ELSEVIER

Aquaculture 167 (1998) 1–15

Aquaculture

The relationship between food availability and growth in *Mytilus galloprovincialis* in the open sea (southern Mediterranean)

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Accepted 5 May 1998

Abstract

With the aim of gathering information about the possibility of culturing mussels (*Mytilus galloprovincialis*) in a south Mediterranean oligotrophic area, different lots of mussels were placed in culture at depths of −5 m and −15 m and their growth monitored on a monthly basis. Temperature and salinity were measured in situ and water samples were collected at different depths each month. Total suspended matter (TSM) and its inorganic (ISM) and organic (OSM) fractions were analysed by gravimetry and loss on ignition. Photosynthetic pigments (chlorophyll-*a* and phaeopigments), particulate organic carbon (POC) and nitrogen (PON), particulate carbohydrate (CHO), protein (PRT) and lipid concentration (LIP) were also measured. The chlorophyll-*a* concentrations highlighted the high degree of oligotrophy of the study site. Moreover, the inorganic fraction of total seston, which exceeded the organic fraction throughout the study period, highlighted the importance of the allochthonous input of suspended particles. Two main phytoplankton abundance peaks were observed, in spring and autumn. These peaks were mirrored by the biochemical composition of the biopolymeric fraction of particulate organic matter (POM, the sum of PRT, CHO and LIP concentrations). The relatively high values of the POC:PON ratio indicated that the major fraction of particulate organic matter in the study area was of detrital origin. A clear dilution effect on the organic matter, caused by high concentrations of suspended inorganic material, was also revealed by the LPOM/TSM ratio, used as a qualitative food index. The mussels were found to activate physiological compensatory mechanisms in order to maintain

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0044-8486/98/$ - see front matter
PII: S0044-8486(98)00281-6

a constant absorption rate of organic matter from the total available seston. In this case study, the mussels survived in an environment in which the quantities of available food were frequently time-varied. The mussels placed in culture as juveniles (total length = 11.20 ± 4.02 mm) reached a length of approximately 40 mm after 12 months, while the mussels placed in culture as sub-adults (total length = 43.16 ± 7.5 mm) reached the commercial size of about 60 mm in the same time interval. The sub-adult mussels spawned in autumn and spring, indicating that they acclimatised well, despite the high degree of oligotrophy of the water.

Keywords: *Mytilus galloprovincialis*; Trophic features; Food availability; Mediterranean

1. Introduction

Mussels are not frequently found in the southwestern Mediterranean Sea and the virtual absence of mussel culturing is due to the lack of a tradition amongst coastal populations of collecting them for consumption. In addition, a shortage of sheltered, shallow areas, such as those found on other Mediterranean and Atlantic coasts (Figueras, 1989; Héral, 1991; Navarro et al., 1991), represents a real limit for the culturing of mussels.

In the southern Mediterranean, mussels are cultured in a number of highly productive and sheltered areas such as gulfs (Gulf of Gaeta and Taranto, southern Italy), lagoons (S. Gilla, Sardinia), coastal lakes (Biserta, Tunisia; Ganzirri and Faro, southern Italy), and coastal areas characterised by the anthropogenic input of suspended organic matter (ports and industrial areas).

The main chemical–physical features of the southwestern Mediterranean could make it suitable for the recruitment of juvenile filter-feeders, such as mussels, whose life cycle falls well within the environmental range of these waters (Dame, 1996). The virtual absence of these edible bivalve molluscs could thus be due predominantly to the oligotrophy of the Mediterranean Sea (Seed and Suchanek, 1992).

Several authors have documented the close relationship between mussel growth efficiency and food availability, indicating growth performance limits in terms of the energetic potential of the food available (Bayne and Newell, 1983; Ceccherelli and Rossi, 1984; Fréchette and Bourget, 1985; Widdows et al., 1997). Despite this well-documented relationship (Widdows and Johnson, 1988; Seed and Suchanek, 1992), most research of this kind on the Mediterranean has been limited to monitoring mollusc growth (mussels or oysters), highlighting the size reached at the end of culture and comparing results to those of other studies (Genovese, 1970; Faranda and Pernice, 1974; Valli, 1980; Geraci and Romairone, 1981; Riggio and Ardizzone, 1981; Faranda et al., 1983; Fabi et al., 1989; D'Anna et al., 1990).

There are very few studies on mollusc growth in Mediterranean areas, on their behaviour in different trophic conditions (Ceccherelli and Rossi, 1984; Dalla Via et al., 1987; Fabiano et al., 1994; Palmerini and Bianchi, 1994; Sarà and Mazzola, 1997). Among the above, Sarà and Mazzola (1997) studied the relationship between *Crassostrea gigas* growth and food availability in suspended culture in the southwestern Mediterranean.

The aims of this study are: (i) to verify whether the trophic features of the study site make it suitable for culturing *Mytilus galloprovincialis* (LMK, 1819) in the open sea and (ii) to verify the relationship between food availability and the growth performance of mussels at different initial sizes.

