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†Comparison of growth and gonad development of farmed green mussel *Perna viridis* L. in three habitats

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Abstract

The green mussel *Perna viridis* was farmed in three different ecosystems, *viz*., a semienclosed bay (Kollam Bay), estuary (Ashtamudi Lake) and open sea (off Narakkal) along Kerala coast during the period 2003-2004. Mussels of the length range 25 to 32 mm were seeded on to nylon ropes and suspended from off bottom structures. Their growth in length, width, depth, total weight and meat weight were measured at monthly intervals. The condition index (CI) and gonad development were also observed. The farm ecology was monitored and the variations in salinity, temperature, nutrients and productivity during the culture period were recorded and correlated with biological parameters. The instantaneous growth rates (IGR) in length, width and depth were the highest at 0.0124, 0.010 and 0.012 mm day^{-1} respectively in mussels grown in the sea and these were significantly different ($p < 0.05$) from those of mussels grown in the bay and estuary. The IGR in total weight was also the higher for the mussels grown in the sea (0.028 mg day^{-1}) and bay (0.022 mg day^{-1}) but were lower and significantly different from those grown in the estuary (0.013 mg day^{-1}). In the bay and open sea farm, all the reproductive stages were observed indicating that mussels were reproductively active at these sites. However, in the estuarine farms, completely spent mussels were not observed. The ecological conditions and growth rates indicate that it is possible to have two crops from bay (August/September to December/January; February/March to May/June) and sea (September/October to December/January; January/February to March/April) while in the estuary only one crop (November/December to May/June) is possible due to the low saline conditions from June to October. The observations on the reproductive stages of mussels indicate that it is also possible to collect seed mussels from bay and sea farms during the spawning period of mussels by placing suitable spat collectors.

Keywords: *Perna viridis,* instantaneous growth rate, gametogenesis, mussel seed

Introduction

Mussels are inhabitants of marine intertidal and subtidal zones and farming trials by suspending the green mussel *Perna viridis* from off bottom structures in estuaries and open sea areas along the Indian west coast have given encouraging results (Qasim *et al*., 1977; Parulekar *et al*., 1982; Rivonker *et al*., 1993; Kripa *et al*., 2000). Though there are seasonal variations in hydrological parameters in marine and estuarine ecosystems, the high survival and production in the mussel farms have implied the capability of this resource to adapt to both the ecosystems. Experimental trials conducted in the open sea along the west coast indicated that the growth of mussels was much faster in the sea than in estuaries (Appukuttan *et al*., 2000). Even then, most commercial mussel farms in the country are located in the estuaries due to lack of security of farm structure and farmed stock in the open sea (Kripa and Mohamed, 2008). In bivalves, the energy balance is directly linked to the quality of the environment (Smaal and Widdows, 1994) and

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positive energy defined as the scope for growth, represents the energy used for growth and/or for reproduction (Resgalla *et al*., 2007). These two biological parameters are significant in mussel farming since they are directly linked to production.

The hydrological conditions of the east and west coasts of India are different. Along the east coast, two spawning peaks for green mussel have been recorded and the potential for seed collection from estuaries has also been indicated (Rajagopal *et al*., 1998). Along the west coast, where mussel farming has developed as a small-scale industry, unavailability of mussel seed in sufficient quantities during the farming period has emerged as a problem. Though there are several mussel farms in the west coast estuaries, large scale settlement of mussel seed in these farms has not been observed.

A study was conducted to evaluate the growth rates of the green mussel farmed in estuary, semi-enclosed bay and open sea, to compare the gonad development of mussels in these three ecosystems and relate it to the hydrological parameters and to explore the possibility of improving the existing mussel farming practices.

Material and Methods

Farm structures and seeding**:** The experiment was conducted along the Kerala coast during the period 2003-04 in the Ashtamudi Lake (estuary), Kollam Bay (semi-enclosed bay) and off Narakkal (open sea). The farm structures were wooden off bottom structures of 5 x 5 m size trestles in the estuary since depth was only 1.5 m and wooden rafts of 5 x 5 m size in the bay and sea where depth was 3 to 5 m. Mussel seed of length 25 to 32 mm collected from the intertidal region between Kollam and Kochi were seeded manually during November 2003 for the sea farm and during January 2004 for farming in the bay and estuary. The core material used was nylon rope of 22 mm diameter having a length of 1 m (estuary), 2 m (bay) and 3 m (sea) and the seeded ropes were suspended at a stocking density of 12 ropes m^{-2} in all the farms. In the estuary, the mussels were to be harvested in June since low saline conditions in the estuary due to heavy rainfall is detrimental to the survival of mussels. Hence, for comparison of growth rates, the Instantaneous Growth Rate (IGR) of the mussels till they attained 70-80 mm, which is considered as harvestable size, was used.

