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Effects of environmental factors on growth and mortality of raft cultivated mussel (*Mytilus galloprovincialis* L.) cultivated in lantern nets in Black Sea

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Abstract. One-year old rope grown mussels (*Mytilus galloprovincialis* L.) were held in three experimental lantern nets in raft system outside of Sinop Harbour. Mortality and growth were monitored from May 2005 to May 2006. Water temperature, salinity, transparency and food availability (total particulate matter, particulate organic matter, particulate inorgnic matter and Chlorophyll-*a*) were also determined. The monthly specific growth rate (SGR%) ranged 1.50-5.72% with a mean of 2.59±0.30%. Shell length increment was found as 13.67 mm and reached to 51.20±0.50 mm. The live weight increment was found 7.91 g, and mussels reached to 12.61±0.39 g. Meat yield ranged from 17.51 to 24.25% with a mean of 21.12±0.63%. Cumulative mortality was higher in winter than spring and summer. Monthly mortality was found maximum with 5.2% in October. This study is the first known experiment to collect data on effect of environmental factors on mussel growth and natural mortality in lantern nets and raft system in the Black Sea.
Key Words: growth, mortality, mussel, Black Sea.

Özet: 1 yaşındaki midyelerin yerleştirildiği üç adet deneysel ağ tepsi, Sinop dış liman bölgesinde bulunan sala asılmıştır. Mayıs 2005'ten Mayıs 2006'ya kadar büyüme ve ölüm oranları izlenmiştir. Ayrıca su sıcaklığı, tuzluluk, bulanıklık ve sudaki besin miktarı (toplam askıdaki madde, partikül organik madde, partikül inorganik madde ve klorofil-a) belirlenmiştir. Aylık büyüme oranı %1.50-5.72 arasında olup ortalama %2.59±0.30'dur. Kabuk boyu artışı 13.67mm olarak bulunmuş ve 51.20±0.50 mm'ye ulaşmıştır. Canlı ağırlığı artışı 7.91g bulunmuş ve 12.61±0.39 g'ma ulaşmıştır. Et verimi %17.51 ile %24.25 arsında olup, ortalama %21.12±0.63'tür. Kümülatif ölüm oranı kışın, bahar ve yaza göre daha yüksektir. Aylık ölüm oranı maksimum Ekim ayında %5.2 bulunmuştur. Bu çalışma, Karadeniz'deki sal sisteminde ve pinter ağlarda çevresel faktörlerin midyelerdeki büyüme ve ölüm oranına etkisi üzerine veri toplayan ilk çalışma olarak bilinmektedir.
Anahtar Kelimeler: Büyüme, ölüm oranı, midye, Karadeniz.

Rezumat. Scoicile în vârstă de un an, din specia *Mytilus galloprovincialis* L. au fost crescute în trei viviere flotabile experimentale de tip "lampă" în largul portului Sinop. În cadrul experimentului au fost monitorizate mortalitatea și creșterea din luna mai a anului 2005 până în luna mai a anului 2006. Au fost determinate: temperatura apei, salinitatea, transparența și prezența hranei (materia particulată totală, materia particulată organică, materia particulată anorganică și Clorofila *a*). Rata de creștere specifică lunară (SGR%) s-a încadrat între 1,50 și 5,72% cu o medie de 2,59±0,30%. Creșterea în lungime constatată a scoicilor a fost de 13,67 mm și a atins 51,20±0,50 mm. Creșterea masei corporale a fost de 7,91 g, iar scoicile au atins masa corporală de 12,61±0,39 g. Partea valorificabilă, carnea, a variat între 17,51 și 24,25% cu o medie de 21,12±0,63%. Mortalitatea cumulativă a fost mai ridicată iarna, decât primăvara și vara. Din punctul de vedere al mortalității lunare, ea a atins un maxim în luna octombrie, cu o valoare de 5,2%. Acest studiu este primul experiment cunoscut cu date concrete cu privire la efectul factorilor de mediu asupra creșterii și mortalității naturale a scoicilor în viviere flotabile de tip "lampă" în Marea Neagră.
Cuvinte cheie: creștere, mortalitate, scoici, Marea Neagră.

