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Preliminary inventory of marine fouling invertebrates' community in Abu-Qir Port, Alexandria, Egyptian Mediterranean Sea

Ola Mohamed NOUR[1], Mar SANTOS-SIMÓN[2,3], Joachim LANGENECK[4], Agnese MARCHINI[2], Alfonso Ángel RAMOS-ESPLÁ[5,6] , and Jasmine FERRARIO[2]

[1] Department of Biology and Geology, Faculty of Education, Alexandria University, Alexandria 21526, Egypt
[2] Department of Earth and Environmental Sciences, University of Pavia, Via S. Epifanio 14, 27100, Pavia, Italy
[3] CBET Research Group, Centre for Experimental Marine Biology and Biotechnology and Dept. of Zoology and Cell Biology, University of the Basque Country, Bilbao, Basque Country, Spain
[4] Consorzio Nazionale Interuniversitario per le Scienze del Mare, U.LR. di Lecce, c/o DiSTeBA, Campus Ecotekne, Strada Provinciale Lecce-Monteroni, 73100 Lecce, Italy
[5] Department of Marine Science and Applied Biology, University of Alicante, 03690 Alicante, Spain
[6] CIMAR, University of Alicante, 03690 Alicante, Spain

Corresponding author: Ola Mohamed NOUR; onour@alexu.edu.eg

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Abstract

Ports constitute hot spots for the introduction of species transported by maritime shipping and are therefore important sites for biological monitoring. The current study investigated the marine fouling community in Abu-Qir Port, Alexandria, Egypt (south-eastern Mediterranean basin), using a modified rapid assessment technique (~6 h of sampling effort). A total of 95 taxonomic units were collected (84 identified to species level), with Annelida and Crustacea being the most diverse groups, comprising 31.5% and 30.5% of the total number of recorded taxa, respectively. The amphipod *Dulichiella fresnelii* was recorded for the first time as a new non-indigenous species (NIS) in the Mediterranean Sea. Overall, 39 NIS, including one questionable species, were found, comprising approximately 41% of the total biodiversity, of which 10 constitute new records for the Egyptian Mediterranean fauna, including 2 Annelida (Polychaeta: *Oenone fulgida* and *Syllis crassicirrata*), 2 Bryozoa (*Celleporaria brunnea* and *Tricellaria inopinata*), 5 Crustacea (Amphipoda: *Ampithoe bizseli*, *Caprella scaura*, *D. fresnelii*, and *Stenothoe georgiana*; Isopoda: *Paranthura japonica*), and 1 Porifera (*Paraleucilla magna*). Studies on fouling communities in ports are strongly recommended in order to obtain a more comprehensive overview of NIS presence and abundance. Baseline assessments in ports are crucial for assessing the potential impacts of NIS in these environments and for evaluating invasion dynamics.

Keywords: Artificial environments; Non-indigenous species; Marine bioinvasions; Egypt; Levantine basin.

Introduction

The Mediterranean Sea is considered a hot spot for marine biodiversity (Coll *et al*., 2010; Lejeusne *et al*., 2010) and for global bioinvasions, due to its geographical location and semi-enclosed configuration (Bianchi *et al*., 2012; Galil *et al*., 2018; Costello *et al*., 2021). In fact, approximately 1000 marine non-indigenous species (NIS) have been recorded in the basin to date (Zenetos *et al*., 2022), of which more than half are considered established (Zenetos & Galanidi, 2020). Most recorded NIS have an Indo-Pacific origin and are likely to have been introduced via the Suez Canal, either as Lessepsian immigrants or through shipping activities (Galil *et al*., 2014; Tsiamis *et al*., 2018). The introduction of NIS originating in the Atlantic Ocean through the Strait of Gibraltar, associated with various pathways and vectors, is also increasing (Crocetta *et al*., 2013; Canning-Clode & Carlton, 2017).

The Suez Canal is one of the main pathways for NIS introduction into the Mediterranean Sea. Since its opening in 1869, a profound alteration in the ecology and biota of the Mediterranean has been observed, with further impacts on human health and the economy (Galil *et al*., 2015; Tsirintanis *et al*., 2022). In particular, south-eastern Mediterranean countries are considered primary gateways for the introduction of Red Sea and Indo-Pacific species (Katsanevakis *et al*., 2013; Galil *et al*., 2015; Zenetos *et al*., 2017; Galil *et al*., 2018).

Generally, one of the main causes worldwide of NIS transfer and spread is maritime transport (Katsanevakis *et* *al*., 2013; Seebens *et al*., 2013; Bouda *et al*., 2018). The Mediterranean basin is an important gateway for commercial and leisure maritime activities, featuring numerous ports where NIS can easily settle and establish (Ulman *et al*., 2019a; Tempesti *et al*., 2020a; Zenetos *et al*., 2022). Therefore, commercial ports and marinas are considered crucial stepping-stone sites for NIS, which can be transported by two main vectors: ballast waters and biofouling (Callow & Callow, 2002; Galil *et al*., 2014; Gollasch *et al*., 2015). The submerged artificial surfaces within ports and marinas, such as floating pontoons, docks, pilings, sea walls, buoys, ropes, and skates, provide suitable hard substrata for many marine sessile and mobile species (Molnar *et al*., 2008; Bulleri & Chapman, 2010; Tanasovici *et al*., 2025). The immersed hard surfaces of ports, usually located in sheltered areas and protected from seabed predators, can support a rich biofouling community, which appears to favour NIS settlement (Glasby *et al*., 2007; Airoldi *et al*., 2015; Megina *et al*., 2016). Despite the sheltered conditions of ports, their physicochemical properties are often unfavourable for species establishment due to several stressors (e.g., chemical, thermal, and light pollution; physical disturbance from boats; and organic enrichment). However, many opportunistic species, such as NIS, can adapt to stressful conditions, showing broader physiological tolerance compared with native species (Lejeusne *et al*., 2014; Tsirintanis *et al*., 2022).

In general, the introduction of NIS represents a major threat to natural ecosystems, biodiversity, and the sustainability of natural resource exploitation (Katsanevakis *et al*., 2014; Howard *et al*., 2019; Tsirintanis *et al*., 2022). Although the issue of bioinvasion is well-known, the impacts of marine NIS remain poorly documented, and further efforts should be promoted to address this knowledge gap (Parker *et al*., 1999; Anton *et al*., 2019; Bédry *et al*., 2021). Examples of NIS impacts include reductions in native seaweed populations caused by epibiotic growth (O'Brien *et al*., 2013), indirect effects from parasite spillover (Goedknegt *et al*., 2018), and declines in native species recruitment due to competition with newly arrived species (Geburzi *et al*., 2018). Accordingly, NIS can cause habitat modification, changes in community structure, and alterations of food webs, jeopardize human health, and ultimately result in substantial economic losses (Katsanevakis *et al*., 2014; Galil *et al*., 2017; Tsirintanis *et al.*, 2022).

