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INFLUENCE OF STOCKING DENSITY ON THE GROWTH, SURVIVAL AND RECRUITMENT OF THE CARPET SHELL CLAMS *RUDITAPES DECUSSATA* AND *VENERUPIS PULLESTRA* BIVALVIA : VENERIDAE)

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ABSTRACT

The effect of stocking density on growth, condition, survival and spat recruitment of the carpet-shell clams *Ruditapes decussata* and *Venerupis pullestra* was studied experimentally in Lake Timsah, Suez Canal. Different sizes of clams reared in on-bottom trays at four densities (0.05, 0.1, 0.5 and 1.5 g/cm^2) and its density-dependent growth and survival were monitored during spring and summer seasons. Clams showed optimum growth and conditions at densities lower than 0.1 g/cm^2 in both seasons with no growth advantage at higher densities. In both species, the animal had a better growth and condition in spring compared to summer; however, survivals were approximately similar *in both seasons. Spat recruitment was quite dense at higher densities particularly during the spawning* season in summer. Criteria of density-dependent growth and recruitment were discussed in relation to the experimental conditions and to the surrounding factors.

INTRODUCTION

THE CARPET SHELL clams are the most commercial edible molluscs in the Suez Canal region (Gabr, 1991; Mohammed *et al.,* 1992) and widely distributed throughout Mediterranean coasts (Korringa, 1976; Breber, 1985). The high overfishing of these clams in Suez Canal lakes threatened its population and performed catastropic decline in its commercial fisheries. Few studies concerning distribution (Gabr, 1991; Ghobashy *et al.,* 1992), reproductive biology (Kandeel, 1993), growth (Mohammed, 1989) and parasitism (Hanafy *et al.,* 1997) of these clams were carried out sporadically though not entirely enough to manage its fishing or to develop ideal commercial aquaculture. Extra studies are urgently required to support its mariculture feasibility and to fulfill its great demands in shellfish markets. Stock-density in the holding trays and density-dependent regulations are among the important factors controlling successful rearing of bivalves (Dare and Davies, 1975; Spencer and Hepper, 1981; Mohammed, 1987; Chummy 1991). Economic systems for growing clams at controlled densities remain to be developed for different hydrographic conditions and scales of commercial operation (Lucas, 1977; Clause, 1981). The aim of the present study is to investigate the influence of stock density on the growth, condition and survival of the most economic carpet-shell clams *(Ruditapes decussata* and *Venerupis pullestra).* Also, the study will focus on the rate of the spat recruitment inside and outside the experimental trays in relation to stocking density.

MATERIAL AND METHODS

Batches of *Ruditapes decussata* and *Venerupis pullestra* were collected from clam grounds in lake Timsah, Suez Canal and sorted out into different size groups (5-10, 10-15 and 15-20 mm shell length). A part of these animals were used for initial measurements (shell length and total live weight) and their means were calculated for each size group. Replicates of these groups were distributed among wooden trays measuring 20 × 10 × 5 cm and covered with 3 mm mesh polythylene netting at different densities (0.05, 0.1, 0.5 and 1.5 g/cm^2) and immersed in muddy bottom on natural clam beds in lake Timsah in the beginning of April (for spring experiment) and August (for summer experiment). After two months (in both spring and summer experiments), the trays were evacuated and the final measurements (shell length and live weight) were taken for living animals. The instantaneous growth rates (G_{30})

