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Not All Aliens Come to Harm (Maybe): *Pinctada radiata* (Leach, 1814) Population and Habitat From a Coastal Lagoon (Central Mediterranean Sea)

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ABSTRACT

Pinctada radiata, Leach, 1814, is considered the first Indo-Pacific bivalve introduced in the Mediterranean Sea after the Suez Canal opening and it is now reckoned among the 100 most invasive species within the basin. It is important to assess and describe its established populations in Mediterranean coastal ecosystems to understand the dynamics of this successful invasion and its adaptability. Present research aims to describe the population of *P. radiata* inhabiting the Capo Peloro Coastal Lagoon (Central Mediterranean Sea, Italy) also analyzing morphometric relationships and growth dynamics. Visual monitoring was carried out along the infralittoral fringe of the Faro Lake and the Faro Canal. Three representative sites have been chosen to investigate their distribution, abundance and associated habitats using the visual census technique, and performing seven strip transects, parallel to the coastline and with constant depth. All the *P. radiata* specimens present have been counted and 115 individuals have been randomly sampled during the entire study period. Several morphometric measurements have been recorded for morphometric relationships and growth dynamic analyses, assessing the growth indexes, natural mortality parameters and recruitment patterns. Results showed the presence of a mature *P. radiata* population, organized in banks and patches, confirming the ability of this species to widely colonize the host environments. The information on morphometric relations and growth dynamics showed that the studied area can promote the growth and the well-being of this species. Future studies are needed to fully understand the negative or positive effects of the spreading of this species.

1 | Introduction

The rayed pearl oyster *Pinctada radiata*, Leach, 1814, is considered the first Indo-Pacific bivalve introduced in the Mediterranean Sea after the Suez Canal opening. Since its first report dated to the end of the VIII century (Gofas et al. 2003), it is now reckoned among the 100 most invasive species within the

Mediterranean basin (Streftaris and Zenetos 2006). It shows a wide global distribution, inhabiting the tropical and temperate marine waters of the Indo-Pacific Ocean and the Mediterranean Sea, having almost entirely colonized it since its introduction (Aguilo-Arce et al. 2023; Gavrilović et al. 2017; Gervis and Sims 1992; Png-Gonzalez et al. 2021; Theodorou et al. 2019; Tlig Zouari and Zaouali 1994). *P. radiata* is an epibenthic

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suspension feeder which exhibits a depth distribution from 0 to 30m, thriving in warm water where it attaches by the byssus to hard natural and artificial substrates (Crocetta 2011; Deidun et al. 2014; Lodola et al. 2013; Scuderi and Terlizzi 2012; Tlig-Zouari et al. 2010, 2009). As a fouling species, its progressive spread in this area could have occurred through the attachment to migratory species (as reported by Oliverio et al. (1992)) who mentioned specimens of *P. radiata* as epibionts of a *Caretta caretta*, (Linnaeus, 1758), individual, and/or floating marine litter (Winston et al. 1997). However, at most introduction sites the spreading mechanism remains still unknown. The maritime transport and aquaculture activities are numbered as the only known introduction vectors (Crocetta 2011; Gofas et al. 2003; Katsanevakis 2011; Zenetos, Çinar, et al. 2005; Zenetos, Koutsoubas, et al. 2005), also thanks to the first three planktonic weeks of the life cycle which can allow the larvae long-distance dispersal (Herdman and Hornell 1903; Meng et al. 1996).

To date, data on established populations of *P. radiata* have been reported from several parts of the Mediterranean basin, especially from the Central and Eastern geographical regions (Barbieri et al. 2016; Lodola et al. 2013; Moutopoulos et al. 2021; Stasolla et al. 2014; Theodorou et al. 2019), providing complete descriptions of morphometric parameters and relations (Deidun et al. 2014; Tlig-Zouari et al. 2010) and preliminary assessments of the population dynamics and life history traits (Manousis and Galinou-Mitsoudi 2013; Mohammed and Yassien 2003; Moutopoulos et al. 2021). Due to its wide diffusion and high population density, the interest on its commercial exploitation is growing, especially in the Eastern Mediterranean Sea countries (mainly in Greece and Turkey) (Katsanevakis et al. 2011; Theodorou et al. 2023; Yiğitkurt et al. 2017). Indeed, *P. radiata* shows good commercial interests, and is widely present from several years in the restaurants and shellfish markets of Greece (Theodorou et al. 2023; Zenetos et al. 2010), despite the lack of a specific legislation, due to its absence from the list of exploited shell mollusks (Katsanevakis et al. 2011). The high commercial value of the pearl oyster species belonging to the *Pinctada* genus was widely documented in the countries that fall within their native distribution range area (such as Qatar, Saudi Arabia and Australia), where they have been fished and cultured from centuries due to their edible muscle, the nacreous shell and the ability to produce pearl (Carpenter and Niem 2001; Giraldes et al. 2023; Mohammed and Yassien 2003; Smyth, Al-Maslamani, Chatting, et al. 2016; Smyth, Al-Maslamani, Giraldes, et al. 2016; Whalan et al. 2021).

Another interesting aspect of the biology of this species is that, as well as other oyster species, *P. radiata* is considered an important ecosystem engineer. It can provide a 3D complexity to the sea bottom, forming large beds and banks which can support considerable biodiversity and influence the trophic relations and patterns involving the benthic domain, also acting in the introduction areas as novel habitats for the autochthonous biodiversity and ecosystems functioning (Abdelsalam and Elebiary 2023; Giraldes et al. 2023; Smyth, Al-Maslamani, Chatting, et al. 2016; Tlig-Zouari et al. 2011). In addition to the stated above ecosystem services associated with the species, it can also provide all the services related to oysters and mussels' beds, increasing biofiltration and, consequently, water quality, providing food, supporting the life cycle of several species,

increasing sedimentation through its filter feeding activity (which can induce a decrease in pelagic production), as stated by the outcomes of recent research highlighting the positive effects related to biological invasions (Çinar et al. 2014). According to literature exploring the negative and positive effects of biological invasions (Çinar et al. 2014; Tsirintanis et al. 2022), *P. radiata* is considered a habitat-modifying species, capable of impacting and altering the native biodiversity thanks to its gregarious habits and its ability to reach very high density and form oyster banks. The most negative impact of its introduction is related to shellfish farming activities, due to its massive spreading (high fouling ability of the species, which can colonize, on a huge scale, commercial shellfish collectors and mussel lines), added to its tendency to dominate benthic communities (competing for resources, such as space and food, with native sessile species). All these effects related to *P. radiata* introduction and spreading make it a high-impacting invasive species for biodiversity and ecosystem services. It is indeed capable of influencing, positively and/or negatively, the well-being of the marine coastal ecosystems. This is causing great concern especially for those environments most sensitive to anthropogenic pressure, exhibiting for decades a constant decline and impoverishment, such as the coastal lagoons.

According to the Habitat Directive (1992), coastal lagoons are priority habitats, listed in the Annex I with the code *1150 (Council Directive 92/43/EEC 1992), and nowadays they are counted among the Natura 2000 sites, preserved by the EU as part of the over 27,852 protected sites numbered in the Natura 2000 network (Röschel et al. 2020). European coastal lagoons have been widely exploited, modified, impacted and degraded by humans. Recently, the attention of the scientific community has been focused on these ecosystems' restoration, due to their naturalistic, ecological and social importance (De Wit and Boutin 2023). Among human impacts, biological invasions are one of the most alarming for the maintenance of ecosystem functioning and native biodiversity. The high sensitivity to this phenomenon is strictly related to the aquaculture activities that are often carried out in these sheltered and productive ecosystems (Saccà 2016). Aquaculture activities are world-wide recognized as one of the main vectors for the introduction of invasive species due to the transfers of cultured species over long distances (Di Blasio et al. 2023). For this reason, several restoration projects involving coastal lagoons have been focused on the control and removal of invasive alien species. This makes the monitoring of their diffusion and establishment a main topic for the conservation of Mediterranean coastal lagoons.

In this context, the present paper aims to assess and describe, through a visual census and a morphometric analysis of sampled specimens, the population of *P. radiata* successfully established in the "Capo Peloro" Coastal Lagoon (Central Mediterranean Sea, Italy, Sicily—Priority Habitat—European Habitats Directive 92/43/EC). This coastal area hosts shellfish farming from the beginning of the XVIII century, and it has been considered for decades a perfect study ground for the monitoring and investigation of non-indigenous species (NIS) spreading in the Central Mediterranean Sea (Manganaro et al. 2012). Data provided on this population of *P. radiata* can improve the knowledge base regarding the adaptation of this species to the different Mediterranean marine and brackish ecosystems, comparing the



FIGURE 1 | (A) Satellite image of the Italian Peninsula, with the Strait of Messina highlighted by a white rectangle; (B) satellite image of the Strait of Messina, with the Capo Peloro Lagoon highlighted by a white rectangle; (C) satellite image of the Capo Peloro Lagoon, with the Ganzirri Lake (d), the Faro Lake (h) and, highlighted by white rectangles, the Due Torri Canal (e), the Margi Canal (f), the Inglesi Canal (g) and the Faro Canal (i).

morphometric and life history data obtained with literature from other geographical areas. This information can provide a first base to understand its suitability for commercial purposes. Moreover, providing information on its establishment in a very sensitive ecosystem can increase the consciousness of the invasion dynamics, and the effects correlated in the Mediterranean coastal lagoons. This is essential for the conservation purposes of native biodiversity and ecosystem functions of these sensitive and important habitats.

2 | Materials and Methods

2.1 | Studied Area

The “Capo Peloro” Lagoon is a site of high ecological, cultural and social interest. It is an Oriented Natural Reserve (ONR), a Special Protection Zone (ZPS), and a priority habitat listed in Annex I of the Habitat Directive (1992) (Ec 2007; European Community 1979; Sicilia 2021). Its cultural and social relevance is related to the shellfish farming activities (mainly involving mussels, cockles, and oysters), carried out in this area from the beginning of the XVIII century to nowadays (Sanfilippo 2000; Mazzola et al. 2010; Manganaro et al. 2012). Geographically located along the northeast Sicily corner, it is very close to the Strait of Messina, a peculiar sea district of the Central Mediterranean Sea (between the Ionian and the Tyrrhenian Sea). The Strait is characterized by a unicity from a physiochemical and ecological/zoological point of view, related to the strong hydrodynamic regime affecting the area (De Domenico 1987; D'Iglio et al. 2024, 2023; Spanò and De Domenico 2017). The closeness of the Capo Peloro Lagoon to the Strait of Messina, to which it is connected through several canals (Catuso, Due Torri, Faro and Inglesi Canals), strongly influences its hydrography, resulting in an instability of the water level of the entire lagoon, strictly related

to the strong tidal currents of the Strait, which change every 6 h following the moon phases. The lagoon comprises two lakes (the Faro and the Ganzirri Lakes, two brackish ponds in which the water salinity is influenced by the interaction between the groundwater and the marine waters), connected to each other via the Margi canal, the canals Catuso and Due Torri connecting the Ganzirri Lake to the water of the Strait of Messina, and the canals connecting the Faro Lake to the Strait of Messina (Faro Canal) and to the Tyrrhenian Sea (Inglesi Canal) (Figure 1).

Concerning the Faro Lake, it is the deepest of the lagoon (it is also the deepest brackish coastal lake of Italy), reaching a maximum depth of 29 m and a total area of 0.263 km². It shows a constant stratification of the water mass, with a well-mixed surface layer (0–15 m of depth), a temperature ranging from 10°C to 36°C, a pH from 7.9 to 8.6, and a salinity from 26 to 36 PSU. Otherwise, the almost total absence of water movement in the layer deeper than 15 m results in a constant physiochemistry, characterized by ca. 15°C of temperature, ca 38 PSU of salinity and a pH ranging from 7.0 to 7.4. Another peculiarity is the mesotrophic character of both water and sediment in the entire basin, supporting a massive productivity. Its connectivity to the sea is provided by the two shallow canals (Faro and Inglesi). The Faro Canal connects it permanently to the Strait of Messina waters, while the Inglesi Canal (artificial) connects it to the Tyrrhenian Sea only during the summer period, being closed for the larger part of the year.

2.2 | Field Operations and Sample Processing

Between 2021 and 2022, a preliminary assessment on the presence and distribution of *P. radiata* in the Faro Lake and relative canals was carried out. The infralittoral fringe of the west coast of the Faro Lake (from 38°16'15" N 15°38'09" E to 38°16'03" N



FIGURE 2 | Satellite image of the Faro Lake, with the relative canals. The areas highlighted by the dashed lines represent the investigated sites (A: Site A, B: Site B and C: Site C). Inside each dashed lined rectangle is reported a continuous orange line representing the extension of the performed transects for each site.

