CHAPTER 3
PHYSIOLOGICAL ADAPTATIONS

Physiological responses of animals towards environmental changes has evoked extensive research at organismal, tissue or cellular levels. In providing an assessment of the condition of an individual the physiological responses have three important attributes. 1. they represent an integration of many cellular and biochemical processes that can alter in response to changes in the environment. 2. they represent non-specific (general) response to the sum of environmental stimuli which are complementary to more specific responses at the biochemical level, and 3. they are capable of reflecting deterioration in the environment before effects manifest themselves in the population or the community level (Widdows, 1985a). An attempt has been made in this chapter to understand the physiological flexibility of *S. scripta* in relation to salinity by studying the physiological parameters such as clearance rate, absorption efficiency, oxygen consumption, ammonia excretion, O:N ratio and ionic (Na⁺, K⁺ and Cl⁻) regulation.

3.1 CLEARANCE RATE

3.1.1 Introduction

The bivalves are predominantly 'suspension' or 'filter' feeders. They obtain their food by filtering of suspended particles from the water passing through the gills. The
filtration rate or clearance rate is the volume of the water cleared of particles in unit time (Bayne et al., 1985).

There are various studies regarding the clearance rate of bivalves (Thompson and Bayne, 1972; Brand and Taylor, 1974; Bayne et al., 1977; Shumway and Youngson, 1979) and the feeding mechanisms of various suspension feeding organisms were summarised by Pandian (1975a). Different types of live algal suspensions were used by Winter (1973), Dunaliella euchlora; Thompson and Bayne (1974), Tetraselmis suecica; Vahl (1972), mixture of Isochrysis galbana and Monochrysis lutheri and Sanina (1976), Chlamydomonas sp. and Scenedesmus quadricauda.

Like other physiological functions filtration rate is affected by a number of environmental factors such as salinity (Loosanoff, 1950; Nagabhushanam, 1956; Bohle, 1972; Mane, 1975; Alagarswami and Victor, 1976; and Widdows, 1985b), temperature (Dame, 1972; Widdows, 1973b; Wilson and Seed, 1974; Schulte, 1975; and Bayne et al., 1976c), food concentration (Winter, 1969; 1970; 1973; 1978; Tenore and Dunstan, 1973; Wilson and Seed, 1974; Schulte, 1975; Sanina, 1976; Epifanio and Ewart, 1977; Navarro and Winter, 1982; Wright et al., 1982) and tides (Widdows and Bayne, 1971; Langton and Gabbott, 1974; Mathers, 1976; Morton, 1977). In addition to the environmental factors clearance rate is also affected by the size of the organism (Waine, 1972; Winter 1973; Thompson and Bayne 1974; Bayne et al., 1975).
Since *S. scripta* shows the behavioural modifications in various salinities, the clearance rate is likely to vary with salinity. So the aim is to delineate the effect of salinity and size on the clearance rate of *S. scripta*.

3.1.2 Materials and methods

3.1.2.1 Acclimation of test animals

*Sunetta scripta* were collected from the area as described in chapter 2 during the pre-monsoon period when salinity was around 30 ppt. Clams were immediately brought to the laboratory in polythene bags containing sea water collected from the same site, cleaned and grouped into three size groups, small (1.5 ± 0.5 cm), medium (2.5 ± 0.5 cm) and large (3.5 ± 0.5 cm). The animals were acclimated in 30 ppt as given in chapter 2. After the acclimation of three days, the salinity of the medium was altered slowly by the addition of filtered water of higher salinity (prepared by the evaporation of sea water) and deionised water so that salinity reached 35 ppt and 25 ppt respectively within three days. Again after three days the process was repeated so that the experimental salinities of 40, 45, 20, 15, 10 and 5 ppt were obtained. Throughout the acclimation period *S. scripta* were fed on *Synechocystis salina* and feeding was stopped 24 hrs before the commencement of experiments. The salinity of the water samples was determined by modified Mohr Knudson method (Strickland and Parsons, 1972).
3.1.2.2 Experimental setup

The filtration rates were determined using an indirect method by monitoring the reduction in particle concentration during definite time interval (Bayne, et al., 1985). The experiments were done in wide mouthed conical flask of 2 litre capacity and completely covered with black paper so as to cut off light for reducing cell division and prevents the aggregation of algal cells, since the blue green algae *S. salina* used for the study is found to be photosensitive. The animals which were acclimated at different salinities were carefully introduced into the conical flask (two numbers of same size group) containing 2 litres of filtered (42 Whatman filter paper) sea water of corresponding salinities and allowed to recover from the handling shock. After observing the animals are actively filtering, added a known quantity of algal culture solution (3 days old culture) so that the algal concentration will be 0.8 mg dry weight/l. This concentration was fixed by conducting piolet experiments and was found to be the optimum concentration for feeding. The solution was allowed to mix thoroughly by gently bubbling air into the vessel without causing apparent disturbance to the animal. After thorough mixing the initial sample of 10 ml was pipetted out and after two hours the next sample was taken. Abel (1976) stated that the equation used for computation of the rate of clearance assumes that the clearance rate is constant over the time (t)
and hence it is advisable to reduce the time interval as far as possible for lessening the experimental error. Hence this experiments were restricted for a period of two hours. The samples were analysed for fluorescence units using Fluorescence Spectrophotometer at emission 286 nm and excitation at 574 nm and converted this units into dry weights (Widdows, personal communication). A concentration of 0.8 mg dry weight/l gives 170 fluorescence units. The experiments were repeated at different salinities ranging from 5 ppt to 45 ppt with an interval of 5 ppt in three size groups. Filtration (clearance) rate was calculated in litres/hour (l/h) using Quayle's equation (1948).

\[ m = \frac{M}{n \cdot t} \log_e \left( \frac{C_0}{C_t} \right) \]

where

- \( m \) = Filtration rate (l/h)
- \( M \) = Volume of the test solution (sea water) (l)
- \( n \) = Number of animals per test vessel
- \( t \) = Time interval between sampling (h)
- \( C_0 \) = Initial concentration of algal suspension
- \( C_t \) = Final concentration of algal suspension
3.1.2.3 Data analysis

The rate of most physiological processes are dependent on individual body size (reviewed by Bayne et al 1976c; d). So the relationship between body weight and physiological measurements were described by the simple allometric equation after the $\log_{10}$ transformation of the values.

$$Y = a W^b$$

where

- $Y$ = physiological rate
- $W$ = dry tissue weight
- $a$ and $b$ are the intercept and slope of the $Y$ vs $W$ regression respectively. The data were analysed statistically (Snedecor and Cochran, 1968).

Physiological rate of clams for a standard dry body weight (1 gm) were calculated for comparison using the relationship given by Bayne and Newell (1983).

$$Y_s = \left(\frac{W_s}{W_e}\right)^b \times Y_e$$

where

- $Y_s$ = standard value for physiological variable
- $W_s$ = standard weight (1 gm)
- $W_e$ = dry weight of the experimental animal
- $Y_e$ = measured value for physiological variable
- $b$ = the corresponding weight exponent
3.1.3 Results

The rate of clearance of algal cells (1/h) for standard sized (1 gm dry weight) animals of different size groups at different salinities are given in the Table 2 and Fig. 7. The values varied from 0.7692 to 2.4127 l/gm/h for smaller size group, 0.7294 to 2.3421 l/gm/h for medium and 0.5701 to 2.3303 l/gm/h for larger size group (Table 2). The weight specific clearance rate showed an inverse relationship with increasing body size and decrease and increase of salinity from 30 ppt. The regressions of log clearance rate vs log dry body weight at different salinities are calculated (Fig. 8 a-g) and r, a and b values are given in the Table 3. The relationship between logarithm of clearance rate (C. R.) and logarithm of dry body weight (W) can be represented in the form of linear equation

\[
\log \text{C. R.} = \log a + b \log W
\]

The regression coefficients were analysed using analysis of covariance (Table 4) and the results showed significant (p<0.01) variation in clearance rate in different salinities.

3.1.4 Discussion

The filtration (clearance) rate is a parameter of great ecological significance, since it is the component of energy
Table 2. Clearance rate (l/h) of different size groups in different salinities
(R ± SD) calculated for a standard sized (1 gm dry weight) animal

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>10</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>15</td>
<td>0.7692 ± 0.2886</td>
<td>0.7294 ± 0.2204</td>
<td>0.5701 ± 0.2022</td>
</tr>
<tr>
<td>20</td>
<td>1.7742 ± 0.3282</td>
<td>1.2210 ± 0.2410</td>
<td>1.1181 ± 0.3504</td>
</tr>
<tr>
<td>25</td>
<td>2.0691 ± 0.4103</td>
<td>2.0480 ± 0.3760</td>
<td>1.9540 ± 0.1943</td>
</tr>
<tr>
<td>30</td>
<td>2.4127 ± 0.5230</td>
<td>2.3421 ± 0.3714</td>
<td>2.3303 ± 0.4168</td>
</tr>
<tr>
<td>35</td>
<td>2.2501 ± 0.3024</td>
<td>2.2006 ± 0.4055</td>
<td>2.1911 ± 0.4565</td>
</tr>
<tr>
<td>40</td>
<td>1.9057 ± 0.2585</td>
<td>1.3030 ± 0.2982</td>
<td>1.2912 ± 0.3756</td>
</tr>
<tr>
<td>45</td>
<td>1.5427 ± 0.6403</td>
<td>1.2367 ± 0.2499</td>
<td>1.2299 ± 0.4951</td>
</tr>
</tbody>
</table>

Table 3. Values of r, a and b for clearance rate at different salinities

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Number of observations</th>
<th>r</th>
<th>a</th>
<th>b</th>
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</thead>
<tbody>
<tr>
<td>15</td>
<td>30</td>
<td>0.6741</td>
<td>0.3772</td>
<td>0.8259</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>0.9068</td>
<td>0.7797</td>
<td>0.7537</td>
</tr>
<tr>
<td>25</td>
<td>39</td>
<td>0.9721</td>
<td>0.5742</td>
<td>0.9102</td>
</tr>
<tr>
<td>30</td>
<td>40</td>
<td>0.9750</td>
<td>0.5343</td>
<td>0.9499</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>0.9667</td>
<td>0.4465</td>
<td>0.9723</td>
</tr>
<tr>
<td>40</td>
<td>33</td>
<td>0.9320</td>
<td>0.4394</td>
<td>0.9006</td>
</tr>
<tr>
<td>45</td>
<td>31</td>
<td>0.9581</td>
<td>-0.7043</td>
<td>1.2891</td>
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</table>
Table 4. Analysis of covariance of clearance rate in different salinities

<table>
<thead>
<tr>
<th>Salinity</th>
<th>df</th>
<th>$x^2$</th>
<th>$y^2$</th>
<th>$xy$</th>
<th>Reg.Coeff</th>
<th>$df$</th>
<th>$ss$</th>
<th>$ms$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>29</td>
<td>2.8293</td>
<td>2.5259</td>
<td>2.3368</td>
<td>0.8259</td>
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<td>0.5959</td>
<td>0.0213</td>
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<tr>
<td>20</td>
<td>29</td>
<td>3.4739</td>
<td>2.4144</td>
<td>2.6337</td>
<td>0.7538</td>
<td>28</td>
<td>0.4291</td>
<td>0.0153</td>
</tr>
<tr>
<td>25</td>
<td>38</td>
<td>3.8602</td>
<td>3.3849</td>
<td>3.5138</td>
<td>0.9103</td>
<td>37</td>
<td>0.1864</td>
<td>0.0050</td>
</tr>
<tr>
<td>30</td>
<td>39</td>
<td>5.2628</td>
<td>5.0148</td>
<td>5.0184</td>
<td>0.9500</td>
<td>38</td>
<td>0.2476</td>
<td>0.0065</td>
</tr>
<tr>
<td>35</td>
<td>34</td>
<td>3.2772</td>
<td>3.3159</td>
<td>3.1868</td>
<td>0.9724</td>
<td>33</td>
<td>0.2170</td>
<td>0.0066</td>
</tr>
<tr>
<td>40</td>
<td>32</td>
<td>4.0671</td>
<td>3.7981</td>
<td>3.6630</td>
<td>0.9006</td>
<td>31</td>
<td>0.4970</td>
<td>0.0161</td>
</tr>
<tr>
<td>45</td>
<td>30</td>
<td>3.6102</td>
<td>6.5359</td>
<td>4.6540</td>
<td>1.2891</td>
<td>29</td>
<td>0.5363</td>
<td>0.0185</td>
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<tr>
<td>Pooled</td>
<td></td>
<td>26.4207</td>
<td>26.9899</td>
<td>25.0065</td>
<td>0.9465</td>
<td>230</td>
<td>3.3219</td>
<td>0.0144</td>
</tr>
</tbody>
</table>

\[
\text{Difference between slopes} \quad 6 \quad 0.6106 \quad 0.1018
\]

**

Comparison of slopes (6,224) = 8.4132

** $p < 0.01$
Fig. 7 Weight specific clearance rate (l/gm/h) of different size groups in different salinities (ppt).
Fig. 8 a, b, c Regression line showing clearance rate (ml) and dry body weight (mg) in different salinities. a 15, b 20, c 25 ppt
Fig. 8 d, e Regression line showing clearance rate (ml) and dry body weight (mg) in different salinities. d 30, e 35 ppt
Fig. 8 f, g Regression line showing clearance rate (ml) and dry body weight (mg) in different salinities. f 40, e 45 ppt
budget which is primarily affected by stress. Having determined
the filtration rate and knowing the concentration of suspended
particles in water, it is possible to calculate the amount of
food retained by the gills and ingested by the animal, as long
as no pseudofaeces are produced. The S. scripta, when subjected
to various salinities, it modifies the rate of filtration which
gives an idea about the physiological flexibility of the
organism and it controls the net energy balance in response to
changes brought about in physiology or metabolism.

