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Original research

Biodiversity of Mollusca on Rocky Intertidal Shore of Abu-Qir Bay, Alexandria, Egypt: A Comparative Study

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Abstract:

Research on marine biodiversity in Egypt is limited.The present study provides a comprehensive survey and ecological analysis of the biodiversity of Mollusca species inhabiting the rocky shores of Abu-Qir Bay. The diversity, abundance, and frequency of occurrence of the surveyed species were compared with those previously documented 25 years ago by Farag *et al.* (1999) in the same station to assess the potential impacts of the previously mentioned threats on Molluscan populations. Qualitative and quantitative surveys were conducted from March 2023 to February 2024. The survey recorded a total of 29 molluscan species belonging to two classes, Bivalvia and Gastropoda. The present study recorded an increase in the number of species, species richness (SR), Shannon diversity index (H'), and Pielou's evenness index (J'). The number of species has increased from 17 to 29, species richness (SR) has increased from 1.689 to 3.2534, the Shannon diversity index (H') has risen from 0.1212 to 2.419, and Pielou's evenness index (J') has increased from 0.0428 to 0.718. On the other hand, species abundance decreased from 12969.9 ind. /m² in 1999 to 5465.4 ind./ m². This kind of study is needed for understanding the long-term impacts of threats on biodiversity and for developing strategies to mitigate these effects and protect marine biodiversity.

Keywords: Rocky shore, Mollusca, Biodiversity, Species Richness, Lessepsian species

1- Introduction

Rocky shores are intertidal areas formed mainly from solid rocks. They are located between the extreme high and low tide levels (Miller, 2004; Coughlan & Crowe, 2009), creating a buffer zone between the sea and the terrestrial environment (Hodge *et al.*, 2021; D'Souza *et al.*, 2022; Gonçalves *et al.*, 2023). These shores are characterized by their complex composition (Substrates such as cobbles, boulders, pebbles, blocks, and rock platforms) and structure (slope and gradient) (Araújo *et al.*, 2005). Such a heterogeneous environment affects the distribution and abundance of rocky shore communities along the gradient (Archambault & Bourget, 1996; Pandey & Thiruchitrambalam, 2019). Rocky shores present valuable insights into the ecology and assemblages of epi- and endolithic communities (EL Hedeny *et al.*, 2021).

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Rocky intertidal shores are frequently subjected to various disturbances. Common disturbances include the fluctuations between submersions at high tide and desiccation at low tide caused by exposure to high temperatures and sunlight (Bertness *et al.,* 2006; Gonçalves *et al.,* 2023). Intertidal organisms face multiple stresses, including fluctuations in temperature, salinity, pH, oxygen, and irradiance (Smith, 2013; Marshall *et al.,* 2013; Chappuis *et al.,* 2014). Thermal stress and desiccation are the primary factors determining the upper limit of zonation (Finke *et al.,* 2007; Sorte *et al.,* 2019). In contrast, biological interactions, such as competition for space, grazing, and predation, determine the lower limit of zonation (Paine, 1974; Shonbeck & Norton, 1980; Moreno & Jaramillo, 1983). The sedentary or slow-moving nature of intertidal species proposed them as ecosystem engineers (Sbrocca *et al.,* 2021). They provide food sources, clear seawater, nurse fish hatchlings (Weckström & Laurén, 2023), shelter from desiccation and predators (Gutiérrez *et al.,* 2003), and protection from physical stress (Scrosati *et al.,* 2011). A large variety of organisms can be categorized as "Ecosystem engineers". These organisms include several groups of invertebrates such as limpets, mussels, oysters, barnacles, tube-dwelling polychaetes, shrimps, and crabs (Borthagaray and Carranza, 2007; Bellgrove et al., 2017).

Abu-Qir Bay is one of Alexandria's most common intertidal rocky shores. It is recognized as one of the most productive natural commercial fishing sites, providing the city with 40% of the market demand and 15% of Egypt's needs. It offers a variety of recreational activities, including swimming, boating, and fishing. However, pollution from several land-based sources and active anthropogenic activities have long affected the bay. Approximately 5.12 x 10^6 m^3 /day of untreated wastewater effluents originating from household activities and other domestic uses reach the bay through the El-Tabia pumping station, the outlet of Lake Edku (Boughaz El-Maaddiya), and the Rosetta mouth of the Nile River (El-Rayis *et al.,* 1993, Badawi & Magdy,2023). The bay is contaminated by industrial effluents from various factories, including those producing fertilizers, textiles, chemicals, petrochemicals, dyes, food processing, canning industries, and paper mills. Additionally, discharges from the Abu-Qir Electrical Power Station contribute to pollution. The volume of agricultural waste varies depending on the types of techniques practiced and the volume of effluents from Lake Edku, which flows directly to the bay. The various toxic pollutants from the previously mentioned resources, along with other factors, severely impact the marine ecosystem by altering the physical, chemical, and biological properties of the water, which in turn affects species distribution, abundance, and ecosystem biodiversity (Abdallah &Mohamed, 2015; Shreadah *et al.,* 2019; Ibrahim *et al.,*2023; Moneer *et al.,* 2023; Abdel Mohsen *et al.,*2024).

Mollusca is the second-largest animal phylum on Earth. It comprises more than 30,000 species (Parker *et al.,* 2013). It is one of the most dominant and key stone species, comprising more than 17,000 species (accounting for 13%) of the Mediterranean Sea fauna (Coll *et al.,* 2010; Sabelli & Taviani, 2014; Poursanidis & Koutsoubas, 2015). Molluscs offer valuable services for their ecosystem. They provide habitat structures for benthic fauna and change other habitat structures. They purify water through filtration for some organisms and provide a rich food source for others (Gutiérrez *et al.,* 2003; Jackson *et al.,* 2008). They are considered significant bioindicators in biodiversity studies. Parker *et al.* (2013) and Wittmann and Pörtner (2013) attributed the distribution and diversity of gastropod communities in intertidal zones to several environmental factors. These include temperature, dissolved oxygen (DO), pH, salinity, and CO2 levels, as well as biological interactions such as grazing, competition, recruitment, and introduction of invasive species (Raffo *et al.*, 2014).

Biodiversity studies have been widely employed in environmental and ecological surveys. Understanding biodiversity is necessary for effective conservation planning and sustainable development. Habitat degradation and climate change are among the adverse stresses caused by anthropogenic activities. Marine biodiversity has a profound influence on the structure and function of ecosystems. According to Cimatti *et al.* (2023), high biodiversity helps protect ecosystems from environmental disturbances. Preserving biodiversity ensures a continuous supply of food and raw materials. Additionally, biodiversity enables the environment to adapt to constant changes in conditions, such as those caused by global warming, leading to alterations in the community structure of marine organisms (Mariappan *et al.*,2023). According to Gray (2000), univariate measures, such as species richness, diversity, evenness, and total abundance, are valuable metrics that provide insights about species assemblages.

The study had two main objectives. The First is to identify rocky shore molluscs inhabiting the rocky shore of Abu-Qir Bay; the second is to conduct a statistical analysis of the collected data to provide insights about the species richness, abundance, diversity, and evenness of the surveyed species with special reference to the research conducted at the same station about 25 years ago by Farag *et al.*,1999.

2.Material and methods

2.1. Ethical approval

The present study, conducted in Abou Qir, Alexandria, Egypt, was accepted after following the ethical standards of scientific research.

2.2. Area of study

The survey was conducted on a rocky shore in Abu-Qir Bay, in Alexandria, Egypt. The bay is a shallow, sheltered, semi-circular basin extending eastward, with an approximate area of 360 Km^2 and a total volume of approximately 5.76 km^3 (Ibrahim *et al.*, 2023). The bay extends 50 km in length and 12 m. in depth. It is bounded to the southeast corner by Abu-Qir headland, with coordinates ranging from 30° 5′ E to 30 ° 22′ N, and to the northeast by the Rosetta mouth of the Nile River, with coordinates from 30 ° 22 ′ E to 31 °28 ′ N.

The study area is situated on the western side of Abu-Qir Bay, east of Alexandria city (Figure 1). The shore is highly exposed, with a rocky seabed densely covered by various species of algae. The bay receives effluent water from three mainland drainage sources: Lake Edku, El Tabia pumping station, and freshwater from the Rashid branch of the Nile (El-Rayis *et al.*, 1993; Abdallah, 2023). These discharges negatively impact the ecosystem by decreasing water salinity (El-Rayis *et al.*, 1993). The high fertility of the bay is attributed to eutrophication. These combined factors created favorable conditions for aquatic fauna to survive, breed, and find suitable shelter (Samaan & Mikhail,1990).

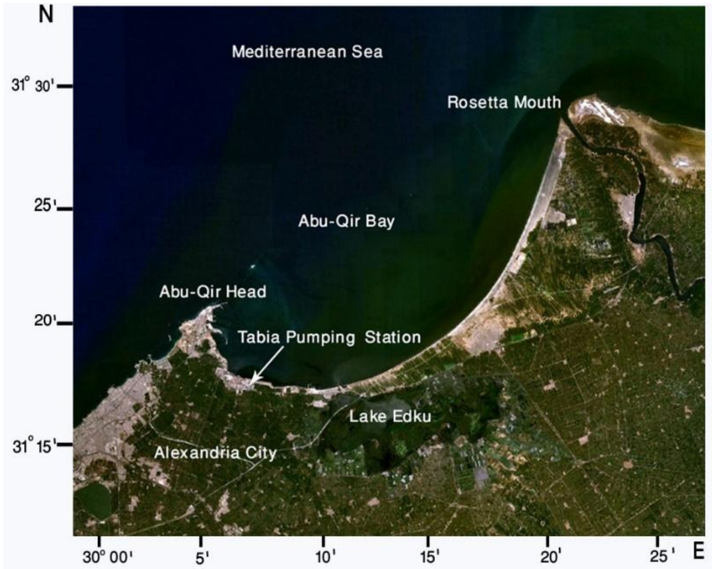

Figure 1: A map showing the area of study, Abu-Qir Head

2.3. Sampling

Rocky shore molluscs were surveyed seasonally from March 2023 to February 2024. Samples were attached to the rocky beach at a low tidal zone, ranging from 0.4 to 0.6 m. Five random replicate units were collected using five randomly placed quadrats, each measuring 1 m² (English *et al.*, 1997; Cruz-Motta *et al.*, 2010). Specimens were collected manually or by dredging using a metal hand dredge and transferred to the laboratory in plastic aquaria containing seawater. Only living specimens were considered for qualitative and quantitative studies; empty shells and dead samples were discarded. All specimens were thoroughly rinsed to remove debris and other calcareous deposits and were preserved in 10% buffered formalin.

2.4. Species identification

Specimens were identified at the species level based on morphological characteristics of the shell, referencing taxonomic identification keys according to Pallary (1912), Abbott (1991), Thiele (1992), Tan and Chou (2000), Crothers (2003), Long and Ramli (2010), and Baharuddin and Marshall (2014). Scientific names were revised and confirmed after the World Register of Marine Species (WoRMS) database (2024). For morphometric data, only shell length was measured for each sample using vernier calipers with an accuracy of ±0.01 mm. For gastropods, shell length was measured from the apex to the base. For bivalves, shell length was measured anteroposteriorly. Specimens were photographed using a Nikon D7000 DSLR camera. All the collected specimens are held in a private archive maintained by the principal author and are available upon request.