15°38'03" E) and the entire Faro Canal were identified as the areas with the largest density of *P. radiata* specimens. Inside these areas, three representative sites (called Sites A, B and C), characterized by high abundance of *P. radiata* specimens, were selected (Sites A and B in the infralittoral fringe of the west coast of the Faro Lake, and Site C which covered the entire Faro Canal) to investigate the distribution and abundance of *P. radiata*.

From July to October 2022, seven strip transects (four in the Faro Lake and three in the Faro Canal), parallel to the coastline and with constant depth of 3 m, inside the three selected sites (2 in the Site A, 2 in the Site B and 3 in the Site C) were surveyed by free divers to collect data regarding the abundance and population density of *P. radiata* using the visual census technique (Bianchi et al. 2003). In the Site C it was chose to perform three transects instead of two since it represents the site with the largest presence of *P. radiata*, as noticed during the preliminary assessment. Free divers swam slowly along strips of different length (transects in the Site A: 124m; transects in the Site B: 219m; transects in the Site C: 350 m) (Figure 2), counting the *P. radiata* specimens present within approximately 1 m on either side, for a total wide of 2 m for each strip, also recording data regarding the substratum preferences showed in each transect.

Two replicates for each transect were performed, and *P. radiata* individuals were randomly sampled during the entire study period, to reduce to the minimum the impact on the population, given its ecological relevance as habitat former species and the sensitivity of the studied ecosystem. Sampled individuals were gently removed by scraping them from the substrate, taking care to collect specimens from all size classes. Indeed, although sampling was random and performed avoiding the collection of too large individuals' number due to conservation concerns,

particular attention was paid to sample specimens from all visible size classes, reducing potential biases in the size distribution and morphometric analyses. Once collected, samples were preserved in a hand net and transported to the laboratory for further analysis.

Once in the laboratory, a digital caliper, with a precision of 0.1 mm, was used to record the following measurements from the largest valves (usually the left): shell height (SH), shell length (SL), shell width (SW), hinge length (HL). The length of the nacreous shell part and the width of the nacreous shell part were measured for both valves (LNR=length of the nacreous right shell, WNR=width of the nacreous right shell, LNL=length of the nacreous left shell, WNL=width of the nacreous left shell) (Figure 3). A precision scale was used to get the total wet weight (TW) and once proceeded with dissection, the shell wet weight (ShW).

2.3 | Data Analysis

A simple linear regression model ($Y = a + bX$), assessed with R (R Core Team 2024) (such as all the other statistical analyses) using the "lm" function of the stats package, was fitted using SH values as an independent variable (X), and the other parameter values as the dependent ones (Y : SL, SW, HL, LNR, WNR, LNL, WNL, TW, SW). The Studentized Deleted Residuals (SDR) method was applied to each linear regression model to identify potential influential points and outliers, through the function "ols_plot_resid_stud_fit" of the "olsrr" package. A threshold of 2 (in absolute value) was used to classify the observations as outliers, removing them from further analysis, improving the robustness of the model. A total of 1 to 3 observations per model were

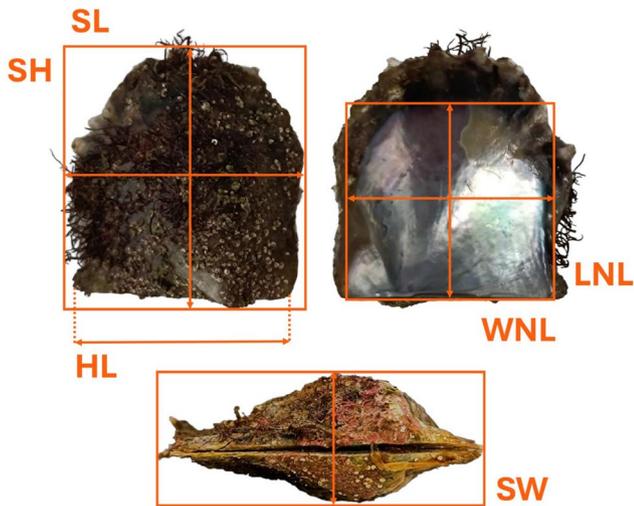


FIGURE 3 | Investigated morphometries of the left shells of the *P. radiata* specimens: HL, hinge length, LNL, length of the nacreous left shell; SH, shell height; SL, shell length; SW, shell width; WNL, width of the nacreous left shell. The length and the width of the nacreous shell were also measured for the right one (LNR and WNR, respectively).

classified as outliers and consequently removed (see Table S1). They were found to be biologically extreme rather than related to measurement error. Subsequent analyses were carried out on the cleaned dataset obtained through the exclusion of the detected outliers. According to the power-law scaling in allometric relationships (Richardson et al. 1995; Warton et al. 2006), the allometric relations among the recorded measurements were established through the linear regression:

$$\ln Y = a + b \ln SH$$

where a and b are respectively the intercept and the slope. A Student's t -test was applied on the b coefficients (slope) of each linear regression to evaluate the significant difference from the isometric growth ($b = 3, p = 0.05$ for TW and ShW; $b = 1, p = 0.05$ for the other morphometries). The visualization of the allometric relations between the log-transformed variables was obtained using a scatterplot with a fitted regression line and 95% confidence intervals, generated with the “ggplot2” package. This package was also used to plot the length-frequency distribution graph (for both the total sample, and for the three investigated sites) and the density distribution graph for each site, creating length classes of 1 mm for the analyzed specimens from the SH measurements.

Electronic Length Frequency Analysis (ELEFAN) was performed on the SH measurements of the specimens collected during the reporting period. The FiSAT II software (Gayaniilo et al. 1996) was first used to group data into size class intervals and then to estimate the non-parametric scoring of the Von Bertalanffy growth function (VBGF), the natural mortality parameters and the recruitment pattern. More specifically, the VBGF (Von Bertalanffy 1938) used to describe growth is shown below:

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)} \right]$$

where L_t is the length at time t , L_∞ is the asymptotic length, e is the base of the neperian logarithm, K is the growth rate constant, t is the time of observation and t_0 the theoretical age at which the size of oyster would be zero (Moutopoulos et al. 2021). The growth constant K , where high values indicate slow growth and low values indicate rapid growth, serves as an index of the intrinsic growth rate of the species and is crucial for intraspecific growth comparisons (Beverton and Holt 2012). The growth performance index (Φ') was assessed according with the equation (Munro and Pauly 1983):

$$\Phi' = 2 \log L_\infty + \log K$$

The above-mentioned variables were also used to estimate the natural mortality (M) using Pauly equation (Pauly 1980):

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

with the mean annual habitat temperature (T) set at 21°C.

Regarding the recruitment pattern, the relative recruitment values in percentages for each month were determined by retroactively projecting the length-frequency data along the time axis using the growth parameters (Pauly 1986). Similar protocols have been followed by other authors for the same species (Derbali et al. 2019; Moutopoulos et al. 2021), as well as for several bivalve species (Yambem Tenjing 2019).

3 | Results

The investigated sites of the Faro Lake and Faro Canal were characterized by differences in sediment features and associated biocenosis, with the wide presence of various kinds of both muddy, soft substrate and hard substrates (such as rock covered by sand and mud, gravel, dead oysters, and other bivalves, shells and small stones). According to Montefalcone and colleagues (Montefalcone et al. 2021), the associated biocenosis was that of both infralittoral rock, mud and sand, characterized by the presence of transitional waters' habitats, and particularly: associations with Fucales, associations with marine angiosperms and/or halophytes (e.g., *Cymodocea nodosa* (Ucria) Ascherson, 1870), association with photophilic algae, except Fucales (e.g., *Halopithys incurva* (Hudson) Batters 1902, and *Gracilaria* sp), facies with Polychaeta (e.g., *Branchiomma luctuosum*, Grube, 1870, *Branchiomma bairdi*, McIntosh, 1885, *Ficopomatus enigmaticus*, Fauvel, 1923, *Hydroides* sp., *Serpula* sp), facies with small sponges (e.g., *Dictyonella incisa*, Schmidt, 1880, *Raspaciona* sp) and facies with Bivalvia (e.g., *Ostrea* sp., *Magallana gigas*, Thunberg, 1793, and the studied species *P. radiata*).

The Site A was mainly characterized by a muddy and mixed sand/gravel substrate, with the irregular presence of hard substrates (both natural and artificial) colonized by oysters, not only belonging to the *P. radiata* species (Figure 4a-f). Indeed, they were widely recognized large patches of the introduced oyster *M. gigas*, and the native oysters belonging to the genus *Ostrea*, often forming beds or reefs on hard substrates, both rocks and anthropogenic debris (Figure 4e,f). *P. radiata* specimens were mainly detected attached to small stones (Figure 4c,d) or marine

litter (Figure 4a,b), often sharing the substrate with the alien ascidian *Botrylloides niger* Herdman, 1886.

The sediment of the Site B was also muddy/sandy, with the almost total absence of hard substrate of natural origin. Indeed, the *P. radiata* specimens were almost always found attached to many different typologies of anthropogenic debris, completely colonized by benthic organisms (Figure 5a–f). Among the other benthic organisms sharing the substrates with the pearl oysters, the most abundant were Ascidiaceans (e.g., *B. niger* Herdman, 1886, *Styela plicata*, Lesueur, 1823), polychaetes belonging to the genus *Branchiomma* and to the family Serpulidae, and brown and red algae.

Concerning the Faro Canal (Site C) this showed a high benthic biocenosis variability, with a sediment characterized by dead oysters, and other bivalves, shells and small stones/gravel. The first part of the canal showed the presence of seagrass meadows formed by *C. nodosa*, (Figure 6a–c) to which are associated *P. radiata*, and other benthic species. In this site the pearl oysters formed diffused patches and beds associated with seagrass, dead bivalves' shells, and, to a lesser extent than Site A and B, anthropogenic debris (Figure 6b,d–f). The second part of the canal showed the presence of diffused pearl oyster beds associated with red algae, on a hard bottom formed by small stones and dead bivalve shells (Figure 7a–f).

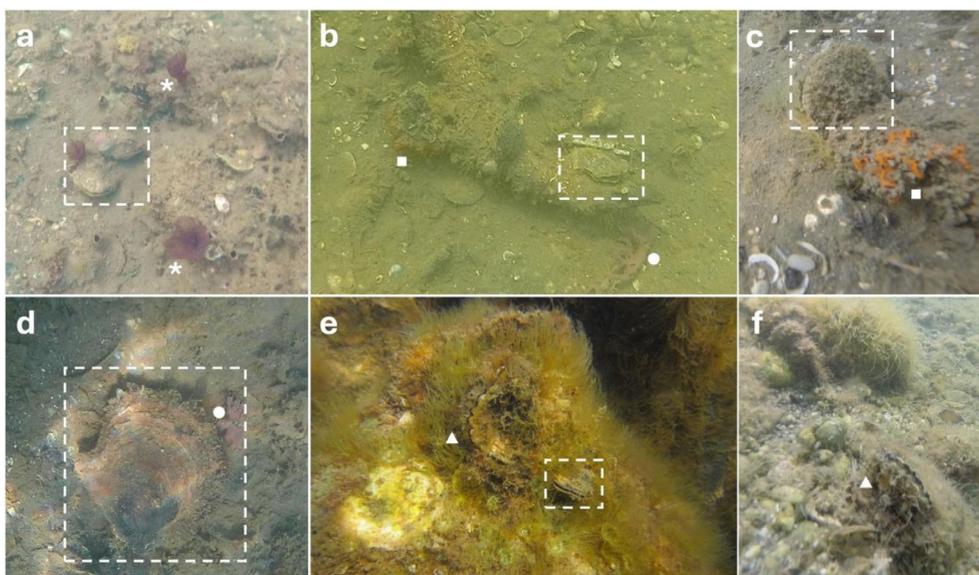


FIGURE 4 | Images from the visual census performed in the Site A, reporting the *P. radiata* specimens (highlighted by white dotted rectangle) associated to *B. luctuosus* (asterisks), Porifera species (white dots), *B. niger* (white squares) and *Ostrea* sp. (white triangles).

