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Within-raft variability of the growth rate of mussels, *Mytilus galloprovincialis*, cultivated in the Ría de Arousa (NW Spain)

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Abstract

The relative influence of three factors on the growth rate of mussels, *Mytilus galloprovincialis*, cultivated in an inner area of the Ría de Arousa (NW Spain), was analysed. The three factors acted within the raft: position of the culture ropes on the raft, depth of cultivation and stocking density. Results indicate that depth of cultivation is the major factor affecting the growth of the mussels. In the two phases of the cultivation process, from seeding to thinning out and from thinning out to harvest, mussels cultivated in the upper part of the water column (2.5 m depth) were significantly longer and heavier than those in the lower part (7.5 m depth). Effect of the position of the ropes on the raft was less important. Only at harvest, were significant differences in the weight of the mussels detected, with lighter mussels occurring at the back (down-current) of the raft. Surprisingly, stocking density showed no significant effect on the growth of the mussels in any of the two cultivation phases. From the results obtained in this experiment, some recommendations, important for the management of the Galician mussel cultivation, are given.

Keywords: Mussels; Depth; Density; Raft culture; *Mytilus galloprovincialis*; Growth

1. Introduction

Mussel cultivation in many parts of the world is based on the transplantation of wild seed occurring in different locations of the coast to culture systems (racks, rafts,

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long-lines, etc.) located in nutrient-rich growing areas of sheltered environments. It has been shown in several studies (e.g. Fuentes et al., 1992, 1994; Stirling and Okumus, 1994; Sukhotin and Maximovich, 1994) that, irrespective of the source of seed, growth rate of cultivated mussels is mainly dependent on the environmental conditions at the sites of cultivation.

In a transplantation experiment carried out by Fuentes et al. (1992, 1994) in Galicia (NW, Spain), it was shown that growth rate of raft-cultivated mussels depends more on micro-scale variation (within-raft differences) of environmental conditions than on the macro-scale differences (between growing sites) in hydrographic characteristics. In that experiment, within-raft differences referred only to those between the front and the back of the rafts. Most Galician mussel rafts are rectangular floating frames with suspended culture ropes, anchored to only one point by a chain tied to one of their sides. This anchorage system permits the rafts to move always facing into the direction of the current (mainly wind and tidal currents) and, therefore, they show a permanent front and back part. Culture ropes suspended from the front part of the rafts alter the speed and direction of the incoming currents (Blanco et al., 1996), which, together with the filtering activity of mussels on these ropes, cause areas at the center and back parts to have lower levels of available food for growth (Cabanas et al., 1979). Although growth rate was mainly affected by the position of the mussels within the raft, most of the total variation was not explained solely by the three factors included in the variance model. This means that other factors acting on a micro-scale level (probably within rope) and not considered in that experiment, such as depth of cultivation and stocking density, are also affecting the growth rate of mussels.

As mentioned in previous papers (Fuentes et al., 1992, 1994), to improve the mussel cultivation in Galicia, a more detailed knowledge of the relative importance of micro-scale factors on the production parameters is required. In this paper, the influences of the position of the culture ropes on the raft, the depth of cultivation and the stocking density on the growth rate of mussels are analysed.

2. Materials and methods

2.1. Experimental design and sampling

In February 1993, mussel seeds (less than 20 mm long) from a natural population of an exposed intertidal zone of the Galician coast (NW of Spain) were transplanted to a commercial mussel raft located in an inner area of the Ría de Arousa (site 1 in Fuentes et al., 1992). A raft in this area was chosen because it was situated in the inner and less turbulent waters of the ''ría'', where within-raft variability of environmental conditions is expected to be highest. The raft was a rectangular wooden frame of 540 m^2 (20×27 m), anchored to only one point by a chain tied to the middle of one of the longest sides (front) and loaded with a maximum of 500 culture ropes (maximum legal number). Mussels were seeded on 18 experimental ropes (9 m long) at three different densities. Six ropes were seeded at a density of approximately 10 000 mussels per meter of rope

(high density = standard density used by the owner of the raft); six ropes were seeded at a density of 7500 mussels per meter of rope (medium density) and six ropes at a density of 5000 mussels per meter of rope (low density). Two ropes of each density were hung at random, between other standard commercial ropes, from the middle part of the front, center and back of the raft, respectively. In July 1993, the thinning out process was carried out. Ropes were hauled up and, from each rope, two replicate samples were taken at depths of 2.5 m and 7.5 m, respectively. Each sample consisted of all the mussels attached to a rope length of 10 cm. After cleaning the mussels, the live mussels were counted and an estimate of the final density (mussels/m) was obtained, from each sample. A subsample of 15 mussels was randomly taken from each sample to estimate the mean values of shell length and total weight.