2. Materials and methods

The study was carried out between May 1994 and April 1995 off the northern coast of Sicily in the Gulf of Castellammare (LAT 38°02′31″; LONG 12°55′28″), an area well known for its trophic potential for shellfish cultivation (Sarà and Mazzola, 1997). *M. galloprovincialis* were cultured in tight nylon net bags (height 1.5 m; 4 cm mesh size) on two suspended lines (at −5 m and −15 m) attached to underwater artificial reefs placed at a depth of 20 m. The seed of *M. galloprovincialis* (about 1000 kg) was from the northern Adriatic Sea. Samples of *M. galloprovincialis* ($n = 200$) were collected monthly from each lot by a scuba diver and tested in the laboratory by means of biometric and gravimetric analysis (Sarà and Mazzola, 1997). Growth performance was analysed by calculating the daily specific growth rate (r; Dame, 1996) in somatic ash free dry weight ($r_{(\mathrm{AFDW})} = [(\ln \mathrm{AFDW}_2 - \ln \mathrm{AFDW}_1)/\Delta t]$. The relationship between the total shell length (L) and somatic ash free dry weight (Ceccherelli and Rossi, 1984) was calculated using a simple allometric equation ($\mathrm{AFDW} = aL^b$; Gould, 1966) and logarithmic transformations.

Temperature and salinity were measured in situ monthly using a multiparametric probe (Hydrolab, Austin, USA). Salinity signals from the probe were tested monthly using $AgNO_3$ titration. Water samples were collected at two different depths (surface/−5, −10/−15), using 10 l Niskin bottles. In the laboratory, water samples were screened through a 200 μm mesh net in order to remove larger zooplankton and debris. Subsamples (500 to 2000 ml) were filtered onto pre-washed, precombusted (450°, 4 h) and pre-weighed Whatman GF/F filters (0.45 μm nominal pore size) to analyse total suspended matter (TSM, mg l^{-1}), photosynthetic pigments, particulate organic carbon (POC, μg l^{-1}) and nitrogen (PON, μg l^{-1}) and the biochemical composition of the particulate organic matter. TSM determination was carried out gravimetrically after desiccation (105°C, 24 h) using a Sartorius M200 balance (accuracy ±1 μg). The organic fraction of seston (OSM, mg l^{-1}) was determined by ignition loss (450°C, 4 h; Strikland and Parsons, 1972) and the chloroplastic equivalents (CPE, μg l^{-1}; the sum of chlorophyll-*a* [Chl-*a*, μg l^{-1}] and phaeopigments [Phaeo, μg l^{-1}]; Pfannkuche, 1993) were determined according to Lorenzen and Jeffrey (1980). POC and PON were determined with a Perkin-Elmer CHN Elemental Analyser (Mod. 2400), using acetanilide at 925°C as a standard, the inorganic carbon having been removed (Hickel, 1984; Iseki et al., 1987).

Particulate carbohydrate concentrations (CHO, μg l^{-1}) were measured according to Dubois et al. (1956) and reported as glucose equivalents. Particulate proteins (PRT, μg l^{-1}) were determined according to Hartree (1972) and reported as bovine serum albumin (BSA) equivalents. Particulate lipid concentrations (LIP, μg l^{-1}), measured according to Bligh and Dyer (1959) and Marsh and Weinstein (1959) were reported as tripalmitine equivalents. The sum of the carbohydrate, protein and lipid concentrations was reported

