Pinctada radiata*; Fouling community; Mediterranean Sea; Egypt; Associations; Levantine basin.

Introduction

Algae, Barnacles, Bivalves, Bryozoans, Hydroids, tube worms, Tunicates, Sponges, and other suspension-feeding invertebrates can be attached to submerged surfaces, forming marine macro-fouling communities. Fouling organisms colonize ship hulls, outfall pipes, the hard surfaces of sea animals (e.g., oyster shells), and any object thrown in the sea (Al-Khayat & Al-Maslamani, 2001). Cifuentes *et al*. (2010) advocated that the initial colonization and subsequent species succession in marine fouling communities depend on many environmental variables, including physical, chemical, and biological parameters (e.g., substratum, currents, organic matter, topography, upwelling, biological competition, and others).

Pearl oysters are a group of bivalve mollusks belonging to the family Margaritidae, which comprises three genera; *Pteria* Scopoli, 1777, *Pinctada* Röding, 1798 and *Electroma* Stoliczka, 1871. These are primarily found in shallow waters of the tropical and subtropical continental shelf zones, with the highest abundance in the Indo-Pacific region (Wada & Tëmkin, 2008). As Lodola *et al*. (2013) mentioned, *Pinctada radiata* is an Indo-Pacific bivalve first recorded in Egyptian Mediterranean waters in 1874 by Monterosato (1878). According to Barbieri *et al*. (2016) and Theodorou *et al*. (2019), this species appears to be well established in some Levantine Sea regions (Egypt, Libya, Tunisia, Israel, and Cyprus), with notable occurrence in Sicily, Malta, nearby islands, and up to France and Spain (Gofas & Zenetos, 2003; Zenetos *et al*., 2004; Pancucci-Papadopoulou *et al*., 2005; Streftaris *et al*., 2005; Tlig-Zouari *et al*., 2011; Antit *et al*., 2011; Lodola *et al*., 2013; Png-Gonzalez *et al*., 2021). *P. radiata* was usually found on artificial substrates, but the species was purposely imported for mariculture, which expanded their population distribution (Gofas & Zenetos, 2003; Lodola *et al*., 2013). Secondary spread may include marine debris (Ivkić *et al*., 2019), maritime transport (Theodorou *et al*., 2019; Png-Gonzalez *et al*., 2021), and natural dispersal (Oliverio *et al*., 1992). Regarding its economic importance, it has been fished for pearls for centuries. Moreover, in various regions of the Indo-West Pacific, it is harvested for its edible muscle, nacreous shell, and capacity to produce pearls (Carpenter & Niem, 1998).

Numerous studies have been conducted on the Mediterranean Sea's pearl oyster *Pinctada radiata* (Leach, 1814). Deidun *et al*. (2014) and Hassan *et al*. (2018) concentrated on the morphometric analyses of populations in the Maltese Islands and Syrian waters, respectively. Theodorou *et al*. (2019) investigated the distribution and occurrence of this rayed pearl oyster in Western Greece (Ionian Sea). Yigitkurt (2021) studied the reproductive biology of the pearl oyster in Izmir Bay, Turkey, while Moutopoulos *et al.* (2021) investigated its population and fishery dynamics in the Eastern Mediterranean. Other studies focused on this oyster's distribution, occurrence, and establishment in different areas of the Mediterranean (e.g., Scuderi *et al*., 2019; Ballesteros *et al*., 2020; Png-Gonzalez *et al*., 2021). In the Western Mediterranean, Tlig-Zouari *et al.* (2011) studied the macro-zoobenthos associated with the pearl oyster *Pinctada radiata* in the Northern coastal waters of Tunisia. Moreover, another study was conducted by Giangrande *et al*. (2020) to investigate the biofouling associated with maricultural facilities in the Western Mediterranean (Tyrrhenian Sea) and the Central Mediterranean (Italian Ionian Sea) over one year.

As previously mentioned, in 1874, the Mediterranean Sea was where *P. radiata* was first identified outside its native biogeographic range as *Meleagrina* sp., which crossed the Suez Canal into the Mediterranean (Lessepsian immigrant). It was discovered on the coasts of Alexandria, Egypt (Doğan & Nerlović, 2008). Later, reports of it came from Tunisia (Bouchon-Brandely & Berthoule, 1891), Israel (Monterosato, 1899), Cyprus (Monterosato, 1899), and Malta (Pallary, 1912). The species is now successfully distributed throughout the Western and Eastern Mediterranean (Gofas & Zenetos, 2003). *Pinctada radiata* is one of the worst invasive species in the Mediterranean Sea regarding its effect and spread (Streftaris & Zenetos, 2006). Its tolerance to emersion (O'Connor *et al*., 2003) and its wide temperature range (13-30°C) are the basis of its invasiveness (DAISIE, 2009). It can also adapt to various environmental conditions (Mohamed *et al*., 2006), including the chemical contamination of the enclosed polluted ecosystems, which facilitates its wide geographic range (Katsanevakis *et al.*, 2008). However, in Egypt, no study was conducted on the invasion history of *P. radiata*.

Although this species has been documented on the Egyptian Mediterranean coast since 1874, little recent scientific research has been conducted on it. However, it was usually used as a food source, for decorative purposes, and sold to local people and tourists/visitors, contributing to Egypt's economic potential (Moussa, 2013).

