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Effects of trophic and environmental conditions on the growth of *Crassostrea gigas* in culture

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Abstract

In order to study the possibility of exploiting protected marine areas, comparative data on the cultivation of the oyster *Cassostrea gigas* in the South Tyrrenian Sea are reported. The oysters were cultured at −7 and −13 m on long lines linked to artificial reefs. The observations, made during a 12-month period, were of the chemical-physical and trophic properties of the water column and growth rates of the oysters. Temperature ranged between 19.81 ± 4.67°C at −7 m and 18.03 ± 3.03°C at −13 m. Salinity showed typical Mediterranean values. The area presented oligotrophic features: the chlorophyll-a (CHLa) concentration ranged between 0.05 ± 0.01 and 0.04 ± 0.02 $\mu g\ l^{-1}$ at −7 and −13 m, respectively. The labile particulate organic matter (LPOM) ranged between 344 ± 201 and 334 ± 228 $\mu g\ l^{-1}$ at −7 and −13 m, respectively, and the CHLa carbon/POM carbon ratio (index of the autotrophic vs heterotrophic conditions) was never above 3%. POM concentration and POM gross energy content showed significant differences ($P < 0.05$) at the two depths, POM bulk being greater at −13 m. The oysters, sampled monthly, had an initial average size of 11.50 ± 2.78 mm (0.0036 ± 0.01 g dry weight) and had reached 47.50 ± 12.30 mm (0.13 ± 0.04 g dry weight) at −7 m and 41 ± 11.43 mm (0.11 ± 0.04 g dry weight) at −13 m, after 12 months. The length–weight relationship showed the best allometric coefficient for the oysters at −13 m, although the growth trends did not show significant differences. Although a correlation between food quantity and quality and somatic and valvar production in situ was not demonstrated, it is probable that the greater POM bulk at −13 m was the cause for the better growth trajectories of these specimens. © 1997 Published by Elsevier Science B.V.

Keywords: *Crassostrea gigas*; Trophic condition; Food availability; Mariculture; Mediterranean Sea

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1. Introduction

In coastal waters, various environmental factors play a decisive role in determining the relationship between food availability and growth in bivalve molluscs in culture. It has been observed that the abundance of suspended natural food in waters varies seasonally (Bacher and Baud, 1992) and that both season and size of the organisms in culture determine their energy requirements (Incze et al., 1981).

Experiments in the laboratory, regarding essential nutrient requirements, have shown that the algae *Tetraselmis suecica* and *Chaetoceros calcitrans* are species from which the oysters *Crassostrea gigas* and *Ostrea edulis* obtain important quantities of lipid, carbohydrate and protein (Utting, 1986; Laing and Millican, 1986; Spencer et al., 1986; Laing and Verdugo, 1991). *C. gigas*, in particular, shows a biochemically determined selectivity in its ingestion of organic particulate (Newell and Jordan, 1983; Deslous-Paoli et al., 1992). However the behavior of *Crassostrea gigas* in culture is not well understood and much of our knowledge is based on experiments in the laboratory. Here temperature, concentration of food and population density are important factors influencing growth (Bacher and Baud, 1992). However little information is available on the effects of variation in the availability and quality of food on the nutritional status of oysters in natural environments (Langdon and Newell, 1990).

In Italy, research has been carried out on reproduction (Blundo et al., 1972; Valli et al., 1978; Valli, 1980), gametes (Blundo et al., 1972), recruitment and cultivation (Specchi et al., 1978; Pastore, 1980; Pellizzato, 1984; Sorvillo et al., 1994). Faranda et al. (1983) have reported data on the capacity of *C. gigas* to adapt to environmental conditions, comparing oysters from Western Sicily with the population of Northern Italy from which the Sicilian seed originated.

The aim of this study was to determine the effects on *C. gigas* (in terms of somatic and valvar production) of the trophic characteristics of a given culture site.