Table 1
Descriptive statistics of measured trophic parameters

	Chl-*a*	Phaeo	ISM	OSM	POC	PON	LIP	PRT	CHO	LPOM-J
May (±s.d.)	0.04 (0.01)	0.01 (0.00)	2.4 (0.1)	1.1 (0.1)	93.8 (20.6)	8.6 (3.2)	60.8 (18.5)	80.3 (8.2)	30.1 (3.2)	4.8 (1.0)
June (±s.d.)	0.04 (0.04)	0.02 (0.00)	3.5 (0.3)	1.6 (0.5)	80.4 (32.7)	9.8 (5.7)	49.3 (17.7)	100.0 (12.2)	33.6 (8.4)	4.9 (1.1)
July (±s.d.)	0.03 (0.00)	0.02 (0.01)	2.2 (0.6)	1.0 (0.4)	86.1 (4.7)	9.1 (2.0)	29.6 (3.4)	54.5 (4.8)	20.2 (3.9)	2.8 (0.2)
August (±s.d.)	0.03 (0.00)	0.01 (0.00)	1.0 (0.9)	0.4 (0.4)	115.7 (18.2)	15.0 (2.3)	146.1 (79.7)	65.6 (2.9)	34.3 (8.8)	8.0 (2.9)
September (±s.d.)	0.05 (0.01)	0.02 (0.00)	1.4 (0.0)	1.1 (0.1)	118.9 (0.1)	20.0 (4.2)	65.9 (15.6)	152.9 (7.7)	45.3 (4.8)	7.0 (0.9)
October (±s.d.)	0.05 (0.00)	0.02 (0.01)	1.0 (0.3)	0.8 (0.0)	159.4 (31.2)	20.5 (20.3)	119.3 (30.9)	111.9 (18.3)	76.2 (22.8)	8.7 (2.1)
November (±s.d.)	0.04 (0.00)	0.02 (0.01)	1.4 (0.4)	1.1 (0.1)	86.4 (7.8)	11.8 (0.6)	161.9 (173.9)	105.3 (25.3)	427.2 (25.1)	16.7 (8.0)
December (±s.d.)	0.04 (0.00)	0.04 (0.00)	1.0 (0.1)	1.1 (0.2)	91.5 (19.1)	14.7 (1.6)	31.7 (5.0)	98.1 (9.4)	80.2 (33.3)	5.0 (0.2)
January (±s.d.)	0.07 (0.00)	0.03 (0.00)	1.5 (0.2)	1.3 (0.1)	74.8 (6.0)	9.9 (1.7)	58.1 (34.7)	47.7 (9.2)	476.6 (33.4)	12.2 (1.0)
February (±s.d.)	0.08 (0.00)	0.04 (0.00)	44.0 (35.7)	2.4 (2.2)	185.0 (13.2)	20.3 (1.4)	76.6 (27.8)	97.4 (15.6)	66.1 (7.3)	6.5 (1.3)
March (±s.d.)	0.04 (0.02)	0.03 (0.01)	1.8 (0.3)	0.9 (0.1)	67.0 (17.3)	12.0 (4.6)	25.6 (5.4)	9.9 (8.8)	170.3 (32.3)	4.4 (1.0)
April (±s.d.)	0.04 (0.02)	0.02 (0.01)	1.3 (0.0)	0.5 (0.2)	21.4 (13.4)	10.3 (3.3)	76.1 (7.8)	85.1 (34.1)	516.7 (184.7)	14.5 (4.5)
Min	0.03	0.01	1.0	0.4	21.4	8.6	25.6	9.9	20.2	2.8
Max	0.08	0.04	44.0	2.4	185.0	20.5	161.9	152.9	516.7	16.7
Average	0.05	0.02	5.2	1.1	98.3	13.5	75.1	84.1	164.7	8.0
±s.d.	0.02	0.01	12.2	0.5	42.7	4.5	44.9	36.5	191.2	4.4

Standard deviations are reported (±s.d.).
See the text for acronyms.

as the labile fraction of particulate organic matter (LPOM, $\mu g\ l^{-1}$). The energy content (cal mg^{-1}) of LPOM was calculated according to Winberg (1971) using the following equation: EPOM = 0.095% LIP + 0.044% CHO + 0.055% PRT, where LIP, CHO and PRT represent the concentrations (transformed into $mg\ l^{-1}$) of lipids, carbohydrates and proteins, respectively. The joule content of POM in the water (LPOM-J, $J\ l^{-1}$) was calculated by multiplying EPOM by 4.186 (Lucas, 1993) and by the LPOM concentration ($mg\ l^{-1}$). The LPOM/TSM ratio was used as a food index (Widdows et al., 1979; Navarro et al., 1993). The POC:PON ratio was used as an index of the contribution of living fresh biomass to the detritus (Poulet et al., 1986). Phytoplankton samples (PHYTO, cell l^{-1}) were collected monthly at two different depths (−5 m and −15 m) and quantitative analysis was carried out in the laboratory according to Utermöhl (1958).

Spatial (depth) and temporal (monthly) changes in hydrological variables were investigated by means of variance analysis (ANOVA; Underwood, 1997), while the degree of correlation between variables was analysed by means of the Spearman correlation (r_s) (Sokal and Rohlf, 1981).

3. Results

3.1. Environmental and trophic conditions and food availability

Tables 1 and 2 report values of the trophic parameters measured and ANOVA results of the environmental and trophic parameters measured. Temperature showed a significant seasonal trend ($P < 0.05$), with the highest values in summer (25.5 ± 3.30°C in