After the thinning out process, the cultivation was continued on the same raft at considerably lower densities (see Pérez-Camacho et al., 1991). Mussels from all the ropes were cleaned, randomly mixed and tied again to new culture ropes (9 m long) at three different densities: six ropes at 700 mussels/m (high density), six ropes at 525 mussels/m (medium density) and six ropes at 350 mussels/m (low density). Again, two ropes at each density were hung from the front, center and back of the raft, respectively. In June 1994, the ropes were retrieved and, from each rope, two replicate samples were taken at depths of 2.5 m and 7.5 m, respectively. Each sample consisted of all the mussels attached to a rope length of 20 cm. After cleaning the mussels, the number of live mussels in each sample was counted and an estimate of the final density (mussels/m) was obtained, from each sample. A subsample of 15 mussels was randomly taken from each sample to estimate the mean values of shell length, wet meat weight and total weight.

In the two phases of this study, we have included in the experimental design a new position (the center of the raft) not considered in the previous experiment (only front and back; Fuentes et al, 1992). This is because, according to Blanco et al. (1996), it is in this part of the raft where current velocity is slowest.

2.2. Environmental conditions

Data on oceanographic conditions were supplied by the ''Phytoplankton and Oceanographic Conditions Monitoring Program'' (Centro de Control da Calidade do Medio Mariño, Consellería de Pesca, Marisqueo e Acuicultura). Raw data of temperature, salinity and in vivo fluorescence of chlorophyll *a*, at depths of 2.5 and 7.5 m, were obtained at weekly intervals. They were obtained with a Sea-Bird 25 CTD equipped with a Seatech Fluorometer, from a permanent sampling station located near to the commercial raft used in this experiment. Row data plots were smoothed by averaging every 3 adjacent weekly data points (Adjacent Averaging Method in Microcal Origin, 4.0; see Press et al., 1993).

2.3. Statistical analysis

Mean values of shell length, wet meat weight, total weight and number of mussels per meter of rope were analysed by mixed nested ANOVAs (Balanced Anova; Minitab

12.1 for Windows), with the random factor ''rope'' nested within the other fixed factors included in the experiment (position, density and depth). Since we were only interested in detecting marked effects, we have considered to be statistically significant only those with P-values ≤ 0.01. After ANOVAs, differences between mean values of significant factors with more than two levels were analysed by the Tukey test of pairwise comparisons.

3. Results

3.1. From seeding to thinning out

At the end of this first phase of the experiment, the greatest difference in the mean value of the shell length of mussels was detected between depths (Fig. 1A). Shell length of mussels at 2.5 m (5.0 ± 0.05 cm; mean $\pm$ S.E.) was significantly greater ($P < 0.001$; Table 1) than at 7.5 m (4.5 ± 0.05 cm). Differences between positions within the raft (4.8 ± 0.07 cm, front; 4.9 ± 0.09 cm, center; 4.6 ± 0.06 cm, back; Fig. 1A) and between densities (4.7 ± 0.08 cm, high; 4.7 ± 0.07 cm, medium; 4.9 ± 0.08 cm, low; Fig. 1A) were not significant ($P = 0.08$ and $P = 0.24$, respectively; Table 1).

Mean value of the total weight of mussels showed a pattern of variability similar to that of shell length (Fig. 1B). Thus, mussels cultivated at 2.5 m (7.5 ± 0.26 g) were significantly heavier ($P < 0.001$; Table 1) than those at 7.5 m (5.4 ± 0.18 g). Differences between the mean values in the front (6.7 ± 0.36 g), center (6.9 ± 0.39 g) and back (5.9 ± 0.27 g) of the raft and between the mean values at high (6.4 ± 0.39 g), medium (6.2 ± 0.28 g) and low (6.8 ± 0.37 g) densities were not significant ($P = 0.028$ and $P = 0.275$, respectively; Table 1).

Final densities of mussels on the ropes at the end of the first phase of the experiment are shown in Fig. 1C. From the differences between the initial and final densities, it can be deduced that mussel losses (mortality plus detachments) were high (average of 67%) during this phase of the experiment. Density at 2.5 m deep (2577 ± 125 mussels/m) was significantly higher ($P = 0.005$; Table 1) than at 7.5 m deep (2124 ± 88 mussels/m). The final number on the ropes seeded at high density (2794 ± 157 mussels/m) was significantly greater ($P = 0.001$; Table 1) than on the ropes seeded at medium and low densities (2179 ± 102 and 2077 ± 109 mussels/m, respectively). Densities on the ropes at the front, center and back (2518 ± 132, 2203 ± 150 and 2330 ± 134, mussels/m, respectively;) were not significantly different ($P = 0.223$; Table 1).

