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FULL LENGTH ARTICLE

Abundance, size composition and benthic assemblages of two Mediterranean echinoids off the Egyptian coasts: *Paracentrotus lividus* and *Arbacia lixula*

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Population density;
Size class;
Associated benthic assemblages

Abstract This study is concerned with the variability in abundance, size composition and benthic assemblages of two echinoid species, the common sea urchin *Paracentrotus lividus* (Lamarck, 1816) and black urchin *Arbacia lixula* (Linnaeus, 1758) in the Southeastern Mediterranean (SEM) along the coast of Alexandria, Egypt. Four seasonal trips were made during the years 2014–2015 covering 55 km of the shore with depths ranging between 3 and 9 m. The sea urchin species composition, density and size structure and distribution were compared. The associated macrobenthic invertebrates with prominent presence and biomass were observed as well as other benthic fauna and flora associations. The present results showed that *P. lividus* was the dominant echinoid spatially and temporally. *A. lixula* showed frequent occurrence in Sidi Bishr and Sidi Gaber stations in the spring season. The most dominant size class was the medium to large-sized classes for *P. lividus* and large-sized classes for *A. lixula*. The commercial size for the edible *P. lividus* represented 33% of the sampled population. Furthermore, the most dominant macrobenthic assemblages beside the echinoid population were primarily oysters, sea cucumbers, and mussels. Beside these, assemblage of seaweeds (red, green, brown and crustose algae), Porifera, Cnidaria, Crustacea, other Echinodermata, Bivalvia, Gastropoda, Tunicata, Bryozoa and Annelida were found. The present study shows that the investigated area represents stable habitats for the echinoid population with rich and diversified algal assemblages as well as other potential food resources.

Introduction

Sea urchins (Echinodermata: Echinoidae) are marine invertebrates that are considered key species in the Mediterranean

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infra littoral rocky shores that can alter the algal resources and thus the associated epibenthic assemblages due to their grazing activities (Elmasry et al., 2013; Bulleri et al., 1999; Guidetti et al., 2004; Hereu et al., 2012). Soliman et al. (2015) made a genetic analysis in order to identify the five color morphs of the echinoid population that were found in the current study sites. They confirmed that the echinoid population comprised only two species, the edible commercial urchin *Paracentrotus lividus* (Lamarck, 1816) and the non-commercial, non-edible black urchin *Arbacia lixula* (Linnaeus, 1758).

Faunal and floral biodiversity in the Mediterranean Sea is undergoing rapid changes under the complex effect of the human impact and the climatic change (Bianchi and Morri, 2000). Unfortunately, protection measures for species and ecosystems remain very scarce. Since the establishment of MAPAMED (Marine Protected Areas in the Mediterranean) in 2011, *P. lividus* was considered by the MPAs as a priority species that needs protection and conservation. There is an extensive need for the coverage of *P. lividus*' distribution patterns as well as of other echinoids and invertebrate species especially in Southeastern Mediterranean (Pais et al., 2012). The pressure of the increased consumption of near shore invertebrates either by recreational or commercial fisheries can lead to overfishing problems (Guidetti et al., 2004). Sea urchin's small scale fishery is practiced in Egypt, especially in cities like Alexandria, where all types of sea food are appreciated by local citizens and tourists. The product was sold locally or consumed directly on the beaches. Unfortunately, Egypt has no sea urchin fishery records or specific enforced management laws for sea urchin fishery, even though some fishery management laws are forced on another closely related echinoderm, which is the sea cucumber, especially after long periods of theft and over exploitation of the Red Sea valuable species (Ahmed and Lawrence, 2007). Furthermore, the status of the wild populations of the sea urchin *P. lividus* and the co-occurring *A. lixula*, and their ecological impact are poorly investigated.

The present study is a part of the strategic plan of the National Institute of Oceanography and Fisheries (NIOF) that started in 2013 to investigate the status of the commercial Echinodermata species in the SEM off Alexandria city, Egypt. The aim of this study is to investigate the spatial and temporal variability in abundance and size composition of the echinoid population. Moreover, recording their associated flora and fauna to reveal the possible connection for the patterns of their distribution and abundance.