Table 2
ANOVA results of the environmental measures and trophic variables

Variables	Month $F_{11.12}$	Month P	Depth $F_{1.22}$	Depth P
T (°C)	9.20	0.00 (***)	0.92	0.35 (ns)
S (‰)	2.13	0.10 (ns)	0.55	0.47 (ns)
Chl-*a* ($\mu g\ l^{-1}$)	2.88	0.04 (*)	1.23	0.28 (ns)
Phaeo ($\mu g\ l^{-1}$)	4.84	0.005 (**)	0.41	0.53 (ns)
OSM ($mg\ l^{-1}$)	1.11	0.42 (ns)	1.81	0.33 (ns)
ISM ($mg\ l^{-1}$)	1.15	0.40 (ns)	0.97	0.19 (ns)
ISM:OSM	2.29	0.08 (ns)	0.52	0.48 (ns)
POC ($\mu g\ l^{-1}$)	11.12	0.00 (***)	0.22	0.64 (ns)
PON ($\mu g\ l^{-1}$)	0.95	0.53 (ns)	0.58	0.45 (ns)
POC:PON	0.90	0.56 (ns)	1.06	0.31 (ns)
LIP ($\mu g\ l^{-1}$)	1.19	0.38 (ns)	0.54	0.47 (ns)
PRT ($\mu g\ l^{-1}$)	10.90	0.00 (***)	0.02	0.89 (ns)
CHO ($\mu g\ l^{-1}$)	22.63	0.00 (***)	0.02	0.88 (ns)
LPOM ($\mu g\ l^{-1}$)	8.55	0.00 (***)	0.01	0.93 (ns)
LPOM-J ($J\ l^{-1}$)	4.41	0.00 (***)	0.08	0.78 (ns)
LPOM/TSM	4.32	0.009 (**)	0.09	0.76 (ns)
PHYTO (cell l^{-1})	0.36	0.95 (ns)	40.77	0.00 (***)

* $P \le 0.05$; ** $P \le 0.01$; *** $P \le 0.001$.
ns = Non-significant difference ($P \le 0.05$).
See the text for acronyms.

August and 23.0 ± 2.70°C September) and the lowest values in winter (14.3 ± 0.4°C). No statistical differences between depths were observed, although the mean value for temperature measured at −15 m was lower (−5 m = 19.18 ± 4.74°C; −15 m = 17.51 ± 3.19). No monthly or depth-related differences were observed for salinity.

CPE concentrations (Chl-*a* vs. PHAEO $r_s = 0.72$; $P < 0.05$; $n = 24$) varied significantly between months, with the highest values from December to March and the main peak in February, the latter involving the entire water column (0.12 ± 0.01 μg l^{-1}).

The concentration of total suspended matter and its inorganic (ISM) and organic (OSM) fractions did not show significant differences between months and depths, although peaks occurred in the corresponding rainfall period (autumn and winter), and an anomalous peak was observed in June. The organic fraction of suspended matter correlated well with CPE concentrations ($r_s = 0.62$; $P < 0.05$; $n = 24$). The ISM/OSM

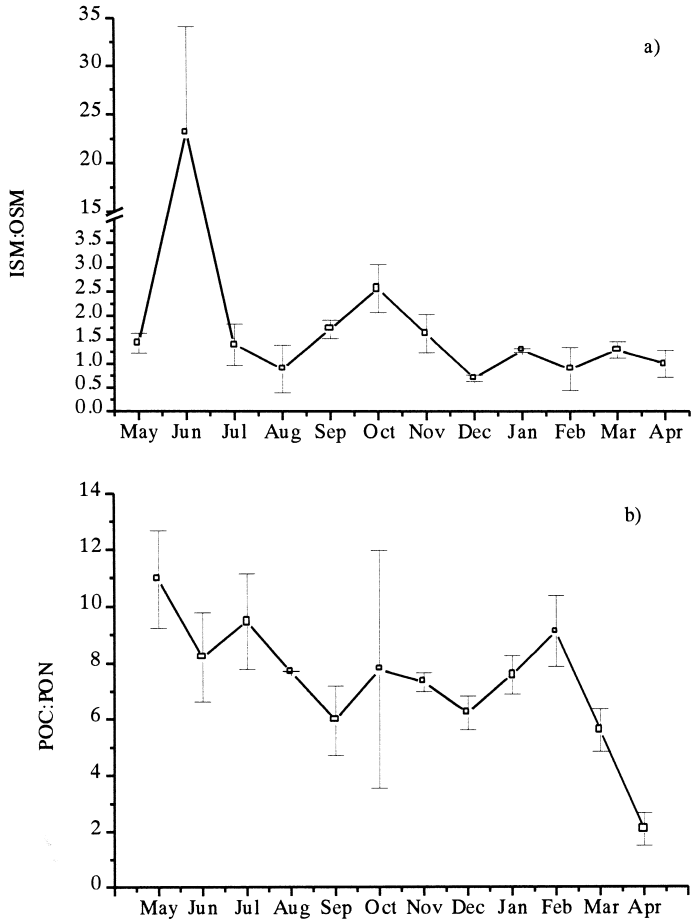

Fig. 1. Monthly trend of ISM:OSM ratio [a], POC:PON ratio [b], LPOM/TSM ratio [c] and phytoplankton cell abundance (cell l^{-1}) [d] in the study area. Standard deviations are reported.