Introduction. The geographic situation offers a great fisheries potential in Turkey. Yet, the performance of the sector is quite modest compared to this potential. Fishery contributes only 3% to agricultural value (Akder & Halis 2005) and as one of the four agricultural sub-sectors in Turkey, fisheries has great importance in national production and food supply, providing raw material for the industrial sector, creating employment possibilities and high potential for export (Deniz et al 2000). Turkish aquaculture has limited species diversity. Currently only the following species are cultured commercially: rainbow trout (*Oncorhynchus mykiss*), sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*), blue-fin tuna (*Thunnus thynnus*) and the mediterranean mussel (*Mytilus galloprovincialis*) (Okumuş & Deniz 2007). Total aquaculture production reached 139,873 t and *M. galloprovincialis* culture is represented 1,100 t in 2007 (TUIK 2008).

There have been several scientific studies on bivalve culture in the Aegean Sea (Alpbaz et al 1991; Hindioglu et al 2001; Serdar & Lök 2005; Lök et al 2006; Lök & Acarlı 2006; Lök et al 2007), Marmara Sea (Yıldız & Lök 2005ab; Yıldız et al 2005; Yıldız et al 2006) and Black Sea (Karayücel et al 2002; Karayücel et al 2003ab) but commercial activites are developing slowly and there is only one functioning mussel farm in Turkey. This farm started to produce mussel (*M. galloprovincialis*) in raft and long-line culture system in Mersin Bay (Izmir) in 2000 and it is still active with a production capacity of 1000 mt/year (Kumlu & Lök 2007).

For mussel farmers the main objective is to get a better quality of meat and a maximal growth of organisms. Sedentary bivalve molluscs are able to tolerate the wide range of water conditions which commonly occur in their natural estuarine or coastal habitats, however their growth rates and flesh conditions are strongly influenced by these fluctuations in environmental conditions. Temperature, salinity, particulate matter, food availiability, current speed and water depth have been examined in multiple- and single-locality sudies, and have been found exert varying degrees of influence upon their growth and condition (Brown & Hartwick 1988ab; Hickman et al 1991; Thorarinsdottir 1994; Pérez-Camacho et al 1995; Stirling & Okumus 1995; Fernandez-Reiriz et al 1996; Sara et al 1998). However, it is declared the close relationship between mussel growth efficiency and food availability, this indicating growth performance limits in terms of energetic potential of food available (Fréchette & Bourget 1985; Karayücel & Karayücel 2000a; Karayücel et al 2003a; Erdemir Yiğin & Tunçer 2004; Ogilvie et al 2004; Lemaire et al 2006; Ozernyurk & Zotin 2006; Strohmeier et al 2008).

The large natural river supply of phosphorus and nitrogen, essential nutrients for marine plants and algae, has always made the Black Sea very fertile (Bakan & Büyükgüngör 2000). Chlorophyll-*a* concentration is a measure of the amount of phytoplankton from water. Phytoplankton is the principal food source for sedentary bivalves (Saxby 2002). When looking from this point of view, the region is suitable for filter feeding organism as mussel in the light of nutrient matter. However, the chlorophyll-*a* content of water alone may not be sufficient to indicate site suitability for bivalve farming. Other environmental factors have been identified as major determinants in productivity of commercial bivalve growing areas in temperate and warm temperate waters throughout the world. Prospects for mussel culture are quite high due to the favorable salinity, temperature, topography, food availability, reproductive potential and socio-economic conditions in the Black Sea area. *M. galloprovincialis* farming can be one of the most important activities in the region. So far, the studies showed that the growth performance of cultured mussels (raft and longline culture system) was considerable high. When the obtained product amount was taken into consideration, mussel culture in this region was advised (Karayücel et al 2002; Karayücel et al 2003ab).