Therefore, early detection and monitoring of NIS in high-risk areas of introduction are crucial to avoid their establishment and further dispersal (Lehtiniemi *et al*., 2015; Ferrario *et al*., 2017; Bouda *et al*., 2018). Monitoring of NIS in port localities is uneven across different areas of the Mediterranean Sea, as most surveys are restricted to the north-western and north-eastern regions (Ulman *et al*., 2017; Ulman *et al*., 2019b; Tempesti *et al*., 2020a, b; 2022a), with only a few studies conducted in the southern part (e.g., Abdelsalam & Abdel Wahab, 2012; Chebaane *et al*., 2019; Bensari *et al*., 2020; Khater *et al*., 2023; Bensari *et al*., 2025). Acknowledging the need to evaluate and make readily accessible the existing knowledge on the biodiversity status of Egyptian Mediterranean ports, the present paper aims to provide an inventory of the macroinvertebrate fouling community in Abu-Qir Port. This important port, located along the Mediterranean coast of Alexandria, was studied almost 15 years ago (Abdelsalam & Abdel Wahab, 2012). The current study provides updated insights into the fouling communities in this port, located near the entrance to the Suez Canal, with particular emphasis on the presence of NIS and the establishment of a baseline dataset. Such baseline biodiversity studies can serve as benchmarks for monitoring changes, especially in data-poor areas. Assessing ecological patterns will improve understanding of the effects of local anthropogenic pressures on marine communities.

Materials and Methods

Study area

The survey was carried out in the Port of Abu-Qir (30.0755º E; 31.3225° N), located in the south-eastern Mediterranean along the Alexandria coast, Egypt, approximately 265 km from the northern opening of the Suez Canal (Fig. 1). The port is situated within Abu-Qir Bay and is mainly dedicated to commercial (small general cargo and bulk carriers) and naval vessels. The 500 km² semi-circular bay has an average depth of 12 m (Nessim & El-Deek, 1993) and is influenced by multiple anthropogenic discharges, including agricultural drainage from Lake Edku via the Boughaz El-Maadia connection (Mohamed & El-Maradny, 2001). Additional sources of anthropogenic pollution in the bay include the El-Tabia pumping station, which discharges wastewater containing organic and inorganic contaminants from various factories (Abdel Ghani *et al*., 2013; Ibrahim *et al*., 2023); sewage from El-Behera Province; and industrial effluents from various plants. Moreover, the Rosetta branch of the Nile flows into the north-eastern margin of the bay (Said *et al*., 1995).

Sample collection and examination

The survey was carried out on September 3, 2022. A rapid assessment survey (RAS) was adopted to monitor the investigated port, following the methodology proposed by Campbell *et al*. (2007) and Ulman *et al*. (2017). The survey provided qualitative data within a time-restricted visual search (i.e., all species recorded within approximately 6 h) at the selected site, using haphazard search patterns determined by site access (Pederson *et al*., 2005; Campbell *et al*., 2007). Similarly to the approach used by Ulman *et al.* (2017), not only target or large-sized species were recorded, but also unknown or small individuals were collected, preserved, and carefully analysed in the laboratory to ensure the collection of all macrozoobenthic taxa. The survey targeted both sessile and mobile fouling macroinvertebrates, but macroalgae were not assessed.

Fouling biota were collected from all accessible hard

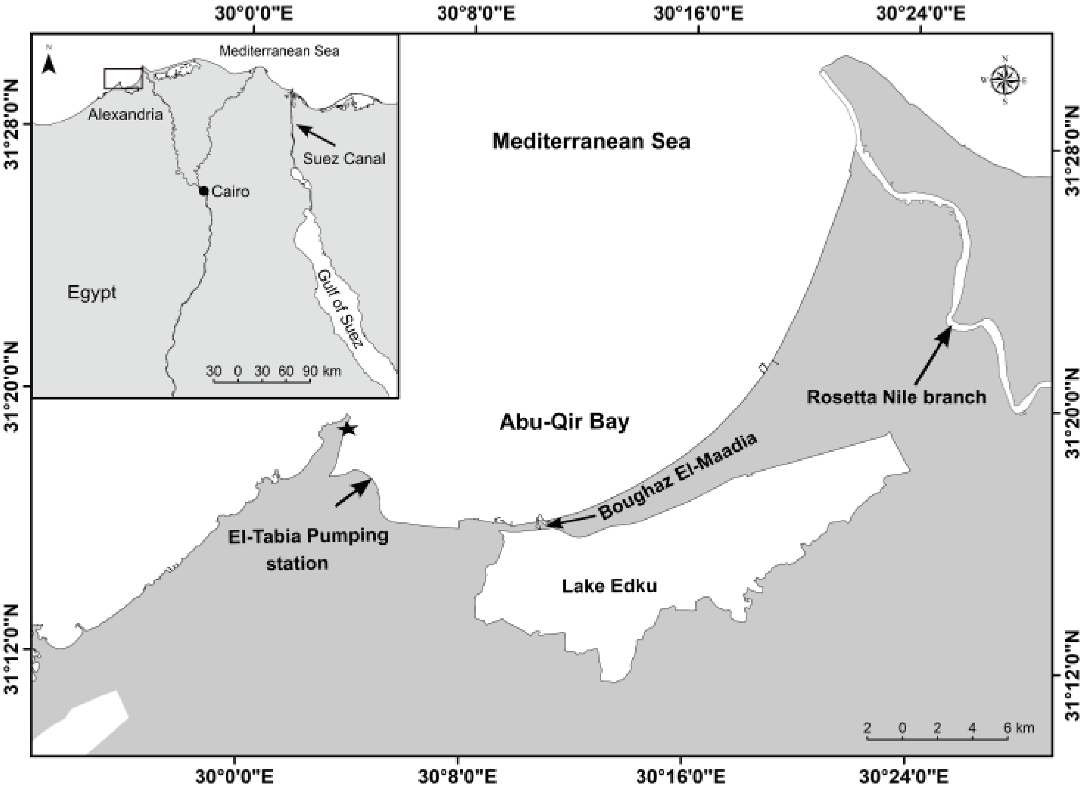

Fig. 1: Geographic location of the study area. Map of Abu-Qir Bay indicating the sampling site at Abu-Qir Port (black star). The inset (upper left) shows the position of Abu-Qir Bay (black square) along the Mediterranean coast of Alexandria, Egypt.