Growth rates and gonad maturity**:** For studying the growth rates, monthly samples of 50 numbers of mussels were taken from a mussel rope randomly and three such samples from different ropes from each farm were analyzed. The mussels were cleaned to remove silt and fouling and the length (L), width (W), depth (D) in millimeters and total weight (Twt) and meat weight (Mwt) in grams were noted using digital vernier calipers and balances respectively. The mean values were computed and used for analyses. The IGR was computed following Hopkins (1992),

$$IGR = \frac{Ln_t - Ln_i}{t}$$

where, Ln_t is the natural log of the length at time t and Ln_i is the natural log of the initial length. IGRs of length (IGR L), width (IGR W), depth (IGR D), total weight (IGR Twt) and meat weight (IGR Mwt) were compared using ANOVA available in SPSS software (Ver. 8). In case of significant differences, Duncan's Multiple Range Test (DMRT) was carried out to find out the significantly different means at 5% level.

Stages of maturity were recorded for each mussel based on gonad smear examined under a microscope and classified as spent/resting, developing, ripe and spawning as described by Narasimham (1980). The percentage occurrence of each stage was used for statistical analysis. Condition Index (CI) was calculated based on internal shell cavity volume and dry weight of soft tissue (Walne, 1970).

$$CI = \frac{Dry\ Soft\ Tissue\ Weight\,(g) \times 1000}{Internal\ Shell\ Cavity\ Volume\,(ml)}$$

Hydrological parameters**:** Salinity, temperature and pH of seawater collected from farm sites were noted at the site itself using respective probes. Ammonia, phosphate, total suspended solids (TSS), nitrate, nitrite and productivity of the water samples were determined using methods suggested by Strickland and Parsons (1972). To determine the correlation between the environmental and biological parameters, Pearson's correlation was used.

Results and Discussion

The IGR in length (0.0124 mm day^{-1}), width (0.010 mm day^{-1}) and depth (0.012 mm day^{-1}) of the mussels were the highest in mussels grown in the sea and these were significantly different ($p < 0.05$) from that estimated for mussels grown in the bay and estuary. Though the IGRs of these parameters were higher in the bay when compared to the estuary, the variations were not significant ($p > 0.05$). The IGRs of total weight were higher and similar for the mussels grown in the sea (0.028 mg day^{-1}) and bay (0.022 mg day^{-1}) but were lower and significantly different ($p < 0.05$) from that grown in the estuary (0.013 mg day^{-1}) (Table 1). These growth rates were higher than

Table 1. Average IGR of length (L), width (W), depth (D), total weight (Mwt) and meat weight of *P. viridis* grown in the bay, sea and estuary when the mussels were grown from 25-32mm to harvestable length of 70-80 mm. Results of Dunchans Multiple Regression Test are shown as superscripts. Non- identical superscripts column-wise indicate significant differences ($p < 0.05$).

Location	IGR L	IGR W	IGR D	IGR Twt	IGR Mwt
Kollam Bay	0.0081^{b}	0.0076^{b}	0.0076^{b}	0.0225^{a}	0.0264^{a}
Narakkal Sea	0.0124^{a}	0.0102^{a}	0.0120^{a}	0.0284^{a}	0.0419^{b}
Ashtamudi Lake	0.006^{b}	0.005^{b}	0.005^{b}	0.013^{b}	0.013^{c}

Table 2. Monthly IGR of length, width, depth, total weight and meat weight of *Perna viridis* grown in Kollam Bay, Narakkal Sea and Ashtamudi Lake (range of length [mm]/ weight [g] given in parenthesis).

