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Spat efficiency in the pearl oyster *Pinctada radiata* (Leach, 1814) in the surface and bottom water at Karantina Island

by

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Abstract

The present study was carried out to determine the spat efficiency in the pearl oyster (*Pinctada radiata*, Leach, 1814) in surface and bottom water at Karantina Island (Izmir/Turkey). Polyethylene mesh bags were used as collectors. An annual average of 175.16 ± 11.32 spat m^{-2} was obtained from PSC (placed surface collectors) and 82.65 ± 3.89 spat m^{-2} was obtained from PBC (placed bottom collectors). The largest number of new spat attachments occurred in August, both on PSC and PBC: 44 ± 3.46 and 26 ± 2.88 spats were found respectively in the outer and inner mesh bags of PSC, and 33 ± 5.77 and 48 ± 6.92 spats were found respectively in the outer and inner mesh bags of PBC. New spat attachments (≥ 10 mm) continued throughout the study period, except April and May. Adult pearl oysters (≥ 50 mm) were found in May. There was a significant difference between PSC and PBC in the total number of spat attachments, the monthly spat attachments and the first spat attachments ($p < 0.05$). The total number of new spat attachments was positively correlated with temperature and chlorophyll *a* for both depths ($p < 0.05$).

Key words: *Pinctada radiata*, pearl oyster, spat settlement, growth, depths, Aegean Sea

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Introduction

Many species of the Pteriidae family have been used in pearl mariculture and valuable pearls are produced in many parts of the world (Beer & Southgate, 2000; Norton et al. 2000). Since ancient times, they have contributed to the natural pearl industry worldwide and played an important role with their meat, shells and pearls (Almatar 1992; Nagai 2013). The pearl oyster *Pinctada radiata* is a bivalve species belonging to the Pteriidae family. *P. radiata* is a Lessepsian species (Dogan & Nerlovic 2008; Deidun et al. 2014) distributed along the Mediterranean and Aegean coasts (Yigitkurt et al. 2017; Theodorou et al. 2019).

Spat collection is a method of collecting juveniles and requires lower costs compared to larvae production in hatcheries (Friedman & Bell 1996). Due to the negative effects of collecting mature oysters from the wild, the spat harvesting procedure has become much more important for enterprises (Knuckey 1995). Furthermore, spat collectors should be placed in areas where the existence of the species is essential to achieve high spat efficiency (Monteforte & Garcia-Gasca 1994).

Artificial collectors collect the required amount of pearl oyster spat in specific seasons. Spat collectors are designed to create a suitable environment for settlement and safe growth (Su et al. 2007). Larvae, including the metamorphosis stage, generally prefer to take refuge on safe materials to protect themselves (Beer & Southgate 2006). Materials such as plastic strips, coconut branches, bushes or commercial polyethylene mesh bags are used for spat collection (Victor et al. 1987; Gervis & Sims 1992; Friedman et al. 1998; Urban 2000). While spat harvesting efficiency is related to the material and shape of a collector, the area, depth, water current, seasonality and water conditions are also important factors (Coeroli et al. 1984; Sims 1990; Monteforte & Garcia-Garca 1994; Knuckey 1995; Friedman et al. 1998; Yigitkurt et al. 2017). The correct timing is also crucial for the collection of target species and high efficiency, otherwise the required amount of spat cannot be harvested because of undesired (by-catch) species (Brand et al. 1980; Cabral et al. 1985; Yigitkurt et al. 2017).

This study aimed to determine the difference in spat collection efficiency between surface and bottom water. The study was based on monthly spat collection and growing activity of spat, using collectors with commercial polyethylene mesh bags at Karantina Island (Izmir/Turkey).

Materials and methods

Study Area

The study was conducted at 30 km west of Izmir (38°22'44N and 26°47'12E) between July 2007 and August 2008 on the west coast of Urla Karantina Island (Fig. 1).

The depth of the water column was between 10 and 11 m, with sandy and muddy, partially stony sediment. Collectors were placed at the surface (1 m depth) and at the bottom (8 m depth) in July.