2. Materials and methods

This experiment was carried out between May 1992 and April 1993 in an area of the northern coast of Sicily, the Gulf of Castellammare (lat. 38°02′31″; long. 12°55′28″), already known for its trophic potential in shellfish cultivation (Riggio et al., 1985). *C. gigas* was cultured (at -7 and -13 m) on two suspended lines attached to underwater artificial barriers placed at a depth of 20 m. This is a system which has been designed to allow the exploitation of protected areas for mariculture (Duedall and Champ, 1989). This culture method, which had previously been used in the north Adriatic Sea (Fabi et al., 1989), was subsequently modified by Sorvillo et al. (1992) for the Gulf of Castellammare. The seed of *C. gigas* (from a hatchery in the north Adriatic Sea) had an initial average size of 15.24 ± 2.78 m^2 when transplanted.

The following chemical-physical variables in the water column at the culture site were determined: temperature (T; °C), salinity (S; ‰), dissolved oxygen (OD; mg l^{-1}), pH, Secchi depth (m), chlorophyll-a (CHLa; µg l^{-1}), phaeopigment concentrations (PHAEO; µg l^{-1}) (Lorenzen and Jaffrey, 1980) and the concentrations of carbohydrate

Table 1
Monthly values of chemical-physical and trophic variables

	Temperature (°C)		Chlorophyll-a ($\mu g\ l^{-1}$)		Chlorophyll/POM index		POM gross energy (kcal g^{-1})		Secchi depth (m)
	−7 m	−13 m	−7 m	−13 m	−7 m	−13 m	−7 m	−13 m	
May	17.97	17.30	0.04	0.04	1.71	2.19	6.33	6.49	−7.00
Jun.	18.80	15.94	0.06	0.01	1.94	0.46	6.51	5.97	−13.0
Jul.	24.41	19.95	0.03	0.04	2.55	2.60	6.36	6.00	−17.0
Aug.	27.84	22.76	0.03	0.02	0.46	0.69	8.44	7.11	−18.0
Sep.	24.90	20.56	0.04	0.06	1.54	1.54	6.29	6.39	−8.50
Oct.	21.14	21.14	0.05	0.05	1.33	1.64	7.10	6.07	−3.00
Nov.	18.79	18.79	0.04	0.04	0.74	0.31	4.83	7.52	−8.50
Jan.	14.81	14.70	0.07	0.07	1.02	1.07	4.47	5.74	−9.50
Mar.	14.19	14.16	0.06	0.03	2.46	0.96	4.51	5.04	−18.0
Apr.	15.21	15.02	0.04	0.03	0.57	0.64	4.84	4.96	−9.50

(CHO; $\mu g\ l^{-1}$) (Dubois et al., 1956), lipid (LIP; $\mu g\ l^{-1}$) (Bligh and Dyer, 1959) and protein (PRT; $\mu g\ l^{-1}$) (Hartree, 1972) in the suspended particulate. The value of particulate organic matter (POM; $\mu g\ l^{-1}$) is the sum of lipid, protein and carbohydrate concentrations (Fabiano et al., 1984). The concentration of carbon in the POM (CPOM) was calculated, using conversion factors of 0.70, 0.45 and 0.40 for lipid, protein and carbohydrate (Fichez, 1991), respectively. The POM values were converted to energy values (kcal g^{-1}) by using the conversion factors $0.055\%\text{PRT} + 0.041\%\text{CHO} + 0.095\%\text{LIP}$ (Winberg, 1971a) where PRT, CHO and LIP are the respective percentage content of particulate protein, carbohydrate and lipid. The ratio between CPOM and carbon in chlorophyll (CCHL), extrapolated by using a factor of 40 (Nival et al., 1972), was calculated.