2.5. Data analysis

The Shannon-Wiener diversity index (H'), Pielou's evenness index (J'), and species richness were measured according to Magurran (2004) and Odum and Barret (2004).

2.5.1. Shannon-Wiener diversity index (H')

Diversity was calculated using the Shannon-Wiener index (H'):

$$H' = -\sum_{I=1}^{s} (pi * ln(pi))$$

where:

H' = Shannon-Wiener index

∑ = summation symbol

pi = proportion of individuals belonging to the i-th species

ln = natural logarithm

S = the number of species in the community

pi represents the proportion of individuals belonging to each species in the community. The values of pi were obtained by dividing the number of individuals of each species by the total number of individuals in the community.

The Shannon-Wiener diversity index is a commonly used measure for comparing diversity among different habitats (Clarke & Warwick, 2001). It assumes that individuals are randomly sampled from a large, independent population and that all species are represented in the sample (Shannon & Weaver, 1949). Typically, the Shannon-Wiener diversity index falls within the range 1.5 to 3.5, with few instances exceeding 4.5. A value of 0 indicates no diversity, meaning only one species is present; higher values indicate a more diverse community with a higher number of species and a more even distribution of individuals among them. The Shannon-Wiener diversity index is classified into three levels: low (H'<2), moderate (2<H'<4), and high (H'>4) (Odum & Barret 2004). This index considers two key aspects that contribute to the concept of diversity in a community: species richness and evenness.

2.5.2. Pielou's evenness index J'

$$J' = H' / H'_{max} \ (H'_{max} = Ln\ S)$$

H′ represents the observed value of the Shannon index, and S is the total number of species observed. Calculating J' allows one to determine how evenly distributed the species are in a community (Odum and Barett, 2004).

Species evenness J′ ranges from zero to one, with zero signifying no evenness and one a complete evenness.

2.5.3. Species richness

Species richness refers to the total number of species in a specific area or community (Magurran, 2004).

Species richness =$S\text{-}1/ln\ N$

Where N represents the total number of individuals in the community.

2.5.4. Statistical analysis was done using Statistical Package for Social Sciences (SPSS/version 24) software at $p < 0.05$.

3. Results and Discussion

3.1. Species identification

A total of 29 molluscan species belonging to 2 classes, Class Bivalvia and Class Gastropoda, were surveyed from the Abu-Qir rocky shore. The surveyed species are illustrated in Plates 1 and 2 and identified in Table 1. Class Gastropoda comprised 10 families, 14 genera, and 23 species, while Class Bivalvia included 2 families, 3genera, and 6 species. The highest number of species collected in this study was in autumn (29 species), and the lowest number was in summer (16 species). In winter and spring, the number of species recorded was 25 and 27, respectively.

The present survey revealed that gastropods were more abundant than bivalves throughout all seasons. Rocky shores provide an ideal substrate for the settlement of molluscan communities, particularly gastropods (Costello *et al.*, 2015; Barrientos-Luján *et al.*, 2021; Besphalaya *et al.*, 2021). Elias *et al.* (2015) noted a direct relationship between the habitat complexity of rocky shores and the diversity and abundance of species.

Three of the twenty-nine species surveyed and identified in this study were Lessepsian migrants: the gastropod *Diodora ruppellii*, the bivalves *Brachidontes punicens, and Brachidontes pharaonis*. These species migrated from the Red Sea to the Mediterranean Sea through the Suez Canal (Zenetos *et al.*, 2010; Halim and Rizkalla, 2011; Costello *et al.*, 2015). This migration has increased in recent years due to several factors, including the construction of the Suez Canal and the changes in environmental conditions. Burrows *et al.* (2014) explained that the Suez Canal acts as a conduit for these species, facilitating their introduction into the Eastern Mediterranean. Several studies focused on Lessepsian migration (Belal, 2019). These invasive species are highly considered in biodiversity studies due to their significant contribution to disturbing natural ecosystems and their economic implications, particularly for the fishing industry. They usually compete with native species and hold control over food resources. They alter habitat structures and can even spread various diseases (Battiata *et al.*, 2024). Accordingly, they reshape the biodiversity of the region.

The present study recorded small numbers of *Diodora rueppellii*, with an average of 15.8 individuals per square meter. Mienis *et al.* (1993) noted that *D. rueppellii* is primarily found in the Eastern Mediterranean. It was previously reported from Palestine (Haas, 1948) and along the southeast coast of Turkey, from the Gulf of Iskenderun to Alanya (Engl, 1995). In Egypt, Emam et al. (2013) recorded *D. rupellii* along the rocky shore of Abu-Qir, while Sghaeir *et al.* (2019) collected samples from beneath the rocks in the Marina El Alamein lagoon in southern Mediterranean Egypt.

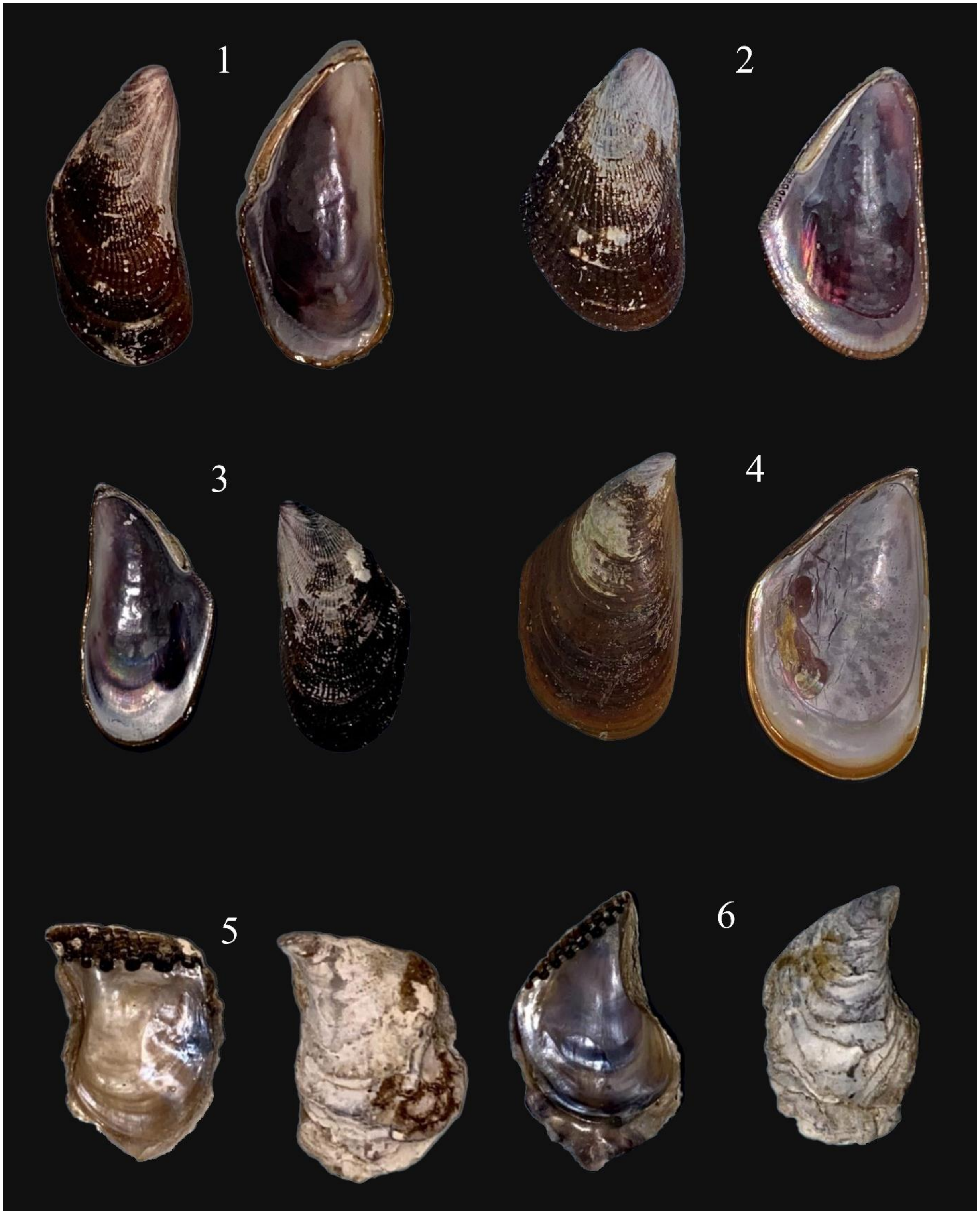

Plate 1. Rocky shore bivalves (1) *Brachidontes puniceus* (28 mm), (2) *Brachidontes pharaonis* (22 mm), (3) *Brachidontes exustus* (20 mm), (4) *Perna perna* (35mm), (5) *Isognomon bicolor* (14 mm), (6) *Isognomon sp.* (9 mm).


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Plate 2: Rocky shore gastropods (1) *Fissurella rosea* (19 mm); (2) *Fissurella volcano* (17 mm) ;(3) *Diodora ruppellii* (18 mm) ;(4) *Diodora aspera* (18 mm) ;(5) *Diodora dorsata* (20 mm) ;(6) *Diodora gibberula* (16 mm) ;(7) *Patella aspera* (35 mm) ;(8) *Patella caerulea* (28 mm); (9) *Patella rustica* (20 mm); (10) *Neverita sp.* (12 mm); (11) *Indothais malayensis* (34 mm) ;(12) *Ocinebrina edwardsii* (20 mm) ; (13) *Muricopsis cristata* (16 mm) ;(14) *Raphitoma azuari* (25 mm) ; (15) *Nassarius unifasciatus* (18 mm) ;(16) *Pisania striata* (20 mm) ;(17) *Columbella fuscata* (11 mm) ; (18) *Columbella rustica* (12 mm) ;(19) *Tritia mutabilis* (27 mm) ;(20) *Nassarius circumcinctus* (17 mm) ;(21) *Conus anemone* (24 mm) ;(22) *Conus vayssierei* (22 mm) ;(23) *Calliostoma zizyphinum* (20 mm)

Table 1: Seasonal abundance of surveyed species

Class	Family	Species	Autumn	Winter	Spring	Summer
Bivalvia	**Mytilidae**	***Brachidontes puniceus* (Gmelin, 1791)**	+	+	+	+
		***Brachidontes pharaonis* (Fischer, 1870)**	+	+	+	+
		***Brachidontes exustus* (Linnaeus,1758)**	+	+	+	+
		***Perna perna* (Linnaeus,1758)**	+	+	+	+
	Isognomonidae	***Isognomon bicolor* (Adams, 1845)**	+	+	+	-
		Isognomon sp	+	-	+	-
Gastropoda	**Fissurellidae**	***Fissurella* rosea (Gmelin, 1791)**	+	-	+	-
		***Fissurella volcano* (Reeve, 1849)**	+	+	+	-
		***Diodora ruppellii* (Sowerby,1835)**	+	-	+	+
		***Diodora aspera* (Rathke,1833)**	+	+	+	-
		***Diodora dorsata* (Monterosato, 1878)**	+	+	+	+
		***Diodora gibberula* (Lamarck,1822)**	+	+	+	+
	Patellidae	***Patella aspera* (Lamarck,1822)**	+	+	+	+
		***Patella caerulea* (Linnaeus,1758)**	+	+	+	+
		***Patella rustica* (Linnaeus,1758)**	+	+	-	-
	Naticidae	***Neverita sp(Risso*, 1826)**	+	+	+	-
	Muricidae	***Indothais malayensis* (Tan& Sigurdsson,1996)**	+	+	+	+
		***Ocinebrina edwardsii* (Payraudeau,1826)**	+	+	+	+
		***Muricopsis cristata* (Brocchi, 1814)**	+	+	+	-
	Raphitomidae	***Raphitoma azuari* (Pelorce & Horst, 2020)**	+	+	+	-
	Nassariidae	***Nassarius unifasciatus* (Kiener,1834)**	+	+	+	+
		Nassarius circumcinctus* (Adams, 1852*)	+	+	+	-
		***Tritia mutabilis* (Linnaeus, 1758)**	+	-	+	-
	Pisaniidae	***Pisania striata* (Gmelin , 1791)**	+	+	+	+
	Columbellidae	***Columbella fuscata* (Sowerby,1835)**	+	+	+	+
		***Columbella rustica*(Linnaeus,1758)**	+	+	+	+
	Conidae	***Conus anemone* (Lamarck, 1810)**	+	+	-	-
		***Conus vayssierei* (Pallary, 1906)**	+	+	+	-
	Calliostomatidae	***Calliostoma zizyphinum* (Linnaeus,1758)**	+	+	+	+
			29	**25**	**27**	**16**

Brachidontes puniceus showed high abundance within the genus *Brachidontes*, recording a high density of 1,362 individuals per square meter (Table 2). However, there are no sufficient studies concerning the distribution of *B. puniceus* in Egypt.

