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Growth of the tropical scallop, *Euvola (Pecten) ziczac*, in bottom and suspended culture in the Golfo de Cariaco, Venezuela

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Accepted 30 April 1995

Abstract

We compared the growth of the scallop *Euvola (Pecten) ziczac* (L.) in three situations which potentially could be used for commercial culture, in cages maintained in suspension, in cages on the bottom and in cages partly buried in a sediment bottom. The latter permitted the scallops to bury themselves as in their natural habitat. Throughout the 7-month study, growth, as measured by shell length and muscle mass, was by far superior for scallops in the partly buried cages. Possible explanations for this are (1) that the scallops are stressed by enclosures which prevent them from burying themselves and (2) that organic material at the sediment/water interface is an important food resource and *E. ziczac* has better access to this when it buries itself flush with the bottom. The timing of gonadal growth and spawning varied markedly among treatments. Some spawnings coincided with temperature increases but others did not. Differences between scallops in suspension compared to those in bottom treatments suggested that reproduction is as much controlled by conditions in the immediate environment of the scallops as by large-scale environmental factors. Survival was highest for the scallops maintained in partly buried cages.

1. Introduction

Maximizing growth is critical to the development of commercial bivalve culture and food availability and temperature are environmental factors considered as major determinants of growth (Bayne and Newell, 1983). A variety of techniques have been developed for the

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SSDI 0044-8486(95)01055-6

commercial culture of scallops and most consist of growing the animals in suspended culture rather than in their natural bottom habitats (Ventilla, 1982; MacDonald, 1986; Hardy, 1991). This is because growth in suspended culture is accelerated due to increased access to sestonic food resources (Leighton, 1979; Wallace and Reinsnes, 1985; MacDonald and Thompson, 1985a, MacDonald and Thompson, 1985b). Suspended culture is further advantageous because mortality due to benthic predators is reduced or eliminated. A major disadvantage of suspended culture is the cost of long lines, buoys, anchors and other equipment and in Japan bottom culture has proven to be more cost effective, in spite of losses from predation and by dispersion of animals (Imai, 1978; Hardy, 1991).

In the present study we compare the growth and mortality of the ziczac scallop *Euvola* (*Pecten*) *ziczac* in suspended and bottom culture in the Golfo de Cariaco, Estado Sucre, northeastern Venezuela (Fig. 1A). In natural beds, *Euvola ziczac* usually buries itself, except for the tentacles which project above the sediment surface (Fig. 2). Thus, we examined growth in cages, in suspension and on the bottom, as well as in cages which were partially sunken into the sediment bottom. The latter permitted the scallops to bury themselves as in their natural habitat. We quantified environmental factors associated with the various treatments (temperature, food availability and other factors potentially affecting scallop growth). *E. ziczac* is an hermaphroditic scallop which is found from Cape Hatteras (North Carolina) and Bermuda, throughout the Gulf of Mexico, and southward to Santa Catalina state in Brazil (Rios, 1985). Previous studies of *E. ziczac* consider its reproduction and methods for producing spat (Rojas et al., 1988; Vélez et al., 1990; Lodeiros et al., 1991; Vélez and Freites, 1993) and one study describes seasonal variations in growth for scallops maintained in pearl nets at 15–20 m in depth (Lodeiros and Himmelman, 1994).

The seasonal cycle in oceanographic conditions in the Golfo de Cariaco generally consists of a period of high temperatures extending from about August until December and then a drop in temperature, caused by wind-driven upwelling (Margalef, 1965; Mandelli and Acuña, 1975; Mandelli and Ferraz, 1982; Okuda, 1981). Primary productivity is generally increased several-fold during the upwelling period (Gade, 1961a; Gade, 1961b). The upwelling continues intermittently until about July.

2. Methods

2.1. Study sites

Our study was conducted at Turpialito in the Golfo de Cariaco (Fig. 1A). The spat were produced from adults which were spawned in late July 1991, using the techniques described by Vélez et al. (1990) and Vélez and Freites (1993). The larvae, and postlarvae up to an age of 1 month, were raised in the laboratory on cultured phytoplankton, as described by Lodeiros and Himmelman (1994). Then they were transferred to a depth of 15 m in the field in pearl nets and maintained there until 22 December 1991 when the growth experiments were begun. At this time the shell length (distance between the anterior and posterior margins) of the spat varied from 31 to 36 mm ($\bar{x}=33$).

Grow-out of the scallops was performed in round plastic cages (designed for oyster culture in Spain), perforated on all sides by holes measuring about 2×2 cm. The cages

