# POPULATION CHARACTERISTICS, FISHERY AND POST LARVAL DISTRIBUTION OF *Macrobrachium rosenbergii* (de Man) AND *M.idella* (Hilgendorf) OF VEMBANAD LAKE

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FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

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COCHIN - 682 016

1997

*Dedicated To*
*My Parents*

## DECLARATION

I, Harikrishnan M., do hereby declare that the thesis entitled "**Population Characteristics, Fishery and Post larval distribution of *Macrobrachium rosenbergii* (de Man) and *M. idella* (Hilgendorf) of Vembanad lake**" is a genuine record of research work done by me under the supervision of **Dr.B.Madhusoodana Kurup**, Reader, School of Industrial Fisheries, Cochin University of Science and Technology and has not been previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any university or institution.

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September 1997

**Harikrishnan,M.**

# CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Sri. **Harikrishnan, M.** under my supervision and guidance in the **School of Industrial Fisheries, Cochin University of Science and Technology** in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** and no part thereof has been submitted for any other degree.

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HARIKRISHNAN.M

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**PLATE 1A.** ***Macrobrachium rosenbergii*** **(de Man)**

PLATE 1A

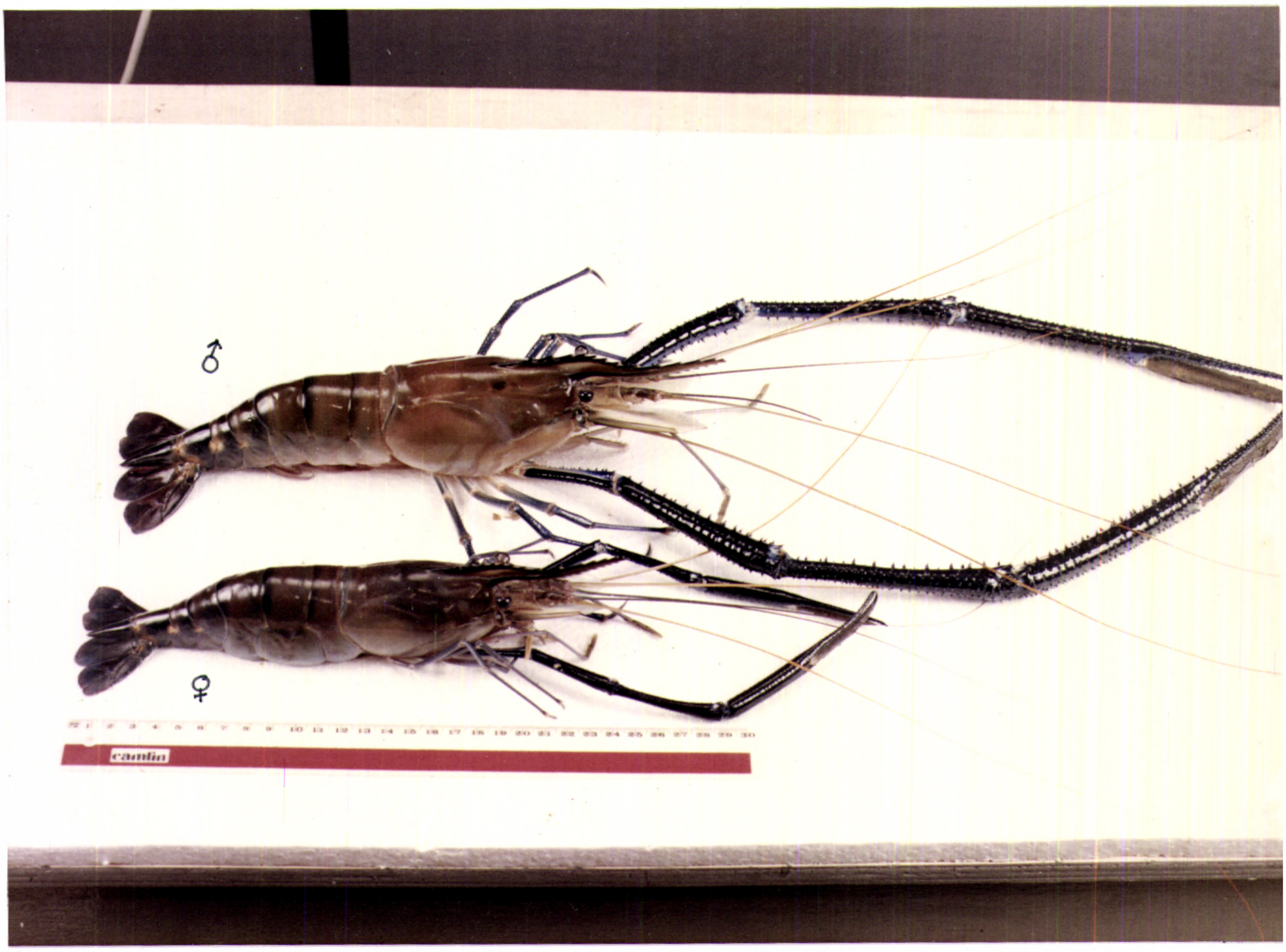
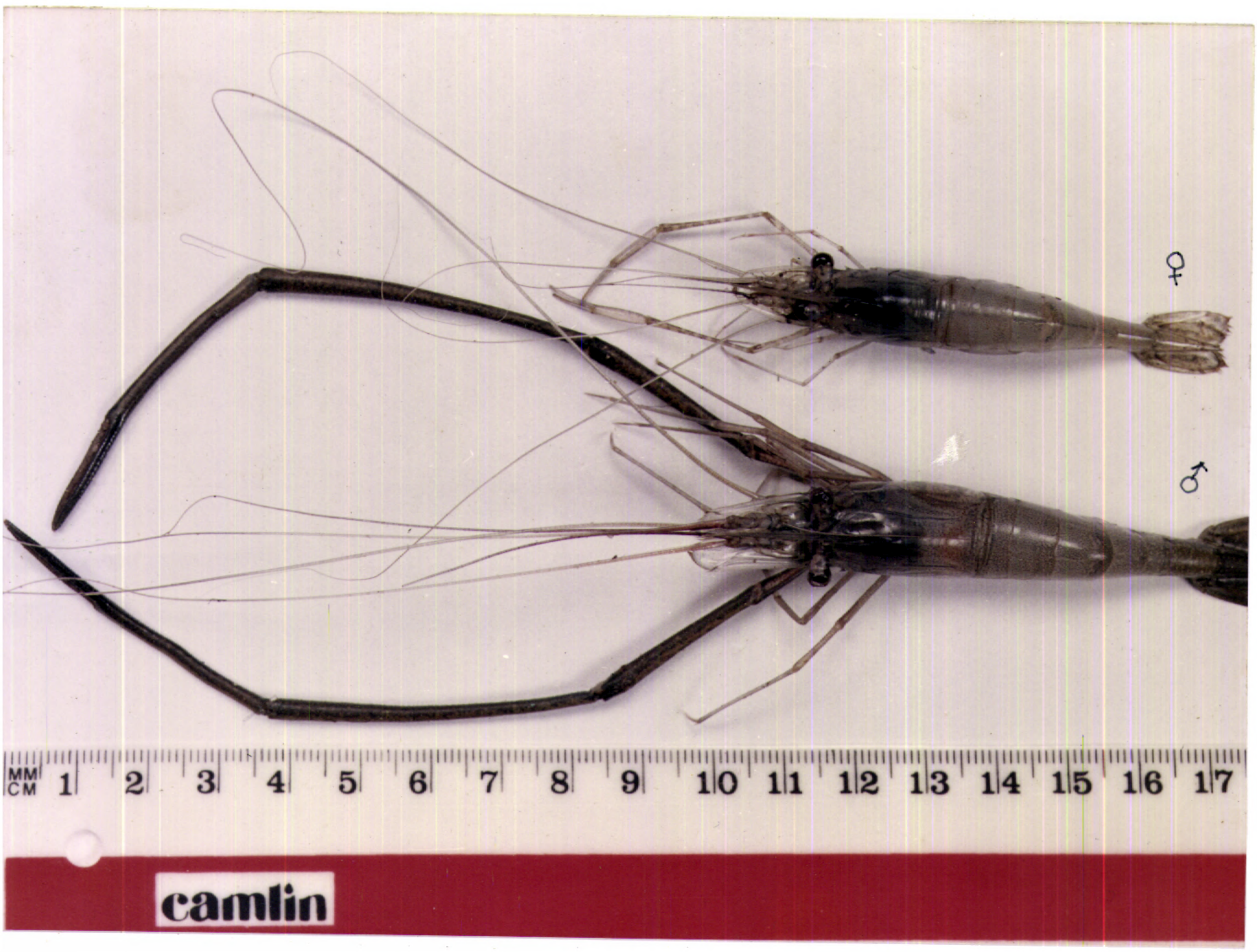


**PLATE 1B.** ***Macrobrachium idella*** **(Hilgendorf)**

**PLATE 1B**



# Section 1

# General Introduction

# GENERAL INTRODUCTION

## 1.1. BACKGROUND OF THE STUDY

Freshwater prawns constitute an important entity of the living aquatic resources and some of them occupy an important place in the export trade owing to their high demand and market value. Of the 7 genera recorded under the family Palaemonidae (Holthuis, 1980), the genus *Macrobrachium* Bate 1868 is represented by more than 100 species (New, 1990) of which about 40 species are reported from India, among them 11 species have been recorded from Kerala (Jayachandran, 1987). The genus *Macrobrachium* has a wide distribution through out the tropics and subtropical regions of the world and are found in most of the inland freshwater bodies including lakes, rivers, swamps, ditches, irrigation canals, ponds, as well as in estuarine areas (New and Singholka, 1985). Though some of the species can complete the life cycle in inland saline and freshwater lakes, majority of the species require brackish water for the completion of their larval metamorphosis. Therefore, it becomes obligatory for the mature population of the latter group to undertake lengthy spawning migration to the brackish water zones for the successful completion of the life cycle.

*M. rosenbergii*, *M. americanum* and *M. carcinus* are the three largest species known under the genus

*Macrobrachium* (New, 1990). *M.americanum* is distributed in Mexico, North Peru and Galapagos Island while *M.carcinus* is found in Florida to Brazil in Atlantic America. *M.rosenbergii* is indigenous to the whole of South and South-East Asia and Pacific Island (Holthuis, 1980). Among them, *M.rosenbergii*, the giant freshwater prawn is the most preferred species which is widely used for commercial farming due to its fast growth rate and large size, good demand and premium price it fetches in domestic as well as export markets. Commercial development of prawn farming based on *M.rosenbergii* has now became widespread, especially in South-East Asian countries. However, in India freshwater prawn culture has not gained much progress till recently.

Of the 40 species represented under the genus *Macrobrachium* Bate 1868 in India, 15 are important from fisheries point of view (Jayachandran and Joseph, 1992). *M.rosenbergii*, the most important commercial freshwater species of Indian rivers and estuaries, is one of the most extensively distributed species in the country. It is reported from lower reaches of Narmada and Tapti river, Thana creek (Bombay) and backwaters of Kerala along the west coast and nearly all the upper tidal zones and associated areas of rivers draining in the Bay of Bengal from Tamil Nadu to West Bengal on the east coast. It constitutes a lucrative fishery in Hooghly estuary (Rao, 1969), Godavari and Narmada river systems, Kolleru lake

(Rao, 1992) and Kerala backwaters (Raman,1967; Kurup *et al.*,1992a). Among other species of commercial importance, the Gangetic riverine prawn *M.choprai* is endemic to the Ganga and Brahmaputra river systems of eastern Uttar Pradesh, Bihar and Assam (Tiwari, 1955) while the monsoon river prawn *M.malcolmsonii* has comparatively wider distribution, mainly in peninsular India south of Narmada river colonizing the upper reaches of almost all rivers that drain into the Bay of Bengal (Pantulu, 1965). *M.lamerrei* is distributed along the north- east coast, mainly in Chilka lake and Hooghly- Matla estuary where it constitutes a minor fishery while *M.mirabile* and *M.javanicum* are known to exist in the deltaic Bengal where they constitute a seasonal fishery of not much importance (Kurian and Sebastian (1982). *M.idella* is abundant in the estuaries, backwaters and rivers of the south-west and south-east regions of India and constitutes a sustenance fishery.

Among the 11 species of *Macrobrachium* recorded from Kerala, *M.rosenbergii* is reported to be abundant in Nileswaram, Kavvayi, Elathur, Kallayi, Ponnani, Chettuva and Kodungallur estuaries and Cochin Backwaters while its occurrence has been reported from other estuaries located in northern Kerala such as Valapatnam, Mahe, Beypore, Kadalundi and Azheekode. However, it is totally absent in the estuaries and backwaters beyond Alapuzha towards south (Jayachandran, 1987). On the contrary, *M.idella* is present in 23 estuaries/ backwaters of Kerala in different magnitudes, showing greater abundance in Nileswaram, Kallayi, Ponnani, Chettuva, Kodungallore, Cochin, Edava, Akathumuri, Poonthura and Poovar backwaters of Kerala and in estuaries and lakes such as Valapatnam, Azheekode, Paravoor, Anchuthengu, Kayamkulam and Veli-Aukulam and constitutes a good fishery during July to December (Jayachandran, 1987).