Seawater samples were collected from both depths. Temperature, pH and salinity were measured using a mercury thermometer, a pH meter (Hanna HI 8314) and a refractometer, respectively. Water samples were collected in a sterilized glass tube and transported to the laboratory. In the laboratory at the Ege University, the content of chlorophyll *a*, particle inorganic and organic matter (PIM and POM) in the samples was determined. PIM, POM and chlorophyll *a* values were calculated according to Strickland & Parsons (1972).

Spat efficiency

The collectors were made of polyethylene mesh bags according to Beer & Southgate (2000). They were prepared by placing polyethylene material with the same surface area into the main collector body. The length and width of the mesh bags were 100 and 29 cm (0.29 m^2), respectively. Mesh bags consisted of two parts, which were an outer mesh bag and an inner mesh bag for the surface and bottom. The mesh size of the outer mesh bag was 5 × 4 mm and of the inner mesh bag – 4 × 2 mm. A collector system was designed as "placed surface collectors" (PSC) and "placed bottom collectors" (PBC) and is presented in Figure 2. In this study, three collector systems were deployed in the area. Each collector system consisted of 24 mesh bags, 12 of which were placed at the surface and 12 at the bottom so as to triple the sets. These mesh bags were tied with a plastic rope to PVC pipes at 15 cm intervals. Two PVC pipes were fixed on the main rope at a depth of 1 and 8 m, with the surface and bottom collectors on both sides. The system was completed by connecting a buoy to the top part and an anchor to the bottom.

Every month, six mesh bags were taken from each collector system for spat efficiency. Length groups were defined as follows: ≤ 10 mm, 11–20 mm, 21–30 mm, 31–40 mm, 41–50 mm and > 50 mm. In this study, individuals with a diameter of 10 mm or less were considered as new spat according to Yigitkurt et al.

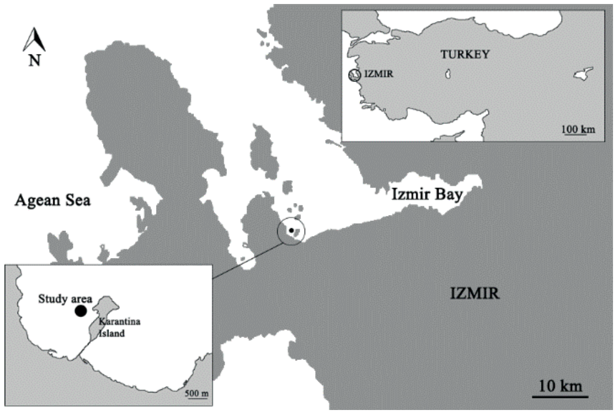

Figure 1

Study area on the west coast of Urla Karantina Island

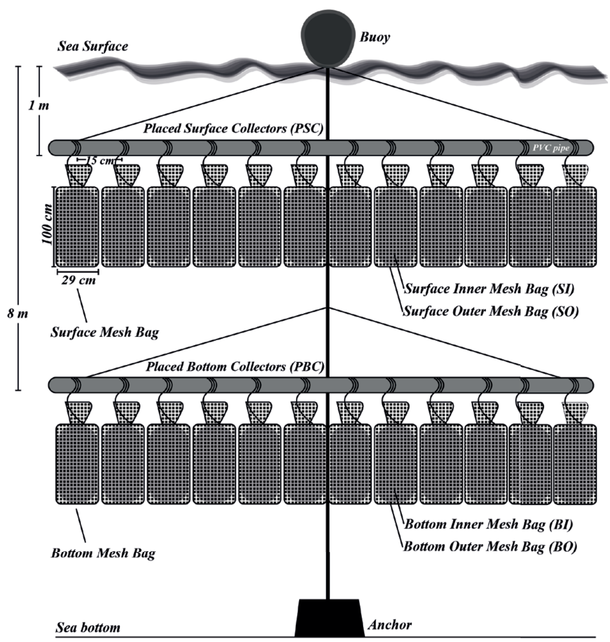

Figure 2

Collector system design at two different depths

(2017). The length (dorsoventral) of the target species *P. radiata* and other bivalve spats were measured using a Mitutoyo (IP66) digital caliper and weights were recorded by a Sartorius (GD603; 0.001 g) digital scale.