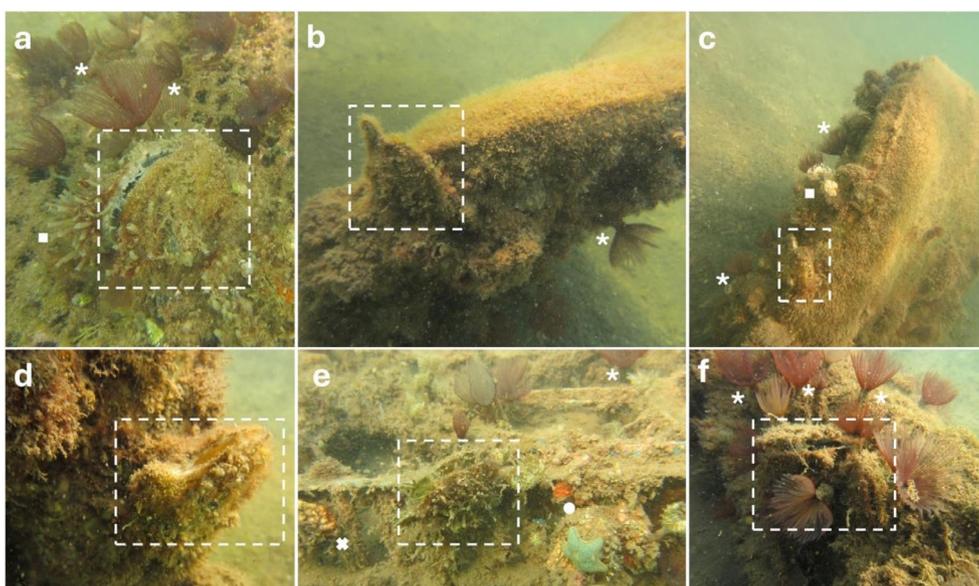


FIGURE 5 | Images from the visual census performed in the Site B, reporting the *P. radiata* specimens (white dotted rectangle) colonizing marine debris of different type, and associated to *B. luctuosus* (white asterisks), Porifera species (white dots), Ascidiacea (x white symbol) and other Sabellidae species (white squares).

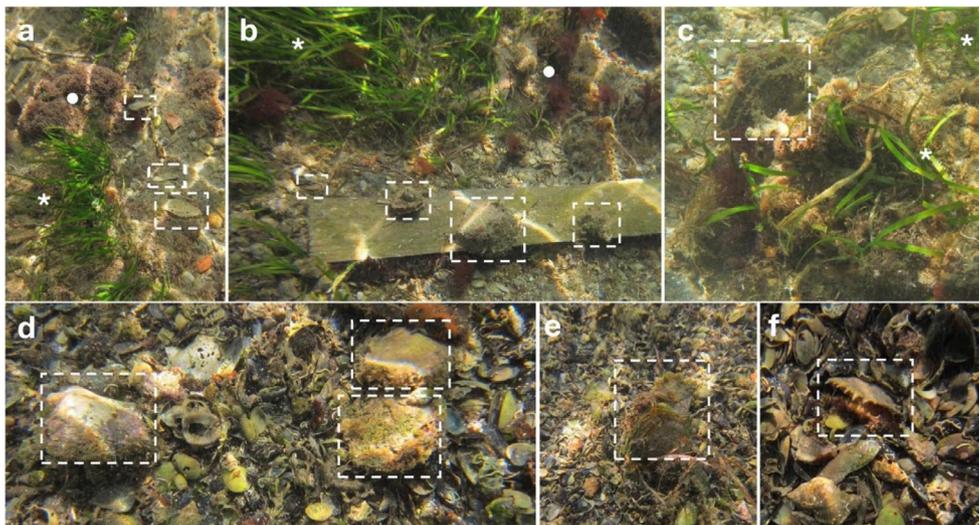


FIGURE 6 | Images from the visual census performed in the first part of Site B, characterized by the presence of *C. nodosa* meadow (white asterisks), reporting the *P. radiata* specimens (white dotted rectangle) associated to Fucales species (white dots).

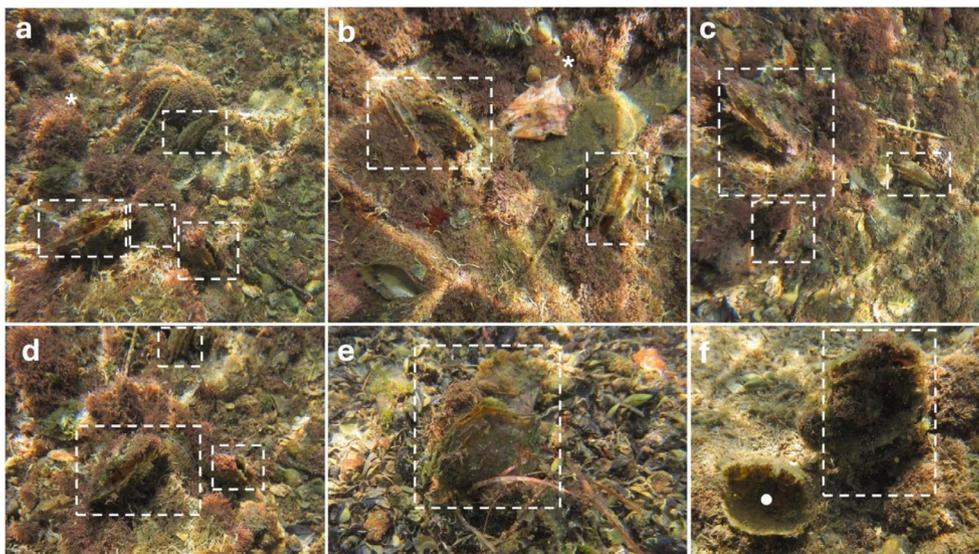


FIGURE 7 | Images from the visual census performed in the second part of Site B, characterized by the presence of *P. radiata* specimens (white dotted rectangle) associated to Fucales species (white asterisks). White dot in figure f highlight the presence of dead *P. radiata* specimens.

3.1 | Visual Census Analysis

Results from the visual census showed the presence of *P. radiata* in all the seven performed transects, with 23, 79 and 1007 total individuals counted respectively in the transects of Site A, B and C (Table 1).

The means individuals' numbers were 11.25 ± 3.86 , 39.25 ± 19.4 and 335.5 ± 76.08 , and abundance were 0.045 ± 0.016 , 0.09 ± 0.044 and 0.48 ± 0.109 respectively for Site A, B and C. Site C showed the highest value of total individuals' number, mean individuals' number and abundance (Figures 8 and 9). Transect 7 showed the highest mean individuals' number (407.5 ± 10.61) and mean abundance (0.582 ± 0.015), followed by transects 5 (Mean N. Ind.: 357 ± 4.24 , Mean Abun.: 0.51 ± 0.006) and 6 (Mean N. Ind.: 242 ± 5.66 , Mean Abun.: 0.346 ± 0.008). Transect 4 was not belonging to the Site C area that showed the

highest individuals' numbers and abundance values (respectively, 56 ± 1.41 and 0.128 ± 0.003).

3.2 | Morphometric Relationships and Growth Analysis

A total number of 115 individuals were collected during six sampling surveys (19 from Site A, 32 from Site B and 64 from Site C). The descriptive statistics (Table 2) of the morphometric parameters showed the SH ranging from 31 to 87 mm, with a mean and a standard deviation of 63.32 and 13.82 mm, respectively. As shown by Figure 10, the length frequency distribution of the 115 analyzed specimens highlighted that the majority of them showed an SH ranging between 60 and 80 mm, with the frequency peaks occurring between the length classes 60 and 70 mm, and between the length classes 70 and 80 mm. The

TABLE 1 | A summary of the numbers of individuals (N. Ind.) and abundances (Abun., expressed in N. Ind./m²) evaluated with the visual census technique for the replicates performed for each transect; the mean individuals' numbers (Mean N. Ind. ± d. st.), total individual numbers (Total N. Ind.), and mean abundances (Mean Abun. ± d. st., expressed in N. Ind./m²) for each transect and site are also reported, along with the relative standard deviations.

	Site A			Site B			Site C		
	1	2	3	4	5	6	7	8	
Transects	1	2	3	4	5	6	7	8	
Transects length	124	124	219	219	350	350	350	350	
Replicates	1	2	1	2	1	2	1	2	
N. Ind.	15	14	7	9	21	24	55	57	
Abun.	0.060	0.056	0.028	0.036	0.048	0.055	0.126	0.130	
Mean N.	14.5 ± 0.71	8 ± 1.41	22.5 ± 2.12	56 ± 1.41	357 ± 4.24	242 ± 5.66	335.5 ± 76.08	407.5 ± 10.61	
Ind. ± d. st.	11.25 ± 3.86	39.25 ± 19.4	79	0.09 ± 0.044	0.051 ± 0.005	0.128 ± 0.003	0.346 ± 0.008	0.582 ± 0.015	
Total N. ind.	23	0.045 ± 0.016	0.032 ± 0.06	0.051 ± 0.005	0.128 ± 0.003	0.346 ± 0.008	0.582 ± 0.015	0.582 ± 0.015	
Mean	0.058 ± 0.03	0.032 ± 0.06	0.051 ± 0.005	0.128 ± 0.003	0.346 ± 0.008	0.582 ± 0.015	0.582 ± 0.015	0.582 ± 0.015	
Abun. ± d. st.	0.045 ± 0.016	0.032 ± 0.06	0.051 ± 0.005	0.128 ± 0.003	0.346 ± 0.008	0.582 ± 0.015	0.582 ± 0.015	0.582 ± 0.015	

Note: Transects' lengths are expressed in m.

length classes below 40 mm and above 80 mm were the least frequent among the analyzed specimens. The length-frequency distribution assessed for each site (upper image of Figure 11) showed for Site A the length classes between 45 and 65 mm as the most frequent (with the presence of three peaks inside this length classes range), between 55 and 75 for Site B (with a peak between 55 and 60 mm) and between 60 and 80 mm for Site C (with 4 peaks inside this length classes range). The density curve of the length distribution for each site (lower image of Figure 11) showed a relatively flat density curve for Site A, with a peak around the length class of 50 mm, for Site B a sharp peak between 65 and 75 mm, and for Site C a broader curve with a peak between 65 and 80 mm.

As reported in Table 2, the morphometric relationships between SH and the other evaluated morphometries were all significant ($p < 0.05$), with the determination coefficients (r^2) ranging from 0.96 (for SL and LNL) to 0.76 (for SW). SL and LNL showed an isometric relation with SH ($b = 1, p > 0.05$). HL ($b < 1, p < 0.05$), TW and ShW ($b < 3, p < 0.05$) showed negative allometry with SH, while SW, LNR, WNR and WNL showed positive allometry ($b > 1, p < 0.05$).

According to Table 3, the analysis on growth rate reported an estimated asymptotic length (L_∞) of 92.4 mm, with a growth coefficient (K) of 0.040 year⁻¹ and a growth performance index (Φ') of 2.53 (Figure 12). The natural mortality (M) showed a value of 0.14 year⁻¹, and the recruitment pattern exhibited the highest values twice, in June and July, with the total absence of recruitment in December, throughout the year (Figure 13).

4 | Discussion

Data here provided allowed, to the best of our knowledge, the first description of an established population of *P. radiata* from European brackish coastal lagoons, and the second from a Mediterranean coastal lagoon (after the research of Tlig-Zouari and colleagues on the distribution, habitat and population densities of this species along the Tunisian Coast, including the Ghar Elmeh Lagoon) (Tlig-Zouari et al. 2009). Moreover, this represents the first investigation, since the first report (at the beginning of the 2000s) (Giacobbe et al. 2010) of the spreading inside the studied area of *P. radiata*, of its population dynamics, structure, abundance and distribution inside the Capo Peloro Lagoon. Obtaining this information on non-indigenous invasive species, especially on those with a strong invasive potential (as *P. radiata*), is essential to monitor their diffusion in the Mediterranean ecosystems, and the effect of their spreading and dominance on the native communities. Moreover, considering the wide diffusion of aquaculture activities carried out in the Mediterranean coastal lagoons, the data on these edible pearl oysters' populations can be useful to understand the possible commercial potential related to their harvesting and fisheries (as still widely explored in other Mediterranean countries and regions, such as Eastern Adriatic, Greece and Turkey) (Jelić Mrčelić et al. 2023; Moutopoulos et al. 2021; Theodorou et al. 2023; Yiğitkurt et al. 2017).