The 'b' values estimated at 15, 20, 25, 30, 35, 40 and 45
ppt are 0.8259, 0.7537, 0.9102, 0.9499, 0.9723, 0.9006, 1.2891
respectively (Table 3). In all the salinities except 45 ppt the
'b' values obtained are indicating a proportionality between
surface area (0.67) and body weight (1.0). These values are
found to be higher than the values reported by Walne (1972),
Winter (1973), Bayne et al. (1976a) and Bayne and Newell (1983).
The weight exponents for filtration rate showed wide variations
among different animals. It varied from negative values to a
value of 0.76 in mussels (Winter, 1969; Walne, 1972). Navarro
and Winter (1982) quantified the relationship between filtration
rate and body size of M. chilensis at three different algal
densities and the 'b' values varied between 0.58 and 0.62. In
the present investigation the analysis of covariance showed
significant variation in different salinities.

The rate of filtration and body weight showed a linear
relationship ie, the filtration rate increased with increasing
body weight under all experimental conditions. But the weight specific filtration rate showed a decreasing trend with increasing body weight. Same trend was also reported by Walne (1972) and Krishnakumar (1987). In the present investigations the weight specific filtration rate of smaller size group is found to be 2.4127 l/gm/h and that of medium and larger size groups are 2.3421 l/gm/h and 2.3303 l/gm/h respectively at 30 ppt (Table 2). When compared to these values Allen (1962), Theede (1963), Thompson (1984) and Clarke and Griffiths (1990) estimated lower values of clearance rate. But higher values were reported by Widdows et al. (1980) and Widdows and Johnson (1988). Widdows et al. (1980) obtained clearance rate ranged between 2.54 to 5.21 l/h for 1.6 gm mean dry weight and 3.19 to 5.91 l/h for 2.2 gm mean dry weight and former at 30 ppt and later at 29.5 ppt salinity.

Although there is a large amount of data in the literature on the biology of filter feeding bivalves, differences in experimental procedures and techniques make it difficult to compare and contrast the effects of particular environmental factors on the functioning of filtration and biodeposition.

At 15, 20, 25, 35, 40 and 45 ppt the weight specific filtration is found to be less than that at 30 ppt (Table 2). But by scrutiny of the results of weight specific filtration rate at above and below 30 ppt, the animals maintained above 30 ppt showed greater capacity to filter than those kept below 30 ppt in all three size groups. This may be due to their greater tolerance to higher salinities when compared to lower
salinities. Same type of adaptation was also observed in *M. edulis* by Widdows (1985b). The rate of adaptation of *M. edulis* to an abrupt rise in salinity from 15 to 30 ppt is more rapid than the rate of adaptation to a decline in salinity from 30 to 15 ppt (Widdows 1985b). In the present observations the clearance rate declined sharply below 25 and above 35 ppt for medium and large size groups. For smaller size group a sudden decrease was only below 20 ppt (Fig. 7) and such a sudden decrease was not observed above 30 ppt. These observations were in agreement with the salinity tolerance of different size groups. The smaller size groups are found to be more tolerant than medium and larger size groups. Below 15 ppt all the size groups showed no filtration.

In the nine salinities studied, at 10 and 5 ppt no filtration was noticed (Table 2) which is due to the reduced movement/closure of valves and cessation of pumping activity. At 5 ppt all the three size groups showed complete closure of valves with or without insignificant openings. But at 10 ppt valve movement nearly ceases for larger size group and much reduced for medium and smaller size groups. In these salinities the animals showed retraction of siphons and closure of valves. This will inturn ceases the pumping activity and hence no food uptake. These types of depressing effect of lower salinity on filtration rate were also observed by Cole and Hepper (1954), Nagabhushanam (1956) and Widdows (1985b). Foster-Smith (1976) considered the various possibilities for control over pumping
activity, confirming that closure of exhalent siphon was the most common means of regulating pumping. For *S. scripta*, in this investigations at 20 ppt the medium and larger size group animals kept their siphon in withdrew condition. This behaviour would account for the cessation of pumping activity. Above 35 ppt *S. scripta* showed reduced filtration. In the present investigations *S. scripta* are observed to filter more efficiently in 30 ppt than 25 and 35 ppt. Eeventhough the animals are filtering at 25 and 35 ppt, a rhythmic opening of valves associated with muscular activity and water pumping is seen as a regular process only at 30 ppt.

3.2 ABSORPTION EFFICIENCY

3.2.1 Introduction

A large and variable proportion of the particulate matter ingested by the organisms is refractory and not available as an energy source. The efficiency with which an organism absorbs ration by the digestive system is the absorption efficiency (Conover, 1966). Because of the difficulty to recover all the faeces produced by an aquatic filter feeder, direct estimation of absorption efficiency by comparing the organic or energy content of the food and faeces is impractical. Hence, Conover (1966) proposed a method by which absorption efficiency may be determined from the ash-free dry weight to dry weight ratios of
food and faecal samples. This method is based on the premise that only the organic component of the food is significantly affected by digestion.

The factors affecting absorption efficiency in bivalves have been considered by Bayne et al. (1976c), Winter (1978), Widdows et al (1979a), Vahl (1980) and Kiorboe and Mohlenberg (1981). Bayne et al. (1976c) concluded that increase in temperature slightly depressed absorption efficiencies in *Mytilus* species. Elvin and Gonor (1979) observed that exposure to elevated temperatures during low tide in spring and summer could enhance absorption efficiency of *Mytilus californianus*. In the laboratory experiments using pure algal cultures, the absorption efficiency is observed to decline rapidly at high cell concentrations (Thompson and Bayne, 1974; Widdows, 1978a; Griffiths, 1980). The presence of inorganic particles in suspension may 'dilute' organic matter present (Widdows, et al., 1979a; Vahl, 1980) and bring about a reduction in absorption efficiency. In addition to the above factors salinity can also influence absorption efficiency (Widdows 1985b). The present study is aimed to find out the absorption efficiency of different size groups of *S. scripta* and also to understand the impact of salinity on this parameter.

3.2.2 Materials and methods

Faeces of *S. scripta* in different salinities were collected with the help of a pipette into washed, ashed and pre-weighed
glass fibre filter (4.5 cm) and washed the filter with distilled water. A known volume (5 liters) of the sea water containing algal culture was also filtered through a washed ashed and pre-weighed GFC glass fibre filters (4.5 cm) (Strickland and Parsons, 1972) and salts were washed out of filters with distilled water. All the filters were dried at 90°C for 24 hours and weighed before and after ashing at 450°C for 3 hours in a muffle furnace. The absorption efficiency (e) was calculated by the ratio method of Conover (1966) and represents the efficiency with which clams absorb material cleared from suspension.

The Conover ratio for absorption efficiency was calculated as follows:

\[ e = \frac{F-E}{(1-E)F} \]

where \( F \) = ash free dry weight : dry weight ratio of food 
\( E \) = ash free dry weight : dry weight ratio of faeces

Data were analysed by the methods given by Snedecor and Cochran (1968).

3.2.3 Results

The mean values of the absorption efficiencies of different size groups at salinities are given in Table 5. Each value is the mean of five experiments. The efficiency of smaller size
group ranged between 0.56 to 0.63 and that of medium and larger size groups are 0.53 to 0.62 and 0.52 to 0.60 respectively. The maximum value of 0.63 is obtained for smaller size group in 25, 30 and 35 ppt and the maximum value of 0.62 and 0.60 for medium and larger size groups respectively are obtained in 30 and 35 ppt. The absorption efficiency is found to be decreasing when the salinity decreases or increases from optimum/nearly optimum conditions. The absorption efficiency of clams in all the salinities are found to be decreasing as the size increases (Fig. 9).

The absorption efficiency of different salinity and size group was analysed using anova technique with repeated number of observations. The anova is given in Table 6. From the table it follows that there is significant difference between salinity and between size at 1% level of significance. The least significant difference among salinity is 0.0292 and that of size group is 0.0191. The absorption efficiency of all the three size groups was found to be maximum in 25 to 35 ppt followed by 40 and 45 ppt, 20 and 15 ppt. Among the size groups the absorption efficiency is more in small followed by medium and large.

3.2.4 Discussion

In the various experiments the absorption efficiency varied
Table 5. Absorption efficiencies of different size groups in different salinities (± SD, n = 5)

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Size Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small (1.5 ± 0.5 cm)</td>
</tr>
<tr>
<td>15</td>
<td>0.56 ± 0.054</td>
</tr>
<tr>
<td>20</td>
<td>0.58 ± 0.055</td>
</tr>
<tr>
<td>25</td>
<td>0.63 ± 0.032</td>
</tr>
<tr>
<td>30</td>
<td>0.63 ± 0.028</td>
</tr>
<tr>
<td>35</td>
<td>0.63 ± 0.031</td>
</tr>
<tr>
<td>40</td>
<td>0.60 ± 0.034</td>
</tr>
<tr>
<td>45</td>
<td>0.60 ± 0.031</td>
</tr>
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</table>

Table 6. Anova for absorption efficiencies of different size groups and salinities

<table>
<thead>
<tr>
<th>Source</th>
<th>ss</th>
<th>df</th>
<th>ms</th>
<th>F</th>
</tr>
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<tbody>
<tr>
<td>Total</td>
<td>0.2923</td>
<td>104</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Salinity</td>
<td>0.0002</td>
<td>6</td>
<td>0.0150</td>
<td>9.375**</td>
</tr>
<tr>
<td>Size</td>
<td>0.0441</td>
<td>2</td>
<td>0.0221</td>
<td>13.813**</td>
</tr>
<tr>
<td>Error</td>
<td>0.1580</td>
<td>96</td>
<td>0.0016</td>
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LSD for Salinity = 0.0292

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<th>Rank</th>
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<td>0.6043</td>
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<tr>
<td>Medium</td>
<td>0.5829</td>
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</tr>
<tr>
<td>Large</td>
<td>0.5543</td>
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</tbody>
</table>

LSD for Size = 0.0191

** (p < 0.01)
Fig. 9 Absorption efficiencies of different size groups in different salinities (ppt)
between 0.52 to 0.63 (Table 5). The values for *S. scripta* are well within the range described by various authors in different lamellibranchiate bivalves (summarised by Winter, 1978; Bayne and Newell, 1983).

In the present investigation the anova technique revealed that the absorption efficiency is significant at 1% level of significance among size groups and salinities (Table 6). In all the size groups the absorption efficiency is maximum in optimum/nearly optimum salinities. When the salinity alters from optimum (either increase or decrease), correspondingly there is decrease in values. The decrease of efficiencies in the unfavourable salinities indicates the loss of energy in the form of faeces, while the energy available for growth and reproduction decreases correspondingly. Widdows (1985b) estimated the absorption efficiency as a result of abrupt changes between 30 ppt and 15 ppt and found that there was no significant differences in the absorption efficiencies.

Among size groups the least significant difference is 0.0191 and the absorption efficiency is more in small size group followed by medium and large size groups. This is in well agreement with the salinity tolerance of different size groups. Among the three different size groups, the smaller size group is found to be more tolerant than medium and large size groups (Thampuran, *et al.*, 1982). The decrease of efficiencies in unfavourable salinities may be due to the impact of salinity stress on the activity of digestive enzymes. Same was also
reported by Moore et al., (1980).

3.3 OXYGEN CONSUMPTION

3.3.1 Introduction

Knowledge regarding the limits of respiratory function are important for understanding the physiological adaptation of a species. The estimation of oxygen consumption offers a useful method to assess stress since it is an index of energy expenditure to meet the demands of environmental alterations (Thompson and Bayne, 1972).