Statistical analysis

The Kolmogorov–Smirnov test was used to test the normal distribution. Pearson correlation analysis was employed to determine the relationship between spat attachment and environmental parameters (temperature, salinity, chlorophyll *a*, PIM and POM). Spat efficiency for PSC and PBC groups was tested by the Mann–Whitney U test. Monthly differences in the amount of spat, newly attached spats and spat efficiency between PSC and PBC were examined by the Kruskal–Wallis test. Descriptive statistics were carried out using Microsoft Excel and statistical analysis was performed using SPSS 15.0 software.

Results

The highest temperatures were measured in July and August and were 30.0°C at the surface and 28.5°C at the seabed, respectively. The minimum values were recorded in February and were 13.2°C and 13.0°C for the surface and bottom water, respectively (Fig. 3a). Mean salinity values were determined as 36.86 ± 0.2 PSU and 36.40 ± 0.16 PSU for the surface and the seabed, respectively (Fig. 3b). The lowest chlorophyll *a* value (0.923 and 0.528 μg l^{-1}) was measured in May at the surface and the seabed, the highest value (7.122 and 6.884 μg l^{-1}) was recorded in August at both depths (Fig. 3c). Mean pH of surface and bottom water was measured as 7.33 ± 0.19 and 7.27 ± 0.30, respectively (Fig. 3d). The maximum and minimum PIM concentrations at the surface were found to be 8.93 mg l^{-1} in September and 7.45 mg l^{-1} in February, respectively. The highest and lowest PIM values at the bottom were determined as 7.45 mg l^{-1} in February and 0.62 mg l^{-1} in August, respectively (Fig. 3e). The maximum POM values were determined in July for both depths (2.45 mg l^{-1}; Fig. 3f).

Spat efficiency

The total number of spats harvested during 12 months was 2059 ± 64.08 spat $year^{-1}$ on both collectors (PSC and PBC). In total, 1401 ± 46.18 spat PSC^{-1} were collected on PSC (surface outer mesh bag: 597 ± 18.47 spat; surface inner mesh bag: 804 ± 27.71 spat). The harvested number in PBC was 658 ± 17.89 spat PBC^{-1}, including the bottom outer mesh bag – 226 ± 14.43 spat and the bottom inner mesh bag – 432 ± 3.46 spat. The total spat attachment values of each collector were significantly different between the two depths and between the inner and outer mesh bags at both depths ($p < 0.05$). In total, 175.16 ± 11.32 spat m^{-2} were harvested from PSC and 82.65 ± 3.89 spat m^{-2} were found on PBC groups ($p < 0.05$).

The maximum spat harvest from both collectors was 235 ± 6.92 spat $(PSC + PBC)^{-1}$ in October and the minimum was 123 ± 2.30 spat $(PSC + PBC)^{-1}$ in April. The total spat efficiency was significantly different in each month ($p < 0.05$). The maximum pearl oyster spat harvest from PSC was in February and amounted to 155 ± 4.61 spat PSC^{-1} and the minimum was 82 ± 6.35