Concerning the visual census performed in the three investigated sites, it has confirmed the ability of this epibenthic

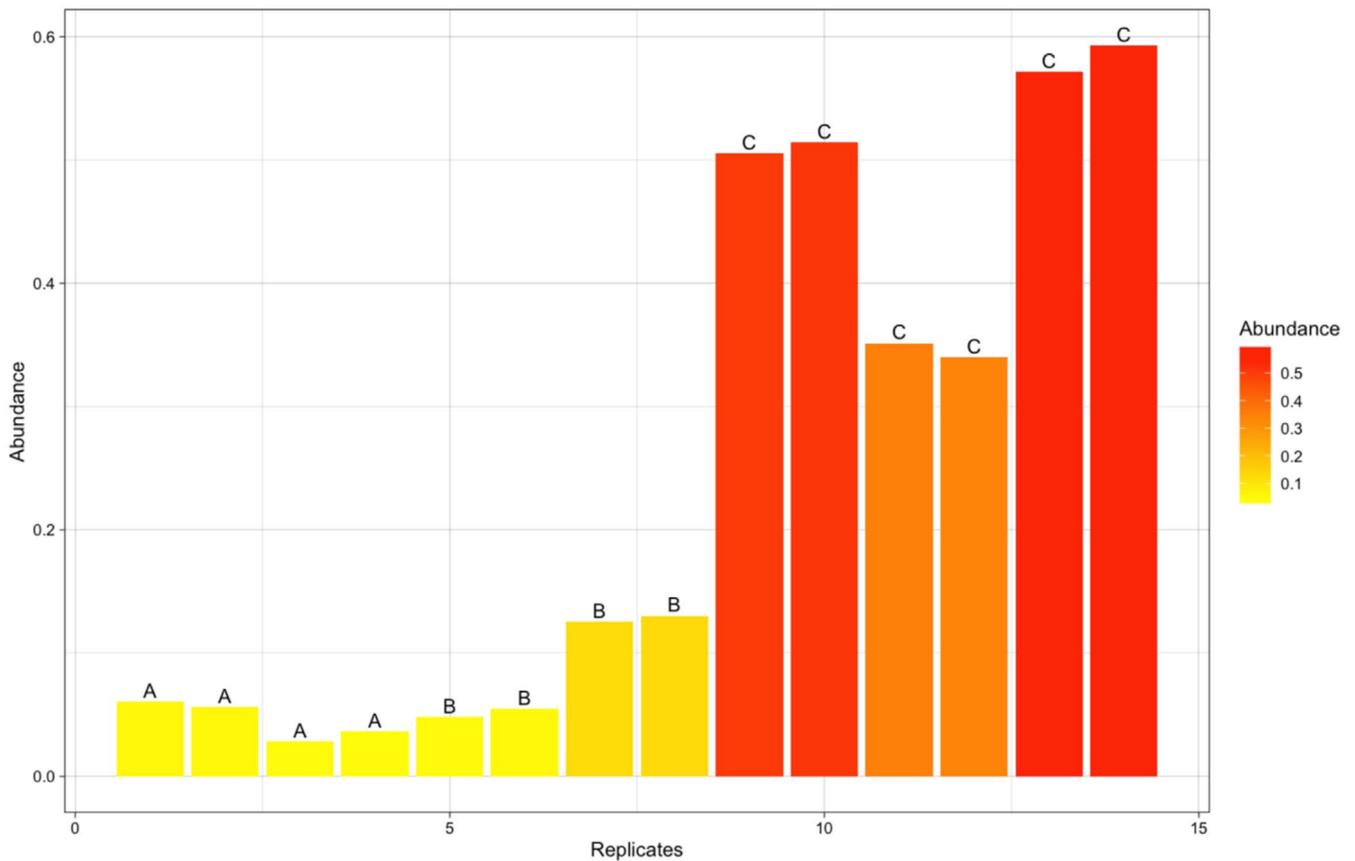


FIGURE 8 | Histogram (created with the “ggplot2” package of R software) representing the Abundances evaluated for each replicate, divided for site to which the replicates belong (A is for Site A, B is for Site B, C is for Site C). The bar colour changes in relation to the abundance values, following a gradient from yellow to red, in which yellow represent a lower abundance value and red a higher abundance value.

species to widely colonize the host environments and communities, forming mature populations, organized in banks (as reported for Site C) and patches (as reported for Sites A and B). The abundances described by results were lower than those reported by literature from other geographical areas. Indeed, in the Tunisian coast they have described the presence of *P. radiata* populations characterized by high abundances and individuals' numbers (Tlig-Zouari et al. 2009). This could be related to the settlement time of the studied species, which spread earlier in the north African coast than in the Sicilian coast of the Central Mediterranean Sea, creating stable and diffused populations. Moreover, the length-frequency and density curve of length distribution showed that Site C was dominated by larger specimens than the other two sites. This could suggest that the population has acclimatized and established firstly in the Faro Canal, and then in the Lake. It was confirmed its capability to create associations with several benthic species, also colonizing many different substrates, both natural and artificial. This was in line with the findings from previous literature from other Mediterranean geographical areas, in which this pearl oyster species has been found associated with a wide spectrum of benthic biocenosis and attached to several anthropogenic structures (e.g., boats, fish cages, plastic collectors, anthropogenic marine litter of different nature) (Barbieri et al. 2016; Carpenter and Niem 2001; Deidun et al. 2014; Doğan and Nerlović 2008; Lipej et al. 2017; Lodola et al. 2013; Oliverio et al. 1992; Png-Gonzalez et al. 2021; Scuderi and Terlizzi 2012; Theodorou et al. 2019; Vio and De Min 1996). This ecological plasticity (added to its quick growth, pollution

tolerance, long life span and high reproduction rate (Jelić Mrčelić et al. 2023; Tlig-Zouari et al. 2011)) allowed this species to spread and adapt to many Mediterranean environments and habitats, causing a growing concern regarding the effects of its invasion on native biodiversity and ecological dynamics. According to literature (Çinar et al. 2014; Tsirintanis et al. 2022), the effects of the spreading of this species have been summarized as both positive and negative. This is common for epibenthic ecosystem engineer species, which can allow for multi-species impacts, out-competing for space and trophic resources with the native filter feeder species, dominating the benthic communities and leading to a decrease in native biodiversity, though also irreversible modification in the epibenthic communities. Regarding the investigated coastal lagoon, the co-occurrence (reported in Site A transects) of *P. radiata* specimens with the native oysters' species, which seem to dominate the colonized substrates of Site A, could be evidence of a “pacific” coexistence. However, the absence of community-level competition experiments or time-series data on the distribution and abundance of the different oyster species doesn't allow for confirming the observed trend. Further studies exploring the competition between *P. radiata* and the native oyster species are required to confirm or deny their pacific co-existence. This is common between bivalves, in which the coexistence between native and non-native species can occur through patterns influenced by multiple complex mechanisms, strictly related to environmental conditions and gradients (Joyce et al. 2021). This is the case, for instance, of *Perna perna*, Linnaeus, 1758, and *Mytilus galloprovincialis*,

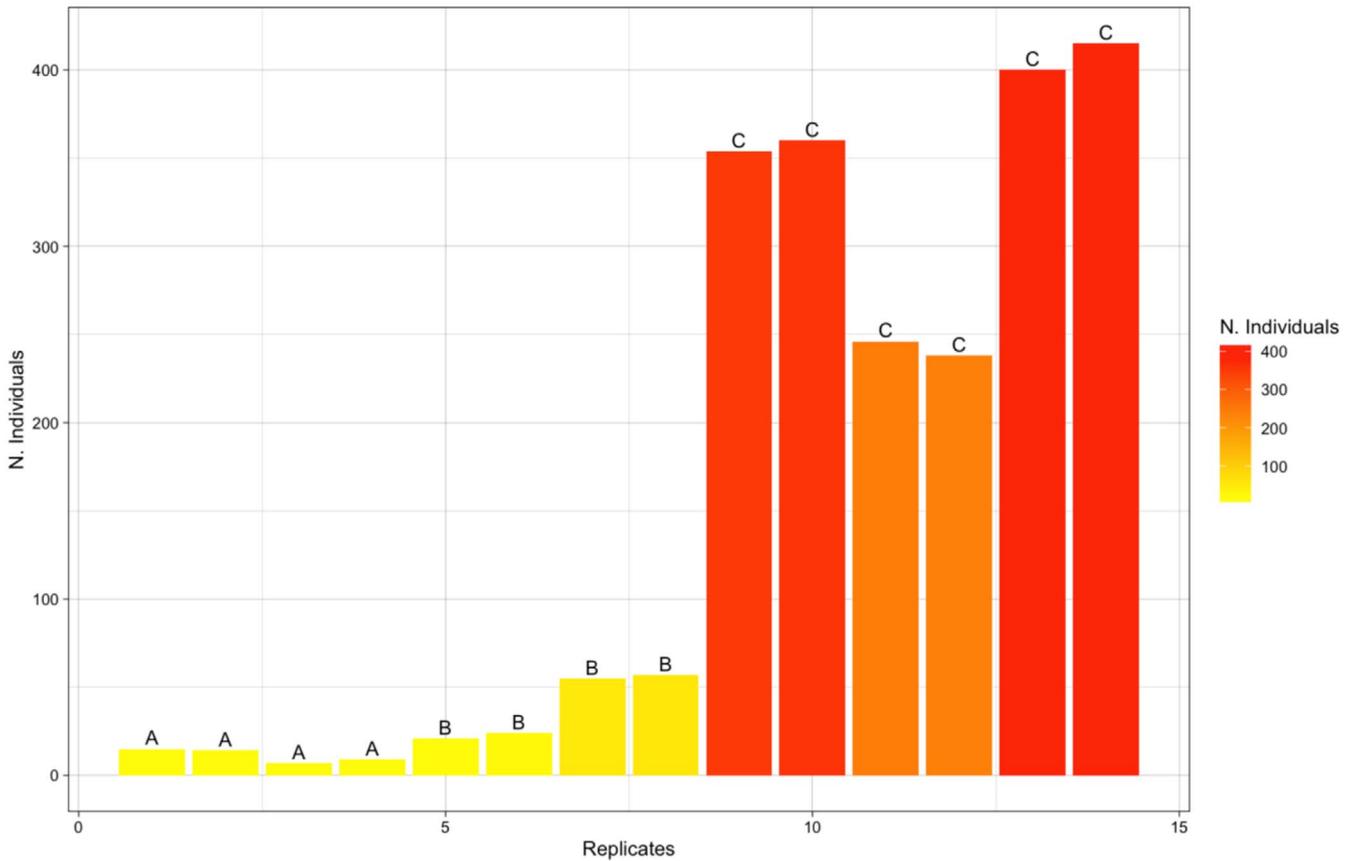


FIGURE 9 | Histogram (created with the “ggplot2” package of R software) representing the number of individuals (N. Individuals) evaluated for each replicate, divided for site to which the replicates belong (A is for Site A, B is for Site B, C is for Site C). The bar colour changes in relation to the N. Individuals’ values, following a gradient from yellow to red, in which yellow represent a lower individuals’ number and red a higher individuals’ number.

TABLE 2 | Descriptive statistic (Max, maximum value; Min, minimum value; m.v., mean value; SD, standard error) and the parameters values estimated for the relations $\ln Y = a + b \ln X$ among morphometric parameters of all the 115 left valves (except for LNR and WNR estimated for the right valves) belonging to the investigated specimens of *P. radiata*; a and b are the coefficients (respectively, intercept and slope) of the relations; SEa and SEb are the standard errors for the coefficients a and b for the 95% confidence interval with 113 degrees of freedom; r^2 is the determination coefficient of the relations; p_1 is the p -value of the correlation test, evaluated on the r^2 coefficient; r_1 is the test statistic on the slope for isometry by comparing the estimated slope with the expected value $b = 3$ for weights (TW and ShW) and $b = 1$ for the other variables; p_2 is the p -value of the test statistic on the slope for isometry; isom. column report the presence of isometry (isom), positive allometry (+) or negative allometry (–).

Measurements	m.v.	SD	Min	Max	a	b	SEa	SEb	r^2	p_1	r_1	p_2	isom.
SH (mm)	63.32	13.82	31	87									
SL (mm)	62.04	13.78	30	89	–0.05	1.01	0.08	0.02	0.96	0.000	0.44	0.6	isom.
HL (mm)	54.51	8.90	27.9	74.6	1.59	0.58	0.12	0.03	0.77	0.000	–14	0.000	–
SW (mm)	22.31	7.83	5	52	–3.47	1.57	0.34	0.08	0.76	0.000	6.87	0.000	+
LNR (mm)	45.88	10.74	19	69	–0.61	1.07	0.09	0.02	0.93	0.000	3.23	0.003	+
WNR (mm)	42.1	11.29	16	74	–1.23	1.19	0.12	0.03	0.94	0.000	6.51	0.000	+
LNL (mm)	49.9	11.36	21	75.5	–0.38	1.03	0.08	0.02	0.96	0.000	1.75	0.08	isom.
WNL (mm)	46.87	11.03	21	66	–0.59	1.07	0.09	0.02	0.95	0.000	2.92	0.004	+
TW (g)	43.94	26.4	4.4	125.52	–7.26	2.62	0.51	0.12	0.80	0.000	–3.05	0.003	–
ShW (g)	21.23	12.56	2.43	58.53	–7.49	2.50	0.50	0.12	0.80	0.000	–4.09	0.000	–

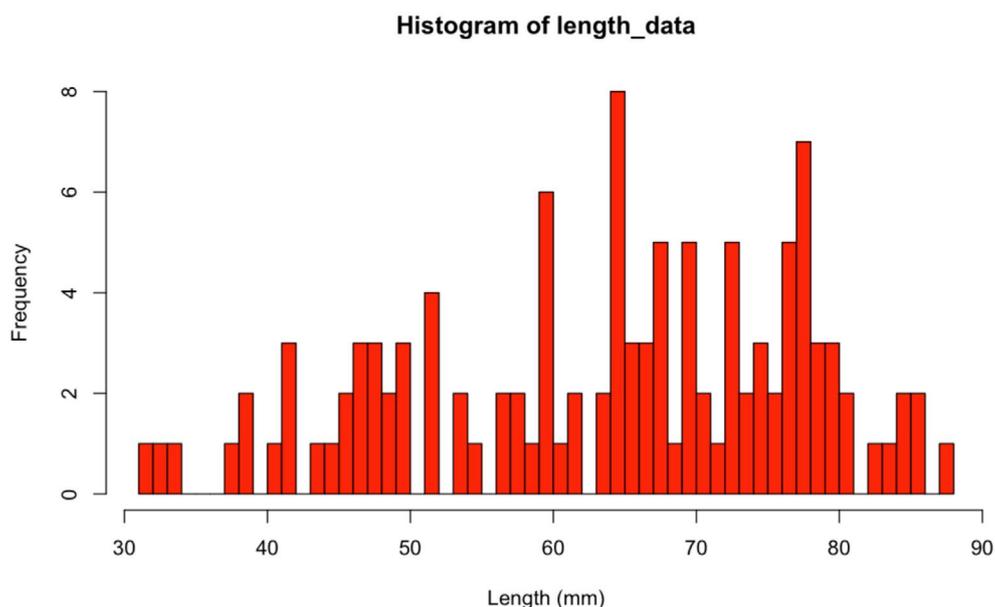


FIGURE 10 | Length–frequency distribution plot of the 115 analyzed *P. radiata* specimens. The length classes of 1 mm reported in the *x* axis have been obtained from the SH measurements.