Brachidontes pharaonis is a small mussel native to the Indian Ocean and the Red Sea. In recent years, this mussel has expanded its range to include other habitats, such as the Mediterranean, partly due to seawater warming and habitat degradation. The remarkable physiological characteristics of this bivalve have enabled it to become one of the most successful invasive species. Extensive populations exceeding 25,000 ind./m² were also recorded on the island of Sicily by Sará *et al.* (2006). Large densities of *B. pharaonis* ranging from 16,000 to 60,000 ind./m² were reported by Çinar *et al.* (2017) in the Levantine Sea, Turkey. *B. pharaonis* has dominated offshore platforms, posing a threat to native bivalve species that have lower reproductive potential and density (Razek *et al.*, 2017, 2020; El-Deeb *et al.*, 2018; Sará *et al.*, 2018). In Egypt, *B. pharaonis*. was first recorded as an invasive species in Port Said in 1876 (Razek *et al.*, 2020). This species commonly inhabits hard substrates, including corals and rocky seabed in the Red Sea and the Mediterranean (Geba *et al.*, 2020). Hamdy *et al.* (2023) reported large populations of *B. pharaonis* in Stanley Bay, the Eastern harbour, El-Mex, and the El Umoum drain, particularly in spring. The animals were attached to concrete blocks and the rocky seabed.They attributed the high densities of the species to several favourable ecological conditions, including hyper- salinity levels reaching 45%, high organic matter content, shallow waters, hard substrates, and the abundance of microflora and macroalgae.

3.2. Data analysis

Rocky shore molluscs in Abu-Qir Bay were surveyed seasonally, and only living individuals were considered for quantitative studies. Seasonal variation in species abundance, average number of species, and individuals was recorded (Table 2, Figures 2 and 3).

Table 2: Seasonal abundance of rocky shore molluscs in Abu-Qir Bay

Class	Family	Species	Season					
			Autumn	Winter	Spring	Summer		
Bivalvia	**Mytilidae**	***Brachidontes puniceus***	777.2	415	144.2	25.6	**1362**	**2275.2**
		Brachidontes pharaonis	416.4	133.4	83.8	22.4	**656**	
		Brachidontes exustus	100	31	27.6	9.8	**168.4**	
		Perna perna	51.6	15.2	19	3	**88.8**	
			1345.2	**594.6**	**274.6**	**60.8**		
	Isognomonidae	***Isognomon bicolor***	11.2	1.6	3.2	-	**16**	**17.6**
		Isognomon sp.	0.8	-	0.8	-	**1.6**	
			12	**1.6**	**4**	**-**		
			1357.2	**596.2**	**278.6**	**60.8**		

Gastropoda	**Fissurellidae**	***Fissurella rosea***	5	-	6.2	-	**11.2**	**220.2**
		Fissurella volcano	10.6	4.2	3.6	-	**18.4**	
		Diodora ruppellii	6.8	-	7.8	1.2	**15.8**	
		Diodora aspera	22	16	2.2	-	**40.2**	
		Diodora dorsata	31.8	6.6	10.6	5	**54**	
		Diodora gibberula	40.8	36.8	2.2	0.8	**80.6**	
			117	**63.6**	**32.6**	**7**		
	Patellidae	***Patella caerulea***	82.2	59.2	40.2	44.6	**226.2**	**299**
		Patella aspera	23.2	14.8	8.4	21.6	**68**	
		Patella rustica	3	1.8	-	-	**4.8**	
			108.4	**75.8**	**48.6**	**66.2**		
	Naticidae	***Neverita sp***	6.8	0.8	4.2	-	**11.8**	**11.8**
	Muricidae	***Indothais malayensis***	613.6	294.8	58.6	17.2	**984.2**	**1133.4**
		Ocinebrina edwardsii	74.4	40.6	14.4	4.8	**134.2**	
		Muricopsis cristata	7.8	5.6	1.6	-	**15**	
			695.8	**341**	**74.6**	**22**		
	Raphitomidae	***Raphitoma azuari***	11.6	5.8	4	-	**21.4**	**21.4**
	Nassariidae	***Nassarius unifasciatus***	85.4	33	17	16.2	**151.6**	**179**
		Nassarius circumcinctus	9	6	4	-	**19**	
		Tritia mutabilis	4.6	-	3.8	-	**8.4**	
			99	39	24.8	16.2		
	Pisaniidae	***Pisania striata***	265.2	112.4	87	37	**501.6**	**501.6**
	Columbellidae	***Columbella fuscata***	110.6	53.6	21.8	10.4	**196.4**	**680.4**
		Columbella rustica	301.2	63.8	93.4	25.6	**484**	
			411.8	**117.4**	**115.2**	**36**		
	Conidae	***Conus anemone***	12.4	2.8	-	-	**15.2**	**41.6**
		Conus vayssierei	14.8	7.4	4.2	-	**26.4**	
			27.2	**10.2**	**4.2**	**-**		
	Calliostomatidae	***Calliostoma zizyphinum***	**43.2**	**22.2**	**13.4**	**5.4**	**84.2**	**84.2**
			1786	**788.2.4**	**408.6**	**189.8**		**5465.4**
			3143.2	**1384.4**	**687.2**	**250.6**		

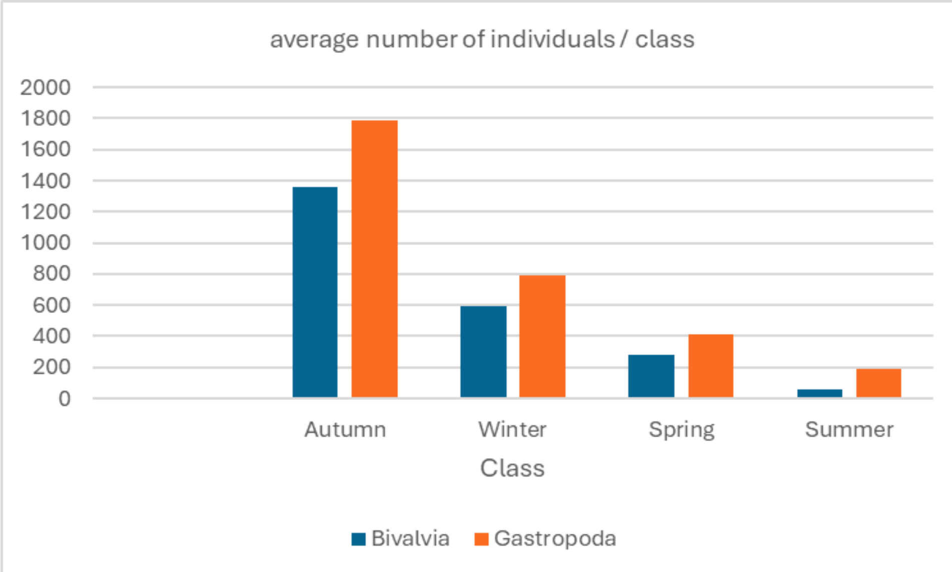

Figure 2: The average number of individuals/classes

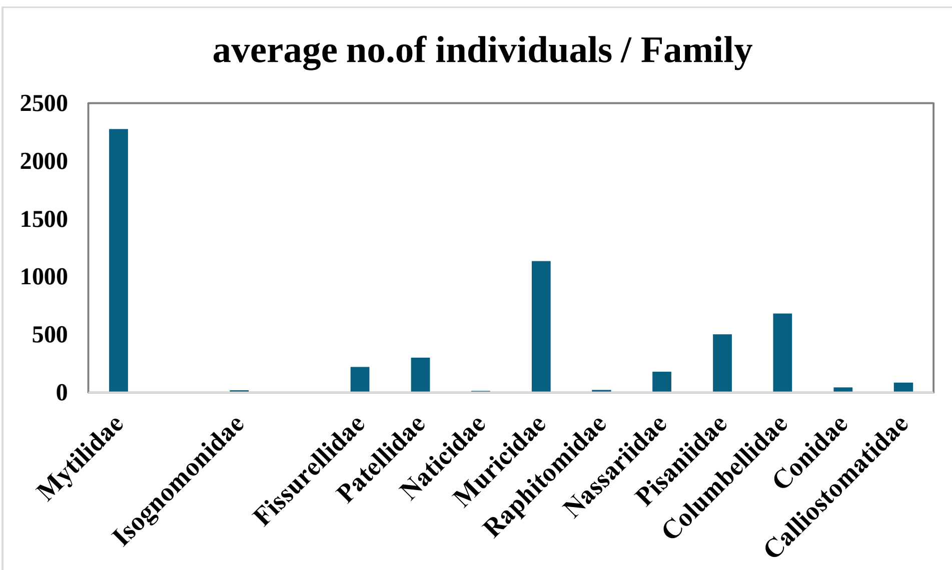

Figure 3: The average number of individuals/ families in classes Gastropoda and Bivalvia

3.2.1. Abundance

The collected molluscan species can be categorized into three groups: Abundantly present families (Mytilidae, Muricidae, Columbellidae, and Pisaniidae), moderately abundant families (Patellidae, Fissurellidae, and Nassariidae), and occasionally or rarely present families (Calliostomatidae, Conidae, Raphitomidae, Isognomonidae, and Naticidae). The family Mytilidae was the most abundant among all families studied in this survey, while the family Muricidae comprised the highest number of individuals among gastropods. On the other hand, the family Naticidae showed the least abundance (Table 2, Figure 3). The species abundance in each family decreased in the order: Mytilidae > Muricidae > Columbellidae > Pisaniidae > Patellidae >

Fissurellidae > Nassariidae> Calliostomatidae > Conidae> Raphitomidae > Isognomonidae > Naticidae (Table 2, Figure 4).