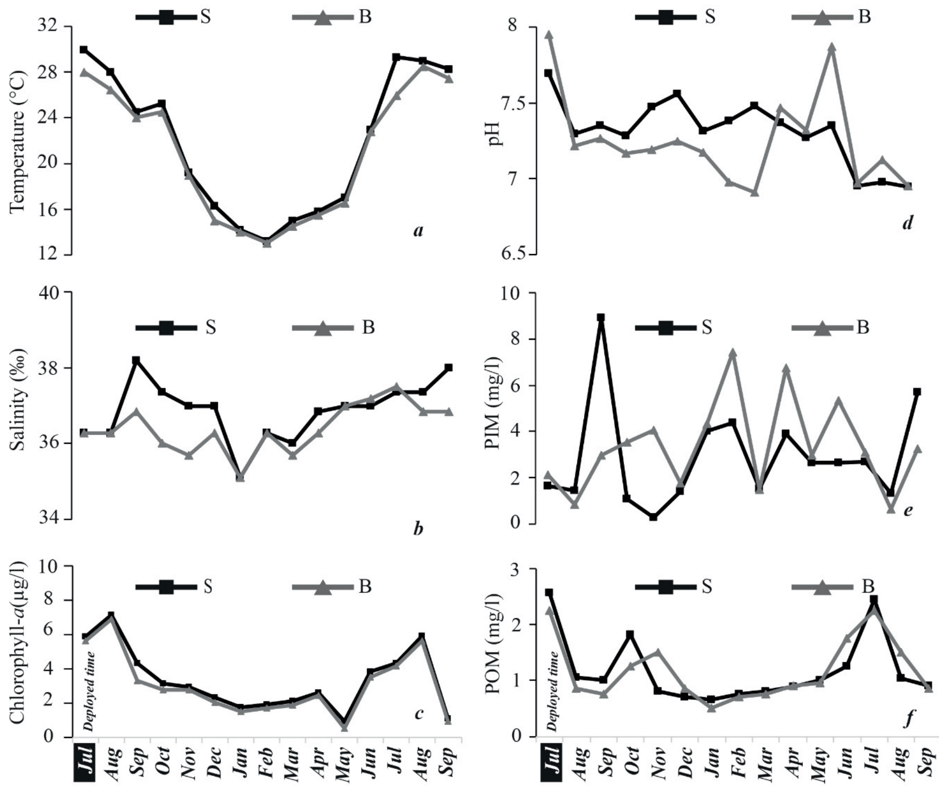

Figure 3

Surface (S) and bottom (B) water parameters in the study area (a – temperature, b – salinity, c – chlorophyll *a*, d – pH, e – PIM, f – POM)

spat PSC^{-1} in May. On average 116.75 ± 25.16 spat PSC^{-1} were harvested per month from PSC during the study period. The highest and the lowest number of collected spats from PBC were 94 ± 1.15 spat PBC^{-1} and 25±1.73 spat PBC^{-1} in August and July, respectively. The average number of spats collected from PBC per month was 54.83 ± 21.81 (Fig. 4). Individual values of monthly spat attachments were significantly different on PSC and PBC ($p < 0.05$).

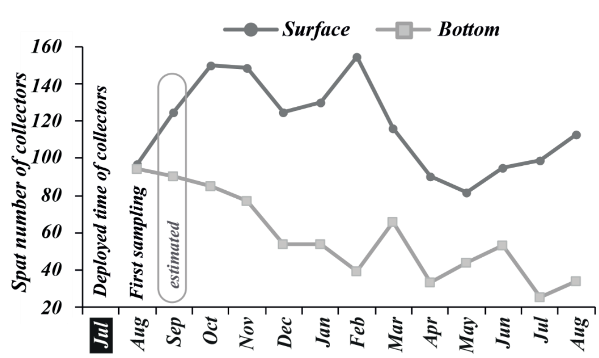

Figure 4

Spat distribution of *P. radiata* on PSC and PBC

New spat (≤ 10 mm) attachments were determined throughout the year, except April and May. The maximum number of newly attached spats was observed in August on both collector groups (151 ± 4.61 spat (PSC + PBC)$^{-1}$). The number of spats with shell length less than 10 mm was determined to be 44 ± 3.46 in the outer mesh bag of PSC and 26 ± 2.81 spats were found in inner mesh bags. The number of attached spats smaller than 10 mm was 33±5.77 and 48±6.92 in the outer and inner mesh bags of PBC, respectively (Table 1). There was a significant difference in the total number of new spat attachments in particular months ($p < 0.05$). A positive correlation was determined between the newly attached spat and temperature ($r = 0.775$), chlorophyll *a* ($r = 0.742$) and POM ($r = 0.666$) at the surface. A negative correlation was found between the newly attached spat and pH ($r = -0.706$) and PIM ($r = -0.751$; $p < 0.05$). In the bottom zone, the correlation between the new attachments and temperature ($r = 0.803$), chlorophyll *a* ($r = 0.774$) and POM ($r = 0.616$) was positive, while the correlation with salinity ($r = -0.653$), pH ($r = -0.577$) and PIM ($r = -0.782$) ($p < 0.05$) was negative.