3.2. From thinning out to harvest

Variation of the shell length of mussels at the end of the second part of the experiment (Fig. 2A) follows a similar pattern to that of the first part. The only significant difference in shell length ($P < 0.001$; Table 2) detected, was again between mussels cultivated at 2.5 m (8.3 ± 0.04 cm; mean $\pm$ S.E.) and those at 7.5 m (7.7 ± 0.05 cm). Differences between positions on the raft (8.0 ± 0.06 cm, front; 8.0 ± 0.09 cm, center; 7.9 ± 0.10 cm, back) and between densities (7.9 ± 0.10 cm, high, 8.0 ± 0.07 cm,

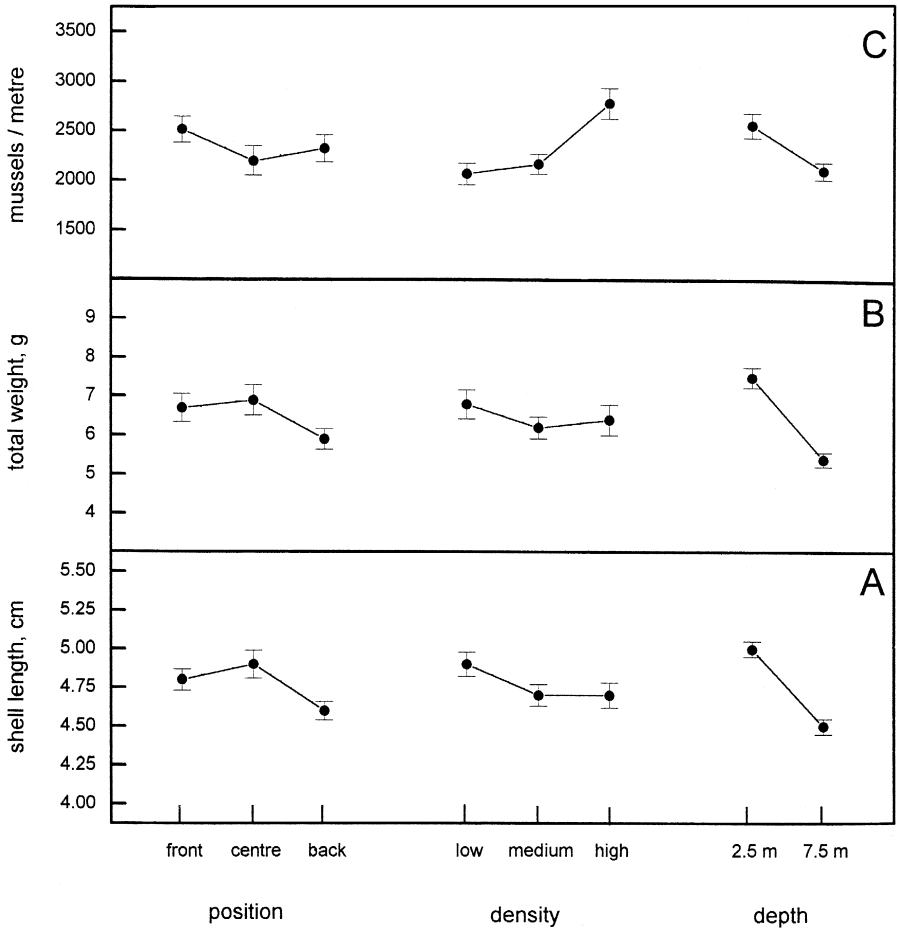

Fig. 1. Mean values of (A) shell length, (B) total weight and (C) number of mussels (*Mytilus galloprovincialis*) per meter of rope at the end of the first phase of the experiment (thinning out), for each position (front, center and back), for each density (low, medium and high) and for each depth (2.5 and 7.5 m). Error bars indicate ± 1 S.E.

medium, 8.0 ± 0.08 cm, low) were not significant ($P = 0.300$ and $P = 0.608$, respectively; Table 2).