Table 2
The mean values (± s.d.) of the chemical-physical and trophic parameters and the significance levels of the *U*-tests

	−7 m		−13 m		*P* level, −7 m vs −13 m
	Mean	± s.d.	Mean	± s.d.	
Temperature (°C)	19.81	4.67	18.03	3.03	0.01 (* *)
Salinity (‰)	37.5	1.11	37.80	0.20	0.28 (n.s.)
O dissolved (% sat.)	85.67	12.78	89.33	9.33	0.009 (* *)
pH	8.31	0.11	8.32	0.11	0.06 (n.s.)
Chlorophyll-a ($\mu g\ l^{-1}$)	0.05	0.01	0.04	0.02	0.40 (n.s.)
Phaeopigments ($\mu g\ l^{-1}$)	0.02	0.01	0.02	0.01	0.80 (n.s.)
Carbohydrate ($\mu g\ l^{-1}$)	188	216	141	133	0.51 (n.s.)
Protein ($\mu g\ l^{-1}$)	76	34	80	43	0.85 (n.s.)
Lipid ($\mu g\ l^{-1}$)	81	87	111	130	0.95 (n.s.)
POM ($\mu g\ l^{-1}$)	344	201	334	228	0.005 (* *)
POM gross energy (kcal g^{-1})	5.97	1.29	6.13	0.80	0.02 (*)
CHLa/POM index	1.43	0.74	1.21	0.76	0.87 (n.s.)

* $P \le 0.05$; * * $P \le 0.01$; * * * $P \le 0.001$; n.s., non-significant difference ($P > 0.05$).

The annual dynamics of the environmental and trophic conditions at the different culture depths was studied using a statistical *U*-test (Sokal and Rohlf, 1981) comparison of the parameters listed above. As distributions were non-normal, the matrixes of environmental data were transformed using Spearman Ranks (Sokal and Rohlf, 1981). Furthermore, a principal component analysis (PCA) (Legendre and Legendre, 1979) was carried out. The PCA results are presented here by means of biplot (Gittins et al., 1987).

Samples of *C. gigas*, taken monthly ($n = 60$) by a scuba diver, were tested in the laboratory through biometrical and gravimetrical analysis. Growth data were normalized by calculating 'daily specific growth rates' between dry meat weight (Cw) and length (Cl) (Winberg, 1971b; Kautsky, 1982); mean total shell length (SL) was regressed to dry meat shell weight (DW) according to the simple allometric equation: $DW = aSL^b$ (Gould, 1966) and logarithmic transformation. The monthly length and weight data at the two different depths were also analyzed with a *U*-test (Sokal and Rohlf, 1981).

3. Results

3.1. Environmental parameters

The values of chemical-physical and trophic variables recorded during the year of sampling at the two depths are reported in Table 1. The significance levels of the differences between the two depths are reported in Table 2. Temperature, salinity, dissolved oxygen and pH trends are not discussed here because they were so similar to the mean values reported for the Gulf of Castellammare (Sarà, 1994). On the other hand temperature and dissolved oxygen showed significant differences at the two depths

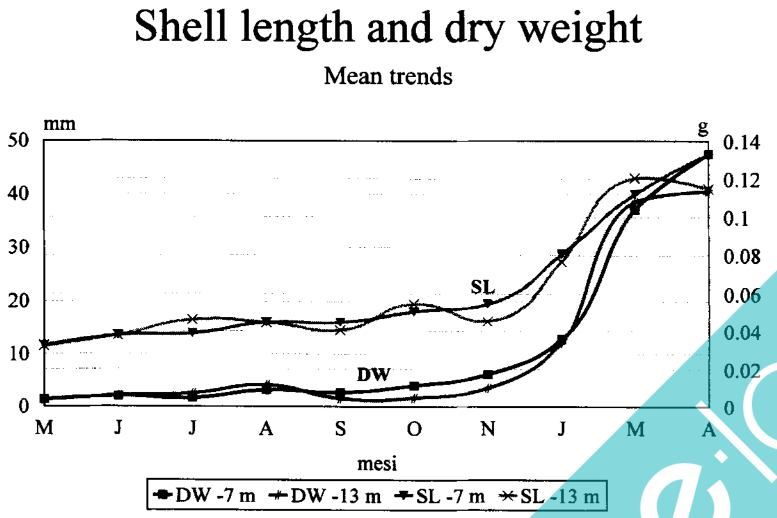

Fig. 1. Monthly trend of the shell standard length (SL; mm) and body dry weight (DW; g) in the comparison between the two depths.