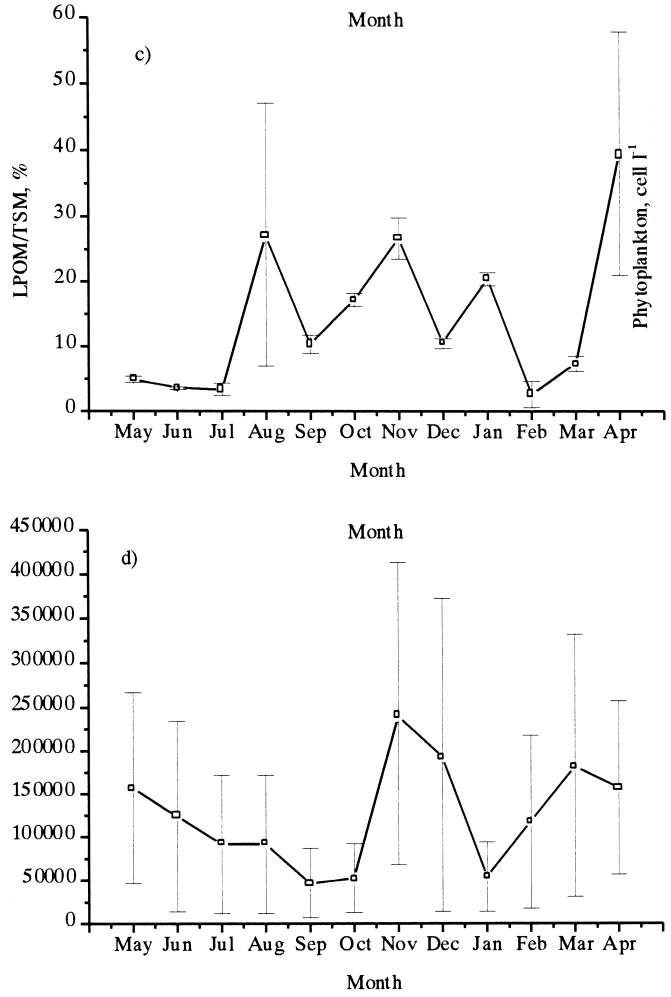

Fig. 1 (continued).

ratio (Fig. 1a) exceeded 1.0 throughout the study period, apart from in December (ISM/OSM = 0.92 ± 0.2).

Seasonal changes in POC concentration showed significant peaks in February and October (185.0 ± 13.2 μg l^{-1} and 159.4 ± 31.2 μg l^{-1}, respectively) while the minimum (21.4 ± 13.3 μg l^{-1}) occurred in April. PON concentrations remained fairly constant throughout the study period and were positively correlated with POC ($r_s = 0.52$; $P < 0.05$; $n = 24$) and CPE ($r_s = 0.60$; $P < 0.05$; $n = 24$). The POC:PON ratio (Fig. 1b) reached its highest value in May, and its lowest in April (approx. 2), in correspondence with the period of phytopigment accumulation.

Carbohydrate concentrations showed significant peaks in January, April and November, while the lowest concentrations were found from May to October. The highest

protein concentrations occurred in February and June and between September and December, while lipid concentrations reached a maximum in August and November. No differences between depth were observed.

Carbohydrate concentrations were positively correlated with CPE concentrations ($r_s = 0.60$; $P < 0.05$; $n = 24$) and negatively with POC:PON ratio ($r_s = -0.56$; $P < 0.05$; $n = 24$); proteins were positively correlated with PON ($r_s = 0.50$; $P < 0.05$; $n = 24$), while lipids were positively correlated with POC ($r_s = 0.52$; $P < 0.05$; $n = 24$).

The LPOM energy content showed significant changes which exceeded approximately 4 J l^{-1} except in July when it reached a minimum (2.80 J l^{-1}) and in January, April and November when it reached its maximum values. Peaks in LPOM energy were in correspondence with peaks in the LPOM/TSM ratio values ($r_s = 0.79$; $P < 0.05$; $n = 24$). This ratio (Fig. 1c) showed values which were above 15%, excluding the main significant peak ($P < 0.05$) in August, April and November (exceeding 25%).

Phytoplankton abundance (Fig. 1d) showed significant peaks in March and November–December. Near the surface, phytoplankton cell concentration was significantly higher (annual average 221,000 ± 97,000 cell l^{-1}) compared to that at −15 m depth (31,000 ± 38,000 cell l^{-1}). No significant correlations were observed between phytoplankton abundance and the other variables measured.