artificial substrates observed inside the port (e.g., buoys, piers, tiers, ladders, pontoons, pilings, seawalls, and ropes that could be pulled out of the water), reachable from the dock or port promenade without immersion of the operator, up to a maximum depth of approximately 1 m, using a 4-inch paint scraper and a 1 mm mesh aquatic net. For some large-sized specimens (e.g., ascidians or molluscs), it was possible to discriminate among species in the field, collecting only a few specimens per species or, in some cases, identifying them directly in situ. Conversely, for small invertebrates (e.g., peracarids, polychaetes), random samples of fouling material were collected, preserved in plastic bags containing 75% ethanol, and transferred to the laboratory for identification. In the laboratory, a 1 mm mesh sieve was used to clean the samples. Individuals were sorted into distinct taxonomic groups and subsequently identified to the lowest possible taxonomic level using a dissecting microscope. When necessary, microscope slides were prepared and examined under light microscopy to enable detailed observation of minute diagnostic features.

The biogeographic status of each species was assessed according to the criteria of Carlton & Schwindt (2024), distinguishing native species from NIS. Species with an uncertain native origin were defined as cryptogenic species, in accordance with Carlton (1996), whereas NIS exhibiting morphological, ecological, and/or genetic discrepancies relative to topotypic individuals were defined as questionable species (Tsiamis *et al*., 2018).

Results

A total of 95 taxonomic units of fouling invertebrates were collected in the Port of Abu-Qir (Table 1), of which 84 were identified to the species level and were represented by 10 phyla. The total fouling community includes Annelida (30 species: 2 Sipuncula and 28 Polychaeta) and Crustacea (29 species: 12 Amphipoda, 5 Cirripedia, 4 Decapoda, 6 Isopoda, and 2 Tanaidacea), constituting approximately 31.5% and 30.5% of the total fouling assemblage, respectively, followed by Bryozoa (14 species, 15%) and Tunicata (Ascidiacea; 10 species; 10.5%). The remaining groups, each contributing total abundances ranging from approximately 1% to 4%, comprised 4 Mollusca, 3 Cnidaria (2 Hydrozoa and 1 Anthozoa), 2 Porifera, 1 Platyhelminthes, 1 Nemertea, and 1 Echinodermata.

Approximately 50% of the total biodiversity in Abu-Qir Port is represented by native and cryptogenic species, whereas 39 NIS, including one questionable polychaete, were recorded, comprising 41% of the total biodiversity. The remaining 9% of the collected taxa were not identified to the species level; therefore, their biogeographic status remains undetermined. Ten previously unreported NIS are recorded here for the first time from Egyptian Mediterranean waters, with one additional species having been recently reported (namely *Laticorophium baconi*; Guerra-García *et al*., 2023) (Table 1). Moreover, the native crustacean *Orchomene grimaldii* and the cryptogenic crustacean *Hexapleomera bultidactyla* represent new additions to the Egyptian Mediterranean fauna. Information on NIS and questionable taxa recorded in the current

Table 1. Marine fouling taxa recorded in Abu-Qir Port, Alexandria, Egypt, in 2022. For non-indigenous, cryptogenic, and questionable species, the country and year of the first Mediterranean record are provided, together with the corresponding references. The location and year of the first record in Egypt are also indicated for these species. Black squares (■) denote the year of publication when the exact year of record was unavailable. New records for Egypt are highlighted in bold, irrespective of biogeographic status. Abbreviations: NAT, native species; CRY, cryptogenic species; NIS, non-indigenous species; Q, questionable species.

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Porifera	Amphoriscidae	***Paraleucilla magna*** Klautau, Monteiro & Borojevic, 2004	NIS	Spain, 2000 (Frotscher & Uriz, 2008; Galanidi *et al*., 2025)	Alexandria, 2022 (This work)
		Sycon sp.	----		
Cnidaria		Actiniidae Ind.	----		
		Hydrozoa Ind.	----		
Platyhelminthes (Polycladida)	Hoploplanidae	*Hoploplana* sp.	----		
Nemertea (Palaeonemertea)	Tubulanidae	*Tubulanus nothus* (Bürger, 1892)	NAT		
Annelida (Sipuncula)	Golfingiidae	*Nephasoma rimicola* (Gibbs, 1973)	NAT		
	Phascolosomatidae	*Phascolosoma agassizii* Keferstein, 1866	NAT		
Annelida (Polychaeta)	Amphinomidae	*Eurythoe complanata* (Pallas, 1766)	CRY	Alexandria, Egypt, 1933 (Fauvel, 1937)	Alexandria, 1933 (Fauvel, 1937)
		Linopherus canariensis Langerhans, 1881	NIS	■Beirut, Lebanon, 1965 (Laubier, 1966, as *L. acarunculata*)	Alexandria, 2005 (Dorgham *et al*., 2014)
	Dorvilleidae	*Dorvillea similis* (Crossland, 1924)	NIS	Tyre, Lebanon, 2002 (Toso *et al*., 2024)	Alexandria, 2018-2019 (Hamdy *et al*., 2023)
	Eunicidae	*Leodice antennata* Savigny in Lamarck, 1818	NIS	Antalya Bay, Türkiye, 1993 (Ergen & Çinar, 1997, as *Eunice* sp., *fide* Kurt Şahin & Çinar, 2009)	Alexandria, 1999-2001 (Abd-Elnaby, 2005, as *Eunice antennata*)
	Hesionidae	*Oxydromus pallidus* Claparède, 1864	NAT		