Abdul-Aziz & Ali (2009) studied the effects of some environmental pollution on this bivalve's health status and genetic variations in two locations (El Max and Miyami) along the Alexandria coast. Moussa (2013) investigated the size and estimated the relative growth parameters of the pearl oyster collected from three stations (Abu Qir, Maamoura, and Miyami) along the Alexandria coast. Moussa *et al.* (2014) examined how this pearl oyster stores and distributes energy concerning the timing of pearl seeding. They revealed that the suitable time for pearl implantation surgery was October, as oysters would be more energetic. Recently, Moussa (2018) investigated the salinity tolerance and condition index of the adult pearl oysters collected from Abu Qir, Alexandria, to determine the appropriate locations for the growing out phase of pearl oyster culture. Even though some of these recent studies in Egypt seem to follow pearl mariculture, no farms have been constructed yet.

On the other hand, studies of marine fouling in the Egyptian Mediterranean waters go back to Banoub (1960), who investigated the sequence of fouling organisms that settled on glass plates in the Eastern harbor of Alexandria. This fishing harbor has received several analogous studies. Al Sayes & Shakweer (1997) studied the development of fouling organisms on fishing net materials concerning the environmental conditions in this harbor. Ramadan *et al.* (2006a) investigated the environmental factors influencing the distribution of marine fouling in three Alexandria City harbors: Abu Qir, Eastern, and El-Dekhaila. Meanwhile, Ramadan *et al.* (2006b) compared marine fouling communities in the Eastern Harbor from 1960 to 1999. Most of these studies depend on the test panel or plate technique to collect the fouling organisms.

One of the significant obstacles to effective and sustainable production in marine aquaculture is biofouling (Dürr & Watson, 2010). Unwanted aquatic organisms colonize and grow on natural and artificial surfaces, causing a global problem for shellfish, fish, and seaweed farming (Bannister *et al*., 2019). In the pearl oyster cultivation industry, marine fouling negatively affects the products' development, marketability, and profitability (Braithwaite & McEnvoy, 2005). The importance of the present study is to estimate the biodiversity of the fouling organisms associated with the pearl oyster *Pinctada radiata* in the natural habitat of Miyami area, Alexandria city, to understand patterns of shell cover, species composition, and colonization abundance. This goal has never been investigated in Egyptian marine waters or the pearl farming industry. This work is a complementary part of a scientific study investigating the negative impacts of fouling organisms on the shells of pearl oysters in natural habitats and how they can adversely affect shell production and cultivation.

Materials and Methods

Study area

The study area is located at Al Dhahab Island in front of Miyami Beach, east of Alexandria city, Egyptian Mediterranean coast at (31.26481° N, 29.97993° E; Fig. 1). Al Dahab is a small sandy island with an area of about 1,960 m^2. The nearest landside to it is 115 meters away. However, localized effects could result from oil contamination, unsustainable fishing methods, and degraded water quality.

Based on the study by Alprol *et al.* (2021) on the Miyami coast for water samples collected monthly from

Fig. 1: Sampling area (Miyami) on Alexandria coast, with enlarged part showing the location of Al Dhahab Island (modified from Google earth).

March 2019 to February 2020, the average water temperature was 23.2 ± 3.28°C, salinity was 35.27 ± 1.69 ppt, pH to the alkaline side was 7.93 ± 0.25, and the average dissolved oxygen concentration was 5.49 ± 0.41 mg L^{-1}.

Sample collection and treatment

In the summer of 2021 (June), samples of the pearl oyster *Pinctada radiata* were collected by hand from the natural habitat of the study area using scuba diving to a depth of 5–6 m. Eighteen shells (individuals) of variable sizes were collected and preserved in 10% formalin solution mixed with seawater to investigate the fouling communities that settled on the shells (Fig. 2). Each shell was kept in a separate plastic container.

In the laboratory, shell length, height, and width measurements were performed using Electric Digital Caliper (VOGEL Germany). The two valves of each shell were carefully washed with a jet of water over a 100 µm mesh sieve to remove and retain all associated fouling organisms. At the same time, hard-attached organisms (such as barnacles and hard Polychaete tubes) were scraped off gently with a sharp stainless spatula to remove them without damage. All the sorted macro-fouling organisms were identified to the lowest possible taxonomic level and counted to find the dominant groups and species. Moreover, the cumulative wet weight of fouling taxa was measured for each shell.

Correlation between the total number of taxa, total abundance, and total wet weight and shell length of the eighteen shells under study were tested with Spearman's