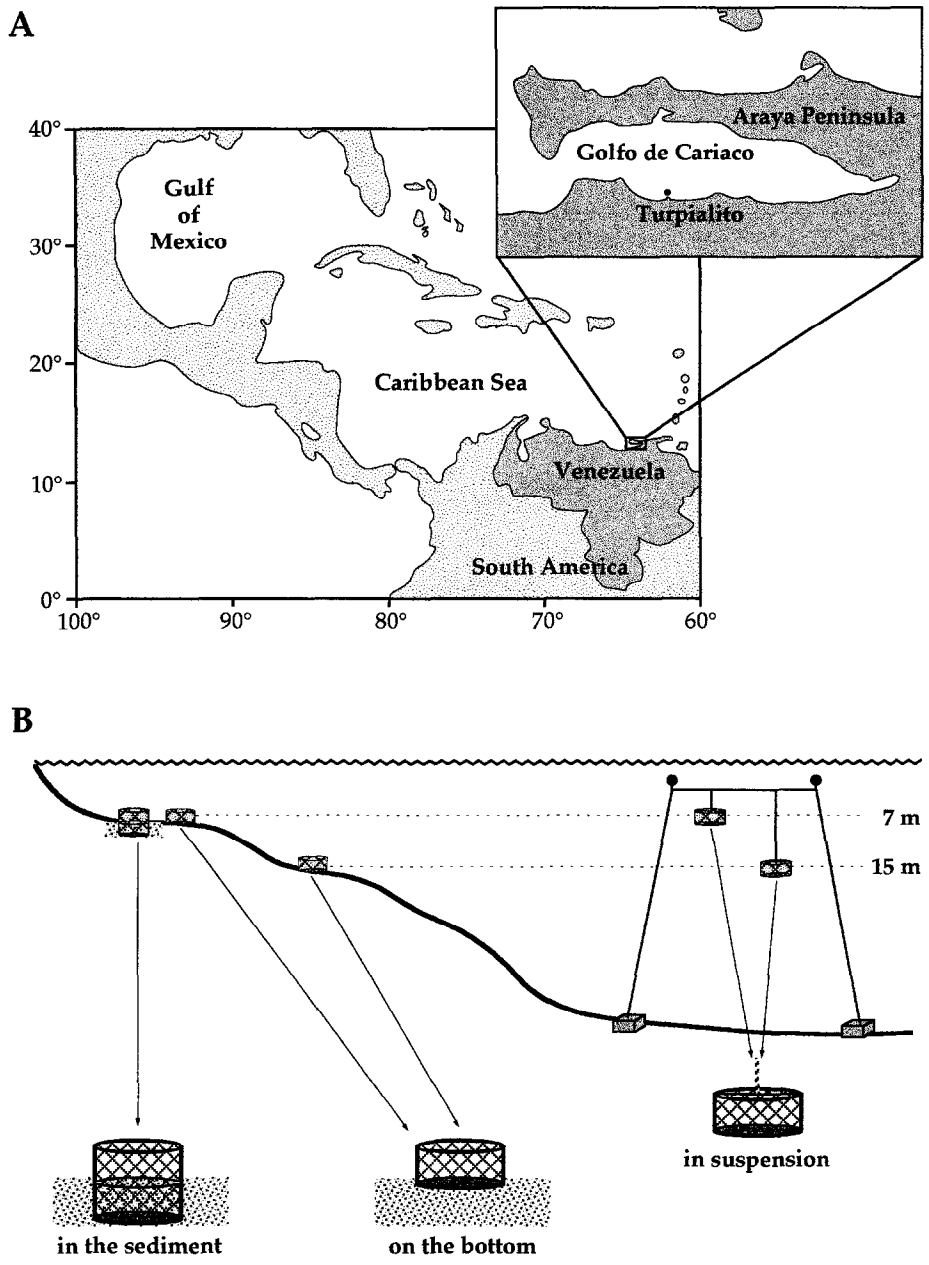

Fig. 1. Location of Turpialito in northeastern Venezuela (A) and illustration of how and where the cages were suspended in the water column or placed on the bottom (B).

were 40 cm in diameter and 10 cm in height. Two groups of cages with scallops were suspended at 7 and 15 m in depth, respectively, and two other groups were placed on the

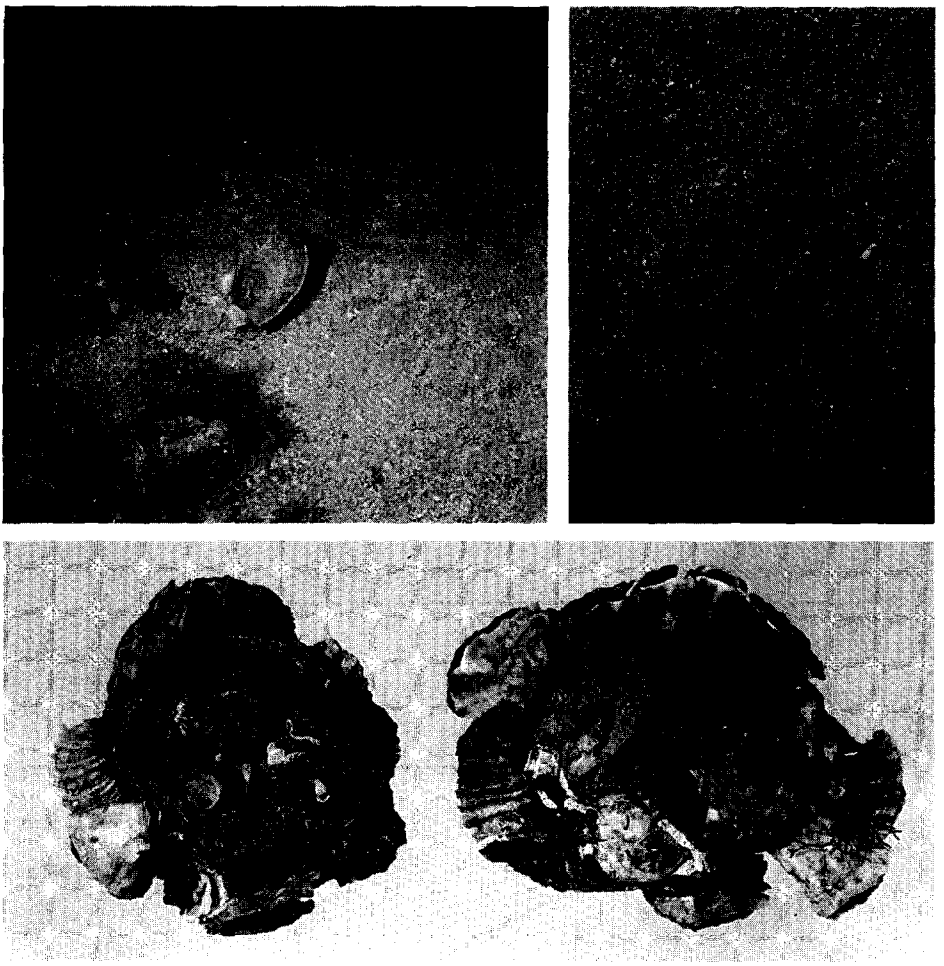

Fig. 2. *Euvola ziczac*. Scallops at the surface and buried in the sediment (upper left and right, respectively) and 50 mm scallops overgrown by oysters (below).

bottom at 7 and 15 m in depth, respectively (Fig. 1B). The cages in suspension were attached to a long line located at approximately 300 m from shore. A fifth group of scallops was grown in cages which measured the same diameter but 20 cm in height. These were sunk to a depth of approximately 8 cm into the sandy bottom at 7 m in depth (Fig. 1B). This was in the same area as the cages on the bottom at 7 m. These treatments will henceforth be referred to as "in suspension" at 7 and 15 m, "on the bottom" at 7 and 15 m and "in the sediment". For each of the five treatments, the experiments began with 27 cages, each containing 8 scallops. At monthly intervals during the following 3 months, three samples (cages with 8 scallops) were retrieved from each of the five conditions for determinations of the size of the scallops. For each scallop, we recorded shell length. The mean dry mass (dried to a constant mass at 80°C) of the muscle and gonad was obtained for each cage by dividing total dry mass (for the muscles or gonads of all scallops together) by the number

of scallops. Since the scallops had grown substantially during the first 3 months (the mean size had attained 40–46 mm), on 22 March 1992 the scallops in each of the remaining cages were separated into two groups. A number of cages were removed so that dead scallops in some cages could be replaced. Thus, 26 cages, each containing 4 scallops, were set out for each treatment. Reducing the density decreased the possibility that growth would be limited by density. At the same time predators and fouling organisms were removed from the cages. In each of the following 3 months three samples (two cages, each with 4 scallops, were considered as one sample) were removed from each treatment to quantify the size of the scallops.