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Annelida (Polychaeta)	Nereididae	*Ceratonereis costae* (Grube, 1840)	NAT		
		Nereis splendida Grube, 1840	NAT		
		Perinereis cultrifera (Grube, 1840)	NAT		
		Platynereis cf. *dumerilii* (Audouin & Milne Edwards, 1833)	NAT		
		Pseudonereis anomala Gravier, 1899	NIS	Alexandria, Egypt, 1933 (Fauvel, 1937)	Alexandria, 1933 (Fauvel, 1937)
	Oenonidae	***Oenone fulgida*** (Savigny in Lamarck, 1818)	NIS	Tyrrhenian Sea, Italy, 1987 (Cantone, 1996, as *Oenone* sp., see Langeneck *et al.*, 2020)	Alexandria, 2022 (This work)
	Opheliidae	*Polyophthalmus pictus* (Dujardin, 1839)	NAT		
	Serpulidae	*Hydroides dianthus* (Verrill, 1873)	NAT		
		Hydroides dirampha Mörch, 1863	NIS	Gulf of Naples, Italy, 1866 (Claparède, 1870, as *Eupomatus lunifer*)	Alexandria, 1924 (Potts, 1928 *in* Zibrowius, 1970)
		Hydroides elegans (Haswell, 1883)	NIS	Gulf of Naples, Italy, before 1840 (Philippi, 1844, as *Eupomatus pectinatus*)	■Alexandria,1973-1974 (Ghobashy, 1976, as *H. norvegica*)
		Hydroides operculata (Treadwell, 1929)	NIS	Shavei Zion, Israel, 1972 (Ben-Eliahu, 1976 as *Hydroides* cf. *dianthus*, *fide* Ben-Eliahu, 1995; Ben-Eliahu, 1975)	Alexandria, 2021 (Abdelsalam & Elebiary, 2023)
		Serpula concharum Langerhans, 1880	NAT		
		Spirobranchus cf. *kraussii* (Baird, 1865)	NIS	Israel, 1958 (Ben-Eliahu, 1991)	■Port Said, 1987 (Heaba,1987)
		Spirobranchus lamarcki (Quatrefages, 1866)	NAT		
		Spirobranchus arabicus Monro, 1937	NIS	Beirut, Lebanon, 1965 (Laubier, 1966, as *S. giganteus coutierei*)	■ Port Said, at the most northern part of the Suez Canal, 1972 (Ben Eliahu, 1972; Ghobashy & Selim, 1976)

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Annelida (Polychaeta)	Syllidae	*Branchiosyllis exilis* (Gravier, 1900)	Q	Israel,1937 (Monro, 1937)	Alexandria, 2005 (Abd-Elnaby, 2005)
		Exogone dispar (Webster, 1879)	NAT		
		Sphaerosyllis austriaca Banse, 1959	NAT		
		Syllis ergeni Çinar, 2005	NIS	Izmir Bay, Türkiye, 2004 (Çinar, 2005)	El Alamein, Matrouh, 2008-2009 (Abd-Elnaby & San Martín, 2011)
		Syllis kabilica Ben-Eliahu, 1977	NAT		
		Syllis crassicirrata (Treadwell, 1925)	NIS	Beirut, Lebanon, 2002 (Toso *et al*., 2024)	Alexandria, 2022 (This work)
	Terebellidae	*Nicolea venustula* (Montagu, 1819)	NAT		
		Terebellidae n.i.	----		
Mollusca (Bivalvia)	Isognomonidae	*Isognomon* sp.	----		
	Mytilidae	*Brachidontes pharaonis* (Fischer, 1870)	NIS	Port Said, Egypt, 1876 (Fuchs, 1878)	Port Said, 1876 (Fuchs, 1878)
		Mytilus galloprovincialis Lamarck, 1819	NAT		
		Mytilaster solidus Monterosato, 1883	NAT		
Crustacea (Amphipoda)	Ampithoidae	***Ampithoe bizseli*** Özaydinli & Coleman, 2012	NIS	Aegen Sea, Türkiye, 2010 (Özaydinli & Coleman, 2012)	Alexandria, 2022 (This work)
	Aoridae	*Bemlos leptocheirus* (Walker, 1909)	NIS	Port Said, Egypt, 1924 (Schellenberg, 1928)	Port Said, 1924 (Schellenberg, 1928)
		Quadrimaera inaequipes (A. Costa in Hope, 1851)	NAT		
	Caprellidae	*Caprella equilibra* Say, 1818	CRY	■Gulf of Naples, Italy, 1882 (Mayer, 1882)	Port Said, 1924 (Schellenberg, 1928)
		Caprella scaura Templeton, 1836	NIS	Taranto, Italy, 1989 (Scipione, 2015)	Alexandria, 2022 (This work)

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Crustacea (Amphipoda)	Corophiidae	*Apocorophium acutum* (Chevreux, 1908)	CRY	■Annaba, Algeria, 1908 (Chevreux, 1908, as *Corophium acutum*)	Alexandria, 1933 (Schellenberg, 1936)
		*Laticorophium bacon*i (Shoemaker, 1934)	NIS	Marina of La Línea, Cádiz and Guardamar del Segura, Alicante, Spain, 2010; La Spezia and Olbia, Italy, 2010 (Guerra-García *et al*., 2023)	Alexandria, 2022 (This work ; record previously published in Guerra-García *et a*l., 2023)
	Ischyroceridae	*Ericthonius brasiliensis* (Dana, 1853)	CRY	■Gulf of Naples, Italy, 1893 (Della Valle, 1893)	Alexandria, 1933 (Schellenberg, 1936)
	Melitidae	***Dulichiella fresnelii*** (Audouin, 1826)	NIS	Alexandria, Egypt, 2022 (This work)	Alexandria, 2022 (This work)
	Podoceridae	*Podocerus* cf. *brasiliensis* (Dana, 1853)	CRY	■Gulf of Naples, Italy, 1893 (Della Valle, 1893)	Port Said, 1924 (Schellenberg, 1928)
	Stenothoidae	***Stenothoe georgian***a Bynum & Fox, 1977	NIS	Alicante and Murcia, Spain, 2010 (Fernandez-Gonzalez & Sanchez-Jerez, 2017)	Alexandria, 2022 (This work)
	Tryphosidae	***Orchomene grimaldii*** Chevreux, 1890	NAT		
Crustacea (Cirripeda)	Balanidae	*Amphibalanus amphitrite* (Darwin, 1854)	CRY	Gulf of Naples, Italy,1871 (*in* Innocenti, 2006, as *Balanus amphitrite communis*)	Alexandria, 1933 (Broch, 1935)
		Amphibalanus eburneus (Gould, 1841)	NIS	Italy, 1818 (Chiereghin, 1818; confirmed by Rigo, 1942)	Alexandria, 1958 (Banoub, 1960)
		Amphibalanus improvisus (Darwin, 1854)	CRY	Egypt, 1933 (Broch, 1935, as *Balanus improvisus*)	Lake Edku and Alexandria,1933 (Broch, 1935)
		Balanus trigonus Darwin, 1854	NIS	Gulf of Catania, Italy, 1927 (Patanè, 1927)	Alexandria, 1933 (Broch, 1935)
		Perforatus perforatus (Bruguière, 1789)	NAT		
Crustacea (Decapoda)	Carcinidae	*Portumnus latipes* (Pennant, 1777)	NAT		
	Grapsidae	*Pachygrapsus marmoratus* (Fabricius, 1787)	NAT		

