

ENVIRONMENTAL PHYSIOLOGY OF RAFT-GROWN MUSSELS IN GOA, INDIA

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(Accepted 1 September 1981)

ABSTRACT

Parulekar, A.H., Dalal, S.G., Ansari, Z.A. and Harkantra, S.N., 1982. Environmental physiology of raft-grown mussels in Goa, India. *Aquaculture*, 29: 83–93.

Mussels (*Perna viridis* L.) transplanted from a marine intertidal region and grown under water in the estuarine environment (on a floating raft) display a wide array of physiological adaptations in growth, osmoregulation and annual reproduction cycle.

The interaction of environmental parameters influencing growth, as assessed by sequential multi-regression technique, indicated salinity as a dominant factor. Abundance of food material was necessary for growth progression.

Development of a physiological mechanism for adjusting water balance in the body to counteract the wide temporal variations in salinity is reported. Synchronization of the annual reproduction cycle with exogenous and endogenous variables and under different environmental and metabolic stresses is discussed. Behavioural, physiological and biochemical adaptations of raft-grown mussels are highlighted.

INTRODUCTION

Ecological, physiological and economic aspects of intertidal and subtidal mussels have been studied in the marine and estuarine environments of both hemispheres (Bayne, 1976; Korringa, 1977). Earlier work on raft-grown mussels (Qasim et al., 1977; Parulekar et al., 1978) has clearly indicated the existence of wide temporal variations in the environmental factors. Of particular significance are the wide fluctuations in salinity, high productivity, fast growth and prolonged spawning. However, no information is available about the environmental physiology of raft-grown mussels and, therefore, it was felt desirable to investigate the changes due to the interaction between exogenous and endogenous factors which the green mussel (*Perna viridis* L.) from a marine intertidal habitat has to undergo when transplanted and grown under constant submergence in an estuarine environment.

MATERIAL AND METHODS

Fortnightly sampling over a period of one year (1978–79) was carried out in order to record biological, biochemical and environmental variations. The methods of collection, analysis and processing are the same as reported earlier (Qasim et al., 1977). In all, 803 raft-grown animals were studied for growth, maturity stages and biochemical composition. Monthly sample size varied from 40 (November) to 97 (May). Data on environmental and biochemical variations are represented by mean values derived from triplicate analysis.

All the statistical analysis was done on a TDC-316 computer. For quantifying growth in relation to the interaction of two or more factors, the most frequently used method (Dalal, 1976) of sequential multi-regression analysis was followed. Data on monthly length measurements were examined as a function of temperature (T), salinity (S), dissolved oxygen (O) and suspended particulate matter (SL). In other words:

$$L = f(T, S, O, SL)$$

The sequential multi-regression of the relation between the dependent variables was first examined in respect of each independent variable, separately by the regression line:

$$L = b_1T + b_2S + b_3O + b_4SL + C$$

where L is the predicted value of the dependent variable, b_1 , b_2 , b_3 and b_4 are coefficients of independent variables and C is the intercept. The values of b_1 , b_2 , b_3 and b_4 depend on the units in which the original variables were measured and, accordingly, for the sake of uniformity, all the values were standardized by expressing each one as the deviation from the mean, measured in units of one standard deviation. The regression line then appears as:

$$L = b'_1T + b'_2S + b'_3O + b'_4SL$$

where b'_1 , b'_2 , b'_3 and b'_4 are standard partial regression coefficients which give a measure of the contributions of each independent variable to the predicted value of the dependent variable. For testing the effectiveness of the multiple regression analysis, R^2 which is an estimate of the proportion of total variance on the dependent variable was calculated. The significance of R^2 was confirmed by F test.