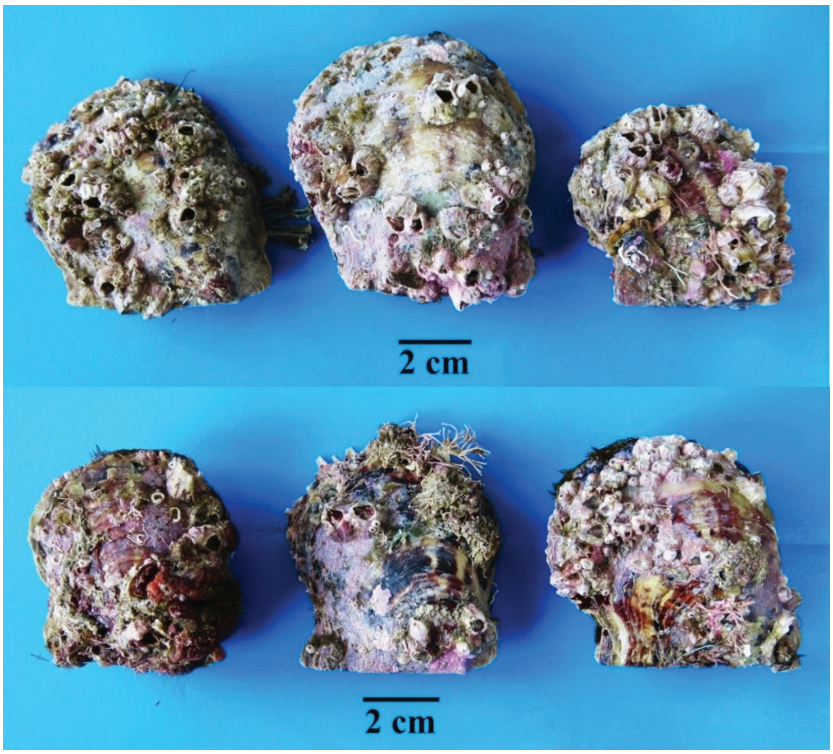

Fig. 2: Examples of examined pearl oysters' shells for the settled fouling community in the natural habitat of Miyami area.

rank correlation, a nonparametric test used to measure the degree of association between variables (Yadav, 2018), using SPSS software version 20.

The fouling organisms were examined with a stereo-zoom microscope (Optika model SZM-2, with a maximum magnification of 45X). On the other hand, samples of Polychaeta were studied using a compound microscope (Model LABOMED Lx 400, with a total magnification of 1000X). The nomenclature of the identified species was checked against the World Register of Marine Species (WoRMS Editorial Board, 2023).

Results

Shell morphometry and fouling

From the eighteen shells being studied, 1674 countable organisms representing 106 fouling taxa were identified in the waters of the Miyami area. The total wet weight of these organisms amounted to 147.98 g.

The length of the studied shells (n = 18) was variable, ranging from 43.6 to 67.1 mm, with a mean of 54.5 ± 7.3 mm. Similarly, the shell height extended between 42.9 and 64.8 mm, with a mean of 54.6 ± 7.2 mm. Meanwhile, the shell's width varied between 14.6 and 24.9 mm, with a mean of 20.2 ± 2.8 mm (Table 1). Figure (3) demonstrates the morphometric data of shells and the biological parameters of marine fouling communities that settled on the examined pearl shells.

The settlement of fouling organisms revealed that larger oysters tended to have more foulers than smaller oysters. Using the Spearman's rank correlation between the shell length and the measured biological parameters in the eighteen studied shells, shell length displayed significant correlations (at 0.01 level, 2-tailed) with a total number of recorded taxa, total abundance of countable species, and total wet weight of 0.909, 0.779, and 0.921, respectively.

The maximum diversity (57 taxa) was observed on the shell with the highest length (67.1 mm) and large height and width (64.3 mm and 23.7 mm), while the minimum diversity (14 taxa) was recorded on the shell with the least length (43.6 mm) and relatively small height and width (47.7 and 17.4 mm). Moreover, the maximum abundance (192 individuals) was registered on the shell with the maximal length and width, while the lowest (35 individuals) was collected on the shell with a short length and width (49.8 and 18.9 mm). Furthermore, the maximal total wet weight value (20.742 g) was calculated for the shell with the highest length and width (67.1 and 23.1 mm), while the minimal value (0.929 g) was measured on the shell with a small length (43.9 mm) and the least height and width (42.9 and 14.6 mm).

Community composition and abundance

The fouling communities prevailing on the examined shells consist in their biodiversity of Polychaetes (52 taxa constituting 49% of the total number of species), Bivalves (10 species), Gastropods (8 species), Amphipods (7 species), Bryozoans (5 species), four species for each of the following groups; Cirripeds, Isopods, and Chordates, Tanaidacea (3 species), two species for Rhodophytes, Anthozoans, and Echinoderms, in addition to only one species for Sponges, Platyhelminthes and Decapods (Table 1 and Fig. 4). The most diversified group Polychaeta was represented by 33 Errantia species belonging to ten families (16 species belonging to the family Syllidae) and 19 Sedentaria taxa belonging to 8 families.

Among the 106 fouling taxa associated with the pearl oyster, 22 are considered alien species, mostly of Indo-Pacific origin (Table 1).

The average species diversity and standard deviation values amounted to 29.8 ± 12.4 taxa. Meanwhile, the average total abundance of countable species is 93 ± 51.5 individuals. On the other hand, the average total wet weight value was 8.221 ± 5.726 g.

Dominant species

Results of abundance indicated that group Cirripedia constituted about 47.8 % of the total fouling number, followed by Polychaeta constituting about 35.2%, then bivalves (8.4%). The remaining groups constituted only from < 1% to 2.9% of the total fouling amount (Fig. 5).