The oxygen consumption of an animal is influenced by a number of intrinsic and extrinsic factors like size, ration, season, salinity, and pollutants. The relationship between body size and metabolic rate has been studied for adult molluscs and larvae (Zeuthen, 1947; 1953; Von Bertalanffy, 1957). Some of the studies on suspension and deposit feeders are: *Pinctudopecten yessoensis* (Fuji and Hashizume, 1974), *Scrobicularia plana* (Hughes, 1970), *Crassostrea virginica* (Dame, 1972), *Ostrea edulis* (Newell et al., 1977; Rodhouse, 1978), *Cerastoderma edule* (Boyden, 1972a, b; Newell, 1977), *Mytilus edulis* (Bayne et al., 1973; 1975; Famme, 1980a; b), *Mytilus californianus* (Bayne et al., 1976a; b), *Modiolus demissus* (Kuenzler, 1961), *Aulacomya ater* (Griffiths and King, 1979), *Crepidula fornicata* (Newell and Kofoed, 1977) and *Barbatia obliquata* (Prasada Rao and

It is well known that salinity has considerable influence on the metabolic activities of animals. Marine and brackish water invertebrates subjected to variations in salinity exhibit different respiratory behaviour (Kinne, 1971). The effect of salinity on the oxygen consumption have been described for *Mytilus galloprovincialis* (Bouxin, 1931), *Mytilus edulis* (Langerspetz and Sirkka, 1959; Shafee, 1976), *Martesia striata* (Nagabhushanam, 1962); *Geolina ceylonica*, *Anadara granosa* and *Mytilus edulis* (Bayne, 1973b); *Katelysia opima* and *Meretrix meretrix* (Ranade, 1973); *Meretrix casta* (Salih, 1978), *Nausitora hedleyi* (Mohan, 1979); *Mytilus edulis* and *Katherine tunicata* (Stickle and Sabourin, 1979); *Meretrix meretrix* (Deshmukh, 1979) and *Sunetta scripta* (Thampuran, 1986). Kinne (1964a; b), Ghiretti (1966), Remane and Schlieper (1971) and Newell (1979) have reviewed the effect of salinity on the oxygen consumption of molluscs.

The aim of this study is to understand and delineate the effect of size and salinity on the oxygen consumption of *S. scripta*.

3.3.2 Materials and methods

For oxygen consumption studies animals which were subjected for the estimation of clearance rate were used. Studies were done using respirometer designed by Mohan and Cherian (1980).
The duration of the sampling was 2 hours. A control was also ran under identical condition without the animal. The temperature and pH were maintained at constant level. The water samples were collected using sampling bottle of 10 ml capacity and were analysed for dissolved oxygen content using Winkler's micro method (Welsh and Smith, 1953).

Oxygen consumption (O.C) (ml O₂/h) = Initial oxygen content (ml O₂/l) - Final oxygen content (ml O₂/l) x (Volume of respirometer - Volume of the animal) x \( \frac{60}{\text{Time interval (min)}} \)

The data were analysed as given in "clearance rate".

3.3.3 Results

The rate of oxygen consumption (ml O₂/gm/h) for different size groups are shown in Table 7 and Fig. 10. From the table it can be noted that the rate of oxygen consumption for a standard sized (1 gm dry body weight) animal decreases with increase in body size and with increase and decrease of salinity from 30 ppt. When the logarithms of the dry body weight (W) (gm) were plotted against the logarithms of oxygen consumption (O.C) (ml O₂/h) the points are found to cluster around a straight line, hence follow the relationship

\[ \log \text{O.C} = \log a + b \log W \]
Table 7. Dissolved oxygen consumption (ml O2/h) of different size groups in different salinities (± SD) calculated for standard sized (1 gm dry weight) animal

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.4477 ± 0.2677</td>
<td>0.4132 ± 0.1371</td>
<td>0.3514 ± 0.1340</td>
</tr>
<tr>
<td>10</td>
<td>0.3423 ± 0.1521</td>
<td>0.3972 ± 0.1324</td>
<td>0.3164 ± 0.1374</td>
</tr>
<tr>
<td>15</td>
<td>0.5976 ± 0.2920</td>
<td>0.6244 ± 0.2381</td>
<td>0.6285 ± 0.1537</td>
</tr>
<tr>
<td>20</td>
<td>0.7672 ± 0.5078</td>
<td>0.6995 ± 0.2106</td>
<td>0.6700 ± 0.2070</td>
</tr>
<tr>
<td>25</td>
<td>1.0062 ± 0.6833</td>
<td>0.9790 ± 0.2547</td>
<td>0.9649 ± 0.1911</td>
</tr>
<tr>
<td>30</td>
<td>1.0310 ± 0.5236</td>
<td>0.9706 ± 0.5123</td>
<td>0.9389 ± 0.3675</td>
</tr>
<tr>
<td>35</td>
<td>1.0114 ± 0.6051</td>
<td>0.9246 ± 0.1749</td>
<td>0.9487 ± 0.2039</td>
</tr>
<tr>
<td>40</td>
<td>0.5545 ± 0.3216</td>
<td>0.5566 ± 0.2123</td>
<td>0.4957 ± 0.1086</td>
</tr>
<tr>
<td>45</td>
<td>0.5902 ± 0.3783</td>
<td>0.5614 ± 0.3159</td>
<td>0.5617 ± 0.1760</td>
</tr>
</tbody>
</table>

Table 8. Values of r, a and b for dissolved oxygen consumption in different salinities

<table>
<thead>
<tr>
<th>Salinity</th>
<th>Number of observations</th>
<th>r</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
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<td>28</td>
<td>0.8049</td>
<td>-0.6963</td>
<td>1.072</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>0.7865</td>
<td>0.6352</td>
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</tr>
<tr>
<td>15</td>
<td>33</td>
<td>0.8403</td>
<td>-0.0391</td>
<td>0.9322</td>
</tr>
<tr>
<td>20</td>
<td>31</td>
<td>0.8558</td>
<td>-0.1756</td>
<td>0.9740</td>
</tr>
<tr>
<td>25</td>
<td>39</td>
<td>0.8681</td>
<td>-0.0016</td>
<td>0.9858</td>
</tr>
<tr>
<td>30</td>
<td>35</td>
<td>0.9226</td>
<td>-0.5469</td>
<td>1.2251</td>
</tr>
<tr>
<td>35</td>
<td>36</td>
<td>0.8426</td>
<td>0.3585</td>
<td>0.8638</td>
</tr>
<tr>
<td>40</td>
<td>34</td>
<td>0.8032</td>
<td>0.4041</td>
<td>0.7600</td>
</tr>
<tr>
<td>45</td>
<td>31</td>
<td>0.8636</td>
<td>-0.3352</td>
<td>1.0421</td>
</tr>
</tbody>
</table>
Fig. 10 Weight specific oxygen consumption (mlO$_2$/gm/h) of different size groups in different salinities (ppt)
The regression of log oxygen consumption vs log dry weight at different salinities were calculated and shown in the Figure 11 a-i. The \( r, a \) and \( b \) values for different salinities were given in the Table 8. To compare the regression coefficients analysis of covariance was employed (Table 9). The slopes were significant \((p<0.01)\) only at 30 ppt.

3.3.4 Discussion

A scrutiny of the results in the present study shows that the 'b' values obtained for \( S. \) scripta at 5, 10, 15, 20, 25, 30, 35, 40 and 45 ppt are 1.1072, 0.6309, 0.9322, 0.9940, 0.9858, 1.2251, 0.8638, 0.7600 and 1.0121 respectively (Table 8). The values ranging from 0.6309 to 1.2251 revealed that the regression coefficient was significantly different only at 30 ppt (Table 9). Von Bertalanffy (1957) has identified three metabolic types, (1) rate of respiration proportional to surface area \((b = 0.67)\) (2) respiration rate proportional to weight \((1.00)\) (3) intermediate group \((b = 0.67-1.00)\). In the present study at 40, 35, 25, 20, and 15 ppt the 'b' values were between proportionality weight and surface area \((0.67 \text{ to } 1.00)\). The 'b' value \(>1\) were obtained at 5, 30, and 45 ppt and \(<0.67\) at 10 ppt. Existence of metabolic type other than those proposed by Von Bertalanffy (1957) has been reported by Kuenzler (1961) and Kennedy and Mihursky (1972). The values obtained in the present study were comparable with the values of Rodhouse (1978). He
Table 9. Analysis of covariance of rate of dissolved oxygen consumption in different salinities

<table>
<thead>
<tr>
<th>Salinity</th>
<th>df</th>
<th>x^2</th>
<th>y^2</th>
<th>xy</th>
<th>Reg.Coeff df</th>
<th>ss</th>
<th>ms</th>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>27</td>
<td>2.7626</td>
<td>5.2280</td>
<td>3.0588</td>
<td>1.1072</td>
<td>26</td>
<td>1.8413</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>3.8128</td>
<td>2.4538</td>
<td>2.4053</td>
<td>0.6308</td>
<td>26</td>
<td>0.9364</td>
</tr>
<tr>
<td>15</td>
<td>32</td>
<td>2.8815</td>
<td>3.5467</td>
<td>2.6862</td>
<td>0.9322</td>
<td>31</td>
<td>1.0426</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>3.6301</td>
<td>4.8968</td>
<td>3.6083</td>
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<td>25</td>
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<td>4.9780</td>
<td>3.8052</td>
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<td>30</td>
<td>34</td>
<td>3.7695</td>
<td>6.6461</td>
<td>4.6179</td>
<td>1.2251</td>
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<tr>
<td>35</td>
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<td>3.6340</td>
<td>3.8193</td>
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</tr>
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<td>40</td>
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<td>4.4669</td>
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<td>3.3948</td>
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<tr>
<td>45</td>
<td>30</td>
<td>3.3325</td>
<td>4.5783</td>
<td>3.3738</td>
<td>1.0121</td>
<td>29</td>
<td>1.1637</td>
</tr>
</tbody>
</table>

Pooled 286 32.1511 40.1461 30.0894 0.9259 285 11.9860 0.0421

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tbody>
</table>

Difference between slopes 8 0.9494 0.1187

** Comparison of slopes (8,277) = 2.979

** p < 0.01
Fig. 11 a, b, c Regression line showing oxygen consumption (mLO₂/h) and dry body weight (gmx1000) in different salinities. a 5, b 10, c 15 ppt
Fig. 11 d, e, f Regression line showing oxygen consumption (mLO₂/h) and dry body weight (g mx 1000) in different salinities. 

a 20, b 25, c 30 ppt
Fig. 11 g, h, i Regression line showing oxygen consumption (mlO$_2$/h) and dry body weight (gm x 1000) in different salinities.
a 35, b 40, c 45 ppt
got 'b' value between 0.899 and 1.090 for *Ostrea edulis*. The value reported for *Crassostrea virginica* (Dame, 1972) vary from 0.603 to 0.734 and that for *Mytilus edulis* (Bayne, et al., 1973) ranged between 0.670 and 0.744. A mean exponent value of 0.7 was reported for molluscs by Bayne and Newell (1983). Zeuthen (1953) and Rao and Bullock (1954) reported that the 'b' values change within a group of animals and is not constant for the same species under different environmental conditions and at different developmental stages.

The weight specific oxygen consumption of different salinities were compared and the results concluded that the weight specific oxygen consumption for smaller clams were greater than the medium and larger clams in almost all the salinities studied (Table 7). These findings are in general agreement with the observations of the earlier workers on the size dependent respiration in molluscs (Zeuthen, 1955; Davies, 1967; Ganapati and Ramasastry, 1972; Kennedy and Mihursky, 1972; Mangapathy Rao et al., 1974). In *Martesia striata* the oxygen consumption decreased with increase of size (Nagabhushanam, 1966). The same trend was also reported by Salih (1978) in *Meretrix casta*, Deshmukh (1979) in *Meretrix meretrix* and Mohan (1979) in *Nausitora hedleyi* and *Teredo furcifera*. Fammme (1980a) also observed high weight specific oxygen consumption in smaller specimens of *Mytilus edulis* when compared to larger ones.

When comparing the weight specific oxygen consumption with other animals, the values were found to be higher in all the
nine salinities (Table 7). Bayne et al. (1973) and Vahl (1978) observed a seasonal variation of 0.081 to 0.256 ml/h in *Chlamys islandica* and 0.263 to 0.164 ml/h in *Mytilus edulis* respectively. Shafee (1976) reported a higher value of 0.8 ml/h at 35 ppt for *Mytilus edulis*. The values obtained for *S. scripta* in this study are comparable with the values reported by Widdows et al. (1980) and Hawkins et al. (1986b). Hawkins et al. (1986b) obtained a value of 1.09 ml/h for *Perna viridis*. Baby and Menon (1986) reported a much higher value of 1.7599 ml/h for *Perna indica*. Since *S. scripta* is an infaunal species it is likely that it need only less oxygen when compared to *Perna indica* which is an epifaunal species.