A major focus of our study was to evaluate the effect of the three culture methods. Since all three were only examined at 7 m in depth, we first applied ANOVAs to the data at 7 m for each sampling date to examine the effect of the three culture methods (in suspension, on the bottom, in the sediment). Following this, we applied ANOVAs to the data for each sampling date considering the two depths (7 and 15 m) and two culturing methods (in suspension, on the bottom). The tests on the shell height data considered the mean values for each of the cages and the measurements for each scallop as subsamples. In contrast, in examining the muscle mass data, since we did not have measurements for each scallop, we could only consider the mean values for each of the cages (three cages per date).

Gonadal size showed both increases (storage of materials or gametogenesis) and decreases (gamete release) and the timing of these changes were of major interest in comparing the culture methods and depths. To determine when drops occurred, as would be caused by spawning, we applied a modified Jonckheere's test to gonadal mass values (Jonckheere, 1954; Capéraà and Van Custen, 1988; Bonardelli, 1994). This permitted comparison of observations at successive points in time where evidence was sought of a downward change.

2.2. *Environmental factors*

To compare conditions in the different treatments, temperature measurements were made at periodic intervals, from late January to late June, at 7 and 15 m in the water column (at the site of the long line, approximately 300 m from shore) and at 7 and 15 m on the bottom. Further, on the same dates we measured water transparency with a secchi disc at the site of the long line and at the site of the cages on the bottom at 15 m (approximately 30 m from shore).

At periodic intervals throughout the study, water samples were taken at 7 and 15 m in the water column and at 7 and 15 m on the bottom for determinations of levels of total particulate nitrogen and phosphorus content. Organic nitrogen and phosphorus were transformed to nitrate and phosphate following the procedure of Valderrama (1981) and then levels were measured using the method of Tréguer and Le Corre (1975). Chlorophyll a determinations were made for the same stations from late January to early April using the spectrophotometric method.

We also analysed the total nitrogen and phosphorus content of the sediment using 10 cm core samples which were obtained in triplicate at 7 and 15 m on three dates: 6 January, 20 February and 18 June. The samples were analysed using the method of Valderrama (1981) with the following modifications: 1 g of sediment was placed in a 50 ml Pyrex container

and treated with 10 ml of oxidizing agent (65 g of potassium peroxodisulphate and 35 g of boric acid dissolved in 400 ml of 1 N sodium hydroxide and diluted to 1 litre with water). The samples were then autoclaved for 30 min, homogenized and cooled. After centrifugation for 4 min, the supernatant and the liquid from three washings of the pellet were obtained and water was added to attain a final volume of 100 ml. Then nitrate and phosphate contents were determined using Tréguer and Le Corre's (1975) method. Three determinations were made for each core sample as well as for blanks. Distilled, deionized (Milli-Q©) water was used for these manipulations.

In March 1992, when the number of scallops per cage was reduced, and at the end of the study, we determined the mass and identity of fouling organisms on three cages in each treatment. Further, we recorded the number and type of predators in the various treatments.

3. Results

3.1. Shell growth

A two-factor nested ANOVA applied to the shell length data from 7 m for each sampling date demonstrated a strong effect of the culture method ($p < .01$, Table 1). Shell length was consistently greater for the scallops in the sediment than for those in cages on the bottom or in suspension (Fig. 3). The shell length of scallops in cages on the bottom and in suspension was similar on all dates except for 20 April, when it was greater for scallops on the bottom. In June, the high mortality of the group on the bottom prevented us from making comparisons with the other groups. On 21 May 1992, shell size of the scallops in the sediment was 19% greater than for those on the bottom and 36% greater than for those in suspension (Fig. 3).

The pattern of increase in shell height was generally similar for the two treatments studied at both 7 and 15 m (Fig. 3). Three-factor nested ANOVAs applied to the shell length data for the two culture methods at two depths indicated an effect of depth (greater at 7 than at 15 m) for only one sampling date (20 April 1992), an effect of culture method (greater on the bottom than in suspension) on three dates (22 January, 20 April and 21 May 1992) and no interaction between these two factors ($p > .05$, Table 2). This indicated that depth had little effect and that growth was only slightly better on the bottom than in suspension.

3.2. Muscle mass

In examining the muscle mass data, since we did not have measurements for each scallop, we could only consider the mean values for each of the cages at each sampling date. One-factor ANOVAs applied to dry muscle mass at 7 m also demonstrated an effect of culture method (Table 3). Growth was markedly greater for scallops maintained in partly buried cages than in cages on the bottom and in suspension (Fig. 4). The difference was even more marked than for shell length; for example, on April 1992, when the growth curves had levelled off, the mean dry mass of the muscle for scallops in the sediment was 59% greater than for scallops on the bottom and 93% greater than for scallops in suspension (Fig. 4).

Table 1
Euvola ziczac. Results of two-factor ANOVAs applied to the shell height data from each sampling date for scallops grown at 7 m in depth using three culture methods. Cages were the random factor nested within the experimental factor, the culture method (cages in suspension, on the bottom, and in the sediment). One experimental condition (cages on the bottom) was missing in June

Source of variation	*df*	Sum of squares	Mean squares	*F*	*p*
January					
Culture method	2	14.20	7.10	20.76	0.002
Cages	6	2.05	0.34	1.93	0.090
Residual	60	10.61	0.18		
February					
Culture method	2	11.65	5.83	19.69	0.002
Cages	6	1.78	0.30	1.49	0.20
Residual	62	12.30	0.20		
March					
Culture method	2	21.16	10.58	149.50	0.0001
Cages	6	0.43	0.07	0.38	0.89
Residual	63	11.63	0.19		
April					
Culture method	2	24.15	12.07	265.25	0.0001
Cages	6	0.27	0.05	0.23	0.97
Residual	59	11.79	0.20		
May					
Culture method	2	30.49	15.24	32.78	0.001
Cages	5	2.33	0.47	2.27	0.062
Residual	48	9.84	0.21		
June					
Culture method	1	30.05	30.05	103.88	0.0005
Cages	4	1.16	0.29	0.96	0.44
Residual	37	11.19	0.30		

Two-factor ANOVAs considering the two treatments (on the bottom and in suspension) at two depths (7 and 15 m, Table 4) indicated an effect of culture method (greater on the bottom than in suspension) on four out of five dates and an effect of depth on only one date (greater at 7 than 15 m in May). The significant interaction on the first date (January) was because growth differed between culture methods at 7 m but not at 15 m. For the scallops in suspension at 15 m, muscle mass showed little change during the last month (21 May to 22 June, Fig. 4) and this contrasted with the rapid increase in shell length for the same scallops (Fig. 3).