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Crustacea (Decapoda)	Pilumnidae	*Pilumnus hirtellus* (Linnaeus, 1761)	NAT		
	Porcellanidae	*Porcellana platycheles* (Pennant, 1777)	NAT		
Crustacea (Isopoda)	Anthuridae	*Mesanthura romulea* Poore & Lew Ton, 1986	NIS	Salerno Harbour, Italy, 2000 (Lorenti *et al*., 2009)	Alexandria, 2021 (Abdelsalam & Elebiary, 2023)
	Joeropsididae	*Joeropsis dollfusi* Norman, 1899	NAT		
	Paranthuridae	***Paranthura japonica*** Richardson, 1909	NIS	Chioggia, Italy, 2005 (Marchini *et al*., 2014)	Alexandria, 2022 (This work)
	Sphaeromatidae	*Dynamene sp.*	----		
		Paracerceis sculpta (Holmes, 1904)	NIS	■Lake of Tunis, Tunisia, 1978 (Rezig, 1978)	Port Said, 1983-1984 (Ramadan, 1986)
		Sphaeroma walkeri Stebbing 1905	NIS	Port Said, Egypt, 1924 (Omer-Cooper, 1927)	Port Said, 1924 (Omer-Cooper, 1927)
Crustacea (Tanaidacea)	Leptocheliidae	*Chondrochelia savignyi* (Krøyer, 1842)	CRY	■Beirut, Lebanon,1931 (Monod, 1931, as *Leptochelia* sp.)	Alexandria, 1933 (Larwood, 1940)
	Tanaididae	***Hexapleomera bultidactyla*** Esquete & Fernandez-Gonzalez, 2016	CRY	Alicante, Spain, 2010 (Esquete & Fernandez-Gonzalez, 2016)	Alexandria, 2022 (This work)
Bryozoa	Bugulidae	*Bugula neritina* (Linnaeus, 1758)	CRY	■Venice, Italy, 1792 (Olivi,1792, as *Sertularia neritina*)	■Alexandria, 1939 (O'Donoghue & Watteville, 1939) ■In addition, the earlier report by Audouin (1826a), as *Acamarchis* sp., may indicate this species
	Candidae	*Cradoscrupocellaria bertholleti* (Audouin, 1826)	NAT		
		Cradoscrupocellaria reptans (Linnaeus, 1758)	NAT		
		Tricellaria inopinata d'Hondt & Occhipinti-Ambrogi, 1985	NIS	Lagoon of Venice, Italy, 1982 (d'Hondt & Occhipinti- Ambrogi, 1985)	Alexandria, 2022 (This work)
	Celleporidae	*Turbicellepora magnicostata* (Barroso, 1919)	NAT		

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Bryozoa	Crisiidae	*Crisia* sp.	-----		
	Electridae	*Conopeum reticulum* (Linnaeus, 1767)	CRY	■France, 1966 (Prenant & Bobin, 1966, as *Millepora reticulum*)	Alexandria, 1998-1999 (Abdelsalam & Ramadan, 2008a)
	Lanceoporidae	*Calyptotheca alexandriensis* Abdelsalam, Taylor & Dorgham 2017	NIS	Alexandria, Egypt, 2015 (Abdelsalam *et al*., 2017)	Alexandria, 2015 (Abdelsalam *et al*., 2017)
	Lepraliellidae	***Celleporaria brunnea*** (Hincks, 1884)	NIS	Lebanon, 2003 (Harmelin, 2014; Galanidi *et al.,* 2025)	Alexandria, 2022 (This work)
	Microporellidae	*Microporella* sp.	----		
	Vesiculariidae	*Amathia verticillata* (Delle Chiaje, 1822)	CRY	Gulf of Naples, Italy, 1822 (Delle Chiaje, 1822, as *Hydra verticillata*)	Alexandria,1820/1823 (Ehrenberg, 1828)
	Savignyellidae	*Savignyella lafontii* (Audouin,1826)	CRY	■Unknown locality (Audouin, 1826a, as *Eucratea lafontii*)	Certain record: Alexandria, 2022 (This work)
	Schizoporellidae	*Schizoporella errata* (Waters, 1878)	NAT		
	Watersiporidae	*Watersipora subtorquata* (d'Orbigny, 1852)	CRY	■Aegean Sea, 1854 (Busk, 1854, as *Lepralia cucullata*)	Alexandria, 1998-1999 (Abdelsalam & Ramadan, 2008a)
Echinodermata	Ophiactidae	*Ophiactis savignyi* (Müller & Troschel, 1842)	NIS	Port Said, Egypt, 1924 (Mortensen, 1926)	Port Said, Egypt, 1924 (Mortensen, 1926)
Tunicata (Ascidiacea)	Ascidiidae	*Ascidia cannelata* Oken, 1820	NIS	Israel, 1955 (Pérès, 1958)	Port Said, 1994 (Abdel Messeih, 1994)
	Cionidae	*Ciona robusta* Hoshino & Tokioka, 1967	NIS	Mediterranean, 1816 (Savigny, 1816, as *Phallusia intestinalis*)	Mediterranean, 1816 (Savigny, 1816, as *Phallusia intestinalis*)
	Didemnidae	*Didemnum perlucidum* F. Monniot, 1983	NIS	Antalya, Türkiye, 2018 (Karahan *et al*., 2023; Galanidi *et al*., 2025)	Port Fouad, 2023 (Elgendy *et al*., 2025). Backdated from Alexandria, 2022 (This work)

Continued

Table 1 continued

Phylum (Class)	Family	Recorded taxa	Status	First record in the Mediterranean Sea: Place/Year (authors)	First record in Egypt: Place/Year (authors)
Tunicata (Ascidiacea)	Polyclinidae	*Polyclinum constellatum* Savigny, 1816	NIS	Port Said, Egypt, 1994 (Abdel Messeih, 1994)	Port Said, 1994 (Abdel Messeih, 1994)
	Pyuridae	*Herdmania momus* (Savigny, 1816)	NIS	Alexandria, Egypt, 1939 (Harant, 1939, as *Pyura momus*)	Alexandria, 1939 (Harant, 1939, as *Pyura momus*)
		Microcosmus exasperatus Heller, 1878	NIS	Lebanon, 1991 (Bitar & Bitar-Kouli, 1995)	Port Fouad, 2023 (Elgendy *et al*., 2025). Backdated from Alexandria, 2022 (This work)
	Styelidae	*Botryllus schlosseri* (Pallas, 1766)	CRY	Adriatic Sea, Italy 1816 (Savigny, 1816, as *Botryllus polycyclus*)	Alexandria, 1939 (Harant, 1939)
		Styela canopus Savigny, 1816	CRY	Naples, Italy, 1828 (Delle Chiaje, 1828, as *Ascidia rustica*)	Alexandria, 1939 (Harant, 1939, as *S. partita*)
		Styela plicata (Lesueur, 1823)	NIS	Naples, Italy, 1877 (Heller, 1877, as *Styela gyrosa*)	Alexandria, 1927 (Harant, 1939)
		Symplegma sp.	NIS		

study is provided as Supplementary Material.