Analysis of the results of the experiment shows that oxygen consumption of *S. scripta* are size dependent in all nine salinities ranging from 5 to 45 ppt at 5 ppt interval. At 35, 30, and 25 ppt the oxygen consumption for smaller group of 1 gm dry body weight are 1.0114, 1.0310 and 1.0062 ml O_2/h respectively. For medium and larger size groups (1 gm) the corresponding values are 0.9246, 0.9706, 0.9790 ml O_2/h and 0.9487, 0.9389 and 0.9619 ml O_2/h respectively (Table 7). From these values it can be seen that there is no significant variation in the oxygen consumption at 35, 30 and 25 ppt within the same size group. But when taking the three size groups together within the same salinity (35, 30 and 25 ppt) the weight specific oxygen consumption is found to be decreasing with increasing body weight. But at 45 and 5 ppt the weight specific
oxygen consumption is found to be increasing when compared with the 40 and 10 ppt respectively (Fig. 10). This may be due to the increased energy demands due to higher osmotic stress. From the Fig. 10 it was further observed in *S. scripta* that in all the three size groups the consumption rises sharply as the dilution increased from 40 ppt to 35 ppt and a steady state upto 25 ppt. After 25 ppt a sharp decline occurs for smaller size group as the salinity approached down to 10 ppt. For medium and larger size groups there is a sharp decline upto 20 ppt and after that upto 15 ppt the decrease is less significant. Below 15 ppt a sharp decrease occurs. From these it can be concluded that the smaller clams are more sensitive in all the salinities than medium and larger ones.

The estuarine and marine organisms subjected to variations in salinity exhibit various metabolic types. Kinne (1971) reported four different types of respiratory behaviour for marine and brackish water invertebrates when salinity varies. Within the tolerance range it can be (1) an increase in sub-normal salinities and/or decrease in supra-normal salinities (2) an increase in sub, and supra-normal salinities (3) decrease in sub, and supra-normal salinities (4) essentially unaffected. The first two types of metabolic responses are represented by euryhaline invertebrates while the third and fourth types are shown by stenohaline and extremely euryhaline animals respectively. Since *S. scripta* exhibited an increase in extreme salinities (5 and 45 ppt), it may be due to the euryhaline
nature. Increased oxygen uptake in response to extreme salinity is common among invertebrates (Newell, 1979) and presumably reflects elevated costs incurred within ranges of salinity tolerance. In *M. edulis* (Lagerspetz and Sirkka, 1959) and *Perna viridis* (Hawkins *et al.*, 1987) reported an increased oxygen consumption with decreased salinities.

In conclusion the oxygen consumption of *S. scripta* was found to be maximum in 30 ppt which was reported as the optimum salinity and when the salinity alters from the optimum (unfavourable salinities) the oxygen consumptions were found to be reduced. But in extreme salinity conditions (5 and 45 ppt) the oxygen consumptions were found to increase which can be due to the additional energy requirement.

### 3.4 AMMONIA EXCRETION

#### 3.4.1 Introduction

A small proportion of the total food uptake by the animal is excreted as metabolic waste products. No organism limits its nitrogen excretion to one product, but the aquatic invertebrates commonly excrete much of their nitrogen in the form of ammonia (Bayne *et al.*, 1985). Using a variety of clams, mussels and oysters held in aquaria, Hammen (1968) found that although ammonia was the major nitrogenous excretory product, some amount of amino acid was also excreted in appreciable amounts in some species. This amino acid excretion is seemed to be proportional
to the relative surface area:mass ratio as well as transaminase levels in the tissues (Hammen, 1968). *Mytilus edulis* excretes 80-90% of the total nitrogen as ammonia, approximately 5-10% as amino-nitrogen (Bayne and Scullard, 1977; Livingstone et al., 1979) and 5% as urea (Bayne, 1973a). Most attention has focused on ammonia excretion as it formed the major end product of protein catabolism. Bayne et al. (1976d) reviewed ammonia excretion in marine mussels and various excretory products of different organisms were summarised by Pandian (1975b).

Following study was conducted to understand the effect of size and salinity on the ammonia excretion of *S. scripta*.

### 3.4.2 Materials and methods

The oxygen consumption and ammonia excretion were estimated simultaneously. A sample of 10 ml was collected and estimated the ammonia content using phenolhypochlorite method (Solorzano, 1969). The rate of ammonia excretion was calculated using the following equation and the control value was deduced.

\[
\text{Ammonia excretion (} \mu\text{g m} \text{NH}_4\text{-N/h)} = \text{Final concentration (} \mu\text{m}) - \frac{14}{1000/V} \times \frac{1}{t} \times \text{Initial concentration (} \mu\text{m)}
\]

where

- \(V\) = Volume of the sea water in which the animal is incubated
- \(t\) = Incubation time
The data were analysed as given in "clearance rate".

3.4.3 Results

The rate of ammonia excretion ($\mu$gm NH$_4^{-}$N/h) for standard sized (1 gm dry weight) animals of three different size groups at different salinities are given in Table 10 and Fig. 12. The values varied from 116.8650 to 242.7360 $\mu$gm NH$_4^{-}$N/h for smaller size group, 108.9071 to 286.9273 $\mu$gm NH$_4^{-}$N/h for medium size group and 113.7688 to 242.8053 $\mu$gm NH$_4^{-}$N/h for larger size group. The ammonia nitrogen-excretion at different salinities showed no specific trend with salinities. The regression of log ammonia-nitrogen excreted vs log dry body weight at different salinities are calculated (Fig. 13 a-i) and the r, a and b values are given in Table 11. The relationship between logarithm of ammonia-nitrogen (NH$_4^{-}$N) excreted and logarithm of dry body weight (W) can be represented in the form of linear equation

$$\log \text{NH}_4^{-}\text{N} = \log a + b \log W$$

To compare the regression coefficients analysis of covariance was employed (Table 12) and the results showed no significant variations in ammonia excretion at different salinities.

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Table 10. Ammonia excretion (μg N-NH₃/N/h) of different size groups in different salinities (X ± SD) calculated for standard sized (1 gm dry weight) animal

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>204.3500 ± 70.1337</td>
<td>218.3775 ± 117.6991</td>
<td>235.9392 ± 46.0059</td>
</tr>
<tr>
<td>10</td>
<td>216.1521 ± 79.3601</td>
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</tr>
<tr>
<td>15</td>
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<td>156.2004 ± 83.0696</td>
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<tr>
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<tr>
<td>35</td>
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<td>108.9071 ± 57.1744</td>
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<tr>
<td>40</td>
<td>242.7360 ± 71.7574</td>
<td>226.6631 ± 126.8495</td>
<td>208.6071 ± 43.4326</td>
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<tr>
<td>45</td>
<td>193.5803 ± 138.8200</td>
<td>210.2740 ± 81.2803</td>
<td>203.6009 ± 60.9431</td>
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</table>

Table 11. Values of r, a and b for ammonia-nitrogen excretion in different salinities

<table>
<thead>
<tr>
<th>Salinity</th>
<th>Number of observations</th>
<th>r</th>
<th>a</th>
<th>b</th>
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</thead>
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Table 12. Analysis of covariance of rate of ammonia excretion in different salinities

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<th>$x^2$</th>
<th>$y^2$</th>
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\[
\text{Difference between slopes} = 8 \quad 0.4406 \quad 0.0551
\]

Comparison of slopes (8,292) = 1.138 (NS)

NS Not significant
Ammonia excretion (µgm/h)

Salinity (ppt)

Fig. 12 Weight specific ammonia-nitrogen excretion (µgm NH₄-N/gm/h) of different size groups in different salinities (ppt)
Fig. 13  a, b, c Regression line showing ammonia excretion (µgm/hrx100) and dry body weight (mg) in different salinities.  a 5,  b 10,  c 15 ppt
Fig. 13 d, e, f Regression line showing ammonia excretion (μg/m/hx100) and dry body weight (mg) in different salinities. a 20, b 25, c 30 ppt
Fig. 13 g, h, i Regression line showing ammonia excretion (µgm/hx100) and dry body weight (mg) in different salinities. a 35, b 40, c 45 ppt
3.4.4 Discussion

In the present investigation 'b' value for ammonia-nitrogen excretion is found to be vary from 0.9061 to 1.2251. At 20, 30, 35 and 40 ppt the values are >1.00 and at 5, 10, 15, 25 and 45 ppt <1.00 (Table 11). To compare the regression coefficient, analysis of covariance was employed (Table 12) and the results shows that there is no significant variation in slopes. The values obtained in the present study are falling between the range of values reported for bivalves, 0.40 to 1.48 (Griffiths and Griffiths, 1987). A wide range of values for M. edulis was reported by Bayne and Scullard (1977), 0.482 to 1.480 and Thompson (1984), 0.021 to 1.312. When comparing with the 'b' values of S. scripta, comparatively less value was reported for P. viridis (0.4155) by Krishnakumar and Damodaran (1986) and Donax serra (0.55) by Brown et al. (1989).

In all the nine salinities studied, the range of ammonia-nitrogen produced by 1 gm dry weight varied from 116.8650 to 242.7360 μgm NH$_4$-N/h for smaller size group, 108.9071 to 286.9273 μgm NH$_4$-N/h for medium size group and 113.7688 to 242.8053 μgm NH$_4$-N/h for larger size group. These values were found to be higher when compared with the values reported for M. edulis (Widdows et al., 1980). Widdows et al. (1980) reported the values ranged between 31.22 to 42.39 μgm NH$_4$-N/h. Widdows and Johnson (1988) determined ammonia excretion of M. edulis as a response to petroleum hydrocarbons...
and copper and the results varied from 0.81 to 20.54 μgm NH$_4$-N/h. Krishnakumar et al. (1990) reported mean value for ammonia excretion of 55.8 and 193.9 μgm NH$_4$-N/h for P. viridis as a result of exposure to mercury and copper respectively. Mathew (1990) reported a value of 2.2 x 10$^{-5}$mg NH$_4$-N/h/mg for Donax incarnatus at 30 ppt.

The results of ammonia-nitrogen excretion of S. scripta show that there is no specific trend in ammonia-nitrogen excretion at different salinities (Fig. 12). This variability may be due to the disproportionate reliance on protein catabolism for energy production by the individual animals. The minimum value of 116.8650 μgm NH$_4$-N/h for smaller size group was recorded in 30 ppt and the minimum value of 108.9071 μgm NH$_4$-N/h for medium and 113.7688 μgm NH$_4$-N/h for larger size group were recorded in 35 ppt (Table 10). By studying the salinity tolerance the optimum salinity recorded for all the three size groups was 30 ppt (Thampuran, et al., 1982) and the minimum amount of ammonia-nitrogen excretion is in optimum (30 ppt) /nearly optimum (25 and 35 ppt) conditions. It was also confirmed by monitoring the valve movement of different size groups at different salinities (chapter 2). A regular and rhythmic partial closures and openings of the valves were noticed only at 30 ppt indicating active ventilation which occur only in favourable salinities. But at 45, 15 and 5 ppt lower values were recorded when compared with 40, 20 and 10 ppt for all the three size groups (Table 10). This can be due to the
lowered movement/closure of valves and also due to the recycling of amino acids for protein synthesis (De Zwaan and Van Marrewijk, 1973). The increased catabolism enhances the demands on protein turnover and may be met by increasing the recycling of amino acids for protein synthesis (Hawkins et al., 1986a). In these circumstances there would be no net change in the rate of ammonia-nitrogen excretion. But Andrews and Reid (1972) suggested that during prolonged periods of valve closure, detoxification of ammonia into urea occurs and De Zwaan and Van Marrewijk (1973) postulated the conversion of ammonia into alanine (involving alanine dehydrogenase). Speeg and Campbell (1969) opined an alternative mechanism that the free amino acid produced may react with hydrogen ions formed by the action of carbonic anhydrase on bicarbonate in the presence of urease, so releasing carbonate ions for deposition in the shell as calcium carbonate.

There is little information available on the range in which environmental factors may affect either the balance between the various nitrogenous end products or the rates of excretion. Hawkins et al. (1986a) estimated increased ammonia-nitrogen production due to the increased catabolism of proteins as a result of starvation and reduced filtration activity in M. edulis. Emerson (1969) investigated the effect of reduced salinity which causes increased ammonia-nitrogen excretion in Macoma inconspicua. Same was also reported by Allen and Garrett (1971) in Mya arenaria and Bayne (1975) in M. edulis. Allen
and Garrett (1971) estimated an increase from 3.22 μgm NH₄-N/d at 34 ppt to a maximum of 64.4 μgm NH₄-N/d at 17 ppt in *Mya arenaria*. Ansell and Sivadas (1973) have documented differences in excretion rates with differences in animal size in *Donax vittatus*. These studies suggest a marked variability in the rates of nitrogen excretion by bivalves and where ever recordings of oxygen consumption have been made there is an evidence that these two physiological process do not always vary in the same direction nor to the same extent in response to changes in the environment.

3.5 OXYGEN:NITROGEN RATIO

3.5.1 Introduction

A general response of bivalve molluscs to stress is the closure of valves and cessation of pumping activity and food intake. Under these circumstances the metabolic requirement is met by the utilization of nutrient reserves. Generally changes in carbohydrate, protein and lipid stores occur only in response to condition of extreme stress (Bayne and Thompson, 1970). A ratio between oxygen consumed and nitrogen excreted (O:N, calculated in atomic equivalents) provides an index of the relative utilization of protein in energy metabolism (Conover and Corner, 1968; Corner and Cowey, 1968; Bayne et al., 1976e; Bayne and Newell, 1983; Widdows, 1978b; 1985a, b; Thompson,

So the aim of this study is to understand the effect of size and salinity on the level of oxidative and protein metabolism in *S. scripta*.

