METABOLIC EFFICIENCY OF *PENAEUS INDICUS* H. MILNE EDWARDS UNDER DIFFERENT SALINITY STRESS CONDITIONS

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D E C L A R A T I O N

I hereby declare that this thesis entitled, "METABOLIC EFFICIENCY OF *PENAEUS INDICUS* H. MILNE EDWARDS UNDER DIFFERENT SALINITY STRESS CONDITIONS" is a genuine record of the research work carried out by me under the scientific supervision of Prof. (Dr) R. Damodaran in partial fulfilment of the requirement of the Ph.D. Degree in the Faculty of Marine Sciences, Cochin University of Science and Technology and that no part of it has previously formed the basis for the award of any degree, diploma or associateship in any university.

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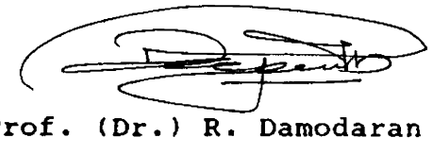
C E R T I F I C A T E

This is to certify that the thesis bound herewith is an authentic record of research work carried out by Mr. C.G. Rajendran under my scientific supervision and guidance in the Division of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin-16 in partial fulfilment of the requirement for the degree of Doctor of Philosophy of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part thereof has been presented for the award of any other degree, diploma or associateship in any university.



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C O N T E N T S

C H A P T E R I

GENERAL INTRODUCTION

The fishery sector in India has remained shrimp-dominated and export-oriented since the first consignment of 13.26 metric tonnes (MT) of frozen shrimp from the Cochin Company left the Cochin harbour for the U.S.A. market in 1953. Demand for tropical shrimp in the world market especially in Japan and U.S.A. has been the major impetus to the development of fisheries in India. Ever since the export market of shrimp got established in the sixties, commercial capture fishery rapidly increased. The year 1993-94 marked a record growth of marine products export from India, the total being 2,43,960 MT worth Rs. 2503.62 crores. The share of frozen shrimp in the export during 1993-94 was 86,541 MT (35.47%) in quantity and Rs. 1770.73 crores (70.73%) in value (Anon., 1994).

India has been one of the world leaders in shrimp production and export for many years. During 1984-89 shrimp export from India increased only marginally from about 55,000 MT to 56,400 MT with a decline in 1985. During 1989-1990 there has been nearly 10% increase in quantity and 34% rise in value. (ADB/INFOFISH, 1991). The rapid increase in commercial fishing resulted in over-fishing in certain regions. Reports show that the stocks have been heavily exploited and that there is very little scope for increasing the catches of shrimp from the traditional fishing

grounds of India (ADB/INFOFISH, 1991). During 1993-94 there was an increase of 16.87% in terms of quantity and 37.68% in terms of value in shrimp export from India, compared to those of 1992-93 (Anon, 1994). To a great extent this is due to the culture practice which is gaining emphasis in prawn production.

In recent years, world shrimp supply has increased rapidly in response to increasing demand. Since the early 1970s landings began to increase and reached 1.6 million MT in 1977 in comparison with 1.09 million MT in 1970. This level remained somewhat stable until 1981 when shrimp production started to rise and reached 2.5 million MT in 1990. The contribution of cultured shrimp has been an important factor in this rise in world production. The share of cultured shrimp in total world shrimp production increased from 6% (90,000 MT) to almost 30% (6,90,000 MT) in 1991 (Yamamoto, 1992). Between 1980 and 1990 the global population grew at a rate of 1.75% per year. Marine capture fisheries increased its production more rapidly than the population growth. However, the growth of capture fisheries leveled off by the end of the decade. On the contrary, aquaculture production grew more than five times as fast as the global population and it may keep growing at a similar pace until and beyond the turn of the century (Imre Csavas, 1994). Despite this rapid growth in aquaculture, shrimp supply continues to be short in all major markets and according to a global fish market

survey by ADB/INFOFISH (1994) in the first seven months of 1994, shrimp prices increased by an average 30%. Imre Csavas (1994) assumes that, based on the UN forecast for population growth, the total volume of captured and cultured fish and seafood for human consumption should be 84.5 million MT in 2000 A.D., 97.2 million MT in 2010 A.D. and 114.8 million MT in 2020 A.D. to meet the demand at the rate prevailed in 1989, when the global supply of fish peaked. Out of these quantities, aquaculture should produce 24.5 million MT, 37.2 million MT and 54.8 million MT respectively for the above years. According to the above report the transition '*from hunting for fish to breeding fish*' is inevitable during the first decades of the next century. Based on the 1984-1992 time series of the FAO Aquaculture statistics, it is assumed that the gap that aquaculture may not be able to fill may increase from 3.4 million MT (or 4% of the total supply) by 2000 A.D. to 12.8 million MT (or 11%) by 2020 A.D. Can the gap between demand and supply be filled by aquaculture is the challenge we have to face. In this context it is expected that the share of cultured crustaceans, however, may increase especially in those countries which are currently lagging behind in aquaculture (Imre Csavas, 1994).

In India very little scope exists for increasing catches of penaeid shrimps from the traditional shrimp grounds. Unlike the shrimp capture fishery, shrimp farming holds excellent potential

for growth along the Indian coasts. Out of the total of 103 shrimp producing countries listed by FAO, 10 of the top countries are from Asia including China, Thailand, India, Indonesia, Philippines, Malaysia and Vietnam (Table 1.1). However, India has the lowest percentage of cultured shrimp among the shrimp producing countries. During 1980-87 her share was approximately 5-8%. Shrimp farming started to grow afterwards and its share in the total production peaked at 12.5% in 1989, but an increase in the output of captured shrimp in 1990 reduced it again to about 10% (Imre Csavas, 1992). The production of shrimp from brackish water culture increased from 10,722 MT in 1981 to 25,000 MT in 1989, registering a growth of 133%. The area under culture steadily increased during the above period from 27,000 Ha to 55,500 Ha; an increase of 105% (ADB/INFOFISH, 1991) (Table 1.2). The potential brackish water area suitable for shrimp farming in India is estimated as 1.4 million Ha of which only 65,000 Ha are under shrimp farming as reported by ADB/INFOFISH (1991). Most of this area, particularly in W.Bengal, Kerala and Karnataka are under the traditional farming system of trapping, holding and harvesting. The productivity has been low ranging from 300 to 500 kg per Ha. Attempts are being made to raise productivity to at least 1 MT per Ha by selective stocking, supplementary feeding and better farm management practices. Recently in Andhra Pradesh, Tamil Nadu and Orissa several new farms have been set up following intensive or semi intensive practices and some of them

Table 1.1 Major cultured shrimp producing countries of the world during 1993

Country	Heads on Production (Metric tonnes)	Hectares in production	Kg/ hectare	No. of hatcheries	No. of Farms
A. Western Hemisphere					
Ecuador	90,000	90,000	1,000	200	1,250
Columbia	9,000	2,700	3,333	14	26
Honduras	9,000	8,000	1,125	5	30
Mexico	9,000	8,000	1,125	12	140
U.S.A.	3,000	900	3,333	7	20
Others	12,000	6,000	2,000	15	150
Sub Total	1,32,000	1,15,600	1,142	253	1616
B. Eastern Hemisphere					
Thailand	1,55,000	60,000	2,583	1,200	14,000
Indonesia	80,000	2,00,000	400	200	15,000
India	60,000	80,000	750	30	4,000
China	50,000	1,40,000	357	800	3,500
Vietnam	40,000	2,00,000	200	120	1,000
Bangladesh	30,000	1,10,000	273	9	4,500
Philippines	25,000	40,000	625	170	3,000
Taiwan	25,000	7,000	3,571	200	2,000
Others	12,000	10,000	1,200	30	1,200
Sub Total	4,77,000	8,47,000	9,959	2,759	48,200
Grand Total	6,09,000	9,62,600	11,101	3,012	49,816

Source: World shrimp farming-1993, Aquaculture Digest-December 1993)

Table 1.2 State-wise details of shrimp farming in India

State	Estimated brackish water area (Ha)	Area under culture (Ha) 1992-93	Estimated production (MT) 1992-93
West Bengal	4,05,000	34,050	16,300
Orissa	31,600	7,760	4,300
Andhra Pradesh	1,50,000	9,500	12,800
Tamil Nadu	56,000	530	1,100
Pondicherry	800	negligible	negligible
Kerala	65,000	13,400	9,750
Karnataka	8,000	2,570	1,150
Goa	18,500	550	350
Maharashtra	80,000	1,980	1,050
Gujarat	3,76,000	360	200
Total	11,09,900	70,700	47,000

(Source: World shrimp farming-1993, Aquaculture Digest-December 1993)

have been able to harvest more than 2 MT per Ha per crop.

India's programme for the promotion of brackish water shrimp farming is a long-term one and it is likely to be continued with more emphasis on semi-intensive method of farming during 1995-2000. The objective is to extend shrimp farming to a further area of 45,000 Ha of which 25,000 Ha would be brought under semi-intensive farming which can yield at least 5 MT per Ha (ADB/INFOFISH, 1991). Although the projected expansion envisages utilization of only about 14% of the estimated potential of about 1 million Ha available for brackish water shrimp farming, it will enable India to achieve a threefold increase in shrimp production by 2000 AD. Considerable scope exists for increased production through the exploitation of the vast potential for shrimp farming and high priority for this has been given in the development programme in the next decade.

Unlike capture fishery, cultured shrimp supply can be planned ahead and at least in the tropics, can be continuous. However, the advantages in this respect are not fully utilized by shrimp farmers in India and their stocking and harvesting are still seasonal. But several major shrimp producers in the tropics are in a position to implement year-round farming. This, according to Imre Csavas (1992) may require some additional investments and certainly more innovative thinking, but would

help to keep shrimp farming profitable in an increasingly competitive economic environment.

All the penaeid shrimps breed in the offshore waters at different depths and the larval and post-larval stages enter the lagoons, creeks, estuaries and brackish waters along the coasts as a part of planktonic migration. The estuarine areas are suitable nurseries offering the required ecological niches for their growth (George and Rao, 1968; Rao, 1983). It has been observed that the larvae of shrimps move towards the shore along with the flow of water during high tide and the juveniles move away from the shore along with the flow of water during low tide and that the regulatory influence of salinity changes on this pattern of migration differs according to the stage of the life cycle of the shrimp (Wikins, 1976). Shrimps suitable for coastal aquaculture are generally endowed with wide range of adaptability to tolerate fluctuations in the physico-chemical conditions of the environment. As Kinne (1971) pointed out, salinity is the major environmental factor whereas the temperature fluctuations characteristic to the tropics are not significant. George (1968) also, has observed that salinity, perhaps more than any other, is the single factor affecting shrimps in the brackish water environment. It is also a factor known to influence the efficiency of a species to utilize the food given (Kalyanaraman and Paul Raj, 1984). Therefore studies of the responses of the

shrimps to the changes in environmental conditions, especially salinity, are essential to determine optimum conditions for successful shrimp farming. High output can be achieved only by exerting control over the environment by reducing stress conditions (Wikins, 1976).

Of the 27 species of shrimps belonging to Penaeidae occurring in Indian coastal waters, 11 species have been reported to be suitable for culture (Rao, 1983). Among these, the Indian white shrimp *Penaeus indicus* and the black tiger shrimp *P.monodon* are the most popular. According to FAO (1992) report *P. indicus* occupied the 7^{th} position among the 15 cultured species of shrimps in different parts of the world in 1990 with a production of 5,61,900 MT and in 1993 6,09,000 MT. The present investigation is aimed at understanding in detail, the effects of salinity on the energy budget of *P. indicus* by studying its food intake and conversion, growth, oxygen consumption and ammonia excretion.

BIOLOGY OF *PENAEUS INDICUS* H.MILNE EDWARDS

The regional distribution of *P. indicus* ranges from the coasts of India and Sri Lanka to the west through the Gulf of Aden to Madagascar and east coast of Africa and to the east through Malaysia and Indonesia to Philippines, New Guinea and

northern Australia (George, 1969).

Large number of larval forms in advanced stages are present in the inshore surface waters in Cochin during all the months of the year except June to September, the peak recruitment being in November to December and February to April (George, 1962).

Post-larval stages of the species (8 to 14 mm in total length) are represented in the plankton of the estuaries and the surf region. Around Cochin, considerable quantity of post-larvae are used as seed for the culture of the species in paddy fields. Seed is usually collected from the surf region as well as from the canals adjoining the backwaters (George and Suseelan, 1982).

The post-larvae migrate to the estuaries and backwaters for feeding and growth and return to the sea for breeding (George, 1979). Sexually mature adults occur only in the sea. The species is heterosexual. The sexes can be distinguished by morphologically differentiated external characters such as petasma in the first pleopod in males and thelycum on the thoracic sternite in females. Females attain larger sizes than males (George, 1979).

The size of the females at first maturity is 130.2 mm and that of males is 102 mm. Fertilization is external (Rao, 1977).

Fecundity ranges from 68,000 mature ova in female of 140 mm size to 731,000 in that measuring 200 mm (Rao, 1977). Spawning season starts from October and extends up to June in Cochin waters with peak spawning in November - December and February - April (Rao, 1977). It has been been reported that individuals spawn 5 times during their life time with an interval of 2 months between two successive spawnings. Breeding of the species takes place in the sea in relatively deeper waters (Rao, 1977).

Larval history consists of 6 nauplii, 3 protozoea and variable number of mysis stages (3-7) before becoming post-larvae. The earliest post-larval stage is observed 12 days after spawning (Rao, 1977).

The maximum size attained by the species is 230 mm. The largest size recorded in the backwater catches is 167 mm (George, 1969). *P. indicus* feeds on both vegetable and animal matter. Vegetable matter includes diatoms, other planktonic and benthic algae and sea weeds whereas animal matter consists of small crustaceans, molluscs, polychaetes, echinoderm larvae, hydroids, trematodes and foramniferans (George, 1969).

Growth rate of the species varies from place to place. In the estuarine environment, juveniles grow at an average monthly rate of 10 mm in the Cochin backwaters and Chilka Lake, 14.4 -

16.0 mm in Ennur and Adayar (Tamil Nadu) estuaries and 17.1 mm for males and 19.5 mm for females in the Manakudy Lake (Kanyakumari District). In the marine regions, the males and females of the species grow at an average monthly rate of 9.8 mm and 7.2 mm, respectively at Ambalapuzha (Kerala), 5.2 and 5.7 mm at Colachel and 5.6 and 7.0 mm at Madras (George, 1969). Studies on the age and growth of the species have indicated that males and females attain a length of 156 and 138 mm, respectively at the end of the first year and 189 and 181 mm at the end of the second year of life (George and Suseelan, 1982).

In India, *P. indicus* is one of the prominent species used for semi-intensive shrimp culture. An understanding of the optimal environmental requirements of the species is one of the prime necessities in any culture operation. Brackish water organisms are generally endowed with wide range of adaptability to withstand extreme fluctuations in physical conditions, especially so in the case of salinity. Salinity is a most important factor that is known to influence the efficiency of a species in food utilization and growth (Kalyanaraman and Paul Raj, 1984). Therefore it is necessary to understand the extent of the influence of salinity on the feed utilization by the cultured organism. It is more significant, because feeds comprise one of the major expenditure items in shrimp farming. Hence, it was found necessary to study the effect of salinity on

food conversion, growth, oxygen consumption and ammonia excretion of different size groups of *P. indicus* and to understand the energy equation.

CHAPTER II

EFFECT OF SALINITY ON GROWTH AND FOOD CONVERSION RATIO

INTRODUCTION

In shrimp culture system salinity is considered to be the major factor influencing growth and survival. Penaeid shrimps spend the early stages of their life cycle in estuaries where salinity may fluctuate drastically as stated. This influence the survival and growth of penaeid shrimps. The effects of salinity on the growth of penaeid shrimps have been subjected to extensive studies. Zein Eldin (1963) found that under conditions of constant temperature and restricted food supply penaeid post larvae survived and grew over a wide range of salinity (2-40 ppt). Zein Eldin and Aldrich (1965) observed that salinity has little effect on either survival or growth of post larvae *Penaeus aztecus* except at extreme temperature. Zein Eldin and Griffith (1967) studied the effect of salinity and temperature on *P. duorarum* and *P. setiferus* from the Gulf of Mexico. Earlier studies have highlighted that salinity influences the survival and growth of penaied post larvae and juveniles (Nair and Krishnankutty, 1975; Verghese et al., 1975; Bhattacharya and Kewalramani 1976; Kuttyamma 1982; Lakshmi Kanthan 1982; Raj and Raj, 1982; and Subramanian and Krishnamurthy, 1986).

The cumulative effect of temperature and salinity on the

feeding level, growth and food conversion efficiency of shrimps was reported by Venkataramaiah et al. (1972 and 1975). Influence of salinity on food intake, conversion efficiency and biochemical composition *P. indicus* was studied by Kalyanaraman and Paul Raj (1984). Most of the earlier studies depended only on length increase as the dependent parameter.

However it is felt that weight changes will be more reflective of the prevailing environment enabling an effective comparison of growth. The present study is an attempt to understand the effect of salinity on growth, oxygen consumption and ammonia excretion, food conversion efficiency and energy budget of *P. indicus*. Such a comprehensive study is vital for the successful operation of any shrimp culture system and this chapter deals with the effect of salinity on growth and food conversion ratio.

MATERIALS AND METHODS

The juverniles of *Penaeus indicus* were collected from the farms of the Kerala Agricultural University Fisheries Station, Puduvype and the College of Fisheries, Panangad in Cochin. They were thoroughly cleaned and kept in hapas (rectangular nylon net screen) for 2-3 hours. Then they were transported to the laboratory in oxygen filled bags and released into circular fibre

glass tanks containing water of the same salinity as that of the habitat. In order to minimize cannibalism, shrimps were grouped into different size groups and each group was maintained in separate tanks,during the entire period of experiment. The shrimps were collected during December to April when the salinity of the habitat ranged between 10-30 ppt. The water in the tanks was well aerated daily. The shrimps were fed *ad libitum* with pelleted feed (Sherief, 1987) and maintained for one week before transferring to different test salinities for experimentation.

Preparation of test media

Sea water brought from the Cochin bar-mouth was used for the experiments. The test media were prepared by mixing filtered sea water and fresh water in proportions calculated using the following formula

$$V = \frac{S_1}{S_2} \times 1000$$

where,

V = volume of sea water to be diluted to make one litre of test medium of required salinity.

S_1 = required salinity

S_2 = salinity of sea water

Hydrographic Parameters

Salinity was determined by Mohr - Knudsen titrometric method and dissolved oxygen by standard Winkler's method (Strickland and Parsons, 1972). Total alkalinity was found out by acidimetric titration method (APHA, 1985), pH by electrometric method using a digital pH meter and the temperature was measured with a mercury bulb thermometer of 0.1°C accuracy.

Circular fibre glass tanks of 20 litre capacity were used for rearing shrimp larvae in the different test salinities. The density of the shrimps were adjusted as 1 animal per 4 litre water. The tanks were continuously aerated except at the time of feeding and removal of waste materials. Water was changed in the experimental tanks daily. The salinity in the tanks were maintained without fluctuation ($\pm$ 0.25 ppt). The oxygen concentration and pH in the tanks were monitored twice daily in the morning and evening. The dissolved oxygen never fell below 90% saturation, while the pH was observed to be in the range of 7 $\pm$ 0.05. The water temperature was maintained at 28 $\pm$ 1° C.

Feed

Pelleted feed was given during acclimatization and experiments. It was prepared as described by Sherief (1987) using clam meat powder (40%), ground nut oil cake (25%), rice bran (25%) and tapioca powder (10%). The proximate composition

of the compounded feed, crude protein 42.32% crude fat 4.39%, carbohydrate 23.45%, crude fibre 14.79%, ash 9.75% and moisture 5.3%. The energy value of the feed was worked out to be 15,860.28j/g applying the conversion rate of 5.68 k cal/g for protein, 9.45 k cal/g for fat and 4.2 k cal/g for carbohydrate.

Optimum feeding ration

In the shrimp farms of Kerala stocking of *P. indicus* seed are usually done during the months of November - December months, when the salinity of the fields never exceeds above 20 ppt. The farms located away from the bar mouth often experience salinity around 10 ppt during this period. Therefore it was decided to restrict the feeding experiments in salinity 10 and 20 ppt for *P. indicus* juveniles. The animals were starved for 24 hours before transferring to the required salinity. The weight of the shrimps were carefully determined using an electronic balance. The experiments were conducted in 20 l round fibre glass tanks and shrimps were stocked at the rate of 1 animal per 4 l of test medium. To understand the optimum feeding level feed was given at 0, 10, 20 and 30% of the weight of the animals stocked and optimum feeding ration was found out. The total period of the rearing was limited to 21 days. For each salinity experiment was replicated 8 times. The weight of the experimental animals were found out by taking the wet weight of the animal after drying with a filter paper. This weight was used to adjust the quantum

of ration for every week. The experiment was terminated on the 21st day and the weight of the animals was taken after starving for a period of 24 hours. During the experiment period water was changed partially and food materials and excreta were collected separately and weighed.

The dissolved oxygen in the experimental tanks varied from 4.2 to 5.6 ml/l, pH from 7 to 7.5, temperature from 27°C to 29°C. The growth rate was determined using the following formula

$$\text{Growth rate \%} = \frac{\dfrac{(\text{Final wt.} - \text{Initial wt.})}{(\text{Initial wt.} + \text{Final wt.})}}{2} \times 100 \times \text{Period of rearing (days)}$$

The optimum feeding ration was determined by the graphical method. Growth rate (Y-axis) was plotted against percentage of ration (X-axis)

The optimum feeding ration was interpolated from the point of the straight line larching the curve and passing through the origin and it was found to be 18% of the body weight for the size groups 30-35 mm and 50-55 mm in two salinities, 10 and 20 ppt. (Fig.2.1, 2.2, 2.3 and 2.4).

Growth in different salinities

Animals after acclimatization were transferred to different test salinities 0, 5, 10, 15, 20, 25, 30 and 35 ppt. The shrimps were starved for 24 hours prior to the transfer to test salinities and the individual weights of shrimps were determined. Pelleted feed was given at the rate of 18% based on the results obtained in the optimum feeding ration studies in 10 and 20 ppt salinity. The daily ration was halved and supplied in the morning and evening. The left-over feed, if any, was collected in the following day, using a pipette and dried in an oven at 60°C to constant weight. The excreta was also collected and treated in the same way. On every 7th and 14th day the shrimps were weighed after starving them for 24 hours. The feeding ration was increased according to the estimated biomass every 7^{th} day. The rearing was terminated on the 21st day , after which the shrimps were starved for 24 hours and used for oxygen consumption and ammonia excretion studies. After the experiments wet weight of the animals was determined and then they were dried in an oven at 60° C to constant weight for dry weight estimation.

The dissolved oxygen, pH and temperature in the tanks were monitored daily. The dissolved oxygen varied in the experiment tanks from 4.2 to 5.6 ml/l, pH from 7 to 7.5 and temperature from 27°C to 29° C. The growth rate and the food intake and food conversion rates were calculated using the formula mentioned earlier.

The relative growth rate was calculated as per the equation given earlier. The food conversion ratio (FCR) was determined in the following way.

$$FCR = \frac{\text{Food intake (dry weight)}}{\text{Weight gain (wet weight)}}$$

Food intake = Total food supplied - food left over

RESULTS AND DISCUSSION

There are only very few studies on the optimum feeding ration by studying the relation between ration, size groups and salinity in *P.indicus*. So an integrated approach was taken to study the optimum feeding ration in two salinities for two different stocking sizes of shrimps. This information is very vital for meaningful shrimp culture operation.