RESULTS

Growth

Data on the influence of environmental abiotic factors on growth are shown in Fig. 1. The inter-relationship between morphometric variables (Table I) as

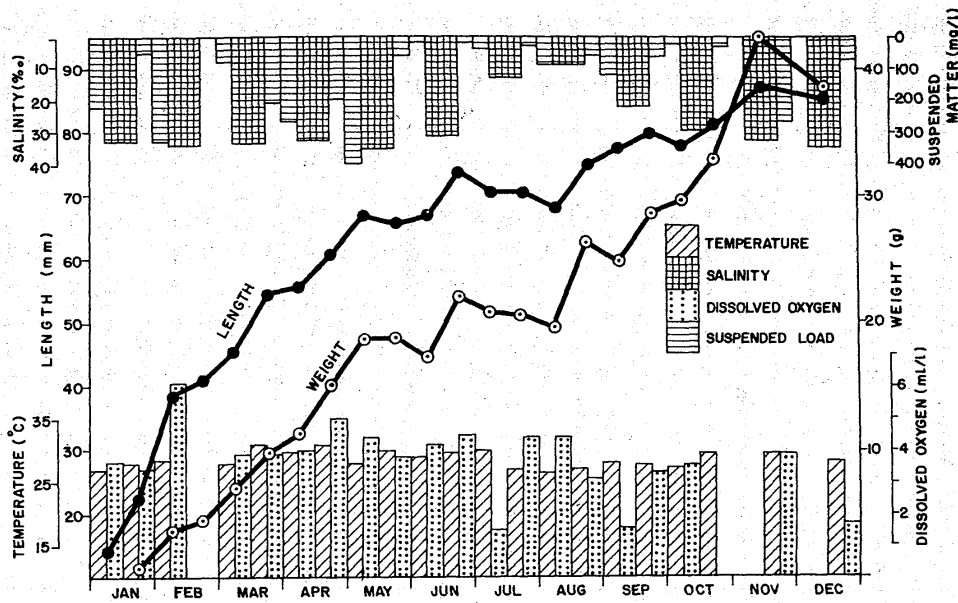


Fig. 1. Environmental factors and growth in raft-grown green mussel (*P. viridis* L.).

assessed from the values of correlation coefficient indicate that length varies linearly with width, depth and total weight. When all three variables are taken together, the multiple correlation coefficient does not show any further improvement ($R^2 = 0.80$).

The relation between length and environmental factors is shown in Table II and the regression equations along with the multiple correlation coefficients and F values based on variance ratio are presented in Table III. Salinity becomes the dominant abiotic parameter in view of its higher frequency of occurrence in combinations of two and three variables at a time.

TABLE I

Simple correlation coefficient (r) between morphometric characters in raft-grown *Perna viridis* L. in Goa, India

	L	W	D	TW
L	1.00	0.91	0.86	0.93
W		1.00	0.60	0.83
D			1.00	0.80
TW				1.00

L = Length; W = Width or breadth; D = Depth or height; TW = Total Weight.

TABLE II

Simple correlation coefficient (r) between length and abiotic factors in raft-grown *Perna viridis* L. in Goa, India

	L	T	S	DO	SL
L	1.00	-0.60	-0.25	-0.43	-0.22
T		1.00	0.59	0.08	0.21
S			1.00	0.24	0.34
DO				1.00	0.42
SL					1.00

L = Length; T = Temperature; S = Salinity; DO = Dissolved Oxygen; SL = Suspended Load.

TABLE III

Multiple regression equations for predicting length from abiotic factors and multiple correlation coefficient along with F values based on variance ratio in raft-grown *Perna viridis* L. in Goa, India

Regression equation	Multiple correlation coefficient R^2	F values based on variance ratio
$L = -0.051 T + 0.112 S + 0.130 DO + 0.310 SL$	0.21	1.08
$L = -0.385 T - 0.009 S + 0.111 DO$	0.18	1.29
$L = -0.035 S + 0.238 DO + 0.300 SL$	0.22	1.57
$L = -0.072 T + 0.185 DO + 0.328 SL$	0.20	1.39
$L = -0.217 T + 0.570 S$	0.39	5.70*
$L = -0.376 S + 0.141 DO$	0.19	2.12
$L = -0.079 DO + 0.339 SL$	0.16	1.75
$L = -0.206 T + 0.203 DO$	0.09	0.88
$L = -0.148 S + 0.281 SL$	0.12	1.30

where L = Length; T = Temperature; S = Salinity; DO = Dissolved Oxygen; SL = Suspended Load.

*Significant at 5% level of significance.

The relatively low magnitude of the variance ratio indicates any or all of the following:

- The variations in abiotic factors are rather large.
- There is hardly any true relationship between length/weight and abiotic factors.
- Observations are inadequate to find the true relationship.
- An additional important variable is lacking in the analysis.