3.5.2 Materials and methods

By using the oxygen consumption and ammonia excretion data from the previous sessions, the O:N ratios were calculated in different size groups and salinities. The calculations were done by the equation given by Bayne et al. (1985).

\[
O : N = \frac{\text{ml} \ O_2/\text{h} \times 1.428}{16} : \frac{\text{mg} \ NH_4-N/\text{h}}{14}
\]

3.5.3 Results

The O:N ratio for small, medium and large size groups are given in the Table 13 and Fig. 14. The range of values for smaller, medium and larger size groups are 2.2080 to 20.5784, 2.3410 to 17.0133 and 1.7457 to 24.1115 respectively. The maximum and minimum value of 24.1115 and 1.7457 are estimated for larger size group. The O:N ratio did not show any dependence on size group, but were found to be decreasing when the salinity altered from 30 ppt. except for medium (Table 13).
Table 13. Oxygen to Nitrogen (O:N) ratio of different size groups in different salinities calculated for standard sized (1 gm dry weight) animal

(\( \bar{x} \pm s_d \))

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Size Groups</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small (1.5 ± 0.5 cm)</td>
<td>Medium (2.5 ± 0.5 cm)</td>
<td>Large (3.5 ± 0.5 cm)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.2880 ± 1.3913</td>
<td>2.4354 ± 1.6374</td>
<td>1.7457 ± 0.8042</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4.5328 ± 2.2291</td>
<td>2.4816 ± 0.9218</td>
<td>2.2900 ± 1.0545</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>5.3810 ± 2.4182</td>
<td>6.1623 ± 3.1541</td>
<td>5.3022 ± 1.3478</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>7.3269 ± 1.1046</td>
<td>6.6528 ± 1.6143</td>
<td>7.6687 ± 2.9471</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>20.5784 ± 5.4332</td>
<td>15.3000 ± 3.6653</td>
<td>24.1115 ± 10.0380</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>13.2572 ± 3.7220</td>
<td>17.0133 ± 3.2181</td>
<td>12.1964 ± 2.7828</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>6.4320 ± 1.5929</td>
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</tr>
<tr>
<td>45</td>
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<td>2.3410 ± 1.2036</td>
<td>3.4430 ± 1.2090</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 14 Weight specific oxygen to nitrogen (O:N) ratio of different size groups in different salinities (ppt)
3.5.4 Discussion

The O:N ratio provides a useful index for understanding the 'level of activity' of the oxidative and protein metabolism (Mayzaud, 1973) which decides the efficiency of an animal to maintain itself in a community. The atomic equivalent of O:N ratio may be used to indicate the proportion of the protein catabolized relative to carbohydrate and lipid.

Present investigation showed a clear cut stress effect on the O:N ratios with salinity (Table 13, Fig. 14). The maximum values of O:N ratios were obtained in optimum (30 ppt)/nearly optimum (25 and 35 ppt) salinity conditions. The maximum value of 24.1115 and 20.5784 for larger and smaller size groups respectively were in 30 ppt but for medium size group a maximum value of 17.0133 was at 35 ppt. The widely publicized assumption is that an O:N ratio value of 30 or less is generally indicative of a stressed condition cannot be accepted in the present instance since the maximum value obtained in the optimum salinity is 24.1115. In all the cases the values were below 30. When the salinity alters from the optimum (30 ppt), the O:N ratios were found to be decreasing. The same trend was observed in all the three size groups. The minimum O:N ratio recorded in the present investigation is 1.7457 at 5 ppt. The basic concept that could be put forward to explain the low O:N ratio is that the mussels rely heavily on the catabolism of proteins than of non-protein substrates to meet the increased demands for energy.
during stress. For *M. edulis* the O:N ratio values above 50 as representative of a healthy mussel and below 30 of stressed ones (Widdows, 1985a). Bayne (1973a) investigated the seasonal changes of O:N ratio in *M. edulis*. He gave a relatively constant value of 100 signifying the predominance of carbohydrate and/or lipid catabolism over the utilization of protein in energy metabolism. Theoretical calculations show that complete catabolism of proteins as the sole energy substrate would give an O:N ratio of 9.33. During periods of minimal or negative growth (<20 and >35 ppt) the O:N ratios of *S. scripata* were reduced to theoretically minimal or less values. Utilization of ammonia-nitrogen in synthetic pathways or failure to oxidise the carbon skeletons of the amino acids will result in deviation from the theoretical expectations of O:N ratio. Since O:N ratio may vary with gametogenic cycle, nature of food and nutrient reserves, the interpretation of the O:N ratio should be based on relative change rather than absolute value (Shirely and Stickle, 1982; Widdows 1985a). This makes it necessary to collect information on this index under different ecological and physiological condition to obtain base line values which can be used as a stress index.

3.6 PHYSIOLOGICAL ENERGETICS

The physiological flexibility of an organism in relation to the environmental demand can be followed by studying the
physiological energetics of the animals. An energetic approach can provide an integration and means of assessing the overall performance in terms of the 'costs' and 'benefits' and the effectiveness of various behavioural, physiological and metabolic responses to environmental change (Shick et al., 1988).

Most of the marine animals are capable of some degree of compensation for environmental changes within its zone of tolerance and zone of resistance (Blackstock, 1984; Akberali and Trueman, 1985). But prolonged unfavourable conditions may exert stress on the animal and chances of survival are significantly reduced. According to Bayne (1975) "stress is a measurable alteration of a physiological (behavioural, biochemical or cytological) steady state which is induced by an environmental change, and which renders the individuals (or the population) more vulnerable to further environmental change". Such alteration in the functional state may result in the improvement of an organism's fitness or a deterioration in well being (Bayne et al., 1985).

The four physiological responses proposed for routine use in environmental monitoring are (Bayne, 1975; Bayne et al., 1975; IMCO et al., 1980).

1. Scope for growth - a measure of the energy status of an organism.

2. Growth efficiency - the efficiency with which an individual converts food into body tissues.


All these physiological stress indices are derived from the integrations of basic biological process.

3.6.1 SCOPE FOR GROWTH

3.6.1.1 Introduction

Growth and reproduction are fundamental properties of all living organisms and is the basis for a population to establish in a particular environment. Warren and Davis (1967) defined the "scope for growth" as "the difference between the energy of the food an animal consumes and all other energy utilisations and losses". This is not measured directly but rather is derived by subtraction of energy respired and excreted from the energy absorbed from food. Alterations in the amount of matter or energy incorporated into growth and reproduction can be obtained by the balanced equation of Winberg (1960).

\[ C - F = A = R + U + P \]

\[ P = A - (R + U) \]

Where \( P \) = Energy incorporated into somatic growth and gamete production.

\( C \) = Food energy consumed.
F = Energy lost as faeces.
A = Energy absorbed from food.
R = Energy respired.
U = Energy excreted.

This energy budget provides an integration of these basic biological processes (feeding, food absorption, respiration and excretion) as an index of energy available for growth and reproduction.

The direct measurement of growth and production is difficult in many species. This is especially true in bivalve molluscs, because 1. a major portion of the total production can be lost in the form of gametes by single or gradual spawning 2. it is impracticable to measure weight changes in animals with shells and variable amounts of sea water 3. it is not sufficient to measure changes in shell length because there is no apparent tight coupling between shell growth and tissue growth (Hilbish, 1986). Under these circumstances the scope for growth is an useful stress index because it reveals the whole organism's response to the environmental stress, both natural and anthropogenic. Brett (1979) opined that the environment acts not directly on growth but on the mechanisms of energy supply and demands, that influence the scope for growth. The scope for growth can range from positive values when there is energy available for somatic growth and production of gametes, to negative values when the animal is severely stressed and
utilizing its body reserves for maintenance metabolism.

Many workers have determined "scope for growth" of aquatic organisms. Warren and Davis (1967) were the first to use scope for growth as a measure of examining the bioenergetics of production in fish in response to environmental temperature change. Scope for growth in response to seasonal cycle was reported in *Mytilus edulis* (Widdows, 1978b; Bayne and Widdows, 1978), *Crassostrea virginica* (Dame, 1972), *Cardium edule* (Newell, 1977). Buxton et al. (1981) studied scope for growth in juvenile *Ostrea edulis* as a function of acclimation and exposure to temperature. The use of this index for assessing the physiological condition of mussels in response to temperature, ration and body size in laboratory and field were described by Widdows and Bayne (1971), Thompson and Bayne (1974), Bayne et al. (1975; 1978; 1979), Widdows (1978b), Griffiths and King (1979), Shafiee (1979) and Widdows et al., 1981). Gilfillan (1975) and Gilfillan et al. (1977) have shown that scope for growth (estimated in terms of carbon flux rather than energy units) declined in three bivalve species (*Mytilus edulis*, *Modiolus demissus* and *Mya arenaria*) as a result of exposure to oil. Scope for growth was studied in response to salinity changes in *Mytilus edulis* by Stickle and Sabourin (1979) and Shumway and Youngson (1979). Bayne et al. (1979; 1981) and Bayne and Worrall (1980) compared estimates of growth, from the physiological measurements in the laboratory and from the two naturally occurring populations of mussels and showed
very good agreement between these two estimates. Evidence of this agreement enables confidence to be placed upon scope for growth measurements, as an index of true physiological condition.

The main physiological components of energy equation are:

1. Food energy consumed

The amount of energy consumed from the food depends upon the food availability and feeding rates, the efficiency of digestion and absorption. Total energy consumed can be calculated from the clearance rate in the case of filter feeders which is defined as the volume of water cleared of particles per unit time (Bayne et al., 1985). Measurement of feeding, digestion and assimilation process provide estimates of the amount of food consumed and assimilated by the animal. This forms an important component of the bioenergetic equation and is generally influenced by stress (Bayne et al., 1985).

2. Energy loss due to respiration

Respiration represents a measure of that part of the food intake or of available body reserves which is required to provide energy to support life process. Energy losses by respiration can be expressed in terms of oxygen utilization, carbon dioxide liberation or heat production (Bayne et al., 1985). Among these the oxygen consumption is a convenient measure of energy transformation (Scott and Major, 1972). Crisp (1971) gave an oxycalorific equivalent of 20.33 Joules for 1 ml
of oxygen which can be used to convert oxygen consumption (ml \(O_2\)) to energy equivalents. The metabolic energy expenditure is affected by a number of environmental and endogenous factors (Newell, 1973; 1979; Newell and Roy, 1973; Widdows, 1978a).

3. Energy loss due to excretion

A small proportion of the total energy absorbed by the animal is excreted as metabolic waste products. The energy lost as excreta therefore forms a negative component of the basic energy equation (Bayne et al., 1985). Among a variety of bivalves ammonia comprised about 90% of total measure of nitrogen excretion (Bayne et al., 1976d; Bayne and Newell, 1983). Therefore the rate of ammonia excretion has to reflect the rate of protein catabolism (Widdows, 1978b). So the estimation of ammonia excretion will give an idea about the loss of energy through excretion.

3.6.1.2 Materials and methods

The mean data of clearance rate, absorption efficiency, oxygen consumption and ammonia excretion were taken from the previous sessions for the calculation of scope for growth. To calculate scope for growth, all the physiological components of energy equation were first converted into energy equivalents (Joules/h) as given by Bayne et al. (1985).
1. Energy consumed (C):
   
   \[ C = \text{Clearance rate (l/h)} \times \text{particulate organic matter (mg/l)} \times \text{energy content of particulate organic matter (J/h)} \]

   The energy content of particulate organic matter (algal) was taken as 23.5 J/mg dry weight (Slobodkin and Richman, 1961).

2. Energy absorbed from the seston (A):
   
   \[ A = C \times e \]
   
   where \( e = \text{absorption efficiency} \)

3. Energy respired (R):
   
   \[ R = vO_2 \times 20.33 \]
   
   \( (1 \text{ ml } O_2/h = 20.33 \text{ J}) \)

4. Energy excreted (U):
   
   \[ U = NH_4-N \text{ excretion (\mu g NH}_4\text{-N/h)} \times 0.0249 \]
   
   \( (1 \text{ \mu g NH}_4\text{-N/h} = 0.0249 \text{ J}) \)

   On the basis of these energy equivalents, the scope for growth were calculated using the following equation (Winberg, 1960).

\[
P = A - (R + U)
\]

where

\( P = \text{scope for growth} \)

\( A = \text{energy absorbed from food} \)

\( R = \text{energy respired} \)

\( U = \text{energy excreted} \)
3.6.1.3 Results

The energy values obtained for clearance rate, absorption efficiency, oxygen consumption, and ammonia excretion in the case of three size groups of *S. scripta* are given in Table 14a,b,c. The values have been calculated for three different size groups (1 gm dry tissue weight) in nine different salinities. The scope for growth for different size groups showed negative trend with increasing body size (Table 14a,b,c). As illustrated in Fig. 15 a,b,c for smaller size group animals positive scope for growth was noticed between 25 and 45 ppt. For medium and larger size groups the range was between 25 and 35 ppt and 30 and 35 ppt respectively. Considering all the salinities and all the size groups, the maximum scope for growth of 4.7059 (J/gm/h) is obtained for smaller size group (Table 14a).