Materials and methods

Sampling sites

In autumn 2013, a survey of 13 stations was made on the coast of Alexandria covering 55 km extending between latitudes (deg.N) (31.11 and 31.20) and longitudes (deg.E) (29.51 and 30.40) for depths ranging between 3 and 17 m (Fig. 1). The aim of the survey is to assess the general presence and abundance of sea urchins on the coast of Alexandria city. From these 13 stations, seven stations were chosen which were on the east side of Alexandria city. It should be noted that the west stations were almost void of any sea urchin (Fig. 1). Sampling from the seven selected stations was done seasonally, from autumn 2014 to summer 2015. The stations were about one to 10 km apart and were 0.8–10 km away from the coast (Fig. 1).

Sampling collection and analysis

At all stations, sea urchin density and size (without spines) were assessed and they differed in space and time. A 1 m × 1 m quadrat in size was used at each station. The quadrats were placed randomly along a 100 m × 100 m transect at the sampling points at depths between 3 and 9 m. Samples were collected taking into consideration individuals under rocks, on vertical walls and from crevices. The collection was seasonal and the specimens were kept in plastic containers filled with sea water from the sampling location. These sea urchins were processed live within 24 h of collection. Density at each station, number of individuals per meter square (ind./m^2), was determined. All individuals were counted and test diameters (TD) were measured by means of a Vernier Caliper (0.05 mm accuracy). Sea urchin sizes were grouped in intervals of 0.5 cm. Specimens with a test diameter less than 20 mm were counted even though they were of low abundance during the study.

Sampling time was random since the dates of collection trips were randomly selected (based on the weather and wave action) along the study period to represent temporal variability. The two species of sea urchins were sampled in the same patches or sampling point.

At each sample position, the associated fauna and flora were collected as subsample according to their percent coverage. The over-story species and the understory species were collected. The identification was recorded for each taxon to the genus level. The abundance of each genus was then assessed according to three keys: low abundance (+), moderate abundance (+ +) and high abundance (+ + +). The water temperature, depths and the type of substrates in each station were recorded seasonally using Fish Finder-140.

Statistical analysis

A one-way analysis of variance (ANOVA) was conducted to test the differences in abundance as well as size group distribution between the two echinoid species using the computer program SPSS (SPSS Version 11.0.0, 2003). Tukey TSD test and Post-hoc test were used to compare means when *F*-values from the ANOVA were significant ($P < 0.05$ and $P < 0.01$).

Results

The biotic system of the different stations consisted of wide varieties of seaweeds and invertebrate species. The area of study was characterized by being rocky-sandy with gentle horizontal slopes except in the station of Sidi Gaber (S7) where we could find large vertical boulders. Temperature throughout the period of study ranged between (16 °C and 29.5 °C). Fig. 2 shows the pooled data of the major macrobenthic fauna found in the study areas. The group of echinoids (*P. lividus* and *A. lixula* combined) is the major macrobenthic group in terms of abundance (49%) followed by the oysters (40%) and the sea cucumber (11%). Fig. 3a and b shows that the echinoid population had the lowest occurrence with respect to the other

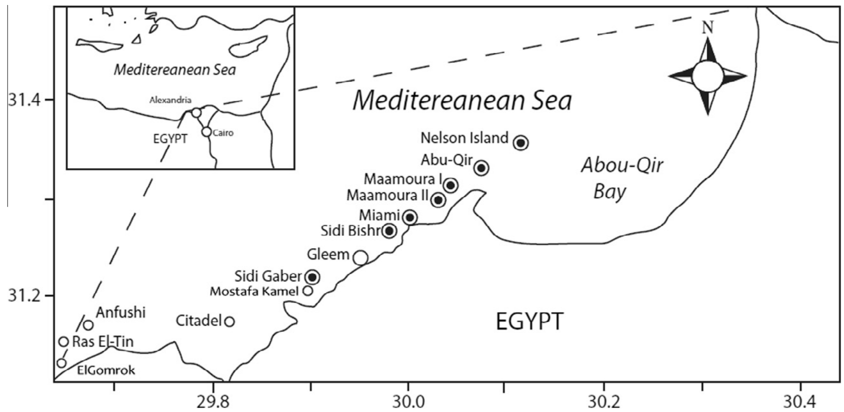

Figure 1 Map showing sample collection sites (closed circles) 1: Nelson Island, 2: Abu Qir, 3: Maamoura I, 4: Maamoura II, 5: Miami, 6: Sidi Bishr, 7: Sidi Gaber. Open circles: areas surveyed with no sea urchins, close circles: selected sampling stations.