*M. rosenbergii* is predominantly observed in limnetic and oligotrophic regions, however, the mature adult population descend to downstream regions of the lake, as part of their breeding migration. Therefore, the dominance of berried females is quite discernible in the mesohaline regions of the lake during the breeding season (Harikrishnan and Kurup, 1996 a & b). This species appears to favour turbid conditions and can surmount weirs and waterfalls and can even migrate short distances over land where vegetation is moist (New, 1990). *M. idella* is also known to occur over a wide range of environmental conditions, ranging from estuaries to freshwater lentic conditions, however, their abundance is always noticed in slightly brackish water habitats. Both the species are sexually dimorphic, mature males being larger and having longer and thicker second pereiopods. In *M. rosenbergii*, the male can easily be differentiated from the female by noticing the proportionately larger cephalothorax and narrow abdomen when compared to that of females. Males of

*M. rosenbergii* are characterised by a condition termed heterogeneous individual growth (HIG) and this acts as the biological limiting factor in freshwater prawn production of aquaculture ponds (Daniels and Abramo, 1994). The morphogenesis in male population coupled with morphotype-related dominance hierarchies and social control of growth cause size heterogeneity problem. This might be the consequence of dominance of various morphotypes in the linear order from Blue Clawed through Orange Clawed to Small Males reflected by competition for resources where the Blue Clawed males always had priority of access to food and shelter (Barki *et al.*, 1992).

Following the pioneering successful work of larval rearing of this species by Ling (1969b), commercial hatcheries have been set up at several places in various countries including India over the past two decades. As the seed availability became a reality, farming of this species under controlled conditions at different levels of scientific management has become very popular especially in Asian countries. The global production of farmed *M. rosenbergii* was 33,297 tonnes in 1991 of which 93% was produced from Asia (New, 1994). Among the non Asian countries, North America and Caribbean and South America contributed to most of the outside production. The global production in 1991 has shown a 3.5 fold increase when compared to 1985, and more than 52% of Asian farmed prawn production came from Taiwan (16,196t) while the contributions from Thailand (7500t) and Vietnam (7000t) were in the order of 24 and 23% respectively. Ecuador (870 t) and Brazil (550t) occupied the fourth and fifth positions in production of farmed *M.rosenbergii*.

*M.rosenbergii* and *M.malcolmsonii* are the two species of cultivable freshwater prawns in India of which the former remains to be the principal species. With the development of economically viable commercial larval rearing techniques in the past decade, the seed availability of this species became a reality from the commercial hatcheries and thenceforth interest and enthusiasm have been generated among farmers to undertake farming of *M.rosenbergii* by adopting different systems of culture. Thus, the farm raised *M.rosenbergii* from India started occupying a position in the global aquaculture production, however, the quantity was found to be less than 200 tonnes/annum and this is far below when compared to Taiwan and Thailand. India is endowed with a freshwater habitat of 4.5 million ha, comprising of 0.2 million ha of rivers, 2.3 million ha of ponds and tanks and 2 million ha of reserviors, nevertheless, an enormous water wealth suitable for undertaking farming of *M.rosenbergii* remained unutilized and therefore, India is considered as the sleeping giant of freshwater prawn farming. Production to the tune of 600-3000 Kg/ha/7-9 months have been invariably reported in India (Raje and Joshi,1992), however, the net revenue from the harvested population is seldom known to reach the level of expectation in view of the fact that there will be the preponderance of individual belonging to smaller size groups in the cultured stock which are having neither export market nor internal demand.

During the process of domestication of *M.rosenbergii* under different levels of scientific management, a major difference in growth strategy of males and of the females became very apparent (Smith *et al.*, 1978; Cohen *et al.*,1981). In single aged population, the size distribution of female population is reported to be rather homogeneous in grow-outs, on the contrary, a clear demarcation of the male on the basis of morphotypes having distinct size variation is possible. The differential growth pattern so evinced by the male population is one of the major obstacles in increasing profitability in the culture of *M.rosenbergii*. The size heterogeneity in male became evident in the post larval population and thenceforth the phenomenon progresses very rapidly which will eventually result in wide disparity in the size frequencies. One group is characterised with rapid growth and transformation into successive morphotypic stages which are designated as 'Jumpers', in contrast, another group is destined to be with retarded growth which are called as 'Laggards' (Ra'anan and Cohen, 1985). The jumpers can grow as much as fifteen times faster than the population mode with in a period of 60 days from metamorphosis (Willis and Berrigan, 1977; Ra'anan,1982).

The sexually mature adult male population of *M.rosenbergii* of the grow outs belonging to same age group has been differentiated into three distinct morphologically distinguishable forms such as Small Males (SM), Orange Clawed males (OC) and Blue Clawed males (BC) representing three phases in the developmental pathway of male (Brody *et al.*, 1980; Cohen *et al.*, 1981). These morphotypes show difference in sexual activity and growth rate, BC and SM are sexually more active while the somatic growth is very fast in OC. Two alternative mating strategies could be observed in different groups of morphotypes. BC shows excellent performance in regard to oviposition, hatchability of eggs and larval survival at 1 male: 4 female ratio, on the contrary, OC males showed very poor performance while SM showed intermediary performance only at lower ratios (Suresh Kumar and Kurup, 1995). There are dismal possibilities of genetic variation among the male morphotypes of *M.rosenbergii* in view of the fact that the SM is capable of transforming in to OC males and eventually becoming BC male, especially while the number of BC male are low in the population. Ra'anan and Cohen (1985) opined that some difference in gene which direct the individual's relative growth may be possible which can very much determine the preliminary size hierarchy. The growth and transformation of various morphotypes are also governed by interaction prevalent with the population. Juvenile prawns have a relatively uniform growth rate when raised in isolation. However, when raised in groups, the difference in size became more pronounced. It can reasonably be inferred that the social interaction among the individuals may probably pay a major role in the development of size disparity. BC male surpasses the growth of SM males (Cohen, *et al.*,1981) and the OC transforms BC only becoming larger than the largest BC at its vicinity. This leapfrog growth pattern results in a series of differently sized BC males where size is positively correlated with the time of their transformation. It is generally believed that the delay caused in transformation from the fast growing OC in to slow growing BC effects in the leapfrog growth pattern and therefore, the whole process is controlled by social interactions among males, as the males in isolation do not show these peculiarities. The BC males, because of their larger size, occupy an alpha position in the population which deems priority of access to food and shelter.

Available information on population profile development, morphotypic differentiation and their transformation, description of morphotypes based on morphology, morphometry and allometric characterisation are only based on harvested male population of *M.rosenbergii* from the grow-outs, mostly from Israel (Brody *et al.*, 1980; Cohen *et al.*, 1981; Kuris *et al.*, 1987). Though the biology and fishery of *M.rosenbergii* was subjected to detailed studies in different parts of the country, the occurrence of morphotypes in the natural population have totally been ignored and therefore aspects related to population structure and morphotypic composition, allometric relationship of various morphotypes inhabiting natural waters, seasonal and spatial variation of morphotyes in the exploited population, morphotype based size disparity in the natural stock and their size characterisation, etc., are hitherto unknown. Similarly, no attempt has so far been made to establish the allometric relationships in female population and explore the possibility of existence of morphotypes in par with that of their male counterparts. Furthermore, though farming of the species is being carried out in India at different levels, virtually no information is available on the relationship between density at harvesting and morphotypic composition - yield characteristics of the harvested population. In the present study, concerted attempt was made to fill up the existing lacunae in the information with regard to this important species.

*M.rosenbergii*, locally known as "Kuttanadan Konchu" or "Attu Konchu" and *M.idella* with its vernacular name "Koona Chemmeen" were known to have contributed a lucrative fishery in the Vembanad lake and confluent rivers during fifties and early seventies. By virtue of being an important component of shrimp export from the state and earner of foreign exchange, *M.rosenbergii* emerged as the most dear species of inland waters of Kerala. However, in recent years, the stock of these species were badly depleted whereby it became a rarity in Kuttanad in Kerala, the home ground. The dwindling nature of the stock of this species is attributed to the impact of human interventions brought about in the ecosystem of Kuttanad owing to intensification of rice cultivation, physical obstruction imposed on the downwardly migratory path of male and female mature specimens of these species and upward migration of post larvae due to the operation of the Thanneermukkam salinity barrier in Vemband lake, indiscriminate fishing pressure exerted on the stock and pollution hazards especially from the pesticides and agrochemicals run off from the paddy fields of Kuttanad (Kurup, 1996). Despite the proneness of the stock of these two species to very serious stresses as described above, no concerted attempt has so far been made either to monitor the stock size of these important resources of the lake from time to time or to study the impact of man made hazards on the resource characteristics and also to bring out the nature of responses and reactions of the stock against the changing ecological conditions of Kuttanad and the high intensity of fishing pressure exerted with stock. Moreover, various conjectures exist behind the dwindling nature of the stock in Vembanad lake and therefore it is also found necessary to verify these factors meticulously by generating authentic data base. Though there is a remarkable decline in the capture fisheries in Kuttanad, recently there is a renewed interest to augment the production of 'Kuttanadan Konchu' by resorting to farming in the derelicted paddy fields. According to Harikrishnan and Kurup (1997c), of the 54,000 ha of paddy fields available in Kuttanad, about 882 ha are lying fallow in upper, lower and northern Kuttanad regions while of the remaining 2946 ha are only utilized for *Virippu* crop alone whereas 42,321ha are used for *Punja* crop. It appears that the prospects for farming of *M.rosenbergii* in Kuttanad either as a perennial crop in the fallow polders or as a seasonal crop in the *Virippu /Punja* fields is very bright. With the availability of seed from the commercial hatcheries of Kerala, the farming of *M.rosenbergii* in the polders or coconut garden channels of Kuttanad has already been commenced, however, no serious attempt is made to generate a database on population structure, production, yield characteristics, retrieval rate, growth performance, marketable yield structure and information in these lines would be helpful for the development of appropriate culture system of this species relevant to Kuttanad ecosystem.

Against this background, the present study was undertaken with the following objectives:

1) to study the population profile development in the natural population of *M.rosenbergii* inhabiting Vembanad lake and adjoining rivers
2) to elucidate the morphotypic differentiation and pattern of transformation of male and female natural population,to establish allometric characterisation and

length-weight relationships and also to delineate the temporal and spatial distribution patterns of morphotypes in relation to the fluctuating hydrographical conditions of the lake

3) to investigate the population profile development, morphotypic composition and marketable yield structure in the commercial grow-outs of *M. rosenbergii* in Kuttanad and also to bring out the relationship of these factors with the density at harvesting, if any

4) to quantify the exploited stock of *M. rosenbergii* and *M. idella* and also to investigate the resource characteristics

5) Investigation on the distribution and abundance of Palaemonid larvae and post larvae of *M. rosenbergii* and *M. idella* in the lake

6) Impact assessment of Thanneermukkam barrier on the return migration of post larvae and juvenile of *M. rosenbergii* by resorting to Mark-release- recovery studies

7) to study the growth rate, exploitation and mortality of various male and female morphotypes of *M. rosenbergii* and males and females of *M. idella* inhabiting the Vembanad lake

The results of the present study are presented in 9 chapters which are organised under five sections. In the first section, a general introduction to the topic is given besides a review of the relevant literature and a brief account on physiography of the study area. The second section deals with the ecology of the Vembanad lake in which the pattern of fluctuation of major physico-chemical parameters of the lake are presented under Chapter 1. The third section deals with the population characteristics of *M. rosenbergii* and *M. idella* and consists of four chapters. In the first part of this section (Chapter 2), descriptive account of various male and female morphotypes differentiated from the natural population are given and their allometric characterisation was also attempted while results of length-weight relationship of male and female morphotypes of *M. rosenbergii* as well as male and female population of *M. idella* are provided in Chapter 3. In Chapter 4, the major findings of the temporal and spatial distribution of male and female morphotypes of *M. rosenbergii* in Vembanad lake are given while Chapter 5 deals with morphotypic composition of *M. rosenbergii* in grow-outs of Kuttanad and their relationship with the density at harvesting. Section 4 deals with post larval distribution and mark-recovery studies and comprises two chapters. The pattern of distribution of Palaemonid larvae and post larvae of *M. rosenbergii* and *M. idella* in the Vembanad lake are summarized in the first chapter (Chapter 6) while results of the mark-release- recovery studies conducted in post larvae and juveniles of *M. rosenbergii* are presented in following chapter (Chapter 7). Section 5 comprises of the fishery and population dynamics of

*M.rosenbergii* and *M.idella* in the Vembanad lake and consists of two chapters. A descriptive account on the fishery of the two species is given in the former (Chapter 8) while the results of estimate on growth, mortality, exploitation rate and cohort size of the morphotypes of *M.rosenbergii* and male and female population of *M.idella* are presented in the latter (Chapter 9). This is followed by summary and detailed bibliography.