3.6.1.4 Discussion

An energetic approach, based on the integration of feeding rate, food absorption, oxygen consumption, excretion, growth and reproduction provides a useful means of assessing the overall performance of an animal. As applied to mussels, the use of basic energy equation (Winberg, 1960) requires the measurement of respiration rate, clearance rate, excretion rate and assimilation efficiency, with all values expressed in energy units (Joules) (Thompson and Bayne, 1974). The net energy
Table 14 a,b. The calculation of energy budget and scope for growth of different size groups in 9 different salinities. a Small (1.5 ± 0.5 cm) b Medium (2.5 ± 0.5 cm) (1 gm dry weight)

<table>
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<tr>
<th>Salinity (ppt)</th>
<th>CR (l/h)</th>
<th>POM (mg/l)</th>
<th>EC (C) (J/h)</th>
<th>AE</th>
<th>EA (J/h)</th>
<th>A = Cxe</th>
<th>ER (J/h)</th>
<th>EE (J/h)</th>
<th>SFG (J/h)</th>
</tr>
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</tr>
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CR Clearance Rate; POM Particulate Organic Matter; EC Energy Consumed; AE Absorption Efficiency
EA Energy Absorbed; ER Energy Respired; EE Energy Excreted; SFG Scope For Growth
Table 14c. The calculation of energy budget and scope for growth of large size (3.5 ± 0.5 cm) group in 9 different salinities (1 gm dry weight)

<table>
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CR Clearance Rate; POM Particulate Organic Matter; EC Energy Consumed; AE Absorption Efficiency
EA Energy Absorbed; ER Energy Respired; EE Energy Excreted; SFG Scope For Growth
Fig. 15 a,b Scope for growth of (a) small (1.5 ± 0.5 cm) and (b) medium (2.5 ± 0.5 cm) size groups acclimated in different salinities (ppt)
Fig. 15c Scope for growth of large (3.5 ± 0.5 cm) size group acclimated in different salinities (ppt)
available for growth and reproduction, the "scope for growth" represents the energy balance of an animal under specified conditions. The scope for growth provides an index of energy balance with out distinction between somatic growth and gamete production. The manner in which growth was altered have more significance than the change in the rate of any single physiological function. The scope for growth will be positive when surplus energy available for growth or it will be negative due to the utilization of animals' own endogenous energy reserves. In other words, when utilization of energy exceeds the energy input, the index becomes negative and under these conditions body reserves must be utilized (Gabbott and Bayne, 1973; Thompson et al., 1974; Dare and Edwards, 1975; Widdows, 1978a) and if this situation is prolonged the animal must eventually die (Bayne et al., 1979). According to Fry (1947) the region of negative scope for growth in which an organism cannot survive indefinitely, can be refereed to as the zone of resistance and the region of positive scope for growth, the zone of tolerance. When the absorbed ration exactly balances the sum of the metabolic demand and the energy losses due to excretion, growth and growth efficiency are zero, the ration level is called maintenance ration (Widdows, 1978b).

A major component in the maintenance of viable organism is the demand for protein synthesis. During stress condition the degradation of proteins into amino acids occurs due to the increased demand for energy. This inturn causes the depletion
of body proteins. Under these conditions some quantity of amino acids are recycled to the metabolic pool for further protein synthesis and are associated with high energy costs (De Zwaan and Van Marrewijk, 1973). According to Hawkins et al. (1986a) under stress condition as much as 30% of the normal energy demand is due to the turnover of proteins.

All the process that comprise the energy balance equation are capable of variation in response to changes in the environment. The animal must be able to balance its gains from the environment against its metabolic losses in order to allocate an optimal distribution of surplus energy to somatic growth and reproduction.

Each physiological response of *S. scripta* vary with salinity change. The sequence of events are similar in salinity increase and in salinity decrease from 30 ppt. When considering the energy budget and scope for growth of *S. scripta*, the positive component of the energy equation is the energy consumed and absorbed from the food and the negative component comprises the energy loss through respiration and excretion. The energy absorbed from the food decreases above and below 30 ppt. The maximum amount of energy consumed for the three size groups were in 30 ppt (45.3588, 44.0315 and 43.8096 J/gm/h for small, medium and large size groups respectively). The maximum energy absorption is also in 30 ppt for the three size groups (28.5760, 27.2995 and 26.2850 J/gm/h for small, medium and large size groups respectively) (Table 14 a, b, c). In 5 and 10 ppt, for all
the three size groups there is no filtration rate and hence no food uptake and energy absorption (Table 14 a,b,c). In lower salinities closure/withdrawal of exhalent siphon and closure of valves/partial closure occurs. This behaviour would account for the cessation of the pumping and feeding activity and consequent energy absorption. Respiratory and excretory loss in all the nine salinities for the three size groups are given in Table 14 a,b,c. The weight specific energy loss due to respiration is found to be higher in smaller size group when compared to medium and larger size groups. In addition to this the energy loss due to respiration were found to be decreasing with increase and decrease of salinity from 30 ppt except 5 and 45 ppt for all the three size groups. But there is no specific trend in energy loss due to excretion and salinity change.

In the present investigations the maximum scope for growth of 4.7059 J/gm/h is found to be for smaller size group in 30 ppt and the scope for growth is found to be decreasing with increasing body size (Table 14 a,b,c). This maximum value obtained is found to be comparable with the values reported by Widdows (1985b) and Widdows et al. (1990). The higher scope for growth for smaller size group is due to the higher proportion of ingestion rate and absorption when compared with respiration and excretion. The reduced scope for growth for medium and large size groups is because as animals grow in size, the increase in feeding rate (and hence the ration obtained) is disproportionate to the increase in metabolic rate. Bayne et al. (1973) reported
at any given ration smaller mussels have a greater scope for growth per unit of body size than larger ones and their optimum scope for growth occurs at a higher ingested ration in relation to body size. Thompson (1984) opined in *Mytilus edulis* that scope for growth is dependent on body weight. Initially there was a rapid improvement in scope for growth as body weight increased but the rate of change fell considerably in larger mussels. In the case of the scallop *Placopecten magallanicus* the scope for growth expressed per unit body weight declined as body weight increased (Mac Donald and Thompson, 1986). Vahl (1981) has recorded a similar phenomenon in the different age classes of the Icelandic scallop, *Chlamys islandica*.

The present study reveals that the scope for growth of the three size groups are found to be salinity dependent and the values ranged from negative to positive values. For smaller size group positive scope for growth is obtained above 25 up to 45 ppt, but for medium and larger size groups it is only above 25 up to 35 ppt and 30 to 35 ppt respectively (Fig. 15 a,b,c). In all the other salinities the scope for growth was negative. The higher scope for growth is obtained at 30 ppt for all the three size groups. When the salinity alters from 30 ppt (either decrease or increase), correspondingly there is a decrease in scope for growth. The negative scope for growth is due to the increase in the negative component of energy equation. In otherwords, the energy loss due to respiration and excretion is found to be greater than the energy absorbed from the food. In
10 and 5 ppt for all the three size groups, there is no food uptake and hence no energy absorption and there occurs only energy loss through respiration and excretion (Fig. 15 a,b,c). Widdows (1985b) reported the reduced scope for growth for *M. edulis* in lower salinity. He acclimated *M. edulis* by the method of Livingston *et al.* (1979) and concluded that the scope for growth depressed between 20 and 15 ppt. In response to salinity changes below 20 ppt, respiration, clearance rate, and scope for growth for *M. edulis* declines (Shumway and Youngson, 1979; Stickle and Sabourin, 1979). Stickle and Bayne (1982) reported negative values of scope for growth for *Thais lapillus* below 20 ppt.

*S. scripta* is affected by salinity variations due to the South-West monsoon which in turn affects the distribution and abundance of this species. The simple salinity tolerance study (Thampuran *et al.*, 1982) revealed that the animal is capable of tolerating wide range of salinity (5 to 40 ppt) for short periods (15 days). Highest percentage of mortality was recorded in 5 ppt salinity and the mortality rate increased as the age of clams advanced (33.31%, 19.99% and 13.32% in larger, medium and smaller clams respectively over a period of 15 days). It was seen that the 100% survival for larger clams in 25 to 35 ppt range of salinities while the medium and small size groups were in 20 to 35 ppt and 15 to 40 ppt respectively for a period of 15 days (Thampuran *et al.*, 1982). But the present investigations show that the positive scope for growth obtained for smaller,
medium and larger size groups are 25 to 45 ppt, 25 to 35 ppt and 30 to 35 ppt respectively. Below and above these salinities, there is negative scope for growth and the maximum scope for growth is at 30 ppt for all the three size groups. This reveals that the optimum salinity for growth is 30 ppt in all the three size groups and the adaptation of S. *scrippta* to an increased salinity from 30 ppt is greater than decrease in salinity from 30 ppt. The studies show that the animal is capable of tolerating lowered salinities for short term fluctuations, but it can not tolerate long term fluctuations, because during this time there is little or no food uptake due to the closure of valves and cessation of pumping activity, and the energy demands are met by the utilization of body reserves.

Eventhough the animal is having wide range of tolerance in salinity, successfully established population can be seen only in the marine zone close to the estuary. The species never colonised in the estuarine habitat though similar substratum are available. This is because the lowest salinity for positive scope for growth is 25 ppt and that too only for smaller and medium size groups. For larger size group it is only above 30 ppt. The salinity of the estuarine area is controlled mainly by the South-West monsoon. During monsoon the salinity goes to very low values in the estuary and this condition prevails for 3 to 4 months. Thus the period in which the animal has to maintain itself in the resistance zone is considerably long, and recur annually. This can be the main reason why *S. scrippta*
occurs only in marine environment, though it is capable of tolerating wide range of salinities. Thus salinity is acting as a limiting factor for *S. scripta* which restrict the potential for energy acquisition and thereby setting limits for the establishment of a population.

3.6.2 GROSS AND NET GROWTH EFFICIENCIES

3.6.2.1 Introduction

In ecological context, growth relationships are best described as efficiencies. The most commonly used indices in molluscan energetics are those of gross and net growth efficiencies. The gross growth efficiency $K_1$ is the proportion of the ingested ration for scope for growth (Bayne and Widdows, 1978). The scope for growth as a proportion of the absorbed ration represents the net growth efficiency ($K_2$; Ivlev, 1961) and is a measure of the efficiency with which absorbed ration is converted into body tissues (Paloheimo and Dickie, 1965; 1966; Thompson and Bayne, 1974; Widdows, 1978b; Ansell, 1982). The values of $K_1$ and $K_2$ are negative when the animals are stressed (Thompson and Bayne, 1974; Bayne and Widdows, 1978). The important factors affecting the gross and net growth efficiencies are food concentration (Paloheimo and Dickie, 1966; Conover and Lalli, 1974; Brett, 1979), Temperature (Widdows 1978b; Newell and Branch, 1980) and size (Rodhouse, 1978).
Since the food intake and absorption efficiency of *S. scripta* is found to be varying with salinity, the salinity may effect gross and net growth efficiencies. This study is aimed to delineate the effect of salinity and size on the growth efficiencies of *S. scripta*.

### 3.6.2.2 Materials and methods

The gross and net growth efficiencies were calculated using the following equations:

\[
\text{Gross growth efficiency } K_1 = \frac{A - (R+U)}{C} \quad \text{(Bayne and Widdows, 1978)}
\]

\[
\text{Net growth efficiency } K_2 = \frac{A - (R+U)}{A} \quad \text{(Bayne et al., 1985)}
\]

where

- \( A \) = energy absorbed from food (J/h)
- \( R \) = energy respired (J/h)
- \( U \) = energy excreted (J/h)
- \( C \) = energy consumed (J/h)

The data of \( A, R, U \) and \( C \) for the three different size groups in different salinities were taken from Table 14 a, b, c.
3.6.2.3 Results

The gross growth efficiency of different size groups in different salinities are given in Tables 15 and Fig. 16. The values ranged between -0.6120 to 0.1166 for small size group. For medium and large size groups the values range from -0.6794 to 0.1001 and -1.0308 to 0.0934 respectively. The efficiency is higher for smaller size group when compared to medium and large size groups. For smaller size group the positive values of gross growth efficiency is obtained between 25 and 45 ppt. But for medium size group the positive values are between 25 and 35 ppt and that of large size group is in 30 and 35 ppt. In all the other salinities, for the three size groups the values are found to be negative.