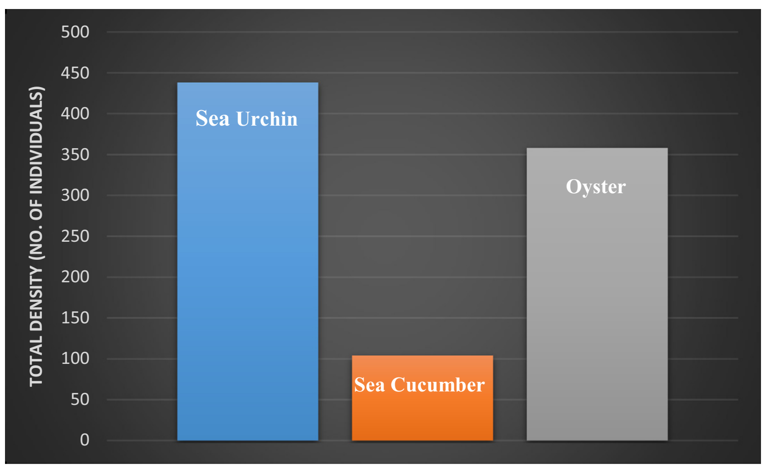

Figure 2 Total density of macrobenthic fauna in the study area during the whole study period.

macrobenthic groups, sea cucumber and oysters, in winter. However, the oysters and the sea cucumbers showed increase in abundance during the winter season. We should note that, station (4) showed the highest occurrence of echinoids and oysters throughout the year. This was confirmed when running the Tukey HSD test where the densities of sea urchin at different stations and seasons were highly significant than the sea cucumber population at ($P < 0.01$), while sea cucumber densities were highly significant ($P < 0.05$) when compared with the oyster population. No significant differences were found between sea urchin and oyster population's densities.

The echinoids are composed of two species *Paracentotus lividus* and *A. lixula*. The collected data show that *P. lividus* was the dominant echinoid (91% of the total collected echinoids) than *A. lixula* (9% of the total collected echinoids) throughout the different seasons in all stations. Both species showed seasonal different distribution in their abundance throughout the year as shown in Fig. 4. In autumn, *P. lividus* is of the highest abundance in stations 5 and 6 (Fig. 4). As for the black urchin *A. lixula*, it was found to occur in autumn in almost all stations except station (3). In winter, it was only detected in stations (1, 2 and 3). In spring, *A. lixula* was present only in stations (4, 6 and 7). While in summer, *A. lixula* showed presence in all stations except S2 and S5. No significant differences were found ($P > 0.05$) between the densities of *A. lixula* densities in different seasons and stations. Similarly, *P. lividus* densities showed also no significant differences in different seasons and stations.

Fig. 5 describes the distribution abundance of *P. lividus* and *A. lixula* according to their sizes. The sizes of *P. lividus* ranged between 15 mm and 65 mm in test diameter (TD). While for *A. lixula* they ranged from 15 mm to 60 mm in test diameter (TD), in the different study stations. The commercial size for the edible *P. lividus* (i.e. >40 mm) amounted for 33% of the collected sample. The peak of densities recorded for the *P. lividus* was observed between size classes ranging between (25–45 mm) test diameter and are represented in all stations. Station (4) showed the highest density of *P. lividus* of the size class 35–40 mm test diameter. Moreover, size classes less than 25 mm and more than 50 mm test diameter for *P. lividus* were present with lower densities in the different stations.

As for *A. lixula*, Fig. 4 shows that the different size classes, from 15 to 60 mm test diameter, are represented with variable occurrence in all sites with much lower densities than that of *P. lividus* in most stations. The size class 40–45 mm test diameter was represented in all stations with variable densities except in station (1) where they showed no occurrence.