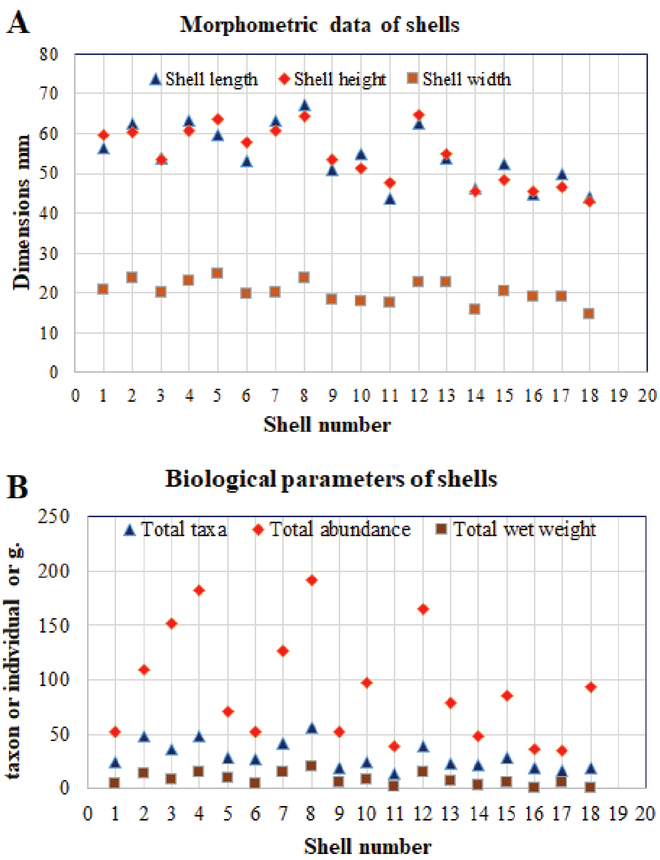

Fig. 3: Morphometric data of shells (A), and biological parameters of marine fouling communities that settled on the examined pearl shells (B).

Table 1. Shell morphometry, community composition and abundance of fouling organisms that settle on both vales of each pearl oyster shell.

			Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	Sh-7	Sh-8	Sh-9	Sh-10	Sh-11	Sh-12	Sh-13	Sh-14	Sh-15	Sh-16	Sh-17	Sh-18	Total
Shell morphometry (mm)		Shell length	56.3	62.4	53.9	63.3	59.5	53.2	63.2	67.1	51.1	54.9	43.6	62.5	53.9	46.1	52.5	44.6	49.8	43.9	
		Shell height	59.7	60.3	53.5	60.6	63.7	58.0	60.9	64.3	53.6	51.4	47.7	64.8	54.9	45.6	48.3	45.6	46.7	42.9	
		Shell width	20.8	23.6	20.2	23.0	24.9	19.8	20.1	23.7	18.3	18.1	17.4	22.7	22.7	15.7	20.6	19.0	18.9	14.6	
Plant	Rhodophyta	***Corallina officinalis***	*	*	*	**	*	*		*	*		*	*	*	*					
		Amphiroa rigida	*		*	**		*	*		*	*	*	*	*	*					
Animal	Porifera	***Sycon ciliatum***		1				1					1								3
	Cnidaria	***Amphisbetia distans***			s.							s.		s.					s.		
		***Anemonia* sp.**							1												1
	Platyhelminthes	***Stylochus* (*Stylochus*) *pilidium***							1												1
	Bryozoa	***Bugula neritina***	s.			s.								M.	M.		M.				
		Bugulina stolonifera				s.			s.			s.			M.				s.		
		Schizoporella errata		s.		M.	s.			M.											
		***Celleporaria* sp.**															s.			s.	
		Conopeum reticulum		L.			s.							M.	L.						
	Polychaeta (Errantia)	***Eurythoe complanata***		1		1				1											3
		+Linopherus canariensis					1			1											2
		Chrysopetalum debile	1	2	1	2	1		2	2	1	2		1			1				16
		+Dorvillea similis	2	8	6	11	9		11	12	7	6		3		2	3			1	81
		Ophryotrocha* cf. *ad-herens		1										1		1					3
		Leodice antennata		1		1			1	2											5
		Oxydromus pallidus		1	1	3	2	1	2	3		2						1	1	1	18
		Syllidia armata		1		2			2			1			1		1				8
		Lumbrineris perkinsi								2											2
		Alitta succinea	1	1	1	2			1	2											8
		Neanthes acuminata				1				2											3
		+Pseudonereis anomala		1		1				3											5
		Eumida sanguinea								1											1

Continued

Table 1 continued

			Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	Sh-7	Sh-8	Sh-9	Sh-10	Sh-11	Sh-12	Sh-13	Sh-14	Sh-15	Sh-16	Sh-17	Sh-18	Total
Animal	Polychaeta (Errantia)	***Mystides* cf. *angolaensis***			1	1															2
		Nereiphylla rubiginosa		1			1					1									3
		Lepidonotus clava	1		1				1	1				1							5
		+*Lepidonotus* cf. *carinulatus*			1																1
		Branchiosyllis exilis		1			1		1	1										1	5
		Brania arminii							3	1						1					5
		Eurysyllis tuberculata									1										1
		+*Exogone africana*	2	3	1	2	3	1	3	4	3	2	2	3	3	4	2	1	3	2	44
		Exogone dispar	1	1	1	1		1		1											6
		Haplosyllis spongicola	2	7	3	8	9	6	8	8	5	11	3	4	2	4	16	2	1	1	100
		Myrianida convoluta			1																1
		Odontosyllis fulgurans	1	3	2	4	2	3	1	2		2	1	1		2		1		1	26
		Salvatoria clavata				1															1
		Sphaerosyllis hystrix		1													2				3
		Syllis armillaris		1		2	3	1	1	1	1		1	2		1				1	15
		Syllis columbretensis		1						1											2
		Syllis gracilis												1							1
		Syllis prolifera		1						1											2
		Syllis variegata			1	1				1				1	1	2	2			1	10
		Trypanosyllis zebra	1	2	1	3	2	1	4	7	1	2	1	1	1	2	1	1			31
	Polychaeta (Sedentaria)	***Branchiomaldane vincentii***												1							1
		Capitella minima					1		2												3
		Caulleriella alata		1		2	1	1	1	2	2	1		1			1		1		14
		Dodecaceria concharum		1																	1
		Kirkegaardia heterochaeta			1	1	1		6	4					1		10			1	25
		Polyophthalmus pictus														1					1