## 1.2. REVIEW OF LITERATURE

Family Palaemonidae accommodates a wide array of species which inhabit different types of water bodies such as freshwater, brackish water and even the sea. Regarding the taxonomy and distribution of Palaemonid prawns in general and *Macrobrachium* species in particular, some of the important works on a global context are those of Lanchester (1901, 1906), Nobili (1903), De Man (1904), Calman (1913), Roux (1935, 1936), Kubo (1940), Holthuis (1949, 1950, 1952 a & b, 1956, 1980), Yaldwyn (1954, 1957), Johnson (1962, 1966, 1973) and Kensley and Walker (1982). In Indian context, valuable contributions on taxonomy and distribution of Palaemonid prawns are those of Henderson and Matthai (1910), Nataraj (1942), Chopra and Tiwari (1947), Tiwari (1947 a & b, 1952, 1955 a & b, 1961), Tiwari and Pillai (1973), Kurian (1954), John (1958), Jayachandran (1984, 1987, 1991, 1992) and Jayachandran and Joseph (1985a, 1986, 1989a, 1992). Jones (1969) listed 8 commercially important species of Palaemonid prawns from India. Raman *et al*. (1986) studied the distribution and abundance of prawns in 53 freshwater habitats located in Bangalore and observed that these habitats invariably harbour only *M.lanchesteri* (de Man) besides three species of Atyids.

Out of 40 species reported under genus *Macrobrachium* Bate 1868 from India, 15 species have been reported from Kerala by Jayachandran and Joseph (1992). Henderson and Matthai (1910) listed 9 species while Nataraj (1942) and Kurian (1954) recorded *M.rosenbergii*, *M.idella*, *M.scabriculum*, *M.equidens* and *M.dayanus* from the erstwhile Travancore. Two species *viz*. *M.idella* and *M.equidens* were reported from Kayamkulam lake by John (1958). Jayachandran and Joseph (1986) described a new species *M.indicum* from Vellayani lake. Jayachandran (1987) reported the important Palaemonid prawn resources of the estuaries of Kerala while a detailed survey on the distribution and abundance of freshwater prawns of the major rivers, estuaries and lakes of Kerala was undertaken by Jayachandran and Joseph (1989a). The striped form of *M.equidens* was elevated to the status of a new species as *M.striatus* by Pillai (1990). John (1957) studied the bionomics and life history of the freshwater prawn *M.rosenbergii*. Detailed studies on the biology and fishery of this species were undertaken by Rao (1967), Raman (1967) and Kurup *et al*.(1992a) while Ibrahim (1962), Rajyalekshmi (1961, 1980) and Rajyalekshmi and

Ranadhir (1969) studied the biology of *M.malcolmsonii*. Rao (1965) described the breeding behavior of *M.rosenbergii* in detail. Similarly, the biology of *M.rude* from Pulicat lake was reported by Kadir *et al.*(1982). Rajyalekshmi (1975) studied the environmental ecology of *M.rosenbergii* and *M.malcolmsonii* in certain drain channels opening into Kakinada bay. Information pertaining to other aspects of biology such as food and feeding habits of *M.equidens* (Murthy and Rajagopal, 1990) and of *M.idella* (Jayachandran and Joseph, 1989 b) are also available. Costa and Wanninayake (1986) reported the food and feeding habits and fecundity of *M.rosenbergii* from Sri Lankan waters. Pandian (1987) discussed some aspects of breeding and migration of *Macrobrachium*. Harikrishnan and Kurup (1996a) described the temporal and spatial availability of ovigerous females of *M.rosenbergii* in Vembanad lake.

Fujimura and Okamoto (1972) reported that though the growth rates are often quite high in intensive culture systems, the male growth rates were highly variable. The difference in growth strategy of males and females were also reported by Smith *et al.*(1978), Brody *et al.*(1980) and Cohen *et al.* (1981). The positively skewed size distribution of juveniles of *M.rosenbergii* was studied by Ra'anan (1983) and Ra'anan and Cohen (1985). Ra'anan (1982) and Ra'anan and Cohen (1985) observed that differences in growth rate of adult prawns were associated with three morphologically distinguishable kinds of males called morphotypes. Ra'anan (1982) differentiated and distinguished the morphotypes as Small Males, Orange Clawed males and Blue Clawed males from grow out ponds. The presence of Orange Clawed males in culture ponds was already reported by Sandifer and Smith (1977). The differences among three male morphotypes pertaining to morphology, physiology and behaviour were studied by Sagi (1984), Telecky (1984), Ra'anan and Sagi (1985), Kuris *et al.*(1987), Sagi and Ra'anan (1988), Govind and Pearce (1993) and Daniels (1993). The growth, size rank and maturation in various male morphotypes and females of *M.rosenbergii* were studied experimentally by marking prawns by Ra'anan *et al.* (1991) and the authors found that while Orange Clawed males and females had high growth rates, Small Males and Blue Clawed males showed slow growth rates. The effect of density on population structure of *M.rosenbergii* was studied by Smith *et al.*(1981) and Karplus *et al.*(1986a) and D'Abramo *et al.* (1991) while Ra'anan and Cohen (1983), Karplus *et al.* (1986 b and 1987), Daniels and D'Abramo (1994) and Daniels *et al.* (1995) studied the effect of size grading juveniles on population structure and production characteristics of *M.rosenbergii* in culture ponds. Cohen and Ra'anan (1983) and Sagi *et al.* (1986) reported the yield characteristics in polyculture and monoculture experiments respectively. In India, not much studies pertaining to morphotypic forms of *M.rosenbergii* have so far been conducted. Kurup *et al.* (1996a) reported the morphotypic composition of *M.rosenbergii* reared in polders of Kuttanad while Suresh Kumar and Kurup (1996a) studied the allometrical relationships of male morphotypes reared in polders of Kuttanad. Harikrishnan *et al*. (1996) and Harikrishnan and Kurup (1997a) distinguished the presence of male morphotypes in natural population of *M.rosenbergii* and also reported the existence of morphotypic forms among female populations with the help of allometric evidences. The population structure and morphotypic composition of *M.rosenbergii* inhabiting Vembanad lake was studied by Harikrishnan and Kurup (1997a) while Kurup *et al*.(1997) reported the length weight relationships of male morphotypes of *M.rosenbergii* collected from Vembanad lake.

Our knowledge about the social behaviour of *M.rosenbergii* is very limited. The first description of prawn behaviour was given by Ling and Merican (1961) and Ling (1969a). Rao (1965) provided an illustration of the behavioral interactions between male and female prior to and during mating. A general account of aggressive group interactions was given by Segal and Roe (1975) while Smith and Sandifer (1979) investigated the shelter occupancy whereas Moller (1978) and Harpaz *et al*. (1987) observed the response to food stimuli. The pioneer attempt to study behavioural patterns of *M.rosenbergii* under field conditions was that of Peebles (1979). Karplus and Harpaz (1990) made an attempt to elucidate the relationship between prawn distribution and behavioural mechanisms governing it under field conditions and came out with the conclusion that morphotypic status affects its position in the male dominance hierarchy and blue clawed males were positioned above orange clawed males irrespective of their size. Barki *et al*. (1991a) made a comparative study on the agonistic behaviour of these male morphotypes viz. SM, OC and BC and the basis of social behaviour and social control of growth of the species has been delineated while Barki *et al*. (1991b) examined the dominance relationship of above three male morphotypes by analysing agonistic interactions and found out that male prawn formed a linear dominance hierarchy in which BC males were dominant over OC males which, in turn, were dominant over SM. Karplus *et al.* (1989, 1991 and 1992 a & b & c) have studied the social control of growth of *M.rosenbergii* with emphasis on leap frog growth pattern, role of claws in bull- runt interactions and the mechanism of growth suppression in runts. Barki *et al.*(1992) also studied the effect of size and morphotype on dominance rank in Blue clawed and Orange clawed morphotypes of *M.rosenbergii* and the results revealed the fact that Blue clawed male dominated Orange clawed male irrespective of size and this effect is interpreted as an advantage of Blue clawed male because of their larger claws. The authors could also observe that the consequences of dominance were reflected in competition for resource, when the alpha male clearly had priority of access to food and shelter.

Mashiko (1981) studied the growth of second chelipeds of males in relation to body length after maturation in *M.nipponense* and a comparative study was made on the segments of second chelipeds in male and female of *M.lamarrei*. The difference in rostral characteristics of *M.lamarrei* of Ramgarh lake, Gorakhpur with that of *M.lamarrei lamarrei* and *M.lamarrei lamarroides* was studied by Murthy and Shukla (1984). Jayachandran and Joseph (1985b) established the allometric relationship in *M.scabriculum*. Jayachandran and Balasubrahmanyam (1987) investigated the rostral length - total length relationship in *M. idella* and *M.scabriculum*. The allometric relationship of *M.rosenbergii* reared in grow out ponds was studied by Suresh Kumar and Kurup (1996a)•

The relationship between length and weight of various freshwater prawns were investigated by many authors notably by Rao (1967) in *M.rosenbergii*, Kadir *et al*.(1982) in *M.rude*, Natarajan *et al*. (1988) in *M.idae* and Singh and Srivastava (1991) in *M.birmanicum choprai*. Besides, Jayachndran and Joseph (1988a) made a comparative study on length and weight relationship of two Palaemonid prawns, *M.idella* and *M.scabriculum*. The length weight relationships of male morphotypes of *M.rosenbergii* collected from natural habitat was reported by Kurup *et al*.(1997).

The farming of *M.rosenbergii* has become so popular globally and research and development activities in these lines are still going on mainly aimed at in improving production from grow-outs of this species and also to minimizing the heterogeneous individual growth (New, 1995). In India, research in these lines have been initiated by Chakraborty *et al.*(1980), Subramanyam (1980, 1984) Rao *et al.* (1989), Padmakumar *et al.* (1992), Raje and Joshi (1992), Sebastian *et al.*(1992), Kurup *et al.* (1996b) and Kurup *et al.*(1997). Dugan and Frakes (1972) have given an account on the culture of *M.acanthurus, M.carcinus* and *M.ohione*. Sankolli and Shenoy (1978) opined that *M.malcolmsonii* would be a prospective competitor for *M.rosenbergii*.

*Macrobrachium* spp. constitute fisheries of different magnitude in natural water bodies, predominantly in Asian countries. Kibria (1983) investigated the prawn fishery of Karnafuli river, Bengladesh while the *Macrobrachium* fishery in Sepik river, Papua New Guinea was studied by Robertson (1983) and reported that the fishery was constituted by seven species of *Macrobrachium* including *M.rosenbergii*. The fishery of *M.rosenbergii* in Northern Bolgoda lake, Sri Lanka was studied by Jinadasa (1985) while a detailed account on the world wide fisheries of freshwater prawns was reported by Rabanal and Soesanto (1985). Yamane and Iitaka (1986) reported pot fishery for catching prawns in lake Biwa in Japan. Catch statistics for *M.rosenbergii* from three major *Macrobrachium* fishing centers in Sri Lanka were reported by Wanninayake and Costa

(1987). In India, fishery of freshwater prawn was studied as early as 1930s and the major pioneering works are those of Panikker (1937, 1952), Chopra (1939, 1943), Menon (1954) Panikker and Menon (1955). Fluctuations in the prawn landings in Chilka lake was studied by Subramanyam (1966). Raman (1967) reported the fishery of *M.rosenbergii* in Vembanad lake while the same in Hooghly estuarine system was described by Rao (1967, 1969). Rajyalekshmi and Ranadhir (1969) gave a detailed accounts on the fishing operations and trend characteristics of population of *M.malcolmsonii* in River Godavari whereas Raman (1975) described the fishing methods and operations for catching *M.rosenbergii* in backwaters of Kerala. The prawn fishery in Krishna river was studied by Ravindranath (1982). Similarly, Rao(1982) studied the fishery of freshwater prawns in Kolleru lake and reported the commercial landings of *M.malcolmsonii* and *M.rosenbergii* during 1978-79 and 1979-80 periods. Three distinct seasons in the landing pattern of *M.birmanicum choprai* in the middle stretch of River Ganga has been reported by Prakash and Agarwal (1985). The Palaemonid prawn fishery in Godavari estuarine system was investigated by Subrahmanyam (1987). Kurup *et al.*(1992a) investigated the fishery and biology of *Macrobrachium* spp. in Vembanad lake during 1988-89. The freshwater prawn resources of Kolleru lake was reported by Rao (1992) giving due emphasis to species composition, seasonal abundance, size ranges, mean and mode in the freshwater prawn fishery of this lake.

Harikrishnan and Kurup (1997d) studied the fishing methods and gear wise intensity of fishing of *M. rosenbergii* in Vembanad lake while the exploitation of berried population of *M.rosenbergii* was discussed by Harikrishnan and Kurup (1997b).

