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# Influence of Environmental Factors on Growth Rate of *Crassostrea madrasensis* (Preston) in Suspended Culture

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## Abstract

Growth response of *Crassostrea madrasensis* to varying environmental factors in the Mulki estuary of Karnataka was investigated from April 2004 to March 2005. Temperature, salinity, pH, particulate organic matter (POM), particulate inorganic matter (PIM), total particulate matter (TPM) and chlorophyll *a* (Chl *a*) levels were correlated with growth in shell length. Marked seasonal patterns in growth rate were observed in relation to changes in environmental factors. Growth curve indicated a rapid phase (16.21±1.2 mm month$^{-1}$) initially (May-June) followed by a slow phase (0.8±0.52 mm month$^{-1}$) coinciding with the drop in salinity (August-September). Considering the temporal variations of environmental factors, their influence on growth rate was analysed seasonally. The growth rate was significantly correlated with Chl *a* concentrations in all the seasons. A pronounced seasonal cycle was noticed in Chl *a* levels resulting from blooms in pre-monsoon (April-May) and post-monsoon (October) seasons.

## Introduction

Environmental conditions can significantly influence the physiology of bivalves, and therefore, modify the growth potential (Widdows et

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al. 1984; Navarro et al. 1991; Wong and Cheung 2003). Even though sedentary bivalves are able to withstand the wide variations in environmental conditions that commonly occur in their natural habitats, their growth rates are strongly influenced by these fluctuations. Factors such as temperature, salinity, food availability, nutrient levels, current speed, water depth etc. can further influence the growth rate by limiting food availability. Therefore, the suitability of a site for bivalve farming is decided by the environmental variables influencing both bivalve physiology as well as food availability.

The Indian backwater oyster, *Crassostrea madrasensis* is endemic to brackish waters such as estuaries, creeks, bays and backwaters. Being an important candidate species for mariculture it has culture potential due to its highly euryhaline nature, fast growth rate and abundant spatfall. Experimental edible oyster culture in the inshore coastal waters and estuarine systems (Rao and Nayar 1956; Joseph and Joseph 1983; Velayudhan et al. 1998) along the Indian coast has developed into a successful aquaculture endeavor as part of rural development programme along the southwest coast (Appukuttan et al. 2000) of India. Such programs indicated location specific variations in spatfall, growth rate and survival. Similar variation in growth rate of *C. madrasensis* along the southeast coast was demonstrated by Yavari (2002). The present study is aimed at analyzing the growth rate of *Crassostrea madrasensis* in relation to various environmental factors such as temperature, salinity, pH, chlorophyll *a* (Chl *a*), particulate organic matter (POM) and particulate inorganic matter (PIM) to investigate the possibility of extending the culture period to the unfavorable monsoon months.

The experiment was conducted in Mulki estuary on the southwest coast of India (Fig. 1). Salinity in the estuary is generally high and stable during December to May (>30 ppt) and low during June to November (<1–26 ppt). Mulki estuary was selected considering the abundance of *C. madrasensis* and conducive environmental parameters for successful development of commercial bivalve culture (Mohamed et al. 1998).

## Materials and Methods

The experimental farm was set up at the mouth of Sambhavi River (Fig. 1) near natural oyster beds. Three racks of 9 $m^2$ each were constructed using bamboo poles at 3-4 m water depth. Spat collectors were fabricated using oyster shells and suspended from the rack in early March 2004. Spat settlement of *C. madrasensis* was observed in April 2004.

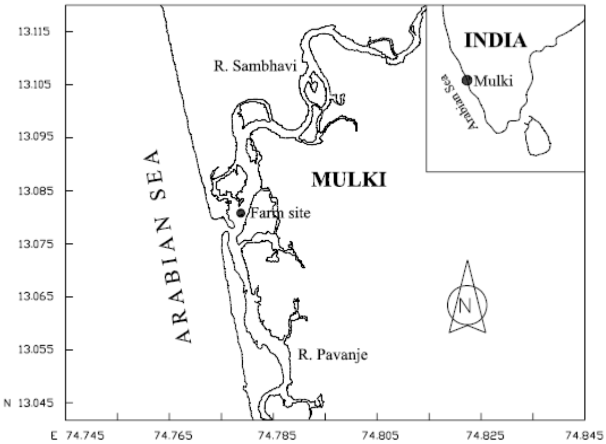


Fig. 1. Map showing the farm site

Temperature, salinity, dissolved oxygen (DO), pH, particulate organic matter (POM), particulate inorganic matter (PIM), total particulate matter (TPM) and Chl *a*, levels of seawater at culture site were recorded fortnightly. Temperature, salinity, DO and pH of seawater were determined using multi-parameter probe (WTW, Germany).