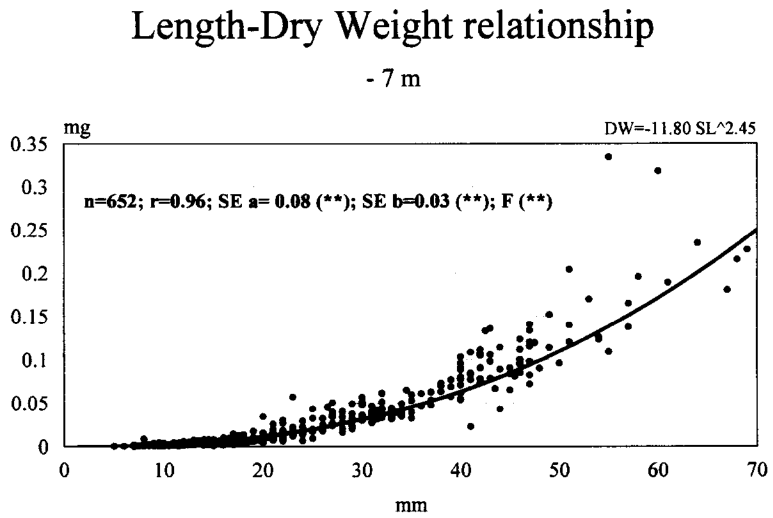

Fig. 2. Monthly standard length–dry weight relationship at −7 m. (n, sample size; r, correlation coefficients; SEa, standard error of the intercept; SEb, standard error of the slope; F, F-ratio of the variance explained to the unexplained variance; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; n.s., non-significant difference, $P > 0.05$.)

($P = 0.01$). The thermocline was around −10 m for the whole summer period. The analysis of transparency values (mean = 11.20 ± 5.11 m) showed that large quantities of suspended particulate matter were present at different periods of the year around the

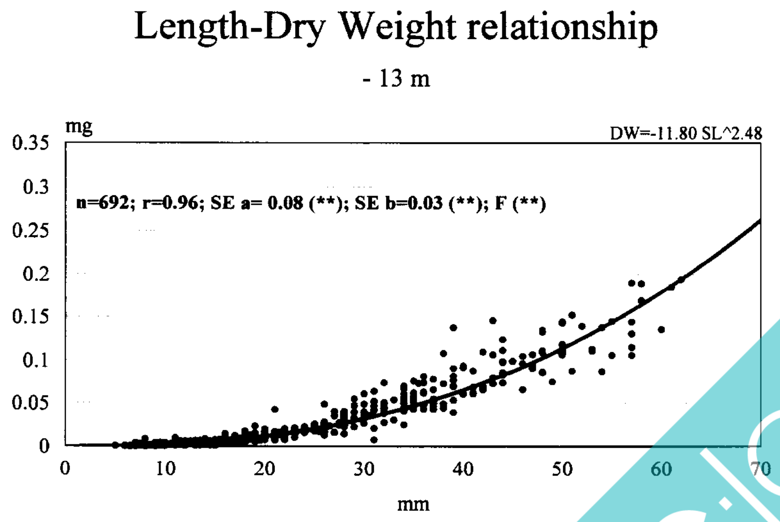

Fig. 3. The monthly standard length–dry weight relationship at −13 m (n, sample size; r, correlation coefficients; SEa, standard error of the intercept; SEb, standard error of the slope; F, F-ratio of the variance explained to the unexplained variance; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; n.s., non-significant difference, $P > 0.05$.)