Physico-chemical characteristics of Vembanad lake have been subjected to detailed study by many workers, notable among them are Balakrishnan (1957), Ramamritham and Jayaraman (1963), George and Kartha (1963), Cherian (1967), Qasim and Gopinath (1969), Devassy and Gopinathan (1970), Josanto (1971), Sankaranarayan and Qasim (1969), Silas and Pillai (1975), Rao *et al.* (1975), Balakrishnan and Shynamma (1976), Lekshmanan *et al.* (1982), Balchand and Nambisan (1986), Kurup and Samuel (1987) and KWBSP (1989). Kurup and Samuel (1987) studied in detail the ecology and fish distribution pattern in Vembanad lake.

The most important works pertaining to plankton distribution in Vembanad lake are those of George (1958), Menon *et al.* (1971), Silas and Pillai (1975), Rao *et al.* (1975). The distribution of Penaeid prawn postlarvae and adults in Cochin estuary was studied by Kuttyamma (1975), Kuttyamma and Antony (1975) and Sosamma Easo and Mathew (1989a and b). The estuarine phase in the life history of commercial prawns including freshwater prawns of west coast of India was described by Mohamed and Rao(1971). Read (1983) discussed the estuarine phase in the life cycle of *Macrobrachium petersi* and investigated the ecophysiology of adult, juvenile, postlarvae and larvae in Keikamma estuary. The recruitment and abundance of juveniles of *M. birmanicum choprai* was studied by Prakash and Agarwal (1986). Similarly, Singh and Srivastava (1989) studied the seasonal abundance of juveniles and adult of *M.birmanicum choprai* in relation to seasonal variations in certain hydrological features in the river Ganga between Buxar and Ballia.

Literature regarding marking and tagging experiments in penaeid prawns are available (Dawson, 1957; Costello, 1959; 1964; Costello and Allen, 1961; Klima, 1965; Ranade, 1967; Subramanyam, 1967; Tiews, 1967; George, 1967; Neal, 1969; Rao, 1972; Marullo *et al.*, 1976, Anon, 1982; Yano *et al.* 1986) however, those regarding similar experiments in freshwater prawns are scanty. Rajyalekshmi (1975) studied the mark recapture techniques, durability of stains and behaviour of marked prawn *M.malcolmsonii* in River Godavari. Tagging experiments in *M.rosenbergii* using electronic tags have been attempted by Peebles (1979) while Kuris *et al.*(1987) successfully tattooed the uropods of *M.rosenbergii* with a mounted insect pin. Ra'anan *et al.* (1991) studied the growth, size rank and maturation of *M.rosenbergii* by tattooing the uropods. Recently, Schmalbach *et al.* (1994) applied a new method of tagging in *M.rosenbergii*.

Horne and Beisser (1977) while studying the distribution of river shrimp in the Guadalupe River, Texas found that the dams on the main course of river restricted the ascent of most of the shrimps. Frusher (1983) reported the ecology of *M.rosenbergii* in Purari River and pointed out that proposed damming of the Purari River would change the productivity of crustacean fauna. Wadie and Razek (1985) brought out the adverse effect of Aswan High Dam in the shrimp population in the south eastern part of the Mediterranean sea. Collart (1991) recorded the dwindling nature of landings of *Macrobrachium amazonicum* due to the impact of closure of Tacruri hydroelectric project in Tocantin river and found that catches decreased from 121 tons in 1985 to 62 tons in 1988. Similarly, Kurup *et al.* (1992a) reported the dwindling nature of stock of *M.rosenbergii* in Vembanad lake as evident from the alarming decline in the annual landings from 300 tonnes during sixties to 36 tons in 1988-89 and one of the main conjectures attributed to this is the operation of Thanneermukkam salinity barrier constructed across the lake in 1976.

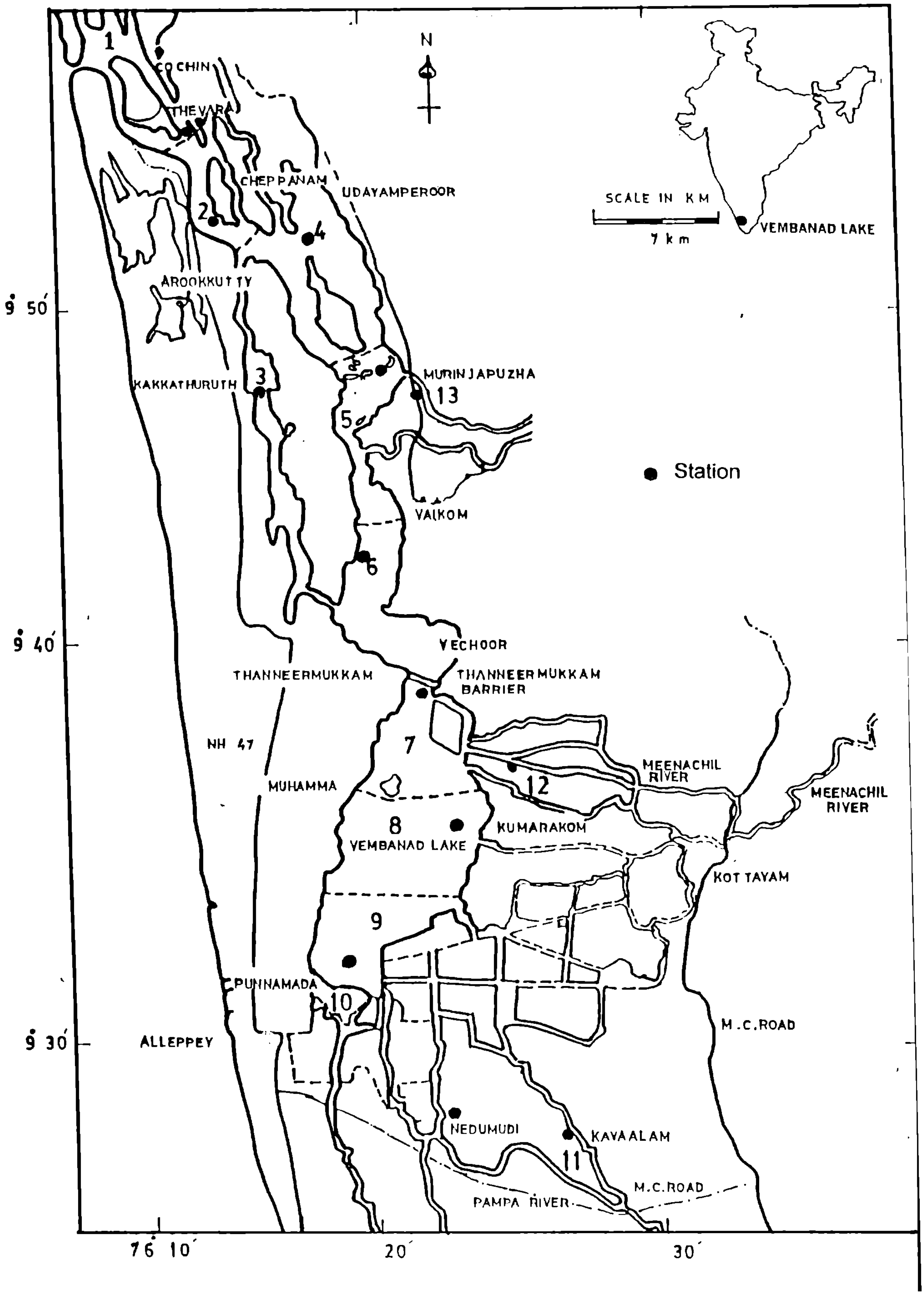
The age and growth of some estuarine prawns including *M.rosenbergii* (P.carcinus) has been reported by Rajyalekshmi (1966). Kurup *et al.*(1992 b) made a preliminary attempt to study the stock characteristics of the male and female population of *M.rosenbergii* and *M.idella* inhabiting Vembanad lake. Dudgeon (1985) studied the population dynamics of three caridean shrimps while Armada *et al.* (1993) reported three groups of population of

*M.nipponense*. Mashiko and Namachi (1993) reported genetic evidence for the presence of two groups of individuals of *M.nipponense* in a single river system which exhibit characteristically different egg sizes. Attempts to estimate growth parameters, mortality rates, exploitation rates and stock sizes of penaeid prawns are those of Lalithadevi (1986), Suseelan and Rajan (1989) and Agasen and Mundo (1988).

## 1.3. PHYSIOGRAPHY OF THE VEMBANAD LAKE

The Vembanad lake (Fig.1), situated in the state of Kerala between latitude 9° 28' and 10° 10' North and longitude 76° 13' and 76° 31' East, is the largest brackish water body in south-west coast of India. Lying between Cochin bar mouth in the north and Alleppey in south, this lake extends over an estimated area of 21,050 ha. The extend of water body designated as "Vembanad lake" was only regarded as the study area whereas the confluent brackish water area lying north of Cochin bar mouth and extending up to Azhikode in the north was excluded in the present study.

In the northern part of study area, the lake is comparatively deeper than its southern region owing to the presence of a navigational channel where depth varies from 8- 12 m. The other parts of the lake are generally shallow with depth ranging from 0.75 to 5 m. The width of the lake varies from about 100 m at a few places to about 9 Kms at



N
COCHIN
THEVARA
CHEPPANAM
UDAYAMPEROOR
SCALE IN KM
7 km
VEMBANAD LAKE
AROOKKUTTY
KAKKATHURUTH
MURINJAPUZHA
Station
VAIKOM
VECHOOR
THANNEERMUKKAM
THANNEERMUKKAM BARRIER
NH 47
MUHAMMA
MEENACHIL RIVER
MEENACHIL RIVER
KUMARAKOM
VEMBANAD LAKE
KOTTAYAM
PUNNAMADA
ALLEPPEY
M.C.ROAD
NEDUMUDI
KAVAALAM
M.C.ROAD
PAMPA RIVER
9° 50′
9° 40′
9° 30′
76° 10′
20′
30′
1
2
3
4
5
6
7
8
9
10
11
12
13

Table 1. Boundaries and area of cruise zones and stations selected for the observation of physico-chemical parameters of water and larval sampling.

| ZONES | BOUNDARIES | AREA (ha) | STATIONS |
|---|---|---|---|
| 1 | Cochin bar mouth -- Thevara | 1745.0 | Thevara |
| 2 | Thevara – Arookkutty | 2497.0 | Edacochin |
| 3 | Arookkutty -- Chenganda | 1237.0 | Kakkathuruthu |
| 4 | Arookkutty -- South Paravoor | 3076.0 | Udayamperoor |
| 5 | South Paravoor -- Manapuram | 1085.0 | Anchuthuruth |
| 6 | Neriakadavu – Thanneermukkam bund | 2803.0 | Pallipurathusseri |
| 7 | Thanneermukkam -- Pathiramanal | 2000.0 | South of Bund |
| 8 | Pathiramanal – North of Marthandam kayal | 3689.0 | Kumarakom |
| 9 | Rani kayal -- Punnamada | 2196.0 | Punnamada |
| 10 | Punnamada – Nedumudi -- Kainakari | 725.0 | Nedumudi |
| 11 | Kainakari – Kavalam -- Cblock | 1087.1 | Kavalam |
| 12 | Kaipuzha river | 395.7 | Kaipuzha |
| 13 | Muvattupuzha river | 150.0 | Murinjapuzha |
| | Total | 22685.8 | |

others. The lake is connected to Arabian sea at Cochin through a 425 m wide channel which is the only source of sea water incursion into the lake. Tides are of semi diurnal type, showing substantial range and time. The average tidal range near the mouth of the estuary is 0.9 m. Until two decades ago, tidal effects were extended up to Pulikizhu, some 80 kms south of Cochin and the deltaic region of the lower Kuttanad used to become brackish gradually from December onwards attaining a salinity of about 5ppt in the interior waters (Josanto,1971).

A 1402 m long salinity barrier at Thanneermukkam was commissioned in 1976 for preventing salt water incursion in to Kuttanad during December to March and thereby protecting the Punja crop. The barrier was originally envisaged to be closed for a period of three months from 15th of December to 15th of March every year while shutters remained open during monsoon months so as to facilitate the evacuation of the flood water. However, alteration in the operation schedule such as prolonged closure period up to April-May has brought in some adverse effects besides causing serious conflicts between fishermen and agriculturists. Furthermore, a shifting of the salinity gradient zone towards the north of the lake has also been resulted. There is practically no tidal exchange between fresh and sea water in the areas south of the barrier during any time of the year. Thus the lake is separated in to two entirely different ecosystems, retaining estuarine conditions in the regions from Cochin to Thanneermukkam and transforming the region from Thanneermukkam to Alleppey in to almost a freshwater habitat. In the present study, the part of the lake extending from Cochin to Thanneermukkam is regarded as "downstream part" of the lake while the region lying between Thanneermukkam and Alleppey was taken as "Upstream part".