Optimum feeding ration (Fig.2.1, 2.2, 2.3 and 2.4)

The salinity of Cochin backwaters never exceeds 20 ppt during the stocking period (November - December) of *P. indicus* (Qasim *et al.*, 1969). Prawn farmers of Kerala stock *P. indicus* larvae usually during November - December months. Farms located away from the barmouth often experience salinity around 10 ppt

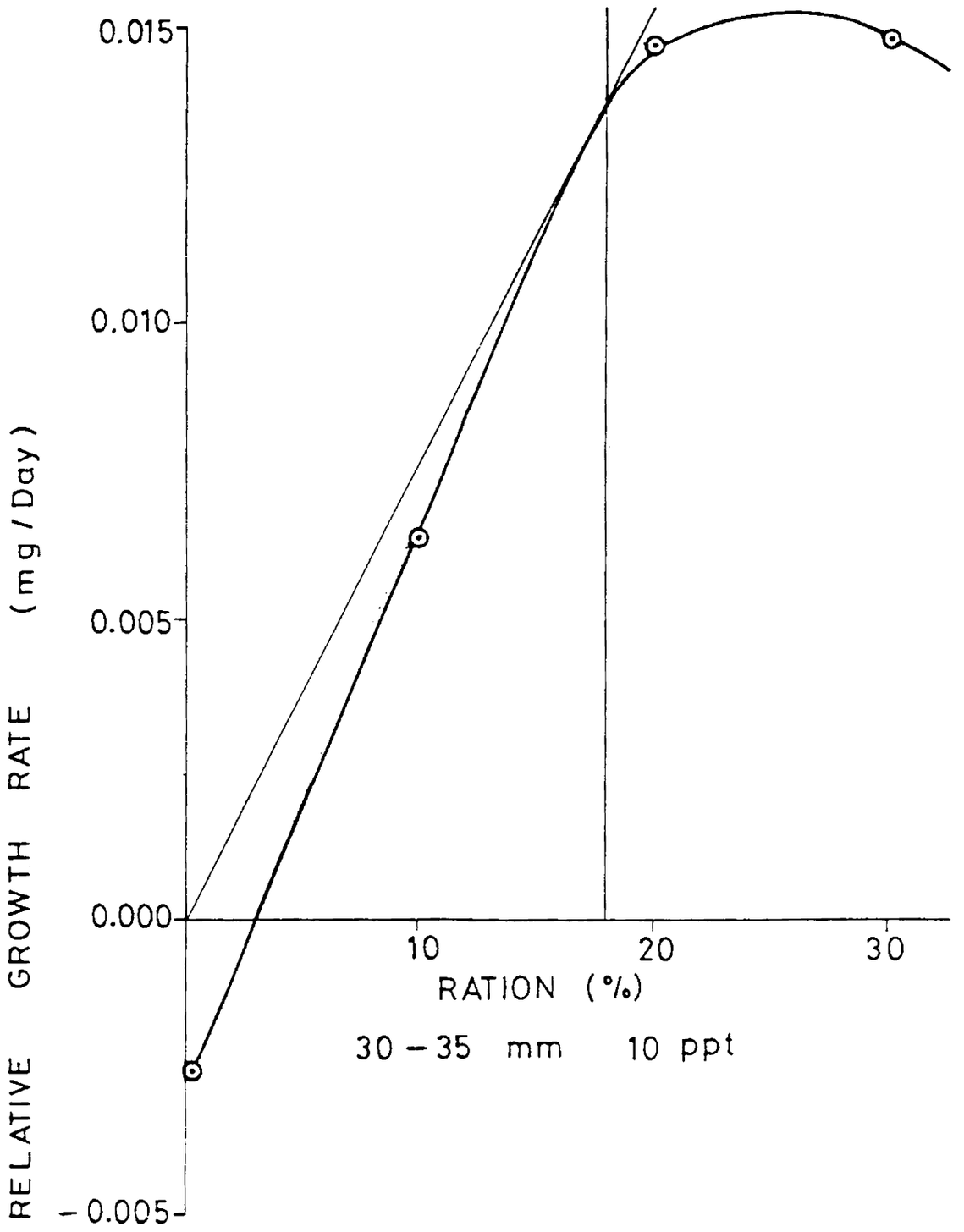

Fig. 2.1 Growth in relation to ration of *P. indicus* of 30-35 mm size group in 10 ppt salinity

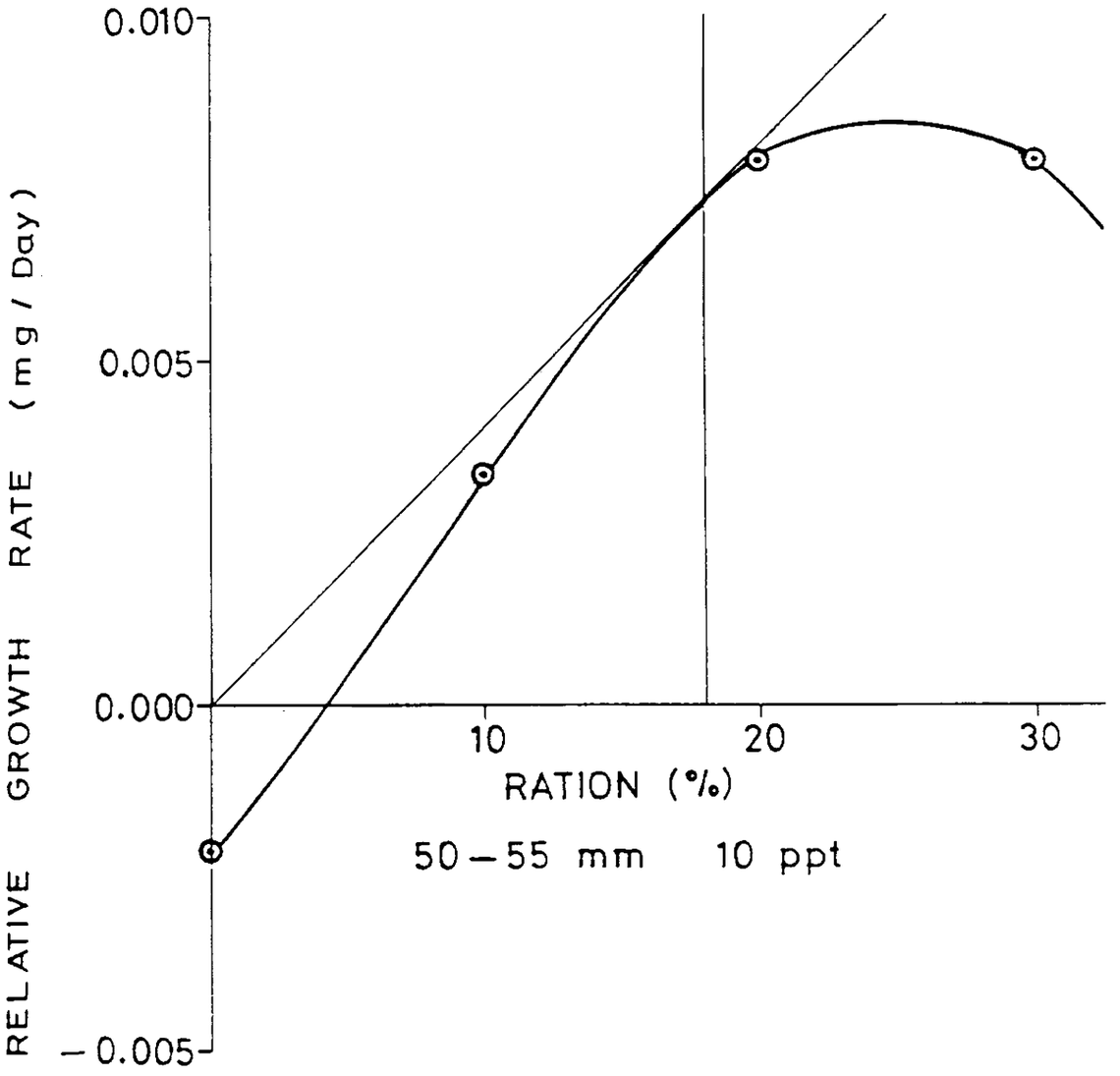

Fig. 2.2 Growth in relation to ration of P. indicus of 50-55 mm size group in 10 ppt salinity

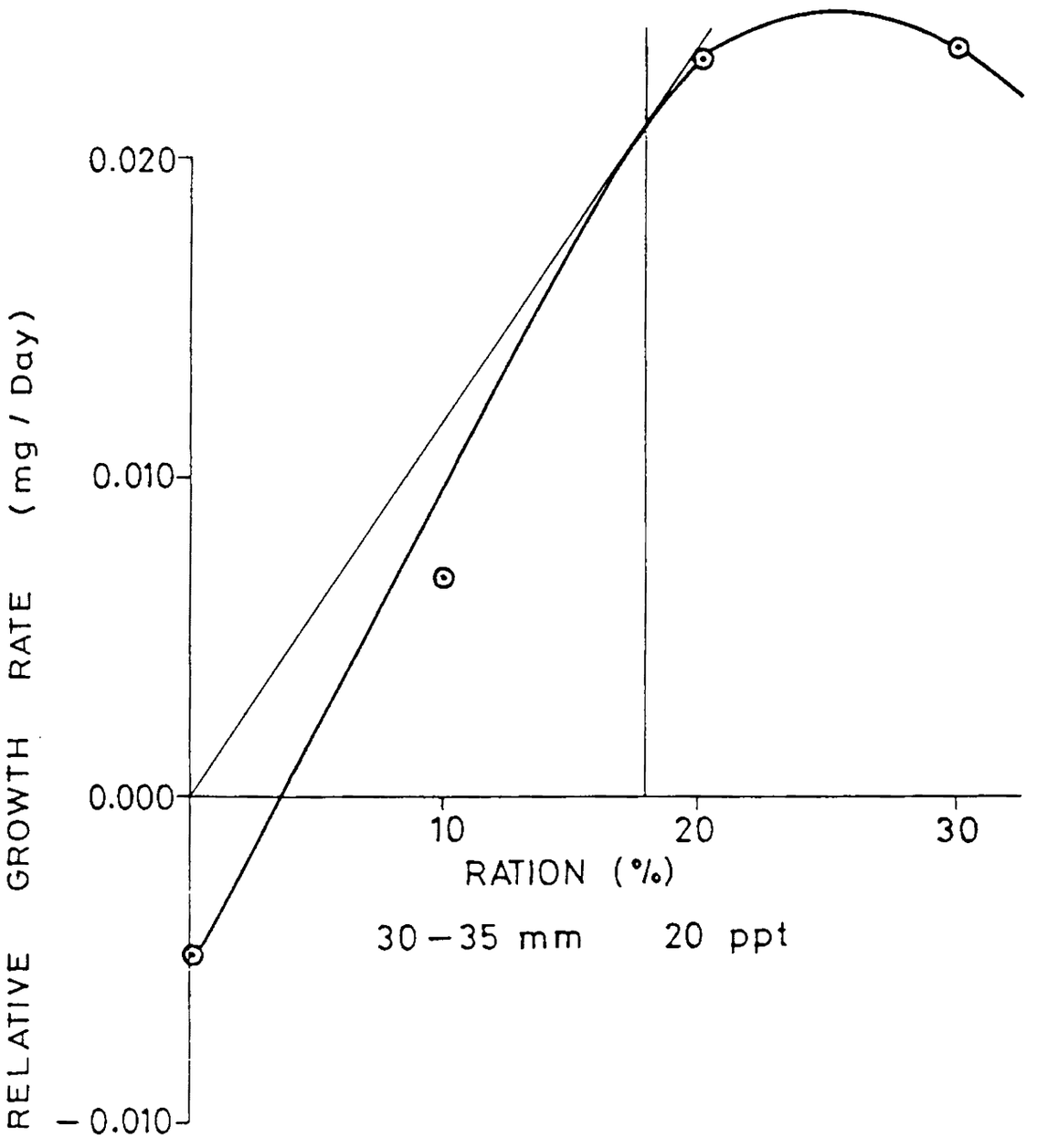

Fig. 2.3 Growth in relation to ration of P. indicus of 30-35 mm size group in 20 ppt salinity

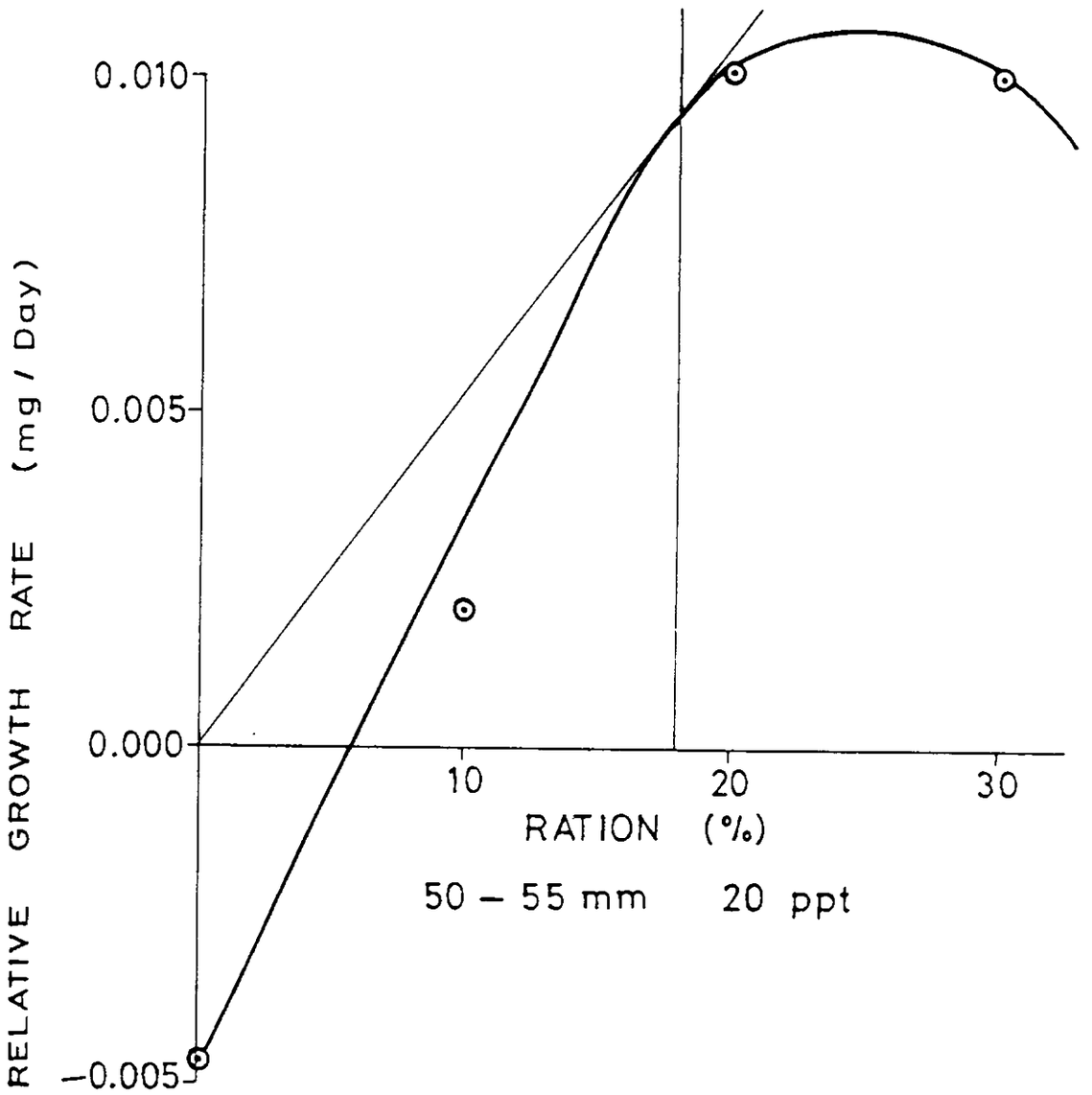

Fig. 2.4 Growth in relation to ration of P. indicus of 50-55 mm size group in 20 ppt salinity

during this period. Therefore to find out the optimum feeding ration, experiment was conducted in 10 and 20 ppt salinity with feeding ration of 0, 10, 20 and 30% for two size groups of *P. indicus*, 30-35 mm and 50-55 mm (Table 2.1). Comparing the relative growth rate between salinities, higher values are recorded at 20 ppt. Comparison of the growth rates between the size groups the smaller size group (30-35 mm) showed faster relative growth rate. The optimum feeding ration interpolated from the graph shows that in 20 ppt salinity as well as in the subnormal salinity of 10 ppt, the optimum daily feeding ration for the two size groups is 18% of the body weight. As the ration increases the growth rate also increases, reaches a peak after which the growth rate is found to be indifferent to any increase in the ration. This optimum ration of 18% was used for growth studies in the different test salinities. However, Kalyanaraman and Paulraj (1984) have reported for juvenile *P. indicus* 20 % as the optimum feeding ration.

Growth rate and food conversion ratio

The relative growth rate and food conversion ratio (FCR)for the two size groups 30-35 mm and 50-55 mm are presented in Table 2.2 and 2.3. Among the different salinities studied (5, 10, 15, 20, 25, 30 and 35 ppt) the highest growth rate was observed in 20 ppt for both size groups. Table 2.4 gives Anova test also indicates that the growth rate at 20 ppt is significantly higher

Table 2.1 Relative growth rate (mg/day) of *P.indicus* for different feeding ration at 10 and 20 ppt salinity (± SD)

	10 ppt					
	30-35 mm			50-55 mm		
Ration	Days					
	7	14	21	7	14	21
0%	-0.0013	-0.0024	-0.0026	-0.0011	-0.0018	-0.0021
	±0.0018	±0.0006	±0.0007	±0.0007	±0.0004	±0.0002
10%	0.0067	0.0066	0.0064	0.0031	0.0029	0.0033
	±0.0013	±0.0007	±0.0008	±0.0006	±0.0005	±0.0003
20%	0.0156	0.0149	0.0147	0.0069	0.0066	0.0079
	±0.0029	±0.0029	±0.0012	±0.0014	±0.0011	±0.0005
30%	0.0160	0.0139	0.0148	0.0083	0.0079	0.0079
	±0.0038	±0.0022	±0.0012	±0.0009	±0.0015	±0.0004
	20 ppt					
0%	-0.0028	-0.0031	-0.0048	-0.0021	-0.0038	-0.0046
	±0.0007	±0.0013	±0.0007	±0.0006	±0.0002	±0.0002
10%	0.0060	0.0061	0.0068	0.0027	0.0029	0.0021
	±0.0009	±0.0009	±0.0008	±0.0008	±0.0005	±0.0001
20%	0.0321	0.0252	0.0233	0.0107	0.0107	0.0108
	±0.0005	±0.0027	±0.0015	±0.0018	±0.0014	±0.0005
30%	0.0252	0.0241	0.0237	0.0123	0.0109	0.0108
	±0.0075	±0.0059	±0.0016	±0.0007	±0.0007	±0.0003

Table 2.2 Relative growth rate and food conversion ratio of *P. indicus* (size group: 30-35 mm) in different salinities

Salinity (ppt)	Initial wt.(mg)	Final wt.(mg)	Relative growth rate (mg/day)	FCR
5	265 ±12.51	268 ±12.60	0.005 ±0.001	6.68 ±0.45
10	279 ±7.55	377 ±13.85	0.0139 ±0.00023	6.01 ±0.23
15	280 ±6.56	411 ±14.33	0.018 ±0.00008	5.01 ±0.33
20	282 ±11.41	531 ±41.67	0.0298 ±0.0043	4.03 ±0.37
25	282 ±9.07	477 ±27.91	0.0240 ±0.0024	4.80 ±0.30
30	279 ±8.24	418 ±16.35	0.0185 ±0.0012	5.53 ±0.21
35	281 ±7.85	306 ±9.30	0.0042 ±0.0004	6.52 ±0.26

Table 2.3 Relative growth rate and food conversion ratio of *P. indicus* (size group: 50-55 mm) in different salinities

Salinity (ppt)	Initial wt.(mg)	Final wt.(mg)	Relative growth rate (mg/day)	FCR
5	698 ±3.06	703 ±3.03	0.00355 ±0.00007	6.60 ±0.23
10	695 ±7.89	802 ±9.35	0.00678 ±0.00052	6.45 ±0.26
15	700 ±11.41	817 ±19.47	0.00726 ±0.00114	4.72 ±0.24
20	705 ±7.04	873 ±9.77	0.01019 ±0.00007	4.46 ±0.27
25	699 ±9.21	782 ±8.05	0.00530 ±0.00072	4.78 ±0.15
30	703 ±12.88	784 ±10.56	0.00520 ±0.00059	5.58 ±0.18
35	699 ±11.58	731 ±11.60	0.00220 ±0.00033	6.62 ±0.17

Table 2.4 Analysis of variance test of growth rate of *P. indicus* between different salinities for the two size groups 30-35 mm and 50-55 mm

Source	SS	d.f	M.S	F
Total	0.0086389	111		
Replication	0.00001849671	7		
Treatment	0.0084599546	13	0.00065076	368.70**
Size	0.0029333817	1	0.00293338	1662.08**
Salinity	0.0041854633	6	0.00069757	395.22**
Size x Salinity	0.0013412	6	0.00022353	126.64**
Error	0.0001606	91	0.00000176	

than the growth rates in all the other salinities for both the size groups.

Table 2.5 shows the result of the Anova test for FCR values. Most advantageous FCR value was recorded in 20 ppt salinity is significantly different from all other salinity levels. The FCR at salinity levels of 25 ppt and 15 ppt are similar and superior to the remaining salinities. The size in salinity interaction effect was not significant.

George (1968) observed that in *Metapenaeus monoceros* growth rate is lower in larger specimens. Rajyalekshmy (1961) reported that in *M. brevicornis* the specific growth rate is the highest in the young animals and it decreases with size. In the case of *P. indicus*, Nair and and Krishnankutty (1975) reported the optimum salinity for growth as 30 ppt. The most suitable salinity range for the pond culture of *M. monoceros* in Taiwan is reported as 15 - 20 ppt (Chen, 1976). Higher salinity levels are found to be preferred by certain penaeid shrimps especially those which do not migrate towards estuaries as in the case of *P. japonicus* which prefers 23-47 ppt salinity (IMAI, 1977) and in the case of *P. lalisukatus* which prefers 25-45 ppt salinity (Ramaswamy and Pandian, 1985). It would be seen that all these salinity levels are somewhere in the middle of their tolerance level.

Table 2.5 Analysis of variance test of food conversion ratio of *P. indicus* between different salinities for the two size groups 30-35 mm and 50-55 mm

Source	SS	d.f	M.S	F
Total	97.3049119	111		
Replication	0.7227679	7	0.10325	1.25
Treatment	89.068661	13	6.8514354	82.98**
Size	0.1222322	1	0.1222322	1.47
Salinity	87.501786	13	6.7309066	81.52**
Size x Salinity	1.4446428	13	0.1111263	1.34
Error	7.5134821	91	0.0825657	

Raj and Raj (1982) observed 25 ppt as the best salinity for growth in *P. indicus* and *P. monodon*. Kuttyamma (1982) reported maximum growth of *M. monoceros* juveniles in 20 ppt salinity during laboratory studies for a period of one month. But when they were grown for a period of one year, she found 25 ppt as the optimum salinity for growth. She obtained maximum growth of post larvae of *P. indicus* in 20 ppt and that of juveniles in 25 ppt. Maximum growth of post larvae of *M. dobsoni* was noticed by her in 15 ppt and that of the juveniles in 20 ppt salinity. In *M. monoceros* juveniles the percentage weight increase was higher in 28 ppt salinity than in 15 ppt (Suresh Babu, 1990).