Furthermore, the amphipod *Dulichiella fresnelii* was recorded for the first time in the Mediterranean basin (Supplementary Material). The morphological features of the examined specimens show the key diagnostic characters of the species as described by Lowry & Springthorpe (2007), namely: the pattern of dorsolateral spines on the pleosomites and urosomites (Fig. 2A); the characteristic, well-developed four spines on the propodus of male gnathopod 2 (Fig. 2B); as well as the straight posterior margin of the pereopod six basis and its accessory spine on the anterior margin of the dactylus unguis (Fig. 2C, D).

Discussion

In marine ecosystems, systematic monitoring of high-risk introduction hubs, particularly commercial ports and harbours, is strongly recommended to facilitate early detection of NIS and emerging bioinvasions (Lehtiniemi *et al*., 2015; Ferrario *et al*., 2017; Tamburini *et al*., 2021). In this context, the present work provides a preliminary assessment of the current biofouling invertebrate community of Abu-Qir Port (Alexandria, south-eastern Mediterranean Sea) through a RAS.

Annelida and Crustacea represented the most abundant taxa in the current study, followed by Bryozoa and Tunicata. The order of taxonomic abundance is consistent with previous studies from the same region (Abdelsalam & Abdel Wahab, 2012). Indeed, earlier investigations have shown that Annelida, Crustacea, and Bryozoa were the dominant taxa in marine fouling communities in Egyptian Mediterranean commercial ports and marinas [e.g., Eastern Harbour of Alexandria (Ramadan *et al*., 2006a; Khater *et al*., 2023); Marina El-Alamein Resort (Abdelsalam & Abd Elnaby, 2021)]. Studies from other Mediterranean ports have reported Crustacea as the most diverse group, followed by Annelida and Mollusca [e.g., Ancona and Bari ports (Italy; Spagnolo *et al*., 2019); Leghorn Port (Italy; Tempesti *et al*., 2023)], whereas Annelida and Mollusca were more abundant in several other ports [e.g., İskenderun Harbour (Türkiye; Sen *et al.,* 2010); Pula Port (Croatia), Bar Port (Montenegro), and Koper Port (Slovenia; Spagnolo *et al*., 2019)].

The present study recorded more than twice the 44 taxa reported by Abdelsalam & Abdel Wahab (2012) from Abu-Qir Port during the 2006–2007 survey. In particular, the previous survey conducted in the investigated port used two sets of 24 polystyrene panels (12.5 × 12.5 cm), oriented horizontally or vertically, and suspended at depths ranging from 0.5 to 5 m (Abdelsalam & Abdel Wahab, 2012). In addition, Khater *et al*. (2023) recently reported 37 invertebrate taxa comprising the marine fouling community of the Alexandria Eastern Harbour (approximately 23 km west of the investigated study area) through a one-year study (2019–2020), deploying six roughened wooden settlement panels (15 × 20 cm) at depths of 0.5 and 1.5 m. From Marina El-Alamein Resort (approximately 120 km west of the study area), 61 marine fouling taxa were collected in 2017 by scraping

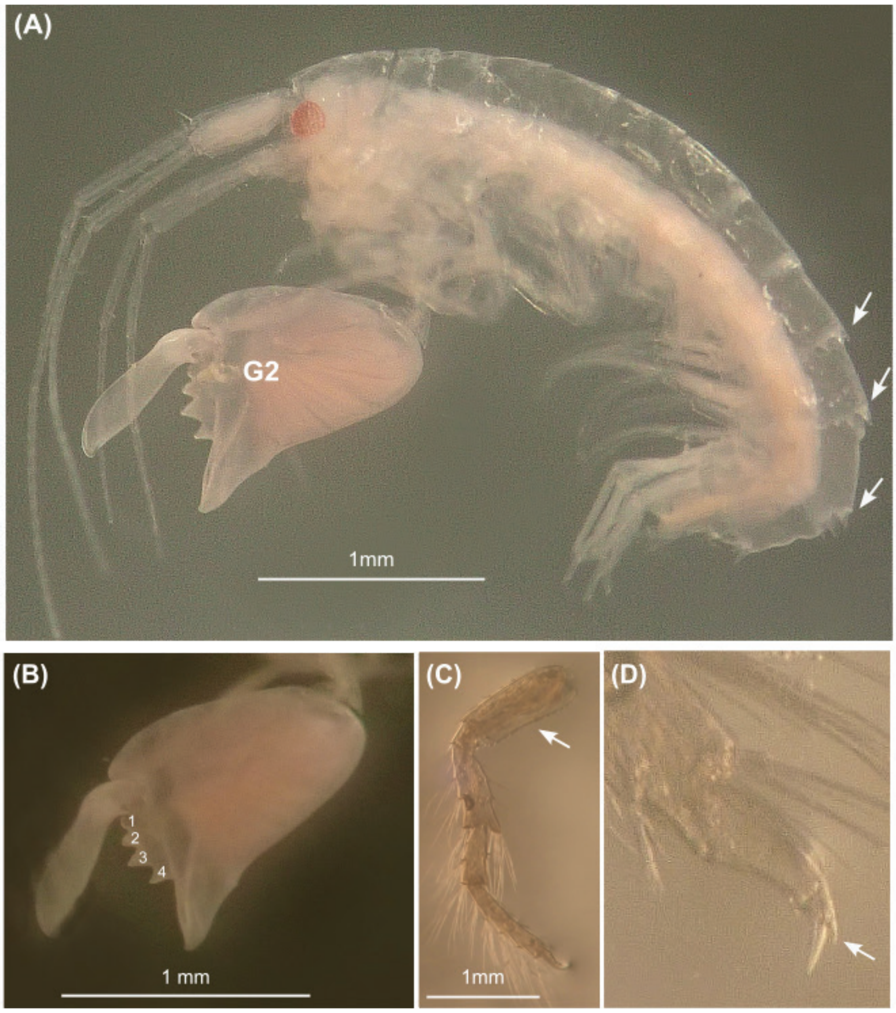

Fig. 2: *Dulichiella fresnelii* from Abu-Qir Port, Alexandria, Egypt. (A) Entire male specimen showing the enlarged gnathopod 2 (G2); arrows indicate pleonites 1–3 bearing sparse dorsal setae. (B) Detail of the propodus of gnathopod 2, illustrating the distolateral crown with four spines. (C) Pereopod 6; arrow indicates the straight posterior margin of the basis. (D) Detail of the anterior margin of the dactylus unguis of pereopod 6, showing a single accessory spine (arrow). Photo credit: Ola Mohamed Nour.