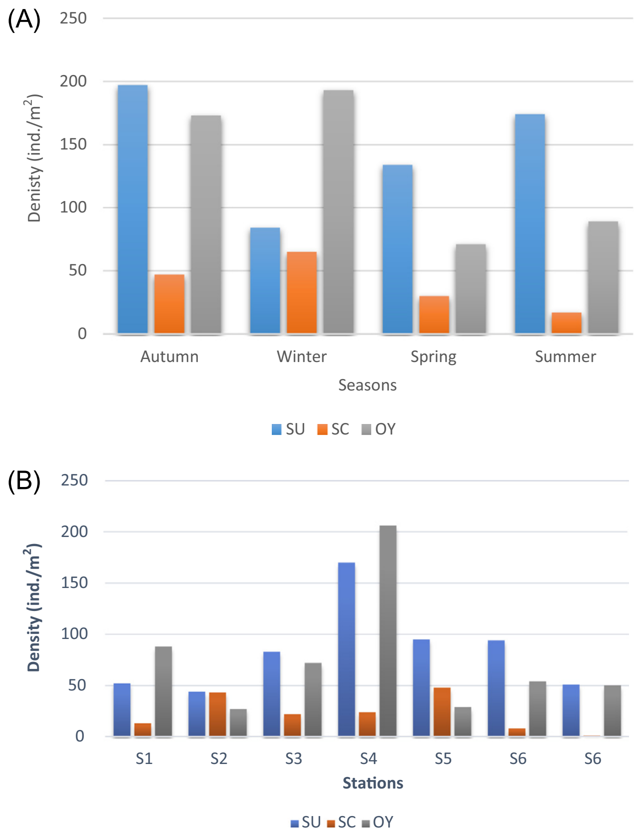

Figure 3 Density of major groups of macrobenthic fauna (SU = sea urchin, SC = sea cucumber and OY = oyster) in different (A) seasons and (B) stations (S1–S7).

Table 1 describes the qualitative and quantitative seasonal distribution of benthic assemblages associated with the echinoid population in the study sites. There are different categories of different species such as seaweeds (erect red, green and brown algae; encrusting algae), Porifera (sponge), Cnidarian (coral and jellyfish), Echinodermata (sea cucumber, irregular sea urchin and brittle stars), Crustacea (snapping shrimp, Isopoda, grammarian Amphipoda, hermit crab, shore crab, barnacles), Bivalvia (*Pinctada* spp. and *Modiolus* spp.), Gastropoda (*Aplysia* spp. and *Thais* spp.), Tunicata (colonial and solitary), Bryozoa (lace coral) and Annelida (bristle worms, flat worms and tube worms). The quantitative abundance of most of these groups is more prominent in warmer seasons as shown in Table 1.

Many seaweeds were recorded especially in spring and summer such as some Rhodophyta (red algae fleshy and coralline) of the genus *Corallina* spp., Chlorophyta (green algae) of the genus *Ulva* spp. and *Codium* spp., Phaeophyta (brown algae) of the genus *Colpomenia* spp. and *Padina* spp. and many crustose algae. The Phaeophyta seaweeds appeared in spring and autumn seasons. The most dominant macroalga in the studied stations, throughout the year, was the green alga *Codium* spp.

The sole occurrence of Rhodophyta especially the coralline algae (*Corallina* spp.) and crustose algae was observed to be correlated with the presence of *A. lixula* especially in autumn season in stations (1 and 2). While in station (3) to station (7) of the same season, the abundance of Rhodophyta decreased especially in the presence of the black *A. lixula*. In spring and autumn, the presence of Phaeophyta (*Colpomenia* spp. and *Padina* spp.) along with red and green algae was coinciding with higher densities of *P. lividus*. In summer, with an increase of water temperature of a range from (22 °C to 29 °C), even though the brown seaweeds disappeared, the green and red algae remained of high and moderate coverage respectively accompanied with relatively high densities of *P. lividus*. Stations (4) and (5) had assemblages of stony corals of the genus *Oculina* spp. observed to be associated with higher densities of *P. lividus* throughout the year. In addition, the presence of sponge genus (*Cinachyra* spp. and *Plaktoris* spp.) in stations (1 and 2) is usually accompanied with the low presence of the common echinoid *P. lividus* throughout the year. In the winter season, with water temperature ranging between 16 and 21 °C, the decrease of the available algal resources was observed to coincide with the lowest recorded density of the sea urchin population.

Discussion

The present study investigates the spatial and temporal variability in the distribution, abundance and size composition of the echinoid population off Alexandria city, Egypt. The results showed dominance of the echinoid species *P. lividus*, in most studied stations, than the black urchin *A. lixula*. The highest density of the echinoid population aggregated mainly in the east side of Alexandria city between depths 3 and 9 m. The density of the echinoid population (considering both species together) ranged between 2 and 63 ind./m^2 along the study stations. Such high echinoid densities usually were on rocky habitats accompanied by an abundant coverage of macroalgae and different seaweeds. A well-structured habitat, with availability of shelter and food sources, is preferable for echnioids allowing the co-existence of *P. lividus* and *A. lixula* due to microhabitats and diet diversification (Privitera et al., 2008; Pinna et al., 2012).