3.3. Gonadal mass

Gonadal mass showed decreases as well as increases during the study (Fig. 5). For the scallops on the bottom and in the sediment at 7 m, a several-fold increase occurred during the first month and then a significant decrease (modified Jonckheere's test, $p < .05$) during the second month. The decrease was marked; for example, when gonadal mass was scaled as a percentage of muscle mass (as a gonadal index, GI), the change between 22 January and 23 February was from 35.0% to 12.7% for the scallops in the sediment and from 23.7%

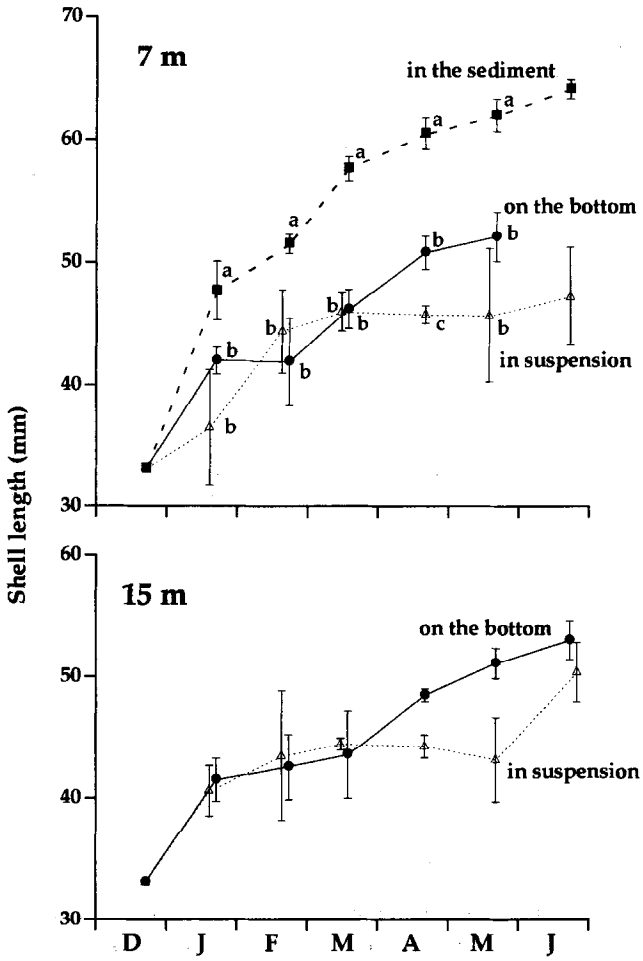

Fig. 3. *Euvola ziczac*. Monthly changes in mean shell length for scallops maintained in cages suspended at a depth of 7 and 15 m (in suspension), in cages on the bottom at 7 and 15 m (on the bottom), and in partly buried cages at 7 m (in the sediment). The vertical bars represent the 95% confidence limits. At 7 m, means sharing the same letter on the same date do not differ significantly (Scheffe's test, $p > .05$).

to 6.5% for those on the bottom. These decreases in gonadal mass likely represented substantial release of gametes. The same groups showed increases in gonadal size during March and April 1992. Then during May and June 1992, gonadal size decreased ($p < .05$) for the scallops in the sediment (GI of 37.1% in April, 15.6% in May, and 9.7% in June). The similarity in gonadal size between April and May 1992 for the scallops on the bottom indicated that this group did not spawn during May. Because of high mortalities, we did not have a sample for this group in June 1992. Gonadal changes for the scallops in suspension at 7 m showed a different pattern, there being a slower and nearly progressive increase during the first 4 months, a drop ($p < .05$) between 20 April and 21 May (GI decreased from 40.0% to 18.6%), and renewed growth in June.

Table 2
Euvola ziczac. Results of three-factor ANOVAs applied to the shell height data from each sampling date for scallops grown at two depths (7 and 15 m) using two culture methods (cages in suspension and on the bottom). Cages were the random factor nested within two crossed factors: culture method and depth

Source of variation	*df*	Sum of squares	Mean squares	*F*	*p*
January					
Culture method	1	2.34	2.34	14.74	0.019
Depth	1	0.81	0.81	5.12	0.087
Culture method × depth	1	1.16	1.16	7.32	0.054
Cages	4	0.63	0.16	0.85	0.50
Residual	86	16.04	0.19		
February					
Culture method	1	0.69	0.69	1.01	0.37
Depth	1	0.002	0.002	0.003	0.96
Culture method × depth	1	0.15	0.15	0.21	0.69
Cages	4	2.73	0.68	3.12	0.019
Residual	88	19.27	0.22		
March					
Culture method	1	0.032	0.032	0.16	0.71
Depth	1	1.04	1.04	5.24	0.084
Culture method × depth	1	0.073	0.073	0.37	0.58
Cages	4	0.80	0.20	0.87	0.49
Residual	88	20.21	0.23		
April					
Culture method	1	4.79	4.79	193.20	0.0002
Depth	1	0.75	0.75	30.25	0.005
Culture method × depth	1	0.058	0.058	2.33	0.20
Cages	4	0.10	0.025	0.13	0.97
Residual	86	16.26	0.19		
May					
Culture method	1	6.10	6.10	11.86	0.026
Depth	1	0.13	0.13	0.26	0.64
Culture method × depth	1	0.43	0.43	0.83	0.41
Cages	4	2.06	0.52	2.35	0.062
Residual	71	15.57	0.22		

At 15 m gonadal changes resembled those in the corresponding treatments at 7 m (Fig. 5). Thus, the scallops in suspension showed a progressive increase in gonadal mass from the beginning of the study until April 1992 (although gonadal to muscle mass was almost constant, 31.1–32.5%, from January to April), and then a single drop ($p < .05$) between April and May (to 19.7%), synchronous with the drop for scallops in suspension at 7 m. The scallops on the bottom at 15 m showed a drop ($p < .05$) between January and February (25.5% to 6.4%), thus in synchrony with scallops on the bottom and in the sediment at 7 m. A second spawning ($p < .05$) in the bottom group did not occur until between 21 May and 22 June 1992 (the GI fell from 60.0% to 19.4%). This contrasted with the scallops in suspension at the two depths and in the sediments at 7 m.