Samples for analyzing TPM, PIM and POM were drawn in triplicate using a universal water sampler (Hydro-Bios, Germany), during high tide. The TPM, PIM and POM were determined after filteration of 500 ml of water (Wong and Cheung 2003) using pre-ashed (450°C) and pre-weighed 47 mm Whatman GF/C filters. The TPM was determined after filters were dried at 100°C for 1 h. The PIM was then determined after burning the filters at 450°C for 6 h in a muffle furnace. The POM was calculated from the difference between TPM and PIM. Chl *a* concentration was measured spectrophotometrically (Strickland and Parsons 1982).

Oysters were sampled from the suspended culture racks, cleared of epibionts and shell length (the distance from the end of umbo to the ventral shell margin) was measured using digital vernier calipers (± 0.01 mm). Mean growth rate (GR) was calculated as $GR = (X_{t+1} - X_t)/D$, where $X_{t+1}$ is the mean shell length (mm) of the current month, $X_t$ is the shell length of the previous month and D is the number of days between consecutive observations (Paterson et al. 2003).

The hydrobiological data were averaged for each month and analyzed for monthly variations. Monthly data was then grouped as pre-monsoon (January to May), monsoon (June to August) and post-monsoon (September to December) to study seasonal variation.

Statistical analysis was performed with SPSS 12.00 software using Analysis of Variance (ANOVA) followed by Duncan's Multiple Range test (DMRT) to identify homogenous groups among the seasons. Pearson's correlation analysis was carried out using the monthly averages to investigate the relative effects of environmental variables on the growth rate of oysters within each season.

## Results

### *Environmental factors at the farm site*

Inter-seasonal variability in environmental factors of the culture site is presented in table 1. Salinity, temperature, DO, pH, Chl *a*, POM, TPM and PIM varied significantly ($P<0.01$) between the seasons. Seasonal variations in the levels of important environmental factors are shown in figure 2.

Salinity showed wide variations between the months and ranged from <1 ppt in monsoon (August) to 35.6 ppt in pre-monsoon season (May).

Peak water temperature was observed in pre-monsoon season and it gradually decreased in monsoon season. Temperature ranged between 27.3°C in August to 30.9°C in April. The DMRT showed that salinity and temperature were significantly ($P<0.05$) lower in the monsoon season.

The pH varied between 6.0 and 8.05 wherein low values were observed during the monsoon and higher values during pre-monsoon. No significant difference was observed between pre-monsoon and post-monsoon seasons.

The DO concentration varied from 5.67 to 7.37 $mg\cdot l^{-1}$ with maximum during monsoon and minimum during the post-monsoon. The DO levels were significantly higher in monsoon season ($P<0.05$), however no significant difference between the pre-monsoon and post monsoon seasons were observed.

A pronounced seasonal cycle was evident in Chl *a* represented by blooms in pre-monsoon (April-May) and post-monsoon (October) seasons. Very low Chl *a* values were observed in monsoon season (August). The Chl *a* concentrations varied significantly ($P<0.01$) between the seasons and the annual mean Chl *a* level was in the order of $0.2 \pm 0.15$ $mg\cdot m^{-3}$. The Chl *a* levels were significantly ($P<0.05$) lower in monsoon season.