M. galloprovincialis is highly adaptable and especially tolerant of a wide range of environmental conditions. However, extremes in physical factors such as storms, temperature and dessication, and excessive deposition of silt are all known to cause mortality in mussels (Seed & Suchanek 1992). Predation is undoubtedly the single most important source of natural mortality in *M. galloprovincialis* (Karayücel & Karayücel 1999ab). However the cause of mortality may be attributed to increased metabolic stress related to spawning (Emmett et al 1987; Tremblay et al 1988). Unfortunately there is no available experiment on growth and mortality in Black Sea region. Therefore this study is the first known experiment to collect data on effect of environmental factors on mussel growth and natural mortality in lantern nets and raft system in the Black Sea.

Material and Method. Experiment was caried out on *M. galloprovincialis* L. in raft system, at depth of 13 m in Sinop, in the Black Sea, Turkey from May 2005 to May 2006. Mussels were stocked to the lantern nets (Figure 1) and hunged from mussels raft system to determine growth and natural mortality.

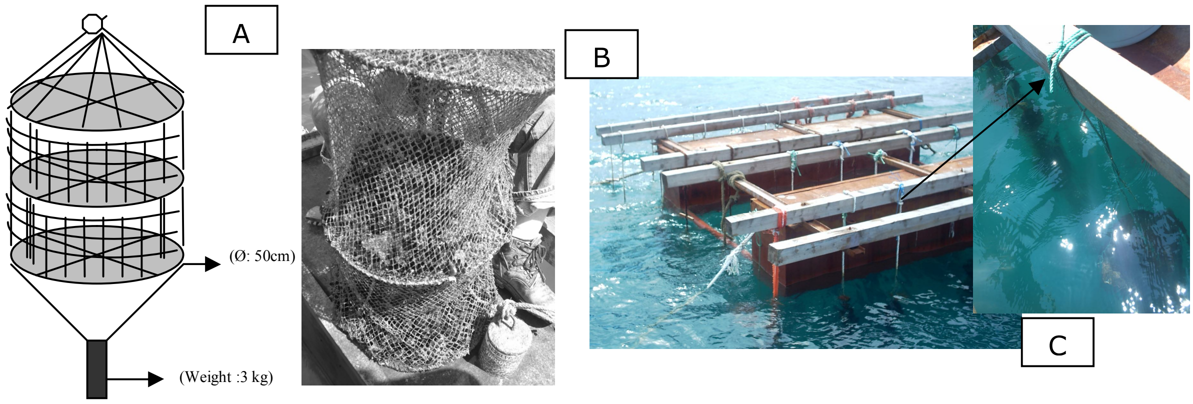

Figure 1. A - lantern net design; B - lantern net was used for experiment; C - lantern net were hanged from the raft system

***System Design*.** Raft system was mainly constructed from steel, pine wood beams and iron sac (see Figure 1). For building raft system, two sac float with 3.5 mm thickness, 50x75x300 cm dimensions were used. Three steel bars (0.8x12x400 cm) were attached to the float diagonally while six pine wood beams (10x10x400 cm) were attached to steel bars by steel screws.

The raft system was moored from four sides of the raft by using concreted block and 32 mm polypropylene riser (4:1 scope). Each concreted blocks with 10 meters of 22 mm open link ground chain were connected to riser rope. Two rectangle sacs with 3.5 mm thickness were used as floats and 4 mm of angle iron welded all over corners of sacs to make the float system strong. Then two rectangle floats were combined by 2 meters galvanised pipe from the bottom of floats.