Among the abiotic factors, only temperature and salinity show a significant relationship. In view of this, when several abiotic factors are taken at a

time, the inter-relationship may bring about a reduction in the value of R^2 and confuse the interpretation of the ratio. The large amount of variation is probably due to wide fluctuations in abiotic factors.

Availability of food and growth

Fig. 2 shows the variations in the distribution of phytoplankton and particulate organic carbon in relation to cumulative growth progression in length and weight. Nannoplankton dominates the mussel farm area (Pant et al., 1977). The curves (Fig. 2) indicate that the growth progression of both the linear (length) and exponential (weight) parameters is to a great extent dependent on the availability of food and the seasonal variations are mainly due to the abundance of the phytoplankton. Because the present data are mainly field-oriented, the effect of quality of food on the growth of mussels could not be assessed.

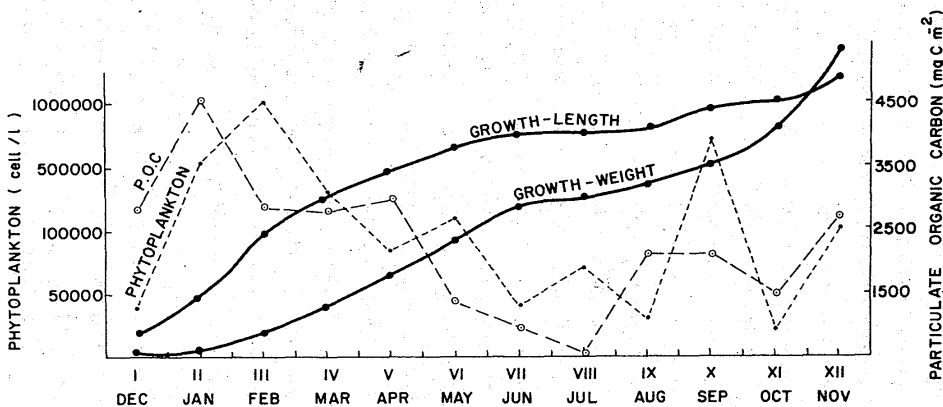


Fig. 2. Variations in abundance of food and its effects on the cumulative growth of raft-grown green mussel (*P. viridis* L.).

Allometric growth

By using the simple allometric equation $y = ax^b$ (where y is some measure of a part; x is a measure of the whole body or another part and a and b are constants to be estimated by least square regression technique), the dependence of morphometric parameters in respect of growth progression on environmental variations is assessed. The relative increase in length, width, depth, total weight, shell weight, wet meat weight and dry meat weight indicates (Fig. 3) that in terms of temporal variations in abiotic and biotic factors, growth continues unabated in one or other morphometric dimension. Accordingly, exponential growth was observed (Table IV) in total weight, wet weight and dry meat weight in relation to length with either cubic or square relationship.

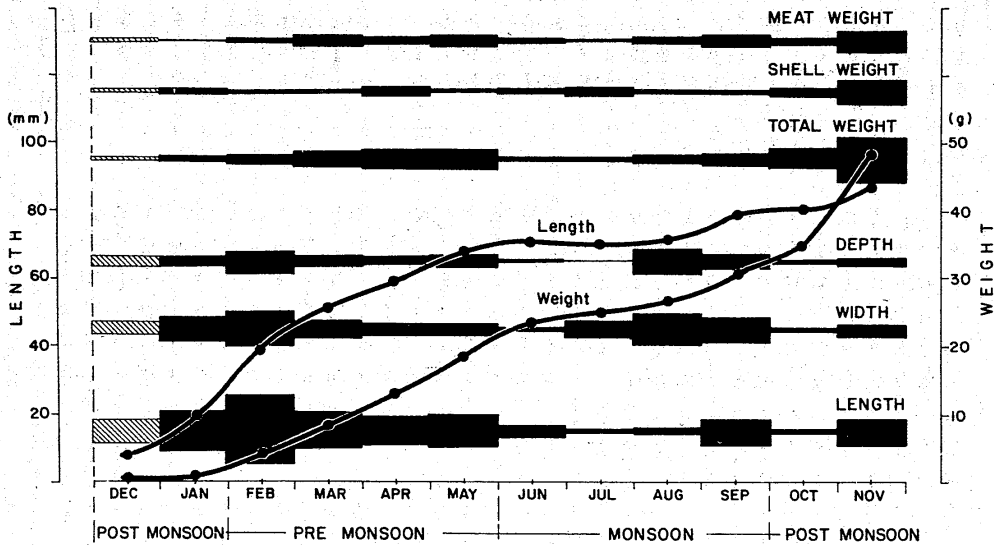


Fig. 3. Allometric growth in raft-grown green mussel (*P. viridis* L.).