The POM corresponded to seasonal patterns in Chl *a*, the maximum value being 8.87 $mg\cdot m^{-3}$ in post-monsoon (October). The POM concentrat-

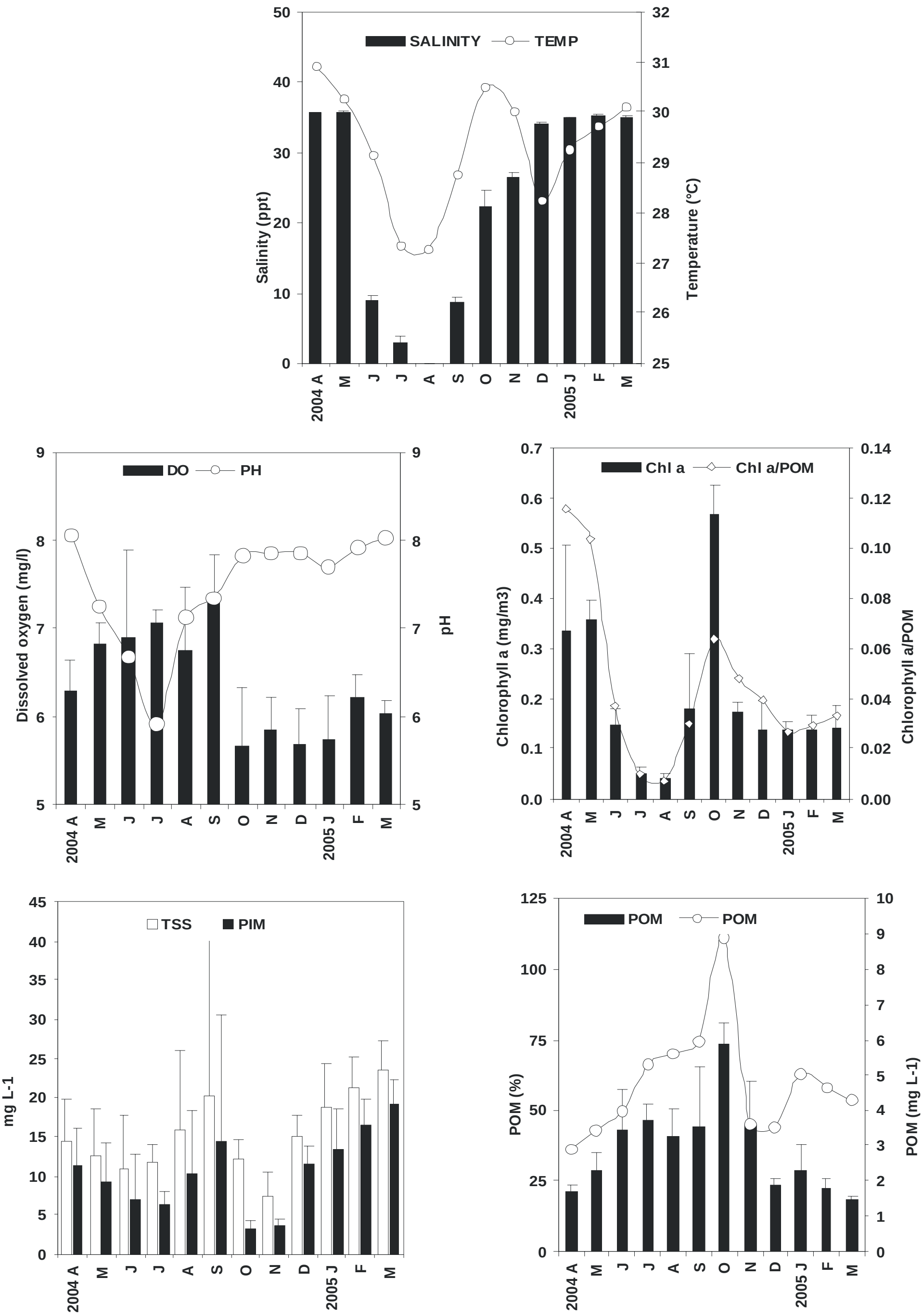


Fig. 2. Seasonal variations (mean ± SD) in salinity, temperature, dissolved oxygen (DO), pH, chlorophyll *a*, chlorophyll *a:*POM ratio, particulate organic matter (POM), total particulate matter (TPM) and particulate inorganic matter (PIM)

ions averaged 4.76 ± 2.22 mg·m$^{-3}$ differing significantly (P<0.05) in the pre-monsoon season. High Chl *a:*POM ratio was observed in April to May (Fig. 2) and low Chl *a:*POM ratio in monsoon. The TSM levels were significantly (P<0.05) low during monsoon and post-monsoon seasons. The PIM levels followed similar patterns with seasons.