***Sampling Procedure*.** One year old mussels were collected from mooring rope of Ak Fish Farm and extra large and small size mussels were removed for uniform size experimental mussels. Then experimental mussels with a mean length of 37.54±0.37 mm (± SE) stocked to into three lantern nets and hunged from raft system. Each lantern net contained three leave two tray (50 cm diameter) at a density of 500 mussel per tray or 1000 mussels per lantern nets. Monthly sampling was carried out and 15 mussels from each experimental tray were randomly taken during 12 months experimental period. On each sampling date, empty shells were counted and removed to determine mortality and lantern nets were brushed and cleaned of fouling organisms. Sub-samples were taken to determine monthly changes in shell length (SL), tissue weight (wet meat weight - WMW), live weight (LW), dry meat weigth (DMW) and ash-free dry meat weigth (AFDMW).

Enviromental Parameters. Temperature, salinity, chlorophyll-*a* (ch-*a*), seston (total particulate matter), particulate inorganic matter (PIM) and particulate organic matter (POM), were determined monthly from May 2005 to May 2006. Water samples were taken at depth of 3 m by using a Niskin bottle at the experimental site. Water temperature and salinity was measured in situ using a probe (YSI 6600). In the laboratory, triplicate water samples (3 l) were filtered onto Whatman GF/C fillters to determine chlorophyll-*a* (μgL^{-1}), seston (mgL^{-1}) and POM (mgL^{-1}) concentration according to Stirling (1995).

Morphological Measurements and Statistical Analyses. Growth was estimated from changes in shell length, live weight and wet meat weight (tissue weight). Live weight (total weight of mussel) was measured by weighing live animals and wet meat weight obtained by weighing the meat after dissecting the mussels and bloted extra water with a tissue paper. Shell length (maximum anterior-posterior axis) was measured to the nearest 0.1 mm with a caliper (Seed 1968). At the end of the experiment, mussels from three ropes were counted and the number of mussels per meter of rope calculated for production. Production was estimated according to the Rivonker et al (1993). Meat yield was calculated by dividing the wet meat weight to live weight of mussel. Monthly specific growth rate (SGR %) were found from following formulate by using:

$(SGR\ \%)=100[(\ln L_2-L_1) / (T_2-T_1)]$,

where L_1 and L_2 are the mean shell lengths at times T_1 and T_2 (T_2-T_1 was an average 30 days) (Chatterji et al 1984).

Cumulative mortality calculation was determined using from following formulate by using:

Cumulative mortality (%)=$100(N_t/N_0)$,

where N_t is the number of empty shells mussels removed from the lantern after t time and N_0 is the number of mussels at the beginning.

A correlation matrix was used to determine the relationships between the enviromental and growth parameters. Statistical analyses were carried out using MINITAB 13.1 software.

Results

Environmental parameters. The temperature ranged from 7.5°C to 25.05°C with a mean of 14.90±1.70°C. Salinity ranged from 16.80 to 17.97 ‰ with a mean of 17.59±0.10‰ and there was not clear seasonal pattern. Chlorophyll-*a* peaked in March (16.30 μgL^{-1}) as a result of spring algal bloom and decreased to the lowest value in January (0.53 μgL^{-1}), with a mean of 3.07±1.18 μgL^{-1}. Seasonal chlorophyll-*a* concentration was significantly different ($p<0.05$) and in general higher in spring and lower in winter. POM ranged 1.58 to 4 mgL^{-1} with a mean of 2.42±0.17 mgL^{-1} while seston ranged from 5.45 to 6.92 mgL^{-1}, with a mean of 6.21±0.12 mgL^{-1} (Figure 2 and Figure 3). There was a positive correlation between chlorophyll-*a* and POM ($p<0.05$). Salinity and temperature did not significantly correlate with chlorophyll-*a*, POM and seston ($p>0.05$). When chlorophyll-*a* and seston reached maximum values in March, the temperature was the maximum in August. There was a clear seasonal pattern in the temperature but the other environmental parameters did not show any clear seasonal pattern.