Month	IGR L	IGR W	IGR D	IGR Twt	IGR Mwt
			Kollam Bay		
Feb 2004	0.008 (30.0-40.9)	0.011 (14.6-22.4)	0.007 (9.3-12.2)	0.029 (1.9–5.6)	0.042 (0.5-2.2)
Mar	0.009 (40.9-56.7)	0.006 (22.4-27.2)	0.010 (12.2-16.9)	0.024 (5.6–12.4)	0.023 (2.2-4.8)
April	0.006 (56.7-79.6)	0.005 (27.2-36.4)	0.006 (16.9-23.0)	0.014 (12.4-27.3)	0.014 (4.8-10.2)
June	0.002 (79.6-88.2)	0.003 (36.4-39.05)	0.004 (23.0-27.6)	0.008 (27.3-38.7)	0.010 (10.2-16.0)
August	0.0005 (88.2-90.3)	0.001 (39.05-40.9)	0.000 (27.6-27.6)	0.004 (38.7-45.8)	0.002 (16.0-17.8)
September	0.002 (90.3-99.1)	0.003 (40.9-43.8)	0.004 (27.6-31.3)	0.010 (45.8-65.5)	0.012 (17.8-27.4)
October	0.001 (99.1-109.7)	0.001 (43.8–45.2)	0.001 (31.3-32.51)	0.003 (65.5-78.9)	0.003 (27.4-33.1)
			Narakkal Sea		
November 2003	0.010 (25.9-38.1)	0.014 (14.6-24.5)	0.010 (9.3-13.2)	0.015 (3.0-5.2)	0.031 (0.3-0.9)
December	0.012 (38.1-53.9)	0.006 (24.5-29.2)	0.015 (13.2-20.0)	0.042 (5.2-16.2)	0.049 (0.9-3.4)
January 2004	0.014 (53.9-70.8)	0.010 (29.2-35.4)	0.011 (20.0-24.8)	0.028 (16.2-28.3)	0.046 (3.4-8.5)
			Ashtamudi Lake		
February2004	0.008 (0-51.2)	0.009 (14.6-27.3)	0.008 (9.3-16.6)	0.027 (1.9-9.9)	0.029 (0.5-3.7)
March	0.006 (51.2-60.7)	0.004 (27.3-31.5)	0.004 (16.6-19.0)	0.016 (9.9-16.2)	0.010 (3.7-5.3)
April	0.002 (60.7-63.6)	0.001 (31.5-32.6)	0.004 (19.0-21.4)	0.003 (16.2-18.9)	0.012 (5.3-7.3)
May	0.009 (63.6-77.9)	0.006 (32.6-37.1)	0.005 (21.4-23.8)	0.016 (18.9-26.3)	0.002 (7.3-7.6)
June	0.004 (77.9-91.4)	0.004 (37.1-43.9)	0.005 (23.8-29.2)	0.003 (26.3-30)	Negative (7.6-6.8)

Table 3. Range in environmental parameters recorded at the mussel farm sites during the study period

Sl. No.	Hydrographic parameter	Kollam Bay	Ashtamudi Lake	Narakkal Sea
1	Salinity (ppt)	32 - 35	9 - 31	32.1 - 33.4
2	Temperature (^{O}C)	27 - 30	26 - 30	28.1 - 29
3	Dissolved oxygen (mg L^{-1})	4.5 - 7.4	3.8 - 6.91	4.5 - 4.8
4	Ammonia (µmol l^{-1})	0.98 - 31.5	0.59 - 49.84	2.05 - 3.25
5	Phosphate (µmol l^{-1})	0.45 - 2.85	0.39 - 1.92	0.29 - 0.96
6	Total Suspended Solids (mg l^{-1})	15.4 - 33.4	21.4 - 57.8	18.3 - 27.1
7	Nitrate (µmol l^{-1})	0.11 - 18.55	0.2 - 0.49	0.04 - 0.47
8	Nitrite (µmol l^{-1})	0.2 - 21.7	0 - 4.59	0.22 - 0.24
9	Productivity mg $C^{-1}L^{-1}$	0.42 - 4.36	0.8 - 4.26	2.35 - 3.25

that observed along the east coast (83 to 85 mm in one year) (Rajagopal *et al.*, 1998). The farming in the bay was continued for six months till the mussels reached a maximum length of 109.7 mm. During this period the IGRs were lower than that observed in the initial stages (Table 2). In Edaiyur estuary also, similar reduction in growth rates were observed in older mussels (Rajagopal *et al*., 1998). It is known that older mussels have poor growth rate due to reduced metabolic activity (Cheung, 1993) and increased gamete production (Hilbish, 1986). The IGR in length, total weight and meat weight in the bay were found to be positively correlated with temperature and negatively with TSS in the bay while in the sea farm, these IGRs had positive correlation with phosphate and nitrate (Tables 3 and 4). Temperatures above 20°C (Incze *et al.*, 1980) and variations in salinity (Bøhle, 1972) have been found to decrease the growth in the blue mussel *Mytilus edulis*. Similar results were found in another mussel species, *Choromytilus chorus* (Navarro, 1988).