TABLE IV

Regression equations describing the allometric growth in raft-grown *Perna viridis* L. in Goa, India

Relationship (y/x)	Regression equation	r^2	S.E.
Total Weight/Length	$y = 0.000513 x 2.5001$	0.9861	0.271
Total Weight/Width	$y = 0.000822 x 2.8756$	0.9826	0.289
Total Weight/Depth	$y = 0.00563 x 2.6710$	0.9964	0.247
Wet Meat Weight/Length	$y = 0.000001 x 3.6422$	0.9653	0.321
Dry Meat Weight/Length	$y = 0.000109 x 2.2609$	0.9010	0.298
Shell Weight/Length	$y = 0.000320 x 2.6810$	0.9312	0.279
Wet Meat Weight/Depth	$y = 0.00419 x 2.5081$	0.9946	0.186
Dry Meat Weight/Depth	$y = 0.000924 x 2.4324$	0.9852	0.214
Wet Meat Weight/Dry Meat Weight	$y = 0.3017 x 0.6524$	0.6561	0.462
Dry Meat Weight/Total Weight	$y = 0.1036 x 0.9135$	0.9115	0.318
Dry Meat Weight/Shell Weight	$y = 0.2129 x 0.8325$	0.8616	0.338
Shell Weight/Total Weight	$y = 0.4478 x 1.0696$	0.8704	0.215
Wet Meat Weight/Shell Weight	$y = 1.1268 x 0.8666$	0.9612	0.238
Depth/Length	$y = 0.4184 x 0.9298$	0.9890	0.296

Compensatory mechanism

As shown in Fig. 4, the transplanted mussels growing on a raft in an estuary develop an isosmotic internal medium to compensate for considerable lowering of salinity during the monsoon season (June–September). The compensa-

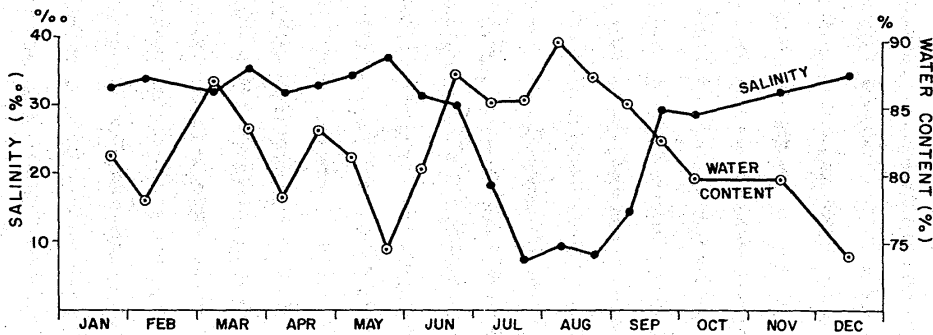


Fig. 4. Salinity and water content in the body tissues — temporal variations in raft-grown green mussel (*P. viridis* L.).

tion is achieved by the dilution of the body fluids, resulting in higher water content in the tissues. In the post-monsoon (October—January) and pre-monsoon (February—May) seasons, an appropriate compensatory mechanism is developed (Fig. 4) to counteract increasing salt content in the environment.

Annual reproduction cycle

A complex of physical variables is thought to influence the sequence and timing of reproduction in mussels (Giese, 1967). As shown in Fig. 5, in the transplanted mussels of mean size 7.8 mm, gametogenesis commences in the first month (December). In the second month (January) more than 70% of the mussels (Fig. 5) were in the maturing stage. Mature gonads were first observed in small proportion (10%) at an average size of 15.5 mm, in the third month (February). The occurrence of mature/ripe gonads increased from 38% to 85% in the succeeding months (March—May). Spawning, as evidenced from the occurrence of ripe as well as spent gonads, commences in February and becomes intensive in March—April before attaining a peak in May. The resting phase coincides with the onset of monsoon rains in June. It is followed by the recurrence of immature gonads in July; maturing in August; spawning commencing in September and intensifying in October and November. Thus, the species exhibits a prolonged breeding behaviour with spawning peaks in the favourable seasons before and after the heavy monsoon rains.