## *Oyster growth*

Inter-seasonal variability in oyster growth in the culture site is presented in table 1. Oyster growth was significantly different between seasons. Oysters grew to an average size of 71 mm during the first eight months (April–December). There was no significant increment from January to March, where the monthly growth rate varied between 0.9 and 2.1 mm and the final size reached was only 75.8 mm. Based on the growth pattern the annual growth cycle could be divided into four phases (Fig.3): (1) a rapid phase during the early months of rearing during May–June (average growth of 16.21±1.2 mm month$^{-1}$); (2) a slow phase during August-September (average growth of 0.8±0.52 mm month$^{-1}$); (3) followed by another rapid phase during October-December (average growth of 9.61±4.9 mm month$^{-1}$); and, (4) a stationary phase in the later months of culture during January-March (average growth of 1.54±0.89 mm month$^{-1}$). Month-wise observation revealed a sudden increase in the growth rate in May, June, October and December.

Table 1. Inter-seasonal variability in growth rates along with the factors affecting growth. F values of ANOVA and results of DMRT are also indicated

| | F Value | Pre-monsoon | Monsoon | Post-Monsoon |
|---|---|---|---|---|
| N | | 30 | 18 | 24 |
| GR (mm) | 3.221* | 4.18$^{a}$ | 8.41$^{b}$ | 7.42$^{b}$ |
| Chl *a* (mg•m$^{-3}$) | 9.488** | 0.221$^{a}$ | 0.080$^{b}$ | 0.264$^{a}$ |
| DO (mg•l$^{-1}$) | 8.459** | 6.19$^{a}$ | 6.90$^{b}$ | 6.15$^{a}$ |
| pH | 69.07** | 7.94$^{a}$ | 6.57$^{b}$ | 7.72$^{a}$ |
| Salinity (ppt) | 164.94** | 35.29$^{a}$ | 3.94$^{b}$ | 22.85$^{c}$ |
| Water Temperature ($^{o}$C) | 36.45** | 30.04$^{a}$ | 27.92$^{b}$ | 29.38$^{c}$ |
| PIM % | 18.05** | 76.16$^{a}$ | 56.83$^{b}$ | 53.46$^{b}$ |
| POM % | 19.25** | 23.83$^{a}$ | 43.16$^{b}$ | 46.53$^{b}$ |
| TPM | 3.067* | 18.09$^{a}$ | 12.83$^{b}$ | 13.65$^{ab}$ |

**Significant at (*P*<0.01); *Significant at (*P*<0.05); Means within rows with a common superscript do not differ significantly.