3.4. Survival

During the first 3 months, December 1991 to March 1992, survival was similar and relatively high (78–84%, $n = 168$ for all groups, $\chi^2 = 3.34$, $p = .503$, Fig. 6). Survival was

Table 3
Euvola ziczac. Results of one-factor ANOVAs applied to the muscle dry mass data from each sampling date for scallops grown at 7 m in depth using three culture methods (cages in suspension, on the bottom, and in the sediment). Culture method was the experimental factor. One experimental condition (cages on the bottom) was missing in June

Source of variation	*df*	Sum of squares	Mean square	*F*	*P*
January					
Culture method	2	0.073	0.036	34.26	0.0005
Residual	6	0.006	0.001		
February					
Culture method	2	0.047	0.023	12.08	0.0079
Residual	6	0.012	0.002		
March					
Culture method	2	0.242	0.121	107.39	0.0001
Residual	6	0.007	0.001		
April					
Culture method	2	0.376	0.188	73.99	0.0001
Residual	6	0.015	0.002		
May					
Culture method	2	0.296	0.148	103.28	0.0001
Residual	5	0.007	0.001		
June					
Culture method	1	0.159	0.159	497.42	0.0001
Residual	4	0.001	0.0003		

less from March to June 1992 (to May on the bottom at 7 m) and varied among treatments ($\chi^2 = 50.61, p < .0001$). At 7 m, 69.6% survived in the sediment and 52.1% in suspension and at 15 m, the rate was 39.3% on the bottom and 35.7% in suspension ($n = 56$ for each treatment). Only 12.5% (10/80) of the scallops on the bottom at 7 m survived from March to May. The cumulative survival for the study period (December to June) was greatest (56.0%) in the sediment and least on the bottom at 7 m (Fig. 6).

3.5. Environmental conditions

Temperature

The temperature data for 7 and 15 m at the site where the scallops were maintained in suspension, and for the bottom sites at 7 and 15 m, showed a similar seasonal pattern (Fig. 7). In all four situations temperatures fluctuated only between 22.5°C and 25.0°C from January to 24 April 1992 and then increased to 26–27°C during May and early June. The mean temperature for the entire study, giving equal weight to the measurements for each month, only varied by 0.6°C among the different treatments (24.3–24.9°C, Fig. 7).

Water transparency and food availability

Water transparency also varied in a seasonal pattern, being generally low from January to late April and thereafter fluctuating at a higher level (Fig. 7). The increase in transparency in late April coincided with the temperature increase and indicated a stratification of the water column. This possibly resulted in decreased phytoplanktonic production. Chlorophyll

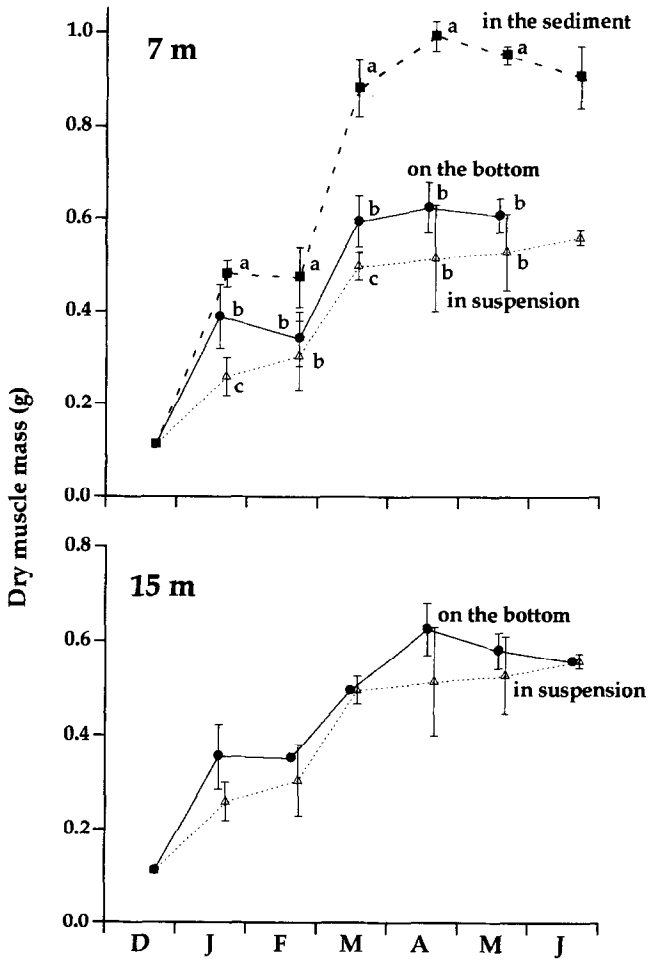

Fig. 4. *Euvola ziczac*. Monthly changes in mean dry muscle mass for scallops maintained in cages suspended at a depth of 7 and 15 m (in suspension), in cages on the bottom at 7 and 15 m (on the bottom), and in partly buried cages at 7 m (in the sediment). The vertical bars represent the 95% confidence limits. At 7 m, means sharing the same letter on the same date do not differ significantly (Scheffe's test, $p > .05$).

a concentrations were only determined during the period of low transparency, January to April. Mean levels were similar for 7 and 15 m in the water column and at 15 m on the bottom (3.3, 3.0 and 3.1 mg m^{-3} of chlorophyll a, respectively, Fig. 8) and less at 7 m on the bottom (2.1 mg m^{-3}). This latter situation corresponded where growth was greatest for scallops in the sediment (partly buried cages) and second greatest for those in cages on the bottom at 7 m (Fig. 3 and Fig. 4).

The levels of particulate nitrogen and phosphorus varied greatly. Nevertheless a seasonal pattern was suggested, values being generally low from late January to mid-February, increased until early April and finally were low for the remainder of the study (Fig. 8). The decrease in the latter period was possibly due to decreased primary productivity associated

Table 4
Euvola ziczac. Results of two-factor ANOVAs applied to muscle dry mass data for each sampling date for scallops grown at two depths (7 and 15 m) using two culture methods (cages in suspension and on the bottom). Culture method and depth were the two experimental factors

Source of variation	*df*	Sum of squares	Mean squares	*F*	*p*
January					
Culture method	1	0.012	0.012	5.80	0.043
Depth	1	0.003	0.003	1.61	0.24
Culture method × depth	1	0.013	0.013	6.60	0.033
Residual	8	0.016	0.002		
February					
Culture method	1	0.002	0.002	1.39	0.27
Depth	1	0.001	0.001	1.31	0.29
Culture method × depth	1	0.0005	0.0005	0.45	0.52
Residual	8	0.009	0.001		
March					
Culture method	1	0.011	0.011	20.35	0.0020
Depth	1	0.012	0.012	21.43	0.0017
Culture method × depth	1	0.003	0.003	4.86	0.059
Residual	8	0.004	0.0005		
April					
Culture method	1	0.070	0.070	18.59	0.0030
Depth	1	0.005	0.005	1.37	0.28
Culture method × depth	1	0.006	0.006	1.57	0.25
Residual	8	0.030	0.004		
May					
Culture method	1	0.031	0.031	23.22	0.0019
Depth	1	0.008	0.008	6.19	0.042
Culture method × depth	1	0.002	0.002	1.76	0.23
Residual	7	0.009	0.001		

with stratification of the water column. Scallop growth did not seem to be related to these indices of food abundance. For example, scallop growth was low in suspension at 15 m where mean particulate nitrogen and phosphorus levels were highest. Nitrogen and phosphorus levels were notably higher in the surface sediments. The values for the samples taken in January, March and June indicated that total phosphorus levels varied from 2.6 to 11.9 mg kg^{-1} and total nitrogen from 18.3 to 25.2 mg kg^{-1} ($n=18$). The increased organic material in the surface sediments could potentially explain the accelerated growth of scallops in the partly buried cages.