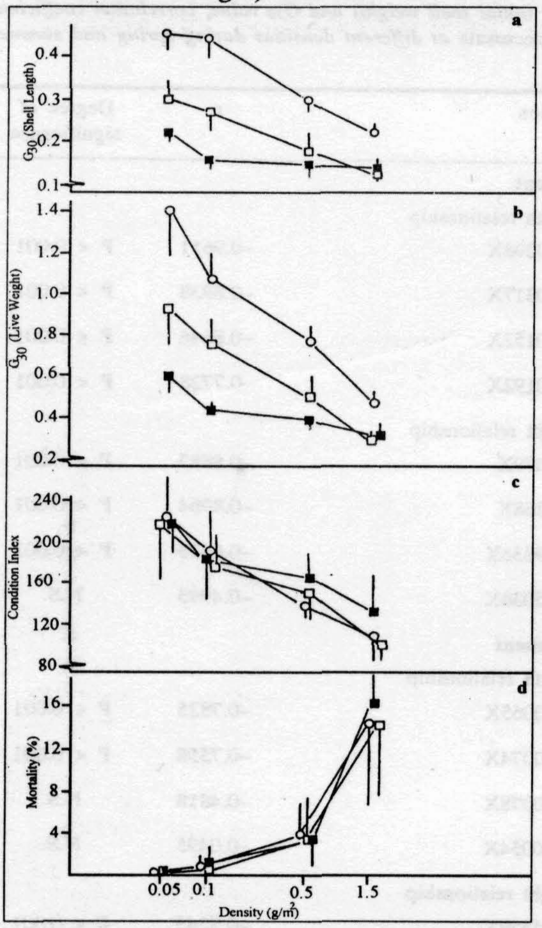

FIG. 1. *Mean values (± S.D.) of G_{30} shell length (a), G_{30} live weight (b), condition index (c) and percentage mortality (d) of three size groups of* Ruditapes decussata *in spring season at different densities. 5-10, 10-15 and 15-20 mm shell length size group.*

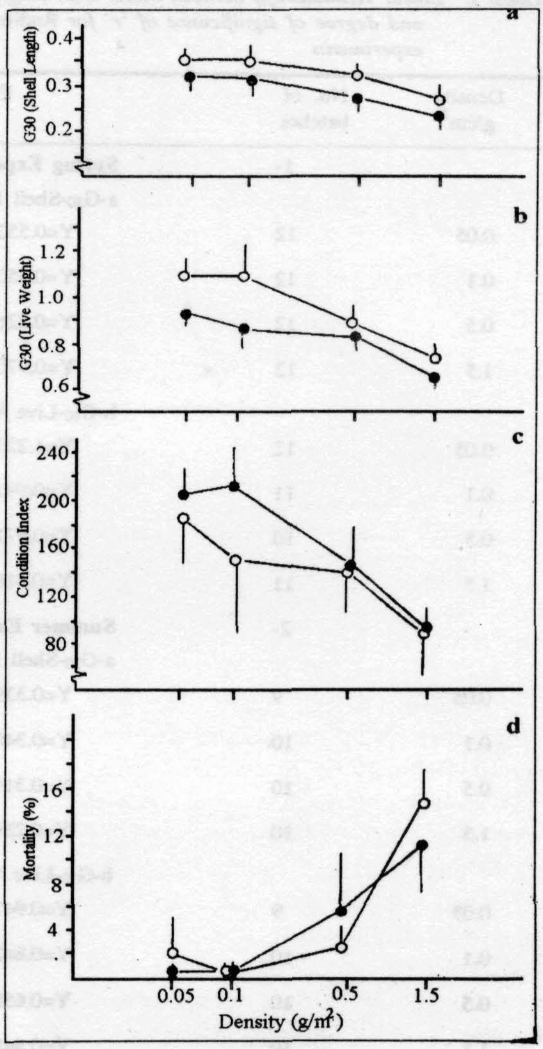

FIG. 2. *Mean values (± S.D.) of G_{30} shell length (a), of G_{30} shell length (a), G_{30} live weight (b), condition index (c) and percentage mortality (d) of two size groups of Ruditapes decussata in summer season at different densities. 5-10, 10-15 and 15-20 mm shell length size group.*

were then calculated from the differences between *initial* and *final* measurements (see Spencer and Gough, 1978). Also, a part of trays were collected by sieving the sediment through 0.1 mm mesh size sieves and its mean numbers were calculated/m^2. Throughout the

TABLE 1. *Linear relationships between initial shell length (or initial shell weight) and G_{30} value, correlation coefficient and degree of significance of 'r' for* Ruditapes decussata *at different densities during spring and summer experiments*