Continued

Table 1 continued

			Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	Sh-7	Sh-8	Sh-9	Sh-10	Sh-11	Sh-12	Sh-13	Sh-14	Sh-15	Sh-16	Sh-17	Sh-18	Total
Animal	Polychaeta (Sedentaria)	***Sabellaria spinulosa***		1	1	1			1	1				1			3			1	10
		***Amphicorina* sp.1**	1	2	1	4	1	2	5	4	2	1	1		1			1	1		27
		***Amphicorina* sp. 2**																		1	1
		+*Branchiomma bairdi*	1			1				1											3
		Hydroides elegans			3					3		2	3	2	1		3	2	1		20
		Hydroides operculata						1							1	1					3
		+*Spirobranchus tetraceros*		1	1	1		1	3	2		1		2	3	2	1	1			19
		Spirobranchus triqueter									1							1			2
		***Spirorbis* sp.**		4	2	2	1	1	2	1	2			2			1			2	20
		Dipolydora coeca		1		1				2								1		1	6
		Dipolydora giardi		1	2	1		1		2	1					2	1		1		12
		Prionospio lighti					1			1											2
		Pseudopolydora pauci-branchiata					1														1
	Mollusca	**+*Diodora funiculata***				1															1
		+*Diodora ruppellii*								1											1
		Diodora graeca		1																	1
		+*Trochus erithreus*							1	1				1							3
		+*Cerithium scabridum*				1				1				1							3
		Hexaplex trunculus							1												1
		Ocenebra hispidula												1							1
		Thylacodes arenarius	1							1											2
		+*Brachidontes pharaonis*	9	3	7	6	7	3	8	12	2	3	3	11	3	2	8	1	3	1	92
		Gregariella ehrenbergi		1					1												2
		+*Septifer cumingii*				1		2						1				2			6
		Anomia ephippium		1										1							2
		+*Isognomon legumen*				1			1	1											3

Continued

Table 1 continued

			Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	Sh-7	Sh-8	Sh-9	Sh-10	Sh-11	Sh-12	Sh-13	Sh-14	Sh-15	Sh-16	Sh-17	Sh-18	Total
Animal	Mollusca	***Saccostrea cucullata***								1						1					2
		Pinctada radiata			2	3			1	1		1		1	1				1		11
		+Malleus regula			2	1	2		1	1											7
		+Chama pacifica	3	1			3	2		1				1			2	1			14
		Glans trapezia								1											1
	Arthropoda	***Amphibalanus amphitrite***		1				6													7
		+Amphibalanus eburneus		1			1								7	8					17
		Perforatus perforatus	17	25	38	29	1	3	13	25	6	26	14	59	29			8	6	71	370
		+Balanus trigonus		10	57	69	13	10	28	52	16	28	7	48	21	10	17	4	12	4	406
		Tanais dulongii	1		3				1							1	1				7
		Chondrochelia savignyi				1			1	1							2				5
		Apseudopsis latreillii		3	2			1								1			1		8
		+Paracerceis sculpta		2					1					2				3			8
		+Sphaeroma walkeri				1				1							1				3
		+Mesanthura c.f. romulea			1				1			2		1	1			2			8
		***Munna* sp.**			1																1
		Elasmopus pectenicrus	2		2			1	1					1					1		8
		Apocorophium acutum	1	2		1				2				1			2	1	1	1	12
		Monocorophium sextonae		3			1		1						1	1		2		1	10
		Ericthonius brasiliensis	1							1											2
		Lysianassina longicornis	1		2					1			2				1		1		8
		Podocerus variegatus				1			1			1					2				5
		Gammarus aequicauda	1									1		2							4
		Sphaerozius nitidus				1				1											2
	Echinodermata	***Amphipholis squamata***		1				1			1			1	1						5

Continued

Table 1 continued

			Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	Sh-6	Sh-7	Sh-8	Sh-9	Sh-10	Sh-11	Sh-12	Sh-13	Sh-14	Sh-15	Sh-16	Sh-17	Sh-18	Total
Animal	Echinodermata	***Macrophiothrix demessa***		1																	1
	Tunicata	***Ciona intestinalis***								1											1
		Styela canopus				3		1	2		1			4			1				12
		+*Styela plicata*		2		2				2							1				7
		Styela partita	2		2		2	1				2									9
Total recorded taxa	25	48	36	48	29	27	42	57	19	24	14	39	23	22	28	19	17	19	106		
Total abundance for countable species	53	110	152	183	71	53	127	192	53	98	39	165	79	49	86	36	35	93	1674		
Total wet weight (g)	4.827	14.299	8.172	14.812	9.683	4.565	14.905	20.742	6.322	9.174	1.779	15.675	7.088	3.365	5.323	1.016	5.304	0.929	147.98		

* = present, ** = common, s.= small colony, M.= medium colony, L.= large colony, + = alien species.

The barnacle *Balanus trigonus* was the most dominant species forming 24.2% of total fouling density, followed by the other barnacle *Perforatus perforatus*, constituting 22.1%. These two barnacles formed > 46% of the total abundance. The Syllidae polychaete *Haplosyllis spongicola* occupied the third order of abundance forming about 5.9% of total abundance, then the alien mytilid bivalve *Brachidontes pharaonis*, which constituted about 5.5%, and the Dorvilleidae alien polychaete *Dorvillea similis*, forming about 4.8% of the total fouling count.