Fouling

Marked differences were recorded in the degree of fouling of cages in the various treatments. The dry mass of fouling on cages which had been set out on 18 March and recovered on 22 June varied from 23 to 25 g for cages in suspension at 7 m and was somewhat less, 16–20 g, for cages in suspension at 15 m. By contrast, the mass of fouling organisms for cages on the bottom at 15 m varied from 2.1 to 2.8 g and for cages which were partly buried at 7 m from 3.5 to 3.9 g. The mass of fouling organisms for cages on the bottom at 7 m varied from 2.5 to 3.2 g when the treatment was terminated in May. The

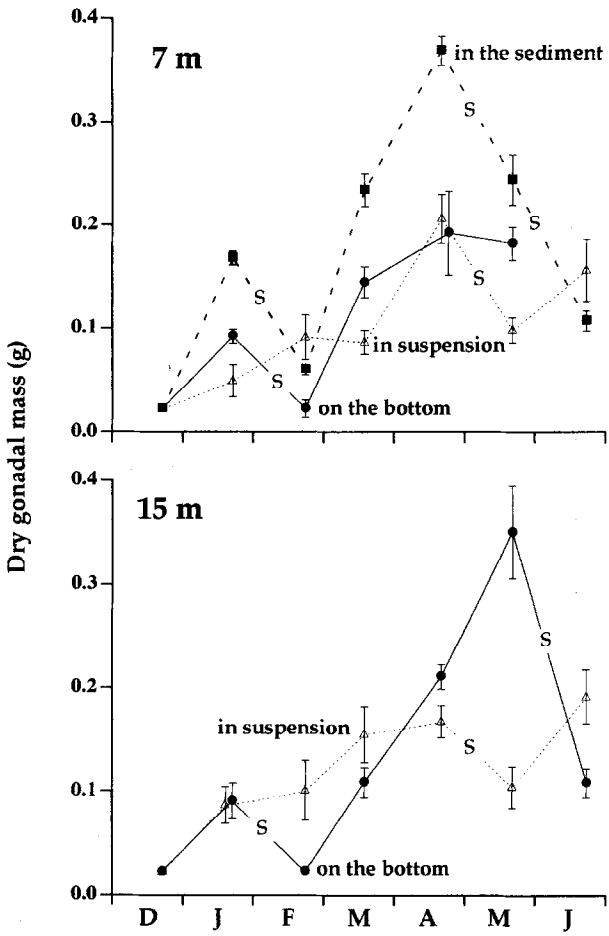

Fig. 5. *Euvola ziczac*. Monthly changes in mean dry gonadal mass for scallops maintained in cages suspended at a depth of 7 and 15 m (in suspension), in cages on the bottom at 7 and 15 m, and in partly buried cages at 7 m (in the sediment). The vertical bars represent the 95% confidence limits. "S" indicates a significant decrease between successive dates (spawning), as shown by the modified Jonckheere's test ($p < .01$).

decreased fouling of cages near the bottom, compared to those in suspension, was likely due to increased browsing by benthic predators, such as crabs and bottom fishes.

Predators

A variety of potential scallop predators were recruited onto the experimental cages during the two sampling periods (March and June). The principal species were the prosobranch gastropods, *Cymatium poulseni* Mörch, 1877, *Thais haemastoma floridana* (Conrad, 1837) and *Murex* (*Chicoreus*) *brevifrons* Lamarck, 1822, and the crabs *Mythrax hispidus* (Herbst, 1790) and *Portunus spinimanus* Latrielle, 1819. At both 7 and 15 m the mean number for each of the above predators was greater in suspension than on the bottom. However, none of the predators attained a large size during the 3-month immersion period of the cages

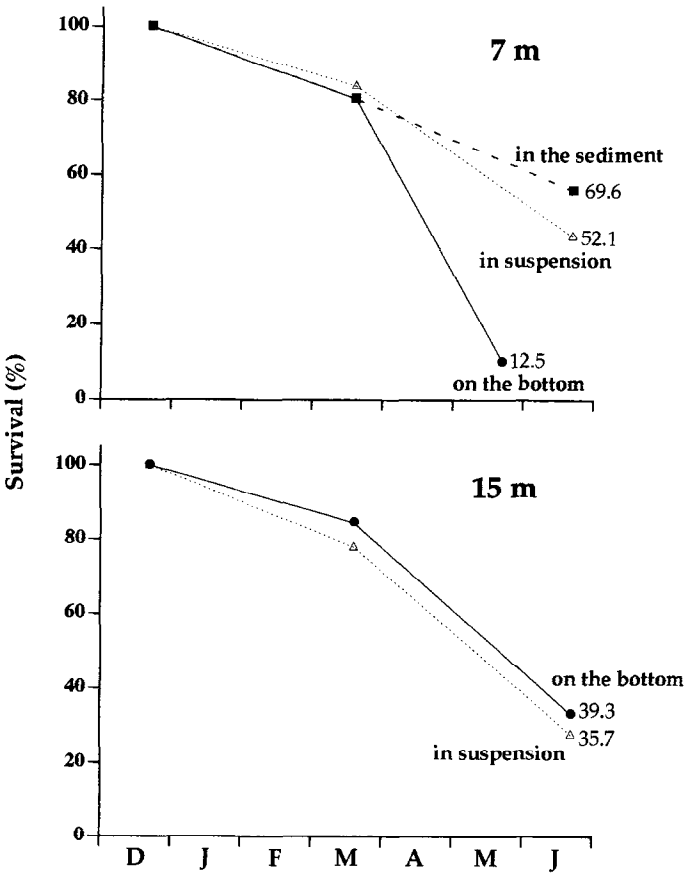

Fig. 6. *Euvola ziczac*. Survival of scallops maintained in cages suspended at depths of 7 and 15 m (in suspension), in cages on the bottom at 7 and 15 m (on the bottom), and in partly buried cages at 7 m (in the sediment). The numbers to the right of each line indicate the percentage survival since 22 March 1992 when the scallops were set out at a reduced density (4 scallops per cage).

(December to March and March to June) and thus probably did not cause mortalities of the scallops.