Effects of salinity and feeding levels on the growth and food conversion rates of *P. aztecus* were studied by Venkata Ramiah *et al*. (1972, 1975). Influence of salinity on food intake, conversion efficiency and biochemcal composition of *P. indicus* was studied by Kalyanaraman and Paul Raj (1984). They found that smaller *P. indicus* (total length, 13-14 mm) requires an optimum salinity of 28 ppt and those of 26 - 32 mm 20 ppt.

Results of the present investigation show that in *P. indicus* salinity influences food intake growth and food conversion rate significantly. In both size groups the best FCR and growth rate were observed at 20 ppt salinity. The 20 ppt salinity appears to be ideal for shrimp farming. But, in most of the Pokkali paddy

fields used for shrimp farming in Kerala, the salinity is found to vary between 10 - 25 ppt. Hence, it indicates that the stocking should be done while the salinity is around 20 ppt and it should be maintained during the entire shrimp farming season to ensure the best harvest of shrimps.

C H A P T E R III

OXYGEN CONSUMPTION AND AMMONIA EXCRETION

INTRODUCTION

The metabolic rates of animals are influenced by various intrinsic and extrinsic factors (Vernberg and Vernberg, 1972). The intrinsic factors are size, activity, nutritive state, sex etc. The various extrinsic factors include salinity, temperature, light, oxygen content, pH etc. Since various intrinsic and extrinsic factors interact together, it is essential to determine the metabolic rate in terms of oxygen consumption and ammonia excretion which are being attempted in the present case as a function of a single factor, keeping the other parameters constant.

Salinity is one of the most important parameters influencing aquatic animals. *Penaeus indicus* is a species cultivated in regions with varying salinities. Further, even in the same region, seasonal and diurnal salinity fluctuations are a common feature. Organisms subjected to salinity stress exhibit various metabolic adaptations. Following a sublethal change in salinity, a new steady metabolic state is attained which is influenced by the past history of the animal as well as the action of various intrinsic and extrinsic factors. Kinne (1971) has generalised the metabolic responses of aquatic invertebrates within the

tolerance range of salinity with respect to the new steady level, into certain categories which are characteristic of stenohaline, euryhaline and holeuryhaline animals.

The oxygen consumption of crustaceans has been studied by several workers. Studies by Lofts (1956) in *Palaemonetes varians*, Subramanyam (1957) in *Emerita asiatica*, Subramanyam (1962) in *Penaeus indicus*, Rao (1958) in *Metapenaeus monoceros*, Kutty (1967) in *P. indicus* and *P. semisulcatus*, Kutty *et al.* (1971) in *P. indicus* Cheriyan (1973) in *Sphaeroma terebrans*, Cherian (1978) in *Sphaeroma annandalei*, *Cirolana fluviatilis* and *C. willeyi* and Kuttiyamma (1982) in *Metapenaeus dobsoni* are some of them..

Information on ammonia excretion of shrimps is scarce. Spaargaren *et al.* (1982) have studied ammonia excretion in *Penaeus japonicus*, Gerhardt (1980) in *P. indicus* and Mohanty *et al.* (1989) in *P. monodon*. Still fewer reports are available on combined investigations of oxygen consumption, ammonia excretion and estimation of the oxygen to nitrogen ratios (O:N) or ammonia quotient (A.Q). In omnivorous *P. varians* O:N ratio fell in winter and rose in summer (Snow and Williams, 1971). Laxminarayana and Kutty (1982) investigated the A.Q. of the shrimp *P. semisulcatus*, fresh water prawn *Macrobrachium rosenbergii* and freshwater crab *Paratelphusa hydrodromus* with

respect to ambient oxygen tension. Stern *et al.* (1984) have conducted similar studies in *Macrobrachium rosenbergii*. Unnikrishnan and Laxminarayana (1984) have studied the oxygen consumption and ammonia excretion of *P. indicus* in different salinities. Oxygen consumption and ammonia excretion in fed and starved tiger prawn, *Penaeus esculentus* have been studied by Dall and Smith (1986).

Juveniles of *P. indicus* survive under wide spectrum of salinity range from 10-30 ppt. Within this wide range of salinity each age group has got an optimum salinity in which metabolic processes are carried out effectively. Being a euryhaline species, *P. indicus* must have behavioural, physiological and biochemical adaptations to attain this euryhalinity which will ultimately express as metabolic energy requirement. One possible way of measuring this energy requirement is through oxygen consumption and ammonia excretion. In culture systems, the post larvae and juveniles are stocked in different salinities. Therefore, information regarding the metabolic responses of the species in different salinities is highly essential for better management of shrimp culture. Though some work has been carried out on the metabolism of *P. indicus*, no information is available on oxygen consumption and ammonia excretion of different size groups of the species in different salinities. Further, such an information is required for

preparing the energy equation.

MATERIALS AND METHODS

Animals subjected to 21 days study to understand the effect of salinity on growth rate and food conversion ratio were used after the termination of the experiment for oxygen consumption and ammonia excretion after starving for 24 hours. In other words the animals were acclimated for 21 days in the respective salinity before measuring their oxygen consumption and ammonia excretion.

The apparatus designed by Mohan and Cheriyan (1980) was used for the experiment. The test media of salinities 5, 10, 15, 20, 25, 30 and 35 ppt were filtered through 42 Whatman filter paper. The capacity of the respirometers varied from 250 ml to 1 litre depending upon the size of the shrimps. Only one animal was used at a time for the experiment. After introducing the animal into the respirometer, a continuous flow of seawater of respective salinity was provided to acclimatise the animal to the experimental conditions and also to nullify the handling stress. After collecting the initial water sample for analysis, the water flow was cut off. The duration of the oxygen consumption was fixed as one hour and in few cases the experiment was terminated before reaching one hour time duration when the oxygen level in

the chamber went low and the animals expressed to stress conditions. In almost all cases the oxygen consumption values were obtained in the oxygen saturated level which is more than 50% saturation and the dissolved oxygen level in the respirometer was not allowed to fall below 50% saturation. Water samples of 10 ml each were collected for dissolved oxygen and ammonia estimation. The dissolved oxygen was determined using Winkler's micro-method (Welsh and Smith, 1953). Phenol hypochlorite method (Solorzano, 1969) was used for estimating the ammonia content.

The rates of oxygen consumption were calculated using the formula:

$$\text{Oxygen uptake rate (ml } O_2/h) = (I_2-I_1)(V_v-V_a) \times 60/t$$

where,

I_1 = initial oxygen content (ml O_2/l)

I_2 = Final oxygen content (ml O_2/l)

V_v = Volume of respirometer (ml)

V_a = Volume of animal (ml)

t = time interval (minutes)

Ammonia excretion rates were determined using the formula:

$$\text{Ammonia excretion } (\mu g\ NH_4\text{-N/h}) = (N_2-N_1) \times \frac{14}{1000/v} \times \frac{1}{t}$$

Where,

V = Volume of sea water in which the animal was incubated (ml)

t = Incubation time (minutes)

N_1 = Initial ammonia concentration (μg NH_4-N/l)

N_2 = Final ammonia concentration (μg NH_4-N/l)

The oxygen to nitrogen ratio (O:N) was calculated using the equation given by Bayne *et al.* (1985):

$$O:N = \frac{\text{ml } O_2 \times 1.428}{16} : \frac{(\mu\text{g } NH_4\text{-N/l})}{14}$$

The oxygen uptake rate (OUR) and ammonia excretion rate (AER) are functions of body weight. The relationship is exponential and can be expressed by the equation:

$$Y = aw^b \qquad (1)$$

Where 'W' is the weight, 'Y' is OUR or AER, 'a' is the 'Y' intercept and 'b' is the slope.

The weight specific oxygen consumption and ammonia excretion are expressed using the equation:

$$\frac{Y}{w} = \frac{aw^b}{w} = aw^{b-1} \qquad (2)$$

Logarithmic transformation of the above equations (1) and (2) respectively yields linear forms (3) and (4) given below.

$$\text{Log } Y = \text{Long } a + b \log w \qquad (3)$$

$$\text{Log } (Y/w) = \text{Log } a + (b-1) \text{ Log } w \qquad (4)$$

The dry weight of animals experimented ranged from 48 to 673 mg. The constants log a and b were determined using regression analysis. The correlation coefficient, standard errors, 'b', student 't', etc. were determined and analysis of co-variance test was performed (Snedecor and Cochran, 1968; Zar, 1974). Rate of oxygen uptake (μg O_2/h), metabolic rate (μg O_2/g/h), rate of ammonia excretion (μg NH_4- N/h) and weight specific ammonia excretion rate were estimated for standard weights 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550 and 600 mg from the respective regression equation. The oxygen uptake rate and ammonia excretion rate for different salinities were compared by analysis of co-variance test (Snedecor and Cochran, 1968).

RESULTS

Oxygen Consumption

Oxygen consumption in 5 ppt salinity (Fig. 3.1)

The oxygen uptake rate varied from 205 to 1189.7 μg O_2/h for dry weight ranging from 50 to 670 mg. In Fig 3.1 the logarithms of oxygen uptake rate are plotted against logarithms of body weight. The log a, b, b-1, r and n values are 1.2723, 0.6347, -0.3653, 0.9867 and 61, respectively.

Oxygen consumption in 10 ppt salinity (Fig. 3.2)

The oxygen uptake rate varied from 183.2 to 1499.1 μg O_2/h for dry weights ranging from 49 to 671 mg. The double logarithmic plotting of oxygen uptake rate against dry weight is presented in Fig. 3.2. The log a, b, b-1, r and n values are 1.0808, 0.7709, -0.2291, 0.9412 and 54, respectively.

Oxygen consumption in 15 ppt salinity (Fig. 3.3)

The oxygen uptake rate varied from 237.2 to 1448.3 μg O_2/h for dry weights varying from 52 to 673 mg. Log oxygen uptake values are plotted against log dry weights in Fig. 3.3. The log a, b, b-1, r and n are 1.2394, 0.7085, -0.2915, 0.9488 and 60 respectively.

Oxygen consumption in 20 ppt salinity (Fig. 3.4)

Oxygen uptake rate ranged between 308.7 to 1384.9 μg O_2/h for dry weight ranging from 52 to 669 mg. The double logarithmic

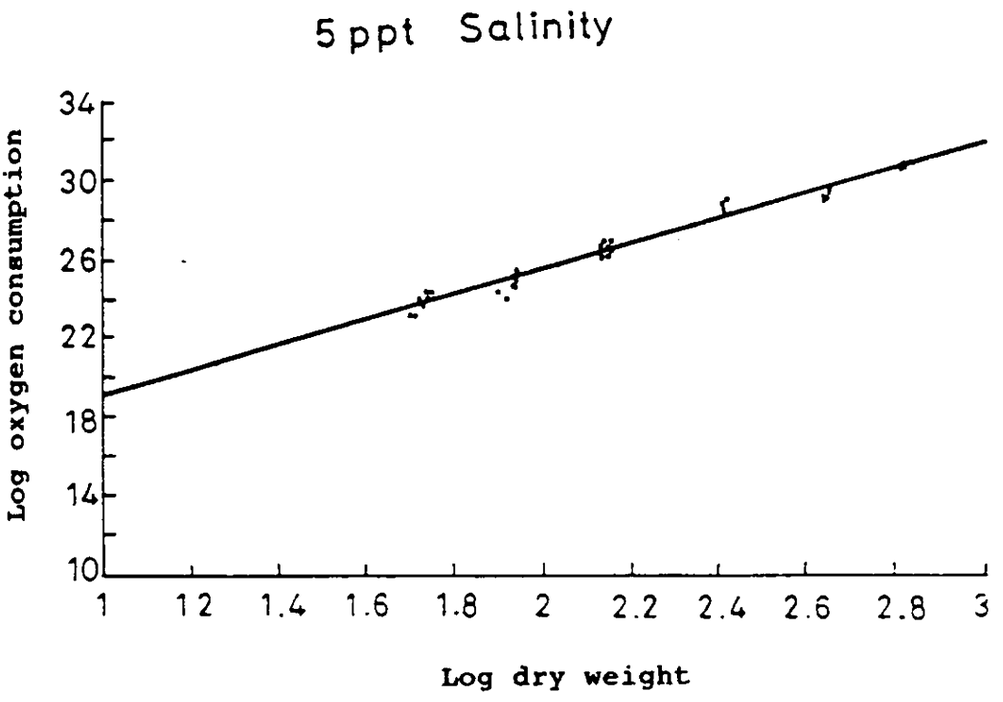

Fig. 3.1 Relation between oxygen consumption and dry body weight of *P. indicus* in 5 ppt salinity

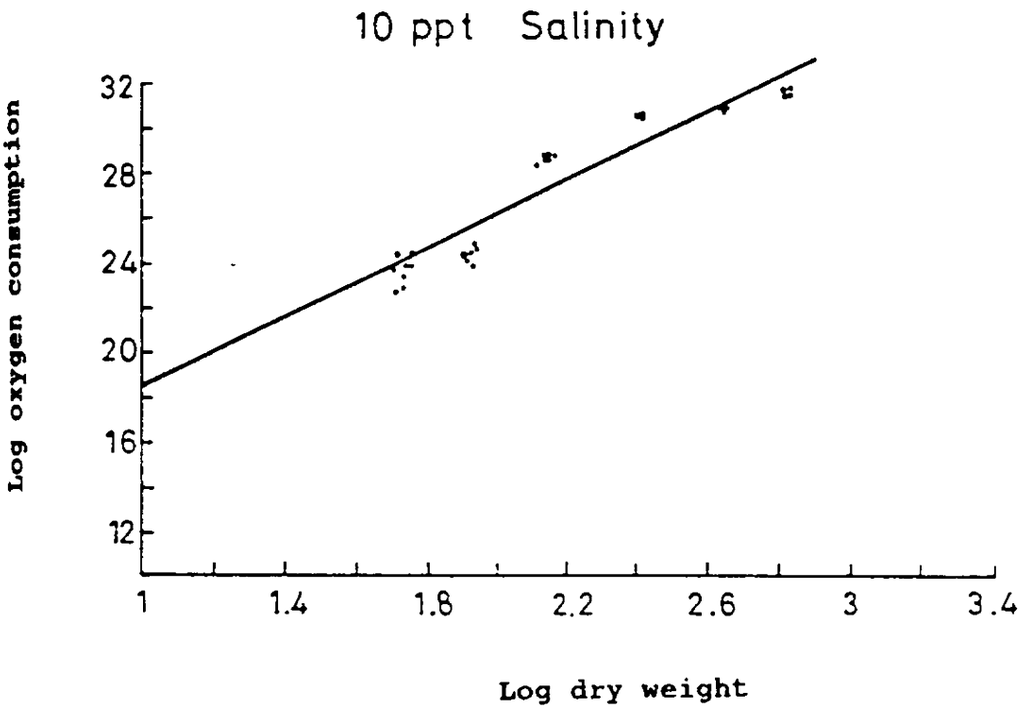

Fig. 3.2 Relation between oxygen consumption and dry body weight of *P. indicus* in 10 ppt salinity

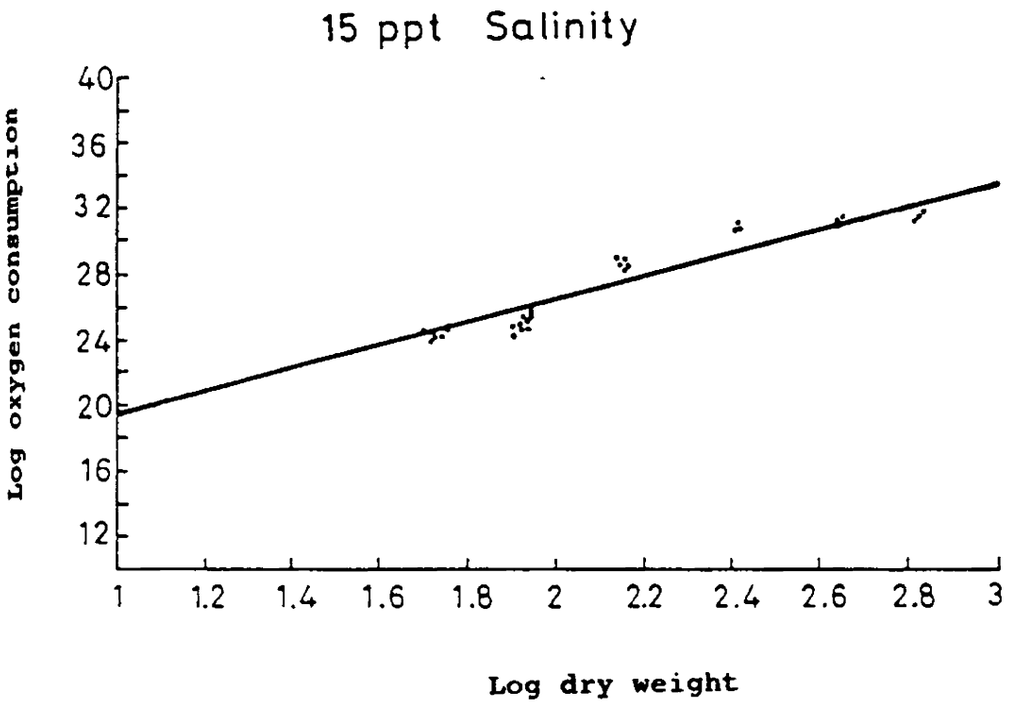

Fig. 3.3 Relation between oxygen consumption and dry body weight of *P. indicus* in 15 ppt salinity

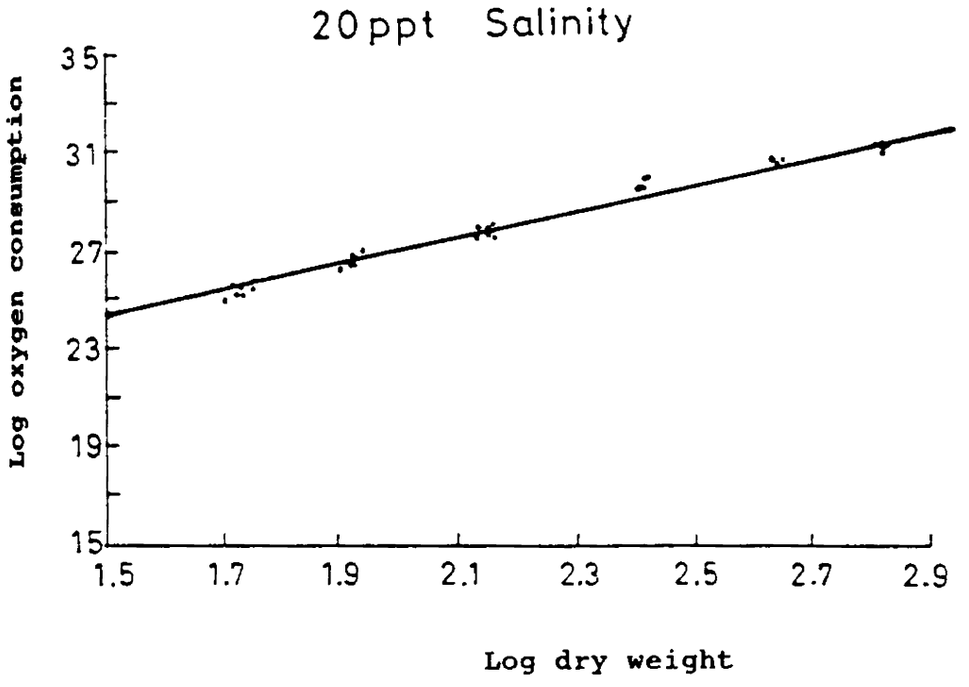

Fig. 3.4 Relation between oxygen consumption and dry body weight of *P. indicus* in 20 ppt salinity

plotting of oxygen uptake rate against dry weight is presented in Fig. 3.4. The log a, b, b-1, r and n values are 1.6106, 0.5455, -0.4545, 0.9906 and 59 respectively.

Oxygen consumption in 25 ppt salinity (Fig. 3.5)

The oxygen uptake rate varied from 416.5 to 1372.7 μg O_2/h for dry weight varying from 48 to 668 mg. The log oxygen uptake is plotted against log dry weight in Fig. 3.5. The values of log a, b, b-1, r and n are 1.9747, 0.4236, -0.5764, 0.9859 and 58 respectively.

Oxygen consumption in 30 ppt salinity (Fig. 3.6)

The oxygen uptake rate varied from 348.2 to 1374.5 μg O_2/h for dry weight ranging between 52 and 672 mg. The double logarithmic plotting of oxygen uptake rate against dry weight is presented in Fig. 3.6. The log a, b, b-1, r and n values are 1.7734, 0.4870, - 0.5130, 0.9860 and 58, respectively.

Oxygen consumption in 35 ppt salinity (Fig. 3.7)

The oxygen uptake rate varied from 201.5 to 1211.5 μg O_2/h for dry weight ranging between 48 and 671 mg. The log oxygen uptake rates are plotted against log dry weights in Fig. 3.7. The log a, b, b-1, r and n values are 1.1943, 0.6823, - 0.3177, 0.9971 and 62, respectively.