In the present study the highest densities recorded for *P. lividus* were during autumn, spring and summer seasons (54–59 ind./m^2). Such high densities might be attributed to many factors such as the availability of many types of fleshy algae, which are the preferred food for *P. lividus* (Lozano et al., 1995; Guidetti et al., 2004; Shpigel et al., 2004), shelter (Privitera et al., 2008), water temperature and photoperiod (Lozano et al., 1995; Shpigel et al., 2004). Furthermore, the occasional low densities of *P. lividus*, in some of the study stations between different seasons, might be attributed to predation (such as some fish, crabs and octopus) as mentioned by Kitching and Thain (1983) or to immigration of *P. lividus* in long trips to different locations in the process for searching either for food or shelter (Pinna et al., 2012).

In contrast, in Israel, Yeruham et al. (2015) reported that in past surveys, conducted in the seventies, the number of *P. lividus* individuals on their coasts ranged between (2 and 10 ind./m^2). Recently, between 2010 and 2014, they made another survey covering over 80 km of the coast of Israel. Their results showed a drastic decrease in the abundance of *P. lividus*, recording only a total number of 19 individuals.

In the present study, despite of the availability of the preferred food of *A. lixula*, the encrusting corallinales (Privitera et al., 2008; Martínez-Pita et al., 2010; Hereu et al., 2012), their densities were very low in all stations throughout the study

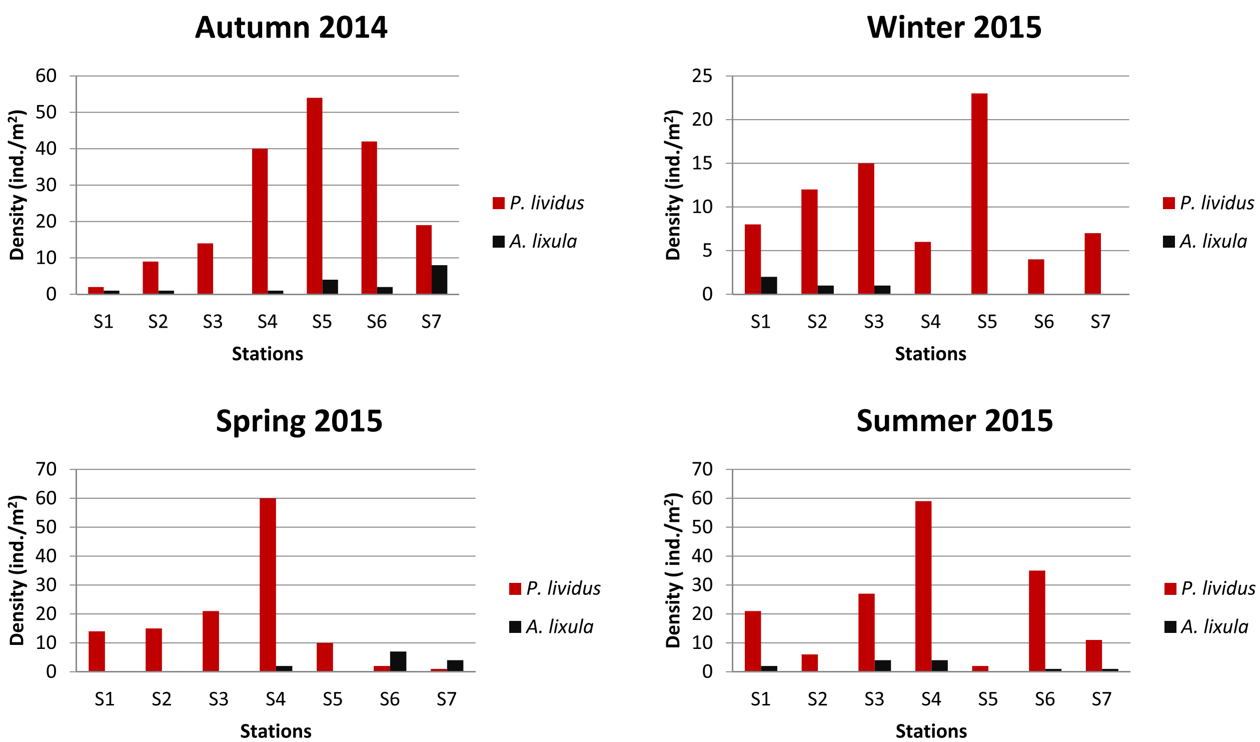

Figure 4 Seasonal density of the two echinoids *Paracentrotus lividus* and *Arbacia lixula* in the study stations (S1–S7).

period. Such low densities might be explained by lack of vertical walls, in the study area, that are preferred by *A. lixula* (Privitera et al., 2008). This is why we could explain the relatively high occurrence of *A. lixula* in the Sidi Gaber station where we could find boulders with vertical walls.