Table 4. Significant correlations between the biological and environmental parameters in the experimental mussel farms (correlation coefficients are given in parenthesis)

Location	Parameter	Correlation	
Kollam Bay	SRG L	Temp (0.76),	TSS (-0.57)
	IGR Twt	Temp (0.78),	TSS (-0.69)
	IGR Mwt	Temp (0.68),	TSS (-0.72)
	Maturity	Sal (-0.83)	
Ashtamudi Lake	IGR Mwt	Sal (0.68)	
Narakkal Sea	SRG L	PO_4 (0.958),	NO_3 (0.958)
	IGR Twt	PO_4 (0.846),	NO_3 (0.846)
	IGR Mwt	PO_4(0.984),	NO_3 (0.984)
	Mature	PO_4 (0.98),	NO_3 (0.97)
	Spent	PO_4(0.97),	NO_3 (0.94)

The gonad of male and female mussels developed and became ripe (mature) in all the three ecosystems. Spent mussels were recorded in the bay and sea farms indicating spawning. Similar to the IGR the maturity of mussels in the sea farm was positively related to phosphate and nitrate while in the bay, maturity was negatively correlated to salinity. It has been observed that high salinities (24 and 30‰) increased the filtration rate in *P. viridis* (Rajesh *et al*., 1998) and dry tissue weight in the mussel *C. chorus* (Navarro, 1988). The condition index (CI) of the mussels were high (>500) in the bay and sea. In the bay the CI was positively correlated with maturity. Temperature has a positive effect on gametogenesis of mussels and for inducing spawning in temperate waters (Seed, 1976; Myint and Tyler, 1982) and in the green mussel farm of Edaiyur backwaters (Rajagopal *et al*., 1998). Most bivalves along the west coast spawn during the postmonsoon period from October to December (Mane and Nagabhushanum, 1988; Kripa, 1998). In the present study, in the estuary there was no correlation between maturity stages and environmental parameters. Spawning had occurred as indicated by the partially spent mussels but completely spent mussels were not observed.

In the bay and sea farms mussel seed (5 to 25 mm) settlement was seen on the anchor ropes, floats and anchors. In the sea farm seed settlement was obtained in February within three months of seeding. In the bay farm seed settlement was obtained in March, August and September. Along the east coast higher spat settlement was obtained in the coastal waters and low seed settlement was observed in the backwaters of Edaiyur estuary (Rajagopal *et al*., 1998). This estuary had a near-stable salinity due to opening of a sandbar which raised the salinity even during the monsoon period. Similarly in Mulky Estuary along the west coast of India, mussel seed settlement was observed during February (Mohamed *et al*., 1998) when marine conditions prevailed. In the present study the salinity profile of the bay was stable which supported gametogenesis and variations in temperature and salinity would have triggered spawning. Seed settlement also occurred here since the salinity was high (>25‰). However in Ashtamudi Lake although spawning occurred successful spatfall did not take place.

The study indicated that all the three ecosystems are favorable for the farming of mussels. The advantage of farms in the sea and bay is that it is possible to obtain mussels larger than 80 mm during an extended farming period. The ecological conditions indicate that it is possible to have two crops from bay (August/September to December/January; February/March to May/June) and sea (September/October to December/January; January/February to March/April) while in the estuary only one crop (November/December to May/June) is possible due to the low saline conditions from June to October.

The gonad development, spawning and seed settlement in the sea and bay farms also imply the potential for collecting mussel seed during February/March from the sea farm and August/September from the bay farm by placing suitable seed collectors. Based on the high IGRs in the open sea ecosystem it is recommended that open sea mussel farming should be encouraged by the governments and development agencies. Since mussel seed was obtained from the experimental rafts, it is suggested that more research and development programmes should be focused on feasibility of large scale collection of mussel seed using seed collectors which can partly resolve the scarcity of seed and also can open up avenues for the development of ancillary activity related to mussel farming. The risk of open sea farms was also evident during the experimental period when part of the mussel crop was lost due to theft. This can be overcome if several raft farms are moored and a common security is arranged on the rafts. However, legal policies supporting open sea farming need to be put in place more farmers to utilize the productive open sea ecosystems.

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