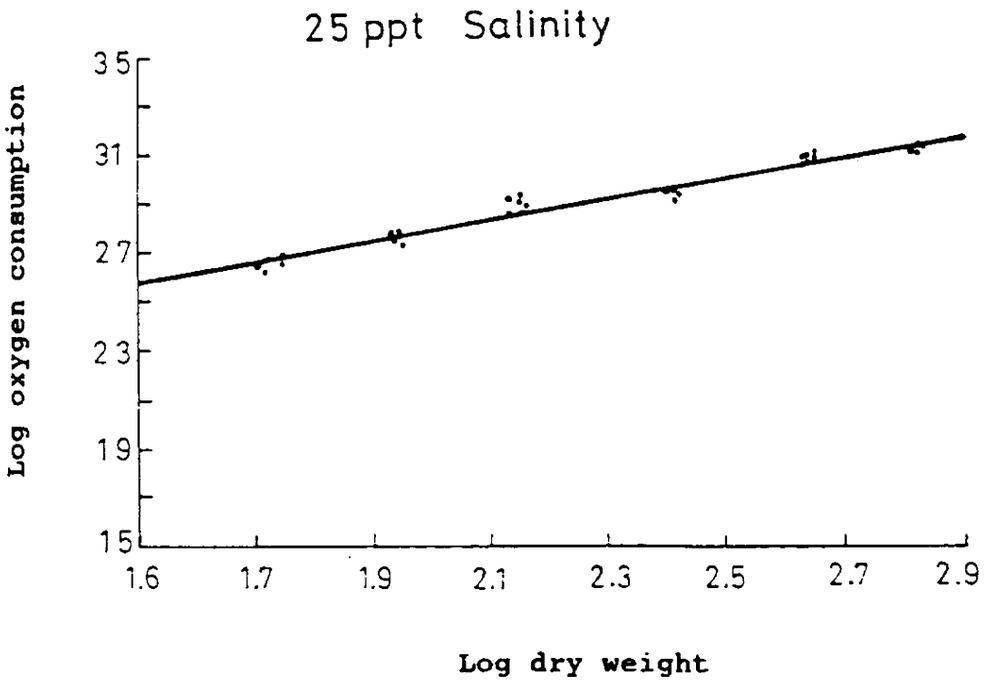

Fig. 3.5 Relation between oxygen consumption and dry body weight of *P. indicus* in 25 ppt salinity

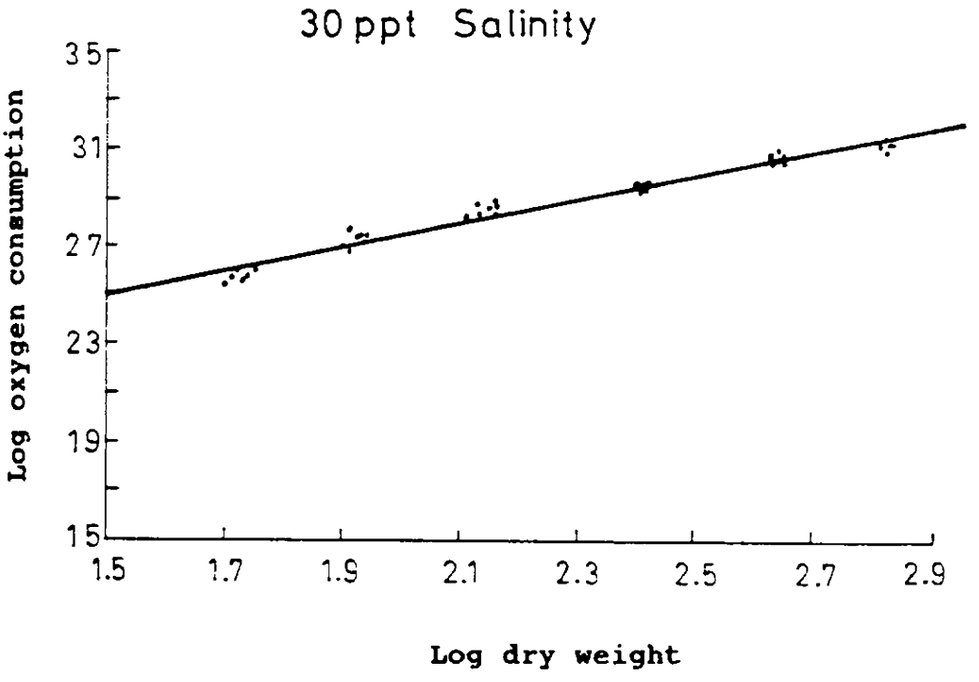

Fig. 3.6 Relation between oxygen consumption and dry body weight of *P. indicus* in 30 ppt salinity

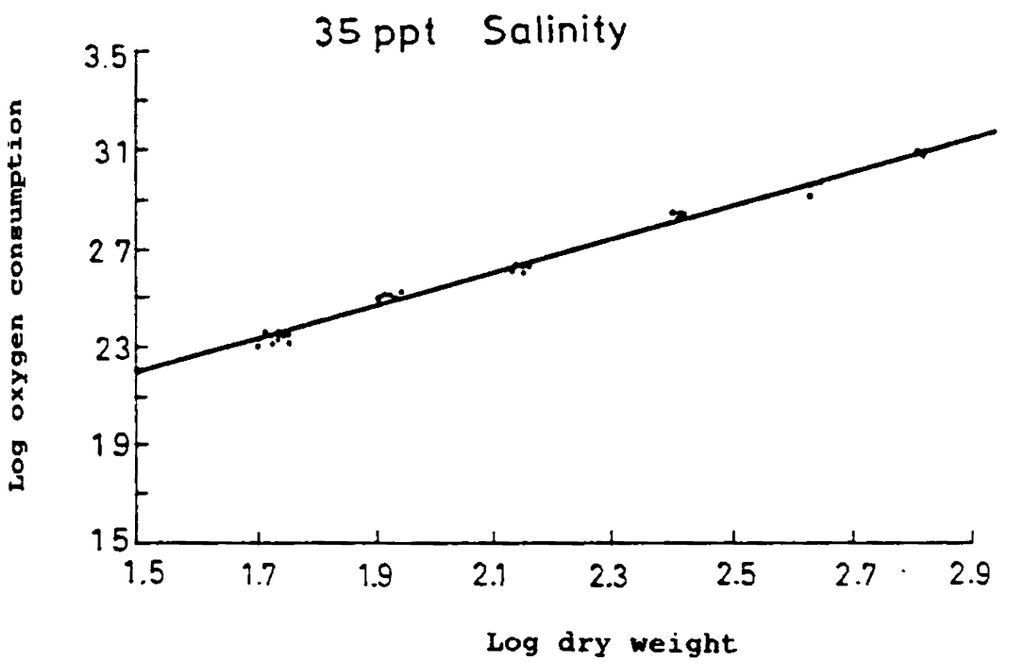

Fig. 3.7 Relation between oxygen consumption and dry body weight of *P. indicus* in 35 ppt salinity

Ammonia Excretion

Ammonia excretion in 5 ppt salinity (Fig. 3.8)

The ammonia excretion rate (AER) varied from 84.0 to 457.3 μg NH_4-N/h for dry weight ranging between 50 and 670 mg. The double logarithmic plotting of AER against dry weight is given in Fig. 3.8. The log a, b, b-1, r and n are 1.1169, 0.5272, -0.4729, 0.9629 and 61 respectively.

Ammonia excretion in 10 ppt salinity (Fig. 3.9)

The AER varied from 81.2 to 564.5 μg NH_4-N/h for dry weight ranging from 49 to 671 mg. The log AER is plotted against log dry weight in Fig. 3.9. The log a, b, b-1, r and n are 0.8346, 0.7022, -0.2978, 0.9668 and 54, respectively.

Ammonia excretion in 15 ppt salinity (Fig. 3.10)

The AER ranged between 82.5 and 518.5 μg NH_4-N/h for dry weight varying from 52 to 673 mg. The log AER is plotted against log dry weight in Fig. 3.10. The log a, b, b-1, r and n are 0.8522, 0.6897, -0.3103, 0.9616 and 60 respectively.

Ammonia excretion in 20 ppt salinity (Fig. 3.11)

The AER varied from 83.9 to 406.8 μg NH_4-N/h for dry weight varying from 52 to 669 mg. The log AER is plotted against log log dry weight in Fig. 3.11. The log a, b, b-1, r and n are

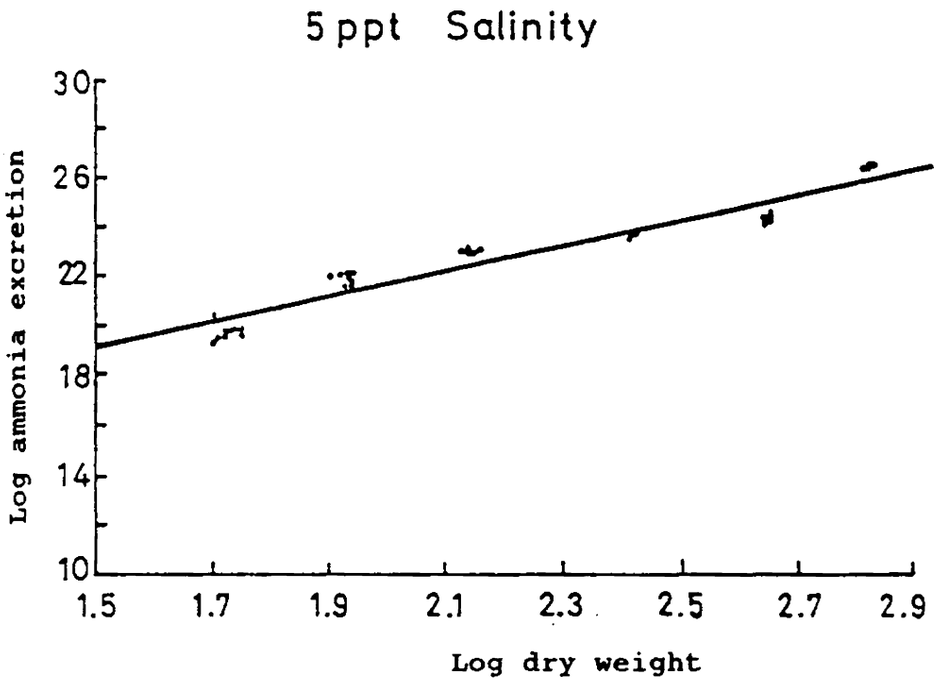

Fig. 3.8 Relation between ammonia excretion and dry body weight of *P. indicus* in 5 ppt salinity

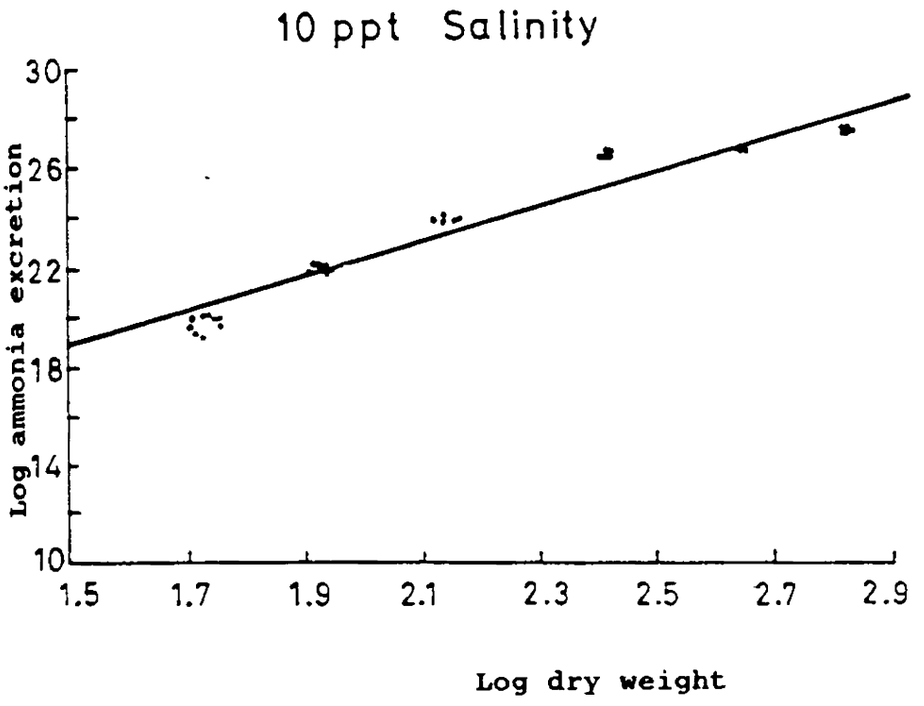

Fig. 3.9 Relation between ammonia excretion and dry body weight of *P. indicus* in 10 ppt salinity

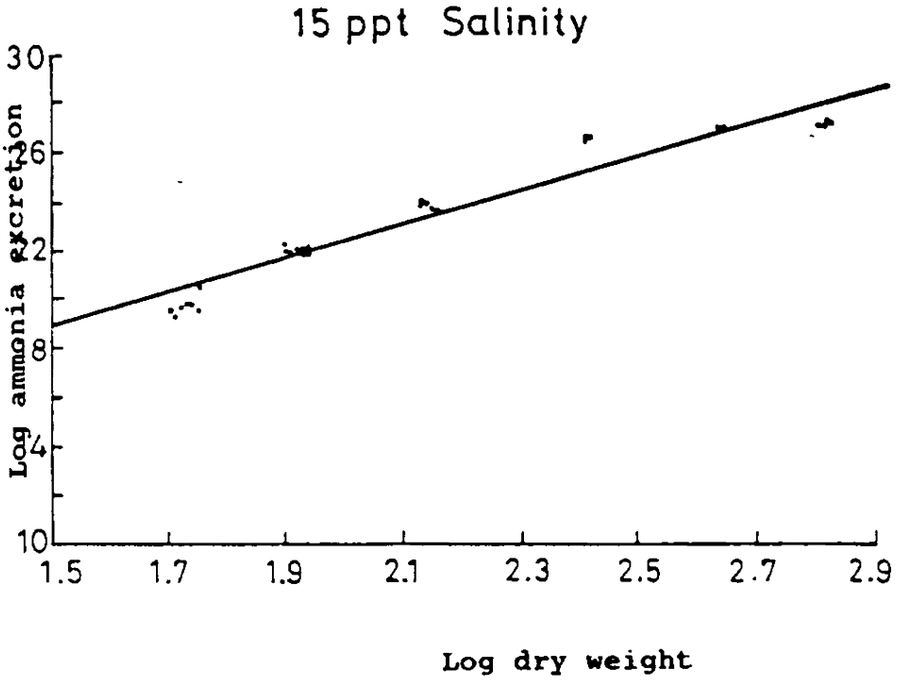

Fig. 3.10 Relation between ammonia excretion and dry body weight of *P. indicus* in 15 ppt salinity

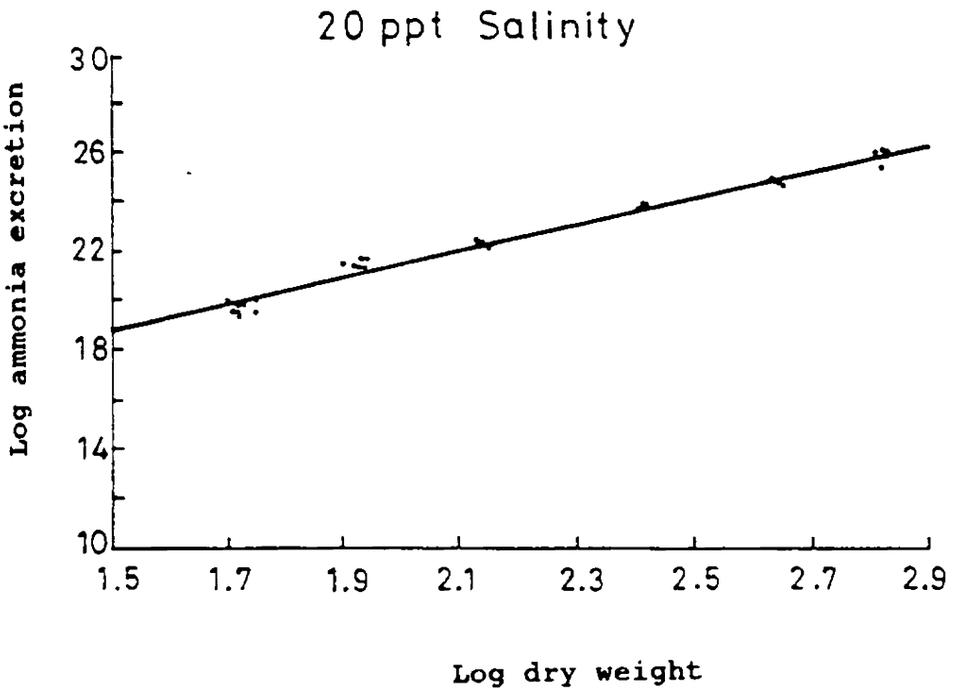

Fig. 3.11 Relation between ammonia excretion and dry body weight of *P. indicus* in 20 ppt salinity

1.0566, 0.5420, -0.4580, 0.9903 and 59 respectively.

Ammonia excretion in 25 ppt salinity (Fig. 3.12)

The AER ranged between 127.6 and 312.4 μg NH_4-N/h for dry weight varying from 48 to 668 mg. The log AER is plotted against dry weight in Fig. 3.12. The log a, b, b-1 r and n are 1.5895, 0.3183, -0.6817, 0.9799 and 58 respectively.

Ammonia excretion in 30 ppt salinity (Fig. 3.13)

The AER ranged between 129.9 and 307.8 μg NH_4-N/h for dry weight varying between 52 and 672 mg. The log AER is plotted against log dry weight in Fig. 3.13. The log a, b, b-1 r and n values are 1.5290, 0.3355, -0.6665, 0.9894 and 58 respectively.

Ammonia excretion in 35 ppt salinity (Fig. 3.14)

The AER ranged between 83.2 and 448.3 μg NH_4-N/h for dry weight varying from 48 to 671 mg. The double logarithmic plotting of AER against dry weight is given in Fig. 3.14. The log a, b, b-1, r and n are 0.8359, 0.6230, -0.3770, 0.9810 and 62 respectively.

DISCUSSION

Oxygen Consumption

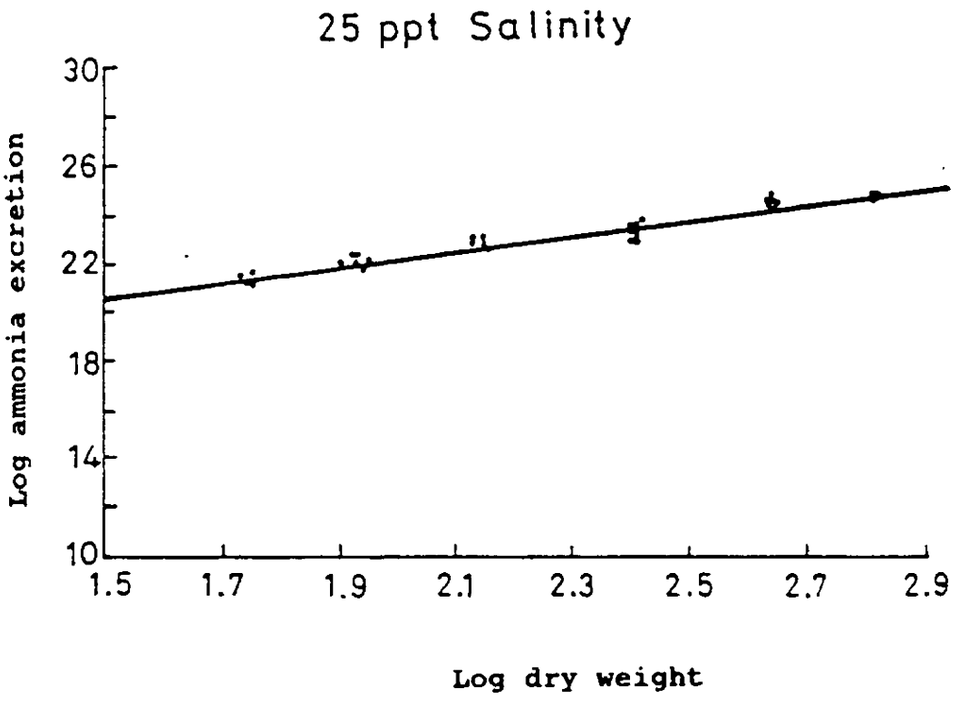

Fig. 3.12 Relation between ammonia excretion and dry body weight of *P. indicus* in 25 ppt salinity

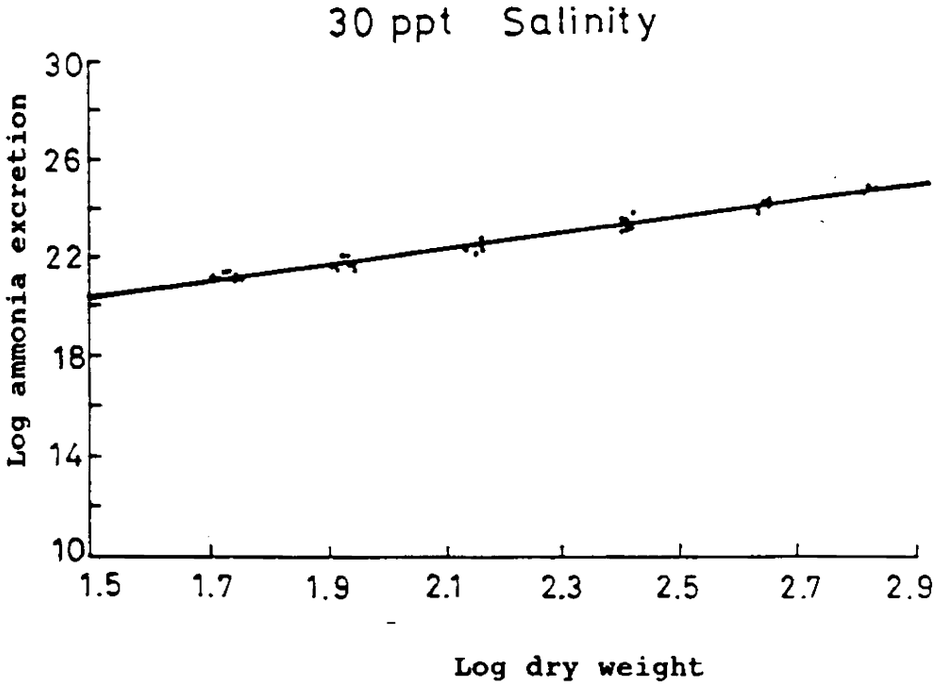

Fig. 3.13 Relation between ammonia excretion and dry body weight of *P. indicus* in 30 ppt salinity

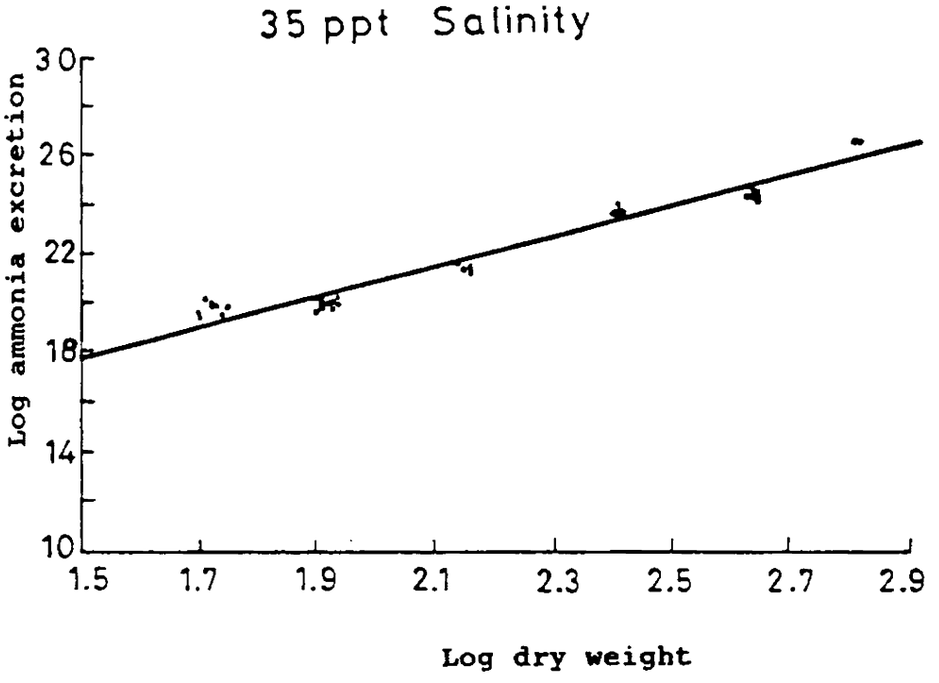

Fig. 3.14 Relation between ammonia excretion and dry body weight of *P. indicus* in 35 ppt salinity

The oxygen consumption rate (μg O_2/h) of *P. indicus* in all the test salinities viz., 5, 10, 15, 20, 25, 30 and 35 ppt increased with body weight as evidenced by the positive values of the regression coefficient. The 'b' values in 5, 10, 15, 20, 25, 30, and 35 ppt are 0.6347, 0.7710, 0.7085, 0.5455, 0.4236, 0.4871 and 0.6683, respectively (Table 3.1). The metabolic rate (μg O_2/g/h) decreased with increasing body weight. The computed values of the slope 'b-1' are given in Table 3.1.

Bertalanffy (1957) has proposed three metabolic types:-
i. metabolic rate proportioned to surface area (b = 0.67),
ii. metabolic rate proportioned to weight (b = 1.0) and
iii. metabolic rate intermediate between surface and weight proportionality (b = 0.67-1.0).

The regression coefficients in 10, 15 and 35 ppt salinities obtained from the present studies are well within the values of the third metabolic type mentioned above. In salinities 5, 20, 25 and 30 ppt, the 'b' values are less than 0.67. However, Ganapathi and Rao (1960), Kuenzler (1961), Kennedy and Mithursky (1972) etc., have reported the existence of metabolic types other than those proposed by Bertalanffy (1957).