The lake receives freshwater supply chiefly through a network of rivers such as Pampa, Manimala, Achencoil, Meenachil and Muvattupuzha. Pampa and Manimala rivers join together before meeting the Achencoil river at Veeyapuram and all these rivers influx at the southern most part of the lake. River Meenachil opens at the middle of the lake whereas River Muvattupuzha opens at northern part in the downstream area. These rivers discharge large quantities of freshwater in to the lake during the south-west and north-east monsoons. However, among the four rivers which discharge into the southern part of the lake, only Pampa has some flow during the dry season.

### 1.3.1 HISTORICAL RESUME

Menon (1913) suggested that Vembanad lake formed part of the Arabian sea until the upliftment of coastal regions of Alleppey and Ernakulam districts in the year 1341 AD. This view was further supported by Rasalam and Sebastian (1976) in their studies on the lime shell deposits of the lake. The lake and adjoining canals and their environs have been supporting a rich and diverse assemblage of fauna. Fishing had been an important traditional occupation of the inhabitants of the area in and around the lake since time immemorial. The general shallowness and well protected nature of the lake compared to all the hazards of sea permit the fishermen to operate during all the seasons using indigenous techniques. Furthermore, the lake fisheries gained much importance as a ready source of supply of esteemed species of fishes and prawns. Although the major activities of fishing takes place during night, when good catches are obtained, day fishing is also prevalent on a smaller scale. However, operation of Thanneermukkam barrier, large scale reclamation of kayal land for agriculture and other purposes, raising of more than one crop of paddy, aquatic pollution from pesticides and discharge of industrial effluents, retting of coconut husks, dredging of the lake for lime shell deposits, use of explosives and poisons for catching fish from rivers and southern part of lake etc., have imposed severe setbacks to fishery exploitation through depletion in resources in the lake and consequently some fishermen have been forced to give up their traditional occupation.

Extensive reclamation of Vembanad lake area which started over a century ago has resulted in habitat reduction by some 16,000 ha from total area of the lake. Large scale dredging in the clam beds between Vaikom and Alleppey using cutter section dredger is very common. It has been reported that such dredging operations result in uneven settlement of sediments and thereby cause formations of islands in the middle regions of the lake (KBWSP, 1989). Besides, prolific spreading of floating aquatic weed, the water hyacinth (*Eichhornia crassipes*) in the southern part of lake and adjoining channels during monsoon and postmonsoon months also cause impediments to fishing operations.

## 1.4. FISHERY CRUISE SURVEYS AND ZONES SELECTED

The entire lake from Cochin bar mouth to Alleppey was apportioned to 10 zones (Fig.1). Besides, each of 5 km stretch of the adjoining rivers viz. Muvattupuzha, Meenachil, Pampa, Manimala and Achencoil were taken as three zones (Fig.1). 13 stations representing each zone were also selected for taking water and larval samples (Fig.1). Details of zones such as boundaries and approximate area are given in Table 1. Fishery survey cruises were carried out in Vembanad lake and adjoining rivers on a monthly basis from March 94 to February 96 with the help of a 25 feet fibre glass boat, M.B.KINGFISHER, owned by the School of Industrial Fisheries. The fishing activity prevailing in each zone was closely observed continuously for a period of 24 hours (day and night) during each cruise and therefore, the duration of monthly cruise surveys extended up to 13 days. The cruises were envisaged to carry out various observations on the fishing activity, physico-chemical parameters of surface and bottom water and abundance of Palaemonid prawn larvae and post larvae in each zone.

# Section 2

# Ecology

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## Chapter 1 Physico-chemical parameters of Vembanad Lake

# CHAPTER 1

## PHYSICO- CHEMICAL PARAMETERS OF VEMBANAD LAKE

### 1. INTRODUCTION

The Vembanad lake is endowed with all characteristics of a tropical positive estuary (Pritchard, 1967; Qasim *et al.*, 1969; Madhupratap *et al.*, 1977). This water body receives freshwater from five major rivers viz. Pampa, Manimala, Achencoil, Meenachil and Muvattupuzha and is also subjected to strong tidal currents of semi diurnal type (Wellershaus, 1973) and therefore, the seasonal and diurnal variations of physico-chemical factors are governed by the freshwater run off from the river and tidal currents from the adjoining sea (Josanto, 1971). However, the construction and commissioning of the Thanneermukkam salinity barrier in 1976 has eventually resulted in the severe alterations in the ecological conditions of the lake and resulted in the separation of the lake into two distinctly different ecosystems, retaining estuarine conditions in the downstream part of the lake (Cochin to Thanneermukkam) and transforming the upstream part (Thanneermukkam to Alleppey) to an almost freshwater habitat(Kurup *et al.*, 1992a).

Distribution and abundance of organisms in the estuarine habitat are profoundly influenced by the variation noticed in the physico-chemical conditions.

Physico-chemical parameters of the Vembanad lake were subjected to many detailed studies (Balakrishnan, 1957; Ramamritham and Jayaraman, 1963; George and Kartha, 1963; Cherian,1967; Qasim and Gopinath, 1969; Sankaranarayan and Qasim, 1969; Silas and Pillai, 1975; Rao *et al.*, 1975; Balakrishnan and Shynamma, 1976; Lekshmanan *et al.*,1982; Kurup and Samuel, 1987), however, most of them confined to either the barmouth region or the downstream part of the lake. Nevertheless, K W B S P (1989) monitored the water quality parameters of this water body giving more representations to the upstream part of the lake and confluent rivers. Josanto (1971) made a sincere attempt to study the salinity characteristics and factors that influence salt water penetration in Vembanad lake prior to the construction of the barrier. Kurup and Samuel (1987) studied the ecology and fish distribution pattern of the Vembanad lake. In the present study, the pattern of fluctuation of seven major physico-chemical parameters of water is presented and it is hoped that these results would be invaluable in delineating the role of prevailing hydrological conditions of the lake in the distribution and abundance of larvae, postlarvae and stock size of *Macrobrachium rosenbergii* and *M. idella* and also the temporal and spatial variations of morphotypes of *M.rosenbergii* of Vembanad lake.

## 2. MATERIALS AND METHODS

Water samples were collected at stations 1 - 13 (Fig.1.) for two years (01.03.94 to 28.02.96) during the monthly fishery survey cruises. Surface water samples were collected using a clean plastic bucket and the bottom water samples were collected using a Hytec water sampler. Temperature was recorded at respective collection centres with a sensitive mercury- in- glass centigrade thermometer. pH of water sample was measured *in situ* using a pH meter (pH scan) having the range from -0.1 to 15 +/- 0.2 and resolution of 0.1. Salinity was measured by the Mohr Knudson method (Strickland and Parsons, 1972) while dissolved oxygen by the azide modification of Winkler method (Greenberg *et al.*, 1992) whereas total hardness, acidity,and alkalinity were estimated following Greenberg *et al.* (1992).

## 3. RESULTS

### 3.1. Rainfall

The annual rainfall in 1994-95 was 2710mm against 2940mm in 1995-96. The pattern of rainfall distribution over the years in the study area is depicted in Fig.1.1. Among the three seasons, monsoon accounted for major discharge of rainfall, registering 65.36 and 67.35% in 1994-95 and 1995-96 respectively while postmonsoon registered 19.06 and 14.10% in the respective years. The premonsoon showers were lowest in 1994-95 (15.04%), however, in 95-96 it was relatively higher (18.54%) when compared to postmonsoon showers.

### 3.2 Water temperature

Monthly variation in surface and bottom water temperature are presented in Fig. 1.2. In both the years, lowest surface temperature of 25 °C was recorded in April while highest of 32 °C was in March 1994 and April 1995. The bottom water temperature in all stations were less than that of surface temperature to the tune of 0.5 °C in most of months, ranging from 24.5 °C (June) to 31.5 °C (March) in both the years. Temperature showed a gradual increase from August onwards, however, during November- December another slight fall could be discernible and thereafter a steady increase could be noticed, reaching a value of 32 °C in March. The temperature showed strong fluctuations coinciding with onset of south-west monsoon with a pronounced drop in June- July (Fig.1.1) and a sudden rise in the month of September. Difference between surface and bottom temperatures were more pronounced in stations of the downstream part of the lake (Stations 1 to 6) than upstream and riverine stations (Stations 7 to 13), especially in the month of July.

### 3.3 Salinity

High surface and bottom salinities ( >25 ppt) were observed in station 1 and 2 (>20 ppt) in March and April 95 respectively while in 1994, the same was 18.6 and 22 ppt in the months of April and March respectively (Fig.1.3). With the onset of south-west monsoon, the surface salinity lowered to <2 ppt during June to August in all stations in 1994-95 while in 1995-96 such decrease could be seen in July- September, especially in stations 1 and 2. Conversely, the bottom salinity was in the range of 5-10 ppt in station 1 during 94-95 while in 95-96 it was in the range of 5-25 ppt during June to August, showing the existence of a core of high saline water in these stations. In station 2 also bottom water salinity was relatively high in June 1994 and June- August in 95, showing 6 ppt in the former against 2-24 ppt in the latter period. In the downstream stations (stations 1-4), surface and bottom salinities showed gradual increase from September onwards, however, during October a fall in salinity values were much pronounced in these stations. A steep increase in surface and bottom salinity values were very much pronounced in downstream stations from November onwards, showing >10 ppt in stations 1-4 and >5ppt in stations 5 and 6 during pre-monsoon season (February - May). Lowering of salinity and resultant freshwater conditions were prevalent with the onset of south- west monsoon, converting the entire lake to freshwater conditions and retaining saline conditions only at the bottom part of the stations adjacent to barmouth.

Among the various stations studied in the upstream and riverine regions of the study area, highest surface and bottom salinities recorded was 7 and 8 ppt in the month of April 95 from station 7 whereas it was less than 3 ppt in 1994 95. The saline water incursions in to these parts of the lake could only be recorded in the month of March and persists till April. In station 8, highest surface and bottom salinities recorded was 4 ppt respectively while in other stations it varied from traces to 2.5 ppt. On the other hand, in station 12, located in river Kaipuzha, surface salinities as high as 6 ppt could be recorded in the month of April 95 while in station 13 which is located at river Muvattupuzha, bottom water salinity up to 7 ppt could be recorded in the month of December 94 and April 95.

### 3.4 Dissolved Oxygen

Monthly variation in dissolved oxygen concentrations of surface and bottom water are depicted in Fig. 1.4. Dissolved oxygen content of surface and bottom waters in most of the stations fluctuated between 4-8 ml/l during both the years. Highest dissolved oxygen content in surface water estimated during 94-95 and 95-96 were 9.21 ml/l from station 3 in the month of February and 10.64 ml/l from station 12 in July respectively. Similar values in regard to bottom water during the above years were 9.21 ml/l from station 3 in January and 8.34 ml/l from station 11 in July respectively. On the contrary, the lowest dissolved oxygen values in surface water recorded during 94-95 and 95-96 were 3.16 from station 4 in August and 3.96 ml/l from station 1 in May respectively. The bottom water dissolved oxygen content registered in 1994-95 was 2.88 ml/l in station 9 in April against 2.31 ml/l from station 10 in February during 95-96. Generally, the dissolved oxygen values were low in premonsoon months in most of stations while postmonsoon months registered higher values.

## 3.5 pH

pH values of the study area varied from 5.1 to 9.9, showing almost consistent around 7 (Fig.1.5). pH values showed slightly varying results during 1994-95 and 1995-96. In general, high pH values indicating alkaline nature of water, were observed during former year from May to December in most of the stations while in the latter year it remained more or less close to 7 except in downstream stations. During 1994-95, surface water pH values ranged between a maximum of 9.9 in July (station 2) and a minimum of 5.1 in February (station 8) whereas during 95-96 it varied from 9.2 in November (station 6) to 5.1 in April in station 8. Similarly, bottom water recorded a maximum of 9.6 in July (station 2) and a minimum of 5.4 in February (station 12) during 94-95 while in 95-96 it showed variations from 9.3 in station 7 in November to 4.8 in station 12 in April. In general, a gradual increase of the pH values of the lake could be seen from September onwards and this trend continued till January, thenceforth, it declined steeply in February in almost all stations. From March onwards, it again showed an increasing trend, showing slight plummeting in June- July periods, thereafter registered a gradually increasing trend in almost all stations studied. The pH values were invariably high in most of the stations of the downstream part of the lake and this may be due to the intrusion of saline waters, in contrast, in stations 8-12, low values less than 7 could be observed, especially during 1995-96 and this may be due to the effect of acid soils of Kuttanad.