Growth Rate and Mortality. At the end of twelve months, shell length increment was occured as 13.67 mm and reached to 51.20±0.50 mm. About 54.06% of total shell length growth was occured from May to October (Table 1). The growth rate was the lowest on January. The highest values of SGR were obtained in the first three months when the mussels were younger and availability of food was higher. The monthly specific growth rate (SGR %) ranged 1.50-5.72% with a mean of 2.59±0.30% (Figure 4). The live weight increasement was found 7.91 g and reached to 12.61±0.39 g. Live weight and shell length correlated with POM ($p<0.05$). At the end of the experiment, the mean wet meat weight (tissue weight) was 1.93±0.16 g and the shell weight was 3.46±0.27 g. Meat yield ranged from 17.51 to 24.25% with a mean of 21.12±0.63%. The shell length increment positively correlated with live weight ($p<0.05$).

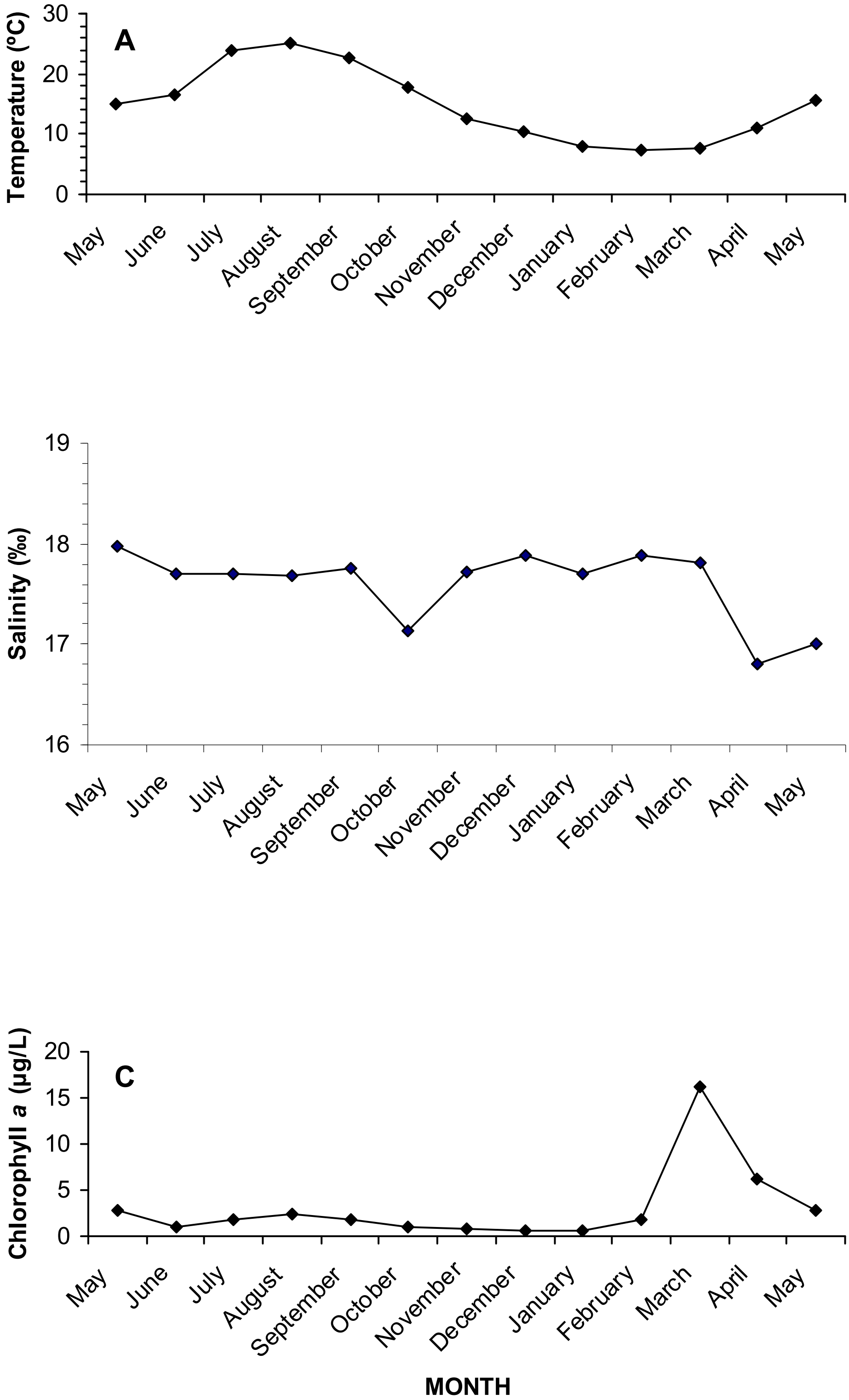

Figure 2. Monthly distribution of mean temperature (A), salinity (B) and chlorophyll-*a* (C)