The net growth efficiency of the three size groups in different salinities are given in Table 16 and Fig. 17. The values ranged between -1.0928 to 0.1944 for small size group. The range of values for medium and large size groups are -1.2818 to 0.1615 and -1.9784 to 0.1557 respectively. The smaller size group showed positive values between 25 and 45 ppt. But for medium and large size groups the range got restricted between 25 to 35 ppt and 30 and 35 ppt respectively. In all the other salinities, the values are negative for the three size groups. Both the growth efficiencies showed maximum values in 40 ppt for smaller size group and that of medium and large size groups are 35 and 30 ppt respectively.
Table 15. Gross growth efficiency of different size groups in different salinities

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<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
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Fig. 16 Gross growth efficiency of different size groups acclimated in different salinities (ppt). (Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm)
Table 16. Net growth efficiency of different size groups in different salinities

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Fig. 17 Net growth efficiency of different size groups acclimated in different salinities (ppt). (Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm)
3.6.2.4 Discussion

The results shown in Table 15 and 16 and Fig. 16 and 17 indicate that gross and net growth efficiencies for smaller size group is higher than medium and larger size groups. They could also maintain this efficiencies in a wider range of salinity than medium and large size groups. The higher growth efficiencies for smaller size group can be due to higher weight specific filtration rate. Jorgenson (1976) and Brown et al. (1989) opined that the growth efficiencies will inevitably decline when the food uptake increases less rapidly than respiration with increasing size. Bayne and Widdows (1978) reported that negative relationship between body size and the ratio of weight specific clearance rate to respiration rate, reduces the growth efficiencies of large animals.

Comparing the scope for growth and growth efficiencies of these different size groups, the scope for growth was found to be maximum in 30 ppt for all the three size groups. But the growth efficiencies were maximum in 40 ppt for smaller size group, 35 ppt for medium size group. For larger size group both were maximum in 30 ppt. The higher growth efficiencies exhibited by smaller size group can be mainly due to substantial reduction in oxygen consumption, i.e., energy expenditure in relation to consumption and assimilation. Even though there is a reduction in consumption and assimilation rate than in 35 and 30 ppt, the reduction in oxygen consumption gives the animal
sufficient surplus energy to maintain a higher growth efficiency in 40 ppt, even after taking into account the increased ammonia excretion. The experiments being short-term it may need further verification to know whether the animal will be able to maintain this efficiency for a larger period because the $K_1$ and $K_2$ were found to be lower in 35 ppt for smaller size group.

The higher growth efficiency of medium size group in 35 ppt is again due to substantial reduction in oxygen consumption compared to 30 ppt. Here also consumption and assimilation is not showing a proportionate reduction which allows the animal to maintain a higher growth efficiencies.

3.7 IONIC REGULATION

3.7.1 Introduction

Among the mussels there is a wide spectrum of salinity tolerance from stenohaline to euryhaline (Pierce, 1970). While considering the physiological adaptation to varying salinity, there are three different degrees of control of body fluid composition 1. control of the composition of various ions 2. extra cellular anisosmotic control 3. intra cellular isosmotic regulation. These are inter-related and together controls the cell volume (Duchateau and Florkin, 1956). Ionic regulation is the maintenance of ionic concentrations in the body fluids which are different from the concentrations to be expected, should occur passive equilibrium between the internal and external
media (Robertson, 1964). Among the solutes encountered in living organisms, inorganic ions are important. They participate as cofactors in many enzyme reactions, provide chemical gradients, and influence the permeability of biological membranes to other solutes.

The haemolymph of marine molluscs constitute about 30-80% of the soft parts. The difference between the haemolymph of marine molluscs and the surrounding sea water are often small. Marine species acclimated to a diluted medium exhibits two types of responses 1. their blood remain isosmotic with the environmental medium down to the lower limiting salinity 2. their blood remain hyperosmotic to the surrounding medium (Kinne, 1971). In species without extracellular fluid anisosmotic regulation, the blood remains near isosmotic in all the salinities encountered. In some molluscan species, the blood has been found hyperosmotic in salinities lower than 15 ppt (Freeman and Rigler, 1957; Todd, 1964).

Pierce (1970) examined four species of Modiolus, among these two are poikilosmotic euryhaline and other two are poikilosmotic stenohaline. In all the cases the extra cellular fluids were hyperosmotic to the medium. Pierce (1970) concluded that the hyperosmoticity of body fluid is not a function of species' habitat nor is it an active process, but is due to passive Gibbs-Donnan equilibrium caused by proteins in solution in the blood. This osmotic difference will result in the influx of water into the animal, unless it is opposed by a hydrostatic
pressure in the body fluids. Potts (1954) reported that the permeability characteristic of body are of crucial importance to survival at low salinities. Bivalves with their large surface area (mantle, convoluted gills etc.) exposed directly to the medium will have higher permeabilities which will impose an upper limit on the extent to which their blood can be maintained hyperosmotic to the medium without incurring a very large metabolic cost.

Among the bivalves in general, behavioural responses probably contribute most to their adaptation to fluctuations in salinity. On exposure to extremes of environmental salinity, many marine and brackish water bivalves promptly seal themselves off by closure of valves. In this way they keep the equilibrium with their environment, not only of their internal body fluids, but also of water in their mantle cavities which buffers from their environment (Gilles, 1972; Freeman and Rigler, 1957; Davenport, 1979; Shumway and Youngson, 1979; Widdows, 1985b). However, this mechanism can only help the organism to wait for better condition during a relatively short period of time.

The ions which regulate the extracellular ionic concentrations of bivalves are sodium, potassium, chloride, calcium, magnesium, sulphate and phosphate. Among these the major ions are sodium, potassium and chloride (Potts, 1958; Bricteux-Gregoire et al., 1964). So the ionic regulation of *S. scripta* in different salinities can be followed by estimating the concentration of the major ions such as Na⁺, K⁺ and Cl⁻ of
the haemolymph. This study was undertaken (1) to establish the ion concentration as a function of different salinities (2) to determine the ability of this species to regulate Na\(^+\), K\(^+\) and Cl\(^-\) concentrations in the haemolymph and (3) to study whether ionic regulatory ability has any variation as a function of size, since the tolerance to salinities depends on size.

3.7.2 Materials and methods

The animals of different size groups (small, 1.5 ± 0.5 cm; medium, 2.5 ± 0.5 cm; and large, 3.5 ± 0.5 cm) were acclimated in salinities ranging from 5 to 45 ppt as given in chapter 3.

After proper acclimation five animals of the same size groups were pooled, opened the valves and the mantle fluid were drained out into absorbent paper. The haemolymph were collected from adductor sinus with the help of a syringe. Then the pooled haemolymph was centrifuged at 6000 rpm for 30 minutes and the serum was separated from blood cells. This separated serum was diluted with distilled water and samples were analysed for Na\(^+\) and K\(^+\) by Flame Photometric method (Robinson and Ovenston, 1951; Oser, 1965) using Flame Photometer (Elico, Type-22). The chloride content of the serum was estimated using Chloride Meter (Elico Chloride Meter Model EE-34) which is designed for automatic colorimetric titration of biological fluids.
3.7.3 Results

The Na⁺ concentration estimated in different size groups and salinities of sea water are given in the Table 17. In all the size groups the minimum value is in 5 ppt and that of maximum in 45 ppt. In 25, 30 and 35 ppt the smaller size group is hypoionic to sea water. But the medium and large size groups showed hypoionic state only in 35 and 40 ppt (Table 17). The hyperionic state of smaller size group is below 20 ppt and above 40 ppt. Below 30 ppt and in 45 ppt the medium and large size groups exhibited hyperionic state (Table 17) (Fig. 18).

Table 18 shows the Cl⁻ values obtained for the different size groups acclimated in different salinities and the corresponding sea water salinities. In none of the salinities and size groups showed isosmotic condition with sea water. Small, medium and large size groups, in all the salinities, showed hyperionic state (Fig 19). This hyperionic state is much more pronounced for smaller size group than medium and large size groups (Fig 19). Among the size groups, the Cl⁻ concentration is found to be decreasing as the size of the animal increases.

The different estimations of K⁺ concentration for small, medium and large size groups at salinities ranging from 5 ppt to 45 ppt are given in Table 19. In all the salinities, the three different size groups showed hyperionic state when compared with sea water (Fig. 20). But among size groups the ionic
Table 17. Na+ concentration in different size groups (\( \bar{x} \pm SD \)) and different sea water salinities (\( \mu \)equivalents/ml)

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Sea water</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>70.50</td>
<td>232.61 ± 9.40</td>
<td>215.94 ± 8.15</td>
<td>213.04 ± 7.39</td>
</tr>
<tr>
<td>10</td>
<td>140.48</td>
<td>268.84 ± 14.58</td>
<td>241.16 ± 10.39</td>
<td>239.13 ± 11.19</td>
</tr>
<tr>
<td>15</td>
<td>216.00</td>
<td>303.62 ± 14.84</td>
<td>255.07 ± 12.48</td>
<td>253.51 ± 12.67</td>
</tr>
<tr>
<td>20</td>
<td>275.00</td>
<td>313.04 ± 14.83</td>
<td>285.65 ± 14.78</td>
<td>278.96 ± 11.18</td>
</tr>
<tr>
<td>25</td>
<td>341.30</td>
<td>337.83 ± 13.74</td>
<td>406.38 ± 18.24</td>
<td>374.26 ± 10.30</td>
</tr>
<tr>
<td>30</td>
<td>408.00</td>
<td>372.61 ± 10.57</td>
<td>457.25 ± 12.22</td>
<td>445.70 ± 8.09</td>
</tr>
<tr>
<td>35</td>
<td>480.83</td>
<td>454.35 ± 12.76</td>
<td>478.19 ± 23.40</td>
<td>480.67 ± 10.73</td>
</tr>
<tr>
<td>40</td>
<td>545.00</td>
<td>574.71 ± 10.38</td>
<td>528.41 ± 13.65</td>
<td>508.17 ± 13.16</td>
</tr>
<tr>
<td>45</td>
<td>626.80</td>
<td>636.90 ± 12.20</td>
<td>650.17 ± 13.43</td>
<td>678.26 ± 10.04</td>
</tr>
</tbody>
</table>

Table 18. Cl- concentration in different size groups (\( \bar{x} \pm SD \)) and different sea water salinities (\( \mu \)equivalents/ml)

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Sea water</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>81.34</td>
<td>213 ± 10.59</td>
<td>208 ± 10.33</td>
<td>208 ± 7.88</td>
</tr>
<tr>
<td>10</td>
<td>163.20</td>
<td>249 ± 8.76</td>
<td>248 ± 10.33</td>
<td>227 ± 6.75</td>
</tr>
<tr>
<td>15</td>
<td>240.10</td>
<td>308 ± 11.40</td>
<td>295 ± 13.50</td>
<td>281 ± 7.38</td>
</tr>
<tr>
<td>20</td>
<td>318.00</td>
<td>380 ± 13.30</td>
<td>322 ± 12.29</td>
<td>322 ± 7.89</td>
</tr>
<tr>
<td>25</td>
<td>392.80</td>
<td>478 ± 16.20</td>
<td>456 ± 20.11</td>
<td>450 ± 7.75</td>
</tr>
<tr>
<td>30</td>
<td>480.10</td>
<td>599 ± 13.70</td>
<td>503 ± 14.94</td>
<td>495 ± 11.79</td>
</tr>
<tr>
<td>35</td>
<td>560.80</td>
<td>664 ± 13.50</td>
<td>569 ± 12.87</td>
<td>568 ± 7.89</td>
</tr>
<tr>
<td>40</td>
<td>630.60</td>
<td>745 ± 11.80</td>
<td>696 ± 32.04</td>
<td>667 ± 16.35</td>
</tr>
<tr>
<td>45</td>
<td>720.10</td>
<td>792 ± 10.30</td>
<td>812 ± 30.11</td>
<td>788 ± 7.89</td>
</tr>
</tbody>
</table>
Table 19. K+ concentration in different size groups (\(\bar{x} \pm SD\)) and different sea water salinities (\(\mu\) equivalents/ml)

<table>
<thead>
<tr>
<th>Salinity (ppt)</th>
<th>Sea water</th>
<th>Small (1.5 ± 0.5 cm)</th>
<th>Medium (2.5 ± 0.5 cm)</th>
<th>Large (3.5 ± 0.5 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.90</td>
<td>4.25 ± 0.72</td>
<td>4.15 ± 0.51</td>
<td>3.85 ± 0.44</td>
</tr>
<tr>
<td>10</td>
<td>1.45</td>
<td>7.09 ± 0.96</td>
<td>5.47 ± 0.50</td>
<td>5.00 ± 0.40</td>
</tr>
<tr>
<td>15</td>
<td>4.37</td>
<td>10.32 ± 0.46</td>
<td>5.62 ± 0.34</td>
<td>5.13 ± 0.54</td>
</tr>
<tr>
<td>20</td>
<td>5.83</td>
<td>10.93 ± 0.64</td>
<td>8.16 ± 0.60</td>
<td>7.95 ± 0.30</td>
</tr>
<tr>
<td>25</td>
<td>7.20</td>
<td>12.82 ± 0.35</td>
<td>10.43 ± 0.76</td>
<td>9.64 ± 0.28</td>
</tr>
<tr>
<td>30</td>
<td>8.70</td>
<td>13.05 ± 0.53</td>
<td>11.52 ± 0.38</td>
<td>11.41 ± 0.54</td>
</tr>
<tr>
<td>35</td>
<td>10.20</td>
<td>14.85 ± 1.12</td>
<td>13.21 ± 0.69</td>
<td>13.03 ± 0.34</td>
</tr>
<tr>
<td>40</td>
<td>14.66</td>
<td>20.30 ± 0.51</td>
<td>15.29 ± 1.20</td>
<td>15.26 ± 0.94</td>
</tr>
<tr>
<td>45</td>
<td>17.11</td>
<td>20.74 ± 0.37</td>
<td>20.88 ± 1.95</td>
<td>18.51 ± 1.29</td>
</tr>
</tbody>
</table>
**Fig. 18 Sodium ion concentration (µ equivalents/ml) of different size groups acclimated in different salinities (ppt)** Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm

**Fig. 19 Chloride ion concentration (µ equivalents/ml) of different size groups acclimated in different salinities (ppt)** Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm
Fig. 20 Potassium ion concentration (μ equivalents/ml) of different size groups acclimated in different salinities (ppt) Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm)
concentration is found to be decreasing as the size increases (Fig 20).