In crustaceans metabolic rates intermediate between surface and weight proportionality (b = 0.67-1.0) have been reported by

Table 3.1 Statistical analysis of oxygen consumption of *P. indicus* in various salinities

Salinity (ppt)	Log a	b	b-1	r	n
5	1.2723	0.6347	-0.3653	0.9867	61
10	1.0808	0.7709	-0.2291	0.9412	54
15	1.2394	0.7085	-0.2915	0.9488	60
20	1.6106	0.5455	-0.4545	0.9906	59
25	1.9747	0.4236	-0.5764	0.9859	58
30	1.7734	0.4870	-0.5130	0.9860	58
35	1.1943	0.6823	-0.3177	0.9971	62

Ellenby (1951), Edney and Spencer (1955), Bertalanffy (1957), Robertson (1957), Subramanyam (1957, 1962), Barnes and Barnes (1959), Teal (1959), Ganapathi and Rao (1960), Small and Hebard (1967), Bulnheim (1974) etc. In several crustaceans values less than 0.67 have been reported. In calanoid copepods Conover (1959) has reported 'b' values less than 0.67. Dehnel (1960) obtained 'b' values ranging from 0.32 to 0.67 in crabs *Hemigrapsus oregonensis* and *H. nudus*. Low regression coefficients have been obtained by Newell and Northcroft (1965) for the barnacle *Balanus balanoides*. Haq (1967) observed values of 0.37 and 0.48 for the copepods *Metrida lucens* and *M. longa*. Fish and Preece (1970) recorded low values ranging from 0.04 to 0.44 for amphipods *Bathyporeia pilosa* and *B. pelagica*. In *Sphaeroma terebrans*, a wood-boring isopod, Cheriyan (1973) obtained values ranging from 0.34 to 0.45. In the isopods *Sphaeroma annandalei*, *Cirolana fluviatilis* and *C. willeyi*, Cherian (1978) observed 'b' values varying from 0.25 to 0.91.

In shrimps 'b' values ranging from 0.3584 to 1.05 have been reported by several authors. Rao (1958) has reported regression coefficients ranging from 0.5 to 1.05 in *Metapenaeus monoceros* in varying salinity conditions. Subramanyam (1962) has reported 'b' value of 0.60 for *Penaeus indicus* in 14.5 ppt salinity. Kutty (1967) has obtained in *P. indicus* a 'b' value of 0.50 in 36 ppt salinity. In *P. indicus*, Kutty *et al.* (1971) obtained a slope of

0.55. Kuttyamma (1982) observed that the 'b' value for *Metapenaeus dobsoni* ranged from 0.36 to 0.50. The 'b' values obtained in the present study ranging from 0.42 to 0.77 for *P. indicus* are within the range already reported for shrimps.

The regression coefficients in different salinities were compared using ANOVA test (Table 3.2 and 3.3). The results show that significant difference exists between salinities. But, slope between salinities 5 ppt and 15 ppt, 5 ppt and 35 ppt, 10 ppt and 15 ppt, 10 ppt and 35 ppt and 15 ppt and 35 ppt are at par. Comparatively low 'b' values are recorded in 20 ppt (0.5455), 25 ppt (0.4236) and 30 ppt (0.4871) salinities. It can be seen that the slope gradually increases as the salinity increases or decreases from 25 ppt.

In *Metapenaeus monoceros* Rao (1958) has reported that the 'b' value ranged from 0.5 to 1.05 as the salinity varied from 0 ppt (tap water) to 35.5 ppt, Cheriyan (1973) has reported in *Sphaeroma terebrans* no statistically significant difference between 'b' values when animals were transferred to higher salinities, but significant increase in 'b' value was found when animals were transferred to lower salinities. Bulnheim (1974) observed that in the isopod *Idothea baltica* the regression coefficient increased as the animals were transferred to higher salinities. Cherian (1977) observed that oxygen consumption rate

Table 3.2 Analysis of co-variance for regression coefficient of oxygen uptake in different salinities

Salinity (ppt)	Reg. Coefficient	D.F.	M.S.
5	0.634704	59	0.001651
10	0.770990	52	0.011785
15	0.708483	58	0.008582
20	0.545521	57	0.000859
25	0.423598	56	0.000769
30	0.487062	56	0.001007
35	0.668254	60	0.000403
Total		398	0.003469
Pooled		404	0.013272
		6	0.663537

f = 191.2762

Table 3.3 Comparison of regression co-efficient of oxygen consumption in different salinities

Salinity (ppt)	t	DF	P
5 vs 10	2.5795	111	*
5 vs 15	1.5402	117	N.S
5 vs 20	3.7259	116	*
5 vs 25	8.9226	115	*
5 vs 30	5.9505	115	*
5 vs 35	0.7015	119	N.S
10 vs 15	0.9038	110	N.S
10 vs 20	4.0842	109	*
10 vs 25	6.2753	108	*
10 vs 30	5.0722	108	*
10 vs 35	1.9398	112	N.S
15 vs 20	3.8366	115	*
15 vs 25	6.1322	114	*
15 vs 30	4.6817	114	*
15 vs 35	0.9097	118	N.S
20 vs 25	6.2294	115	*
20 vs 30	2.7685	113	*
20 vs 35	7.3341	117	*
25 vs 30	3.0855	112	*
25 vs 35	15.0653	116	*
30 vs 35	10.1541	110	*

* Significant

with respect to body weight showed significant variations in different salinities in the isopods *Sphaeroma annandalei, Cirolana fluviatilis and C. willeyi* and the 'b' value increased when the animals were subjected to increased salinity. But in *C. willeyi* no such difference was observed. In *S. annandalei* and *C. willleyi* lowering of salinity showed an increase in 'b' values. In *C. fluviatilis* the value increases only when the animals are subjected to extreme lowering of salinity. Kuttyamma (1982) observed that the regression coefficient in *M. dobsoni* which varied from 0.3898 to 0.5031 showed no significant difference.

The oxygen uptake rate (/µg O2/h) and metabolic rate (/µg O2/g/h) of *P. indicus* for different salinities are given in Table 3.4 and Table 3.5 respectively. It can be observed that in all the salinities oxygen uptake rate increased with increase in body weight, while the metabolic rate decreased. The oxygen uptake rate were compared using ANOVA (Table 3.6). It can be seen that the rate in 25 ppt in significantly higher than that in 5, 30 and 35 ppt. The rates in 10, 15 and 20 ppt are at par with that in 25 ppt.

Kinne (1971) has stated that most of the aquatic invertebrates respire at the most economic rates in which they are genetically adjusted or they have been acclimated over prolonged period of time. In *P. indicus* juveniles migrate from

Table 3.4 Oxygen uptake rate ($\mu g\ O_2/h$) of *P.indicus* in different salinities for standard weight

Standard weight (mg)	Salinity						
	5	10	15	20	25	30	35
50	221.28	241.89	273.37	340.86	490.53	394.84	222.52
100	348.09	419.37	453.31	503.15	663.74	558.98	362.15
150	446.27	567.09	598.19	622.93	783.46	676.37	473.03
200	539.64	714.28	739.52	733.44	889.39	782.52	580.21
250	615.50	838.01	856.47	821.22	971.60	865.62	668.33
300	691.84	965.87	975.87	908.04	1049.82	946.86	757.84
350	766.36	1093.66	1093.93	991.50	1124.01	1024.18	854.94
400	836.60	1216.57	1206.42	1069.12	1191.76	1095.46	929.56
450	900.02	1329.48	1308.95	1138.43	1251.33	1158.64	1005.52
500	954.20	1427.31	1397.22	1197.09	1301.12	1211.68	1070.74
550	1026.54	1559.78	1515.96	1274.79	1366.15	1281.68	1158.24
600	1072.55	1645.10	1592.00	1323.65	1406.72	1325.53	1214.14

Table 3.5 Metabolic rate ($\mu g\ O_2/h$) of *P.indicus* in different salinities for standard weight

	Salinity						
Standard weight (mg)	5	10	15	20	25	30	35
50	4425.60	4837.80	5467.40	6817.20	9810.60	7896.80	4450.60
100	3480.90	4193.70	4533.10	5031.50	6637.40	5589.80	3621.50
150	2975.13	3780.60	3987.93	4152.87	5223.07	4509.13	3153.53
200	2698.20	3571.40	3697.60	3667.20	4446.95	3912.60	2901.05
250	2462.00	3352.04	3425.88	3284.88	3886.40	3462.48	2673.32
300	2306.13	3219.57	3252.90	3026.80	3499.40	3156.20	2526.13
350	2189.60	3124.74	3185.51	2832.86	3211.46	2926.23	2416.97
400	2091.50	3041.43	3016.05	2672.80	2979.40	2738.65	2323.15
450	2000.04	2954.40	2968.78	2529.84	2780.73	2574.76	2234.49
500	1908.40	2854.62	2794.44	2394.18	2602.24	2423.58	2141.48
550	1866.44	2835.97	2756.29	2317.62	2483.91	2330.33	2105.89
600	1785.58	2741.83	2753.33	2206.08	2344.53	2209.22	2023.57

Table 3.6 Analysis of variance of oxygen uptake rate for salinity and body weight

Source	SS	DF	MS	F
Total	10356697.0	83		
Block	8842036.6	11	803821.5	150.3*
Treatment	1161756.9	6	193626.2	36.2*
Error	352903.5	66	5437.0	

C.D. for Block 78.2

C.D. for Treatment 59.7

*Significant

the marine habitat to estuaries and migrate back to the sea for breeding. During their life cycle itself they are subjected to wide variations in salinity. When migrate from sea to estuary they are subjected to considerable lowering in ambient salinity and in the estuary they are subjected to diurnal variation in salinity. Thus the shrimp exhibits continuous metabolic adjustments in response to salinity variations. Kinne (1971) has identified the following metabolic types based on the new steady state attained by the animal within the tolerance range.

(i) Increase in subnormal salinities and a decrease in supra normal salinities.

(ii) Increase in sub-and supra normal salinities.

(iii) Decrease in sub-and supra normal salinities,

(iv) Remain essentially unaffected. Euryhaline invertebrates are representative of the first two types of metabolic responses. The third and fourth types are represented by stenohaline and extremely euryhaline animals, respectively.

Kutty *et al.* (1971) found that oxygen uptake rate of *P. indicus* was not significantly influenced by salinity, when acclimation was prolonged. Similar observations were made by Karmandayera, (1966) and Panikkar (1969). But Unnikrishnan and Laxminarayana (1984) observed that in *P. indicus* (14.33+0.16q) the oxygen uptake rate increased as the salinity decreased or increased. The present work reveals that *P.indicus* falls under

the second category of metabolic type mentioned by Kinne (1971).

Ammonia Excretion

Positive values of regression coefficient are observed in all test salinities, 5, 10, 15, 20, 25, 30 and 35 ppt ('b' values 0.5273, 0.7022, 0.6897, 0.5420, 0.3182, 0.3335 and 0.6231 respectively) indicating that the weight specific ammonia excretion rate decreases with increasing weight (b-1) in all salinities as indicated by the negative values (Table 3.7)

The regression coefficients in different salinities were compared using the analysis of co variance test and the statistical significance was determined at 5% level (Table 3.8 and 3.9). The test showed significant difference between regression coefficients. Pair wise comparison of 'b' values shows that the slopes between salinities 5 and 20 ppt, 10 and 15 ppt, 10 and 35 ppt, 15 and 35 ppt, and 25 and 30 ppt are at par.

The total ammonia excretion rates and the weight specific ammonia excretion rates are presented in Table 3.10 and 3.11. In all the test salinities the former increases with body weight, while latter decreases with increase in size. In general, ammonia excretion was higher in lower salinities than in

Table 3.7 Statistical analysis of ammonia excretion of different size groups in various salinities

Salinity (ppt)	Log a	b	b-1	r	n
5	1.1169	0.5272	-0.4728	0.9629	61
10	0.8340	0.7022	-0.2978	0.9668	54
15	0.8522	0.6897	-0.3103	0.9616	60
20	1.0566	0.5420	-0.4580	0.9903	59
25	1.5895	0.3183	-0.6817	0.9799	58
30	1.5290	0.3335	-0.6665	0.9894	58
35	0.8359	0.6230	-0.3770	0.9810	62

Table 3.8 Analysis of co-variance for regression coefficient of ammonia excretion in different salinities

Salinity (ppt)	Reg. Coefficient	D.F.	M.S.
5	0.527270	59	0.003301
10	0.702157	52	0.013503
15	0.669686	58	0.005980
20	0.542027	57	0.000867
25	0.318266	56	0.000629
30	0.333539	56	0.000359
35	0.623083	60	0.002389
Total		398	0.002675
Pooled		404	0.005715
		6	0.207372

F = 77.522305 significant

Table 3.9 Comparison of regression co-efficient of ammonia excretion in different salinities

Salinity (ppt)	t	DF	P
5 vs 10	2.7716	111	*
5 vs 15	3.9123	117	*
5 vs 20	0.4781	116	N.S
5 vs 25	6.9298	115	*
5 vs 30	6.6460	115	*
5 vs 35	2.7204	119	*
10 vs 15	0.4782	110	N.S
10 vs 20	2.7201	109	*
10 vs 25	6.5354	108	*
10 vs 30	6.3260	108	*
10 vs 35	1.3057	112	N.S
15 vs 20	3.2311	115	*
15 vs 25	8.9946	114	*
15 vs 30	8.7698	114	*
15 vs 35	1.0922	118	N.S
20 vs 25	16.4502	115	*
20 vs 30	9.9469	113	*
20 vs 35	22.6209	117	*
25 vs 30	1.2035	112	N.S
25 vs 35	11.6923	116	*
30 vs 35	11.6189	110	*

* Significant

Table 3.10 Ammonia excretion rate (μg NH4-N/hr) in different salinities for standard weight groups

Standard weight (mg)	Salinity (ppt) 5	10	15	20	25	30	35
50	101.82	104.88	104.18	93.88	134.09	123.73	77.40
100	148.35	173.14	170.45	138.22	168.30	157.03	120.75
150	182.35	227.91	223.47	170.89	190.63	178.93	154.10
200	213.53	281.22	274.47	201.00	209.69	197.71	185.69
250	238.18	325.28	316.65	224.84	223.99	211.86	211.28
300	262.47	370.19	359.54	248.50	237.52	225.29	236.97
350	285.47	414.56	401.82	271.19	250.02	234.73	262.01
400	307.34	456.79	441.99	292.28	261.26	248.94	285.56
450	326.57	495.25	478.52	311.09	271.01	258.68	306.79
500	342.82	528.34	509.90	327.02	279.07	266.75	324.91
550	364.27	572.83	552.04	348.08	289.49	277.19	349.07
600	377.78	601.30	578.98	361.30	295.43	283.65	364.42

Table 3.11 Weight specific ammonia excretion rate (μg NH4-N/hr) in different salinities for standard weight groups

Standard weight (mg)	Salinity (ppt) 5	10	15	20	25	30	35
50	2036.40	2097.60	2083.60	1877.60	2681.80	2474.60	1548.00
100	1483.50	1731.40	1704.50	1382.20	1683.00	1570.30	1207.50
150	1215.67	1519.40	1488.47	1139.27	1270.87	1192.87	1027.33
200	1067.65	1406.10	1372.35	1005.00	1048.45	988.55	928.45
250	952.72	1301.16	1266.60	899.56	895.96	847.44	845.12
300	874.90	1233.97	1198.47	828.33	791.73	750.97	789.90
350	816.43	1184.40	1148.06	774.83	714.34	670.66	750.48
400	768.35	1141.98	1104.98	730.70	653.15	622.35	713.90
450	725.64	1101.29	1063.37	691.31	602.24	574.84	681.76
500	685.64	1056.68	1019.80	654.04	558.14	533.50	649.82
550	662.31	1041.51	1003.71	632.87	526.33	503.98	634.67
600	629.63	1002.17	964.97	603.22	493.22	472.75	607.67

Table 3.12. Analysis of variance of ammonia excretion rate for salinity and body weight

Source	SS	DF	MS	F
Total	1165934.6	83		
Block	724644.8	11	10979.4	5.5*
Treatment	310344.3	6	51724.1	26.0**
Error	130945.4	66	1984.0	

C.D. for Block 47.6

C.D. for Treatment 36.4

*Significant

higher salinities and the lowest ammonia excretion was expressed in 25 ppt for majority of the weight groups. As the salinity increase from 25 to 35 ppt a slight increase in ammonia excretion was noticed in some cases. This can be due to an increased metabolic rate of the animal. Ammonia excretion was low in 5 ppt salinity compared with 10 and 15 ppt salinity. This can also be attributed to reduced activity of the animal and consequent metabolic demand. ANOVA test was conducted to determine the statistical difference between ammonia excretion rate in different salinities (Table 3.12).

In *P. indicus* (14.33+0.16q) Unnikrishnan and Laxminarayana (1984) observed that the rate of ammonia excretion increased with decrease in salinity. The present study shows that in all size groups the AER is higher in lower salinities.

O: N Ratio

O: N ratio is a useful index for measuring the organisms physiological state and its reaction to a given set of environmental conditions. The O: N ratios calculated for different weight groups in different salinities are presented in Table 3.13. ANOVA test shows that the O: N ratio in the salinity level 25 ppt is significantly higher than those in all other

Table 3.13. O:N ratio in different salinities for standard size groups

Standard weight(mg)	Salinity (ppt) 5	10	15	20	25	30	35
50	1.90	2.00	2.30	3.18	3.20	2.76	2.52
100	2.00	2.12	2.32	3.18	3.45	3.11	2.62
150	2.14	2.17	2.34	3.19	3.59	3.30	2.68
200	2.21	2.22	2.35	3.19	3.73	3.53	2.73
250	2.26	2.25	2.36	3.19	3.79	3.57	2.76
300	2.30	2.28	2.37	3.19	3.86	3.67	2.79
350	2.34	2.30	2.38	3.20	3.93	3.81	3.10
400	2.38	2.33	2.38	3.20	3.99	3.85	2.84
450	2.41	2.34	2.39	3.20	4.04	3.92	2.86
500	2.43	2.36	2.39	3.20	4.08	3.97	2.88
550	2.46	2.38	2.40	3.20	4.13	4.04	2.90
600	2.48	2.39	2.40	3.20	4.16	4.08	2.91

Table 3.14 Analysis of variance of O:N ratio for salinity and body weight

Source	SS	DF	MS	F
Total	34.523670	83		
Block	2.157595	11	0.196145	9.3*
Treatment	30.976267	6	5.162710	245.2*
Error	1.389505	66	0.0210531	

C.D. for Treatment 0.1187

C.D. for Size group 0.1551

*Significant

salinity levels (Table 3.14). The salinity levels 30 and 20 ppt in their order of merit are significantly superior to one another and the rest.

The high O:N values were recorded in 20, 25 and 30 ppt salinity compared to other salinities. These values can be due to disproportionate reliance on protein catabolism for energy production.

C H A P T E R IV

PHYSIOLOGICAL ENERGETICS

INTRODUCTION

Study of the physiological energetics of an animal gives valuable information on the physiological flexibility of the organisms in relation to the environment. 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 condition may exert stress on the animal and chances of survival are significantly reduced. 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 individual (or the population) more vulnerable to further environmental change (Bayne, 1985). 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 few physiological responses for routine environmental monitoring proposed by Bayne (1985); Bayne *et al.* (1985) and IMCO (1980) are:

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

ii. Growth efficiency - The efficiency with which an individual converts food into body tissue.

iii. O:N ratio - a measure of the balance between catabolic processes.

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

Growth and reproduction are fundamental properties of all living organisms and form 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 subtracting the energy required for respiration and energy lost through excretion from the energy derived through absorbed food. Alternations 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 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. 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) explained 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 utilising its body reserves for maintenance metabolism.

Many workers have determined 'scope for growth' of aquatic organisms. Warren and Davis (1967) were the first to study scope for growth as a measure of examining the bioenergetics of production in fish in response to environmental temperature change. Scope for growth was studied in response to salinity changes in *Sunetta scripta* by Supriya (1992). The above studies highlights the use of the scope for growth as an index of physiological condition of an organism. The main physiological components of the energy equation are the food energy consumed and assimilated and energy loss due to respiration and excretion. The amount of energy consumed from the food depends upon the food availability, feeding rates, the efficiency of digestion and absorption. The last three being especially influenced by stress. Measurement of feeding, digestion and assimilation processes provides estimates of the amount of food consumed and assimilated by the animal. The above information forms an important component of the bioenergetic equation (Bayne *et al.*, 1985).

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 utilisation, carbon dioxide liberation or heat production (Bayne *et al*; 1985). Among these, oxygen consumption is a convenient measure of energy transformation (Scott and Major, 1972). Crisp (1971) reported an oxycalorific equivalent of 20.33 Joules for 1 ml of oxygen which can 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, 1978b).

A proportion of the total energy absorbed by the animal is excreted as metabolic waste products. The energy lost as urine therefore forms a negative component of the basic energy equation (Bayne *et al*, 1985). In crustaceans, ammonia form a major portion in nitrogen excretion. 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.

In eco-physiological studies growth relationships are well explained as efficiencies. The most commonly used indices in crustacean energetics are those of gross and net growth efficiencies. The gross growth efficiency K_1, is the ingested ration for scope for growth (Widdows *et al.*, 1990). The scope

for growth as 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,Widdows *et al.*, 1990). 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 consumption (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 *P. indicus* is found to be varying with salinity, the salinity will affect gross and net growth efficiencies. This study is aimed at finding the effect of salinity on the growth efficiency of *P. indicus* under different salinity conditions.

Very few works have been carried out on the energy budget of shrimps in India. The energy budget of *M. monoceros* was estimated using estuarine detritus as food by Qasim and Easterson (1974) and Ramdhas and Sumitra Vijaya Raghavan (1979) also worked on the energy budget of *M. monoceros* by feeding mangrove leaves in combination with rice bran as feed. The efficiency of slaughter house waste as feed to *M. monoceros* and *M. dobsoni* was also studied by Sumitra Vijaya Raghavan *et al.* (1981). Growth

and food conversion efficiency of *P. monodon* fed on decapsulated cysts of *Artemia* was studied by Sumitra Vijaya Raghavan *et al.* (1988). There is practically no work on the energetics of *P. indicus* which is one of the main species cultured widely in this country. Therefore a study on the energetics of the species especially in relation to salinity is warranted as the species survives and is being cultivated under a wide spectrum of salinity conditions.

MATERIALS AND METHODS

Mean data of initial weight, final weight (dry weight basis), and feed consumed were as described in Chapter II. Oxygen consumption rate and ammonia excretion rate were interpolated using respective regression equations (Chapter III). To develop the energy equation, all the physiological components were converted to energy equivalent (Joules/h) for two size groups of 30-35 mm and 50-55 mm length.

Energy consumed (C)

Energy of the feed was worked out to be 15,860.28 J/g (1 calorie = 4.184 Joules) applying conversion rate of 5.65 K cal/g for protein (42.32%), 9.45 K cal/g for fat (4.39%) and 4.2 K

cal/g for carbohydrate (23.45%).

Production (P)

The energy of prawn samples was worked out during the beginning and end of the feeding experiments and production was obtained by subtracting initial energy (J/g) from final energy (J/g).