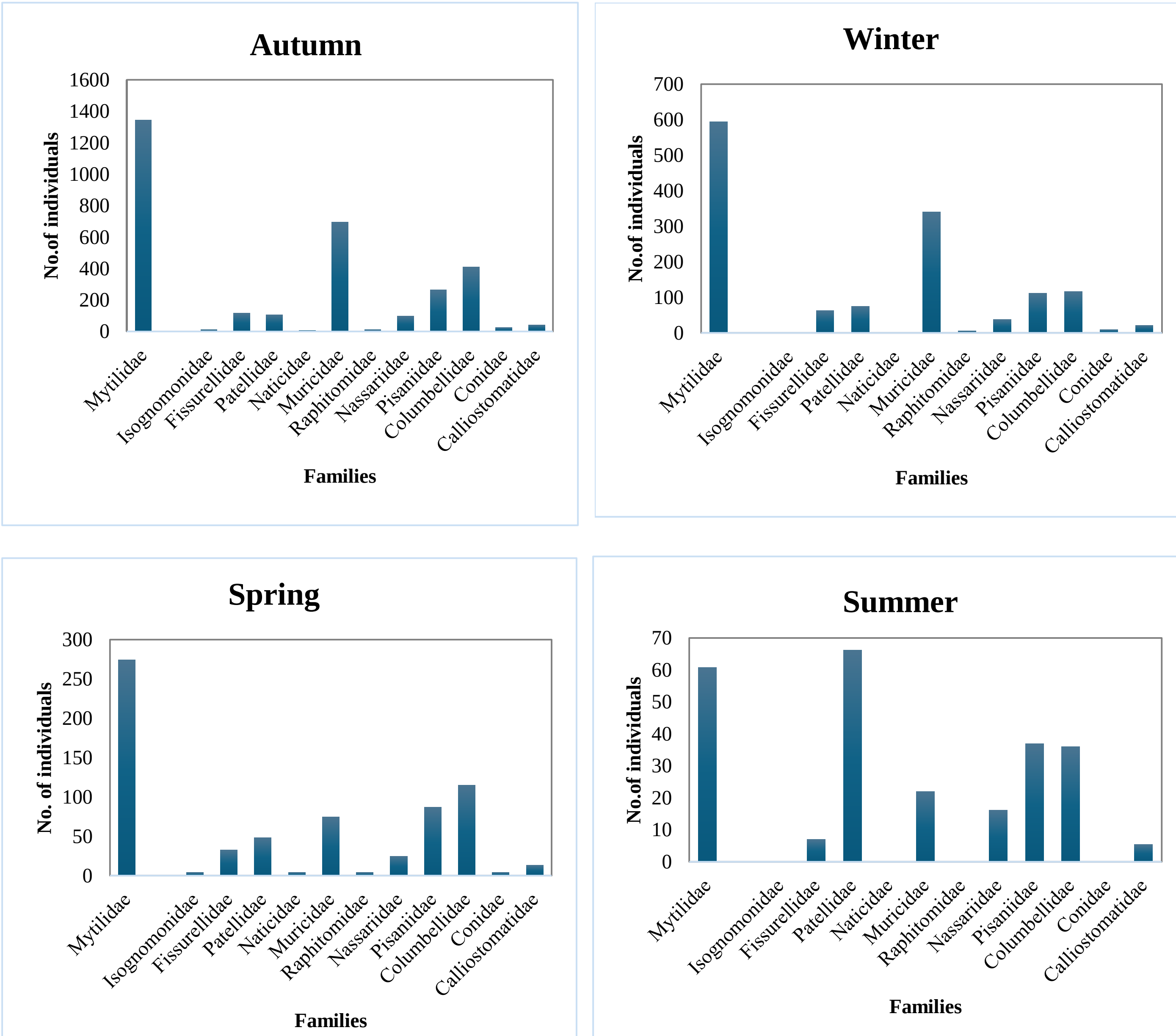

Figure 4: Seasonal distribution of molluscan families in Abu-Qir Bay

The maximum species abundance was recorded in autumn, while the minimum was recorded in summer, with a decreasing order: autumn > winter > spring> summer (Table 2). The seasonal fluctuations in species abundance may be attributed to the seasonal changes in water pollution. Water quality analysis is crucial for assessing the environmental condition of water bodies, as changes in water quality affect all aquatic organisms, from microorganisms to large creatures (El-Feky *et al.*, 2018; Ashour *et al.*, 2018; El Raey and Abo-Taleb, 2019). Heavy metal analysis plays a crucial role in determining the quality of water. Numerous studies have documented seasonal fluctuations in metal concentrations within aquatic ecosystems, noting the highest concentrations of metals in seawater samples during summer and the lowest during winter (Ali *et al.*, 2016; El-Damhogy *et al.*, 2019; Duysak & Uğurlu, 2020; Abd-Ellah *et al.*, 2020 & 2025). El-Damhogy *et al.* 2019, and Abd-Ellah *et al.* 2025 recorded the highest concentrations of heavy metals in seawater samples collected from Abu-Qir Bay during summer. El-Serafy *et al.*(2003a) & Elewa *et al.* (2007) attributed the summer peaks in metal concentrations to decomposition of sediments and organic matter under high temperatures. El-Haddad (2005), Maanan (2008), and Peng *et al.*, (2011) explained that elevated summer temperatures decrease free oxygen content, which in turn increases dissolved metal concentrations. Additionally, low rainfall during the dry season results in a decrease in water flow and higher concentrations of heavy metals (Ali *et al.*, 2016). The drop in temperature and pH in winter enhances metal mobilization (Gaber *et al.*, 2017). Moreover, the level of agricultural pollutants in Abu-Qir Bay fluctuates seasonally, influenced by the type and extent of agricultural activities, as well as the volume of effluents from Lake Edku, which is considerably higher during summer and autumn seasons but limited in winter (Ibrahim *et al.*, 2023).

The results of the present study were compared with a previous study conducted by Farag *et al.* (1999), which also involved a seasonal survey of rocky shore molluscs from the same area (Table 3).

Table 3: Comparative analysis of family and species distribution of rocky shore molluscs: a study of 1999 and present data.

Class	Family	Species	Present study	1999
Polyplacophora	**Chitonidae**	***Chiton squamosus***	-	+
	Lepidopleuridae	***Lepidopleurus cancellatus***	-	+
Gastropoda	**Fissurellidae**	***Fissurella rosea***	+	-
		Fissurella volcano	+	-
		Diodora ruppellii	+	-
		Diodora aspera	+	-
		Diodora dorsata	+	-
		Diodora gibberula	+	+
		Diodora italica	-	+
	Patellidae	***Patella aspera***	+	+
		Patella caerulea	+	+
		Patella rustica	+	-
		Patella vulgata	-	+
		Patella miniate	-	+
		Patella tarentina	-	+
	Naticidae	***Neverita sp***	+	-
	Muricidae	***Indothais malayensis***	+	-
		Ocinebrina edwardsii	+	-
		Ocinebrina scrobiculata	-	+
		Muricopsis cristata	+	-
	Raphitomidae	***Raphitoma azuari***	+	-
	Nassariidae	***Nassarius unifasciatus***	+	-
		Nassarius circumcinctus	+	-
		Tritia mutabilis	+	-

	Pisaniidae	***Pisania striata***	+	+
	Columbellidae	***Columbella rustica***	+	+
		Columbella fuscata	+	-
	Conidae	***Conus anemone***	+	-
		Conus vayssierei	+	-
		Conus ventricosus	-	+
	Calliostomatidae	***Calliostoma zizyphinum***	+	-
		Clanculus cruciatus	-	+
	Littorinidae	***Littorina neritoides***	-	+
Bivalvia	**Mytilidae**	***Mytilus minimus***	-	+
		Brachidontes variabilis	-	+
		Brachidontes puniceus	+	-
		Brachidontes pharaonis	+	-
		Brachidontes exustus	+	-
		Perna perna	+	-
	Isognomonidae	***Isognomon bicolor***	+	-
		Isognomon sp	+	-
Total			**29**	**17**

In the current survey, 29 species were identified. The species belong to 2 classes, Gastropoda and Bivalvia, across 12 families, exceeding the number of species documented by Farag *et al.* (1999), which recorded a total of 17 molluscan species belonging to 3 classes: Polyplacophora, Bivalvia and Gastropoda. Class Polyplacophora comprised 2 families, 2 genera, and 2 species. Class Gastropoda included 8 families, 8 genera, and 13 species, while Class Bivalvia included one family, 2 genera, and 2 species. Farag *et al.* (1999), recorded 17 species belonging to 11 families. Notably, the families Chitonidae, Lepidopleuridae, and Littorinidae were absent in the present study. On the contrary, the Families Naticidae, Raphitomidae, Nassariidae, and Isognomonidae were recorded in this study and were not observed in the 1999 study.

In the present study, the Mytilidae family, which included the most abundant species, was represented by four species: *Brachidontes puniceus*, *Brachidontes pharaonis*, *Brachidontes exustus*, and *Perna perna*. All these species were absent in the 1999 study. On the contrary, *Mytilus minimus* and *Brachidontes variabilis*, which were documented in the 1999 study, were not observed in the current study. Three Lessepsian species were identified: *Diodora rueppellii*, *Brachidontes puniceus*, and *Brachidontes pharaonis*. Farag *et al.* (1999) did not record any Lessepsian species in their study.

When comparing the abundance of individuals per square metre across different seasons for the two studies, the total number of individuals was much less than that reported in the 1999 study. The total abundance was 12969.6 in the 1999 study, far exceeding the value 5465.4 recorded in the present study (Table 4 and Figures 5 & 6). Species diversity has suffered tremendously from several threats in recent years, most of which are related to human activities. Among these threats are different types of pollution, eutrophication, habitat degradation, exploitation of marine resources, climate change, and invasive species. Unfortunately, these threats are expected to escalate in the future, with aquatic resources and fisheries being heavily exploited. Finke *et al.* (2007) linked the changes in diversity and species abundance to the increase in surface water temperature observed for the past 50 years. Coastal and shelf areas are the most threatened zones (Coll *et al.*, 2012; Coutinho *et al.*, 2016). D'Souza *et al.* (2022) emphasized that water temperature is a significant ecological factor influencing biodiversity. Furthermore, Mendez *et al.* (2025) noted the negative impacts of anthropogenic activities on biodiversity.

Table 4: Comparison between different statistical parameters in the present study and the 1999 study

Abu-Qir	Season	No. of species	No. of Individuals / m²	SR	H'	J'
Present study	Autumn	29	3143.2	3.476	2.3467	0.697
	Winter	25	1384.4	3.318	2.285	0.7099
	Spring	27	687.2	3.980	2.554	0.775
	Summer	16	250.6	2.715	2.436	0.8786
	Total study period	29	5465.4	3.2534	2.419	0.718
1999	Autumn	11	6028.2	1.149	0.037	0.015
	Winter	11	207.2	1.875	0.906	0.378
	Spring	9	4379.6	0.954	0.019	0.009
	Summer	13	2354.6	1.546	0.223	0.087
	Total study period	17	12969.6	1.689	0.1212	0.0428

The recorded results indicate a statistically significant difference between the total study periods of the present study and the 1999 study for all metrics. The present study recorded a significantly higher number of species compared to the 1999 study (p=0.029). Species Richness (SR), Diversity (H'), and Evenness (J') were significantly higher in the present study compared to the 1999 study, with p values of 0.001, 0.001, and 0.003, respectively. This suggests that the present study period had a significantly richer, more diverse, and more evenly distributed mollusc community than the 1999 period.