3.2. Mollusc biometrics and growth performance

Table 3 summarises the biometric features of the different lots of *M. galloprovincialis* cultured in the Gulf of Castellammare. Adult lots (A5 and A15) were initially

Table 3
Biometrical features of different lots

	A5	A15	J5	J15
L (InS)	43.16 ± 7.5	43.16 ± 7.5	11.20 ± 4.02	11.20 ± 4.02
AFDW (InS)	0.21 ± 0.04	0.21 ± 0.04	0.004 ± 0.0001	0.004 ± 0.0001
L (InM)	47.24 ± 0.55	47.24 ± 0.55	11.39 ± 0.36	11.39 ± 0.36
L (FS)	57.91 ± 6.56	62.90 ± 8.32	36.88 ± 5.51	42.09 ± 4.94
AFDW (FS)	0.44 ± 0.12	0.33 ± 0.09	0.10 ± 0.02	0.13 ± 0.05
L (FM)	57.63 ± 0.50	58.92 ± 0.72	35.01 ± 0.22	38.26 ± 0.80
%Pop	18	23	50	43
Sp	Autumn; February–April	September; Spring	–	–
%Sp	36; 65	~ 35; 55	–	–
t	12	12	11	11

InS = Initial mean size.
InM = Initial modal size.
FS = Final mean size.
FM = Final modal size.
%Pop = percentage of stocks.
Sp = spawning period.
%Sp = percentage of stock in spawning.
t = cultivation period.
L (mm) = length.
AFDWS (g) = Somatic ash free dry weight.

composed of sub-adult specimens. The specific growth rate trend (Fig. 2a) showed that the rates of the two sub-adult lots during three periods (a total of 8 months), were coupled (May–July; September–November and March–April), while the rates were uncoupled for the rest of the year, with the main de-growth period occurring in autumn. The allometric coefficients of lot A15 (Fig. 2b) showed minimum values in September, November and March. The lot A15 were found to be spawning in September and March (about 35 and 55% of the population, respectively). The lot A5 displayed main peaks of allometric coefficient in August and November and minimum values in July, January and March. In particular, the specimens were spawning in November and March (about 36 and 65% of population, respectively).

Throughout the year, the specific growth rates of the juvenile lots (J5 and J15) alternated between positive and negative values (Fig. 3a). Excluding the peak in May–June, the specific growth rate of the two juvenile lots did not show the same

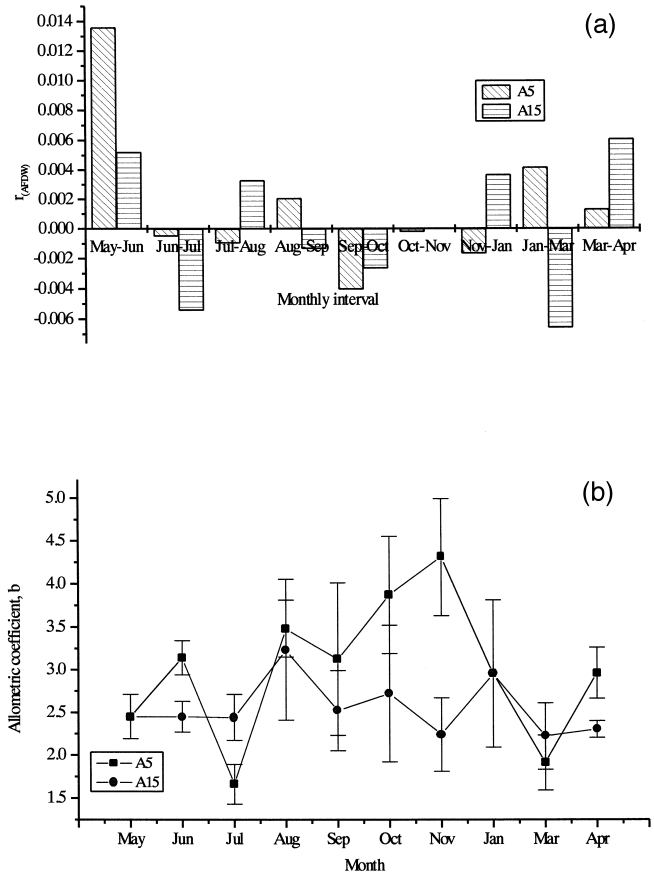

Fig. 2. Monthly trend in growth performance of the sub-adult lots (A5 and A15): [a] daily specific growth rate in somatic ash free dry weight ($r_{(AFDW)}$) and [b] trend of allometric coefficients.