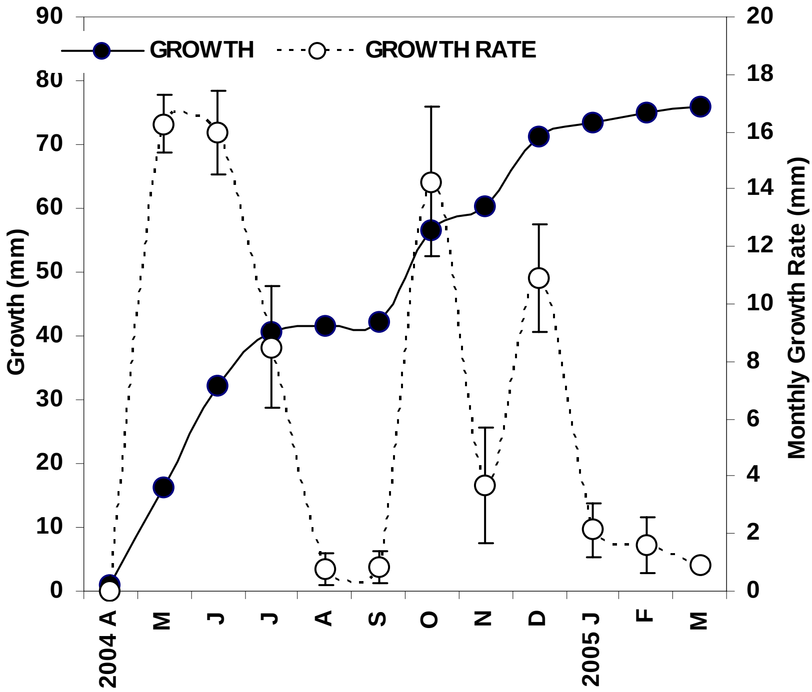


Fig. 3. Monthly mean shell length and growth rate of oysters cultured in Mulki estuary

## *Factors affecting growth*

Inter-seasonal variability in environmental factors being significant, Pearson's correlation analysis between environmental variables and growth rate was carried out only within the three seasons (Table 2). During pre-monsoon season Chl *a*, POM %, PIM %, TPM and salinity showed significant influence on growth rate, the influence of PIM and TPM being negative. In monsoon, Chl *a*, salinity and water temperature exhibited highly significant positive correlations ($P<0.01$) with growth rate. Chl *a*, content during the season was also noticed having high significant cross correlation with salinity and water temperature. During post-monsoon only Chl *a* and salinity showed significant influence on growth rate.

Table 2. Correlation matrix (r values) of environmental variables and growth rates in pre-monsoon (PRS), monsoon (MS) and post-monsoon (PMS) seasons

| SEASON | | GR | Chl *a* | PIM (%) | POM (%) | pH | S | WT | TPM |
|---|---|---|---|---|---|---|---|---|---|
| PRS | GR | 1.000 | | | | | | | |
| | Chl a | 0.463** | 1.000 | | | | | | |
| | PIM % | -0.466** | -0.077 | 1.000 | | | | | |
| | POM % | 0.466** | 0.077 | -1.000** | 1.000 | | | | |
| | pH | 0.116 | 0.471** | 0.404** | -0.404* | 1.000 | | | |
| | S | 0.475** | 0.678** | 0.045 | 0.045 | 0.557** | 1.000 | | |
| | WT | 0.064 | 0.449* | 0.096 | -0.096 | 0.711** | 0.538** | 1.000 | |
| | TPM | -0.416* | -0.267 | 0.645** | -0.645** | -0.094 | -0.416* | -0.527** | 1.000 |
| MS | GR | 1.000 | | | | | | | |
| | Chl *a* | 0.800** | 1.000 | | | | | | |
| | PIM % | -0.087 | -0.129 | 1.000 | | | | | |
| | POM % | 0.087 | 0.129 | -1.000** | 1.000 | | | | |
| | pH | -0.286 | 0.073 | 0.407 | -0.407 | 1.000 | | | |
| | S | 0.945** | 0.888** | -0.025 | 0.025 | -0.126 | 1.000 | | |
| | WT | 0.857** | 0.919** | -0.012 | 0.012 | 0.067 | 0.927** | 1.000 | |
| | TPM | -0.297 | -0.095 | 0.820** | -0.820** | 0.250 | -0.234 | -0.237 | 1.000 |
| PMS | GR | 1.000 | | | | | | | |
| | Chl *a* | 0.575** | 1.000 | | | | | | |
| | PIM % | -0.229 | -0.613** | 1.000 | | | | | |
| | POM % | 0.229 | 0.613** | -1.000** | 1.000 | | | | |
| | pH | 0.326 | 0.317 | 0.353 | -0.353 | 1.000 | | | |
| | S | 0.535** | -0.092 | 0.328 | -0.328 | 0.524** | 1.000 | | |
| | WT | 0.254 | 0.600** | -0.725** | 0.725** | 0.054 | -0.098 | 1.000 | |
| | TPM | -0.111 | 0.123 | 0.383 | -0.383 | 0.396 | -0.225 | -0.406* | 1.000 |

**Significant at ($P$<0.01), *Significant at ($P$<0.05)

# Discussion

## *Environmental parameters*

Inter-seasonal variability in salinity, temperature, dissolved oxygen and pH in the culture site were comparable with earlier works reported in the estuarine waters of Karnataka (Vijayakumar et al. 2000; Gowda et al. 2002). The onset of monsoon contributed to a decrease in salinity, temperature and pH levels and increase in DO levels in the culture site.