Mean value of the wet meat weight of the mussels cultivated at 2.5 m (12.5 ± 0.23 g; Fig. 2B) was significantly higher ($P < 0.001$; Table 2) than those at 7.5 m (9.5 ± 0.26 g; Fig. 2B). We have also detected significant differences ($P < 0.001$; Table 2) between the positions on the raft. Mussels at the front (11.8 ± 0.34 g) and center (11.2 ± 0.44 g) were significantly heavier ($P < 0.001$ and $P = 0.003$, Tukey pairwise comparisons) than those at the back (10.0 ± 0.40 g). Wet meat weight of mussels cultivated at the different densities was very similar (10.8 ± 0.42 g, high; 11.1 ± 0.45 g, medium and 11.1 ± 0.38 g, low, $P = 0.561$; Table 2).

Table 1
ANOVAs for the effects of position (ps), density (ds), depth (dp) and rope (rp, nested factor) on shell length, total weight and number of mussels (*M. galloprovincialis*) per meter of rope, at the end of the first phase of the experiment

Source	*df*	Shell length			Total weight			Mussels/m		
		MS	*F*	*P*-value	MS	*F*	*P*-value	MS	*F*	*P*-value
ps	2	0.320	2.91	0.080 ns	7.390	4.40	0.028 ns	6015	1.63	0.223 ns
ds	2	0.170	1.55	0.239 ns	2.329	1.39	0.275 ns	36087	9.80	0.001***
dp	1	3.712	33.82	0.000***	79.111	47.12	0.000***	36992	10.04	0.005**
rp (ps ds dp)	18	0.110	1.66	0.096 ns	1.679	1.45	0.169 ns	3683	1.33	0.230 ns
ps × ds	4	0.107	0.97	0.447 ns	5.753	3.43	0.030 ns	3491	0.95	0.459 ns
ps × dp	2	0.083	0.75	0.485 ns	0.536	0.32	0.731 ns	351	0.10	0.910 ns
ds × dp	2	0.046	0.42	0.664 ns	2.628	1.56	0.236 ns	8581	2.33	0.126 ns
ps × ds × dp	4	0.056	0.51	0.726 ns	1.739	1.04	0.416 ns	3026	0.82	0.528 ns
Error	36	0.066			1.161			2779		
Total	71									

ns = Not significant (when $P > 0.01$).
** $P \leq 0.01$.
*** $P \leq 0.001$.

Total weight of mussels shows a similar pattern (Fig. 2C). Mussels at 2.5 m were significantly ($P < 0.001$; Table 2) heavier (30.0 ± 0.60 g) than those at 7.5 m (23.0 ± 0.67 g). Mussels at the back of the raft (23.7 ± 0.88 g) were significantly lighter ($P < 0.001$ and $P = 0.001$, Tukey pairwise comparisons) than those at the center (26.8 ± 1.05 g) and front (29.1 ± 0.97 g, respectively). Mussels cultivated at high, medium and low densities were very similar (26.5 ± 1.03 g, high; 26.6 ± 1.15 g, medium; 26.6 ± 1.03 g, low; $P = 0.995$, Table 2).

Final numbers of mussels on the ropes at harvest are shown in Fig. 2D. From these numbers, it can be deduced that, in spite of the longer duration of the second part of the experiment, mussel losses were clearly lower (around 24%) than in the first part. Final densities of mussels on the ropes were very similar in the different positions on the raft (403 ± 27 mussels/m, front; 379 ± 27 mussels/m, center; 414 ± 19 mussels/m, back; $P = 0.422$; Table 2) and at the two depths of cultivation (398 ± 21 mussels at 2.5 m and 399 ± 19 at 7.5 m; $P = 0.970$; Table 2). On the contrary, final number of mussels on the ropes seeded at high, medium and low densities (495 ± 19, 391 ± 18 and 309 ± 21 mussels/m; Fig. 2D) were significantly different ($P < 0.001$; Table 2).

3.3. Environmental conditions

Water temperature ranged between 12°C in winter and 19°C in summer (Fig. 3A). During autumn and winter, temperature was very homogeneous throughout the water column. However, during spring and summer, temperature at 2.5 m was clearly higher than at 7.5 m.