In the present study, *P. lividus* and *A. lixula* co-existed with dominance of the common sea urchin *P. lividus*. According to Privitera et al. (2008), both species, *P. lividus* and *A. lixula*, are found in the Mediterranean subtidal rocky coasts in depths reaching (50–80 m). The authors also mentioned that *A. lixula* is less affected by human impact and fish predation than *P. lividus* and could benefit from this to dominate the fishery sites of *P. lividus* (Guidetti et al., 2004). However, this is not the case in our study. This suggests the presence of interspecific competition between the two species, in the area of study, favoring the dominance of *P. lividus*.

The present study shows that the largest size classes (> 60 mm test diameter) of *P. lividus* are found with low densities in station (7). The stations (3, 4 and 5), are the most popular areas for sea urchin recreational fishery and are called "sea urchin grounds" (personal communication). They have high occurrence of size classes at the threshold of the commercialization size (> 40 mm test diameter). Such occurrence of large size classes suggests a well-structured population and habitat according to Turon et al. (1995). Moreover, Guidetti et al. (2004) mentioned that the locations that suffer from an overexploitation of *P. lividus* in rocky reefs in the Mediterranean might reduce the mean size of *P. lividus* population by truncating the size class structure of the harvested population.

Furthermore, the small size classes (< 25 mm) were found in low densities in all the study sites. This might be due to collection of samples by SCUBA diving during daytime. As mentioned by Kitching and Thain (1983), even though sea urchins are nocturnal foragers, large size classes tend to feed by daytime under the effect of hunger or diurnal migration, while most small size classes of *P. lividus* remain sheltered underneath rocks during daytime.

The present investigation shows that, even though, sea urchin densities were high (> 50 ind./m^2), the algal biomass remained abundant with no apparent barren spots in the area. This contradicts Privitera et al. (2008) who indicated that barren grounds are formed when sea urchin densities are more than 15 ind./m^2. Also, Kitching and Thain (1983) mentioned that *P. lividus* is likely to exert the most influence on its habitat and co-occurring benthic organisms and standing biomass of erect and fleshy algae (Jeon et al., 2015) where its population density is high. *P. lividus* grazing effect has a leading role in the formation of barren areas (Agnetta et al., 2015). However, this is not the case in our study as the algal assemblages were rich and diversified along the whole period of study.

Based on the present results, no fixed food consumption pattern was observed that might relate the distribution and abundance of the commercial and edible *P. lividus* to the surrounding available algal resources. This might suggest that this echinoid species has a certain degree of selective feeding behavior (Agnetta et al., 2015) and relocation capabilities that is driven by the search for the suitable food (foraging trips) that fits the physical requirements of the urchin (Pinna et al., 2012). Lemée et al. (1995) discussed the food selectivity of *P. lividus* in different seasons and their study revealed that some algal species, such as the Mediterranean Chlorophyta, Ulvophyceae (*Caulerpa taxifolia*), and other Phyophyceae, have a chemical defense mechanism that secretes secondary metabolites, at different times of the year, that repel *P. lividus*. This might force the urchin to explore other types of food or other less favorable algal resources. Moreover, the magnitude of the echinoid popu-