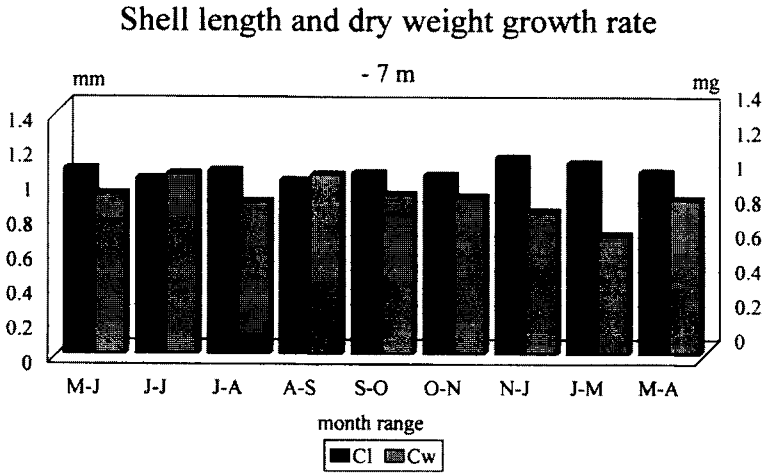

Fig. 4. The shell standard length (Cl; mm) and body dry weight (Cw; mg) daily specific growth rates at −7 m.

chain at −13 m. The very low values of chlorophyll characterize the area as oligotrophic. The values of total POM showed a significant difference ($P < 0.01$) between the two depths of culture. The CCHLa/CPOM ratio indicates that the presence of phytoplanktonic carbon in the labile fraction of particulate organic matter was different for the two depths during the months of June, November and March and that the index remained less than 3% for the whole year. The two depths had different energy levels ($P = 0.02$), with the highest values observed during August and in autumn. These differences may have been due to a greater accumulation of detritus or to a higher frequency of events leading to resuspension.

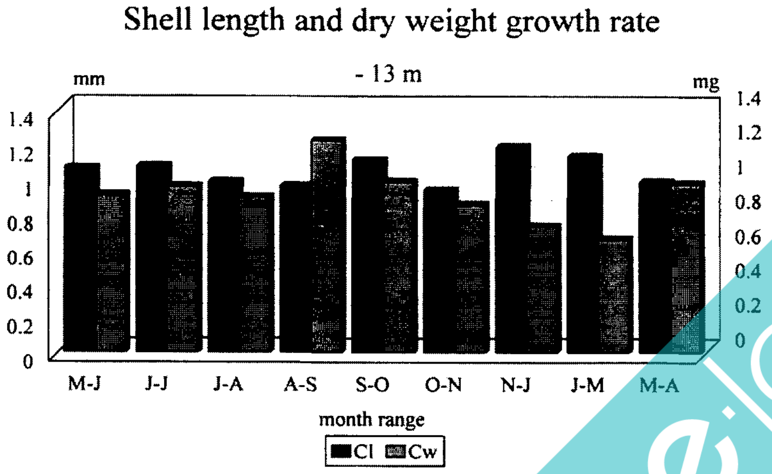

Fig. 5. The shell standard length (Cl; mm) and body dry weight (Cw; mg) daily specific growth rates at −13 m.

Table 3
U-test. Values of P in the comparison between the length and dry weight recorded monthly at the two depths

Month	SL	DW
Jun.	0.03 *	0.03 *
Jul.	0.55 n.s.	0.13 n.s.
Aug.	0.12 n.s.	1.00 n.s.
Sep.	2.08–10 * * *	2.31–11 * * *
Oct.	0.14 n.s.	0.13 n.s.
Nov.	0.02 *	0.05 *
Jan.	0.33 n.s.	0.20 n.s.
Mar.	0.001 * *	0.001 * *
Apr.	0.1 n.s.	0.02 *
Total	0.26 n.s.	0.49 n.s.