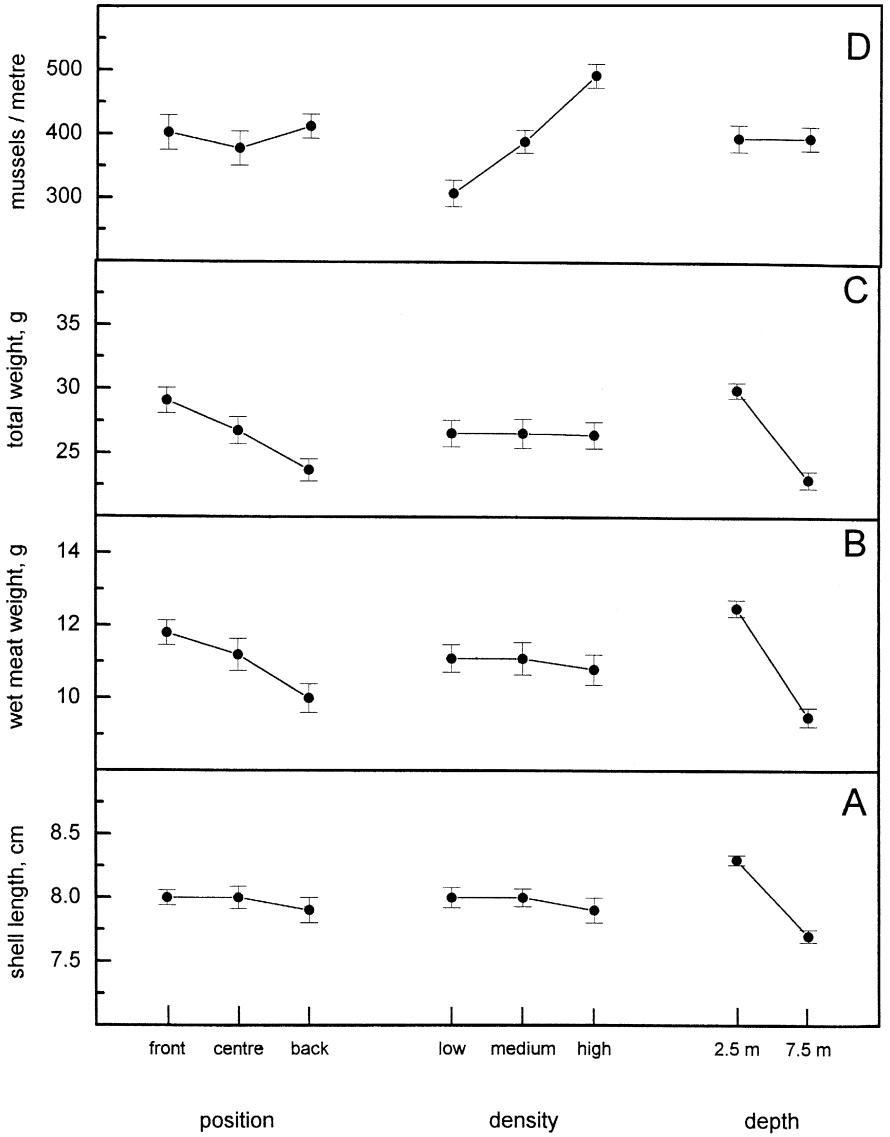

Fig. 2. Mean values of (A) shell length, (B) wet meat weight, (C) total weight and (D) number of mussels (*M. galloprovincialis*) per meter of rope at the end of the second phase of the experiment (harvest), for each position (front, center and back), for each density (low, medium and high) and for each depth (2.5 and 7.5 m). Error bars indicate ± 1 S.E.

Salinity at 2.5 m was always lower and more variable than at 7.5 m, particularly during May 1993 and the winter of 1994 (Fig. 3B). Salinity varied between 35.2‰ in August 1993 and 28.3‰ in February 1994, at 2.5 m, and between 35.7‰ in July 1993 and 32.3‰ in February 1994, at 7.5 m.

Table 2
ANOVAs for the effects of position (ps), density (ds), depth (dp) and rope (rp, nested factor) on shell length, wet meat weight, total weight and number of mussels (*M. galloprovincialis*) per meter of rope, at the end of the second phase of the experiment

Source	*df*	Shell length			Wet meat weight			Total weight			Mussels/m		
		MS	*F*	*P*-value	MS	*F*	*P*-value	MS	*F*	*P*-value	MS	*F*	*P*-value
ps	2	0.096	1.29	0.300 ns	20.998	12.99	0.000 ***	180.511	14.29	0.000 ***	315.3	0.91	0.422 ns
ds	2	0.038	0.51	0.608 ns	0.966	0.60	0.561 ns	0.061	0.00	0.995 ns	8305.0	23.84	0.000 ***
dp	1	6.554	88.17	0.000 ***	152.849	94.58	0.000 ***	888.874	70.35	0.000 ***	0.5	0.00	0.970 ns
rp (ps ds dp)	18	0.074	1.34	0.222 ns	1.616	1.29	0.249 ns	12.635	2.07	0.031 ns	348.3	2.30	0.016 ns
ps × ds	4	0.069	0.93	0.470 ns	1.685	1.04	0.413 ns	11.609	0.92	0.474 ns	665.7	1.19	0.152 ns
ps × dp	2	0.391	5.26	0.016 ns	5.507	3.41	0.056 ns	18.208	1.44	0.263 ns	1547.5	4.44	0.027 ns
ds × dp	2	0.043	0.57	0.574 ns	0.049	0.03	0.970 ns	5.376	0.43	0.660 ns	1554.9	4.46	0.027 ns
ps × ds × dp	4	0.111	1.49	0.246 ns	3.063	1.89	0.155 ns	28.816	2.28	0.101 ns	817.3	2.35	0.094 ns
Error	36	0.056			1.250			6.099			151.4		
Total	71												

ns = Not significant (when $P > 0.01$).
** $P \leq 0.01$.
*** $P \leq 0.001$.