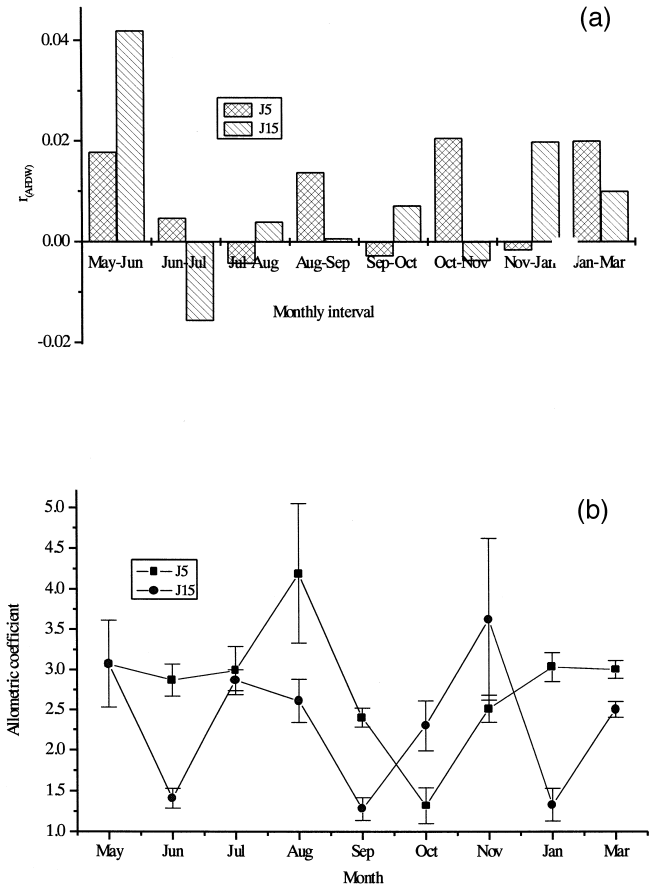

Fig. 3. Monthly trend in growth performance for the juvenile lots (J5 and J15): [a] daily specific growth rate in somatic ash free dry weight ($r_{(AFDW)}$) and [b] trend of allometric coefficients.

temporal pattern. The widely observed fluctuations in specific growth rates was quite evident from the analysis of the temporal patterns of the allometric coefficients (Fig. 3b). Lot J15 showed three periods of negative allometry (June, September and January), while lot J5 showed a fairly constant allometry until October, when it reached its lowest values.

4. Discussion

A number of studies have emphasised the importance of the characteristics of particulate organic matter (Danovaro and Fabiano, 1997) and the interplay between physical and hydrodynamic features in determining food supply to suspension feeders (Seed and Suchanek, 1992).

The temperature and salinity of this study area fell within the normal range for the Mediterranean. In contrast, total organic matter, POC, nitrogen and LPOM concentrations were lower, compared to those of other highly productive areas in which bivalves are normally cultivated (Ceccherelli and Rossi, 1984; Navarro et al., 1991; Pérez-Camacho et al., 1991; Pusceddu et al., 1997b; Sorokin et al., 1996).

Our data have shown that the quantity of particulate organic matter in the study area did not change significantly with depth, although its quality was higher in the layer nearest the surface compared to that of the bottom layer (Sarà and Mazzola, 1997). Mussels of different lots reached different (but not significantly different) final sizes, by showing feeding behaviour which differed throughout the year. This led us to hypothesise that the mussels adapted their feeding strategy, intercepting organic material (i.e., refractory) which they do not generally exploit, when the nutritional value of the particulate organic matter was low.

The POC:PON ratio values (annual average 8.3) indicated that the freshly-generated organic matter contributed greatly to the particulate organic matter pool (Valiela, 1984). However, the freshly-generated organic matter was continually diluted in a large pool of inorganic suspended matter derived from terrigenous or allochthonous detritus input. The pool of freshly-generated organic matter did not originate directly from phytoplankton, as indicated by the values of the POC/Chl-*a* ratio (Zeitzschel, 1970) which exceeded 1000 in the Gulf (average = 2461 $\pm$ 968; max = 5200; min = 400; Sarà, 1994) throughout the year, while values of only approximately 400 were found during the spring bloom. In consequence, we can hypothesise that other sources of freshly-generated organic matter, other than phytoplankton, were responsible for the relatively low values of the POC:PON ratio. In this scenario, phytoplankton might represent the 'real limit' for mussel recruitment, with extremely low chlorophyll-a concentrations (< 1 μg l^{-1}) determining the ultra-oligotrophic feature of the water. When the primary organic matter component (i.e., phytopigments) is scarce, heterotrophic detritus and bacteria might provide the main food resource during periods of energy shortage (Langdon and Newell, 1990; Dame, 1996).

As a result of the dilution effect on the particulate organic matter discussed above, the contribution of the labile fraction (LPOM) to the bulk of the suspended matter was quite low (approx. 14% annual average). This value was lower than that reported by Navarro et al. (1993) at Yaldad Bay, Chile (average 34%), where edible molluscs are intensively cultivated. Pusceddu et al. (1997a) have reported similar values for a Mediterranean shallow oligotrophic environment (Stagnone di Marsala, Italy) which is limited by refractory material from resuspension input and in which edible bivalve molluscs are not frequently observed. On the other hand, the LPOM/TSM ratio values observed in the study area were lower than those reported for a Mediterranean coastal lagoon (Pusceddu et al., 1997b), where the chlorophyll-a concentrations were very high (up to 40 μg l^{-1}) and the cultivation of mussels is a normal commercial activity. Thus, the Gulf of Castellammare may be indicated as an area in which both the concentration and the nutritional value of the particulate organic matter are limited by the dilution effect of inorganic suspended material from terrigenous and/or resuspension input. This renders the organic matter refractory for the most part, and therefore 'available with difficulty' to edible suspension filter feeders.