* $P \leq 0.05$; * * $P \leq 0.01$; * * * $P \leq 0.001$; n.s., non-significant difference ($P > 0.05$).

3.2. Biological variables

The two groups of oysters set in culture at the two different depths had very similar mean growth trends ($P > 0.05$) (Fig. 1) even though the −7 m group reached sizes and mean weights which were a little greater. This was confirmed by the allometric size–weight regressions (Figs. 2 and 3) which gave very similar '*b*' coefficients. The daily specific growth rates (Fig. 4) showed similar growth of both the somatic and valvar components at −7 m, while at −13 m (Fig. 5) the two components showed a clear difference ($P < 0.05$) in energy allocation during different months. A comparison of the mean monthly trends in length and weight (Table 3) showed that there was a significant difference between the two depths during the months of June, September, November, March and April.

4. Discussion

Mollusc are filter-feeders which regulate the quantity of food taken in by adapting the rhythm of filtration to the concentration of available food (Foster-Smith, 1975; Bayne, 1991). Both the quality and quantity of food determine the resulting growth. The results of this experiment indicate a relationship between the quality and quantity of available food (labile POM) and the growth of the animals in culture. The analysis of the principal components of the chemical-trophic characteristics of the water column for different months showed that the two depths of culture were affected by different events. At −7 m (Fig. 6) temperature, dissolved oxygen, chlorophyll concentration and particulate carbohydrate were the parameters which determined the variance of the system, whereas at −13 m (Fig. 7) the salinity as well as phaeopigment concentration, particulate protein and carbohydrate and dissolved oxygen were most important.

Even though quantitative differences were not clear, the two depths did differ qualitatively; oyster growth near the surface was heavily influenced by the presence of phytoplankton and also by various meteorological factors. At −13 m oyster growth was directly influenced by detritus, and to a lesser extent by phytoplankton. This site

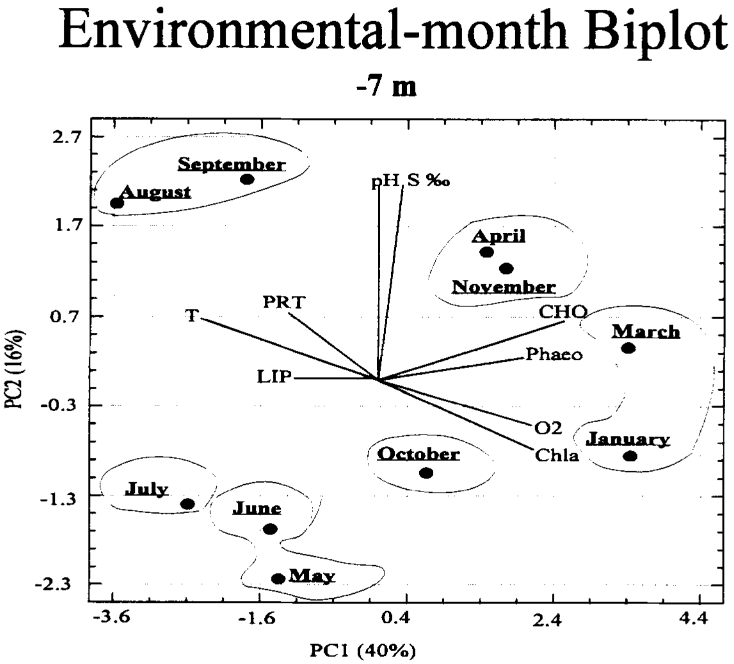

Fig. 6. Principal components analysis: the biplot at −7 m.