## 3.6 Total Hardness

Monthly variation in surface and bottom water hardness in various stations of the lake during March 94 to February 96 are depicted in Fig.1.6. In most of the stations, water hardness was high in bottom water samples when compared to that of surface water. High levels of total hardness could be recorded in both surface and bottom water samples during April 94 to August 94 in almost all stations. Highest values of surface water total hardness during 94-95 was recorded from station 7 in April ( 94 mg $CaCO_3$/l) whereas in the case of bottom water samples the same was recorded from station 2 in May (143.9 mg $CaCO_3$/l). The values again showed an increasing trend from November 94 to January 95 in most of downstream stations. On the contrary, during 95-96, high values of total hardness during April to August could be recorded only in stations 1 and 2. In these stations, the bottom water samples showed higher values of total hardness than surface water samples and the values gradually increased from September 95 to January 96. The highest values of surface and bottom water hardness recorded during 95-96 were from station 2 in April (44.92 and 53.44 mg $CaCO_3$/l respectively). In all other stations, total hardness was noticeable in both surface and bottom water samples during March to May periods except in station 10 where only insignificant values of total hardness could be recorded during the same period.

### 3.7 Alkalinity

Monthly variations in surface and bottom water total alkalinity in various stations of the lake during March 94 to February 96 are shown in Fig.1.7. In general, high alkalinity values were recorded in almost all stations during 94-95 when compared to 95-96. Highest values of surface and bottom water alkalinity during 94-95 were recorded from station 3 in February (160 mg $CaCO_3$/l) and station 7 in December (148 mg $CaCO_3$/l). During 1995-96, the alkalinity values of surface and bottom water were found to be very low ranging from 22 mg $CaCO_3$/l (stations 2,February) to 40 mg $CaCO_3$/l (station 3, February).

### 3.8 Acidity

Monthly variation in surface and bottom water acidity in various stations of the lake during March 94 to February 96 are depicted in Fig.1.8. During 94-95 high values of acidity in both surface and bottom water in most of stations could be recorded during August to October. Similarly, very high values of acidity could be recorded during January to June 95 in almost all stations, thereafter it showed a declining trend except in September, 95. In general, acidity values were high in most of months during 95-96 when compared to its previous year. The highest values of surface and bottom water acidity recorded during 94-95 were 180 mg $CaCO_3$/l (station 1, January ) and 200 mg $CaCO_3$/l (station 2, January) respectively whereas the same during

95-96 were 190 mg CaCO3/l (station 3 March) and 270 mg CaCO3/l (station 3, May) respectively.

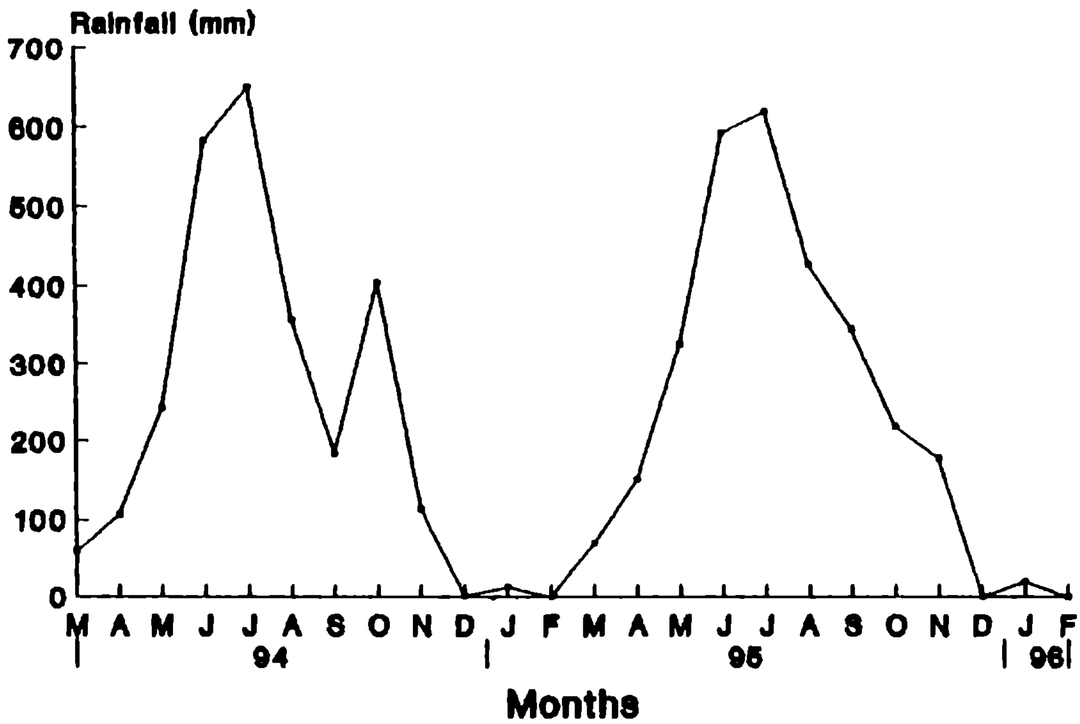
## 4. DISCUSSION

The pattern of fluctuations of surface and water temperatures observed in the present study fully agree with earlier findings (Pillai, *et al.*, 1975; Silas and Pillai, 1975; Kurup and Samuel, 1987; KWBSP, 1989). Temperature showed a steeply increasing trend during premonsoon months (February to May) and during post monsoon period (November to January) whereas during monsoon months (May to October) invariably low values could be observed from the lake. It may also be seen that monsoon months (June to September) contributed to more than 60% of total annual rainfall during both the years under study. The highest and lowest temperatures observed in the present study were in premonsoon and monsoon seasons respectively which fully corroborate with the observations of Haridas *et al.* (1973), Lekshmanan *et al.* (1982), Kurup and Samuel (1987) and KWBSP (1989). With regard to the fluctuations of pH, in general, higher values were observed during the first year which also coincided with the high levels of hardness and alkalinity recorded from the study area. As per the data compiled by KWBSP (1989) highest pH of 8.5 was recorded from Punnamada area (station 9 in the present study) while lowest of 5.1 was in Kumarakom (station 8). However, in the present study pH was found to vary from 4.8 to 9.9. Similarly, wide fluctuation of dissolved oxygen content was also observed during the present study in contrast to the findings of Silas and Pillai (1975), Kurup and Samuel, (1987) and KWBSP (1989). In the present study higher levels of total hardness and alkalinity were observed during the first year when compared to second year. Correspondingly, lower levels of acidity values could also be recorded in the first year.

Salinity is the ecological master factor contributing to the life of estuarine animals (Kinne, 1966). The distribution of salinity is profoundly influenced by a combined action of water movements induced by freshwater discharge and tidal action from the sea. Salinity slowly travels upstream during dry months when there is practically no freshwater discharge and during monsoon months, the freshwater flow pushes salt water down the lake and limits the incursion almost near to mouth of the lake (Josanto, 1971). Among the various physico- chemical parameters studied, salinity appears to be the most fluctuating parameter of the lake. The incursion of sea water through bottom is very much pronounced in stations 1 and 2 where the stratification is clear when compared to other stations. During the monsoon, the entire water body except stations 1 and 2, especially in the bottom, became near to freshwater. This finding is very much similar to that of Wellershaus (1973) who attributed this due to the formation of salinity tongue due to the formation of a bottom reverse current caused by outflow at surface. In all months, the bottom salinity remains higher than surface water in stations 1-6 and this conforms with the finding of Lakshmanan *et al.*

(1982). The results of the present study when compared against Josanto (1971) revealed that the salinity distribution pattern of this lake has totally been changed over a span of last two decades. Prior to the construction of salinity barrier, the bottom salinity of downstream part of the lake (stations 1-6) ranged from 23 to 31ppt in the month of March, on the contrary, in the present study, it varied from 6-23ppt in 1994-95 and 12-28ppt in 1995-96. Similarly, in upstream part of the lake (stations 7-10) the bottom salinity varied from 18-22ppt, conversely, the variations during the present study was 0-3ppt in 1994-95 and 0-8ppt in 1995-96. It would thus appear that a substantial reduction in the prevailing salinity values have taken place. This transformation was brought about by the human interventions, in the form of constructing the physical barrier across the lake in 1976 in order to arrest the saline water incursion in to Kuttanad for facilitating the raising of an additional Punja crop. While the lowering of salinity values in the upstream part of the lake can be attributed to the prevention of tidal action due to the commissioning of the barrier whereas the reduction of salinity values in the downstream part of the lake may be due to the diminishment of tidal action as the same is strongly sensitive to physical obstructions (Josanto, 1971). Kurup and Samuel (1987) reported a maximum salinity from the upstream part of the lake as 3.5ppt while the present estimate, the maximum value recorded is 8ppt and this in comparison with the above is slightly on a higher side.

According to KWBSP (1989), the maximum salinity conditions (6ppt) occurred by March just south of the barrier and salinity in the southern most part of the lake did not exceed 2ppt. Similarly, in the present study, range of surface and bottom salinity in stations 1-5 was in the order of 10-25ppt and 14-31.5 ppt respectively while Lekshmanan *et al.* (1982) reported that maximum salinity value in these regions varies from 10-30 and 20-32 ppt in surface and bottom waters respectively. It would thus appear that a further reduction in salinity value could be observed in stations which are located in between Cochin barmouth and influxing part of Muvattupuzha river of the lake and this significant variation might be due to the commissioning of the Idukki hydroelectric project and the subsequent diversion of part of Periyar river water in to the Muvattupuzha whereby a perennial flow is being maintained in the Muvattupuzha, the latter influx in to the downstream part of the lake.



Rainfall (mm)
700
600
500
400
300
200
100
0
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
Months