In Mulki estuary, Chl *a* peaks were recorded in pre-monsoon and post-monsoon seasons, whereas, monsoon recorded a low value. Earlier studies have also revealed similar seasonal patterns and higher values for phaeopigments (the degraded forms of chlorophylls) and Chl *a* during pre-monsoon and post-monsoon period in estuarine waters (Gowda et al. 2002; Krishnakumari et al. 2002).

## *Oyster growth*

The growth rate obtained in the present study was comparable with that reported for the same species by earlier works in estuarine waters (Table 3). Comparison of growth rate obtained in present experiment with previous studies was not attempted due to variations in culture season, method of culture and culture locations. However, monthly variations observed in the present study closely correspond to the results of a study conducted in Mulki estuary during 1994-95 (K. S. Mohamed, pers. comm.) where better growth rates were recorded in December and May**.**

## *Factors affecting oyster growth*

### *Chlorophyll a and POM*

Concentration of Chl *a*, which is a quantitative measure of the amount of phytoplankton, the principal food of bivalves (Page and Hubbard 1987), available in the environment has been identified as a controlling factor in bivalve growth (Page and Richard 1990; Toro et al. 1995). It has been found that the presence of adequate particulate food is the consistent stimulus for good growth or condition of bivalves at culture sites (Saxby 2002). Positive correlations between growth rate and Chl *a* levels indicate that, food availability is an important factor governing the growth of oysters. Studies in other regions along the Indian coast by Rivonkar et al. (1993) and Yavari (2002) have also demonstrated difference in bivalve growth rate with food availability.

Table 3. Growth details of *Crassostrea madrasensis* reported along the Indian coast

| Location | Initial size (mm) | Final size (mm) | Culture Duration (Months) | Reference |
|---|---|---|---|---|
| Vellar estuary, India | Spat | 82 | 12 | Patterson and Ayyakkannu (1997) |
| Mulki estuary, India | 20-30 | 72 | 7 | Joseph and Joseph (1983) |
| Mulki estuary, India | 27.2 | 75.9 | 6 | Mohamed K. S. (1994-95) (*Pers. Comm.)* |
| Ashtamudi lake, India | 28.2<br>24<br>23.2 | 63.9<br>68.0<br>68.3 | 11<br>11<br>11 | Appukuttan et al. (1998) |
| Tuticorin, India | Spat | 75.67 | 16 | Yavari (2002) |
| Mulki estuary, India | 16<br>Spat | 71<br>75.8 | 7<br>12 | Present study |

The periods of faster growth from April to May (pre-monsoon season) and from October to December (post-monsoon season) coincided with high Chl *a* levels. However, it is interesting to note that, higher growth rates were also recorded with the onset of monsoon (June-July) in spite of an obvious drop in the Chl *a* level (Fig. 2). The Chl *a* peaks indicate an increase in primary production by May and from late September to early November associated with the increase in water temperature.

The high Chl *a*:POM ratio observed in April, May (Fig. 2) and October points towards low detritus fraction whereas, the low ratio in monsoon indicates a poor quality of organic seston i.e. high detritus fraction. It also corroborates to an increase in detritus fraction subsequent to the high primary productivity during April and May due to decay of phytoplankton as well as the particulate matter brought in by the freshwater inflow. Consumption of this organic detritus could partially explain the resumption of growth in early monsoon, when water temperature (> 27$^{o}$C) observed was favourable for normal growth.

In an estuary, bivalves are exposed to large fluctuations in food supply both in terms of composition and concentration. At the culture site POM fraction of the seston recorded an increasing trend from June to October. Both the total seston available (quantity) and the proportion (quality) of organic fraction in the seston affect seasonal growth patterns of bivalves (Page and Richard 1990; Toro et al. 1995) and can become insufficient to maintain growth and reproduction because of the spatial and temporal variation in production. In consequence, bivalves feed on various other potential food, apart from phytoplankton, which are available in the seston of estuarine environments *viz.* detritus from sediment and dead phytoplankton (Crosby et al. 1990; Newell et al. 1998), zooplankton and bacteria (Langdon and Newell 1990). Kasai and Nakata (2005), using the carbon and nitrogen isotopic ratios in bivalves, demonstrated that they could assimilate terrestrial organic materials, when the river discharge increases and terrestrial materials occupy their habitat.