Density g/cm^2	No. of batches	Equation	r	Degree of significance
	1-	**Spring Experiment**		
		a-G_{30}-Shell Length relationship		
0.05	12	Y=0.5521-0.0298X	–0.9611	P < 0.001
0.1	12	Y=0.5505-0.0317X	–0.8938	P < 0.001
0.5	12	Y=0.3262-0.0152X	–0.8646	P < 0.001
1.5	12	Y=0.9704-0.0192X	–0.7728	P < 0.001
		b-G_{30}-Live Weight relationship		
0.05	12	Y=1.2273-1.479X	–0.8887	P < 0.001
0.1	11	Y=0.9917-1.568X	–0.8964	P < 0.001
0.5	10	Y=0.6719-0.9838X	–0.8673	P < 0.001
1.5	11	Y=0.4160-0.5038X	–0.4993	N.S.
	2-	**Summer Experiment**		
		a-G_{30}-Shell Length relationship		
0.05	9	Y=0.3393-0.0065X	–0.7825	P < 0.001
0.1	10	Y=0.3403-0.0074X	–0.7558	P < 0.001
0.5	10	Y=0.3194-0.0078X	–0.4818	N.S.
1.5	10	Y=0.2395-0.0054X	–0.0495	N.S.
		b-G_{30}-Live Weight relationship		
0.05	9	Y=0.9476-0.4359X	–0.8243	P < 0.001
0.1	10	Y=0.8424-0.3052X	–0.9832	P < 0.001
0.5	10	Y=0.6583-0.1712X	–0.3459	N.S.
1.5	10	Y=0.4481-0.0957X	–0.0239	N.S.

living clams were used for condition index measurements (dry-weight/total weight-shell weight). Dead individuals were counted and the mean mortalities were estimated at each density tested. The recruited spat (<1.0 mm shell length) inside and outside the experimental experiment, temperatures, salinites, and pH were measured each other day. Also, samples of phytoplankton were collected by plankton net to investigate the seasonal variations in its species composition and biomass (no. of cells/l).

RESULTS

Environmental parameters

Temperature readings in spring (24.1±1.8°C S.D.) were significantly lower (one way ANOVA, $p < 0.01$) than in summer (31.0±2.1°C), while salinity (34.6±0.75‰) and pH (7.7±0.2) were approximately similar in both seasons. On the other hand, phytoplankton counts in spring ($23.5±2.7×10^3$ cell/l) were statistically greater than in summer ($10.1±4.6×10^3$ cell/l) ($p=0.001$). The most dominant species in the spring were *Chaetoceros* sp., *Ceratium* sp., *Skeletonema* sp., *Navicula*

TABLE 2. *Linear relationships between initial shell length (or initial shell weight) and G_{30} value, correlation coefficient and degree of significance of 'r' for* Venerupis pullestra *at different densities during spring and summer experiments*

Density g/cm²	No. of batches	Equation	r	Degree of significance
	1-	**Spring Experiment**		
		a-G_{30}-Shell Length relationship		
0.05	10	Y=0.6276-0.0271X	–0.9392	P < 0.001
0.1	10	Y=0.6961-0.0216X	–0.9161	P < 0.001
0.5	10	Y=0.4859-0.0138X	–0.8023	P < 0.002
1.5	10	Y=0.2886-0.0061X	–0.0324	N.S.
		b-G_{30}-Live Weight relationship		
0.05	10	Y=1.4750-0.4983X	–0.7785	P < 0.005
0.1	10	Y=1.3442-0.4561X	–0.8515	P < 0.002
0.5	10	Y=0.9250-0.3663X	–0.6651	P < 0.002
1.5	10	Y=0.4590-0.0358X	–0.6878	P < 0.002
	2-	**Summer Experiment**		
		a-G_{30}-Shell Length relationship		
0.05	13	Y=0.1885-0.0071X	–0.8377	P < 0.002
0.1	13	Y=0.1697-0.0076X	–0.7992	P < 0.005
0.5	13	Y=0.0934-0.0104X	0.8983	P < 0.001
1.5	7	Y=0.1346-0.0054X	0.7413	N.S.
		b-G_{30}-Live Weight relationship		
0.05	13	Y=1.1350-0.2021X	–0.9341	P < 0.002
0.1	13	Y=0.9599-0.0276X	0.7925	P < 0.005
0.5	13	Y=0.9290-0.0746X	0.8161	P < 0.001
1.5	7	Y=0.6183-0.0113X	0.762	P < 0.001

sp., *Thalassiosira* sp. and *Nitzchia* sp. In summer, phytoplankton samples were dominated by *Coscinodiscus* sp., *Navicula* sp., *Protoperidenium* sp., *Pleurosigma* sp. and *Nitzchia* sp.