4. Discussion

Numerous studies demonstrate that scallops grow more rapidly when maintained in suspended culture; however, this is not true for *Euvola ziczac*. Our experiments at two depths show a similar or slightly decreased rate of growth for scallops maintained in cages in the water column, compared to scallops in cages on the bottom. However, growth is accelerated when scallops are maintained in cages which are partly sunken into a sediment bottom. A possible explanation for this is that *E. ziczac* is adapted to feeding on organic material at the sediment/water interface. This hypothesis is suggested because natural beds

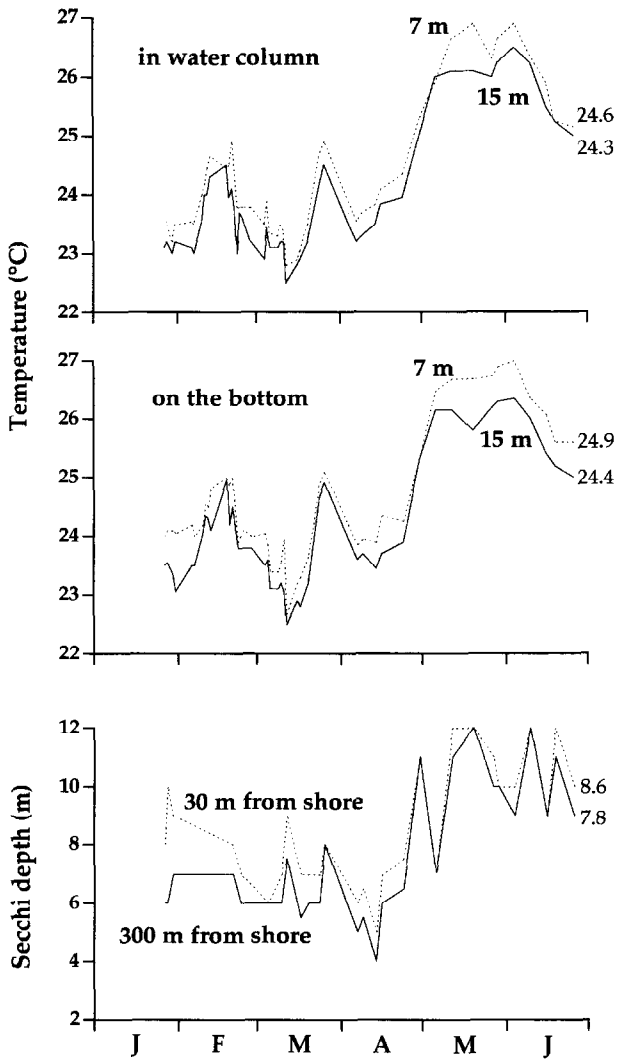

Fig. 7. Seasonal variations in temperature, at the sites where scallops were maintained in the water column and on the bottom at 7 and 15 m in depth, and seasonal variations in water transparency at 300 m from the shore (where the scallops were maintained in suspension) and at 30 m from the shore (where scallops were maintained on the bottom at 15 m in depth). Mean values for the study period are indicated to the right of each line.

of *E. ziczac* are only found on sandy bottoms and approximately 95% of the individuals bury themselves flush with the bottom. The upper valve is usually thinly covered with sediment so that the scallop's presence is only evident from close inspection which reveals the circle of tentacles at the surface of the substratum (Fig. 2). Our determinations of total phosphorus and nitrogen content indicate that organic matter is more abundant in surface sediments than in the water column. An alternative and complementary hypothesis is that the growth in bottom cages and in suspension is decreased because the scallops are behaviourally stressed by not being able to bury themselves.

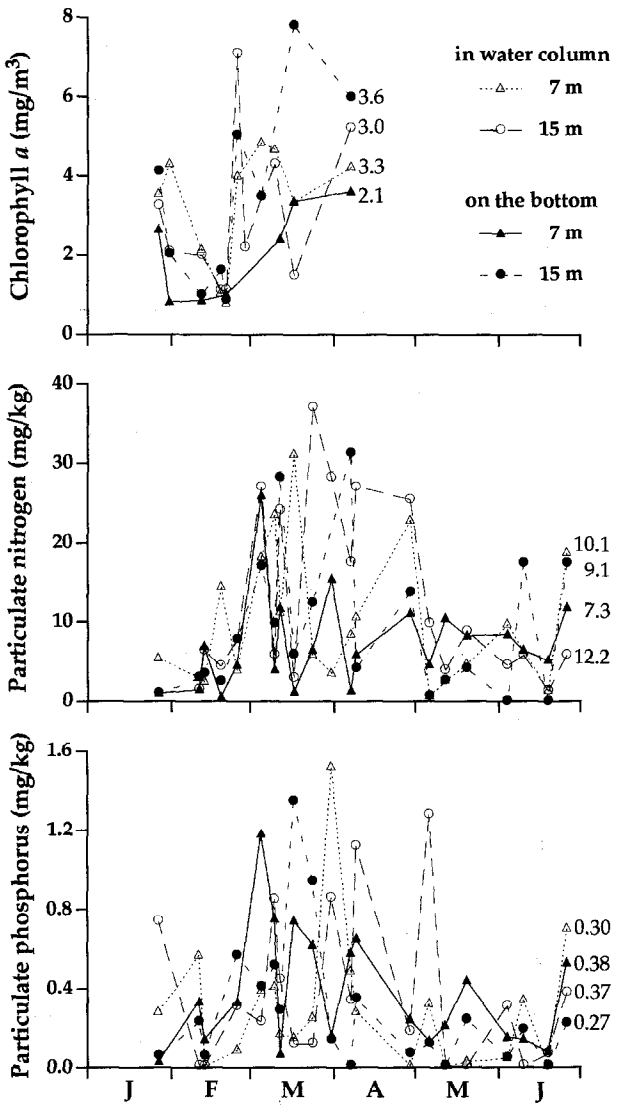

Fig. 8. Seasonal variations in chlorophyll a concentration, particulate organic nitrogen and particulate organic phosphorus, at the sites where the scallops were maintained in suspension and on the bottom at 7 and 15 m. Mean values for the study period are indicated to the right of each line.

Our data show generally low temperatures, indicative of upwelling (Margalef, 1965; Mandelli and Acuña, 1975; Mandelli and Ferraz, 1982; Okuda, 1981), from January to mid-April. The temperature rise in late April is earlier than indicated for the region by Okuda (1982). This could be because our measurements were made nearer the coast, or because stratification of the water column occurred earlier in 1992. The data on water transparency and on particulate nitrogen and phosphorus suggest high food availability

during the period of upwelling. Thus, an abundance of particulate organic matter was probably available to the scallops during the first 5 months of the study (December to April). This was when the major burst of somatic and gonadal growth occurred. Although a decrease in particulate organic matter was indicated for May and June, we nevertheless recorded marked gonadal growth at 15 m on the bottom in May and at 7 and 15 m in suspension during June, and marked shell growth at 15 m in suspension during June. Both the temperature measurements and the indicators of food abundance from the water samples show that conditions were similar on the bottom and in suspension at the two depths. This could account for the similarity in the growth curves for scallops in suspension and on the bottom at the two depths.