Lamarck, 1819, inhabiting the South African intertidal rocky shore (Petes et al. 2008; Zardi et al. 2006). The first species is autochthonous, while the second one is a non-indigenous species that has widely colonized the entire South African coast. In the rocky habitats of the intertidal fringe they have partitioned the space, coexisting with no alarming impact on the abundance and development of either of the two species, despite sharing the same trophic and spatial niches. This space partitioning has occurred thanks to the different tolerances to environmental stressors, related to their different physiology (*M. galloprovincialis* better resists desiccation, settling in the high intertidal zone, while *P. perna* better resists wave action, settling in the low intertidal zone). Moreover, the inter-specific relations between these two bivalves can provide some data regarding the facilitation processes that often can be related to biological invasion. Indeed, in the mid intertidal zone the presence of the more tolerant non-indigenous *M. galloprovincialis* facilitates the survival of the more sensitive autochthonous *P. perna* (Rius and McQuaid 2009). Concerning the studied area, further analyses are required to explore the inter-specific relation between the studied species and other native bivalves (especially the native oysters) to fully understand the impact of *P. radiata* on the native epibenthic community and ecological dynamics. According to literature, a yearly manipulation experiment on the field can be used to examine growth dynamics, condition indices, mortality and morphometrics of *P. radiata* and native filter feeder species occurring in heterospecific and monospecific groups in the studied area (Joyce et al. 2021). Exploring the variability of these parameters can enlarge the knowledge base on the competition degree between the alien pearl oyster species and the native ones, exploring the effect of coexistence on native biodiversity. Indeed coexistence can induce detrimental effects on both native and non-native feeder species (as testified for the native mussel, *Mytilus edulis*, Linnaeus, 1758, and the invasive Pacific oyster, *M. gigas* in Northern Ireland), strongly shaping also the associated benthic communities. Competitive interactions can be strongly influenced also by local environmental features (such as

water circulation), highlighting the need to improve information on a local scale about the effects of biological invasion on native ecosystems, especially the most sensitive ones, such as Brackish Coastal lagoons.

The presence of *P. radiata* patches detected in Site B, an area heavily impacted by the presence of anthropogenic debris on the bottom, can not only confirm the necessity of this species to find new space available for its settlement, but could also give some data regarding the positive facilitation effects related to the spreading of this non-indigenous species in the heavily anthropized Mediterranean environments. Indeed, the successful settlement and colonization of *P. radiata* on the marine debris can allow for an increase in habitat complexity (enhancing biodiversity, the complexity of the benthic communities and the settlement dynamics of other epibenthic species), environmental quality (related to the filter feeders' activity of this species) and community structure (creating a new habitat for different kinds of benthic species, which can become new sources of food, essential for the well-being of several species exploiting this kind of community) in areas strongly affected by anthropogenic pressure (evidenced by the massive presence of debris of different kinds, sizes, and origins). The capability of this pearl oyster species to become a fundamental ecosystem engineer, positively altering the host environment, was also confirmed by the visual census data performed in Site C. Indeed, in the Faro Canal, it was reported (to our best knowledge, for the first time from a Mediterranean coastal lagoon) the presence of massive oyster banks and beds. The great abundance of *P. radiata* in Site C could be strictly related to its environmental conditions (Ferrarin et al. 2013; Manganaro et al. 2012; Sanfilippo et al. 2022). Indeed, the Faro Canal is characterized by environmental instability, with large fluctuations in physiochemical parameters (such as temperature, salinity and pH), water levels and turbidity. Being this the canal connecting Faro Lake to the Sea, there is a 24 h water flow, with direction and intensity regulated

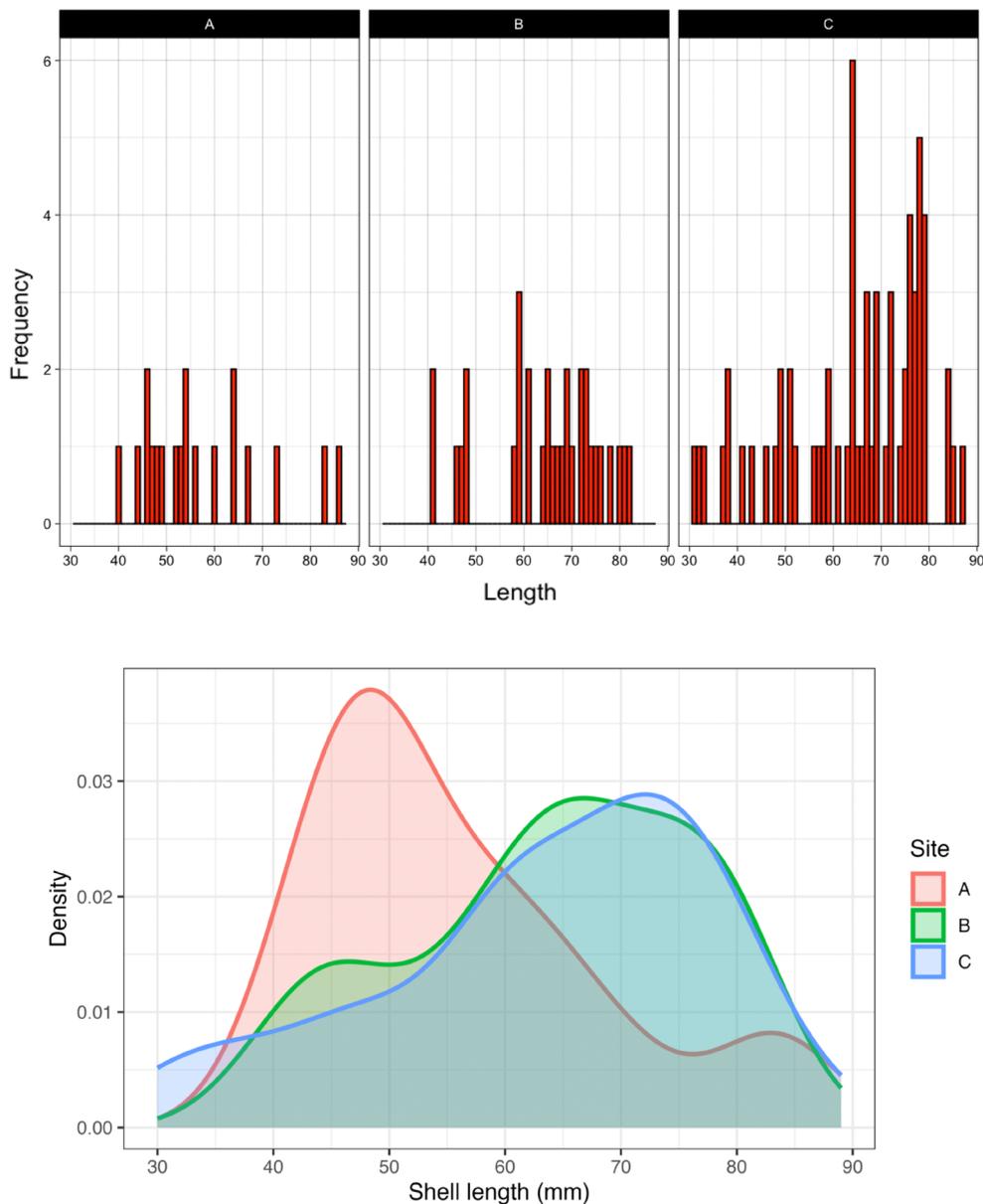


FIGURE 11 | Length–frequency (upper image), and the density curves of length distributions (lower image) of the analysed *P. radiata* specimens for each site. The length classes of 1 mm reported on the *x* axis have been obtained from the SH measurements.

TABLE 3 | Evaluated growth and natural mortality parameters for the studied population of *P. radiata*, using the ELEFAN I software.

Asymptotic length (L_{∞} , mm)	92.4
Growth coefficient (K , year ⁻¹)	0.040
Growth performance index (Φ')	2.53
Temperature (°C)	21
Natural Mortality (M , year ⁻¹)	0.14

by moon phases (Ferrarin et al. 2013; Umgiesser et al. 2014). These environmental features, added to the intense currents and the waters rich in nutrients, could have created the perfect conditions for the massive settlement and proliferation of this species, differently from the other parts of the lagoon

(as shown by the smaller number of individuals and abundance values reported in Sites A and B, compared to Site C). Another peculiarity reported from Site C was the association between *P. radiata* patches and beds, and the *C. nodosa* meadow, a sensitive and ecologically essential habitat which is suffering regression worldwide, related to climate change and to the effects of coastal urbanization. According to the literature (Ramteke et al. 2023), the association between oysters and seagrass habitats can facilitate the latter, thanks to the oysters' capability to filter large volumes of water, reducing water turbidity and assimilating organic matter. In addition, the deposition in the sediment of feces and pseudo-feces, notably rich in nutrients, benefits all the neighboring aquatic vegetation (seagrasses included), as well as microbes and benthic feeders. On the other hand, some evidence from the Tunisian coast has highlighted the risk related to the massive overgrowth of *P. radiata* populations on *Posidonia oceanica*,

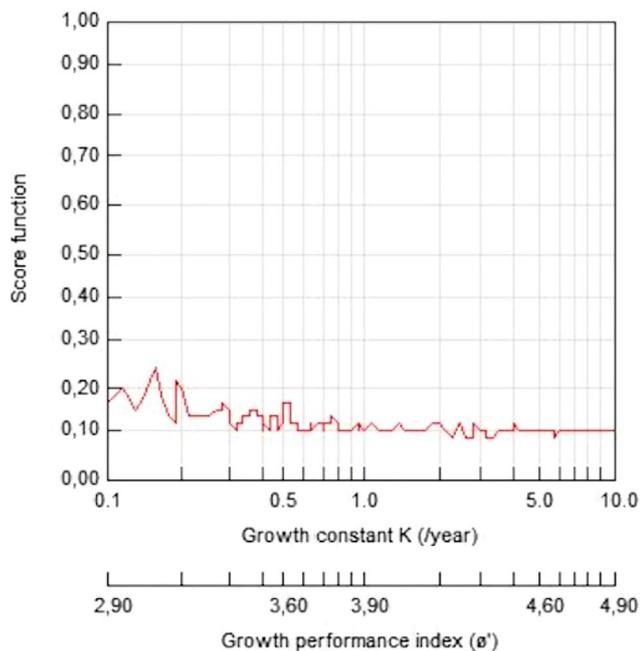


FIGURE 12 | Growth performance index estimation through the ELEFAN I software.