Energy respired (R)

Oxygen uptake rates were calculated using the respective regression equations for mean size of prawn. The following conversion was used to get energy value.

$$R = VO_2 (ml\ O_2/h) \times 20.33$$

$$(1ml\ O_2/h = 20.33\ J/h)$$

Energy excreted (U)

Ammonia excretion rates were also interpolated from relevant regression equation:

$$U\ (J/h) = NH4\text{-}N\ excretion\ (/\mu g\ NH4/h) \times 0.0249$$

$$(1/\mu g\ NH4\text{-}N/h = 0.0249\ J/h)$$

Energy absorbed (A)

Energy absorbed was calculated following the equation given by (Winberg, 1960).

$$A = P + (R + U)$$

Where,

A = energy absorbed from food

P = scope for growth

R = energy respired

U = energy excreted

Gross growth efficiency (K_1)

$$K_1 = \frac{A - (R+U)}{C} \times 100$$ (Bayne *et al.*, 1985)

Net growth efficiency (K_2)

$$K_2 = \frac{A - (R+U)}{A} \times 100$$ (Bayne *et al.*, 1985)

RESULTS

The initial dry weight, final dry weight, P - Scope for growth (J/h), R - respiration (J/h), U - Ammonia excretion (J/h), A - Assimilation efficiency (J/h), K_1, gross growth efficiency and K_2- net growth efficiency for two size groups 30-35 mm and 50-55 mm in different salinities are presented in Table 4.1 and 4.2. In 30-35 mm size group P varied from 0.0231 J/h to 1.977 J/h, C from 6.772 J/h to 36.3667 J/h, R from 3.3375 J/h to 9.2607 J/h, U from 2.2144 J/h to 4.1284 J/h, A from 6.0179 J/h to 14.9295 J/h, $K_1$from 0.34 to 5.44 and K_2 from 0.38 to 15.28. In 50-55 mm size group P varied from 0.0366 J/h to 1.3339 J/h, C from 11.8123 J/h to 26.6847 J/h, R from 6.1503 J/h to 11.4206 J/h, U from 3.8122 J/h to 6.0108 J/h A from 10.6066 J/h to 16.9999 J/h, K_1 from 0.28 to 4.94 and K_2 from 2.37 to 5.67.

DISCUSSION

The overall performance of an animal can be best understood from the balanced energy equation (Winberg, 1960). This equation comprising energy values of consumption, production, respiration and excretion is expressed in energy units, Joules (Thompson and Bayne, 1974). The Production (Scope for growth) will be positive when surplus energy is available for growth and negative when the reserves are used for its survival (Dare and Edwards, 1975;

Widdows, 1978a). An animal will normally have positive scope for growth when it is in the zone of tolerance and a negative scope for growth when it is on the zone of resistance. When absorbed ration is exactly balanced by the energy expenditure (respiration plus excretion) the scope for growth will be zero. During stress condition, degradation of body proteins into amino acids occurs due to the increased demand for energy which results in depletion of body proteins. Under such conditions some quantity of amino acids are recycled to the metabolic pool for further protein synthesis and demands high energy (de Zwaan and van Marrewijk, 1973). According to Hawkins *et al.* (1986) about 30% of normal energy demand is the turnover of protein under stress condition.

The food consumption for the size group 30-35 mm at different salinities, 5, 10, 15, 20, 25 30 and 35 ppt were 6.772 J/h, 17.2718 J/h, 24.123 J/h, 36.3667 J/h, 34.8761 J/h, 27.997 J/h and 6.4059 J/h. The least food consumption was recorded in extreme salinities of 5 and 35 ppt, maximum consumption was found in 20 ppt followed by 25, 30, and 15 ppt (Fig.4.1). The assimilation was also lowest in extreme salinities, 5 and 35 ppt (6.0207 J/h and 6.0179 J/h), maximum assimilation was recorded in 25 ppt (14.9295 J/h) followed by 20 ppt (12.939 J/h) and 30 ppt (12. 0419 J/h). In the extreme salinities consumption and assimilation was lowest. Food consumption as well as

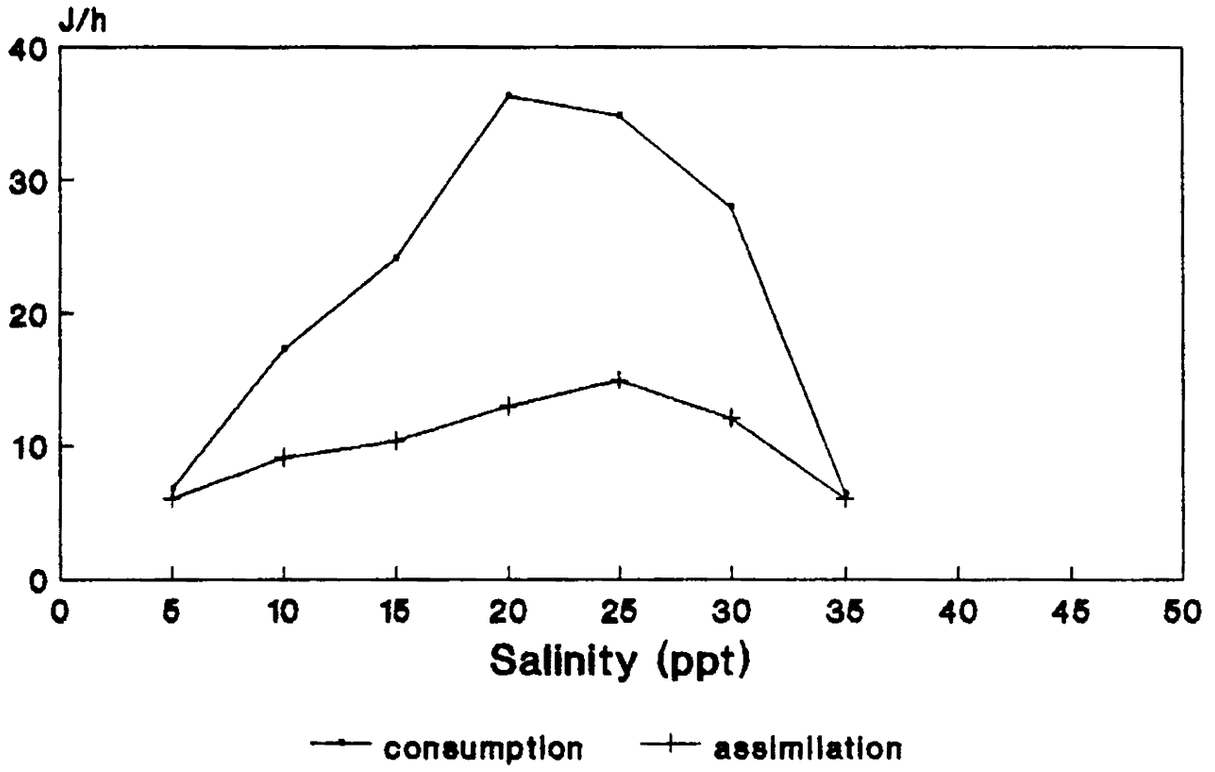

Fig. 4.1 Consumption and assimilation in different salinities for 30-35 mm size group of *P.indicus*

assimilation were appreciable in salinities 10, 15, 20, 25 and 30 ppt.

In the case of large size group animals, 50-55 mm, the lowest consumption was again recorded in the extreme salinities of 5 and 35 ppt (12. 753 J/h and 11.8123 J/h). Maximum value was obtained in 20 ppt (26.9826 J/h) and in 10 and 15 ppt salinities consumption was almost on par (25.2951 J/h, and 25.3008 J/h). In 25 and 30 ppt salinities consumption was found to be lower (20.6847 J/h and 16.7037 J/h). Food consumption increased from 10 upto 20 ppt, then declined (Fig.4.2). The assimilation was lowest in extreme salinities (10.6066 J/h and 10.4597 J/h), assimilation increased from 10 upto 20 ppt then gradually decreased. The highest assimilation was in 20 ppt salinity (16.999 J/h) followed by 25 ppt (16.7208 J/h) and 15 ppt (16.0097 J/h). In 10 and 30 ppt assimilation was on par (15.4211 J/h and 15.0763 J/h)

In the present study for the smaller size group (30-35 mm) maximum values for food consumption (36.3667 J/h) and scope for growth (1.9770 J/h) were obtained in 20 ppt salinity while the higher values for respiration (9.2607 J/h) and ammonia excretion (4.1284 J/h) were obtained in 25 ppt. Very few work has been carried out on the energy budget of shrimps in India. Qasim and

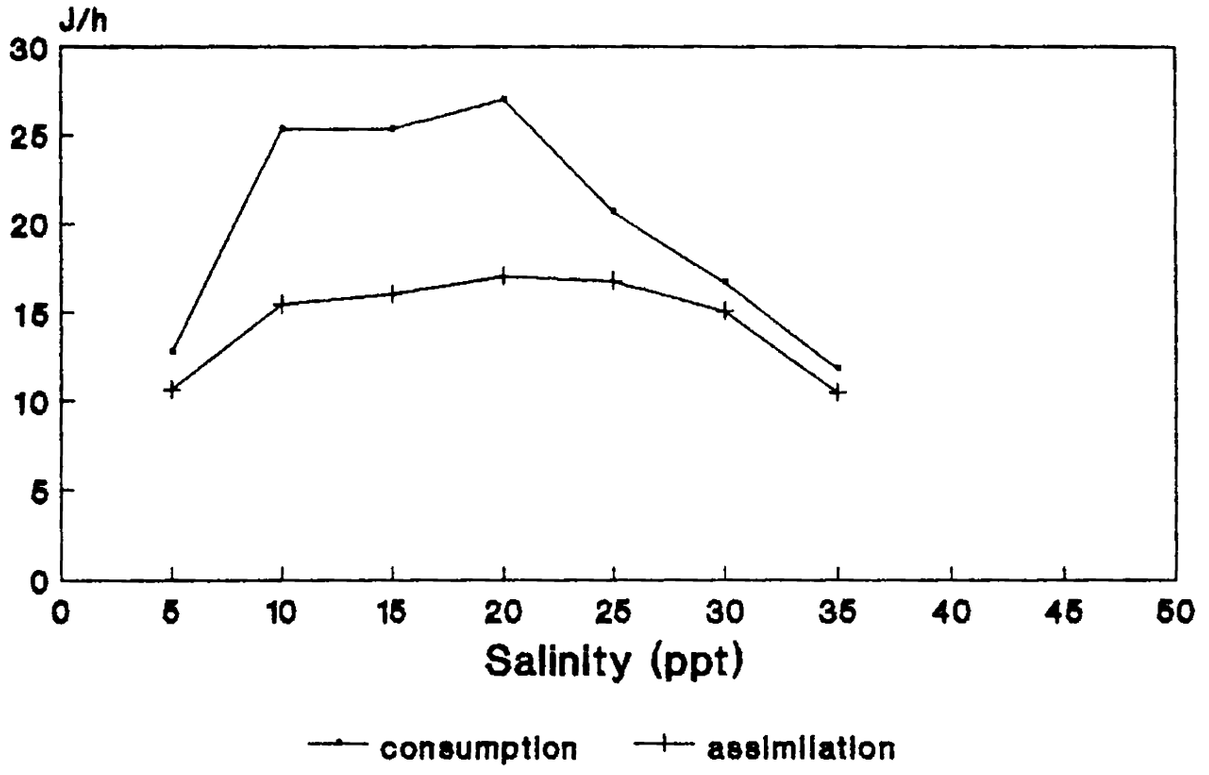

Fig. 4.2 Consumption and assimilation in different salinities for 50-55 mm size group of *P.indicus*

Easterson (1974) worked out the energy budget of *M.monoceros* using estuarine detritus as food and found that rates of consumption, defecation, assimilation, growth and metabolism in the juvenile shrimp increased with the size of the animal. Gross growth efficiency (P/C or K_1) and net growth efficiency (P/A or K_2) were higher in the size range 17-20 mm. Average gross and net efficiencies were 21.6 and 24.1% respectively. Food efficiency was inversely related to growth efficiency and the assimilation efficiency was of the order 93%. Ramdhas and Sumitra Vijaya Raghavan (1979) by conducting feeding experiment with mangrove leaves in combination with rice bran in *M. monoceros* have also worked out the energy budget and reported that high assimilation efficiency (86%) and low conversion efficiencies (K_1= 6.45 and K_2=7.49). Sumitra Vijaya Raghavan and Ramdhas (1980) by studying the conversion efficiency of the shrimp *M. monoceros* fed on decomposed mangrove leaves in combination with rice bran found that there are wide variations in gross and net growth efficiency and assimilation efficiency. The K_1(gross efficiency) varied from 0.34 - 30%, K_2(Net growth efficiency) varied from 0.4 - 34.9% and assimilation efficiency from 64-93.3%. The growth and food conversion efficiency of *P. monodon* fed on decapsulated cysts of *Artemia* was also studied by Sumitra Vijaya Raghavan *et al.*, (1988) and found that conversion efficiencies were high (K_1 = 26 to 32%; K_2 = 29 to 36%) than

feeding with freshly hatched nauplii of *Artemia*.

In the present study for the smaller size group (30-35mm) maximum value for food consumption (36.3667 J/h) and scope for growth (1.9770 J/h) was obtained in 20 ppt salinity, while the higher values for respiration (9.2607 J/h) and ammonia excretion (4.1284 J/h) were in 25 ppt. As the salinity decreases or increases from 20 ppt, the scope for growth decreases. Poor values were obtained in 5 ppt and 35 ppt salinities. Effect of salinity on growth rate (Chapter II) also reveals supporting evidence as relative growth rate was poor in the extreme salinities 5 and 35 ppt. Perusal of the Table 4.1 and 4.2 shows in these extreme salinities consumption (C) and gross and net growth efficiencies (K_1 and K_2) were poor particularly for the smaller size group (30-35 mm). The lower value for scope for growth in 5 ppt and 35 ppt salinities is not associated with an increase in respiration or excretion but due to the lower rate of food consumption and poor efficiencies of food conversion rate. In 50-55 mm size group the maximum value for production (1.3339 J/h) and food consumption (26.9826 J/h) were obtained in 20 ppt. Respiration was maximum (11.4206 J/h) in 25 ppt while excretion was the highest (6.0108 J/h) in 10 ppt. In general the scope of growth values decreased with increase or decrease in salinity from 20 ppt salinity.

Table 4.1 Energy budget of *P. indicus* (30-35 mm) in different salinities (ppt)

ppt	Initial dry wt (g)	Final dry wt. (g)	P (J/h)	C (J/h)	R (J/h)	U (J/h)	A (J/h)	K_1 (%)	K_2 (%)
	0.0530	0.0536	0.0231	6.7720	3.3375	2.6601	6.0207	0.34	0.38
0	0.0558	0.0754	0.7511	17.2718	4.8026	3.5358	9.0896	4.35	8.26
5	0.0561	0.0822	1.0090	24.1231	5.6169	3.7076	10.3334	4.18	9.76
0	0.0564	0.1063	1.9770	36.3667	7.4042	3.5577	12.9390	5.44	15.28
5	0.0564	0.0954	1.5404	34.8761	9.2607	4.1284	14.9295	4.42	10.32
0	0.0559	0.0836	1.0650	27.9770	7.2933	3.6835	12.0419	3.81	8.88
5	0.0564	0.0612	0.1857	6.4059	3.6881	2.2144	6.0179	2.90	3.08

P: Production C: Consumption R: Respiration

U: Excretion A: Assimilation

K_1: Gross growth efficiency K_2: Net growth efficiency

Table 4.2 Energy budget of *P. indicus* (50-55 mm) in different salinities (ppt)

ppt	Initial dry wt (g)	Final dry wt. (g)	P (J/h)	C (J/h)	R (J/h)	U (J/h)	A (J/h)	K_1 (%)	K_2 (%)
5	0.1396	0.1406	0.0366	12.7530	6.1503	4.4197	10.6066	0.29	3.45
10	0.1393	0.1605	0.8131	25.2951	8.5975	6.0108	15.4211	3.21	5.27
15	0.1400	0.1635	0.9077	25.3008	9.1428	5.9586	16.0097	3.59	5.67
20	0.1410	0.1747	1.3339	26.9826	9.7080	4.6563	16.9999	4.94	5.34
25	0.1398	0.1565	0.6437	20.6847	11.4206	4.8331	16.7208	3.11	3.85
30	0.1406	0.1568	0.6243	16.7037	9.9073	4.5443	15.0763	3.74	4.14
35	0.1398	0.1463	0.2476	11.8123	6.3994	3.8122	10.4597	2.09	2.37

P: Production C: Consumption R: Respiration

U: Excretion A: Assimilation

K_1: Gross growth efficiency K_2: Net growth efficiency

Gross and net growth efficiency

It can be seen from the tables that in general, the gross and net growth efficiencies are higher in smaller size group of 30-35mm than in the larger size group of 50-55mm. As far as size group are concerned higher values of K_1 are observed in smaller size group compared to larger size group, 0.34 against 0.29 (5 ppt), 4.35 against 3.21 (10 ppt), 4.18 against 3.59 (15 ppt.), 5.44 against 4.94 (20 ppt.) 4.42 against 3.11 (25 ppt.), 3.81 against 3.74 (30 ppt.) and 2.90 against 2.09 (35 ppt). In K_2values also higher values are recorded in smaller size group except in 5 ppt where the K_2 value is high in large size group (0.38 against 3.45) while the values are higher in small size groups in all other salinities, 8.26 against 5.27 (10 ppt.), 9.76 against 5.67 (15 ppt.) 15.28 against 5.34 (20 ppt.), 10.32 against 3.85 (25 ppt), 8.88 against 4.14 (30 ppt.), and 3.08 against 2.37 (35 ppt). It can be seen on the basis of the above data, especially, K_2values that efficiencies are better for the smaller size group, 30-35 mm in 20 ppt (15.28) and corresponding value was only 5.34 for large size group (50-55 mm) in 20 ppt.

The smaller size groups could maintain this higher efficiencies in a wide range of salinity from 10 to 30 ppt. Jorgenson (1976) and Brown *et al.* (1989) have suggested that when food intake increases less rapidly than respiration with

increasing size, the growth efficiencies will decrease.

It can also be seen that the maximum gross and net growth efficiencies are observed in 20 ppt salinity for the smaller size group. In larger size group maximum value of K_1 was observed in 20 ppt while maximum K_2 value (5.67) was in 15 ppt which is almost comparable with the K_2value (5.34) obtained in 20 ppt. In general the K1 and K_2 values decreases from the maximum value with increase or decrease in salinity. The above observation once again confirms that for the size groups tested 20 ppt is the ideal salinity level for optimum growth.

In Fig. 4.3 and 4.4, A (assimilation) and R + U are plotted against salinity for the two size groups. The difference between the two is the scope for growth (P). Scope for growth is maximum in brackish water habitat, the larvae and juveniles of prawn adjust to changes in salinity and are pre-adapted to juvenile growth phase in the low saline estuarine areas (Rao, 1973). Hence it is recommended that in grow out ponds an optimum salinity of 20 ppt should be maintained by flushing the pond with high saline water or diluting the pond water with fresh waters as per the situation. In culture operation which are now under practice the post larvae are supplied in higher salinities (25

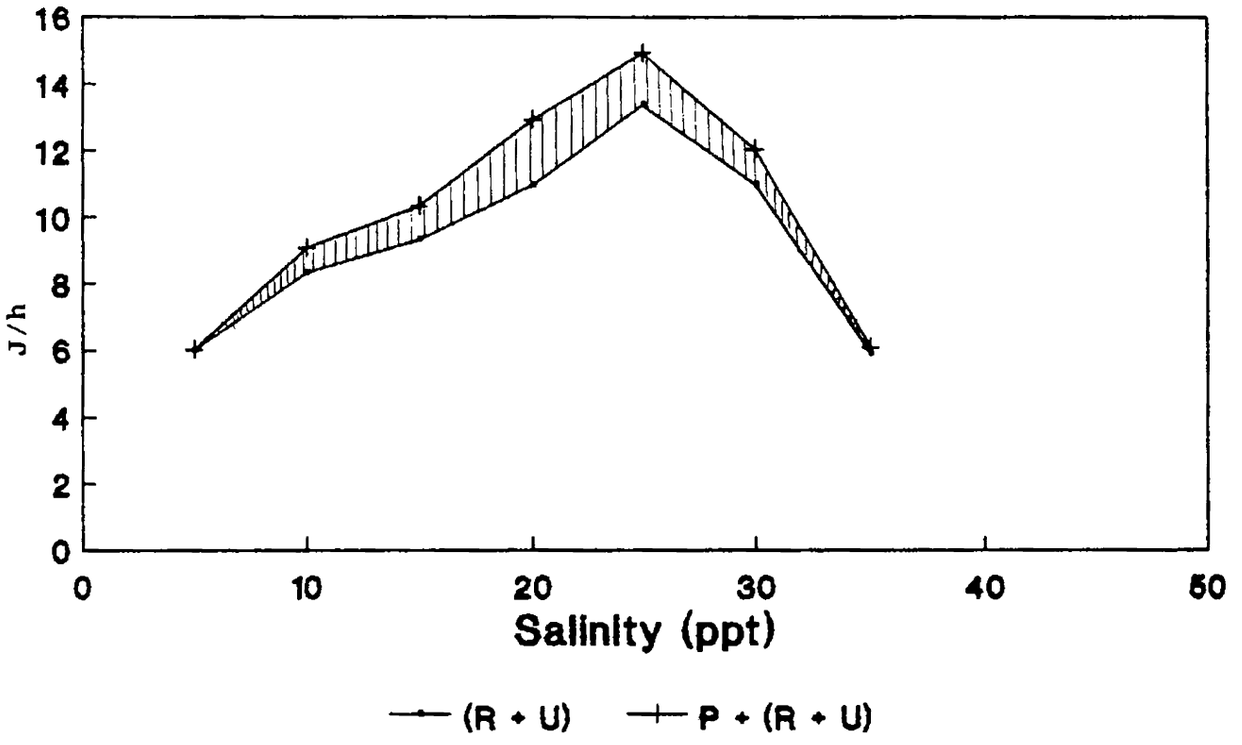

Fig. 4.3 Scope for growth of *P. indicus* (30-35 mm) in different salinities

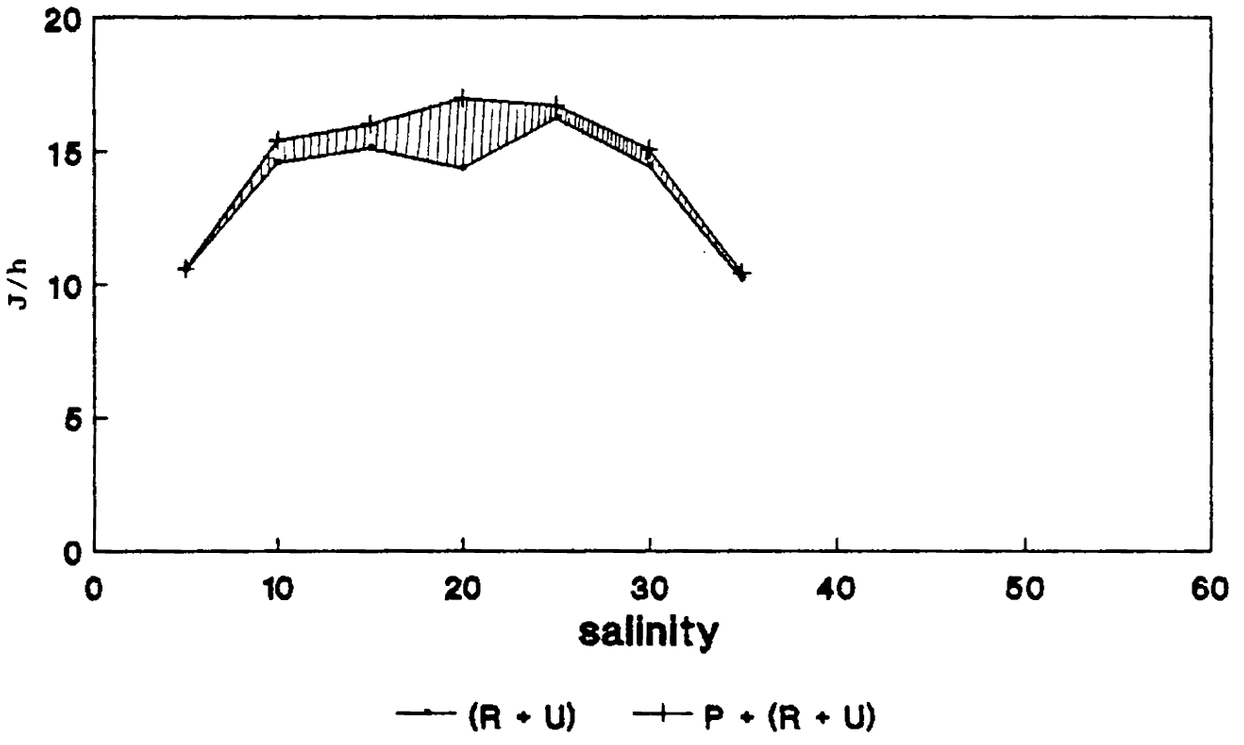

Fig. 4.4 Scope for growth of *P. indicus* (50-55 mm) in different salinities

-30 ppt) from shrimp hatcheries and they are gradually acclimated to 5 - 10 ppt in regions of lower salinities. The present study shows that, growth will be better if the smaller juveniles are stocked in grow out ponds having a salinity of 20 ppt.