Maturation and spawning were closely associated (Fig. 5) with temporal variations in temperature and salinity. While proliferation of the germinal epithelium, maturation of gametes and spawning maxima coincide with favourable conditions of temperature, salinity and abundance of food material (Fig. 2), the resting phase coincides with the lowering of temperature, salinity (Fig. 5) and scarcity of food.

Similarly, the seasonal changes in some of the biochemical constituents are associated with different phases of the annual cycle of reproduction. Accordingly, the protein and lipid contents (Fig. 5) show a decline coinciding

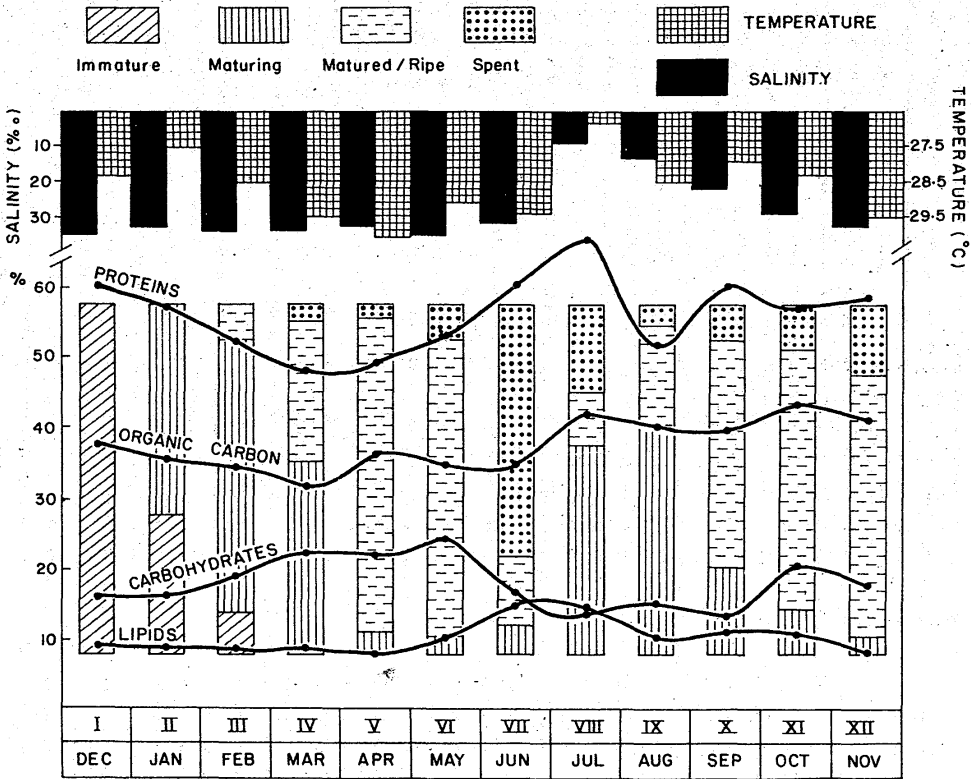


Fig. 5. Effect of environmental factors and biochemical composition on the reproduction cycle of raft-grown green mussel (*P. viridis* L.).

with the maturation, spawning and phase of recovery during the resting stage of the gonads. A second maximum of protein content in September (Fig. 5) can be attributed to the abundance of food material (Fig. 2). Carbohydrate content exhibits an inverse relationship with the lipid content and thus serves as an index of high glycogen metabolism during the period of high environmental stress in the monsoon season (Fig. 5).

DISCUSSION

The foregoing account of some aspects of the environmental physiology of raft-grown mussels can be considered as a case history for assessing the physiological adaptations which an organism from the marine intertidal regime acquires when transferred and made to thrive in an estuarine subtidal biotope. Not only does *Perna viridis* L. thrive under the changed environmental conditions, but establishes, and in the most successful way.