If these trophic features do not permit the recruitment of mussels, they might permit the growth of transplanted seed of different sizes. Sarà and Mazzola (1997) have already documented that transplanted populations of *Crassostrea gigas* grow well in the Gulf, reaching a commercial size in 12 months, although in this case the spawning period was not documented. Although mussels started from a sub-adult size and at least 12 months were needed to reach a commercial size, the results of this study are similar to those obtained for *M. galloprovincialis* and *M. edulis* at different latitudes (Table 4).

The sensitivity of allometric regression in studying the growth performance of bivalves has been well documented (Rodhouse et al., 1984) and it is also well known that a relationship verified between two body parts persists throughout stable growth periods (Dame, 1996, sensu pers. comm. J. Cigarria). In this study we have shown that, in terms of allometric regression, length-weight relationships fluctuated widely, probably as result of widely fluctuating trophic conditions (i.e. quantity and quality of particulate organic matter). In particular, we have highlighted that length and weight growth showed an asynchronous pattern, with uncoupled growth trajectories. Even if lot A5 was able to utilise phytoplankton as food directly and more frequently, its monthly growth trajectory was floating, as isometric growth was maintained only in June, September and April and 'asynchronous growth' was shown for the remainder of the year. The abundance of fresh food resources in autumn permitted the A5 population to spawn. Unlike that of lot A5, the spawning of lot A15, which took place in September and lasted for some weeks, was probably affected by a breakdown in the thermocline which determined water mixing and an increase in water temperature in deeper layers. The effect of temperature on gonad activity in invertebrates is well known (Seed and

Table 4
Literature comparison data

Site	Species	L_{in}	L_f	t	Troph	References
Northern Adriatic	*M. galloprovincialis*	Settlement	50	14	Eu	Ceccherelli and Rossi (1984)
Northern Adriatic	*M. galloprovincialis*	42	73.1	15	Eu	Fabi et al. (1989)
Eastern Sicily	*M. galloprovincialis*	10	31	12	Meso	Genovese (1970)
Eastern Sicily	*M. galloprovincialis*	32	57	12	Meso	Genovese (1970)
Spain	*M. galloprovincialis*	Settlement	82	16	Meso	Pérez-Camacho et al. (1991)
Spain	*M. galloprovincialis*	18	50	5	Meso	Pérez and Romàn (1979)
Iceland	*M. edulis*	Settlement	51	24	Meso	Thorarinsdòttir (1996)
Northern Adriatic	*M. galloprovincialis*	46	60	12	Eu	Valli (1980)
Northern Adriatic	*M. galloprovincialis*	47	62	4	Eu	Valli (1980)
Norway	*M. edulis*	Settlement	50	60	–	Wallace (1980)
Southern MED	*M. galloprovincialis*	10	40	12	Oligo	This paper
Southern MED	*M. galloprovincialis*	43	63	12	Oligo	This paper

L_{in} / L_f (mm) = initial mean and final mean length.
t = Cultivation period in month.
Site = geographic area of cultivation.
Troph = trophic degree.
Oligo = oligotrophic.
Meso = mesotrophic.
Eu = eutrophic.

Suchanek, 1992), and in particular, a sudden increase in temperature has been shown to determine spawning events.

Besides the 'temperature-induced spawning' in September, lot A15 showed a good growth performance, as revealed by good initial acclimatisation, an allometric coefficient of between 2.4 and 3, and the occurrence of true spawning in spring (Bayne, 1976), the latter being observed also for A5.

If 12 months was required for sub-adult lots to reach a commercial size, about 11 months would be needed for juvenile lots to reach a sub-adult size. While for adults, resource allocation depends on both trophic availability and physiological status (above all, gonad activity), juvenile resource allocation depends more on food availability. To this regard, the juvenile lots in this study showed a pulse-like growth, alternating between growth and de-growth phases with fluctuations in food resource quality and quantity. Despite the unpredictable changes in the trophic and chemical–physical features of the study area, juvenile mussels reached sizes which were comparable to those reported in the current literature after 11 months (Table 4).

In conclusion, as regards the role of physiological compensation in the maintenance of a relatively constant food absorption rate in environments which are characterized by time-varying resources, this study is in agreement with other recent work (Bayne et al., 1993) in suggesting that the Gulf of Castellammare could represent a suitable site for the culturing of mussels.

Acknowledgements

The authors would like to thank two anonymous referees for their indispensable help in improving the original version of the manuscript. We are also grateful to Giovanni Maio and Nello Ruggeri (University of Messina) for their generous technical support during field sampling and laboratory analyses and Prof. M. Fabiano (University of Genoa) for his continual contribution in the analysis and discussion of LPOM data. We would also like to tank Helen Maine for the proof-reading the manuscript. This work was funded by the Ministero Politiche Agricole (MiPA, Italy).

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