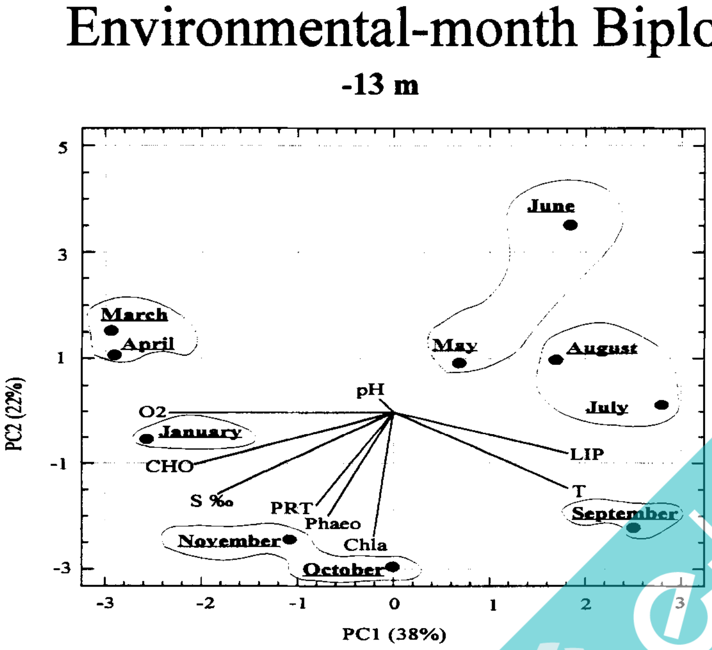

Fig. 7. Principal components analysis: the biplot at −13 m.

receives input of a detritic nature through the resuspension of sediments, from sinking vegetable detritus and from terrigenous particulate derived naturally from the streams that flow into the Gulf. The concentration profile of carbohydrate in the particulate organic matter showed that this component is of little importance except during spring and autumns months.

For most of the year, the oysters set at −7 m seemed to draw the most benefit from food of phytoplanktonic origin and presumably from the detritus of vegetable origin associated with it (cf. Epifanio et al., 1981; Bacher, 1989). This is reflected in the rhythms of growth and is shown by the relative uniformity of the ratio of somatic and valvar productions. The differences observed during the various months may be explained by the fact that in June, November and March greater differences in the quality and quantity of particulate organic matter were noted.

Although both in September and April there were no differences in the trophic characteristics of the two depths, growth differences were observed. This is probably a consequence of the higher August temperature recorded at −7 m, and the annual particulate suspension energy level maximum, also highest in August. The differences in growth between the two groups in April were probably due to the organisms at −7 m being exposed to a greater quantity of phytoplankton in the particulate. The widest seasonal changes in the chemical-physical variables at the surface were also reflected in the growth rates of the −7 m group in August and January.

The oysters set at −13 m live below the thermocline, so chemical-physical variation has a smaller influence on their growth. They seem to draw nourishment from the particulate of a detritic nature, which is very abundant at this depth, but they, like the oysters of the surface layer, seem to have a preference for vegetable particulate, reaching maximum annual growth when this is present. The changes in energetic terms of both quality and quantity of available food at this depth were greater than at the other, this seems to stress the organisms, which consume much energy adapting their filtration rhythm to new conditions. However, at this depth, other environmental conditions vary little, and *C. gigas* consume little energy adapting to them. It is probable that here, as in other environments (Heral et al., 1980), the elevated quantity of inorganic material in suspension inhibits growth at some times of the year.

The lack of a clear relationship between oyster growth and trophic conditions is probably due to the difficulty in defining the carbon and energy content of the free bacterial fraction and of the bacterial fraction linked to the suspended particulate itself. These represent important components in the diet of filter-feeders in coastal environments (Langdon and Newell, 1990). These two fractions probably play an important role in the diet of the oysters cultured in the Gulf of Castellammare shallow waters where the environmental conditions are more variable and greatly affect the growth of *C. gigas*. It is clear, however, that even at these depths, the growth rates of *C. gigas* make their cultivation feasible in these waters.

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