C H A P T E R V

CULTURE EXPERIMENTS OF *P.INDICUS* IN VARYING SALINITIES IN POKKALI RICE FIELDS

INTRODUCTION

Penaeus indicus is a euryhaline species capable of withstanding wide range of salinities. After the early stages of development in marine ecosystem, the post-larvae and juveniles enter the backwaters, estuaries and pokkali paddy fields and are capable of withstanding lower salinities but comparatively higher salinities are required for faster growth rate during the later stages (George, 1980). Post-larvae and juveniles of shrimps enter the backwaters and estuaries and pokkali paddy fields for feeding and growth. Taking advantage of the migratory habit of the shrimp larvae and juveniles, a traditional method of shrimp culture popularly known as prawn filtration (chemmeenkettu) is prevalent in more than 4,500 hectares of low lying coastal brackish water fields adjoining the Vembanad lake in Kerala State (Menon, 1954; Gopinathan, 1956; Muthu, 1978). These fields varying in size from less than 0.5 Ha to more than 10 Ha (George, 1983) are located in the coastal villages of Trichur, Ernakulam, Alleppey, and Kottayam Districts, are confluent with the Vembanad lake through canals and are subjected to tidal influence. The coastal belt has a unique system of rice cultivation in the saline soils known as "Pokkali cultivation". The term pokkali refers to saline tolerant rice variety largely cultivated in

these areas. The rice cultivation is done usually during southwest monsoon -June to October- when the salinity in the field is very low. After the harvest of paddy when salinity builds up in the field from November onwards the fields are utilized for traditional shrimp farming. Shrimp larvae and juveniles coming along with high tides are attracted into the field using a lantern during night and during low tide the water is allowed to drain through a split bamboo or velon screen retaining the shrimp larvae in the fields taking advantage of the tide . This operation begins generally in late November and continues till the end of February. The shrimps thus trapped are allowed to grow in the fields. Harvesting of shrimp is usually done from March onwards during full moon and new moon periods using a conical bag net (thoombu vala). The shrimp filtration operation is done upto middle April. The average shrimp yield ranges between 400-1200 Kg/Ha (Unnithan, 1986). The catch is composed of smaller shrimps having low economic value mainly species like *Metapenaeus dobsoni*, *M. monoceros* and *M. affinis*. The percentage of high priced shrimps, *P. indicus* and *P. monodon* is very low. This affects the income from shrimp filtration. It is estimated that about 4,000 tonnes of shrimps were annually caught from the pokkali fields. The pokkali fields still account for almost the entire quantity of shrimp produced under culture in Kerala. The production rate and the share of economically important shrimps in the catch are showing a steady decline due to urbanization and shrinkage of backwaters. To increase the

percentage of *P. indicus* in the catches shrimp farmers have started supplementary stocking of shrimp seed in the shrimp filtration field. Here the stocking density ranges between 10,000 to 30,000 larvae/Ha. Some farmers also have started culturing *P. indicus* in well prepared pokkali fields having facility for water management. The stocking density varies between 50,000 to 1,00,000/Ha (Gopalan *et al.*, 1980). The present experiment is aimed at establishing the effect of salinity on the culture performance of *P. indicus* in pokkali fields. The purpose of the experiment was to study the effect of salinity on growth and survival of *P. indicus* at low (10-15 ppt) and high salinity (20-25 ppt) for a short period and also to find out the growth performance of *P. indicus* at wide range of salinity (10-25 ppt) for a longer period.

MATERIALS AND METHODS

The experiments were laid out in Pokkali fields at the Rice Research Station, Vyttila of Kerala Agricultural University. Fields (A , B and C) having an area of 1000m^2 each were selected for the experiments. The bunds of the fields were strengthened. Peripheral and diagonal trenches of 1-2 metre width and 30-50cm depth were excavated. The purpose of the trenches is to give shrimps shelter during low tide. Wooden sluices were fitted in the fields towards the feeder canal, with provision for shutters and velon net screens for maintaining water level in the fields.

Velon screen is to prevent the entry and exit of unwanted fishes and escape of cultured prawns.

The fields were prepared for shrimp stocking after the harvest of Pokkali rice. The water in the fields was reduced to the minimum during low tide. The unwanted weed and predatory fishes were killed by applying Mahua oil cake at 200 ppm. After stabilizing the habitat by exchange of water, post larvae of *P. indicus* were stocked at 50,000 per hectare. The post-larvae were procured from Regional Shrimp Hatchery, Azhikode and transported to the site in oxygenated plastic bags. The post-larvae were released slowly after allowing gradual mixing of water in the bag and the field water in order to facilitate gradual acclimation so as to avoid sudden stress.

The water in the culture fields were regularly exchanged through sluices provided with velon screens. No feed was given during the period of experiments. The pH, temperature, salinity and dissolved oxygen of the water were periodically monitored. The prawns were harvested after specific durations in the low and high saline periods. Three fields were prepared for culture in the low, high and wide range of salinity. In two fields A and B, shrimps were reared in the salinity range 10-15 ppt. In field C, the shrimps were allowed to grow at wide range of salinity, *i.e.*, 10-25 ppt. The shrimps in the field A and B were harvested when the salinity attained 15 ppt and the fields were prepared and

restocked with *P. indicus* at the same stock density of 50,000 no./Ha when the salinity reached 20ppt and harvested when the salinity was 25 ppt.

RESULTS AND DISCUSSION

Details of water quality parameters and growth characteristics of culture field are given in Table 5.1 to 5.7. Experiments on feeding and growth (Chapter II) and physiological energetics (Chapter IV) show that *P. indicus* has preference for higher salinities around 20-25 ppt for better growth. Even though *P. indicus* survives at low salinities (less than 10ppt) during the early stages of growth , higher salinity (20ppt) ensures faster growth and survival. *P.indicus* cultured in salinity 10-15ppt for a period of 60 days had grown to a size of 9.45cm average length and 4.4g average weight and the yield was 178.65 kg/Ha/crop while in salinity 20-25ppt within 45 days the species has grown to a size of 12.65 cm average length and 7.85 g average weight, with an yield 361 kg/Ha/crop. In continuous rearing experiment at wide range of salinity (10-25 ppt),the yield was 345.6 Kg/Ha/crop for a rearing period of 120 days and the shrimp has grown to a size of 13.6 cm average length and 9.6 g average weight. The daily increment of growth in the low saline fields were 1.58 mm and 74.2 mg, in high saline fields 2.8 mm and 174.4 mg and in the wide range salinity fields, 1.13 mm and 80 mg.

Table 5.1 Water Quality Parameters (Low Saline Phase)

Expt. Field No. and Area	Temperature (^{o}C)	pH	Salinity (ppt)	Dissolved O_2 (ppm)
Field A (1000m^2)	30-32	7.0-7.5	10-15	3.5-4.3
Field B (1000m^2)	30-32	7.0-7.5	10-15	3.5-4.3
Field C (1000m^2)	30-32	7.0-7.5	10-15	3.5-4.3

Table 5.2 Culture details of *P.indicus* during low saline phase

	Field A	Field B
Area of the field	1000m^2	1000m^2
Date of Stocking	1-12-'89	1-12-'89
Stocking density	50,000 No./ha	50,000 No./ha
Size at the time of stocking	PL 20 (13mm)	PL 20 (13mm)
No. of larvae stocked	5,000	5,000
Date of harvesting	31-1-'90	31-1-'90
Period of culture	60 days	60 days
No. of prawns harvested	4000	4100
Survival rate	80%	82%
Av.length at the time of harvest	9.5 cm	9.4 cm
Av.weight at the time of harvest	4.52 g	4.32 g
Total biomass (Kg)	18.10	17.63
Yield Kg/ha/crop	181	176.3

Table 5.3 Water Quality Parameters (High Saline Phase)

Expt. Field No. and Area	Temperature (^{o}C)	pH	Salinity (ppt)	Dissolved O_2 (ppm)
Field A (1000m^2)	30-32	7.0-7.5	20-25	3.5-4.5
Field B (1000m^2)	30-32	7.0-7.5	20-25	3.5-4.5
Field C (1000m^2)	30-32	7.0-7.5	10-15	3.5-4.3

Table 5.4 Culture details of *P.indicus* during high saline phase in pokkali rice fields, Vyttila

	Field A	Field B
Area of the field	1000m^2	1000m^2
Date of Stocking	25-2-'90	25-2-'90
Stocking density	50,000 No./ha	50,000 No./ha
Size at the time of stocking	PL 20 (13mm)	PL 20 (13mm)
No. of larvae stocked	5,000	5,000
Date of harvesting	12-4-'90	12-4-'90
Period of culture	45 days	45 days
No. of prawns harvested	4500	4700
Survival rate	90%	94%
Av.length at the time of harvest	12.6 cm	12.8 cm
Av.weight at the time of harvest	7.8 g	7.9 g
Total biomass (Kg)	35.10	37.13
Yield Kg/ha/crop	351	371

Table 5.5 Culture details of *P.indicus* during wide range of salinity in pokkali rice fields, Vyttila

	Field C
Area of the field	1000m^2
Date of Stocking	1-12-'89
Stocking density	50,000 No./ha
Size at the time of stocking	PL 20 (13mm)
No. of larvae stocked	5000
Date of harvesting	16-4-'90
Period of culture	120 days
No. of prawns harvested	3600
Survival rate	72%
Av.length at the time of harvest	13.6 cm
Av.weight at the time of harvest	9.6 g
Total biomass (Kg)	34.56
Yield Kg/ha/crop	345.6

Table 5.6 Details of growth and production of *P. indicus* cultured during low, high and wide range of salinity in Pokkali rice fields at Vyttila

	Low Salinity	High Salinity	Wide range of salinity
Species stocked	*P. indicus*	*P. indicus*	*P. indicu*
Stocking size	PL 20	PL 20	PL 20
Salinity range	10-15 ppt	20-25 ppt	10-25 p
Culture period	60 days	45 days	120 day
Rate of survival	81%	92%	72%
Av.length at the time of harvest	9.45 cm	12.6 cm	13.6 c
Av.weight at the time of harvest	4.4 g	7.85 g	9.6 g
Yield Kg/ha/crop	178.65	361	345.6

Table 5.7 Details of growth rate and production of *P. indicus* cultured during low, high and wide range of salinity in Pokkali rice fields at Vyttila

	Low Salinity	High Salinity	Wide range of salinity
Species stocked	*P. indicus*	*P. indicus*	*P. indicus*
Stocking size	PL 20	PL 20	PL 20
Salinity range	10-15 ppt	20-25 ppt	10-25 ppt
Culture period	60 days	45 days	120 days
Rate of survival	81%	92%	72%
Av.length at the time of harvest	9.45 cm	12.6 cm	13.6 cm
Daily increment of growth	1.58mm-74.2 mg	2.8mm-174.4mg	1.13mm-80mg
Av.weight at the time of harvest	4.4 g	7.85 g	9.6 g
Yield Kg/ha/crop	178.65	361	345.6

Informations on the effect of salinity on the culture performance of *P. indicus* has been scarce. In traditional prawn filtration, the white shrimp forms only a part the catch, and the quantity is subjected fluctuations depending upon the natural recruitment of the species. The size range of *P. indicus* harvested from the filtration fields has been reported to be 41 to 145mm (George, 1980). Mathew (1986) has reported a production rate of 350 Kg/Ha/97days from selective culture of *P. indicus* in pokkali fields. Unnithan (1986) reported a yield of 700 Kg of shrimps and fishes from pokkali fields through traditional culture method. The yield of *P.indicus* stocked at a density of 60,000 no./Ha in two pokkali fields at Narakkal and Edavanakadu in Ernakulam district was 552 Kg/Ha and 382 Kg/Ha at a rearing period of 83 and 90 days respectively. The individual shrimps had reached an average size of 130 mm and average weight 14.2 g and 126 mm and 13.5 g. The salinity in the fields ranged between 20-32.5 ppt (Jose *et al.*,1987).

The results of the experiment clearly establish that shrimps when stocked at higher salinity (20-25 ppt) for 45 days has given higher growth, survival and production than those stocked at lower salinity (10-15 ppt) in all the above parameters even when the culture experiment was maintained for longer periods in lower salinity. In the prolonged culture experiments conducted for 120 days in 10-25 ppt salinity, the results were poorer than the short period culture in higher salinity and the production values

were similar to lower saline culture. This clearly establishes the importance of salinity as an ecological factor which will have profound influence in shrimp farming operations. *P. indicus* is mainly used for freezing and specimens from 5 g onwards are used for export. In the present expereiment they have attained an average size of 12.6 cm and 7-8 g within 45 days and are easily marketable.

The shrimp culture operation in pokkali fields starts from November and extends upto middle of April. Instead of stocking the post larvae of shrimp during November and continuing the farming operation upto middle of April, it may be advantageous to start shrimp farming operations a little later in the middle of December and to take two crops of short term duration during one season before the middle of April. This can be easily achieved by making in built nurseries. The above experiment clearly suggests the advantage of such shrimp farming method than the prolonged culture now generally practiced by farmers.

SUMMARY AND CONCLUSIONS

Shrimps form a prominent export commodity among marine products in India. Shrimp fishery also plays a vital role in providing livelihood for thousands of families by way of extending employment opportunities. The demand for shrimp is, however, ever increasing in the world market. The growth and survival of the shrimp industry depend upon the uninterrupted production and supply of shrimps. It is essential to safeguard the production trend against any fluctuation or decline. Therefore any step taken to augment production of shrimps would be of national importance. Natural resources for shrimp farming in the country are very favourable. The country have an estimated 17,000,000 hectares of cultivable brackish water areas in the coastal sector. Out of this only 30,000 hectares lying in the coastal belt of Kerala, Karnataka and West Bengal are only now being used for shrimp and fish farming. Recently a number of shrimp hatcheries are established for the mass production of shrimp seed. In Kerala, the total brackish water resources including the lower reaches of rivers, the brackish water lakes, the backwaters and adjacent low lying fields and mangrove swamps cover an estimated area of about 2,43,000 hectares. Out of these only 5,117 hectares of low lying fields adjacent to Vembanad lake are at present utilised for the traditional shrimp and fish farming. From among 27 species of shrimps belonging to Penaeidae

occurring in Indian coastal waters, 11 species have been reported to be suitable for culture. Among these, the Indian white shrimp *Penaeus indicus* and the black tiger shrimp *P. monodon* are the most popular.

Penaeus indicus is a euryhaline species capable of withstanding wide range of salinities. After the early stages of development in their natural ecosystem, the post-larvae and juveniles enter the backwaters and estuaries for feeding and growth, withstanding lower salinities. But comparatively higher salinities are required for faster growth rate during the later stages.

P. indicus is one of the prominent species used for semi-intensive shrimp culture in the country. An understanding of the optimal environmental requirement of the species is one of the prime necessity in any culture operation. Brackish water organisms are generally endowed with wide range of adaptability to withstand extreme fluctuations in physical conditions, especially so in the case of salinity. Salinity is known to influence the efficiency of a species in food utilization and growth. Therefore it is necessary to understand the extent of the influence of salinity on the feed utilization by the cultured organism. It is more significant, because feeds form a major expenditure item in shrimp farming. Hence, it is necessary to

gain an understanding in detail, the effects of salinity on the energy budget of *P. indicus* by studying its food intake and conversion, growth, oxygen consumption and ammonia excretion.

The thesis consists of five chapters:

The first chapter includes introduction, the general account on habit and habitat of the animal and the scope and objectives of the present investigation.

In shrimp culture system, salinity is considered to be one of the major factors influencing growth and survival. Salinity influences the survival and growth of penaeid shrimps. The effects of salinity on the growth of penaeid shrimps have been subjected to extensive studies. Most of the earlier studies depended only on length increase. However, it is felt that weight changes will be more reflective of the prevailing environment enabling an effective comparison of growth. The second chapter deals with the effect of salinity on growth and food conversion ratio of *P. indicus*. The experiments were conducted to find out optimum feeding ration and growth rates in different salinities. Based on the salinity prevailing in the culture systems during the period of stocking it was decided to restrict the feeding experiment in 10 and 20 ppt salinity. To study the optimum feeding ration two size group of shrimps were

selected (30-35 mm and 50-55 mm) and feed was given at 0, 10, 20 and 30% ration for 21 days.The results indicated that the optimum feeding ration for the two size groups was 18% of the body weight. Growth rate studies were conducted at 5, 10, 15, 20 ,25, 30 and 35 ppt salinity at fixed ration of 18% of the body weight for 21 days. In both size groups studied, the best and statistically significant growth rate and FCR were observed in 20 ppt salinity.

Being a euryhaline species, *P. indicus* must have behavioural, physiological and biochemical adaptations to attain this euryhalinity which will ultimately express as metabolic energy requirement. One possible way of measuring this energy requirement is through oxygen consumption and ammonia excretion. In culture systems, the post-larvae and juveniles are stocked in different salinities. Hence, information regarding the metabolic responses of the species in different salinities is highly essential for shrimp culture management. The third chapter deals with oxygen consumption, ammonia excretion and O:N ratio of *P. indicus*. These parameters were studied for different weight groups ranging 50-600 mg at different salinities, 5, 10, 15, 20, 25, 30 and 35 ppt. The results showed that in all the test salinities, the oxygen uptake rate increased with increasing body weight while the metabolic rate decreased. The oxygen uptake rate is minimum at 25 ppt and as salinity increased or decreased

the rate also increased except at extreme salinities, which is characteristic of euryhaline animals. The ammonia excretion rate was minimum at 25 ppt and as salinity increased or decreased the rate also increased except in 5 ppt. O;N ratio is a useful index for measuring the organism's physiological state. In the present study, O:N was calculated at different salinities for different weight groups and the results showed that the ratio was highest in 25 ppt.

Study of the physiological energetics of the animal give valuable information on the physiological flexibility of the organisms in relation to the environment. 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 the various physiological and metabolic responses to environmental change. The above aspects form the fourth chapter of the thesis. To develop the energy equation, all the physiological components (production, consumption, assimilation, respiration and excretion)were converted to energy equivalents (Joules/h) for two size groups of 30-35 mm and 50-55 mm. THe results indicated that gross and net growth efficiencies are higher in small size group (30-35) than in the large size group (50-55 mm). Maximum values for scope for growth and food consumption were obtained in 20 ppt.

Culture experiments of *P. indicus* in varying salinities in pokkali rice fields form the basis of the fifth chapter. The investigation was aimed at establishing the effect of salinity on the culture performance of *P. indicus* in pokkali fields and also to find out the growth performance of the shrimp at varying salinities. The experiments were laid out at Rice Research Station, Vyttila of Kerala Agriculture University in three fields of area 1000 m^2 each. The results of the experiment clearly establish that shrimps when stocked at higher salinity (20-25 ppt) for 45 days has given higher growth, survival and production than those stocked at lower salinity (10-15 ppt) in all the above parameters even when the culture experiment was maintained for longer periods in lower salinity. In the prolonged culture experiments conducted for 120 days in 10-25 ppt salinity, the results were poorer than the short period culture in higher salinity and the production values similar to lower saline culture. This clearly establishes the importance of salinity as an ecological factor which will have profound influence in shrimp farming operations.

Conclusions:

1. The relative growth rate of smaller (30-35 mm) and larger (50-55 mm) size groups of *P. indicus* were studied at four feeding rations of 0, 10, 20 and 30% of body weight in 10 and 20 ppt salinities. The optimum feeding ration was found to be 18% of the body weight.

2. In *P. indicus* salinity influences food intake, assimilation, food conversion ratio and growth rate. In both size groups studied, the best and statistically significant growth rate and FCR were observed in 20 ppt salinity.

3. The oxygen uptake of *P.indicus* was found to increase with body weight. Minimum oxygen uptake rate was found in 25 ppt salinity. As salinity increase or decrease from 25 ppt oxygen consumption increased except at extreme salinities (5 and 35 ppt). This decrease may be because of the reduced activity of the animal.

4. Ammonia excretion was also found to increase with increase in body weight. Minimum ammonia excretion was noticed in 25 ppt.

5. O:N ratio at 25 ppt salinity was significantly higher. O:N ratio may not be an useful index to understand stress in *P. indicus.*

6. Maximum values of scope for growth and food consumption were obtained in 20ppt. The scope for growth decreases as the salinity decreases or increases.

7. The smaller size group maintained higher efficiencies, gross growth efficiency (K_1) and net growth efficiency (K_2) in a wide range of salinity from 10-30 ppt.

8. The maximum K_1 and K_2 were observed in 20 ppt for small size groups. In larger size group the maximum K_1 was again in 20 ppt while K_2 was in 15 ppt, the value was very close to that of 20 ppt. Hence, 20 ppt can be considered as the most suitable salinity for the species.

9. The shrimp culture operation in pokkali fields starts from November and extends upto middle of April. Instead of stocking the post larvae of shrimp during November and continuing the farming operation upto middle of April, it may be advantageous to start shrimp farming operations a little later in the middle of December and to take two crops of short duration during one season before the middle of April. This can be easily achieved by making in built nurseries. The study clearly suggests the advantage of such shrimp farming method than the prolonged culture now practiced by farmers.

REFERENCES

ADB/INFOFISH, 1991. Fishery Export Industry Profile: India. ADB/INFOFISH, 1-40.

Akberali, H.B. and Trueman, E.R., 1985. Review: Effects of environmental stress on marine bivalve molluscs. Adv. Mar. Biol., 22: 101-198.

Anon, 1994. Statistics of marine products export from India. *Seafood Trade Journal*, Aug., 29-35.

Ansell, A.D., 1982. Experimental studies of a benthic predator prey relationship. II. Energetics of growth and reproduction and food conversion efficiencies in long-term cultures of the gastropod drill *Polinices alderi* (Forbes) feeding on the bivalve Tellina *tenuis* (da Costa). J. Exp. Mar. Biol. Ecol., 61: 1-29.

APHA, 1985. "Standard Methods for the Examination of Water and Wastewater Treatment". 16th Edition, American Public Health Association, Washington DC, 1268p.