Table 1

The number of *P. radiata* spats and the percentage distribution of length in the outer and inner mesh bags of collectors during the study (n – the number of individuals, SO – surface outer mesh bag, SI – surface inner mesh bag, BO – bottom outer mesh bag, BI – bottom inner mesh bag)

Months/Collectors		*n*	< 10 mm	11–20 mm	21–30 mm	31–40 mm	41–50 mm	> 50 mm
August	SO	49	89.8	10.2	0.0	0.0	0.0	0.0
	SI	48	54.2	45.8	0.0	0.0	0.0	0.0
	BO	35	94.3	5.7	0.0	0.0	0.0	0.0
	BI	59	81.4	18.7	0.0	0.0	0.0	0.0
Sampling failed in September								
October	SO	58	5.2	50.0	44.8	0.0	0.0	0.0
	SI	92	1.1	28.3	68.5	2.2	0.0	0.0
	BO	25	16.0	56.0	28.0	0.0	0.0	0.0
	BI	60	5.0	38.3	56.7	0.0	0.0	0.0
November	SO	55	5.5	14.6	72.7	7.3	0.0	0.0
	SI	94	3.2	30.9	48.9	17.0	0.0	0.0
	BO	33	18.2	24.2	51.5	6.1	0.0	0.0
	BI	44	11.4	15.9	59.1	13.6	0.0	0.0
December	SO	52	7.7	19.2	46.2	26.9	0.0	0.0
	SI	73	0.0	16.4	56.2	27.4	0.0	0.0
	BO	10	20.0	10.0	40.0	30.0	0.0	0.0
	BI	44	4.6	18.2	65.9	11.4	0.0	0.0
January	SO	40	2.5	12.5	40.0	45.0	0.0	0.0
	SI	90	2.2	18.9	55.6	22.2	1.1	0.0
	BO	18	5.6	33.3	44.4	16.7	0.0	0.0
	BI	36	11.1	27.8	44.4	16.7	0.0	0.0
February	SO	74	1.4	16.2	47.3	35.1	0.0	0.0
	SI	81	1.2	16.1	44.5	38.3	0.0	0.0
	BO	8	0.0	12.5	50.0	37.5	0.0	0.0
	BI	31	3.2	16.1	51.6	29.0	0.0	0.0
March	SO	45	2.2	15.6	53.3	28.9	0.0	0.0
	SI	71	4.2	29.6	47.9	16.9	1.4	0.0
	BO	34	11.8	35.3	32.4	20.6	0.0	0.0
	BI	32	0.0	28.1	65.6	6.3	0.0	0.0
April	SO	42	0.0	14.3	50.0	35.7	0.0	0.0
	SI	48	0.0	18.8	50.0	25.0	6.3	0.0
	BO	16	0.0	6.3	62.5	31.3	0.0	0.0
	BI	17	0.0	17.7	35.3	47.1	0.0	0.0
May	SO	38	0.0	13.2	50.0	31.6	5.3	0.0
	SI	44	0.0	18.2	47.7	22.7	11.4	0.0
	BO	9	0.0	11.1	33.3	44.5	11.1	0.0
	BI	35	0.0	17.2	25.7	42.9	14.3	0.0
June	SO	46	4.3	10.9	37.0	21.7	17.4	8.7
	SI	49	4.1	14.3	36.7	20.4	18.4	6.1
	BO	22	4.5	18.2	27.3	13.6	27.3	9.1
	BI	31	3.2	9.7	35.5	29.0	19.4	3.2
July	SO	49	8.2	18.4	30.6	16.3	12.2	14.3
	SI	50	12.0	14.0	26.0	16.0	14.0	18.0
	BO	6	16.7	0.0	0.0	16.7	16.7	50.0
	BI	19	0.0	10.5	5.3	31.6	31.6	21.1
August	SO	49	4.1	16.3	14.3	14.3	26.5	24.5
	SI	64	10.9	9.4	17.2	10.9	25.0	26.6
	BO	10	0.0	20.0	10.0	20.0	10.0	40.0
	BI	24	0.0	16.7	20.8	20.8	37.5	4.2

In August, the shell length distribution of newly attached spats (≤10 mm) was 89.79% in the outer PSC mesh bag and 51.46% in the inner PSC mesh bag. These abundance ratios in the same month were calculated as 94.28% and 81.35% in the outer and inner mesh bags of PBC (Table 1). Oysters with a size of 21–30 and 31–40 mm indicated a steady growth. The number of oysters in the 41–50 mm size class increased in May. New spat attachments were observed in June and it was found that previously attached individuals grew up to 50 mm. In June, all length groups of pearl oysters were observed on the collectors. Adult specimens of *P. radiata* from the 41–50 mm and over 50 mm groups were abundant in the last period of the study, i.e. in July and August (Table 1).