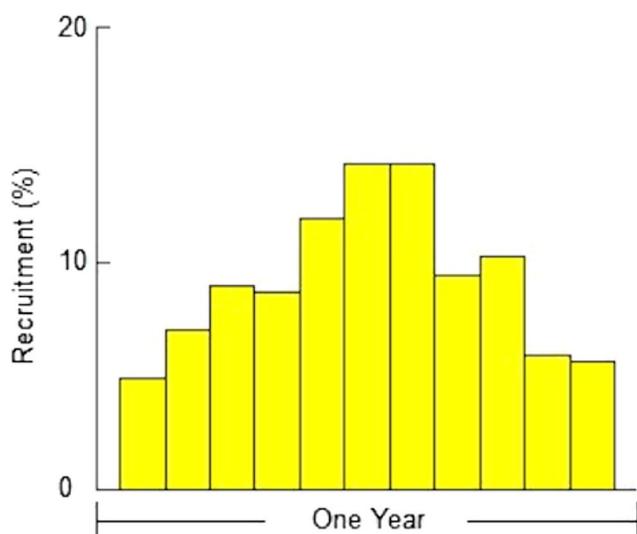


FIGURE 13 | Recruitment pattern (estimated using the ELEFAN I software) of the collected *P. radiata* specimens for the studied area, with the highest recruitment values in June and July, and the absence of recruitment in December (as highlighted by the absence of the 12th bar in the figure).

(Linnaeus) Delile, 1813, rhizomes, affecting the well-being of the entire meadows (Amor et al. 2016). However, it should be noted, according to the evidence provided by the performed visual census, that the seagrass meadow was in excellent quality status. This can represent a preliminary observation on the interaction between *P. radiata* and *C. nodosa* which requires further studies to confirm or deny the no-harm coexistence between these two ecologically relevant species. Indeed, a seasonal monitoring of the ecological dynamics between the *C. nodosa* meadow and the *P. radiata* patches and beds in the Faro Canal is required to fully understand the effects of the

spread and perfect adaptation of this non-indigenous bivalve on this protected seagrass.

Despite their ecological relevance, oyster habitats (reefs, banks and beds) are showing an alarming decrease worldwide. In Europe and in the Mediterranean basin, they are recognized (especially those related to native oyster species, which are disappearing at a regional scale) as sensitive habitats, with great social and ecological value, requiring an improvement in conservation policies and the adoption of active restoration actions (Baggett 2014). In 2011, it was estimated that the loss of 85% of the oyster habitats worldwide occurred, with the surviving wild oyster populations of the Mediterranean basin considered poor (with 90%–99% of lost oysters' habitats, based on the historical abundance data) (Baggett 2014; Beck et al. 2009). Among the main impacts, over-harvesting, together with habitat loss, pollution, biological invasion of non-native species (with the related introduced diseases), coastal urbanization, dredging activities and sedimentation increase, are considered the main factors that have induced this alarming decline worldwide. This large concern regarding the conservation and loss of oyster habitats in the Mediterranean basin highlights the necessity to improve the information regarding their distribution and species composition, such as on the community structure and ecological dynamics which they support. Moreover, considering the widespread nature of *P. radiata* in the entire Mediterranean basin, the necessity to protect this species and the habitats it forms should be considered by the academic community and the entire society, despite this species being considered a non-indigenous invader, which can strongly affect and dominate the native Mediterranean benthic communities. This is particularly necessary especially in the geographic areas (such as the studied one) in which it creates large beds and banks, considering the essential ecosystem services and functions provided by these habitats to the entire marine ecosystem (Coen et al. 2007; Coen and Humphries 2017; Grabowski and Peterson 2007). For this reason, it is essential to improve the knowledge base on the spreading, distribution, population dynamics, ecological plasticity and adaptation shown by this species in the different colonized Mediterranean habitats and geographical areas, focusing also on the negative and positive local effects related to its diffusion. Indeed, according to literature, the impacts of its spreading in the Mediterranean Sea ecosystems and coastal economy can be multiple, with both positive and negative effects (Çinar et al. 2014; Galil 2007; Tsirintanis et al. 2022). It was among the first invaders, having entered thanks to the Suez Canal opening, and, since then, it has colonized almost the entire basin, reaching very high densities in several parts of it (Ballesteros et al. 2020; Crocetta et al. 2017; Crocetta et al. 2013). It has been considered one of the invasive species with the greatest potential impact on Mediterranean marine protected areas (MPAs) (Otero et al. 2013), being capable of altering their ecological dynamics (given the ability to strongly modify the native habitat structures and benthic communities by forming extensive beds, and the potentially strong competition that it can assert to native filter-feeding species). Moreover, its tendency to affect shellfish farming and aquaculture activities by forming fouling aggregations represents a great economic loss in several areas of the basin (Deidun et al. 2014; Theodorou et al. 2019). However, the

TABLE 4 | Growth and morphometric parameters of the studied species reported in literature from populations inhabiting other geographical areas.

References	Area	SH	TW	L_{∞}	Φ'
Derbali et al. (2019)	Tunisia	—	—	78.75	4.04
	Tunisia	—	—	105	3.86
Mohammed and Yassien (2003)	Arabian Gulf	—	—	132	3.77
Moutopoulos et al. (2021)	Saronikos, Greece	61.1	30.2	103.04	3.61
	Evoikos, Greece	—	—	100.63	3.68
Mohammed (1994)	Qatar	—	—	107	3.46
Yassien (1998)	Red Sea	—	—	102.3	3.63
Yassien et al. (2000)	Mediterranean Sea	—	—	69.20	3.43
Pafras et al. (2024)	South Evoikos Gulf, Greece	64.5	49.1	109.1	3.35
Lodola et al. (2013)	Linosa Island, Italy	23.2	1.9	—	—
Deidun et al. (2014)	Maltese Islands	43.9	—	—	—
Gavrilović et al. (2017)	Eastern Adriatic, Croatia	72.3	46.5	—	—
Tlig-Zouari et al. (2009)	Tunisia	52.08	—	—	—
	Tunisia	33.57	—	—	—
	Tunisia	38.46	—	—	—
	Tunisia	63.5	—	—	—
	Tunisia	49.86	—	—	—
Theodorou et al. (2019)	Greece	23.7	40.9	—	—
Present Study	Capo Peloro Lagoon, Italy	63.3	43.9	92.4	2.53

habitat-forming *P. radiata* can strongly contribute to improving habitat complexity, enhancing native biodiversity (giving shelter and available substrates for other settlers), providing food (for humans included), biofiltering the water, sequestering carbon and regulating climate (as all the other mollusk species), and helping a great variety of species to maintain their life cycles (Çinar et al. 2014; Coen et al. 2007; Coen and Humphries 2017; Grabowski and Peterson 2007; Tsirintanis et al. 2022). It can also be an economic resource, as reported in many areas of the world, being edible and capable of producing pearls, and being a source of bioactive molecules and pharmaceutical products (Ben Ammar et al. 2019; Mona et al. 2018). In Mediterranean countries, despite consumers not being used to this resource (excluding some exceptions, such as Lebanon and Egypt) (Jelić Mrčelić et al. 2023), it can become a new valuable commercial species able to substitute the main ones in times of scarcity, as testified by literature exploring its marketing as a new edible bivalve product on the Greek market (Theodorou et al. 2023). To improve its farming and exploitation in the Mediterranean region, creating a new economy and reducing the pressure on native scarce oyster species, market promotion campaigns encouraging the consumption of a non-native oyster species assume utmost importance (Jelić Mrčelić et al. 2023). According to results, the Capo Peloro Coastal lagoon, an area widely explored for centuries for bivalve farming, can become a study ground to explore the feasibility, cost-effectiveness and sustainability of *P. radiata*

farming in European countries, increasing the familiarity of consumers with a novel bivalve.

In this context, the information on morphometric relations and growth dynamics provided in this study could give some useful data to compare with those given by literature from other Mediterranean stable populations. This can provide a picture of the well-being and adaptation dynamics of *P. radiata* in the studied area, also regarding the possibility of being farmed, given the widespread presence of an economically valuable shellfish farming activity in the Capo Peloro coastal lagoon. The population from the studied area showed morphometric values much higher than those shown by the species from other coastal locations of the central and eastern Mediterranean Sea. Indeed, specimens from Capo Peloro showed much higher left shell (SH mean values of 63.32 ± 13.82 mm) than those reported for populations of *P. radiata* from Turkey (with the highest SH mean value of 23.9 ± 3.7 mm) (Gokoglu et al. 2006), other locations of Southern Italy (61.3 ± 12.7 mm) (Lodola et al. 2013), Tunisian coast (60.98 ± 0.68 mm) (Derbali et al. 2019; Tlig-Zouari et al. 2010, 2009), Montenegro waters (38.3 ± 6.1 mm) (Petović and Mačić 2017), and parts of Greece (58.96 ± 13.24 mm) (Moutopoulos et al. 2021). Otherwise, specimens from the Gulf of Evoikos (64.21 ± 14.91 mm) (Moutopoulos et al. 2021) and Evia Island (64.5 ± 11 mm) (Pafras et al. 2024) in Greece showed slightly higher values than those reported by other results. Concerning TW mean value (43.94 ± 26.4 g), another very

indicative morphometric parameter representative of the biomass and the production of the studied species, it confirmed the greater growth promoted in the studied area by the environmental conditions of the Capo Peloro lagoon, with TW higher than parts of Greece (30.2 ± 17.7 g) (Moutopoulos et al. 2021) and other locations of Southern Italy (1.9 ± 5.07 g) (Lodola et al. 2013). Indeed, Faro Lake is a very productive environment, characterized by waters rich in nutrients, salinity and pH in line with those of a purely brackish lagoon permanently connected to the sea, a temperature which varies seasonally, as reported by literature (Manganaro et al. 2012; Sanfilippo et al. 2022). These environmental conditions could be able to promote the growth and the well-being of this pearl oyster species, as also testified by the results from the analysis of the growth dynamics, which showed L_{∞} , Φ' , M values (respectively 92.4 mm, 2.53, 0.14 year^{-1}) in line with those shown by other Mediterranean populations (see Table 4).

According to literature (Derbali et al. 2019; Moutopoulos et al. 2021), geographical differences in growth indexes have been detected between the studied specimens and those exhibited by populations from other Tunisian and Greek localities. Indeed, the Faro lakes' population were characterized by a slower growth rate, as highlighted by the higher L_{∞} value, and the lower K and Φ' values those of the others. However, it is important to notice that the data provided by results from growth analysis are not from the entire year, so they give only a fragmentary picture of the growth dynamics of the studied population. This can be also the reason why the M and K values from Capo Peloro Lagoon was the smallest ever reported from the entire basin. Moreover, the absence of recruitment in December is another aspect strictly related to the lack of year-round sampling. Indeed, under sampling and seasonal biases can strongly influence data from the growth and recruitment pattern analysis. Given the high sensitivity and ecological relevance of the studied area, and the essential ecosystem services related to the studied species, samplings have been organized and performed to cause the least damage possible to both, and to obtain data regarding the population which can be the base for future investigations (such the recruitment period, completely in line with those showed by the species in the entire Mediterranean basin, which is an essential information to known for future sampling designs and researches). Further analyses are required, with a larger samples number from all the seasons, to deepen the knowledge and fully confirm the growth dynamics described by results. This will definitely give a complete picture on the population dynamics, life cycle and stock assessment of the *P. radiata* population from Capo Peloro lagoon.

5 | Conclusions

The information provided on the *P. radiata* population inhabiting the studied coastal lagoon gives a source of data which can be helpful to build a complete picture regarding the adaptation and spreading of this invasive non-indigenous species, which entered the Mediterranean Sea at the beginning of the Lessepsian invasion era. Understanding how this non-indigenous pearl oyster interacts with the host environments and native communities, especially those with which it has been in contact for more time, can inform on how much this habitat former invader negatively or positively interacts with

marine Mediterranean coastal habitats. Results have provided a picture of how *P. radiata* interacts with the studied area, creating a mature and diffused population, perfectly adapted to the surrounding environment. The stable habitat formed by the species (as reported for the Faro Canal) could provide essential space and resources for the well-being and life cycle of several benthic and benthopelagic species, which could exploit it to get sources of food and available space to settle. Moreover, concerning the ecological relevance of transitional waters and coastal lagoons, widely protected at the community level, the ecosystem services and functions that could be related to this filter feeder bivalve could make it an important factor in the maintaining of the environmental quality of the Capo Peloro lagoon. More data from systematic studies exploring the positive or negative effects of this species on habitats and/or ecosystem services of the area are necessary to confirm this hypothesis. Finally, considering the economic value of this species, widely exploited in several parts of the world, the data regarding the growth dynamics and morphometric relation of the studied population can be the first step to describe its population structure and dynamics, providing a useful knowledge base for its farming and stock assessment. Future studies are needed to fully understand the effect of this species on the focused environment, especially regarding the native filter feeders' species which can strongly suffer from the spreading of *P. radiata*, and the population dynamics of this species which could become from a threat to be eradicated and contained to a resource to be protected and valued.