Growth and survival of the reared clams

(a) Ruditapes decussata

In both seasons, the growth parmeters and condition indices affected dramatically at higher densities (> 0.5 g/cm^2). Clams performed a remarkable increase in growth and survival at low densities (< 0.1 gcm^2) tested and thereafter showed a pronounced decline (Fig. 1 & 2) with increase in stock densities. In spring, growth parameter values were significantly greater than summer ones (for the same size group) particularly at low densities (P < 0.05 in case of shell length and live weight). However, condition indices and mortalities were more or less similar in both seasons. At all densities, the instantaneous growth rates decreased with body size. Linear regressions of G_{30} on initial shell length and live weight (Table 1) were significant (except at highest density). Slopes of these regressions were statistically steeper at low densities than at high ones (ANCOVA test, p < 0.05) indicating that variations in growth parameter ranges (between small and bigger sizes) were quite narrow at high densities than at low ones.

(b) Venerupis pullestra

Similar to *R. decussata,* the growth rates and condition indices declined with stock density (Fig. 3 and 4). For the same size group, spring values of G_{30} and condition indices were statistically greater (p < 0.05) than summer values particularly at low densities (0.05 & 0.1 g/cm^2). However, at high densities, spring growth parameters significantly declined than summer ones (p < 0.05). In both seasons, modalities among animals at low densities were quite few, but increased with stock density particularly during spring (Fig. 3). The linear relationships between initial length (or live weight) and its relative G_{30} were significant at

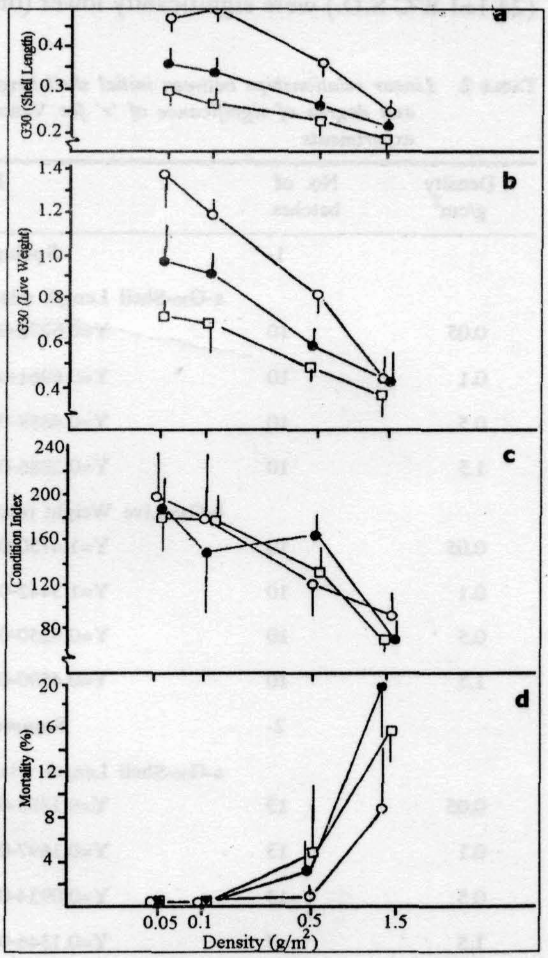

FIG. 3. *Mean values (± of G_{30} shell length (a), G_{30} live weight (b), condition index (c) and percentage mortality (d) of three size groups of* Venerupis pullestra *in spring season at different densities. 5-10, 10-15 and 15-20 mm shell length size group.*

most densities tested in spring and the first two densities in summer (Table 2). Its slope values showed no conspicuous increase or change with density in summer, but were in gradual increase in spring.

TABLE 3. *Seasonal variations in spat settlement inside and outside experimental trays*

Density g/cm^2	No. settled spat/m^2 ± S.D. (inside tray)		No. settled spat/m^2 ± S.D. (outside tray)	
	Spring	Summer	Spring	Summer
R. decussata				
0.05	25.2 ± 6.2	62.6 ± 8.8	21.9 ± 5.7	66.2 ± 7.7
0.01	27.0 ± 5.4	47.5 ± 11.2	(live spat)	(live spat)
0.5	23.7 ± 4.2	110.5 ± 14.5	51.2 ± 12.2	200.1 ± 11.3
1.5	31.2 ± 4.4	98.5 ± 9.7	(dead spat)	(dead spat)
V. pullestra				
0.05	6.1 ± 2.2	30.3 ± 5.8	8.1 ± 2.3	34.2 ±
0.1	4.2 ± 1.7	33.5 ± 4.1	(live spat)	(live spat)
0.5	10.5 ± 4.2	36.2 ± 6.9	2.1 ± 0.5	119.6 ± 15.4
1.5	13.1 ± 4.8	61.7 ± 19.8	(dead spat)	(dead spat)

Spat recruitment

(a) Ruditapes decussata

318 spat were collected from the experimental trays during spring, 31% of them from the highest density tray (1.5 g/cm^2) (Table 3), whereas the remaining (69%) gathered from other trays without any difference between tested densities (G test, $p < 0.5$). All collected spat were found alive (except 17 with broken shells). Outside the trays, moderate number (22/m^2) of live spat and about 242 (51/m^2) of broken spat shells gathered from sieved sediments.