Other species of the family

The percentage distribution of bivalve families on PSC and PBC during the year was determined (Fig. 5). The total number of bivalve spats in the collector groups during the year was 3316 ind./year. Ten bivalve families were identified, the majority of which were species of Pteriidae – 62.23%. The percentage of families *Pinnidae, Ostreadae, Pectenidae, Mytilidae* on the collectors were as follows: 5.09%, 4.91%, 11.08% and 4.76%, respectively.

Twelve bivalve species were identified: *P. radiata*, *Pinna nobilis*, *Chlamys varia*, *Chlamys glabra*, *Ostrea edulis*, *Mytillus galloprovincialis*, *Mytilus barbatus*, *Arca noea*, *Cardium tuberculata*, *Lima lima*, *Hietalla* sp. and *Anomia ephippium*.

We also encountered crabs: *Pisidia longimana*, *Pilimnus hirtellus* and *Macropodia longirostris*, gastropods *Bulla striata* and *Cerithium vulgatum*.

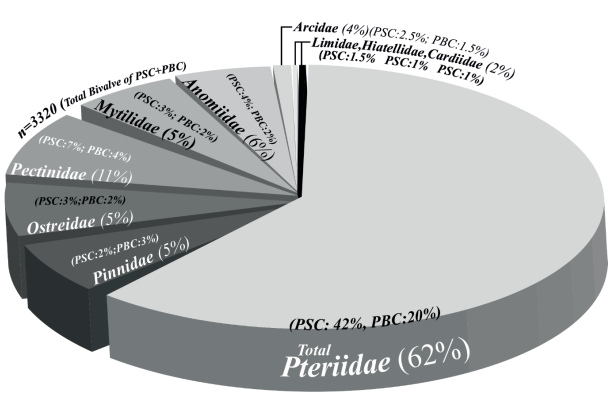

Figure 5

Percentage distribution of bivalve families on PSC and PBC during the year

Discussion

The collection of pearl oyster spats is affected by many factors: (1) availability of metamorphosing larvae, (2) timing of collector deployment, (3) type of collectors and mesh, (4) placement depth of collectors, (5) environmental parameters. The formation of pearl oyster spat after fertilization takes between 16 and 30 days, depending on the water temperature, food availability and the presence of a suitable substrate (Gervis & Sims 1992; Kanjanachatree et al. 2005). This reproduction period is also the time when collectors should be placed in water, because they should be placed in the area where the spat is planned to be collected approximately 30 days before the metamorphosis. In this study, we deployed spat collectors in July, before spawning, taking into account the reproduction cycle of the species. This period, selected on the basis of metamorphosis, also shows the importance of correct timing for collector deployment. The time of deployment of spat collectors is very important due to the availability of larvae at the early metamorphosis stage in sufficient quantity. Crossland (1957) reported that a timing error in the deployment of spat collectors would cause the presence of undesired species on collectors. In this study, the timing for settling and immersion of collectors was also observed. July was the best month for collector deployment in this region. The Pteriidae family accounted for 62.23% of all organisms collected. The obtained results show the accuracy of timing for the deployment of collectors in water.