Author Contributions

Claudio D'Iglio: formal analysis, investigation, software, writing – original draft. **Gioele Capillo:** conceptualization, methodology, supervision, validation, visualization, writing – review and editing. **Dario Di Fresco:** data curation, investigation, methodology. **Sergio Famulari:** data curation, formal analysis, investigation, methodology, software. **Marco Albano:** supervision, validation, visualization, writing – review and editing. **Damir Valić:** supervision, validation, project administration. **Nunziacarla Spanò:** supervision, validation, project administration. **Serena Savoca:** conceptualization, resources, supervision, validation, visualization, writing – review and editing.

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Ethics Statement

Sampling activities have been performed under the permission and monitoring of the managing body of the Oriented Natural Reserve “Laguna di Capo Peloro” (Prot. n.1138/A, 15.03.2021).

Data Availability Statement

Data will be made available on request.

References

Abdelsalam, K. M., and N. H. Elebiary. 2023. “Preliminary Estimation of Fouling Organisms Associated With the Pearl Oyster *Pinctada Radiata* in the Natural Habitat of the Egyptian Mediterranean Sea.” *Mediterranean Marine Science* 24: 338–352.

- Aguilo-Arce, J., J. Ferragut, L. Png-Gonzalez, A. Carbonell, and M. Capa. 2023. "First Genetic Survey on the Invasive Rayed Pearl Oyster *Pinctada Radiata* (Leach, 1814) Populations of the Balearic Islands (Western Mediterranean)." *Mediterranean Marine Science* 24: 666–678.
- Amor, K. O.-B., M. Rifi, R. Ghanem, I. Draeif, J. Zaouali, and J. B. Souissi. 2016. "Update of Alien Fauna and New Records From Tunisian Marine Waters." *Mediterranean Marine Science* 17: 124–143.
- Baggett, L. 2014. *Oyster Habitat Restoration Monitoring and Assessment Handbook*. Nature Conservancy.
- Ballesteros, E., E. Marsinyach, M. Bagur, et al. 2020. "The Pearl Oyster *Pinctada imbricata radiata* (Leach, 1814)(Bivalvia: Pteriidae) Reaches Minorca, Balearic Islands." *Bolletí de la Societat d'Història Natural de Les Balears* 63: 97–108.
- Barbieri, M., A. Deidun, F. Maltagliati, and A. Castelli. 2016. "A Contribution to the Phylogeography of *Pinctada imbricata Radiata* (Leach, 1814)(Bivalvia: Pteriidae) From the Eastern Mediterranean Sea by Means of the Mitochondrial COI Marker." *Italian Journal of Zoology* 83: 113–120.
- Beck, M. W., R. Brumbaugh, L. Airoidi, et al. 2009. *Shellfish Reefs at Risk: A Global Analysis of Problems and Solutions*. The Nature Conservancy.
- Ben Ammar, R., M. Piet, A. Brion, et al. 2019. "Induction of Osteogenic MC3T3-E1 Cell Differentiation by Nacre and Flesh Lipids of Tunisian *Pinctada Radiata*." *Lipids* 54: 433–444.
- Beverton, R. J. H., and S. J. Holt. 2012. *On the Dynamics of Exploited Fish Populations*. Springer Science & Business Media.
- Bianchi, C., R. Pronzato, R. Cattaneo-Vietti, et al. 2003. "Hard Bottoms. In: Mediterranean Marine Benthos: A Manual of Methods for Its Sampling and Study." *Biologia Marina Mediterranea* 11: 185–216.
- Carpenter, K. E., and V. H. Niem. 2001. *FAO Species Identification Guide for Fishery Purposes. The Living Marine Resources of the Western Central Pacific. Volume 6. Bony Fishes Part 4 (Labridae to Latimeriidae), Estuarine Crocodiles, Sea Turtles, Sea Snakes and Marine Mammals*.
- Çınar, M. E., M. Arianoutsou, A. Zenetos, and D. Golani. 2014. "Impacts of Invasive Alien Marine Species on Ecosystem Services and Biodiversity: A Pan-European Review." *Aquatic Invasions* 9: 391–423.
- Coen, L. D., R. D. Brumbaugh, D. Bushek, et al. 2007. "Ecosystem Services Related to Oyster Restoration." *Marine Ecology Progress Series* 341: 303–307.
- Coen, L. D., and A. T. Humphries. 2017. "Oyster-Generated Marine Habitats: Their Services, Enhancement, Restoration and Monitoring." In *Routledge Handbook of Ecological and Environmental Restoration*, 274–294. Routledge.
- Council Directive 92/43/EEC. 1992. "Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora (Eur-Lex)." Official Journal of the European Union.
- Crocetta, F. 2011. "Marine Alien Mollusca in the Gulf of Trieste and Neighbouring Areas: A Critical Review and State of Knowledge (Updated in 2011)." *Acta Adriatica* 52: 247–260.
- Crocetta, F., G. Bitar, H. Zibrowius, and M. Oliverio. 2013. "Biogeographical Homogeneity in the Eastern Mediterranean Sea. II. Temporal Variation in Lebanese Bivalve Biota." *Aquatic Biology* 19: 75–84.
- Crocetta, F., S. Gofas, C. Salas, L. P. Tringali, and A. Zenetos. 2017. "Local Ecological Knowledge Versus Published Literature: A Review of Non-Indigenous Mollusca in Greek Marine Waters." *Aquatic Invasions* 12: 415–434.
- De Domenico, E. 1987. "Caratteristiche Fisiche e Chimiche Delle Acque Nello Stretto di Messina." *Documents et Travaux de l'Institut Géologique Albert de Lapparent* 11: 225–235.
- De Wit, R., and N. Boutin. 2023. "European LIFE Projects Dedicated to Ecological Restoration in Mediterranean and Black Sea Coastal Lagoons." *Environments* 10: 101.
- Deidun, A., F. Gianni, D. P. Cilia, A. Lodola, and D. Savini. 2014. "Morphometric Analyses of a *Pinctada Radiata* (Leach, 1814)(Bivalvia: Pteriidae) Population in the Maltese Islands." *Journal of Black Sea/Mediterranean Environment* 20: 1–12.
- Derbali, A., K. E. Kandeel, and O. Jarboui. 2019. "Comparison of the Dynamics Between Coastal and Midshore Populations of *Pinctada Radiata* (Leach, 1814)(Mollusca: Bivalvia) in the Gulf of Gabes, Tunisia." *Turkish Journal of Fisheries and Aquatic Sciences* 20: 301–310.
- Di Blasio, L., S. Chiesa, G. Arcangeli, V. Donadelli, and G. Marino. 2023. "Alien Species Associated With New Introductions and Translocations of Commercial Bivalves in Italian Marine Waters." *Sustainability* 15: 3536.
- D'Iglio, C., S. Famulari, M. Albano, et al. 2023. "Intraspecific Variability of the Saccular and Utricular Otoliths of the Hatchetfish *Argyropelecus hemigymnus* (Cocco, 1829) From the Strait of Messina (Central Mediterranean Sea)." *PLoS One* 18: 1–31. <https://doi.org/10.1371/journal.pone.0281621>.
- D'Iglio, C., S. Famulari, J. Ferri, et al. 2024. "Ecomorphological Adaptation of *Scorpaena Porcus* (Linnaeus, 1758): Evidence From Two Different Environments Revealed by Sagittae Features and Somatic Growth Rates." *Frontiers in Marine Science* 11: 1347897.
- Doğan, A., and V. Nerlović. 2008. "On the Occurrence of *Pinctada Radiata* (Mollusca: Bivalvia: Pteriidae), an Alien Species in Croatian Waters." *Acta Adriatica* 49: 155–158.
- Ec. 2007. "Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora." *Official Journal of the European Communities* 206, no. 7: 50.
- European Community. 1979. "Council Directive of 2 April 1979 on the Conservation of Wild Birds (79/409/EEC)." *Official Journal of the European Communities* 103: 1979.
- Ferrarin, C., A. Bergamasco, G. Umgiesser, and A. Cucco. 2013. "Hydrodynamics and Spatial Zonation of the Capo Peloro Coastal System (Sicily) Through 3-D Numerical Modeling." *Journal of Marine Systems* 117–118: 96–107. <https://doi.org/10.1016/j.jmarsys.2013.02.005>.
- Galil, B. S. 2007. "Loss or Gain? Invasive Aliens and Biodiversity in the Mediterranean Sea." *Marine Pollution Bulletin* 55: 314–322.
- Gavrilović, A., M. Piria, X. Z. Guo, et al. 2017. "First Evidence of Establishment of the Rayed Pearl Oyster, *Pinctada imbricata Radiata* (Leach, 1814), in the Eastern Adriatic Sea." *Marine Pollution Bulletin* 125: 556–560. <https://doi.org/10.1016/J.MARPOLBUL.2017.10.045>.
- Gayanilo, F. C., Jr., P. Sparre, and P. Pauly. 1996. *Fisat: Fao-Iclarm Stock Assessment Tools. User's Manual*. Food and Agriculture Organization (FAO).
- Gervis, M. H., and N. A. Sims. 1992. *The Biology and Culture of Pearl Oysters (Bivalvia Pteriidae)*. WorldFish.
- Giacobbe, S., F. De Domenico, S. P. M. Larrera, M. C. Mangano, E. Porporato, and N. Spanò. 2010. "Alien Molluscs and Crustacean Decapods in the Straits of Messina (Central Mediterranean Sea)." *Rapport de La Commission Internationale Pour L'exploration Scientifique de La Mer Méditerranée* 39: 528.
- Giraldes, B. W., D. Smyth, M. Chatting, et al. 2023. "Increasing Knowledge to Restore Oyster Beds and Related Services in the Arabian-Persian Gulf." *Regional Studies in Marine Science* 66: 103172.
- Gofas, S., A. Zenetos, R. N. Gibson, and R. J. A. Atkinson. 2003. "Exotic Molluscs in the Mediterranean Basin: Current Status and Perspectives." *Oceanography and Marine Biology* 41: 237–277.
- Gokoglu, N., M. Gokoglu, and P. Yerlikaya. 2006. "Seasonal Variations in Proximate and Elemental Composition of Pearl Oyster (*Pinctada Radiata*, Leach, 1814)." *Journal of the Science of Food and Agriculture* 86: 2161–2165.
- Grabowski, J. H., and C. H. Peterson. 2007. "Restoring Oyster Reefs to Recover Ecosystem Services." *Ecosystem Engineers: Plants to Protists* 4: 281–298.