In summer (Table 3), more than 900 spat were collected from the experimental trays. High density trays (0.5 & 1.5 g/cm^2) together contributed about 67% of the settled spat without significant difference between them (G test, $p < 0.1$). In lowest density trays, spat numbers were statistically greater ($p < 0.05$) than in 0.1 g/cm^2 density. Outside the trays, settlements were more or less similar to the low-density trays, (65/m^2). Also, many broken spat shells (> 200/m^2) were gathered from the surrounding sediments reflecting the high predation outside the trays.

(b) Venerupis pullestra

In spring a total of 101 spat collected from experimental trays, 72 of them concentrated in high density trays (0.5 & 1.5 g/cm^2) and the rest (29 spat) gathered from low density ones. Outside the trays the number of live spat varied between 60 and 100/m^2, whereas dead broken spat shells were quite few (2-3/m^2). In summer, a total of 587 spat collected, 47% from the highest density trays whereas the rest distributed randomly among other density trays without significant difference between them ($p < 0.1$). Outside the trays, its number approximated those in 0.05 & 0.1 g/cm^2 trays (35 individuals/m^2) while the dead spat were quite high (> 120 shell/m^2).

DISCUSSION

The present results indicate that with the increase in the clam biomass in the experimental trays, the growth parameters as well as the condition indices decline. At low initial stock densities, water circulation is unimpeded by the presence of shellfish and food supply is not limiting (Mann & Ryther, 1977). As density proceeds, equilibrium is approached between available food supply and maintenance ratio of the shellfish biomass. However, water flow is impeded gradually by the growing animal, as shell growth continues, food supply became inadequate and increased mortality occurs (Mason, 1972; Frechette and Bourger, 1985). The depressions in growth at high densities are commonly assumed to be linked to depletion of food resources and intraspecific competition for food. Orensanz (1986) and Chummy (1992) however attributed the growth depression and mortalities in high dense populations to the synergetic effect of starvation of large fractions of individuals and harsh environmental conditions surrounding it.

In the tray system, Parsons (1974) and Spencer & Gough (1978) recommended 1-1.5 g/cm^2 as ideal for better growth of the bottom small oyster. However, Quayle (1969), Breber (1985) and Mohammed (1987) recorded a good growth at densities between 0.05 and 0.2 g/cm^2 for mussels and oysters. In the present study, the best growth condition and survival were achieved in the trays with stock density of about 0.1g/cm^2 or less indicating that water circulation is unimpeded by the presence of shellfish at these biomasses and food supply is not limiting. Although, this is lower than recorded by Parsons (1974) and Spencer and Gough (1978) and similar to that recorded by Breber (1985) and Mohammed (1987), it is inappropriate to compare between them due to the variations of the initial sizes and biomasses tested as well as the experimental conditions.

The reared clams showed a better growth and condition in spring than in summer. The high ration and the suitable temperature in spring are the most favourite factors enhancing the growth and body conditions of the clams, while the low ration and high temperature in summer suppressed its growth and survival particularly at high densities. Periods of environmental stress (in summer) could be more harmful to individuals exposed to food shortage due to high density (Peterson and Black, 1988, Mohammed, 1997). Clams reared in high-density conditions during growth seasons maybe less able to survive periods of poor