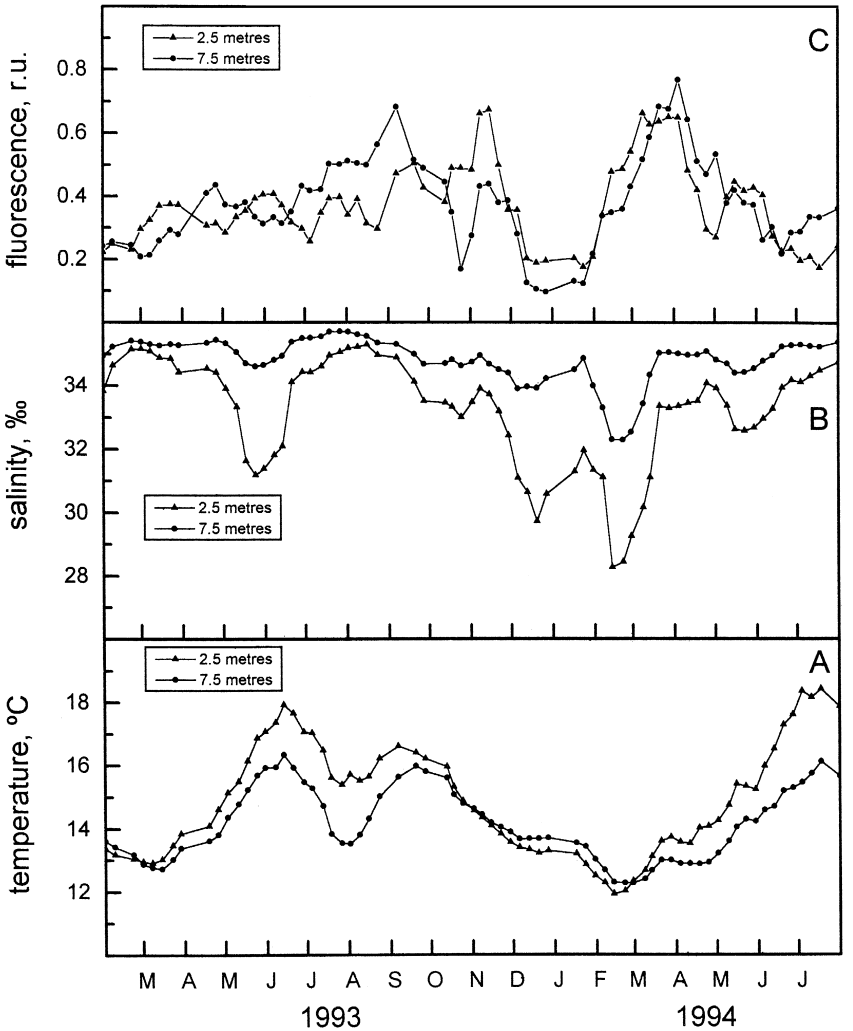

Fig. 3. Values of (A) temperature, (B) salinity and (C) fluorescence, at 2.5 and 7.5 m, in a permanent sampling station near the site of the study, Ría de Arousa.

Patterns of fluorescence at 2.5 and 7.5 m were very similar, with minimum values in December 1993–January 1994 and maximum values in March–April 1994 at both depths (Fig. 3C).

4. Discussion

Results presented in this study indicate that depth of cultivation is the major micro-scale factor affecting the growth of the raft-cultured mussels, *M. galloprovin-*

cialis, in the Ría de Arousa (NW of Spain). In the two phases of the cultivation process, from seeding to thinning out and from thinning out to harvest, mussels cultivated in the upper part of the water column were significantly longer and heavier than those in the lower part. Effect of the position of the culture ropes on the raft was less clear. Only at harvest and only for the total weight and wet meat weight of mussels were significant differences detected, mussels being lighter the further back in the raft they were positioned. Density of cultivation showed no significant effect on the growth of the mussels in any of the two phases of the cultivation process.