Fig. 1.2

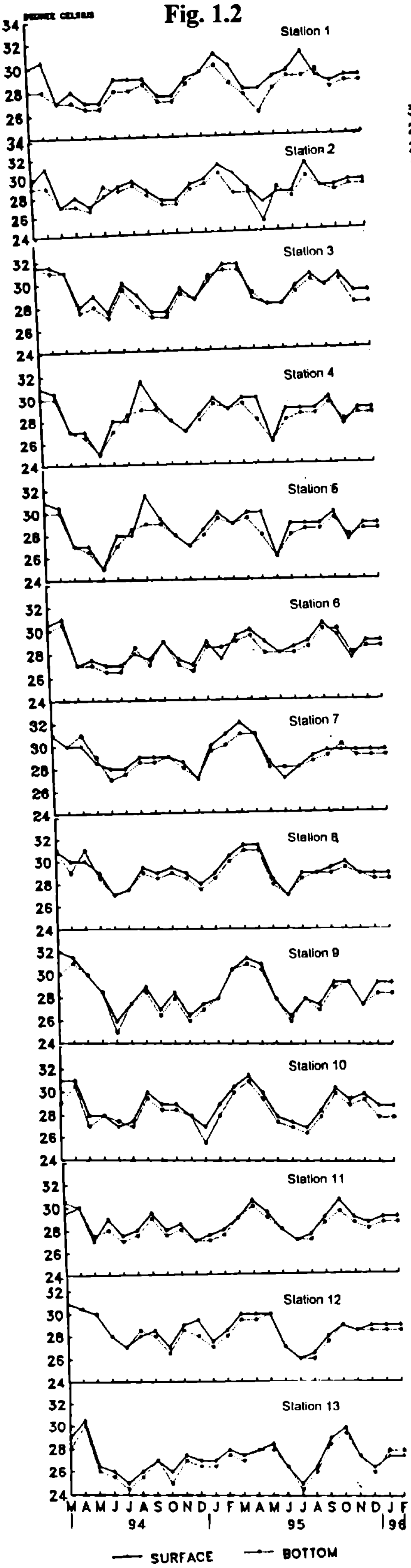

Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM

Fig. 1.3

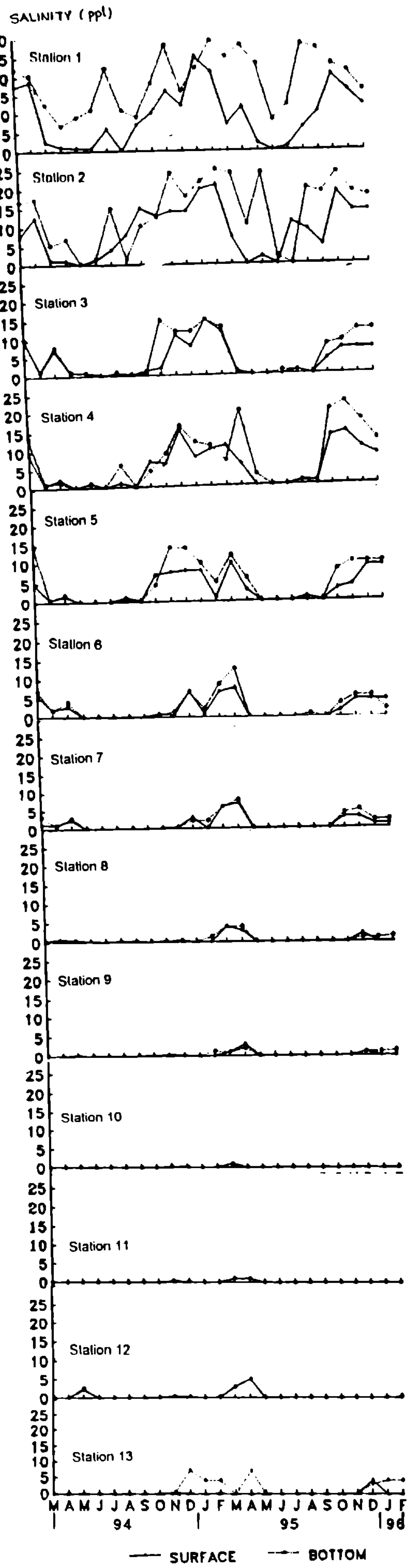

SALINITY (ppt)
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM

**Fig. 1.4**

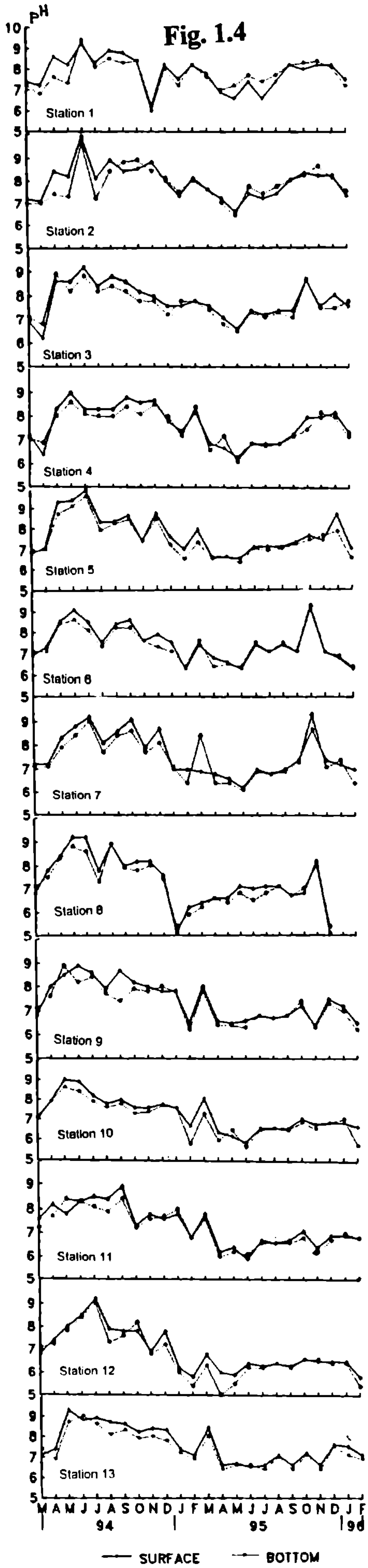
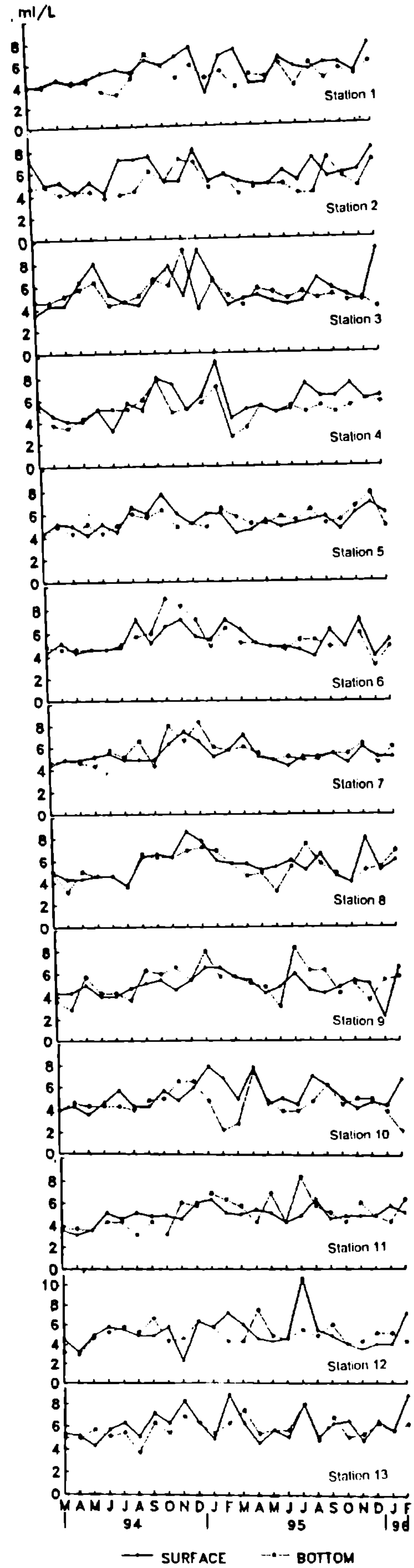
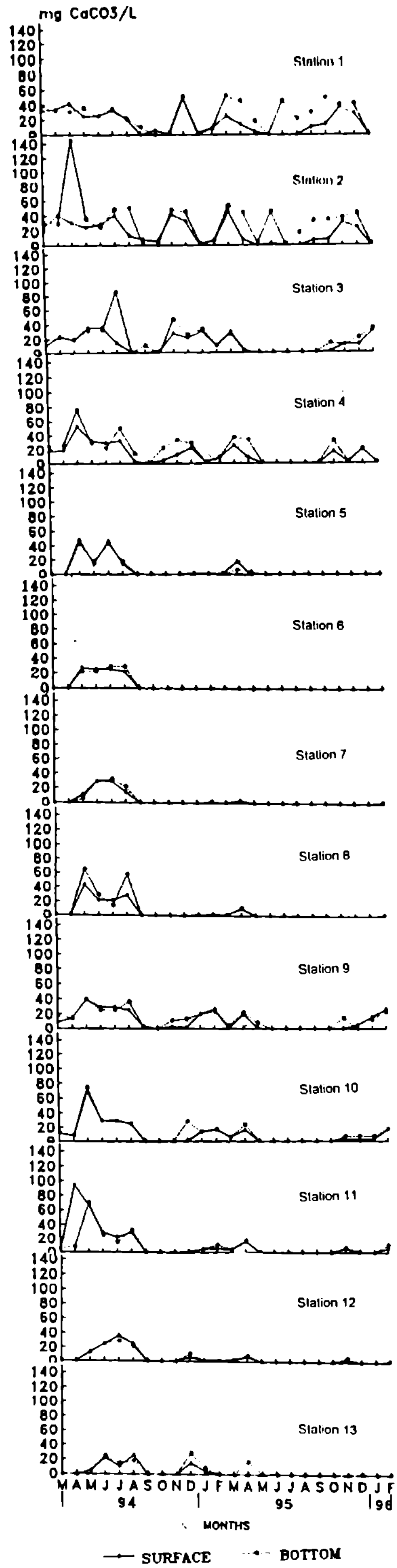

pH
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM

**Fig. 1.5**


ml/L
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM



mg CaCO3/L
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
MONTHS
SURFACE
BOTTOM

**Fig. 1.7**

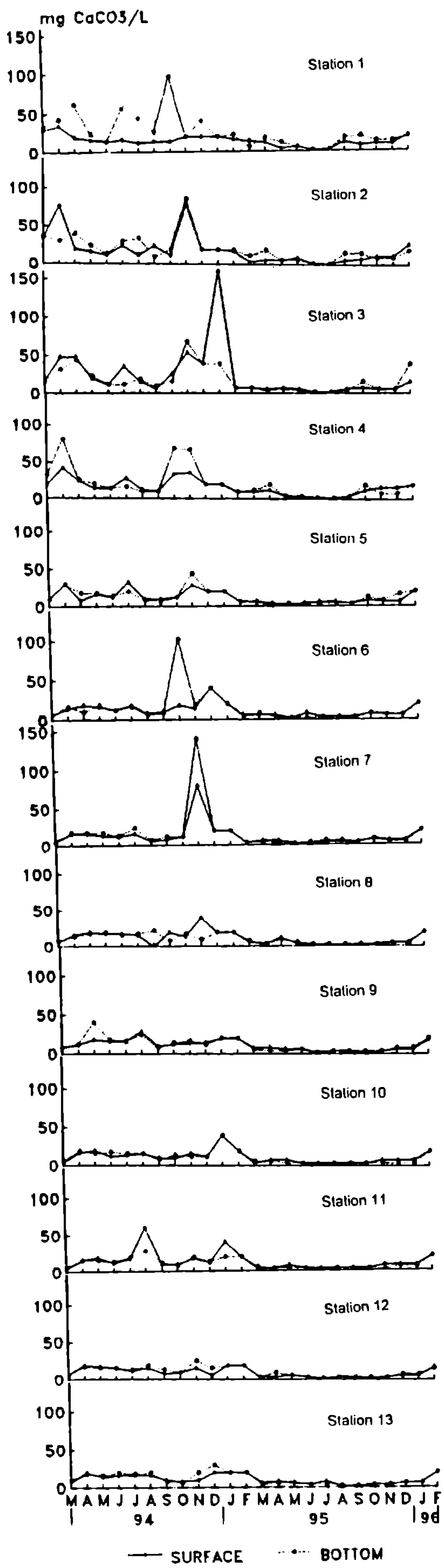
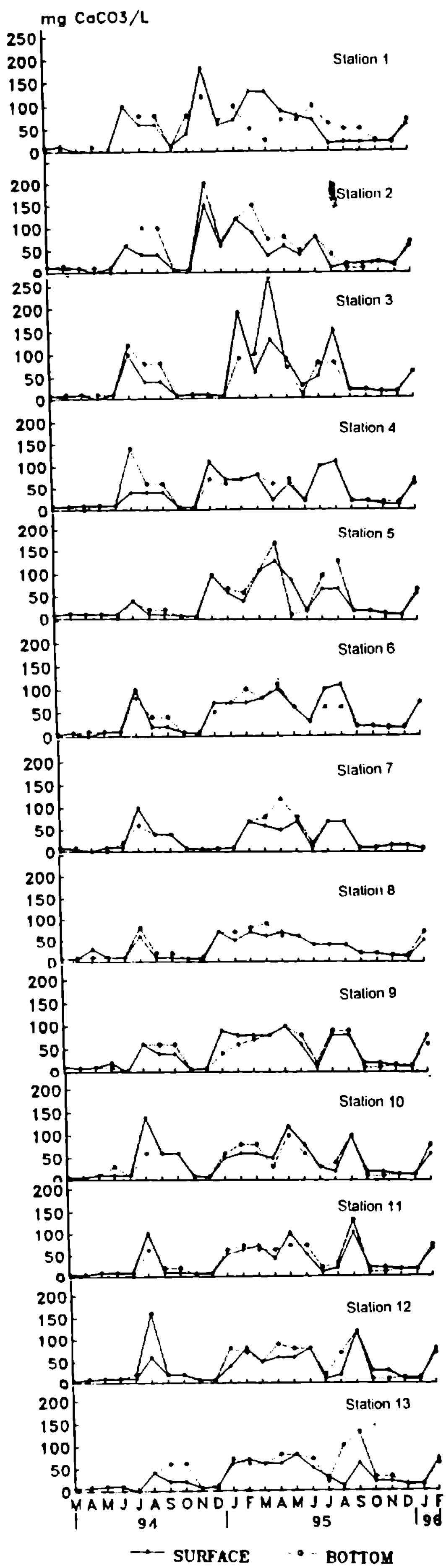

mg CaCO3/L
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM

**Fig. 1.8**


mg CaCO3/L
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F M A M J J A S O N D J F
94
95
96
SURFACE
BOTTOM

# Section 3

# Population Characteristics of *Macrobrachium rosenbergii* (de Man ) and *M. idella* (Hilgendorf)

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# CHAPTER 2

# POPULATION PROFILE DEVELOPMENT AND MORPHOTYPIC DIFFERENTIATION OF *Macrobrachium rosenbergii* (de Man) AND *M. idella* (Hilgendorf) IN NATURAL POPULATION

## 1. INTRODUCTION

*Macrobrachium rosenbergii* (de Man) and *M. idella* (Hilgendorf) are two sexually dimorphic freshwater prawns of which males are easily distinguishable from females by noticing their relatively large body sizes and cephalothorax, longer and stouter second chelipeds and also by the presence of appendix musculina on the endopod of second pairs of swimmerets. However, single aged adult male population of the former species is known to exhibit remarkable variations in their morphological characteristics. Sexually matured male population of *M. rosenbergii* reared in ponds are differentiated into three morphologically distinguishable forms such as Small Males(SM), Orange Clawed Males(OC) and Blue Clawed Males(BC) based on differential growth pattern, relative body size, second cheliped characteristics, differential reproductive behavior and social hierarchical dominance (Cohen *et al.*, 1981; Ra'anan, 1982; Sagi, 1984; Telecky, 1984; Ra'anan and Cohen, 1985; Ra'anan and Sagi, 1985). It is also known that males reared in culture systems follow a complex social hierarchy as manifested by the presence of dominant, sub dominant and subordinate individuals which are characterized themselves into distinct morphotypes. Small males occupy the initial stage of developmental pathway(Cohen, *et al.*, 1981). They are subordinate, not territorial, sexually competent and are known to fertilize females by using "sneak mating strategy" in the absence of large dominant males(Ra'anan, 1982; Sagi, 1984; Telecky, 1984; Ra'anan and Sagi, 1985). In contrast, Orange Clawed males are sub dominant, not territorial, less reproductively active when compared to other two morphotypes and represent a stage of high somatic growth (Ra'anan, 1982, Ra'anan and Sagi, 1985). Blue Clawed males, on the contrary, are large, dominant, territorial and sexually competent animals which represent the final stage in the course of development(Cohen *et al.*, 1981; Ra'anan,1982). These males sequestered post molt adult female prawns prior to mating and grew slowly. (Ra'anan,1982; Sagi, 1984; Ra'anan and Sagi, 1985).These morphotypes represent three developmental stages of male maturation process and are known to undergo transformation from SM to OC to BC (Cohen *et al.*, 1981; Ra'anan, 1982; Kuris *et al.*,1987).Two transitional stages of OC males viz, WOC (Weak Orange Clawed) and t-SOC (pre- transforming Orange Clawed) were also recognized, former being transitional between SM and SOC (Kuris *et al.*, 1987) and therefore, the fully differentiated OC males are known as SOC (Strong Orange Clawed)and the latter being transitional between SOC male and BC male (Sagi and Ra'anan, 1988).