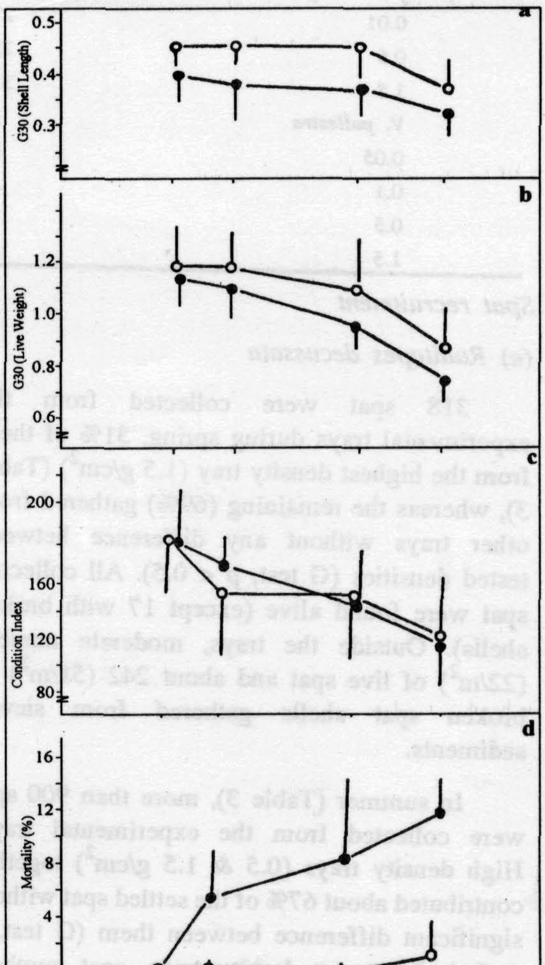

FIG. 4. *Mean values (± S.D.) of G_{30} shell length (a), G_{30} live weight (b), condition index (c) and percentage mortality (d) of two size groups of Venerupis pullestra in summer season at different densities. 5-10, 10-15 and 15-20 mm shell length size group.*

food supply. The effect was more marked among small sizes (spat & juveniles) due to smaller amounts of stored reserves relative to the requirements of stressed summer.

Clams showed a decrease in growth with increase in body size. The growth efficiency and other physiological activities assumed to be declined with increasing body size (Vahl, 1973, 1983; Widdows, 1978) as absorption efficiency does not change significantly with size (Winter, 1973; Thompson and Bayne, 1974). Winter and Langton (1976) and Bayne and Worall (1980) found that, although the maintenance ration was higher in small individuals than in large ones, they were more efficient at utilizing the available ration for maintenance or in converting it to body tissue than are larger individuals. Vahl (1981) and Orensanz (1986) recorded similar phenomenon in the different age classes of scallops, where larger individuals performed significant low growth than smaller animals. These finding could explain the differences in growth rates among different size groups and also indicate a negative correlation between density and size-at-age.

The regression relationships between the growth rates and the initial sizes for *R. decussata* (Table 1) showed that although the smallest sizes had the highest growth rates at low densities, the rate of decrease in growth with size was greater at low densities. This means biologically that, the smaller sizes can grow better at low densities than the large sizes.

The rate of spat recruitment were generally low in low dense trays compared to high dense ones particularly during the spawning period in summer (Kandeel, 1993). This indicates that density-dependent regulations acted upon settling process of young clams at higher stock densities. The significant interaction between density of filter feeder bivalves and their recruitment still form unclear pictures about its density-dependent settlement (Orensanz, 1986; Seed, 1993). Mussels, for example can reduce settlement by ingestion of larvae (Cowden *et. al.*, 1984), but the presence of shells stimulate larval settlement into mussel beds (Mohammed, 1997) and reduce the rate of ingestion of incoming larvae. Clams and cockles, on the other hand, have a deleterious impact on their own recruitment (Williams, 1970, Andre *et. al.*, 1993). These authors found that spat settled more heavily in areas with no or only moderate adult densities than in areas with high densities. In addition, Peterson (1982) and Orensanze (1986) attributed such negative influence on young to the intra and interspecific competition in its adult populations. The present results disagree with Williams and Andre *et. al.*, foundation, as the spat settled heavily in dense packed trays than in low dense ones. This presumably attirbuted to the presence of more dead (empty) shells in high dense trays than in low dense ones which correspondingly increase the chances of spat settlements. Peterson and Andre (1980) and Eckman (1983) pointed out the importance of empty shells in enhancing the spat recruitment in dense populations and recorded a high grouping of settled spat inside the empty clam shells than outside it. High amounts of dead spat shells were found outside the trays. This must have been due to predation by the sea bream *(Sparus auratus)*, starfish *(Astropecten polycanthus)* and the small crabs (*Carcinus* spp.) which are frequently observed in the experimental locality. These species are known to consume bivalve spat in high quantities (Orensanz *et. al.*, 1992) and could have a destructive impact on its population (Hylleberg *et. al.*, 1978; Seed, 1993). Inside the trays, no significant mortalities among spat were recorded as these predators could not pass through tray's meshes.

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