submerged artificial substrata (concrete blocks) within a rectangular frame (40 × 25 cm), using three locations as replicates (Abdelsalam & Abd Elnaby, 2021). Therefore, the current work reports the highest taxonomic diversity among Mediterranean Egyptian fouling community studies.

Various environmental and anthropogenic factors (e.g., substratum type, water flow, sea surface temperature, and pollution level) influence the recruitment and settlement of marine benthic invertebrates in ports (Gestoso *et al*., 2017; Abdelsalam & Abd Elnaby, 2021; Ramalhosa *et al*., 2021; Tamburini *et al*., 2022a, b). Seasonality strongly affects the composition of fouling communities in temperate seas (Dziubińska & Janas, 2007; Fortič *et al*., 2021), as these communities largely depend on the spawning, recruitment, settlement, and growth of fouling organisms (Lehaitre *et al*., 2008; Hellio & Yebra, 2009). Typically, the collection of fouling material is strongly recommended during the summer season to investigate communities during their period of maximum growth and peak recruitment (Marraffini *et al*., 2017; Lord, 2017; Ulman *et al*., 2019a; Bae *et al*., 2023). Accordingly, recruitment and growth earlier in the summer season may explain the abundance of different taxa observed in the fouling community of Abu-Qir Port, as also reported in previous studies from the same area (Ramadan *et al*., 2006b; Abdelsalam & Abdel Wahab, 2012). Similarly, Khater *et al*. (2023) recorded higher biomass of fouling organisms during summer (average seawater temperature of 30° C) compared with winter (16° C) in the Eastern Harbour of Alexandria. The present survey was conducted in late summer, with seawater temperature approximately 32° C on the sampling day; however, based on the collected data, it was not possible to assess seasonal differences in species richness or abundance.

The higher number of taxa observed in this study compared with previous investigations may also be attributed to different sampling techniques employed, interannual variability in the structure of fouling communities (e.g., Tamburini *et al*., 2021), and possibly to the taxonomic identification approach adopted for fouling organisms. The detection of biofouling species can be particularly challenging due to the high diversity of taxonomic groups that compose these communities, each presenting specific difficulties for species-level identification, especially among small-sized phyla. The scattered spatial distribution of NIS records is often related to the ongoing decline in expert taxonomists and their uneven geographical distribution (Ojaveer *et al*., 2014). To address the taxonomic challenges posed by such a highly diverse community, the present study adopted an approach involving an international network of experts, which has previously proven effective for the detection of new or poorly known NIS (Ulman *et al*., 2017; Martínez-Laiz *et al*., 2020; Guerra-García *et al*., 2023).

Therefore, collaboration among taxonomists enables the compilation of a more comprehensive species inventory; however, further seasonal and interannual investigations are strongly recommended to assess variability and changes in the structure of fouling communities, as well as to clarify the role of water temperature in structuring fouling assemblages in Abu-Qir Port.

The introduction of marine NIS and their subsequent spread are facilitated by the availability of free substrata in ports and by the distinct features (e.g., material and orientation) provided by artificial structures (Glasby & Connell, 2001; Mineur *et al*., 2012). The fouling community of Abu-Qir Port was collected from artificial substrates, where 39 NIS were recorded, representing approximately 41% of the total species richness. Many of the NIS reported herein are likely to have been introduced through multiple transport mechanisms, with evidence indicating that shipping is a major vector accelerating and facilitating their spread, particularly for species with short, lecithotrophic larval stages, such as *Caprella scaura* and *Celleporaria brunnea*, which are unable to disperse naturally over long distances (Ulman *et al*., 2017).

The present study identified 10 previously unreported NIS new to the Egyptian Mediterranean waters, with the record of *L. baconi* already published in an earlier review of the species (Guerra-García *et al*., 2023). Furthermore, the native amphipod *Orchomene grimaldii* and the cryptogenic tanaid *H. bultidactyla* represent new records for the Egyptian fauna. These findings highlight the still-inadequate knowledge of Egypt's marine fauna and reveal the lack of focused studies and taxonomic expertise, which have likely hindered proper identification and timely detection of new arrivals (Ricciardi *et al*., 2021). Therefore, many of the "first records" documented in the present work may have reached Egyptian waters much earlier than the year of discovery reported here. For example, the polychaete *Oenone fulgida* has been known as an NIS in the Mediterranean Sea since the second half of the 20th century and is likely to have been introduced via the Suez Canal. However, it is recorded here for the first time along the Egyptian Mediterranean coast, similarly to another non-indigenous polychaete, *Syllis crassicirrata*. Nevertheless, the latter species has only recently been reported from the Mediterranean coast (Greece: Chatzigeorgiou *et al*., 2022; Lebanon: Toso *et al*., 2024), although evidence from specimens housed at the Senckenberg Natural History Museum suggests that it may have arrived more than twenty years ago. The late detection of *O. fulgida* and *S. crassicirrata* is likely attributable to the lack of monitoring and taxonomic studies in the south-eastern Mediterranean Sea (Toso *et al*., 2024).

Our results indicate that peracarids, including four Amphipoda and one Isopoda, account for approximately half of the total new NIS recorded (Table 1). Unlike in the present study, these taxa may have been overlooked in previous surveys due to their small size, as NIS monitoring through RAS and citizen-science initiatives typically targets larger and more conspicuous organisms (Zenetos *et al*., 2013; Mannino *et al*., 2017). Furthermore, amphipods constitute a major component of the mobile fauna colonising erect or bushy substrates, such as bryozoans, hydrozoans, or macroalgae (Saenz-Arias *et al*., 2022a, b; Guerra-García *et al*., 2025). In different Mediterranean ports, colonies of arborescent bryozoans have been shown to host higher numbers of NIS compared with other sessile taxa, such as mussels, algae, solitary ascidians, and sponges (Tempesti *et al*., 2022b). Thus, the presence of arborescent bryozoans, such as *Amathia verticillata*, *Bugula neritina*, and *Tricellaria inopinata*, growing in ports may have facilitated the establishment and subsequent spread of their associated species, including NIS (Ros *et al*., 2013; Marchini *et al*., 2015; Guerra-García *et al*., 2024).