Previous studies of *Euvola ziczac* in natural beds (Brea, 1986; Vélez et al., 1987) and in suspended culture (Lodeiros and Himmelman, 1994) indicate synchronous gonadal development, gonadal size and condition being similar amongst individuals at any given time. This contrasts with many tropical species for which reproduction is continuous once the gonads are developed or for which a portion of the population is reproducing at any given time (Vélez, 1977, Vélez, 1985; Hadfeld and Anderson, 1988). Our data indicated synchronous gonadal development within any given treatment, but striking differences among treatments. Thus, a February spawning occurred for the groups in cages on the bottom and in those which were partially buried, but not for those in suspension. Temperature is often considered to contribute to gamete maturation and spawning (Loosanoff and Davis, 1963; Sastry, 1979; Barker and Blake, 1991) and Vélez et al. (1993) show that *E. ziczac* can be brought into spawning condition by being exposed to 26°C in the laboratory. The February spawnings in our study coincided with a slight increase in temperatures (>24°C) for 2 weeks. However, temperature conditions were similar for all treatments and thus temperature could not account for the lack of spawning for scallops in suspension. For example, prior to the February spawning on the bottom at 15 m the mean temperature was 23.9°C, which compares to 24.0°C for scallops in suspension at 7 m, which did not spawn. An alternative hypothesis is that the scallops in suspension did not spawn in February because of a lack of food resources. This is suggested by the smaller size of the gonad, muscle and shell in late January for the scallops in suspension in 7 m (Figs. 3-5). However, this hypothesis is contradicted by the data for 15 m. At 15 m the body components for scallops in suspension (which did not spawn) had attained about the same size as for scallops on the bottom (which spawned). By 21 April, relative gonadal mass was high for all groups (31–40%); however, only three spawned during the major temperature increase that followed in later April. The lack of spawnings by scallops in cages on the bottom further contradicts the hypothesis that temperature controls spawning. The striking differences in the timing of spawning occurred for scallops on the bottom compared to those in suspension suggests that spawning is controlled more by conditions in the immediate habitat of the scallop than by large scale oceanographic conditions.

Our data show interactions in the growth of the shell, muscle and gonad. In all cases in the same month where a decrease in gonadal size indicated spawning activity, muscle mass showed a decrease in size or no change and the rate of shell size decreased or remained static. This suggests that *Euvola ziczac* cannot invest energy in somatic growth when spawning is occurring.

Survival was relatively high during the first 3 months but dropped during last 3 months. Decreased space in the cages could not have accounted for the mortality in the latter period because the density had been decreased by half in March. Although the potential for temperature stress was greater in the last 3 months, temperature was probably not a major mortality factor. This is suggested because temperatures were virtually the same for the various treatments (mean temperatures from 24 March to 26 June varied by $<0.42°C$) whereas mortality rates varied markedly. Mortality was more likely associated with factors in the immediate vicinity of the scallops. We suspect that organisms colonizing the scallops themselves caused mortality. This seemed particularly likely at 7 m on the bottom where the shells were covered by the oysters *Crassostrea rhizophorae* Guilding 1928, and *Ostrea equestris* Say 1824 (Fig. 2). In many cases this growth prevented normal valve closure. Mortality of scallops in suspension might have been caused by heavy colonization of cirripedes and the anemone *Bunodactis stelloides* McMurrich 1889. The latter anemone was absent on scallops in the bottom treatments. Virtually no organisms colonized the shells of scallops in the partly buried cages, probably because the scallops were usually buried. This may explain their higher rate of survival.

In suspended culture, shell length generally attains a plateau, at about 46 mm in shell length at 7 m, and slightly less (43 mm) at 15 m, after 7 months (the scallops had been grown from September to December 1991 in pearl nets and then in cages until March 1992). A slowing of growth at approximately 44 mm is also shown by Lodeiros and Himmelman (1994) for *E. ziczac* grown in pearl nets at 15–20 m. A somewhat greater growth rate occurs in cages on the bottom. At these growth rates, several years would be required for scallops to attain 70–80 mm, the predominant size in natural beds. By contrast, a projection of the growth curves for scallops in partly buried cages suggests they could attain 70–80 mm in about 1.5 years.

A close relationship with the bottom seems to be advantageous for *Euvola ziczac*. In this respect, *E. ziczac* resembles infaunal clams such as *Venerupis semidecussata* and *Ruditapes philippinarum*, for which studies in Spain demonstrate a reduced rate of growth in suspension compared to on the bottom (Domenech, 1990; Guerra et al., 1990). For the latter species, the importance on being on the bottom is primarily an attribute of larger individuals, since small individuals also have a high rates of growth and survival in suspension. Our study, beginning with scallops measuring 33 mm in length, demonstrated enhanced growth for individuals in partly buried cages within a month.

Numerous questions must be answered before a rational strategy can be developed for culturing *Euvola ziczac*. Although scallops can probably be grown to the size in natural beds in approximately 2 years, harvesting after 7–8 months (September to March or April in our study), when most of the gain in muscle size has been attained, may be advantageous. Predator populations which developed over 3 months in enclosures do not appear to cause mortalities; however, studies are needed to determine their impact when scallops are grown to a commercial size without eliminating predators at an intermediate point. Heavy fouling of suspended cages likely reduces growth and organisms colonizing scallop shells may cause mortalities. By contrast, fouling appears to be a minor problem when scallops are maintained in partly buried cages, since it is slight on the cages and negligible on the scallops themselves. We show that scallops grow rapidly in partly buried cages; however, densities in our study were low (the scallops covered about 25% of the surface area in the cages at

the end of the study). Growth rates at higher densities must be examined. Possibly, the Japanese technique of growing juveniles in suspended culture for later release on the bottom (without cages) could be applied to *E. ziczac*. To asses this strategy (and to determine the optimal size for bottom release), changes with scallop size in (1) vulnerability to benthic predators and (2) dispersion rates from release sites, need to be investigated.

Acknowledgements

We are indebted to P. Nuñez and A. Sotillet for their aid with the fieldwork, to J. Côté and J. Bonardelli for aid with the statistical tests and figures, to C.J. Lodeiros for critical comments on the manuscript and J. Pablo Blanco for identifying crustacean predators. The field research was supported by the Consejo Nacional de Investigaciones Científicas y Tecnológicas de Venezuela (CONICIT, project SI-2456 and F-131).

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