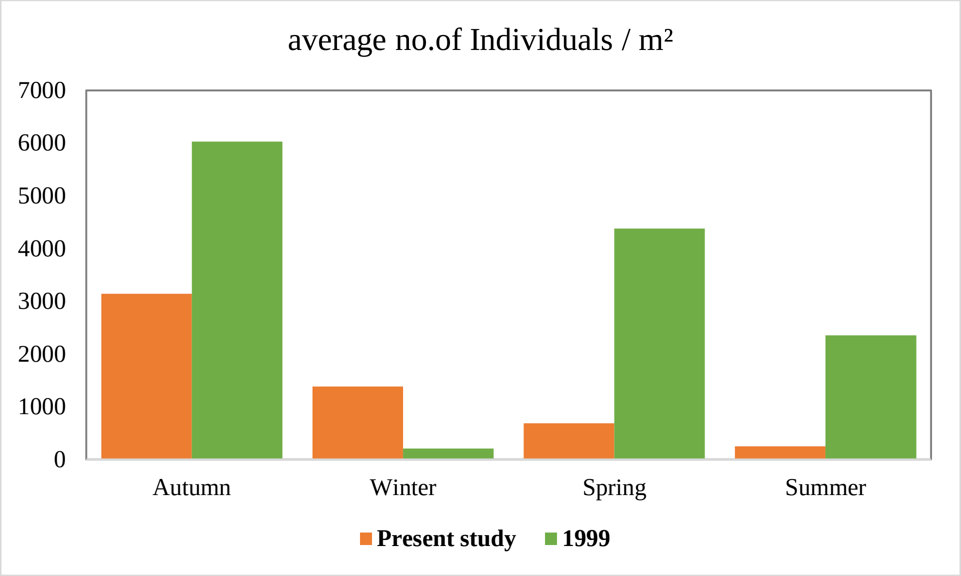

Figure 5: The average number of individuals/m² compared to the 1999 study across the different seasons

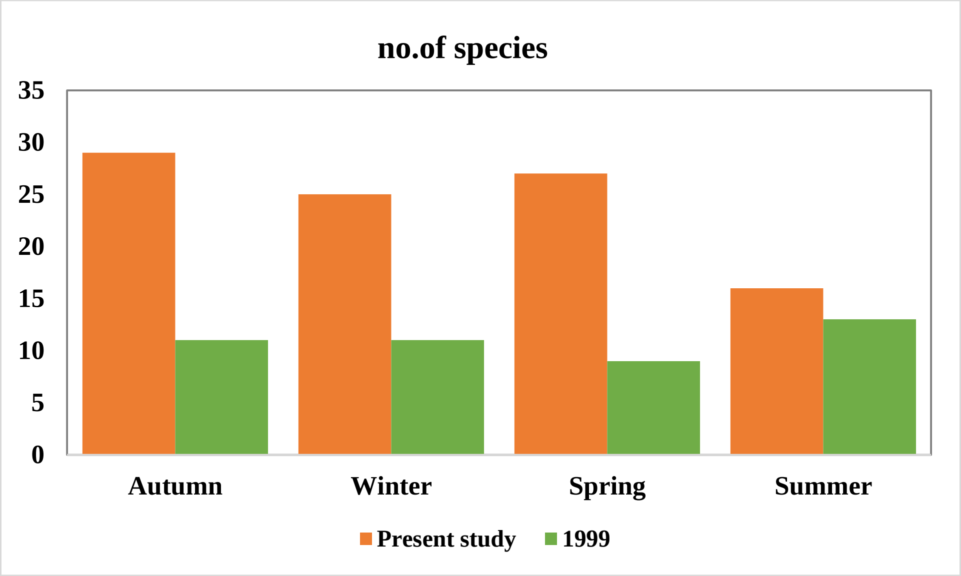

Figure 6: The number of species compared to the 1999 study across the different seasons

3.2.2. The Shannon-Wiener diversity index

According to Scrosati *et al.* (2011), Belal (2019), and Benjamin *et al.* (2022), the Shannon-Wiener diversity index considers abundance, species richness (SR), and evenness (J′), which contribute to the overall diversity of a community. These three parameters were used to evaluate the biodiversity condition of the rocky shore area and compared with the previously recorded values in 1999. These parameters were significantly higher in the present survey compared to the1999 study across all seasons (Table 4 and Figures 7 - 9). Becherucci *et al.* (2016) mentioned that all these parameters increased with successional times.

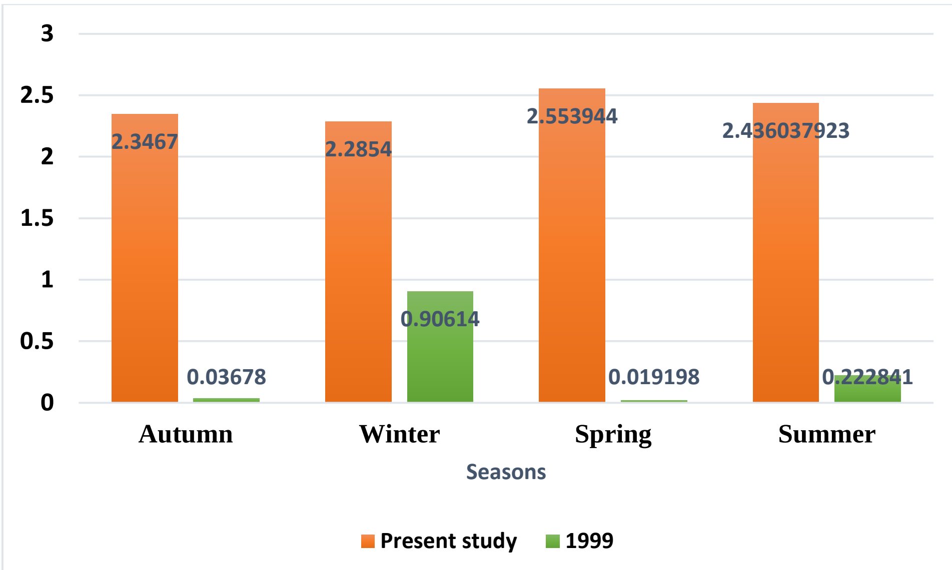

Figure 7: Comparison between Species diversity across the seasons in the present study and 1999

Several authors applied the Shannon-Wiener diversity index in their research. Villéger *et al.* (2010) recommended various diversity indices in biodiversity studies. Belal *et al.* (2019) noted that this index is a valuable indicator in water pollution research. They concluded that species diversity is higher in environmentally stable areas than in polluted ones. In Abu-Qir Bay, El-Hedeny *et al.* (2021) recorded low species diversity, which aligns with the heavily polluted nature of the area. The present study recorded moderate diversity when applying the Shannon-Wiener diversity index.

3.2.3. Species Richness SR

Species richness (SR) refers to the number of species available in a definite area. In this study, SR was applied to indicate the total number of molluscan species in the study area. Higher species richness was recorded in spring compared to other seasons, while the lowest species richness was detected in summer. The overall species richness is significantly higher than in the 1999 study (Figure 8).

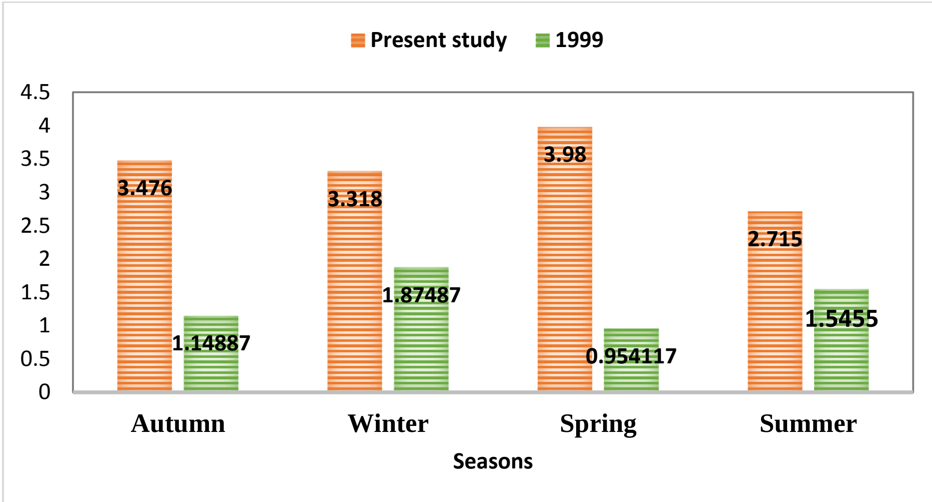

Figure 8 Comparison between Species richness across the seasons in the present study and 1999

Borja *et al.* (2013) found that subtidal species usually have higher species richness than intertidal species. This difference can be attributed to various habitat factors, particularly the contribution percentage of intertidal species. Rocky shores, coral reefs, and other hard substrates usually show the highest species richness (Scrosati *et al.*, 2011; Barrientos-Luján *et al.*, 2021), with areas inhabited by larger populations of mussels having higher species richness compared to those with fewer individuals (Borthagaray and Carranza, 2007). Sessile organisms, attached to those substrates, generally display higher species richness compared to free-living predators (Scrosati *et al.*, 2011). Several factors influence species richness, including nutrient supplies, sampling intensity, and environmental stressors, such as sewage effluent discharge. These stressors can reduce species richness, which could ultimately lead to decline or loss of biodiversity (Bellgrove *et al.*, 2017).

2.2.4. Species Evenness J’

Pielou’s evenness index (J’) determines how evenly distributed species are in a community (D’Souza *et al.*, 2022). It is also known as equitability and is estimated as the ratio of observed diversity to maximum diversity (Emara and Belal, 2004). Species evenness is beneficial in determining changes in abundance and distribution among different species (Villéger *et al.*, 2010; D’Souza *et al.*, 2022). The value of (J') ranges from 0 to 1; values close to 1 indicate a more even distribution among species, and values close to 0 indicate an uneven distribution of species, with some being dominant and others being rare (D’Souza *et al.*, 2022). In this survey, the value of (J') ranged from 0.697 in autumn to 0.8786 in summer, indicating a more even distribution of molluscs during summer compared to other seasons. When comparing these results with Farag *et al.* (1999), the species were unevenly distributed throughout all seasons, with the values of (J') ranging from 0.009 in spring to 0.378 in winter. The total evenness in the present study was significantly higher than that recorded in the 1999 study (0.0428) (Figure 9).