The effect of depth of cultivation on the growth of mussels has been dealt with in several studies. In some of them, no significant effect of depth on growth has been detected. For example, Richardson et al. (1990) found no consistent relationship between growth rate of *M. edulis* and water depth on two offshore production platforms in the Irish Sea and North Sea. Similarly, Mallet and Carver (1991) found that shell and tissue growths of *M. edulis* in Nova Scotia (Canada) were similar for mussels suspended at depths of 2 and 10 m in long line cultivation systems. However, a relationship between mussel growth and depth has been described in other studies. In a Baltic *M. edulis* population, Kautsky (1982) showed that growth rate of caged mussels at a depth of 15 m was clearly lower than at 4 m. This difference was mainly attributed to the difference in temperature between the two depths, although a good correlation between growth and phytoplankton abundance was also obtained. In a gas production platform located offshore from Goleta (CA, USA), Page and Hubbard (1987) found that *M. edulis* living at a depth of 9 m grew faster than those at 2 and 18 m. Therefore, these authors concluded that the differences cannot be associated with temperature, since water temperature decreased with depth. They found that higher growth rate at 9 m was correlated with the high chlorophyll *a* and particulate organic carbon (POC) concentrations at that depth. However, lower growth at 18 m was only associated with low POC, but not with low chlorophyll *a* concentrations. In Northern Puget Sound (WA, USA), Mueller (1996) found that the mussel *M. trossulus*, raft-cultured under low culture rope density conditions, grew faster at 1 and 3 m than at 5 m, although no clear differences were detected when mussels were cultured under high density conditions. The author also attributed this higher growth at 1 and 3 m to the high POC values occurring in the nutrient-rich surface layers.

In our experiment, although differences in temperature between the two depths were not very great, temperature at 2.5 m during the period of higher growth (spring and summer) was always higher than at 7.5 m (Fig. 3A). Therefore, we can consider temperature as an important factor explaining differences in mussel growth with depth in this experiment. However, we cannot exclude food abundance as another important factor determining the growth differences, despite the fact that values of in vivo fluorescence (IVF) between the two depths were not consistent throughout the experiment (Fig. 3C). Firstly, IVF is not always a reliable indicator of phytoplankton biomass (Falkowski and Kiefer, 1985; Estrada et al., 1996), so that from similar values of IVF, we cannot necessarily infer similar levels of available biomass for growth. High values of IVF could reflect high levels of phytoplankton cells, but cells too small to be used as source of food for mussels. In contrast, high densities of larger cells, but with small chloroplasts, could produce lower values of IVF (Alpine and Cloern, 1985). Secondly,

there are other sources of non-phytoplanktonic food and silt particles, which are transported by the low salinity waters of the river. There affect mainly the upper layers of the column water above the thermocline (Fig. 3B) and could improve the growth of the mussels. In this regard, Navarro et al. (1996) have shown that composite diets of phytoplankton cells and bottom sediments result in the highest rates of absorption in mussels from the Ría de Arousa. They suggest a possible mechanical role of silt particles in digestion and absorption similar to the mechanical action of the crystalline style.

Differences in the growth of mussels suspended from different positions in the rafts, have been detected in a previous experiment in the same ''ría'' (Fuentes et al., 1994). In that experiment, the average value of the total weight increase of mussels suspended from the front of three rafts was 46% greater than that of the mussels suspended from the back. However, in the present experiment, the maximum differences detected both in the first phase (mussels in the center 17% heavier than at the back) and in the second phase (mussels at the front 31% heavier than at the back), were considerably lower. These results merit some additional explanation. First, at the end of 1990, just when our first experiment was finishing, a maximum legal density of 500 culture ropes per raft (1 rope/m^2) was established by the *Consellería de Pesca, Marisqueo e Acuicultura* (Galician Fisheries Department), in order to both lower the total load of cultivated mussels in the ''rías'' and reduce the differences in growth between the different parts of the rafts. Therefore, this legal reduction in the number of ropes per raft could explain the different results found in the two experiments. Second, while in the first phase of this experiment the differences in total weight of the mussels in the different parts of the raft were not significant, in the second one, they were highly significant. From seeding to thinning out, the diameter of the culture ropes is considerably smaller than from thinning out to harvest, due to the smaller size of the mussels. Therefore, the reduction and the deflection of the incoming currents brought about by the ropes in the front of the rafts (Blanco et al., 1996) is expected to be lower in the first than in the second phase of the experiment. This would permit higher replenishment of food at the back of the rafts in the first than in the second phase of the experiment and, in consequence, produces lower differences in the growth rate of the mussels.