- Herdman, W. A., and J. Hornell. 1903. "Observations and Experiments on the Life-History and Habits of the Pearl Oyster." In *HERDMAN, WA Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Manaar. Part I*, 125–146. Royal Society.
- Jelić Mrčelić, G., V. Nerlović, and A. Doğan. 2023. "Sustainable Management of High-Impact Non-Native Molluscs and Their Potential Commercial Importance in the Eastern Adriatic Sea." *Sustainability* 15: 11384.
- Joyce, P. W. S., D. M. Smyth, J. T. A. Dick, and L. T. Kregting. 2021. "Coexistence of the Native Mussel, *Mytilus Edulis*, and the Invasive Pacific Oyster, *Crassostrea (Magallana) Gigas*, Does Not Affect Their Growth or Mortality, but Reduces Condition of Both Species." *Hydrobiologia* 848: 1859–1871. <https://doi.org/10.1007/S10750-021-04558-1/FIGURES/5>.
- Katsanevakis, S., D. Poursanidis, Y. Issaris, et al. 2011. "'Protected' Marine Shelled Molluscs: Thriving in Greek Seafood Restaurants." *Mediterranean Marine Science* 12: 429–438.
- Katsanevakis, S. 2011. "Rapid Assessment of the Marine Alien Megabiota in the Shallow Coastal Waters of the Greek Islands, Paros and Antiparos, Aegean Sea." *Aquatic Invasions* 6: 133–137.
- Lipej, L., I. Acevedo, E. H. K. Akel, et al. 2017. "'New Mediterranean Biodiversity Records' (March 2017)." *Mediterranean Marine Science* 18: 179–201.
- Lodola, A., L. Nicolini, D. Savini, A. Deidun, and A. Occhipinti-Ambrogi. 2013. "Range Expansion and Biometric Features of *Pinctada imbricata* Radiata (Bivalvia: Pteriidae) Around Linosa Island, Central Mediterranean Sea (Italy)." *Italian Journal of Zoology* 80: 303–312.
- Manganaro, A., G. Pulicanò, and M. Sanfilippo. 2012. "Temporal Evolution of the Area of Capo Peloro (Sicily, Italy) From Pristine Site Into Urbanized Area." *Transitional Waters Bulletin* 5: 23–31.
- Manousis, T., and S. Galinou-Mitsoudi. 2013. "New and Uncommon Bivalvia Mollusca of Thermaikos Gulf (NW Aegean Sea)." *Journal of Biological Research* 20: 339.
- Mazzola, A., A. Bergamasco, S. Calvo, et al. 2010. "Sicilian Transitional Waters: Current Status and Future Development." *Chemistry and Ecology* 26: 267–283. <https://doi.org/10.1080/02757541003627704>.
- Meng, Z., Y. Li, and K. Xing. 1996. *Theory and Techniques on Pearl Culture*, 253. Science Press.
- Mohammed, S. Z. 1994. *Pearl Oyster Project, Phase I: Survey & Ecological Studies on Qatari Pearl Oyster Beds*. Qatar. Qatar University (QU) Press.
- Mohammed, S. Z., and M. H. Yassien. 2003. "Population Parameters of the Pearl Oyster *Pinctada Radiata* (Leach) in Qatari Waters, Arabian Gulf." *Turkish Journal of Zoology* 27: 339–343.
- Mona, M. H., E.-S. T. Rizk, M. Nassef, W. Salama, and M. L. Younis. 2018. "In Vitro Evaluation of Antibacterial Activity of Total Protein Extracts of Some Invertebrates Against Human Pathogenic Bacteria." *Egyptian Journal of Experimental Biology* 14: 137–143.
- Montefalcone, M., L. Tunesi, and A. Ouerghi. 2021. "A Review of the Classification Systems for Marine Benthic Habitats and the New Updated Barcelona Convention Classification for the Mediterranean." *Marine Environmental Research* 169: 105387. <https://doi.org/10.1016/j.marenvres.2021.105387>.
- Moutopoulos, D. K., A. Ramfos, J. A. Theodorou, and G. Katselis. 2021. "Biological Aspects, Population and Fishery Dynamics of the Non-Indigenous Pearl Oyster *Pinctada imbricata* Radiata (Leach, 1814) in the Eastern Mediterranean." *Regional Studies in Marine Science* 45: 101821.
- Munro, J. L., and D. Pauly. 1983. "A Simple Method for Comparing the Growth of Fishes and Invertebrates." *Fishbyte* 1: 5–6.
- Oliverio, M., G. Gerosa, and M. Cocco. 1992. "First Record of *Pinctada radiata* (Bivalvia, Pteriidae) Epibiont on the Loggerhead Sea Turtle *Caretta caretta* (Chelonia, Cheloniidae)." *Bollettino Malacologico* 28: 149–152.
- Otero, M., E. Cebrian, P. Francour, B. Galil, and D. Savini. 2013. *Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): A Strategy and Practical Guide for Managers*, 136. IUCN.
- Pafras, D., A. Theocharis, G. Kondylatos, A. Conides, and D. Klaoudatos. 2024. "Population Biology of the Non-Indigenous Rayed Pearl Oyster (*Pinctada radiata*) in the South Evoikos Gulf, Greece." *Diversity* 16: 460.
- Pauly, D. 1980. "On the Interrelationships Between Natural Mortality, Growth Parameters, and Mean Environmental Temperature in 175 Fish Stocks." *ICES Journal of Marine Science* 39: 175–192.
- Pauly, D. 1986. On Improving Operation and Use of the Elefan Programs. Part 2, Improving the Estimation of L.
- Petes, L. E., B. A. Menge, and A. L. Harris. 2008. "Intertidal Mussels Exhibit Energetic Trade-Offs Between Reproduction and Stress Resistance." *Ecological Monographs* 78: 387–402.
- Petović, S., and V. Mačić. 2017. "Novi Podaci o Vrsti *Pinctada radiata* (Leach, 1814)(Bivalvia: Pteriidae) u Jadranskom Moru." *Acta Adriatica* 58: 359–364.
- Png-Gonzalez, L., J. Aguilo-Arce, M. Vázquez-Luis, and A. Carbonell. 2021. "New Occurrence of *Pinctada imbricata radiata* (Leach, 1814) in the Balearic Archipelago (NW Mediterranean Sea) Centro Oceanográfico de Baleares." *BioInvasions Records* 10: 853–858.
- R Core Team. 2024. *R A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.
- Ramteke, D., K. Paramasivam, C. Viswanathan, et al. 2023. "Assessment of Benthic Habitats of Highly Threatened Oyster Reefs of Pulicat Lake, India." *Regional Studies in Marine Science* 66: 103122.
- Richardson, C. A., R. Seed, N. A. Brotohadikusumo, and R. Owen. 1995. "Age, Growth and Allometric Relationships in Septifer Virgatus (Bivalvia: Mytilidae)." *Asian Marine Biology* 12: 39–52.
- Rius, M., and C. D. McQuaid. 2009. "Facilitation and Competition Between Invasive and Indigenous Mussels Over a Gradient of Physical Stress." *Basic and Applied Ecology* 10: 607–613.
- Röschel, L., R. Noebel, U. Stein, et al. 2020. *State of Nature in the EU-Methodological Paper Methodologies Under the Nature Directives Reporting 2013–2018 and Analysis for the State of Nature 2000*. European Environment Agency.
- Saccà, A. 2016. "Confined Coastal Lagoons: Extraordinary Habitats at Risk." In *Coastal Lagoons: Geology, Characteristics and Diversity*, 1–23. Nova Science Publishers, Inc.
- Sanfilippo, M. 2000. *La Componente Organica Del Seston Nel Lago di Ganzirri: Qualità e Valore Nutrizionale Come Risorsa Ambientale*. Messina University Press.
- Sanfilippo, M., M. Albano, A. Manganaro, G. Capillo, N. Spanò, and S. Savoca. 2022. "Spatiotemporal Organic Carbon Distribution in the Capo Peloro Lagoon (Sicily, Italy) in Relation to Environmentally Sustainable Approaches." *Water* 14: 108.
- Scuderi, D., and A. Terlizzi. 2012. *Manuale di Malacologia Dell'Alto Jonio*. Edizioni del Grifo.
- Sicilia, R. 2021. "D.A. 21/06/2001; Istituzione Della Riserva Naturale Laguna di Capo Peloro, Ricadente Nel Comune di Messina."
- Smyth, D., I. Al-Maslamani, M. Chatting, and B. Giraldes. 2016. "Benthic Surveys of the Historic Pearl Oyster Beds of Qatar Reveal a Dramatic Ecological Change." *Marine Pollution Bulletin* 113: 147–155.
- Smyth, D., I. Al-Maslamani, B. W. Giraldes, M. Chatting, E. Al-Ansari, and L. Le Vay. 2016. "Anthropogenic Related Variations in the Epibiotic Biodiversity and Age Structure of the 'Pearl Oyster' *Pinctada Radiata* Within the Eulittoral Zone of Qatar." *Regional Studies in Marine Science* 5: 87–96.

- Spanò, N., and E. De Domenico. 2017. "Biodiversity in Central Mediterranean Sea." In *Mediterranean Identities—Environment, Society, Culture*, vol. 6, 129–148. <https://doi.org/10.5772/intechopen.68942>. IntechOpen.
- Stasolla, G., F. Riolo, A. Macali, C. Pierri, and F. Crocetta. 2014. "Further Spreading in the Italian Seas of Already Established Non-Indigenous Mollusc Species." *Marine Biodiversity Records* 7: e120.
- Streftaris, N., and A. Zenetos. 2006. "Alien Marine Species in the Mediterranean-The 100 'Worst Invasives' and Their Impact." *Mediterranean Marine Science* 7: 87–118.
- Theodorou, J. A., V. Minasidis, A. Ziou, et al. 2023. "Value Chain for Non-Indigenous Bivalves in Greece: A Preliminary Survey for the Pearl Oyster *Pinctada Imbricata* Radiata." *Journal of Marine Science and Engineering* 11: 95.
- Theodorou, J. A., C. Perdikaris, and E. Spinos. 2019. "On the Occurrence of Rayed Pearl Oyster *Pinctada Imbricata radiata* (Leach, 1814) in Western Greece (Ionian Sea) and Its Biofouling Potential." *Biharean Biologist* 13: 4–7.
- Tlig Zouari, S., and J. Zaouali. 1994. "Reproduction of *Pinctada radiata* (Leach, 1814, Mollusque, Bivalve) Dans Les Iles Kerkennah (Tunisie)." *Marine Life (Marseille)* 4: 41–45.
- Tlig-Zouari, S., L. Rabaoui, A. Cosentino, I. Irathni, H. Ghrairi, and O. K. B. Hassine. 2011. "Macrofauna Associated With an Introduced Oyster, *Pinctada radiata*: Spatial Scale Implications of Community Differences." *Journal of Sea Research* 65: 161–169.
- Tlig-Zouari, S., L. Rabaoui, I. Irathni, and O. K. Ben Hassine. 2009. "Distribution, Habitat and Population Densities of the Invasive Species *Pinctada Radiata* (Molluca: Bivalvia) Along the Northern and Eastern Coasts of Tunisia." *Cahiers de Biologie Marine* 50: 131.
- Tlig-Zouari, S., L. Rabaoui, I. Irathni, M. Diawara, and O. Hassine. 2010. "Comparative Morphometric Study of the Invasive Pearl Oyster *Pinctada radiata* Along the Tunisian Coastline." *Biologia (Bratislava)* 65: 294–300.
- Tsirintanis, K., E. Azzurro, F. Crocetta, et al. 2022. "Bioinvasion Impacts on Biodiversity, Ecosystem Services, and Human Health in the Mediterranean Sea." *Aquatic Invasions* 17: 308–352.
- Umgiesser, G., C. Ferrarin, A. Cucco, et al. 2014. "Comparative Hydrodynamics of 10 Mediterranean Lagoons by Means of Numerical Modeling." *Journal of Geophysical Research, Oceans* 119: 2212–2226. <https://doi.org/10.1002/2013JC009512>.
- Vio, E., and R. De Min. 1996. "Contributo Alla Conoscenza Dei Molluschi Marini del Golfo di Trieste." *Atti del Museo Civico di Storia Naturale di Trieste* 47: 173–233.
- Von Bertalanffy, L. 1938. "A Quantitative Theory of Organic Growth (Inquiries on Growth Laws. II)." *Human Biology* 10: 181–213.
- Warton, D. I., I. J. Wright, D. S. Falster, and M. Westoby. 2006. "Bivariate Line-Fitting Methods for Allometry." *Biological Reviews* 81: 259–291.
- Whalan, S., M. Puotinen, M. Wakeford, I. Parnum, and K. Miller. 2021. "Distribution of the Pearl Oyster *Pinctada Maxima* Off Eighty Mile Beach, Western Australia." *Frontiers in Marine Science* 8: 679749.
- Winston, J. E., M. R. Gregory, and L. M. Stevens. 1997. "Encrusters, Epibionts, and Other Biota Associated With Pelagic Plastics: A Review of Biogeographical, Environmental, and Conservation Issues." *Marine Debris: Sources, Impacts, and Solutions*: 81–97. Springer.
- Yambem Tenjing, S. 2019. "Population Dynamics of Edible Wedge Clam, *Donax Lubricus* Hanley, 1845 (Bivalvia: Donacidae): A First Study in Asia." *Regional Studies, Marine Science* 32: 100819.
- Yassien, M. H. 1998. *Biological and Ecological Studies on the Pearl Oyster, Pinctada Radiata (Mollusca, Lamellibranchia) From the Red Sea, With Special Reference to Its Tolerance to Water Pollution*. Faculty of Science, Ain Shams University.
- Yassien, M. H., F. A. Abdel-Razek, and R. W. Kilada. 2000. "Growth Estimates of the Pearl Oyster, *Pinctada Radiata*, From the Eastern Mediterranean." *Egyptian Journal of Aquatic Biology and Fisheries* 4: 105–118.
- Yiğitkurt, S., A. Lök, A. Kırtık, A. Küçükdermenci, and E. Kurtay. 2017. "Preliminary Results of Spat Collection of Rayed Pearl Oyster (*Pinctada radiata*) in Turkey." *Ege Journal of Fisheries and Aquatic Sciences* 34: 211–218.
- Zardi, G. I., K. R. Nicastro, C. D. McQuaid, M. Rius, and F. Porri. 2006. "Hydrodynamic Stress and Habitat Partitioning Between Indigenous (*Perna perna*) and Invasive (*Mytilus galloprovincialis*) Mussels: Constraints of an Evolutionary Strategy." *Marine Biology* 150: 79–88.
- Zenetos, A., M. E. Çınar, M. A. Pancucci-Papadopoulou, et al. 2005. "Annotated List of Marine Alien Species in the Mediterranean With Records of the Worst Invasive Species." *Mediterranean Marine Science* 6: 63–118.
- Zenetos, A., S. Gofas, M. Verlaque, et al. 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." *Mediterranean Marine Science* 11: 381.
- Zenetos, A., D. Koutsoubas, and E. Vardala-Theodorou. 2005. "Origin and Vectors of Introduction of Exotic Molluscs in Greek Waters." *Belgian Journal of Zoology* 135: 279.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Number of outliers identified and removed using the Studentized Deleted Residuals (SDR) method per morphometric allometric model.