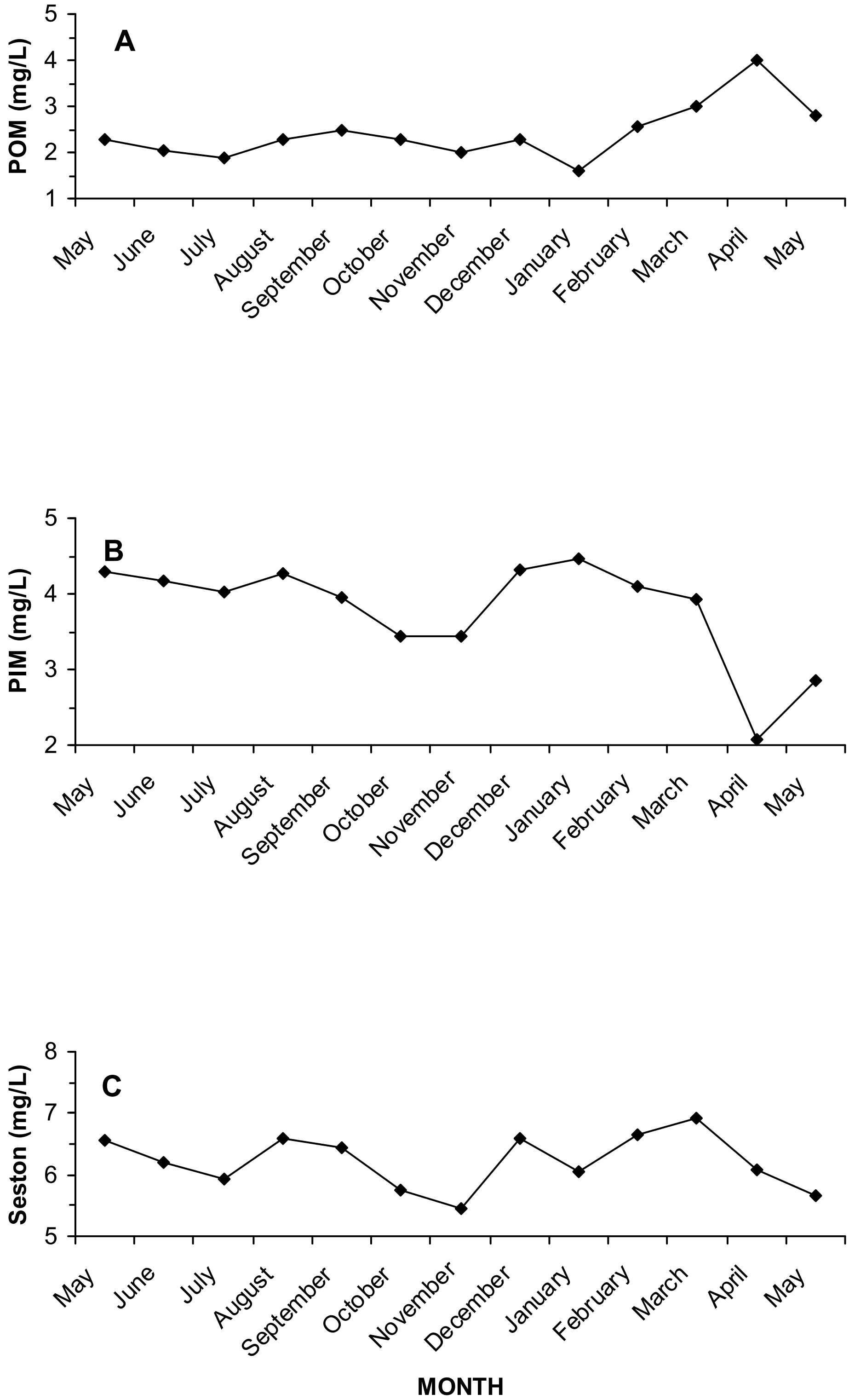

Figure 3. Monthly distribution of mean particulate organic matter (A), particulate inorganic matter (B) and seston (C)

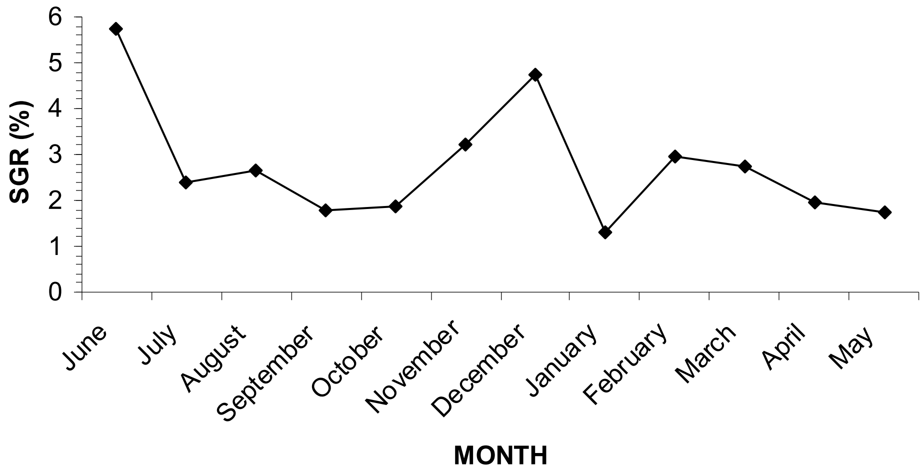

Figure 4. Monthly distribution of specific growth rate (SGR)

Table 1

The main parameters observed in *M. galloprovincialis* for the present study

Parameters		Value
	Initial	37.53±0.37
Length (mm)	Final	51.20±0.50
	Increment	13.67
	Initial	4.70±0.14
LW (g)	Final	12.61±0.37
	Increment	7.91
	Initial	1.51±0.21
WMW (g)	Final	2.51±0.02
	Increment	1
	Initial	0.26±0.03
DMW (g)	Final	0.42±0.003
	Increment	0.16
	Initial	0.09±0.01
AFDMW (g)	Final	0.16±0.001
	Increment	0.07

Monthly mortality was found maximum with 5.2% in October (see below Figure 5).