Discussion

In any natural habitat of the Egyptian marine waters, there is no information about the fouling biota that settles on the alien pearl oyster shells (*Pinctada radiata*), their distributional abundance, and the structure of this community. So, the current investigation was designed to fill this gap. Such data is necessary to customize a suitable management plan to maximize the outcomes. It is well-known that fouling filter-feeder organisms such as sponges, cnidarians, bivalves, crustaceans (including barnacles), and ascidians decrease the water flow, causing a food competition, which might slow down the pearl oyster shell growth, as well as, the fouling organisms could cause shell deviations responsible for its less marketable product (Lodeiros & Himmelman, 1996; Taylor *et al.*, 1997; Pit & Southgate, 2003). However, the effects of boring polychaete worms include nacreous layer blisters, weakened shells, devaluation, and mortality based on infestation density (Fitridge *et al.*, 2012). Moreover, cleaning is necessary to avoid effects that could hinder productivity, adding another expenditure to the aquaculture industry (Ross *et al.*, 2004; Willemsen, 2005).

The current study exhibited that a total of 1674 individuals affiliating to 106 taxa representing 10 phyla were recorded from the eighteen studied oysters' shells, with Cirripedia (crustacean) constituting about (47.8 %) of the total fouling count, followed by Polychaeta (Annelida, 35.2%), bivalves (Mollusca, 8.4%), and the other remaining groups constituted from < 1% to 2.9% of total abundance. Although the study of Tlig-Zouari *et al.* (2011) in the Tunisian waters is not directly comparable with this study, as their benthic samples were collected from various habitats using a square of 0.25 m^2, both studies investigated the macrofauna associated with the pearl oyster *Pinctada radiata*. Moreover, it was the only available study to be compared along the southern Mediterranean Sea. The study of Tlig-Zouari *et al.* (2011) revealed that 2208 individuals belonging to 158 species and representing 7 different phyla were associated with the invasive species *P. radiata*. Mollusca were the first ranked group of abundance (45.57%), then Crustaceans (24.05%), Annelids (17.09%), Echinoderms (6.33%), Ascidians (3.80%), Cnidarians (1.90%), and Sipunculids (1.27%). The significant difference in the number of recorded taxa or species between the two studies may be explained in light of the trophic characterization of the study area, the habitats or environments being surveyed in each, and the different sampling methods.

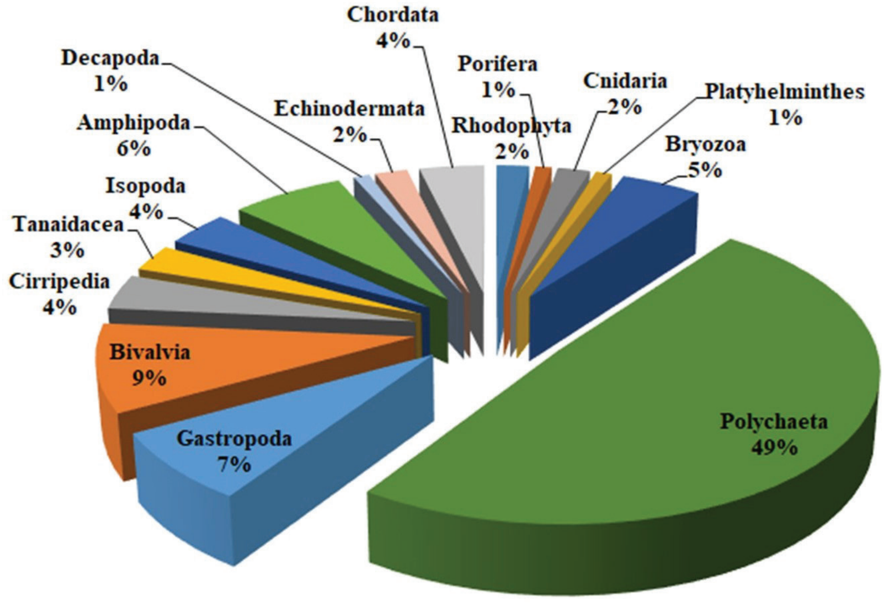

Fig. 4: Percentage of community composition of the marine fouling invertebrates' groups that settled on the examined pearl shells.

The study by Tlig-Zouari *et al*. (2011) was carried out along the Northern and Eastern Tunisian coastline. This area represents a part of the Western and Central Mediterranean Sea (Zenetos *et al*., 2012), whereas our study area is located in the Eastern Mediterranean Sea. Danovaro *et al*. (1999) and Coll *et al*. (2010) reported that the Mediterranean basin is characterized by strong environmental gradients, in which the Eastern end is more oligotrophic than the Western. Moreover, most of Tunisia's coastline perimeter, including protected lagoon-type environments and more exposed real marine environments, were surveyed. On the other hand, samples of the present study were collected only from the sandy Island. Different habitats or ecosystems, i.e., habitat complexity, support a greater diversity of invertebrate communities (Alfaro, 2006).