One of the most important environmental parameters triggering reproduction is temperature and chlorophyll *a*. An increase in temperature and an increase in chlorophyll *a* content in water coincide with each other. When the first spats started to be detected in the collector systems, high temperature (28°C) and chlorophyll a (7.12 ug l^{-1}) values were observed. Behzadi et al. (1997) reported the beginning of the reproduction period of *P. fucata* (= *P. radiata*) between April (27.6°C) and June (31.7°C) in the northwestern part of the Gulf of Iran. Although Numaguchi & Tanaka (1986a) accepted the optimum temperature range for *P. fucata* spat from 17.5°C to 29°C, they determined the upper and lower temperature limits as 32°C and 15°C. Galil (2006) specified this range from 13°C to 30°C for *P. radiata*. In this study, the water temperature range in the study area was between 13°C and 30°C at both depths throughout the year. We collected the spat from collectors throughout the study period, but the newly attached spat allowed us to comment on the monthly reproduction. The intensive collection of the newly attached spat took place in August (28°C), when environmental parameters (temperature, chlorophyll *a*) were also high. Barnes (1957) stated that the reproduction in epibenthic assemblages occurred when the phytoplankton peaks were observed. The highest chlorophyll *a* value was also recorded in surface (7.122 μg l^{-1}) and bottom water (6.884 μg l^{-1}) in August, when the maximum newly attached spat (≤ 10 mm) was observed. A positive correlation was determined between the new spat attachments and temperature, chlorophyll *a* and POM values at both depths. An increase in the values of POM, consisting of seawater organisms – picoplankton, nanoplankton and mesoplankton, detritus and mucus (Lucas, 2008), triggers the reproductive activities of an organism and the larval development is completed in periods when the availability of nutrients is important for larvae. The highest POM values at both depths were recorded in July when the collectors were placed in water, and during the larval period until August, when POM became the source of food and was consumed extensively. The comparison of the environmental conditions observed in this study and the values presented in previous studies showed that the study area was suitable for reproduction, spat attachment and development of the species.

The largest total spat harvest in both collectors was in October (235 ± 6.92 spat $(PSC + PBC)^{-1}$) and the lowest in April (123 ± 2.30 spat $(PSC + PBC)^{-1}$). As mentioned earlier, there was no newly attached spat in April. The whole spat harvested in April was larger than 10 mm as it attached in the previous months. Although there was a difference in the number of spat attachments between PSC and PBC, the values of environmental parameters such as temperature, salinity, chlorophyll *a* and POM changed similarly. The difference in attachments at different depths is attributable to a positive phototaxis of bivalve larvae (Forward & Costlow 1974; Tomaru et al. 1999; Lucas 2008). Sensitivity to light may contribute to vertical migration of larvae of these bivalves (Forward & Costlow 1974). Finally, in this study, more individuals were found on PSC.

In addition, the number of < 10 mm individuals in the outer mesh bags of PSC was 44 ± 3.46 spats and in the inner mesh bag – 26 ± 2.81 spats, resulting in a total of 70 ± 4.61 spat PSC^{-1} in August. The comparison of the results obtained by Yigitkurt et al. (2017) with the present study shows an increase from 35 spat PSC^{-1} to 70 ± 4.61 spat PSC^{-1} in the *P. radiata* population in the study area. New spat attachments occurred in August and were observed throughout the year, except April and May. Therefore, it can be concluded that the spawning phase of mature pearl oysters in this region did not take place during these two months. In August, the maximum chlorophyll *a* values were recorded at both depths along with the largest number of new spat attachments. The maximum temperature values were also recorded in the same period (Fig. 2). Correlations between the total number of newly attached spat, temperature and chlorophyll *a* were found to be positively significant, however salinity, PIM and pH were found to be negatively significant ($p < 0.05$).

Knuckey (1995) reported that the attachment of Pteriidae family members in Australia was 198 spat m^{-2} throughout the year. The author also stated that the annual average of *Pteria* sp. (pearl oyster) attachments to collectors was 60 spat m^{-2}. Friedman & Bell (1996) reported that the average number of spat attachments was 60 spat m^{-2} and 2.4 spat m^{-2} for *P. maculata* and *P. margaritifera* in the Solomon Islands, respectively. Friedman et al. (1998) determined 10 spat m^{-2} of *P. margaritifera* in the Solomon Islands. In 1999, the researcher reported an average of 21 spat m^{-2} in the same area. Furthermore, Urban (2000) reported the annual average of *P. imbricata* (= *P. radiata*) spats in Colombia as 85.06 spat m^{-2}. Rodgers et al. (2000) reported the annual average of *P. margaritifera* spats to be 41 spat m^{-2}. Previous studies have explained that the number of spats varied according to species, collector type, study area and study period (Knuckey 1995; Friedman & Bell 1999; Rodgers et al. 2000; Urban 2000; Yigitkurt et al. 2017). Wada (1990) emphasized the success of surface collectors and suggested placing them as close to the surface as possible. An annual average of 175.16 ± 11.32 spat m^{-2} was obtained from the PSC groups and 82.65 ± 3.89 spat m^{-2} was determined for the bottom groups in the present study conducted around Karantina Island. The total annual average of pearl oyster spat was found to be 129.33 ± 6.97 spat m^{-2} in the study area. A considerable number of spats were collected in the present work compared to the above-mentioned studies.