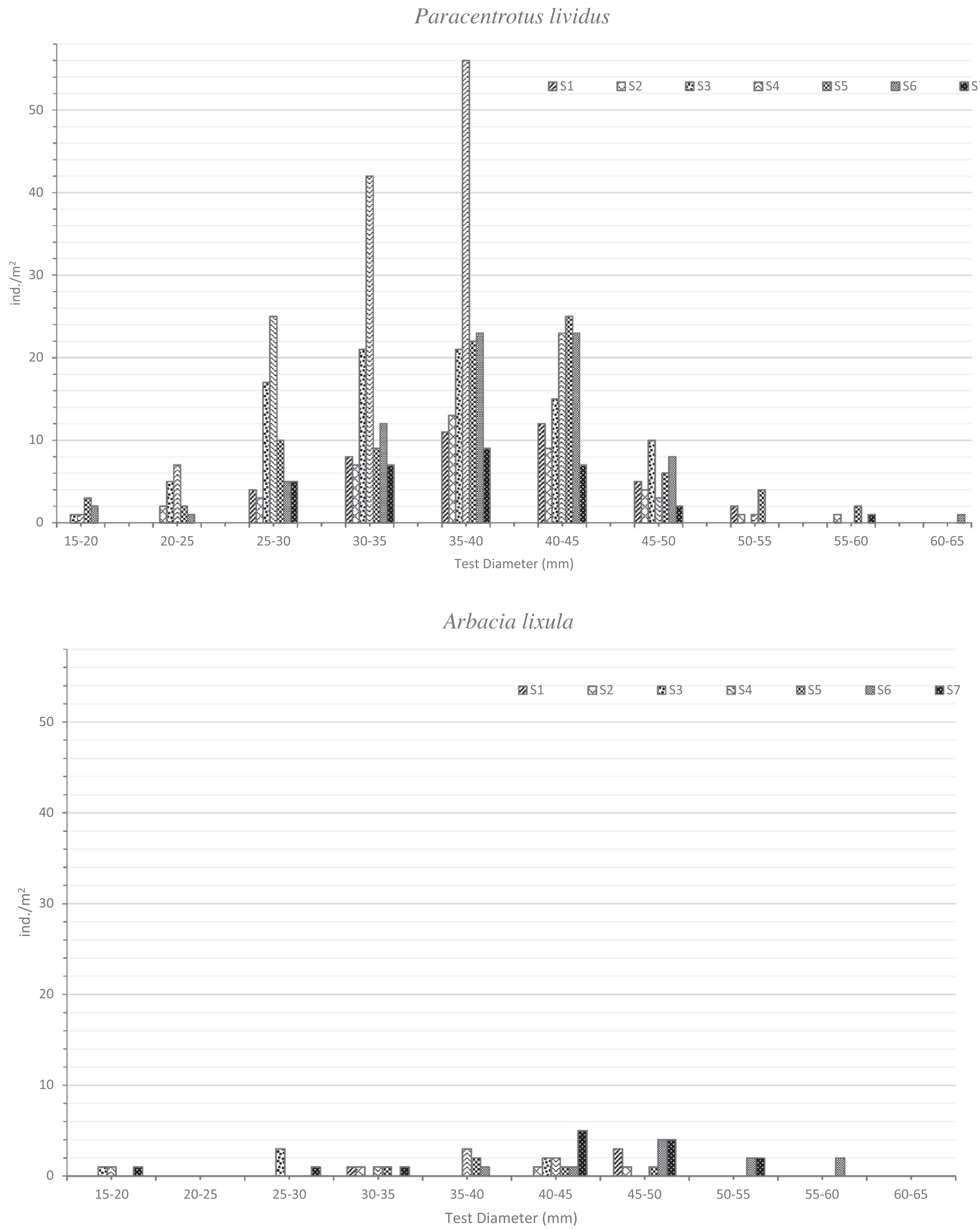

Figure 5 Denisty distribution of *Paracentrotus lividus* and *Arbacia lixula* according to size classes in different study stations (S1–S7).

lation might affect the type of algal food selected. Hence, at high population density, *P. lividus* tends to consume readily *Codium* spp., which is a fast recolonizing species able to recover fast after foraging attacks of *P. lividus* (Kitching and Thain, 1983).

Nevertheless, the study area had diverse and rich food resources other than algae suitable for the echinoid populations. Martínez-Pita et al. (2010) discussed the feeding behavior of *P. lividus* as being an opportunistic generalist species able to exploit a number of food resources (such as organic particles, microalgae, sponges, hydrozoa or copepods), although brown macroalgae (i.e. *Padina pavonica*) and seagrasses (i.e. *Posidonia oceanica*) constitute the main and preferable feeding resource. *A. lixula* also has a considerable trophic plasticity, ranging from omnivory to strict carnivory and has a scraping predatory behavior on erect, encrusting algae and sessile animals (Wangensteen et al., 2012; Agnetta et al., 2015).