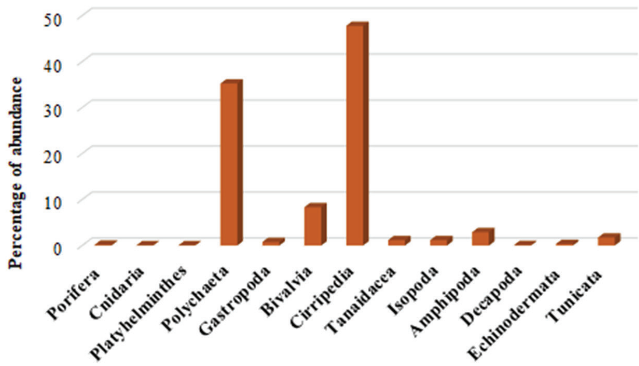

Fig. 5: Percentage of abundance for the marine fouling invertebrates' groups that settled on the examined pearl shells.

The results of dominant species in the Tunisian study showed that the invasive oyster *Pinctada radiata* occupied the first rank, followed by barnacles (crustaceans), especially (*Balanus eburneus, Balanus trigonus,* and *Perforatus perforatus)*, then Polychaetes, especially species (*Sabella pavonina*, *Nereis irrorata*, and *Sabellaria alveolata)*. In this study, the two barnacles (*Balanus trigonus* and *Perforatus perforatus)* were the most dominant species, followed by the Syllidae polychaete (*Haplosyllis spongicola)*, then the alien mytilid bivalve (*Brachidontes pharaonis)*, and the Dorvilleidae alien polychaete (*Dorvillea similis)*. It is evident that both studies supported the dominance of barnacles (crustaceans), polychaetes, and bivalves, but with different ranks.

The polychaete *H. spongicola* is a common species in the Mediterranean and is associated with all Sponges and hard substrates (Lattig *et al*., 2007). The alien bivalve *Brachidontes pharaonis* is a common and abundant species found in the Eastern and Western Mediterranean and extended its range to the North Aegean Sea (Zenetos *et al*., 2004; Doğan *et al*., 2008). Çinar (2009) first recorded *Dorvillea similis* in the Mediterranean Sea, which seems to be well established along the Levantine coast. Later, this species was recorded from different parts of the Mediterranean (Corsini-Foka *et al*., 2015; Langeneck & Tempesti, 2019; Langeneck *et al*., 2020), while Elebiary (2022) was the first study to record this species in Egyptian Mediterranean waters.

Moreover, many of the examined Polychaeta species in the current study were recorded within recent studies of Polychaetes in hard substrata from Alexandria city. They represent the most diverse group (Hamdy *et al*., 2018; Hamdy & Ibrahim, 2019; Elsayed & Dorgham, 2019; Elebiary, 2022; Hamdy *et al*., 2023). The Syllidae are the most numerous and species-rich family, and they are considered the major contributor to the hard-bottomed polychaetes of the Mediterranean (Çinar & Gönlügür-Demirci, 2005; Gambi *et al*., 2016; Mikac *et al*., 2020). In addition, Syllidae preferentially inhabits structurally complex articulated calcareous algae because of their ability to trap large amounts of silt and organic matter (Tena *et al*., 2000; Serrano *et al*., 2006; Mikac *et al*., 2020).

Regarding shell-boring spionids, *Polydora websteri* is the most famous global invader and is widespread in different shellfish farming regions (Waser *et al*., 2020). It has a wide host range that includes seven oysters, one mussel, and three scallop species (Simon & Sato-Okoshi, 2015). Although it was not recorded in this study, it was recorded in the Suez Gulf by Abd Elnaby (2019), considered the first record in Egyptian waters.

Using PVC artificial panels, two case studies of fouling colonization patterns were conducted in the Western Mediterranean (Tyrrhenian Sea) and in Central Mediterranean (Italian Ionian Sea) to investigate the biofouling associated with maricultural facilities over one year (Giangrande *et al*., 2020). Throughout the investigation, 117 taxa were recorded, 93 of which were in the Mar Grande of Taranto (Tyrrhenian Sea) and 75 in the Gulf of Gaeta (Italian Ionian Sea). This relatively small variance in biodiversity between the two locations is explained by the difference in trophic levels of the two sites. The Gulf of Gaeta is a semi-enclosed basin characterized by extremely eutrophic conditions. Meanwhile, Mar Grande of Taranto is a sizable coastal inlet impacted by freshwater inputs from the Garigliano River, which discharges terrigenous inputs into the sea, a condition that supports higher species richness, especially alien species.

In the present study, a large number of fouling taxa were recorded (106 taxa) compared to all previous Egyptian studies, which mainly concentrated in the Eastern Harbor of Alexandria city, where the recorded taxa ranged from 19 to 35 species (Ramadan *et al*., 2006b). This is reasonable because all these studies used artificial test panels (e.g., glass, PVC, or acrylic artificial panels; this method is known as the coupon technique) within a limited time interval (monthly interval or cumulative up to 15 months). Smith & Rule (2002) indicated that the macro-invertebrate fauna recruiting to artificial substrata showed the lowest diversity and evenness values and were unrepresentative of the local species aggregation. Moreover, the heterogeneity of natural habitats may support a more diverse fouling community compared with the artificial substrates (e.g., test panel), which usually sustain more alien species (Ruiz *et al*., 2009). They added that of the 232 non-native species found on hard substrata in North America, over 200 occur on artificial structures.