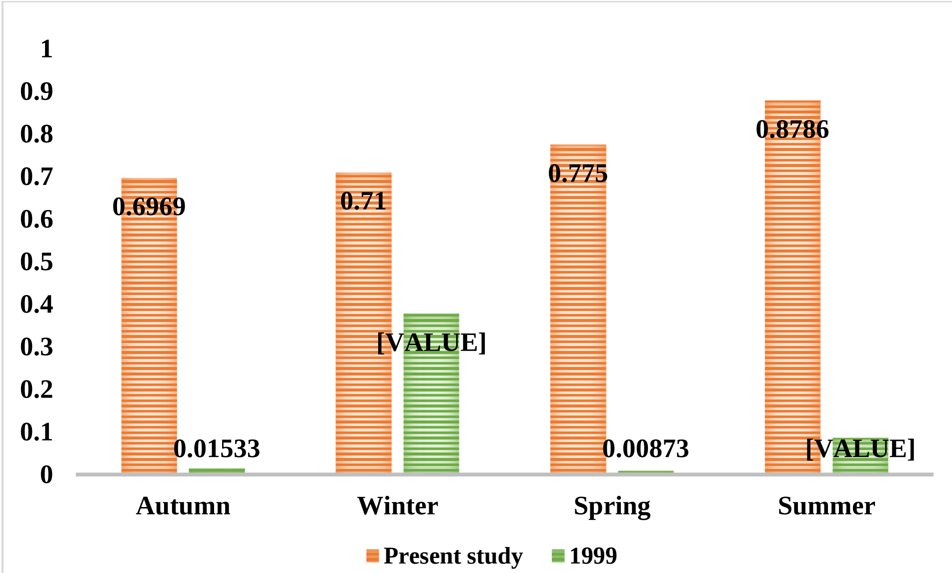

Figure 9: Comparison between Species Evenness across the seasons in present study and 1999

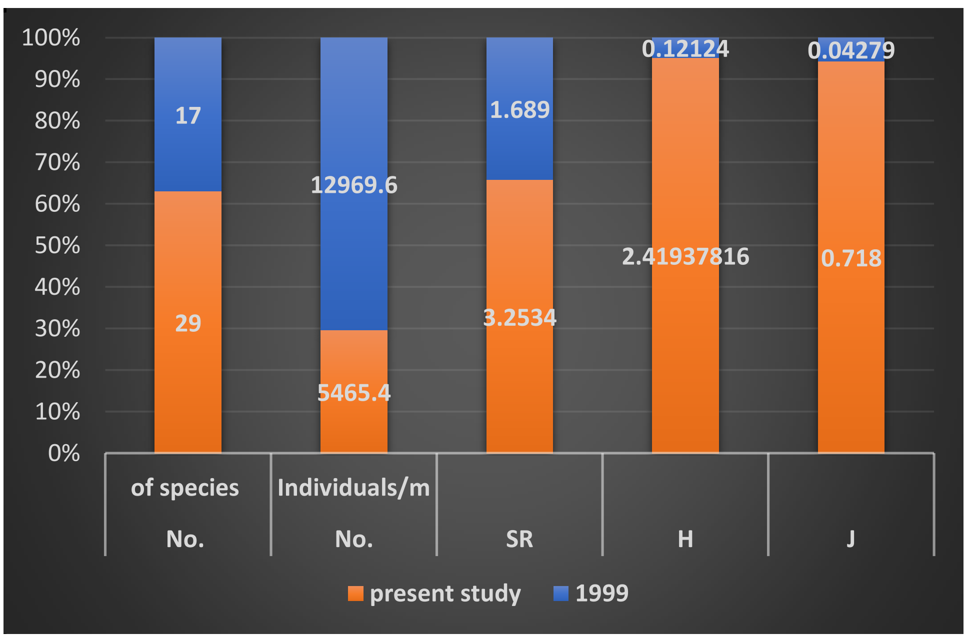

Figure 10: Comparison between the number of species, number of individuals/m2, SR, H', and J in the present study and 1999

Finally, by comparing the results of the current study with those of Farag *et al.* (1999), we observed an overall increase in all the measured parameters (Figure 10). However, species abundance was lower in the present study compared to that recorded in the 1999 study. The current study was conducted on one of the most polluted shores in Alexandria, which has always been subjected to various ecological stresses. We observed a significant increase when comparing the different statistical parameters with the study conducted since 1999, indicating that the problem is chronic and is accelerating. There are several interpretations for the recorded results that need further investigation. Yet, literature proposed global climate change as a major threat to biodiversity. One of the most critical impacts of global climate change is the rise in the surface water temperature in the Mediterranean Sea, which closely follows the increase in atmospheric temperatures. The accelerating global warming poses a growing threat to marine biodiversity, particularly in coastal ecosystems (Trisos *et al.*,2020). Numerous studies have highlighted water temperature as a key ecological factor shaping biodiversity. Elevated temperatures often exceed the thermal tolerance of native species, leading to population collapses and facilitating the invasion of non-indigenous tropical species (Rilov, 2016; Albano *et al.*, 2021b; Amarasekare & Simon, 2020). Such invasions permanently alter the functional composition of Mediterranean ecosystems (Steger *et al.*, 2021; Zenetos *et al.*, 2022). As a result, global warming and rising seawater temperatures are reshaping the community structure of marine organisms, especially those inhabiting rocky shores (Coutinho *et al.*, 2016; Bianchi and Morri, 2000; Mariappan *et al.*, 2023).

Abu-Qir Bay has consistently received substantial amounts of sewage, agricultural runoff, and industrial discharges, which have significantly altered its physical and chemical properties.The Bay is highly polluted by wastewater derived from two primary sources: El-Tabia Pumping Station, which receives a substantial amount of raw industrial wastes from approximately 36 factories(Badr and Hussein, 2010), and Boughaz El-Maadiya ,which receives agricultural runoff and brackish water from Lake Edku (Masoud *et al.*, 2005). These different types of pollutants received via the previously mentioned sources severely impact the water quality of the Bay, which ultimately affects marine life in the Bay. Abdallah and Mohamed (2017) recorded elevated levels of total metal content in the sediments from Abu-Qir Bay, particularly lead (Pb) and cadmium (Cd). The Cd concentrations indicated that the sediments could be classified as "highly to very highly contaminated," and organisms inhabiting these sediments are prone to adverse effects. Additionally, El-Damhogy *et al.* (2019) recorded high concentrations of Pb and Zn in Abu-Qir. According to Abdel-Mohsen *et al.* (2024), Abu-Qir exhibited the highest concentrations of Cu and Cd among the five sites they studied along the Alexandria coast. Concentrations of Fe, Pb, Cd, and Co in Abu-Qir Bay exceeded WHO permissible levels (Abd-Ellah *et al.*,2025). The various types of toxic pollutants from the previously mentioned resources along with climatic changes, severely impact the marine ecosystem of Abu-Qir by altering the physical, chemical, and biological properties of the water, which in turn affects species distribution, abundance, and ecosystem biodiversity (Abdallah and Mohamed, 2017; Shreadah *et al.*, 2019; Badawi & Magdy,2023; Ibrahim *et al.*,2023; Moneer *et al.*, 2023; Abdel Mohsen *et al.*,2024).

4. Conclusion

This present study is pivotal for understanding the long-term impacts of environmental threats on marine biodiversity and for developing effective strategies to mitigate these effects and protect marine biodiversity. It can be concluded that the community structure and biodiversity of the rocky shore molluscs are highly sensitive to long-term impacts of persistent stressors such as global warming and anthropogenic activities. These stressors have resulted in an increase in the species diversity index and the dominance of certain species. Further research is necessary to comprehend the specific factors contributing to the changes in the structure of shore communities and their biodiversity. Moreover, it is highly recommended to investigate the impact of excessive invasion by Lessepsian species on the overall integrity of the ecosystem to protect marine biodiversity.

References

Abbott, R. T. (1991). Seashells of Southeast Asia: A Guide for Collectors and Naturalists. American Malacologists, Inc.

Abdallah, M. A. M. (2023). Accumulation and distribution of heavy metals in surface sediments from the continental shelf adjacent to Abu-Qir Bay, Egypt, as a function of grain size. *Geo-Marine Letters*, *43*(1), 2.

Abdallah, M. A. M., Mohamed, A.A. (2015). Assessment of heavy metals by sediment quality guideline in surficial sediments of Abu-Qir Bay, southeastern Mediterranean Sea, Egypt. Environmental Earth Sciences, 73, 3603-3609.

Abd-Ellah, S.M., El-Sherif, S.S., El-Morshedy, R. (2020). Seasonal effects of heavy metals on the date mussel *Lithophaga lithophaga* (Mollusca:Bivalvia) at Eastern harbor, Alexandria, Egypt. Swedish Journal of Biological Science Research, 1(1): 62 - 77.

Abd-Ellah, S.M., El-Sheri, S.S., Abd-El Latif, H.A., Nour, O.M. (2025). Assessment of the Seasonal Effects of Heavy Metals on Kuruma Prawn (*Marsupenaeus japonicus*) and Its Impacts on the Ovary and Biochemical Composition. Journal of Environmental Studies, Vol. 37(1): 8-22

Abdel-Mohsen, H. A., Ismail, M. M., Moussa M. R. (2024). Hazardous impacts of heavy metal pollution on biometric and biochemical composition of pearl oyster *Pinctada radiata* from five sites along Alexandria coast, with reference to its potential health risk assessment. *Environmental Science and Pollution Research*, *31*(15), 23262-23282.

Albano, P. G., Steger, J., Bošnjak, M., Dunne, B., Guifarro, Z., Turapova, E., ... & Zuschin, M. (2021). Native biodiversity collapses in the eastern Mediterranean. Proceedings of the Royal Society B, 288(1942), 20202469.

Ali, M.M., Ali, M.L., Islam, M.S., Rahman, M.Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. Environ. Nanotechnology. Monit. Manag., 5: 27–35.

Amarasekare, P., & Simon, M. W. (2020). Latitudinal directionality in ectotherm invasion success. Proceedings of the Royal Society B, 287(1920), 20191411.

Araújo, R., Bárbara, I., Sousa-Pinto, I., Quintino, V. (2005). Spatial variability of intertidal rocky shore assemblages in the northwest coast of Portugal. *Estuarine, Coastal and Shelf Science*, *64*(4), 658-670.

Archambault, P. and Bourget, E. (1996). Scales of coastal heterogeneity and benthic intertidal species richness, diversity and abundance. *Marine Ecology Progress Series*, *136*, 111-121.

Ashour, M., Abo-Taleb H.A., Abou-Mahmoud M.M., El-Feky M.M. (2018). Effect of the integration between plankton natural productivity and environmental assessment of irrigation water, El-Mahmoudia Canal, on aquaculture potential of *Oreochromis niloticus*. Turkish Journal of Fisheries and Aquatic Sciences.18:1163-1175

Badawi, A. and Magdy, S. M. (2023). Evaluation of the pollution extent of heavy metals in the sediment of the Nile Delta, Mediterranean Coast, Egypt. *Egyptian Journal of Aquatic Research*, *49*(2), 221-228.

Badr, N.B. and Hussein, M.M. (2010). An input/output flux model of total phosphorous in Lake Edku, a northern eutrophic nile delta lake. GJER 4, 64e75.

Baharuddin, N. and Marshall, D. J. (2014). Common aquatic gastropods of Brunei. Education and Technology Centre, Universiti Brunei Darussalam, Brunei.

Barrientos-Luján, N. A., Rodríguez-Zaragoza, F. A.,López-Pérez, A. (2021). Richness, abundance and spatial heterogeneity of gastropods and bivalves in coral ecosystems across the Mexican Tropical Pacific. *Journal of Molluscan Studies*, *87*(2), eyab004.

Battiata, M., Curatolo, T., Naser, M. D., Sarà, G., Lo Brutto, S. (2024). The State of the Art of the Global Distribution of the Invasive Mytilid Species *Brachidontes pharaonis* (P. Fischer, 1870). *Diversity*, *16*(7), 381.

Becherucci, M. E., Llanos, E. N., Garaffo, G. V., Vallarino, E. A. (2016). Succession in an intertidal benthic community affected by untreated sewage effluent: A case of study in the SW Atlantic shore. *Marine Pollution Bulletin*, *109*(1), 95-103.