Barnes, H. and Barnes, M. 1959. Studies on the metabolism of cirripedes. The relation between body weight, oxygen uptake and species habitat. Veroff. Inst. Meereforsch Bremerhaven, 6: 515-523.

Bayne, B.L., 1985. Responses to environmental stress:Tolerance

resistance and adaptation. In: " Marine biology of Polar Regions and Effect of Stress on Marine Organisms". J.S. Gray and M.E. Christansen (ed.), John Wiley and Sons Ltd, 3331-3349.

Bayne, B.L., Brown, D.A., Burns, K., Dixon, D.R., Ivanovici, A., Livingstone, D.R., Lowe, D.M., Moore, M.N., Stebbing, A.R.D. and Widdows, J., 1985. The effects of stress and pollution on marine animals. Praeger Special Studies. Praeger Scientific Publishers, 314pp

Bertalanffy, L. Von, 1957. Quantitative loss in metabolism and growth. Quart. Rev. Biol., 32: 217-231.

Bhattacharya, S.S. and Kewalramani, H.G. 1976. Salinity and temperature tolerance of post-larvae of *Penaeus indicus*. J. Ind. Fish. Assoc., 182: 105-113.

Blackstock, J., 1984. Biochemical and metabolic regulatory responses of marine invertebrates to natural environmental change and marine pollution. Oceanogr. Mar. Biol. Ann. Rev., 22: 263-314.

Brett, J.R., 1979. Environmental factors and growth. In: "Fish Physiology, W.S. Hoar, D.R. Randall and J.R. Brett (Eds.), Vol.8, Academic Press, New York, pp 599-675.

Brown, A.C., Stenton-Dozey, J.M.E. and Trueman, E.R., 1989. Sandy-Beach Bivalves and Gastropods: A comparison between *Donax serra* and *Bullia digitalis*. Adv. Mar. Biol., 25: 179-247.

Bulnheim, H.P., 1974. Respiratory metabolism of *Idothea baltica* (Crustacea, Isopoda) in relation to environmental variables, acclimation processes and moulting. Helgolander Wiss. Meeresunters, 26: 464-480.

Chen, T.P. 1976. Shrimp Culture. In: "Aquaculture in Taiwan", Fishing News Books Ltd., London, pp 111-122.

Cherian, C.J. 1977. Studies on some boring and fouling Crustaceans. Ph.D. thesis, University of Cochin.

Cherian, C.J., 1978. Studies on the oxygen consumption of some estuarine isopods in relation to body size, salinity and declining oxygen tension. Bull. Dept. Mar. Sci., Univ. Cochin. 9: 15-95.

Cheriyan, P.V., 1973. Studies on *Sphaeroma terebrans* (Crustacea, Isopoda) of the Port of Cochin. Forma et Functio., 6: 1-68.

Conovor, R.J., 1959. Regional and seasonal variation in the respiratory rate of marine copepods. Limnol. Oceanogr., 4: 259-268.

Conover, R.J. and Lalli, C.M., 1974. Feeding and growth in *Clione limacina* (Phipps), A pteropod mollusc: Assimilation, metabolism and growth efficiency. Vol.II, J. Exp. Mar. Biol. Ecol., 16: 131-154.

Dall, W. and Smith, D.M., 1986. Oxygen consumption and ammonia-N excretion in fed and starved tiger prawns, *Penaeus esculentus* Haswell. Aquaculture, 55: 23-33.

Dare, P.J. and Edwards, D.B. 1975. Seasonal changes in flesh

weight and biochemical composition of mussels (*Mytilus edulis* L.) in the Conwy estuary, North Wales. J. Exp. Mar. Biol. Ecol., 18: 89-97.

Dehnel, P.A., 1960. Effect of temperature and salinity on the oxygen consumption of two intertidal crabs. Biol. Bull., 118: 215-249.

de Zwaan, A. and van Marrewijk, W.J.A. 1973. Anaerobic glucose degradation in the sea mussel *Mytilus edulis* L. Comp. Biochem. Physiol., 44 (B): 429-439.

Edney, E.B. and Spencer, J.O., 1955. Cutaneous respiration in woodlice. J. Exp. Biol., 32: 256-269.

Ellenby, C., 1951. Body size in relation to oxygen consumption and pleopod beat in *Ligia oceanica*. J. Exp. Biol., 28: 492-507.

FAO, 1992. Fishery Statistics- Catches and landing-1990. *FAO Year book*, Vol. 70, FAO, Rome, 646p.

Fish, J.D. and Preece, G.S., 1970. The ecophysiological complex of *Bathyporeia pilosa* and *B. pelagica* (Crustacea, Amphipoda)-1. Respiration rates. Mar. Biol., 5: 22-28.

Ganapathi, P.N. and Prasada Rao, D.G.V., 1960. Studies on the respiration of the barnacles. Oxygen uptake and metabolic rate in relation to body size in *Balanus amphitrite communis* (Darwin). J. Anim. Morph. Physiol., 7(1): 21-31.

George, K.V. 1980. Economics of traditional prawn culture in Kerala with a note on the advantages of intensive prawn

culture. Nat. Symp. Shrimp Farming, Bombay, 16-18 August 1978 : 131-137.

George, K.V. 1983. Culture fishery of prawns - Existing practices and future prospects. *Proc. Summ. Inst. Hatchery Production of Prawn Seed and Culture of Marine Prawns.* 18th April-17th May 1983, CMFRI, Cochin

George, M.J., 1961. Studies on the prawn fishery of Cochin and Alleppey coast. Indian J. Fish., 8: 75-95.

George, M.J., 1962. On the breeding of penaeid and the recruitment of the post-larvae into the brackish water of Cochin. Indian J. Fish., 9A (1): 110-116.

George, M.J., 1968. The influence of backwaters and estuaries on marine prawn resources. *Proc. Symp. on Living Resources of the Seas around India.,* ICAR, CMFRI, 563-569.

George, M.J., 1969. Genus *Macrobrachium* (Bate, 1968) Prawn fisheries of India. Bull. Central Marine Fish. Inst., 14: 168-216.

George, M.J., 1979. Taxonomy of Indian Prawns (Penaeidae, Crustacea, Decapoda). In: "Contributions to Marine Sciences", pp. 21-59.

George, M.J. and, Suseelan, C. 1982. Distribution of species of prawns in the backwaters and estuaries of India with reference to coastal aquaculture. *Proc. Symp. Coastal Aquaculture,* Part I, 273-284.

*George, M.J. and Vedavyasa Rao, 1968. *J. Mar. Biol. Assoc.*

India, 10, 52-70.

Gerhardt, H.V., 1980. Nitrogen excretion by juveniles of *Penaeus indicus* Milne Edwards at various temperatures. S. Afr. J. Sci., 76: 39-40.

Gopalan, U.K., Purushan, K.S. and Rao, T.S.S. 1980. Case studies on the economics of an improved method of paddy field shrimp culture in Vypeen island, Kerala, *Proc. Symp. Shrimp Farming*, Bombay 175-186.

Gopinathan, K. 1956. Prawn culture in the rice fields of Travancore-Cochin, India, *Proc. Indo-Pacif. Fish. Coun.*, 6th session, 18: 419-424.

Haq, S.M., 1967. Nutritional physiology of *Metrida luceans* and *M. Longa* from the Gulf of Mexico. Limnol. Oceanogr., 12: 40-51.

Hawkins, A.J.S., Bayne, B.L. and Day, A.J. 1986. Protein turnover, physiological energetics and heterozygosity in the blue mussel *Mytilus edulis*: the basis of variable age specific growth. Proc. Res. Soc. London, 229 (B): 161-176.

Imai, T. 1977. Aquaculture in shallow seas. *Progress in shallow sea culture*, Amerind Publishing Co.(Pvt.) Ltd., New Delhi. pp. 1-613.

IMCO/FAO/UNESCO/WHO/IAEA/UN/UNEP, 1980. Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). Monitoring Biological variables to Marine Pollution. Rep. Stud. GESAMP, 12: 20pp.

Imre Csavas, 1992. Impact of aquaculture on the shrimp industry. *Shrimp92, Hongkong*, INFOFISH, 6-

Imre Csavas, 1994. World aquaculture status and outlook. *INFOFISH International*, Sept-Oct., 47-54.

INFOFISH, 1994. Globe fish market survey. *INFOFISH International*, 5, 41-44.

Ivlev, V.S. 1961. "Experimental ecology of the feeding of fishes". Yale University press, New Haven, 302pp.

Jose, M.M., Mathew, P.M. and Susheela Jose, 1987. Feasibility and economic viability of selective culture of *Penaeus indicus* in pokkali fields. Proc. Natn. Estuarine Management, Trivandrum, pp: 379-381.

Jorgenson, C.B. 1976. Growth efficiencies and factors controlling size in some mytilid bivalves, especially *Mytilus edulis* L. A review and interpretation. Ophelia, 15: 175-192.

Kalyanaraman, M. and Paul Raj, R. 1984. Effect of salinity on food intake, growth, conversion efficiency and proximate composition of juvenile *Penaeus indicus* H. Milne Edwards. CMFRI, Special Publication No. 19, 26-29.

Karmandayera, O.G., 1966. Process to insure osmoregulation in water invertebrates (In Russ). In:"Physiology of Marine Animals". V.S. Ivlev (ed.), Moscow, Nanka, p. 176-232.

Kennedy, V.S. and Mihursky, J.A., 1972. Effect of temperature on the respiratory metabolism of three Chesapeake Bay bivalves. Chesapeake Sci., 13: 1-22.

Kinne, O. 1971. Salinity: Animals-Invertebrates. In: *Marine Ecology*, Vol. I, Part 2, O.Kinne (ed.). Wiley Inter Science, London. pp. 821-995.

Kuenzler, E.T., 1961. Structure and energy flow of a mussel population in a Georgia salt marsh. Limnol. Oceanogr., 6: 191-204.

Kutty, M.N., 1967. Oxygen consumption of the prawns *Penaeus indicus* H. Milne Edwards and *Penaeus semisulcatus* Dellan. FAO Fish. Rep., 57: 957-969.

Kutty, M.N., Murugapoopathy, G. and Krishnan, T.S. 1971. Influence of salinity and temperature on oxygen consumption in young juveniles of Indian prawn *Penaeus indicus*. Mar. Biol., 11: 125-131.

Kuttyamma, V.J., 1982. The effects of salinity on the growth of some penaeid prawns. Bull. Mar. Sci. Univ. Cochin, 13: 1-34.

Lakshmikanthan, K.P. 1982. Salinity tolerance of post larvae of *Penaeus indicus* H. Milne Edwards. Ph.D. Thesis, Cochin University of Science and Technology, Cochin.

Laxminarayana, A. and Kutty, M.N. 1982. Oxygen consumption, ammonia excretion and random activity in *Penaeus semisulcatus, Macrobrachium malcolmsonii* and *Paratelphusa hydrodromus* with reference to ambient oxygen. Proc. Symp. Coastal Aquaculture, 1: 117-122.

Lofts, B. 1956. The effects of salinity changes on the respiratory rate of the prawn, *Palaemonotes varians* (Leach).

J. Exp. Biol., 33: 730-736.

Mathew, P.M. 1986. Selective culture of prawn in pokkali fields. Paper presented in the Seminar on "Brackish water Prawn Farming", MPEDA, Cochin.

Menon, M.K. 1954. On the paddy field prawn fishery of Travancore-Cochin and an experiment in prawn culture., *Proc. Indo-Pacif. Fish. Coun.* 5th Session (II) 1-5.

Mohan, M.V. and Cheriyan, P.V. 1980. Oxygen consumption of the green mussel *Perna viridis* L. in relation to body weight and declining oxygen tension. Bull. Dept. Mar. Sci. Univ. of Cochin, 11(1): 75-84.

Mohanty, A.W., Ravichandran, P., Rajyalekshmi, T. and Pillai, S.M., 1989. Rate of ammonia excretion in *Penaeus monodon* (Fabricus) J. Aqua. Trop., 4: 93-95.

Muthu, M.S. 1978. A general review of Penaeid prawn culture. *Summer Institute in Breeding and Rearing of Marine Prawns* CMFRI Spl. Pbln., 3: 25-33.

Nair, S.R.S. and Krishnankutty, M.K. 1975. Notes on the varying effects of salinity on the growth of the juveniles of *Penaeus indicus* from the Cochin backwater. Bull. Dept. Mar. Sci. Univ. Cochin, 7 (1): 181-184.

Newell, R.C. 1973. Factors affecting the respiration of intertidal invertebrates. Amer. Zool., 513-528.

Newell, R.C. 1979. Biology of Intertidal Animals, 3rd Ed., Marine Ecological Surveys Ltd., Faversham, Kent, 781pp.

Newell, R.C. and Branch, G.M. 1980. The effects of temperature on the maintenance of metabolic energy balance in marine invertebrates. Adv. Mar. Biol., 17: 329-396.

Newell, R.C. and Roy, A. 1973. A statistical model relating the oxygen consumption of a mollusc (*Littorina littorea*) to activity, body size and environmental conditions. Physiol. Zool., 46 (4): 252-275.

Newell, R.C. and Northcroft, H.R. 1965. The relationship between cirral activity and oxygen uptake in *Balanus balanoides*. J.Exp. Biol. Assoc. U.K., 45: 387-403.

Paloheimo, J.E. and Dickie, L.M. 1965 Food and growth of fishes. I. A growth curve derived from experimental data. J. Fish. Res. Bd. Can., 22: 521-542.

Paloheimo, J.E. and Dickie, L.M. 1966 Food and growth of fishes. II. Effects of food and temperature on the relation between metabolism and body weight. J. Fish. Res. Bd. Can., 23: 869-908.

Panikkar, N.K. 1969. New perspective in estuarine biology. First All India Symposium in Estuarine Biology, Madras, Dec. 27-30,(Mimea) 8 pp.

Qasim, S.Z. and Easterson, D.C.V. 1974. Energy conversion in the shrimp, *Metapenaeus monoceros* (Fabricus) fed on detritus. Indian J. Mar. Sci., 3 (2): 131-134.

Qasim, S.Z., Wellershaus, S. Bhattathiri, P.M.A. and Abidi, S.A.H. 1969. Organic production in a tropical estuary.

Proc. Indian Acad. Sci., 69(2) B: 51-94.

Raj, R.P. and Raj, P.J.S. 1982. Effect of salinity on growth and survival of three species of penaeid prawns. Proc. Symp. Coastal Aquaculture, Part I: 236-243.

Rajyalekshmi, T. 1961. Studies on maturation and breeding habits of some estuarine palaemonid prawns. Proc. Natl. Inst. Sci. India, 27B (4): 177-188.

Ramadhas, V. and Sumitra Vijayaraghavan. 1979. Efficiency of energy utilisation in the shrimp *Metapenaeus monoceros* fed mangrove leaves. Indian J. Mar. Sci., 8 (2): 114-115.

Ramaswamy, A. and Pandian, P.A.I. 1985. Environmental physiology of the prawn *Penaeus* (Melicertus) *latisulcatus*. Proc. First International Conference on Culture of Penaeid prawns/shrimps, Iloilo City, 177.

Rao, K.P. 1958. Oxygen consumption as a function of size and salinity in *Metapenaeus monoceros* Fab. from marine and brackish water environments. J. Exp. Biol., 35: 307-313.

Rao, P.V. 1973. The influence of salinity and temperature on the breeding and development of some cultivable marine penaeid prawns. Proc. All India Seminar on Mariculture and Mechanised Fishing, 28-29 Nov. 1972. Govt. of Tamil Nadu, 67-69.

Rao, P.V. 1977. Maturation and spawning of cultivable marine penaeid prawns. *Summer Institute in Breeding and Rearing of Marine Prawns*. CMFRI Special Publication No., 3: 57-67.

Rao, R.M. 1983. Shrimp seed resources of India. *Proc. Natl. Symposium on Shrimp seed Production and Hatchery Management.* MPEDA, Cochin, 49-67.

Robertson, J.D. 1957. Osmotic regulation in aquatic invertebrates. In: " Recent Advances in Physiology". B.T. Scheer (Ed.), Univ. of Orogon Press, Orogon, pp 229-245.

Rodhouse, P.G. 1978. Energy transformations by the oyster *Ostrea edulis* L. in a temperate estuary. J. Exp. Mar. Ecol., 34: 1-22.

Scott, D.M. and Major, C.W. 1972. The effect of copper (II) on survival, respiration and heart rate in the common blue mussel *Mytilus edulis*. Biol. Bull., 143: 679-688.

Sherief, P.M. 1967. Clam meat as animal protein source in the diet of *Macrobrachium rosenbergi*. In: "Recent Trends in Processing Low Cost Fish. Society of Fisheries Technologists (India), 213-217.

Shick, J.M., Widdows, J. and Gnaiger, E. 1988. Calorimetric studies of sessile intertidal animals. Amer. Zool., 28: 161-181.

Small, L.F. and Hebard, J.F. 1967. Respiration of vertically migrating maritome crustacean *Euphausia pacifica* Hansen. Limnol. Oceanogr., 12: 272-280.

Snedecor, G.W. and Cochran, W.G. 1968. "Statistical Methods". 6^{th} edition, Oxford and IBH Publishing Co., 66 Janpath, New Delhi. pp 593.

Snow, M.B. and Williams, P.J. le B. 1971. A simple method to determine the O : N ratio of small animals. J. MAr. Biol. Assoc. UK., 51: 105-109.

Solorzano, L. 1969. Determination of ammonia in natural water by the phenol-hypochlorite method. Limnol. Oceanogr., 14: 799-801.

Spaargaren, D.H. Richard, P. and Ceccaldi, H.J. 1982. Excretion of nitrogenous products by *Penaeus japonicus* Bate in relation to environmental osmotic conditions. Comp. Biochem. Physiol., 72A: 673-678.

Stern, S. Borut, A. and Cohen, D. 1984. The effect of salinity and ion composition on oxygen consumption and nitrogen excretion of *Macrobrachium rosenbergei* (De Man). Comp. Biochem. Physiol., 79A: 271-274.

Strickland, J.D.H. and Parsons, T.R. 1972. A practical Hand Book of Seawater Analysis. Bull. Fish. Res. Bd. Can., 167: pp 331.

Subramanian, P. and Krishnamurthy, K. 1986. Effects of salinity and body size on metabolism and growth of juvenile penaeid prawns. Indian J. Exp. Biol., 24 (12): 773-778.

Subramanyam, C.B. 1957. Relationship between body weight and the oxygen consumption in *Emerita aslatica* (M. Edw.). Curr. Sci., 26: 155-156.

Subramanyam, C.B. 1962. Oxygen consumption in relation to body weight and oxygen tension in the prawn *Penaeus indicus* Milne Edwards. Proc. Indian Acad. Sci., 55: 153-161.

Sumitra Vijayaraghavan and Ramadhas, V. 1980. Conversion efficiency in the shrimp *Metapenaeus monoceros* (Fabricus), fed decomposed mangrove leaves. Indian J. Mar. Sci., 9 (2): 123-125.

Sumitra Vijayaraghavan, Royan, J.P. and Krishnakumar, L. 1981. Use of slaughter house waste as feed for shrimps and prawns. Ind. J. Mar. Sci., 10 (4): 390-392.

Sumitra Vijayaraghavan, Krishnakumar, L. and Royan, J.P. 1988. Food conversion by *Penaeus monodon* (Fabricius) fed on decapsulated cysts of *Artemia*. Indian J. Mar. Sci., 17: 172-173.

Supriya, R. 1992. Studies on the survival of *Sunetta scripta* in different salinities. Ph.D. thesis, Cochin University of Science and Technology, Cochin.

Suresh Babu, C. 1990. Effect of salinity on food intake, conversion efficiency and growth of the prawn *Metapenaeus monoceros* (Fabricius). M.F.Sc. Thesis, College of Fisheries, Kerala Agricultural University.

Teal, J.M. 1959. Respiration of crabs in Georgia salt marshes and its relation to their ecology. Physiol. Zool., 32: 1-14.

Thompson, R.J. and Bayne, B.L. 1974. Some relationships between growth, metabolism and food in the mussel, *Mytilus edulis*. Mar. Biol., 27: 317-326.

Unnikrishnan, T.N. and Laxminarayana, A. 1984. Oxygen consumption and ammonia excretion of *Penaeus indicus* H. Milne Edwards in different salinities. In: "CMFRI Special Publication No. 19, pp 10-13.

Unnithan, K.A. 1986. Prospects of prawn farming in Kerala. Paper presented in the Seminar on "Brackish water Prawn Farming", MPEDA, Cochin.

Venkataramiah, A., Lakshmi, G.J. and Gunter, G. 1972. The effects of salinity and feeding levels on the growth rate and food conversion efficiency of the shrimp, *Penaeus aztecus*. Proc. Third Ann. Workshop, World Mariculture Soc. La. state Univ. Baton Rouge, La, 267-283.

Venkataramiah, A., Lakshmi, G.J. and Gunter, G. 1975. Effect of protein level and vegetable matter on growth and food conversion efficiency of the brown shrimp, Aquaculture, 6: 115-125.

Verghese, P.U., Ghosh, A.W. and Das, P.B. 1975. On growth, survival and production of Jumbo tiger prawn *Penaeus monodon* Fabricius in brackish water ponds. Bull. Dept. Mar. Sci. Univ. Cochin, 7(4): 781-789.

Vernberg, W.B. and Vernberg, P.J. 1972. "Environmental Physiology of Marine Animals". Springer-Verlag, New York.

Warren, G.E. and Davis, G.E. 1967. Laboratory studies on the feeding, bioenergetics and growth of fish. In: "The Biological Basis of Freshwater Fish Production". S.D. Gerking (Ed.), Blackwell Scientific Publications, Oxford, pp 175-214.

Welsh, J.H. and Smith, R.I. 1953. "Laboratory Exercises in Invertebrate Physiology". Burges Publishing Co., Minneapolis.

Widdows, J. 1978a. Combined effects of body size, food concentration and season on the physiology of *Mytilus edulis* L. J. Mar. Biol. Assoc. U.K., 58: 109-124.

Widdows, J. 1978b. Physiological indices of stress in *Mytilus edulis* L. J. Mar. Biol. Assoc. U.K., 58: 125-142.

Widdows, J., Burns, K.A., Menon, N.R., Page, D.S., and Soria, S. 1990. Measurement of physiological energetics (scope for growth) and chemical contaminants in mussels (*Arca zebra*) transplanted along a contamination gradient in Burmuda. J. Exp. Mar. Biol. Ecol., 138: 99-117.

Winberg, G.G. 1960. Rate of metabolism and food requirements of fishes. Fish. Res. Bd. Can. Transl. Ser., 194: 1-253.

Wikins, J.F. 1976. Prawn biology and culture. In: H. Barnes (Ed.) *Annual Review Oceanogr. Mar. Biol.*, 14, 435-507.

Yamamoto, T. 1992. Keynote address: *Shrimp' 92, Hongkong.*

Zar, J.H. 1974. "Biostatistical Analysis". Prentice-Hall, Inc. Englewood Cliffes, NJ.

Zein-Eldin, Z.P. 1963. Effect of salinity on growth of

post-larval penaeid shrimp. Biol. Bull. Mar. Biol. Lab., Woods Hole, 125: 188-196.

Zein-Eldin, Z.P. and Aldrich, D.V. 1965. Growth and survival of post-larval *Penaeus aztecus* under controlled conditions of temperature and salinity. Biol. Bull. Mar. Biol. Lab., Woods Hole, 129: 199-216.

Zein-Eldin, Z.P. and Griffith, G.W. 1967. An appraisal of the effects of salinity and temperature on growth and survival of post-larval penaeids. FAO Fish. Rep. 3(57): 1015-1026.