3.7.4 Discussion

The results obtained in the present investigations shows that the Cl\textsuperscript{−} and K\textsuperscript{+} concentrations of body fluid are found to be hyperionic to sea water in all the size groups and salinities (Fig. 19, 20). The values showed direct relationship between ionic concentrations of sea water and haemolymph. When the salinity of the water decreases or increases there is a corresponding decrease or increase in Na\textsuperscript{+}, Cl\textsuperscript{−} and K\textsuperscript{+}concentrations (Fig. 18, 19, 20). Among the size groups the smaller size group showed more hyperionic state for Cl\textsuperscript{−} and K\textsuperscript{+} than medium and large size groups. But in the case of Na\textsuperscript{+}, the hyperionic state is not observed in all the salinities. For smaller size group the Na\textsuperscript{+} is found to be hypoionic to sea water in 25 to 35 ppt. But the medium and large size groups showed hypoionic state in 35 and 40 ppt (Table 17). When compared to sea water the hyperionic state of Na\textsuperscript{+} is more pronounced in lowered salinities for all the three size groups (Fig. 18). The difference between the Na\textsuperscript{+} and Cl\textsuperscript{−} of sea water and that of haemolymph is more in 5 ppt than the other salinities. The hyperionic condition of various ions can be due to anisosmotic extracellular regulation. The hyperionic state of ions were also reported by Krogh (1965), Pierce (1970; 1971), Deaton
(1981), Widdows (1985b) and Deaton et al. (1989).

There are various conclusions put forward for the hyperionic state of ions. Pierce (1970) reported that hyperosmoticity of body fluid is due to a passive Gibbs-Donnan equilibrium caused by the proteins in solution in the blood. Another observation is that the difference between ionic concentrations of medium and blood is an indication of active extracellular osmotic control (Wilson, 1968; Bedford and Anderson, 1972). In addition to these Potts (1954) reported the importance of the permeability characteristics of body in the survival of animals. He reported that the bivalves with their large surface area (mantle, convoluted gills etc.) exposed directly to the medium will impose blood hyperosmotic to the medium without incurring very large metabolic cost.

Assuming the Na\(^+\), K\(^+\) and Cl\(^-\) are contributing nearly 100% of the total inorganic ions, their percentage contribution in haemolymph was followed in salinities in the three size groups. It was found that the K\(^+\) concentration remains more or less steady in all the salinities from 5 to 45 ppt (Fig. 21 a,b,c). While the Na\(^+\) concentration showed a decrease when the salinity increased, a corresponding change in Cl\(^-\) was noticed with the salinity decreased. The trend was really pronounced in smaller size group though exhibited by medium and large size group (Fig. 21 a,b,c) The reason for Na\(^+\) accumulation in lower salinities and Cl\(^-\) accumulation in higher salinities needs further investigation.
Fig. 21 a,b Percentage concentrations of Na⁺, Cl⁻ and K⁺ ions for smaller (1.5 ± 0.5 cm) and medium (2.5 ± 0.5 cm) acclimated in different salinities (ppt)
Fig. 21c Percentage concentrations of $\text{Na}^+$, $\text{Cl}^-$ and $\text{K}^+$ ions for large (3.5 ± 0.5 cm) acclimated in different salinities
Although initial changes in the cellular osmolarity are attributed to changes in the levels of inorganic ions, intracellular amino acids (taurine and glycine) play a major role in the total osmolarity of *S. scripta* in various salinities (George, personal communication). Same was also reported by Hochachka and Somero (1973), Gilles (1975) and Hoyaux et al. (1976).

### 3.8 BODY CONDITION INDEX

#### 3.8.1 Introduction

The variations in meat content of bivalve molluscs are depending upon their physiological conditions and impact of environmental parameters. There is a marked seasonal cycle in body condition index of bivalves and this will depend upon the balance between food availability, rates of feeding and rate of catabolism. An increase in body condition index reflects an increase in the organic constituents associated with growth.

Since *S. scripta* is an inhabitant of sandy intertidal regime, it is affected by tidal and seasonal changes in salinity. This variation in salinity causes the reduction in time available for feeding. In addition to this, during monsoon season the animal is severely affected by the very low salinity prevailing on the clam bed (1.5 ppt). During this period energy needed for the maintenance metabolism may be met from the body
reserves. The salinity also plays a major role in the gametogenic condition of *S. scripta* (Katticaran, 1988) which in turn affects the body condition index. So the proportion of internal shell volume which is occupied by the body tissues is likely to vary with salinity condition and hence the estimation of body condition index has its own significance. The body condition index shows the relation between internal shell volume and the total soft tissue mass (Baired, 1966). The body condition index of various mussels and oysters were estimated by Bayne and Thompson (1970); Walne (1970); Gabbott and Stephenson (1974); Gee *et al.* (1977) and Bayne *et al.* (1985). So this study is aimed to understand the effect of salinity on the body condition index of *S. scripta*.

### 3.8.2 Materials and methods

*S. scripta* were collected (from January 1988 to December 1989) from the area as given in chapter 2, were brought in to the laboratory in polythene bags containing sea water collected from the same site. The animals were cleaned and grouped into three size groups, small (1.5 ± 0.5 cm), medium (2.5 ± 0.5 cm) and (3.5 ± 0.5 cm). The body condition index (B.C.I) was calculated using the following equation (Widdows 1985b).

\[
B.C.I = \frac{\text{Dry tissue mass (gm)}}{\text{Shell cavity volume (ml)}} \times 1000
\]
The dry tissue mass was determined by dissecting out the soft body parts and dried at 90°C for 24 hours to constant weight and shell cavity volume was calculated by subtracting empty shell volume from the total displacement volume of the completely closed clam.

3.8.3 Results

Body condition index of three different size groups of *S. scripta* are calculated as monthly mean values for two years (1988 to 1989) and the results are given in Table 20 and Fig. 22. Changes in body condition index are found to be related to the environmental salinity prevailing in the area. The maximum values of body condition index were obtained in January associated with the fattening of tissues in all the three size groups. Variations in body condition index is more pronounced in large and medium size groups than smaller size group (Fig. 22). During South-West monsoon the salinity of the environment decreased due to the influx of fresh water. During the two years of observations the salinity showed wide variations due to the impact of monsoon. The various salinities recorded during the study can be classified into three phases. The first one is the higher salinity period which extended from January to April. During this time the salinity ranged between 32.1 to 34.3 ppt (1988) and 33.1 to 35.1 ppt (1989). The second is the decreasing salinity period which extended from May to August and
Table 20 Monthly variations in Salinity (ppt) and Body condition index of three different size groups

<table>
<thead>
<tr>
<th>Months</th>
<th>Salinity (ppt)</th>
<th>Size Groups</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small (1.5 ± 0.5cm)</td>
<td>Medium (2.5 ± 0.5cm)</td>
<td>Large (3.5 ± 0.5cm)</td>
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<td></td>
</tr>
<tr>
<td>JAN</td>
<td>34.3</td>
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<td>140.8</td>
<td>153.2</td>
<td>246.8</td>
<td>248.8</td>
</tr>
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<td>FEB</td>
<td>34.0</td>
<td>34.3</td>
<td>142.6</td>
<td>148.6</td>
<td>229.6</td>
<td>219.6</td>
</tr>
<tr>
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<td>33.6</td>
<td>34.2</td>
<td>140.6</td>
<td>141.8</td>
<td>174.6</td>
<td>184.6</td>
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<td>135.7</td>
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<td>120.8</td>
<td>136.3</td>
<td>121.6</td>
</tr>
<tr>
<td>JUN</td>
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<td>23.3</td>
<td>116.2</td>
<td>108.8</td>
<td>140.3</td>
<td>120.6</td>
</tr>
<tr>
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<td>100.2</td>
<td>96.6</td>
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</tr>
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<td>112.6</td>
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<td>4.8</td>
<td>122.8</td>
<td>125.8</td>
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<td>NOV</td>
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<td>17.1</td>
<td>144.8</td>
<td>139.8</td>
<td>222.8</td>
<td>216.6</td>
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<td>31.0</td>
<td>150.6</td>
<td>158.1</td>
<td>238.6</td>
<td>241.6</td>
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</tbody>
</table>
Fig. 22 Monthly variations in salinity (ppt) and body condition index of three different size groups. Small, 1.5 ± 0.5 cm; Medium, 2.5 ± 0.5 cm; Large, 3.5 ± 0.5 cm.
salinity decreased from 20.3 to 2.6 ppt (1988) and 23.3 to 1.5 ppt (1989). The third is the rising salinity period, extends from September to December and the values varied from 3.0 to 29.3 ppt (1988) and 2.1 to 31 ppt (1989) (Table 20).

3.8.4 Discussion

The meat content of the bivalve molluscs is depended mainly upon the food availability, environmental and reproductive conditions of the animal. The reproductive cycles of *S. scripta* is related to salinity (Katticaran, 1988) and gametogenic condition interturn affects body condition index. The observations of gametogenic activity indicated a relationship between the three salinity periods (Katticaran, 1988), (a) recovery and slow early gametogenic activity occur during the low salinity period (b) the rising salinity period is associated with gametogenically active phase (c) high and stable salinity period induces the spawning activity.

The maximum values of body condition index for medium and large size groups are obtained in January when there prevails higher salinity conditions (Fig. 22). This is due to the higher food availability and feeding rate. During this time the deposition of maximum amount of fat and the proliferation of reproductive elements occur (Katticaran, 1988) and interturn causes the increased body condition index. Eventhough at the end of January prevails high salinity, a decline in body condition
index occurs for medium and large size groups due to spawning. The very low values of body condition index for medium size is in August but for large is in September. This is due to the compound impact of gametogenic spent condition and the lowered salinity. The lowered salinity due to the influx of fresh water during South-West monsoon inhibit the feeding mechanisms in *S. scripta*. So the body condition index decreases due to the lack of feeding. This condition in turn affects the utilization of body reserves for maintenance metabolism. But on late September the salinity increases and feeding, somatic growth accelerates and it in turn causes the increasing of the body condition index.

For smaller size group the variations in body condition index during the two years observations is less when compared with medium and large size groups (Fig. 22). On the onset of rising salinity period the body condition index is found to be increasing. But during the decreasing salinity due to South-West monsoon, inhibits the feeding rate and the body condition index is also found to be decreasing. This can be due to the utilization of body reserves. Seasonal variations in body condition index were also given for *Ostrea edulis* (Gabbott and Stephenson, 1974); *Mytilus edulis* (Gee et al 1977); *Perna viridis* (Ramachandran, 1980) and *Villorita cyprinoides* (Reddy, 1983) and *Donax incarnatus* (Thippeswamy and Mohan Joseph, 1987). Increase of body condition index starts much earlier in smaller size group than medium and large size groups. For smaller size group it starts from July and for medium and large size groups,
August and September respectively. This is in well agreement with the salinity tolerance of size groups as smaller size group is found to be more tolerant than medium and large size groups.

From the above results it can be concluded that for medium and large size groups both the salinity and gametogenic condition plays a major role in the body condition index while for smaller size group it is due to the impact of salinity because none of the animals below 20 mm are reported for sexual maturity (Katticaran, 1988). The annual reduction in the body condition index in the case of S. scripta population therefore is partly due to salinity and partly due to spawning. Reduction in the body condition index of small size group during low saline period is an indication that salinity plays a role in maintaining the body condition index of the animal.