Belal, A. A. M. (2019). Macro-benthic invertebrates as a bio-indicator for water and sediment quality in Suez Bay, Red Sea. *Egyptian Journal of Aquatic Research*, *45*(2), 123-130.

Bellgrove, A., McKenzie, P. F., Cameron, H., Pocklington, J. B. (2017). Restoring rocky intertidal communities: Lessons from a benthic macroalgal ecosystem engineer. *Marine Pollution Bulletin*, *117*(1-2), 17-27.

Benjamin, E. D., Handley, S. J., Hale, R., Toone, T. A., Jeffs, A., Hillman, J. R. (2022). Biodiversity associated with restored small-scale mussel habitats has restoration decision implications. *Biodiversity and Conservation*, *31*(11), 2833-2855.

Bertness, M. D., Crain, C. M., Silliman, B. R., Bazterrica, M. C., Reyna, M. V., Hildago, F., Farina, J. K. (2006). The community structure of western Atlantic Patagonian rocky shores. *Ecological Monographs, 76*(3), 439-460.

Bespalaya, Y. V., Aksenova, O. V., Sokolova, S. E., Shevchenko, A. R., Tomilova, A. A., Zubrii, N. A. (2021). Biodiversity and distributions of freshwater mollusks in relation to chemical and physical factors in the thermokarst lakes of the Gydan Peninsula, Russia. *Hydrobiologia, 848,* 3031-3044.

Bianchi, C. N. and Morri, C. (2000). Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. *Marine Pollution Bulletin*, *40*(5), 367-376.

Borja, Á., Chust, G., Del Campo, A., González, M., Hernández, C. (2013). Setting the maximum ecological potential of benthic communities, to assess ecological status, in heavily morphologically modified estuarine water bodies. *Marine Pollution Bulletin*, *71*(1-2), 199-208.

Borthagaray, A. I. and Carranza, A. (2007). Mussels as ecosystem engineers: their contribution to species richness in a rocky littoral community. *Acta oecologica*, *31*(3), 243-250.

Burrows, M. T., Schoeman, D. S., Richardson, A. J., Molinos, J. G., Hoffmann, A., Buckley, L. B., Pippa, J., Moore, C. J. ,Brown, J. F. ,Bruno, C. M., Duarte, B. S., Halpern, O., Hoegh-Guldberg, C. V. ,Kappel, W. K., Mary, I. ,O'Connor, J. M., Pandolfi, C. P., William, J. S., Simon ,F., Kristen, J. W. , Poloczanska, E. S. (2014). Geographical limits to species-range shifts are suggested by climate velocity. *Nature*, *507*(7493), 492-495.

Chappuis, E., Terradas, M., Cefalì, M. E., Mariani, S., Ballesteros, E. (2014). Vertical zonation is the main distribution pattern of littoral assemblages on rocky shores at a regional scale. *Estuarine, Coastal and Shelf Science*, *147*, 113-122.

Cimatti, M., Chaplin-Kramer, R., Di Marco, M. (2023). The role of high-biodiversity regions in preserving Nature's Contributions to People. *Nature Sustainability*, *6*(11), 1385-1393

Çinar, M. E., Bakir, K., Öztürk, B., Katağan, T., Doğan, A., Açik, S., Kurt-Sahin, G., Özkan, T., Dağli, E., Bakir, B.K., Kirkim, F. (2017). Macrobenthic fauna associated with the invasive alien species *Brachidontes pharaonis* (Mollusca: Bivalvia) in the Levantine Sea (Turkey). *Journal of the Marine Biological Association of the United Kingdom*, *97*(3), 613-628.

Clarke, K. R. and Warwick, R. M. (2001). A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Marine ecology Progress series*, *216*, 265-278.

Coll, M., Piroddi, C., Albouy, C., Lasram, F.B.R., Cheung, W. W.L., Christensen, V., Karpouzi, V.S., Guilhaumon, F., Mouillot,D., Paleczny,M., Palomares, M.L., Steenbeek, J., Trujillo, P, Watson, R., Pauly, D. (2012). The Mediterranean Sea under siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves. *Global Ecology and Biogeography*, *21*(4), 465-480.http://www.jstor.org/stable/41415041

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Rais Lasram, F. B., Aguzzi, J., Ballesteros, E., Bianchi, C. N., Corbera, J., Dailianis, T., Danovaro, R., Estrada, M., Froglia, C., Galil, B. S., Gasol, J. M., Gertwagen, R., Gil, J., Guilhaumon, F., Kesner-Reyes, K., . . . Voultsiadou, E. (2010). The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. PLOS ONE, 5(8), e11842. https://doi.org/10.1371/journal.pone.0011842

Costello, M. J., Claus, S., Dekeyzer, S., Vandepitte, L., Tuama, É. Ó., Lear, D., Tyler-Walters, H. (2015). Biological and ecological traits of marine species. *PeerJ*, *3*, e1201.

Coughlan, J. and Crowe, T. (2009). Rocky shore survey. *School of Biology and Environmental Science, University College Dublin*.

Coutinho, R., Yaginuma, L. E., Siviero, F., Santos, J. C. Q. D., López, M. S., Christofoletti, R. A., Berchez, F., Ghilardi-Lopez, N.P., Ferreira,C.E.L., Gonçalves, J.E.A., Masi,B.P., Correia,M.D., Sovierzoski,H.H., Skinner, L.F., Zalmon, I. R. (2016). Studies on benthic communities of rocky shores on the Brazilian coast and climate change monitoring: status of knowledge and challenges. Brazilian Journal of Oceanography, 64(spe2), 27-36.

Crothers, J. H. (2003). Rocky shore snails as material for projects (with a key for their identification). *Field studies*, *10*, 601-634.

Cruz-Motta, J. J., Miloslavich, P., Palomo, G., Iken, K., Konar, B., Pohle, G., Trott, T., Benedetti-Cecchi, L., Herrera, C., Hernández, A., Sardi, A., Bueno, A., Castillo, J., Klein, E., Guerra-Castro, E., Gobin, J., Gómez, D., Riosmena-Rodríguez , R., Mead, A., Bigatti, G., Knowlton ,A. , Shirayama, Y. (2010). Patterns of spatial variation of assemblages associated with intertidal rocky shores: a global perspective. *PloS one*, *5*(12), e14354.

Duysak, Ö. and Uğurlu, E. (2020). Trace Metal Concentrations in the Seston of the Gulf of İskenderun (Turkey, North- Eastern Mediterranean). Thalassas, 36: 125–132.

D'Souza, S. L., Gangadhara Bhat, H., Bhasker Shenoy, K. (2022). Study of intertidal molluscan diversity of the Dakshina Kannada coast, India using remote sensing and GIS techniques. *Current Science (00113891)*, *122*(12).

El-Damhogy, K.A., Abo-Taleb, H.A., Ahmed, H.O., Aly-Eldeen, Abdel-Aal, M.M. (2019). The relationship between the concentrations of some heavy metals in the water of Abu-Qir Bay and within the tissues of the blue crab *Portunus pelagicus*. Egyptian Journal of Aquatic Biology &Fisheries, 23(3): 347 –359

El-Feky, M.M.M., Alprol, A.E., Heneash, A.M.M., Abo-Taleb, H.A., Omer, M.Y. (2018). Evaluation of Water Quality and Plankton for Mahmoudia Canal in Northern West of Egypt. Egyptian Journal of Aquatic Biology & Fisheries, 22(5): 461 - 474

El-Haddad, E.S. (2005). Physicochemical studies for domestic water for Ismailia canal from El-Mazalat to Anshas. M.Sc Thesis Faculty of Science, Al Azhar University, Cairo Egypt.

El Hedeny, M., Rashwan, M., Richiano, S., Al Farraj, S., Al Basher, G. (2021). Epi-and endobiont faunal communities on an Egyptian Mediterranean rocky shore: species composition and their competition for space. *Journal of Oceanology and Limnology*, *39*, 198-207.

El Raey, M.and Abo-Taleb, H. (2019). A Survey of Satellite-borne Biosensors Applications. *Advances in Environmental Monitoring and Assessment. Suriyanarayanan Sarvajayakesavalu, Editor. Intechopen, London. UK ISBN*, 978-953.

El-Deeb, R. S., Razek, F. A. A., Omar, H. A., Khafage, A. R., Abdul-Aziz, K. K. (2018). The gametogenic cycle and spawning of the mussel *Brachidontes pharaonis* (Fischer, 1876) (Bivalvia: Mytilidae) from Alexandria Coast, Egypt. *Egyptian Journal of Aquatic Research*, *44*(4), 353-359.

Elías, R., Jaubet, M. L., Llanos, E. N., Sanchez, M. A., Rivero, M. S., Garaffo, G. V., and Sandrini-Neto, L. (2015). Effect of the invader *Boccardia proboscidea* (Polychaeta: Spionidae) on richness, diversity and structure of SW Atlantic epilithic intertidal community. *Marine Pollution Bulletin*, *91*(2), 530-536.

Elewa, A.A., Saad, E.A., Shehata, M.B., Ghallab, M.H. (2007). Studies on the effect of drain effluents on the water quality of Lake Manzala, Egyptian Journal of Aquatic Biology and Fisheries. 11(2): 65-78.

El-Rayis, O. A., Saad, M. A. H., El-Nady, F. E. (1993). Dispersion patterns of fresh water in Abu-Qir Bay, Egypt. In *Environmental protection is a Must, HIPH of Alex. Univ. 3rd int. conf. on Alex* (pp. 13-15).

El-Serafy, S., Sayed, D., EI-Gamal, M. (2003). Seasonal variations of trace metals levels in water and the limpet *Patella caerulea* of Alexandria coast, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, *7*(4), 283-312.

Emam, W. M., Emam, W. W., Ghareb, T. A. (2013). Morphological and morphometric study on the keyhole limpet *Diodora rupellii* (Sowerby, 1834) from the Egyptian rocky shores of the Mediterranean and Red Seas. *J. Egypt. Acad. Soc. Environ. Develop.*, *14* (1), 1-1

Emara, A. M., Belal, A. A. (2004). Marine fouling in Suez Canal, Egypt. *Egyptian Journal of Aquatic Research*, *30*(1), 198-206.

Engl, W. (1995) Specie prevalentemente Lessepsiane attestate lungo le coste turche. *Bollettino Malacologico 31*(1-4): 43-50.

English, S., Wilkinson, C., & Baker, V. (1997). Survey manual for tropical marine resources.

Farag, E. A., El-Sherief, S. S., Mahmoud, A. D., Abd Ellah, S. M. (1999). A study of rocky shore Molluscs from Alexandria, Egypt. Journal – Egyptain German Society of Zoology, *30*, 1-12.

Finke, G. R., Navarrete, S. A., Bozinovic, F. (2007). Tidal regimes of temperate coasts and their influences on aerial exposure for intertidal organisms. *Marine Ecology Progress Series*, *343*, 57-62

Gaber, H.S., Mohamed, Y.M., EL-Kashif, M.M., AL-Afify, A.D.G. (2017). Assessment of some heavy metals and histological alterations in gills and muscles of *Oreochromis niloticus* from Lake Nasser, Egypt. J. Egypt. Acad. Soc. Environ.Develop., 18 (1):193- 207.

Gonçalves, I., Vinagre, C., Silva, A. (2023). Patterns of rock pool molluscs in differing shore exposures. *Marine Biology, 170*(6), 77.