*Temperature*

Over the months, growth increments strongly correlated with Chl *a* than with temperature. While, the rise and decline in Chl *a* level in the estuarine water was in sequence with the temperature changes, there was no significant correlation between growth rate and temperature in the pre-monsoon and post-monsoon seasons when the amplitude of variation was much higher for primary production than for water temperature. Nevertheless, in monsoon season, the growth rate correlated more strongly (positive) with changes in temperature than with Chl *a*. On the other hand, rapid growth rate occurred even in early monsoon (June–July) suggesting that the temperature changes during the period were not sufficiently significant to effect growth provided that food is available in sufficient quantities. Drop in temperature recorded during this period was within the optimum range of 26-31°C reported for the species (Rao and Nayar 1956). Temperature changes appear to have much less influence on growth rates in the tropical zone.

*Salinity*

Growth rate in monsoon season was significantly correlated ($P<0.01$) with salinity. Cessation of growth in *C. madrasensis* was recorded in late monsoon when salinity levels dropped below 1 ppt in August amongst abundance of particulate organic material. Salinity is known to influence oyster growth (Brown and Hartwick 1988a; 1988b). Prolonged exposure to low salinity can depress shell and meat growth in oysters through reduced mineral availability and stress-induced depressions of metabolic activity (Brown and Hartwick 1988a). The salinity ranges reported for *C. madrasensis* is 0-41 ppt. *C. madrasensis* exhibited higher growth in Adyar estuary whenever water exchange with the Bay of Bengal increased, as indicated by higher salinity in the estuary (Rao and Nayar 1956). The effect of salinity on growth rate may also reflect changes in the nutritional quality or abundance of food organisms or materials due to variations in salinity. Adequate nutrition for growth of oysters requires food sources, which are more abundant in higher saline waters (Angell 1986), which enter estuaries in high tide from the adjacent seas. High runoff would dilute intruding seawater; flush out detritus, alter temperature, salinity and light penetration affecting the growth of phytoplankton, as well as species composition of the plankton community.

In the present study resumption in oyster growth rate occurred following monsoon with increase in salinity of the estuarine waters. Appukuttan et al. (1998) reported similar trends in oysters of Dharmadam estuary. These observations indicate the potential for farming *C. madrasensis* throughout the year even in unfavorable monsoon season in estuarine system due to the physiological adaptations of the species in the prevailing environmental conditions.

*TSM and PIM*

Following the rapid post-monsoon growth there was a reduction in growth rate towards the end of the culture period (January–March), while an increase in the levels of TSM and PIM were observed. Significant negative correlation ($P<0.05$) was observed between TSM levels and growth rates in pre-monsoon season. The increase in TSM and PIM could partially explain the reduction in growth rate apparent in January-March. Thangavelu (1988) reported a significant reduction in feeding in *C. madrasensis* during periods of high turbidity despite abundant availability of phytoplankton. Yavari (2002) accorded the reduction in oyster growth to increase in PIM and turbidity.

The results of the present study indicated a distinct seasonality in the growth of oyster in relation to their environmental conditions, particularly food availability. While phytoplankton has been identified elsewhere as the principal food source of farmed bivalves, supplementation by detrital organic matter seems to be very important in tropical estuaries. Physico-chemical conditions appear to be suitable for the growth of *C. madrasensis* in this tropical estuary even in unfavorable monsoon months. Growth curve of *C. madrasensis* indicated a faster growth initially followed by a seasonal drop during the later part of SW monsoon and a recovery in the post-monsoon months. Thus, the results of the study throw light on the possibility of starting spat collection for culture operation in estuary during the spawning season from March to May preceding the SW monsoon in addition to the generally followed practice of setting spat collectors in the months of December and January.

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