Growth as a response to the integrated activity of an organism as a whole

is a sensitive parameter, reflecting on the suitability of the environment (Warren, 1971). It depends on the metabolic state of the animal, the energy expended in maintenance and behaviour, and the quality and quantity of food consumed; all these are the functions of the environment. Growth in mussels as defined by Seed (1976) is not simply an increase in linear dimensions or mass (weight or volume) but also includes tissue formation and related activities that precede and follow the actual changes in linear dimensions or in body size. Hence the progressive changes, as observed in the present investigation, either in length, weight and/or volume, may be used as an appropriate parameter for interpreting the growth of raft-grown mussels.

Biotic factors, especially the availability and the abundance of food, as reported earlier by Seed (1976), are observed to be of immense importance for enhancing growth progression in raft-grown mussels. Lubinsky (1958), while discussing the possible adaptive advantages that mussels may encounter, particularly in connection with adverse environmental conditions in relation to allometric growth, had indicated that irrespective of variations in abiotic and biotic factors either jointly or independently, growth as an indication of metabolic rate progresses unabated in raft-grown mussels.

As reported earlier by Newell (1976), of all the environmental variables, salinity, because of its wide seasonal variations and its relevance to osmoregulation in aquatic organisms, plays a dominant role in the estuarine environment. Animals often become excited (Gross, 1957) when the salinity of the medium is changed and consequently expend increased energy on physical activity as well as on basal metabolic processes. The long-term response to a given ionic condition is an enzymatic induction producing conditions for energy supply (Lange, 1968), whereas for short-term changes, the animal, in the present case the green mussel, reacts by developing a compensatory response (Lockwood, 1976).

The results on the maturation and spawning of raft-grown mussels highlight the influence of a complex of abiotic and biotic factors on the sequence and timing of reproduction. Besides the regulatory influence of exogenous factors such as temperature and salinity, the annual cycle of reproduction is also dependent on seasonal changes in the biochemical composition of the tissues (Dare, 1973).

As seen from Table V, the transplanted mussels, grown in an estuarine environment with rope culture on floating rafts in Goa, India, exhibit the high annual growth of 92.7 mm. This is the highest growth so far recorded for any cultured mussels, in tropical, semi-tropical or temperate waters (Table V). In our experiments, we have observed that some of the transplanted mussels even attain a maximum size of 105 mm in one year as against 75 mm in the natural beds of Goa. Propagation is attuned to changes in environmental factors and a better metabolic condition is maintained than in the natural marine bed (Qasim et al., 1977). Thus, the raft-grown mussels adapt behaviourally, physiologically and biochemically to wide-ranging external conditions and also respond appropriately to the rapid and irregular variations in these conditions.

TABLE V

Comparison of annual mean growth of mussels in suspended culture

Area	Species	Annual mean growth (mm)	Source
Venezuela	<i>Perna perna</i>	85.0	Carvajal (1969)
U.S.A.	<i>Mytilus edulis</i>	43.2	Lutz et al. (1977)
Canada	<i>Mytilus edulis</i>	38.0	Platt and Irwin (1971)
Spain	<i>Mytilus edulis</i>	67.5	Davies (1969)
Wales (U.K.)	<i>Mytilus edulis</i>	47.5	Dare and Davis (1975)
New Zealand	<i>Perna canaliculus</i>	73.0	Hickman (1979)
Malaysia	<i>Mytilus viridis</i>	55.0*	Sivalingam (1977)
Goa (India)	<i>Mytilus viridis</i>	92.7	Qasim et al. (1977)

*Size at the time of transplant was 23 mm.

As discussed by Lockwood (1976), the breadth and flexibility of response is not based on the development of any fundamental new process but rather on the evolutionary adaptation and modification of different processes already present in marine species. However, it must be recorded here that the present set of data has further to be substantiated by experimental work especially on oxygen uptake, grazing rate, quality of food, energy conversion efficiencies, etc. in order to get an insight into the physiological ecology of raft-grown mussels.

ACKNOWLEDGEMENTS

We record our sincere thanks to Dr. S.Z. Qasim, Director, and Dr. T.S.S. Rao, Head, Biological Oceanography Division, National Institute of Oceanography, India, for valuable comments on the paper. Suggestions by Dr. Anand Prakash, Myticulture International Inc., Ottawa, Canada, are gratefully acknowledged.

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