In fact, arborescent basibionts and structurally complex sessile species, such as bryozoans, are well-known habitat-forming organisms (Bradshaw *et al*., 2003; Wood *et al*., 2012; Rosso *et al*., 2023). The current survey documented 14 different bryozoan species, compared with a maximum of 4–8 bryozoan species identified in previous Egyptian studies (Abdelsalam & Ramadan, 2008a, b; Abdelsalam & Abdel Wahab, 2012; Abdelsalam, 2014, 2016; Abdelsalam & Abd Elnaby, 2021; Khater *et al*., 2023; Abdelsalam *et al*., 2024), a pattern that may also be related to the higher total number of species recorded in the present study compared with earlier investigations. An example is the spaghetti bryozoan *A. verticillata*, a well-known habitat provider for various invertebrates, including NIS, due to the development of large bush-like colonies during the summer season (Ros *et al*., 2013; Ferrario *et al*., 2014; Guerra-García *et al*., 2024; Zavacki *et al*., 2025). Extensive mats of this uncalcified bryozoan can also occur as drifting aggregates, thereby facilitating the dispersal of associated NIS from the site of introduction to other localities (Pederson & Peterson, 2002). Other NIS or cryptogenic bryozoans, such as *Watersipora subtorquata* (Sellheim *et al*., 2010), *T. inopinata* (Ros *et al*., 2013, 2014; Hobbs *et al*., 2015; Gavira-O'Neill *et al*., 2018), and *Calyptotheca alexandriensis* (Hamdy & Dorgham, 2019), have also been reported to host numerous associated non-indigenous peracarids.

A facilitation effect in NIS introduction mediated by habitat-forming species was not directly assessed in the present study, as specific samples targeting bryozoans (e.g., for evaluation of their associated mobile fauna) were not collected. However, given the presence of non-indigenous habitat-forming bryozoans alongside the notable abundance of non-indigenous peracarids, such facilitation cannot be ruled out, as previously observed in southern Spain by Ros *et al*. (2013).

Besides long-established or widespread invaders in the Mediterranean basin, such as the serpulids *Hydroides elegans* and *H. dirampha*, the bivalve *Brachidontes* *pharaonis*, and the bryozoan *A. verticillata*, this study detected the amphipod *D. fresnelii* (Audouin, 1826), previously known from the Bitter Lakes in the Suez Canal (Audouin, 1826b; Lowry & Springthorpe, 2007) but not from the Mediterranean Sea. The detection of *D. fresnelii* in the surveyed port, together with the limited autonomous dispersal capacity of gammarid amphipods (Marchini & Cardeccia, 2017), strongly suggests that this species was most likely introduced via vessel traffic. It is therefore advisable to pay particular attention to detecting small and/or taxonomically challenging species during monitoring activities.

The RAS approach employed in this study involved 6 h of sampling, providing an accessible, cost-effective method for surveying fouling communities and serving as a preliminary assessment tool in other localities. Similarly, Corsini-Foka *et al*. (2015) surveyed Faliraki Marina and Mandraki Harbour (Greece) through sampling efforts of up to 2 h conducted by 4–6 students, while Ulman *et al.* (2019a) documented a survey of 34 marinas throughout the Mediterranean with 8 h of sampling effort by one or two researchers per marina.

Considering the results obtained using the RAS approach, the number of NIS recorded at Abu-Qir Port (i.e., 39) is remarkably high. This elevated number likely reflects the specific environmental and geographic conditions of the port, including its proximity to a major introduction pathway (i.e., the Suez Canal) and its location within the warmer southern Mediterranean basin. These findings underscore the importance of prioritising this area for NIS management, as Abu-Qir Port may be considered among the most heavily invaded ports in the Mediterranean Sea (Corsini-Foka *et al*., 2015; Ferrario *et al*., 2016; Ulman *et al*., 2019; Tempesti *et al*., 2020b), being situated just outside the entrance of the Suez Canal and therefore at very high risk of invasion.

The Egyptian Mediterranean coast, extending over more than 1000 km, is among the first areas of the basin where Lessepsian species and other thermophilic NIS are likely to settle and establish (Al Mabruk *et al*., 2020). Nevertheless, information regarding the taxonomic distribution, abundance of NIS, and temporal trends of marine fauna along the Egyptian Mediterranean coast remains scarce and requires updating. Therefore, the initiation of a national monitoring programme for marine biodiversity and NIS in Egypt is strongly recommended. Such an initiative would facilitate the early detection of new NIS in the Levantine region and enhance our understanding of biodiversity patterns within the Egyptian Mediterranean ecosystem.

Conclusion

The fouling community of Abu-Qir Port is highly diverse and exhibits the highest biodiversity and the greatest number of NIS records among similar sites along the Egyptian coast. The study documented 95 taxonomic units, predominantly Annelida and Crustacea. Thirty-nine NIS, including one questionable polychaete, were recorded, 10 of which are new to the Egyptian Mediterranean fauna. Additionally, *O. grimaldii* (native; Crustacea) and *H. bultidactyla* (cryptogenic; Crustacea) are reported for the first time from the Egyptian Mediterranean Sea. The habitat-forming bryozoans detected may provide suitable habitat and space for other fouling species, thereby promoting higher biodiversity, while potentially facilitating the introduction and establishment of associated NIS.

This study, conducted in a single port area, highlights that the number of NIS recorded along the Egyptian Mediterranean coasts is likely underestimated, owing to the lack of taxonomic expertise and structured biomonitoring programmes. Fouling communities represent an important target for assessing NIS introduced via maritime navigation. The data obtained from this monitored port provides baseline information on the distribution of NIS in Egypt and along the south-eastern Mediterranean coast. Therefore, follow-up studies to assess future changes in fouling biodiversity and community composition in the study area, including the implementation of comprehensive national monitoring programmes, are strongly recommended.

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Supplementary Data

The following supplementary information is available online for the article:
Notes on non-indigenous species (NIS), and the questionable species, recorded from Abu-Qir Port, Alexandria, Egypt, through a rapid assessment survey.