The effect of stocking density on the growth rate of bivalves is a well-documented aspect that has been studied in several species under different culture and environmental conditions. In most of these studies, a negative relationship between growth rate and density has been established. So, in the European oyster, *Ostrea edulis*, cultivated in lantern nets suspended from long lines at Blind Bay (Nova Scotia, Canada), Jarayabhand and Newkirk (1989) found that growth rate decreases as stocking density increases. Similar results were obtained with juveniles of the Sydney rock oyster, *Saccostrea commercialis*, grown in both trays (Holliday et al., 1991) and cylinders (Holliday et al., 1993) in intertidal areas of New South Wales (Australia). In juvenile sea scallops, *Placopecten magellanicus*, cultivated in pearl nets suspended from long lines at the Baie of Chaleurs (Quebec, Canada), Côté et al. (1993) reported that an increase in stocking density greatly reduced the growth rate of the shell, adductor muscle and other tissues. In juveniles of the silver-lip pearl oyster, *Pinctada maxima*, held in either suspended or bottom culture in Western Australia, Taylor et al. (1997) also showed that growth rate

decreases as the stocking density increases. In the north coast of Spain, similar results were detected for the Manila clam, *Ruditapes philippinarum*, cultivated in intertidal beds of the Eo estuary using oyster bags (Cigarría and Fernández, 1998), and in juveniles of the queen scallop, *Aequipecten opercularis*, held in suspended culture in the Ría de Arousa (Román et al., 1999). However in mussels, results from this and other experiments with *M. edulis* in Canada (Mallet and Carver, 1991) and with *Aulacomya ater*, *Choromytilus meridionalis*, and *M. galloprovincialis* in South Africa (Van Erkom Schurink and Griffiths, 1993), show that the negative relationship between density of seeding and growth cannot be considered as a general rule. Two hypotheses, not mutually exclusive but both linked to the typical behaviour of some species of mussels of forming multi-layer clumps, may be considered as an explanation. First, a density-dependent reduction in the number of mussels per unit of area (ropes, surface, socks, etc) could happen, with a higher reduction in more dense clumps. This reduction could take place either just at the first moments of the cultivation due to rapid dislodgement of mussels, (see Fuentes et al, 1998, for a discussion) or it could be a progressive process due to competition for food or space (self-thinning in the sense of Hughes and Griffiths, 1988). In both cases, a more or less rapid and complete transition from multi-layer to mono-layer structure of the clumps should take place. Second, due to the high mobility of the mussel seed, individuals within the clump could reorientate their umbos in such a way that all of them have a similar chance to filter the incoming seawater. In this second case, both the initial density and initial multi-layer structure would be maintained. Results from this experiment seem to indicate that the first hypothesis applies in the case of the Galician mussel cultivation. An important reduction in the number of mussels per unit of rope took place in each cultivation phase (see also Fuentes et al., 1998) and, comparing initial and final densities, it can be shown that this reduction is density-dependent.

Finally, from the results obtained in this experiment, some conclusions, important for the management of the Galician mussel cultivation, can be deduced. First, the legal reduction of the number of culture ropes per raft established in 1990 by the Galician Fisheries Department produced a reduction in the differences between the growth rate of mussels cultivated in the front and the back of the rafts. Second, from seeding to thinning out, cultivation should be carried out in the upper part of the water column (above the thermocline), where the growth of the mussels is highest. With this practice, the duration of the first phase of the cultivation will be considerably reduced. This can be easily done by a method, already used by some mussel farmers, called ‘‘chicoteo’’, which involves hanging the ropes tied to the raft by the two ends in a U shape. Although the real density of ropes per square meter in the upper water column will be twice the standard, the speed and direction of the incoming currents will not be altered by this system, due to the small diameter of the culture ropes at this phase of cultivation. Third, since the present tendency of the Galician mussel culture is more towards increase in quality rather than quantity, we suggest that, in the inner areas of the ‘‘rías’’, the second phase of cultivation be also carried out in the upper parts of the ropes, where the biggest mussels are produced, even assuming a reduction in the total production per raft. Fourth, although results from this experiment indicate that a reduction in the standard density of seeding does not result in improved biomass, it should not be concluded that the current

densities used by mussel farmers are the optimum ones. Mussel farmers now obtain the seed for cultivation free or at a very low cost, so they can afford to use high stocking densities, in spite of the considerable density-dependent losses that take place from seeding to thinning out. However, if the price of mussel seed were to increase (this is a real possibility), mussel farmers would lose a considerable amount of money in the form of dislodged mussels.

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