Table 1 Qualitative and quantitative seasonal distribution of benthic assemblages in the study stations (+) low, (+ +) moderate and (+ + +) high abundance.

Groups	Seasons																											
	Autumn 2014							Winter 2015							Spring 2015							Summer 2015						
	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4	S5	S6	S7
Algae																												
Rhodophyta	+ + +	+ + +	+ +	+		+ +	+ +	+ + +	+ +	+	+ +			+	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ + +	+ + +	+	+ + +	+ +
Chlorophyta		+		+ +	+ + +				+ +			+ + +			+ +	+ +	+ + +	+ +	+ +	+ +	+ + +	+	+ +	+	+		+	+
Phaeophyta		+			+										+	+	+ + +	+	+	+	+							
Crustose Algae		+	+	+	+	+						+			+		+										+ + +	
Porifera																												
Sponge	+ + +	+ +						+ +	+ + +			+			+ +				+		+		+ + +		+	+ + +	+	
Cnidaria																												
Coral		+ +		+ +	+			+	+ +		+ +	+				+ +		+ +	+				+ +		+ +	+		
Echniodermata																												
Heart sea urchin																							+	+				
Sea cucumber	+ +	+ +	+ + +	+ + +	+ +	+ +		+	+ + +	+ +	+ +	+ + +			+ +	+ +	+ +	+ +	+ + +	+		+	+ +	+	+	+ +	+	+
Brittle Star		+ + +		+ +	+ +	+ +			+ + +				+ +				+ +	+ + +				+		+ +		+ +		+ + +
Crustacea																												
Snapping shrimp					+	+			+				+															
Gammarus spp.		+ +		+ +	+ +												+ + +	+ + +		+ + +	+ + +	+		+	+ + +		+ + +	+ + +
Isopods																		+ + +		+ +	+ +			+ +	+ +	+	+ +	+ +
Shore crabs		+		+ +	+ +				+ +	+	+										+			+	+ +	+	+ +	+
Hermit crab			+							+	+		+							+	+							
Barnacles	+	+ + +	+ +	+ +	+ + +		+ +	+ +	+ + +	+	+		+	+	+ +	+ +		+ +	+ +	+ +	+ +	+ +	+	+ + +		+	+ +	+ +
Bivalves																												
Pinctada spp.	+ + +	+	+ + +	+ + +	+	+	+ +	+ +	+ +	+ +	+ + +	+ +	+ +	+	+ +	+ +	+	+ + +	+ + +	+ + +		+		+ + +	+ + +	+	+ +	+ + +
Modiolus spp.			+ + +	+ +			+ +	+ +		+ + +	+ + +			+ +	+	+	+ + +	+	+	+	+	+ + +	+	+ + +	+ + +			+ + +
Gastropods																												
Thais spp.	+	+			+ +	+ +	+ +	+	+			+	+		+ + +	+	+	+	+	+ + +	+ + +	+	+	+ + +	+ +	+		+ + +
Aplysia spp.																	+ +		+ +							+		
Conus spp.																						+						
Patella spp.			+							+	+																+	
Tunicates	+ + +	+ + +	+	+ +	+ +			+	+	+	+	+		+						+	+							
Bryozoa	+	+ +		+ +	+ + +	+ +		+ +	+ + +						+ +	+ +	+ +	+ + +	+ +	+ + +	+ + +	+ +	+		+ +	+	+	+ +
Annelids	+ +	+		+ +	+ +	+ +	+ +	+	+ + +					+			+ + +	+ + +	+ +	+ +	+ + +	+ +	+	+ + +	+ + +	+	+ + +	+ + +

In conclusion, the current study suggests interspecific competition between both echinoid species *P. lividus* and *A. lixula*. The dominance of *P. lividus* shows its higher ecological adaptive plasticity than the black *A. lixula*. It appears that the study stations are well-structured habitat for the presence and recruitment of the edible *P. lividus*. The low presence of the non-edible *A. lixula* is not currently of major concern as its co-occurrence appears not to inflict any threats on the valuable commercial population of *P. lividus*.

Finally, it is recommended that this study should be extended to all the Egyptian coasts on the Mediterranean Sea and the Red Sea to know the status of the Egyptian commercial sea urchin population in order to sustain such valuable wild resource. Furthermore, it is important to investigate the potential of these sea urchins as successful aquaculture candidate species.

Conflict of interest

The authors state that there is no conflict of interest to declare.

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