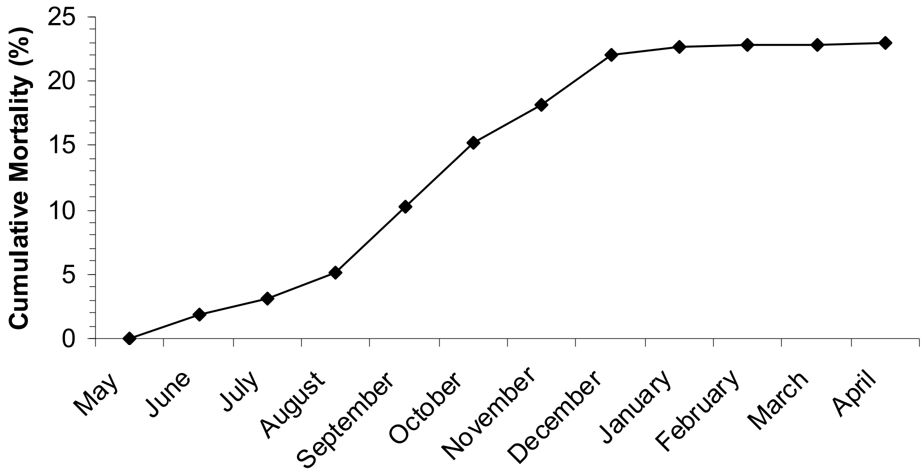

Figure 5. Distribution of mean cumulative mortality (%)

Discussion. One of the most important factors affecting the growth rate is temperature. When temperature is above 10°C and food is available, growth rate is high (Bayne et al 1976). Also, the studies showed that number of environmental factors including water temperature, quantity and quality of food principally affects growth in marine bivalves, but phytoplankton availability is the most important factor (Seed 1976; Jones & Iwama 1991; Karayücel & Karayücel 1999ab; Manoj Nair & Appukuttan 2003; Ren & Ross 2005). The present study showed that when the temperature was below 10°C (in March) chlorophyll-*a* reached the highest value (16.3 μgL^{-1}). POM reached the maximum (4.00±0.29 mgL^{-1}) in April and positively correlated with chlorophyll-*a* ($P<0.05$). When the seston was lower, the increase in shell length and live weight were lower, too. However, when the POM and chlorophyll-*a* were higher in the spring and summer, the increasement of live weight and shell length were higher, too. POM was positively correlated with shell length and live weigth ($P<0.05$). Chlorophyll-*a* and POM had higher values compared with those of other highly productive areas for bivalve culture and had a significant correlation with the seston (Stirling & Okumuş 1994; Stirling & Okumuş 1995; Sarà et al 1998; Lök et al 2007).

In the present study, when mussels were younger, the highest SGR was obtained during spring and summer due to high temperature and food availability. The lowest SGR (1.50%) in January and the highest SGR (5.72%) in June was obtained. Some authors (Karayücel & Karayücel 2001; Karayücel et al 2002; Lauzon-Guay et al 2005; Lök et al 2007) declared similar findings. Growth rate was slower at older mussels (Seed 1969; Lauzon-Guay et al 2005; Lök et al 2007). Almada-Villela et al (1982) and Blanchard & Feder (2000) indicated that growth in mussels (*Mytilus* spp.) was rapid during the spring and summer (at temperatures of 10-20°C) and slow or absent during the colder months (at temperatures below 5°C) in temperate waters. Karayücel et al (2003b) reported that the SGR was lower during the winter due to the low availability of food but it resumed in March and continued through the spring and summer in Sinop, in the Black Sea. Other studies have shown that food availability and quality were the main determinants of growth rate in mussels (Ceccherelli & Rossi 1984; Page & Hubbard 1987; Frechette & Bourget 1987; Mohlenberg & Riisgård 1979; Ogilvie et al 2004; Lök et al 2007; Lemaire et al 2006). These findings are similar with the results discussed in present study.

In general, natural mortality in mussel populations results from an interaction of many biological and physical factors (Dare 1976). Yanick et al 2003 declared that increased metabolic stress in mussels has been correlated with mortality of mussels. In this study, increase in natural cumulative mortality that was monitored may be attributed to increased metabolic stress related to spawning in October. Increased metabolic stress in mussels has been correlated with reduced food quality in winter and resulted with higher mortality. The cumulative mortality was significantly correlated with dry meat weight ($p<0.05$). Also cumulative mortality was higher in winter than spring and summer. The combined effects of reduced feeding rate, low temperature and increased gamete production may be responsible for mortality. The mortality rate was higher in younger mussels than in older ones (Karayücel & Karayücel 2000b). This finding was similar with ours that lower mortality was obtained in older mussels.

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