Gray, J. S. (2000). The measurement of marine species diversity, with an application to the benthic fauna of the Norwegian continental shelf. *Journal of experimental marine biology and ecology*, *250*(1-2), 23-49.

Gutiérrez, J. L., Jones, C. G., Strayer, D. L., Iribarne, O. O. (2003). Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. *Oikos*, *101*(1), 79-90.

Haas, G. (1948). Sur l'immigration de mollusques de l'Indo-Pacifique dans les eaux côtières de la Palestine. *Journal de Conchyliologie*, *88*, 141-144.

Halim, Y. and Rizkalla, S. (2011). Aliens in Egyptian Mediterranean waters. A checklist of Erythrean fish with new records. *Mediterranean Marine Science*, *12*(2), 479-490.

Hamdy, R., Elebiary, N., Naby, F. A., Borghese, J., Dorgham, M., Hamdan, A., Musco, L. (2023). Hard-Bottom Polychaetes Exposed to Multiple Human Pressure along the Mediterranean Coast of Egypt. *Water*, *15*(5), 997.

Hodge, M. B., Adsul, A. D., Indulkar, S. T., Mestry, C. M., Sawant, N. S. (2021). Seasonal variation of molluscs of Varwade rocky shore, Ratnagiri. *Journal of Entomology and Zoology Studies, 9*(1): 358-362

Ibrahim, O., N., Ismail, S., El-Baz, A. (2023). Impact of drainage effluents and wind direction on the copper distribution and balance in Abu-Qir Bay, Alexandria, Egypt. *Egyptian Journal of Aquatic Research*, *49*(2), 213-219.

Jackson, A. C., Chapman, M. G., Underwood, A. J. (2008). Ecological interactions in the provision of habitat by urban development: whelks and engineering by oysters on artificial seawalls. *Austral Ecology*, *33*(3), 307-316.

Long S. M.and Ramli R., (2010). Kekunci siput dan kerang-kerangan perairan pantai Malaysia timur. Penerbit Universiti Malaysia Terengganu, Malaysia.

Magurran, A. E. (2004). Measuring biological diversity Blackwell science. *Biological diversity: frontiers in measurement and assessment. Oxford*, *105*.

Maanan, M. (2008). Heavy metal concentrations in marine mollusks from the Moroccan coastal region. Environ. Pollut., 153:176–183.

Mariappan, S., David Raj, A., Kumar, S., Chatterjee, U. (2023). Global warming impacts on the environment in the last century. In *Ecological footprints of climate change: Adaptive approaches and sustainability* (pp. 63-93). Cham: Springer International Publishing.

Marshall, D. J., Baharuddin, N., McQuaid, C. D. (2013). Behaviour moderate's climate warming vulnerability in high-rocky-shore snails: interactions of habitat use, energy consumption and environmental temperature. *Marine biology*, *160*, 2525-2530.

Masoud, M.S., Elewa, A.A., Ali, A.E. Mohamed, E.A. (2005). Metal distribution in water and sediments of Lake Edku, Egypt. Egypt Sci Manage 1, 13e22.

Mendez, M. M., Román, M., Livore, J. P. (2025). Anthropogenic Threats on Intertidal Rocky Shores. *Volume 2: Marine Ecology: An Ecosystemic View of Anthroogenic Impacts*, 144.

Mienis, H. K., Galili, E., Rapoport, J. (1993). On the presence of the Indo-Pacific bivalve Chama pacifica in the Eastern Mediterranean. *Gloria Maris*, *32*(2), 13-18.

Mohammed-Geba, K., Sheir, S. K., Hamed, E. A. E. A., Galal-Khallaf, A. (2020). Molecular and morphological signatures for extreme environmental adaptability of the invasive mussel *Brachidontes pharaonis* (Fischer, 1870). *Molecular and Cellular Probes*, *53*, 101594.

Moneer, A., Agib, N. S., Khedawy, M. (2023). An overview of the status of Lake Edku environment: status, challenges, and next steps. *Blue Economy*, *1*(1), 3.

Moreno, C. A. and Jaramillo, E. (1983). The role of grazers in the zonation of intertidal macroalgae of the Chilean coast. *Oikos*, 73-76.

Odum E. P. and Barret G. W. (2004). Fundamentals of ecology (5th ed.). Thomson Brooks Cole Publishing, Belmont USA.

Paine, R. T. (1974). Intertidal community structure: experimental studies on the relationship between a dominant competitor and its principal predator. *Oecologia, 15*, 93-120.

Pallary, P. (1912). *Catalogue des mollusques du littoral méditerranéen de d'Égypte.*. (Vol. 3). Institut égyptien.

Pandey, V. and Thiruchitrambalam, G. (2019). Spatial and temporal variability in the vertical distribution of gastropods on the rocky shores along the east coast of South Andaman Island, India. *Marine Biodiversity*, *49*(2), 633-645.

Parker, L. M., Ross, P. M., O'Connor, W. A., Pörtner, H. O., Scanes, E., Wright, J. M. (2013). Predicting the response of molluscs to the impact of ocean acidification. *Biology*, *2*(2), 651-692.

Peng, S.H., Hung, J.H., Hwang, J.S. (2011). Bioaccumulation of trace metals in the submarine hydrothermal vent crab *Xenograpsus testudinatus* of Kueishan Island, Taiwan. Mar. Pollut. Bull.,63(5-12): 396-401.

Poursanidis, D. and Koutsoubas, D. (2015). A computerized database (CorMol) on the molluscan fauna from the Mediterranean reef ecosystems: Part I, the coralligenous formations. *Quaternary International*, *390*, 29-43.

Raffo, M. P., Russo, V. L., Schwindt, E. (2014). Introduced and native species on rocky shore macroalgal assemblages: zonation patterns, composition and diversity. *Aquatic Botany*, *112*, 57-65.

Razek, F. A. A., El-Deeb, R. S., Abdul-Aziz,K., Omar, H. A., Khafage, A. R. (2017). Hermaphroditism in *Brachidontes pharaonis* (Fischer, 1876) (Bivalvia: Mytilidae) from the Alexandria Coast, Egypt. *Egyptian Journal of Aquatic Research*, *43*(3), 265-268.

Razek, F. A., Omar, H. A., El-Deeb, R. S., Abdul-Aziz, K. K. (2020). Morphometric Features of the Shell Population of *Brachidontes pharaonis* (Fischer, 1876) (Bivalvia: Mytilidae) from Alexandria Coast of Egypt. *Asian Journal of Emerging Research (AJER)*,*2* (3),114-123.

Rilov, G. (2016). Multi-species collapses at the warm edge of a warming sea. Scientific reports, 6(1), 36897.

Sabelli, B. and Taviani, M. (2014). The making of the Mediterranean molluscan biodiversity. *The Mediterranean Sea: its history and present challenges*, 285-306.

Samaan, A. A. and Mikhail, S. K. (1990). Distribution of phytoplankton in Abu-Qir Bay (Egypt). Bull. Nat. Inst. Oceanogr. & Fish., AR E, 16(1), 65-73.

Sarà, G., Porporato, E. M., Mangano, M. C., Mieszkowska, N. (2018). Multiple stressors facilitate the spread of a non- indigenous bivalve in the Mediterranean Sea. *Journal of Biogeography*, *45*(5), 1090-1103.

Sarà, G., Romano, C., Mazzola, A. (2006). A new Lessepsian species in the western Mediterranean (*Brachidontes pharaonis* Bivalvia: Mytilidae): density, resource allocation and biomass. *Marine Biodiversity Records*, *1*, e8.

Sbrocca, C., De Troch, M., Losi, V., Grassi, E., Balsamo, M., Semprucci, F. (2021). Habitat-diversity relations between sessile macrobenthos and benthic copepods in the rocky shores of a Marine Protected Area. *Water*, *13*(8), 1020

Schonbeck, M. W. and Norton, T. A. (1980). Factors controlling the lower limits of fucoid algae on the shore. *Journal of Experimental Marine Biology and Ecology*, *43*(2), 131-150.

Scrosati, R. A., van Genne, B., Heaven, C. S., Watt, C. A. (2011). Species richness and diversity in different functional groups across environmental stress gradients: a model for marine rocky shores. *Ecography*, *34*(1), 151-161.

Sghaier, Y. R., Zakhama-Sraieb, R., Hmida, A. B., Charfi, F. (2019). An inventory of non-indigenous species (NIS) inside and outside three tourist marinas from the southern Mediterranean coast. *Journal of the Black Sea/Mediterranean Environment*, *25*(1).

Shannon, C. E. and Weaver, W. (1949). A mathematical model of communication. *Urbana, IL: University of Illinois Press*, *11*, 11-20.

Shreadah, M. A., El Sayed, A., Taha, A., Ahmed, A. M. M., Rahman, H. A. (2019). Evaluation of different anthropogenic effluents impacts on the water quality using principal component analysis: a case study of Abu-Qir Bay-Alexandria-Egypt. *International Journal of Environmental Monitoring and Analysis*, *7*(3), 56-67.

Smith, D. (2013). Ecology of the New Zealand rocky shore community. *New Zealand: New Zealand Marine Studies Centre*.

Sorte, C. J., Bernatchez, G., Mislan, K. A. S., Pandori, L. L., Silbiger, N. J., Wallingford, P. D. (2019). Thermal tolerance limits as indicators of current and future intertidal zonation patterns in a diverse mussel guild. *Marine Biology*, *166*, 1-13.

Steger, J., Bošnjak, M., Belmaker, J., Galil, B. S., Zuschin, M., & Albano, P. G. (2022). Non-indigenous molluscs in the Eastern Mediterranean have distinct traits and cannot replace historic ecosystem functioning. Global Ecology and Biogeography, 31(1), 89-102.

Tan K. S. and Chou L. M., (2000). A guide to common seashells of Singapore. National University of Singapore: Singapore Science Centre, Singapore.

Thiele, J., (1992)." Handbook of systematic Malacology". Amerind Publishing Co. Pvt.Itd.,66 Janpath, New Delhi 110001.

Villéger, S., Miranda, J. R., Hernández, D. F., Mouillot, D. (2010). Contrasting changes in taxonomic vs. functional diversity of tropical fish communities after habitat degradation. *Ecological applications*, *20*(6), 1512-1522.

Weckström, K.and Salovius-Laurén, S. (2023). Diel activity patterns of rocky shore macroinvertebrates in the northern Baltic Sea. *Journal of Sea Research*, *193*, 102376.

Wittmann, A. C. and Pörtner, H. O. (2013). Sensitivities of extant animal taxa to ocean acidification. *Nature Climate Change*, *3*(11), 995-1001.

WoRMS Editorial Board (2024). World Register of Marine Species. Available from https://www.marinespecies.org at VLIZ. Accessed 2024-07-18. doi:10.14284/170

Zenetos, A., Gofas, S., Verlaque, M., Çinar, M. E., García Raso, J. E., Bianchi, C. N., Morri, C., Azzurro E., Bilecenoglu M., Froglia C., Siokou I., Violanti D., Sfriso A., San Martin G., Giangrande A., Katagan T., Ballesteros E., Ramos-Espla A., Mastrototaro F., Ocana O., Zingone A., Gambi M., Streftaris, N. (2010). Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution.

Zenetos, A., Tsiamis, K., Galanidi, M., Carvalho, N., Bartilotti, C., Canning-Clode, J., ... & Outinen, O. (2022). Status and trends in the rate of introduction of marine non-indigenous species in European seas. Diversity, 14(12), 1077.