The retention time of spat collectors in water may vary depending on the desired spat size and quantity, because as the residence time increases, the collection systems start to function like growth systems. In our study, we harvested 20 mm individuals from the collectors during one or two months and individuals larger than 50 mm during 11–12 months. Approximately the same results as ours were published for French Polynesia and the Cook Islands, as 55–60 mm dorsoventral length individuals were harvested from spat collectors (Coeroli et al. 1984; Sims 1993; Pouvreau & Prasil 2001). During the study, all length groups of *P. radiata* were determined on collectors (Table 1). While spat attachment was high during the first months of the study, the attachment capacity of collectors started to decrease in the following period. In this period, the intraspecific competition started on the collectors and the growth was confirmed by measurement of individuals. The attached spats can reach a certain size if the resistance capacity of the collector material is suitable. This result shows that obtaining pearl oysters of the required size is closely related to the time the collectors stay under water.

A large number of bivalve species were determined in the collector groups. It was found that these species were the cause of different attachment ratios of *P. radiata* spat between PSC and PBC. For example, in August, when the maximum attachment spat was observed on PSC, the abundance ratio of *P. radiata* spat was 75.8% and of *P. nobilis* – 13.3%. The ratio of *P. nobilis* increased up to 27.5% on PBC resulting in a reduction in *P. radiata* spat to 52.8% in the same month. It was found that *P. nobilis* suppressed *P. radiata* spat in PBC. In the same month, taxa of the Pectinidae family – *C. glabra, C. varia* and of the Mytilidae family – *M. galloprovincialis* dominated in the species composition on PSC and PBC. The competition within the collector affected the attachment. The low effect during the first month was due to the recent settlement of collectors. The reduction in the attachment capacity is related to the attachment of other species and the growth of these species resulted in the reduction of the collector surface area. Although the effect of abiotic factors on the attachment is critical, the effect of biotic factors on the spat distribution within a collector is also significant (Southgate et al. 2008).

Natural predators are attached to collectors in their larval stages and they develop within the collectors, destroying the living organisms (Friedman & Bell 1996; Urban 2000). Crabs harmful to spat, such as *Pisidia longimana*, *Pilimnus hirtellus*, and the gastropod *Cerithium vulgatum* were encountered on collectors. It was observed that these species are generally destructive to *P. nobilis*, *C. glabra*, *C. varia*, *A. ephippium*. Many broken shells of these species were found in collectors. A decrease in the size of the harvest was observed after February in the surface collectors. One of the reasons for this case was the occurrence of predators in the collectors. PIM values in January and February increased due to the deposition of chemical $CaCO_3$ solution and the decay of shells as a result of deaths in the collectors caused by predators.

Moreover, spat was harvested from sheltered and high water flow parts of the collectors. This attachment behavior can be aimed at protection against predators. At the same time, it was observed that spat of pearl oysters preferred dark areas for settlement (Coeroli et al. 1984; Sims 1990). Yigitkurt et al. (2017) collected *P. radiata* spat from the entrance and curved parts of collectors in Karantina Island. In this study, a large number of spats were harvested from the inner mesh bags. This is associated with the tendency to attach to sheltered and dark sites after the metamorphosis stage of pearl oyster larvae.

Eventually, if the spat is harvested from a collector to increase the stock, surface collectors should be preferred and the collectors should remain in the sea for 6–7 months, which will allow us to collect the desired amount of individuals. However, if the spats below 10 mm are needed for scientific studies, the collectors should be removed from water in the following month and the spat should be harvested. The number of similar studies such as the present one, which are the primary scientific source on pearl farming, should be increased and more comprehensive studies are required. This study aimed to determine the efficiency of spat collectors at the surface/bottom of the water and findings were presented in relation to this objective. It is believed that the results of this work will lead to further research.

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