Nonetheless, water pollution may partly explain the low biodiversity value recorded in the Eastern Harbor, as reported by Ramadan *et al*. (2006b), who concluded that nutrient enrichment (related to sewage discharge) was one of the main driving factors of the fouling communities in the Eastern harbor of Alexandria. The area of the current study (Al Dhahab Island), where the pearl oysters were collected, is in close proximity (115 meters) to Miyami Beach that may be affected by the recreational activities of visitors, reducing the biodiversity (Murray *et al*., 1999). Alprol *et al.* (2021) studied the physicochemical parameters of eight beaches along the Alexandria coast, including Miyami. The nitrite (NO_2^-) concentration was low, ranging between 0.01 and 1.98 μM, and Miyami Beach had a low average of 0.49 ± 0.47. The nitrate (NO_3^-) concentration varied between 1.54 and 33.21 μM with a lower average in Miyami (5.40 ± 3.78). In addition, ammonia (NH_4^+) concentration showed significant variations from 0.40 to 9.45 μM, where Miyami Beach exhibited a lower average value of 2.74 ± 2.92. Meybeck *et al*. (1988) indicated that primary production is responsible for the remarkable depletion of nutrients. At the same time, marine phytoplankton is an essential factor (main food source) that affects the whole structure of marine ecosystems, including fouling organisms (Naeem, 2012). Watson *et al*. (2009) mentioned that biofouling effects on shellfish and shellfish culture vary depending on geographic location, species, habitat, and culture method. They added that shells and culture gear immersed permanently are more likely to get fouled than others. The current study represents the former situation where the shells were permanently immersed and thus susceptible to harboring more biodiverse marine fouling communities. Additionally, the age of fouling communities is not restricted to a specific time interval, promoting cumulative fouling succession and development.

On the other hand, the occurrence of 22 taxa as alien species in the fouling community indicates that these organisms have been presumably introduced with *P. radiata*, either unaided or attached to ship hulls that passed through the Suez Canal.

Alagarswami & Chellam (1976) found that infection by shell-boring polychaetes, as evidenced by blisters and tumor-like growths on the inner surface of the shells, was 78.4% and infection by Sponge was 20.7% among the shells examined in a farm of pearl oysters of the species *Pinctada fucata* in Mannar, India. Moreover, Rodriguez & Ibarra-Obando (2008) mentioned that fouling communities negatively affect oyster farmers because they increase the time it takes to clean and package oysters. The negative effects may extend to the content of the essential fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in the cultivated pacific oyster *Crassostrea gigas*, as reported by Fujibayashi *et al*. (2021).

Concerning the boring polychaete worms, there are highly destructive genera (*Polydora* and *Boccardia*) and less destructive species (such as *Spirobranchus triqueter* and *Hydroides elegans*) (Simon *et al*., 2006; Fitridge *et al*., 2012). Their effects include nacreous layer blisters, weakened shells, devaluation, and mortality based on infestation density (Fitridge *et al*., 2012). This study recorded some examples of destructive genera (such as *Dipolydora coeca* and *D. giardi*) but with relatively small numbers of 6 and 12 worms, respectively. The same situation was observed for the less destructive species (such as *Spirobranchus triqueter* and *Hydroides elegans*) represented in the community by two and 20 individuals, respectively.

Regarding the farmed pearl industry worldwide, many authors (e.g., Daigle & Herbinger, 2009; Sievers *et al*., 2013) have indicated the negative impacts of fouling organisms on this industry, even though without effect on the product's safety for human consumption, as reported by Watson *et al*. (2009). These negative effects can be generally summarized as decreased water flow or food competition, which might slow down bivalve growth. Furthermore, shell deviations caused by fouling organisms may make the product less marketable (Lodeiros & Himmelman, 1996; Taylor *et al*., 1997; Pit & Southgate, 2003). Moreover, cleaning is required to prevent production-harming impacts, representing an additional financial expense for aquaculture (Ross *et al*., 2004; Willemsen, 2005). In contrast, Lacoste *et al*. (2014) reported that neither the survival nor the reproduction indices were negatively affected by biofouling. Simultaneously other authors (e.g., Armstrong *et al*., 1999; Ross *et al*., 2004; Farren & Donovan, 2007) have observed some positive effects of biofouling, such as protection of cultured bivalves from predators or harmful epibionts through the release of bioactive substances, or camouflage.

Even though there are two contrasting lines of evidence regarding the positive and negative effects of marine fouling on the farmed pearl industry, it clearly has a negative effect from an economic perspective. Therefore, before conducting manipulative studies on how biofouling communities might affect productivity, it is first necessary to ascertain the composition of these organisms within the desired aquaculture locations.

Conclusion

Marine fouling organisms associated with the pearl oyster *Pinctada radiata* in the natural habitat of the Alexandria coast, Egypt, are well-diversified. Over the eighteen studied shells, 1674 organisms representing 106 fouling taxa were identified, weighing a total wet weight of 147.98 g. The fouling community consisted of 52 taxa of Polychaeta, 19 species of Arthropods, 18 species of Mollusks, 5 species of Bryozoans, 4 species of Chordates, 2 species each for Rhodophytes, Anthozoans, and Echinoderms, and one species each for Sponges and Platyhelminthes. Species diversity, total abundance of countable species, and total wet weight were variable among the eighteen studied shells, with higher recorded values on larger shells. The two barnacles (*Balanus trigonus* and *Perforatus perforatus)* were the most dominant species, followed by the Syllidae polychaete (*Haplosyllis spongicola)*, then the alien mytilid bivalve (*Brachidontes pharaonis)*, and the Dorvilleidae alien polychaete (*Dorvillea similis*). Before conducting manipulative studies on how biofouling communities might affect aquaculture productivity, it is first necessary to ascertain the composition of these organisms within the desired aquaculture locations.

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