However, existence of such morphologically distinguishable forms in natural population of

*M. rosenbergii* have not so far been reported. Besides, no morphotypic differentiation in female population similar to that of male has hitherto been reported. The existence of morphotypes in female population remained unnoticed mainly due to the lack of perceptible size heterogeneity associated with morphotypes as shown by their male counterparts and therefore, the female population was considered rather homogenous (Cohen *et al.*, 1981). The growth of males in grow out systems were found highly differential in view of their distinct variation of size and they also exhibit difference in morphological features (Fujimura and Okamoto, 1972; Smith *et al.*,1978, Brody *et al.*, 1980; Ra'anan, 1982; Malecha *et al.*, 1984). This variability was found to be associated with morphotypic existence (Ra'anan, 1982; Ra'anan and Cohen, 1985), on the contrary, female population showed a relatively uniform size distribution (Cohen *et al.*,1981). Similar possibility of existence of morphotypes in *M. idella* also have not so far been explored. Therefore, the present study was undertaken with the following objectives -

a) to examine the possibility of existence of male morphotypes of *M. rosenbergii* in natural population similar to that of culture systems
b) to examine to possibility of existence of morphologically distinguishable forms of females similar to that of their male counterparts
c) to find out the possibility of existence of morphotypic existence in male and female populations of *M. idella*.

Studies regarding morphotypic characteristics of male *M.rosenbergii* are those of Cohen *et al.*(1981), Ra'anan (1982), Sagi(1984), Telecky(1984), Ra'anan and Sagi(1985) Ra'anan and Cohen(1985), Kuris *et al.*(1987) and Sagi and Ra'anan (1988). Kuris *et al.*(1987) provided operational allometric criteria to recognize the male morphotypes and described the transition between morphotypes. Size characterisation of male morphotypes collected from grow out systems have been studied in detail (Cohen *et al.*,1981; Kuris *et al.*, 1987; Sagi and Ra'anan,1988). Morphotypic differentiation of female morphotypes was studied by Harikrishnan *et al.*(1996, 1997) and Harikrishnan and Kurup(1997a). The biology of *M.rosenbergii* inhabiting Vembanad lake was studied by Raman(1967) and Kurup *et al.*(1992a). The growth pattern of *M. idella* was studied by Jayachandran and Joseph(1988b).

## 2. MATERIALS AND METHODS

The exploited stock of *M.rosenbergii* and *M. idella* in Vembanad lake was thoroughly examined during monthly fishery survey cruises conducted from March 1994 to February 1996 with the help of M.B.Kingfisher (refer section 1.4 for details). The catches from various fishing gears and methods employed for the two species were thoroughly examined and 2488 males and 2073 females of *M.rosenbergii* and 4000 males and females of *M. idella* were collected for detailed examinations. Male morphotypes of *M.rosenbergii* and their transitional stages were identified and classified following Kuris *et al.*(1987), Sagi and Ra'anan (1988) and Telecky (1984) whereas female morphotypes were differentiated following Harikrishnan and Kurup (1997a). The identification of morphotypes and their transitional stages were primarily based on morphological characteristics of second cheliped podomeres such as colouration, spineation, stoutness, etc., and also on the basis of relative differences in the body size.

Morphometric measurements were taken in 454 male and 467 female specimens of *M.rosenbergii* ranging in the size 71-354mm and 130-280mm total length respectively whereas similar observations were made in 300 males of *M.idella*. Sixteen such measurements *viz.* total length, carapace length, rostral length, pleural length, telson length, second cheliped length, lengths of podomeres of first cheliped (ischium I, merus I, carpus I, propodus I and dactylus I) and lengths of podomeres of second cheliped (ischium II, merus II, carpus II, propodus II and dactylus II) were taken for allometric studies. All measurements were taken to the nearest millimeter. Total length was measured with a ruler from tip of the rostrum to the tip of the telson while the carapace length was measured with a vernier caliper from the posterior margin of the right orbit to the posterior margin of the carapace at the mid line. Total cheliped length was measured along the extended cheliped length with a ruler from the proximal basis of the ischium to the distal tip of propodus along the ventro-lateral surface. Measurements of each podomere was taken following Kuris *et al.*(1987). Telson was measured from its distal tip to the proximal margin. Pleural length was measured at the widest part of the pleural flap on the second abdominal segment and total weight was recorded to 0.1 gram using a top loader scale. Observation on colouration and spination were made on fresh specimens. Allometric growth technique (Kuris *et al.*, 1987) was employed by applying the equation Y= a + bx where a and b being regression parameters to be estimated. Rate of growth of dependent variable relative to the reference character was considered negatively allometric if b <1, positively allometric if b >1 and isometric if b= 1 following Kuris *et al.* (1987). Regression coefficients were estimated for various morphometric measurements by treating total length and carapace length as independent variables and the values so arrived at were compared using analysis of covariance technique (ANACOVA) (Snedecor and Cochran,1967). $D^2$ statistic was employed on nine morphometric characters such as total length, carapace length, rostral length, second cheliped length, ischium (II), merus (II), carpus(II), propodus (II) and dactylus (II). For size characterization, length frequency and weight frequency distributions were prepared following 20 mm and 10 g intervals respectively. The number of male morphotypes belonging to various length and weight classes were enumerated on a monthly basis and average frequencies were worked out for two years. Since female morphotypes did not show perceptible variation in size characteristics, size characterisation of male morphotypes was only attempted in the present study.

# 3. RESULTS

## 3.1. *Macrobrachium rosenbergii* (Plate 1 A)

The results of the morphological and allometric studies revealed that there exist morphologically distinguishable forms among male and female populations of *M. rosenbergii* inhabiting Vembanad lake.

### 3.1.1. MALE MORPHOTYPES

Three morphotypes such as Small Males (SM), Strong Orange Clawed Males (SOC) and Strong Blue Clawed Males (SBC) could be differentiated and distinguished in the exploited stock of Vembanad lake during the study period. Two transitional stages of SOC such as Weak Orange Clawed Males (WOC) and pre-transforming Orange Clawed males (t-SOC) could be distinguished among Orange Clawed males. Similarly, two transitory stages of SBC such as Weak Blue Clawed males (WBC) and Old Blue Clawed males (OBC) could also be differentiated.

#### 3.1.1.1 Description of male morphotypes and their transitional stages

i). SMALL MALES (SM) (Plate 2 A)
(I male morphotypic stage)

Individuals with very small body size ranging from 71 to 139 mm in total length and translucent body colour. Second chelipeds also appear transluscent, however, propodus may have traces of light blue shades at the sides and on the fixed finger. Most of propodus is translucent white while carpus has a red band on the distal end. A red spot is present on propodus at the point of articulation with dactylus. Dactylus is slightly yellowish.

ii) WEAK ORANGE CLAWED MALES (WOC) (Plate 2 B)
(Transitional stage between SM and SOC)

Possess weak second pereiopods characterised with feeble spination and first appearance of orange colour on propodus. Inner and median sides of ischium, merus and carpus whitish with tinges of orange chromatophores whereas outer proximal area is suffused with blue pigments. Most of propodus is orange while dactylus is yellowish orange and naked.

iii) STRONG ORANGE CLAWED MALE (SOC) (Plate 3 A)
(II male morphotypic stage)

Large animals with strong second chelipeds, most of them are orange in colour. Colouration of ischium, merus and carpus are similar to that of WOC, however, these podomeres show difference by possessing stout spines on them. Most of propodus is orange with whitish medial face. Spines on propodus are stout with horny tips and appear as orange in colour. Dactylus is fully covered with grayish brown hairs.

iv) PRE- TRANSFORMING ORANGE CLAWED MALE (t-SOC) (Plate 3 B)
(transitional stage between SOC and WBC)

Animals having varying body sizes similar to both WOC and SOC. They are transitional between Orange Clawed males and Blue Clawed males. The colouration shows resemblance with that of WOC or SOC but can easily be distinguished by the presence of patches of blue colouration on propodus replacing orange colour, which may manifest the first signs of transformation into BC.

v) <u>WEAK BLUE CLAWED MALE</u> (WBC) (Plate 4 A)

(Transitional stage between t-SOC and SBC)

Animals with wide range of body sizes ranging from 100 to 280mm in total length. Characterised by the presence of blue colouration on all podomeres of second cheliped. Ischium, merus and carpus have whitish inner and medial faces, however, deep blue colour persists on major portion. Entire propodus is blue in colour while dactylus is dark and naked. The spines on podomeres are small and feeble and appear bluish in colour.

vi) <u>STRONG BLUE CLAWED MALE</u> (SBC) (Plate 4 B)

(III male mmorphotypic stage)

Large animals with very strong second chelipeds. All podomeres are dark blue coloured with long, stout and robust spines. Dactylus has a thick covering of short greyish brown hairs.

vii) <u>OLD BLUE CLAWED MALES</u> (OBC) (Plate 4 C)

(Transitional stage of SBC)

Largest animals occupying the terminal position of the transformation path way characterised with the presence of exceptionally strong and stout second chelipeds longer than that of total length and disproportionate with the body length. Colouration and spination are almost similar to that of SBC.

3.1.1.2. <u>Allometric characterisation</u>

**i) Regression analysis in male morphotypes**

Regression analysis with fourteen morphometric measurements of male population by using total length and carapace length as reference dimensions were carried out and regression parameters were estimated separately for the three morphotypic forms such as Small Males, Orange Clawed males (from pooled data of WOC, SOC and t-SOC) and Blue Clawed males (from pooled data of WBC, SBC and OBC) and also separately for the various stages of Orange Clawed males viz. WOC, SOC and t-SOC and Blue clawed males viz.WBC, SBC and OBC. The growth of second cheliped in SM was found to be isometrical when compared to total length whereas regressions of the same on total length in both Orange Clawed males and Blue Clawed males showed strong allometrical growth pattern. On the contrary, regression of rostral length on carapace length in SM was found to be positively allometrical while the same in respect of both Orange clawed males and Blue clawed males were isometric. However, in all the three groups, regressions of cheliped length and propodus length (II) on carapace length showed positively allometric growth pattern. Similar results could also be obtained while working out regression parameters of the transition stages of both Orange clawed and Blue clawed males. It could be seen that second cheliped showed an isometric growth while regressing with total length not only in SM but also in WOC, WBC and OBC. On the contrary, in SOC, t-SOC and SBC, it showed positively allometric growth pattern. Results of regression of rostral length on carapace length were also showed isometric growth pattern in WOC, SOC, t-SOC and SBC.

Regression coefficients of fourteen morphometric measurements of male morphotypes on total length and carapace length were tested statistically using ANACOVA and the results are shown in Table 2.1. to 2.12. Regressions of cheliped length and rostral length on total length showed significant difference at 1% (p= <0.01) level while that of ischium of first cheliped and dactylus of second cheliped differed at 5% level (p= <0.05). Regressions of cheliped length, lengths of ischium, propodus and dactylus of second cheliped with carapace length as reference dimension differed significantly at 1% level (p= <0.01) whereas that of rostral length, ischium of first cheliped and merus and carpus of second cheliped showed difference at 5% level (p= <0.05). The regressions of second cheliped podomeres on carapace length of various male morphotypes are depicted in Fig. 2.1.

Comparison of regression coefficients using *t*-test showed that the growth pattern of second cheliped with reference to total length showed no significant variation between SM and WOC, WOC and WBC, SOC and t-SOC, SOC and SBC, t-SOC and WBC, t-SOC and SBC and WBC and SBC. In contrast, the same while regressing against carapace length showed significant difference between SOC and t-SOC, t-SOC and SBC and between WBC and SBC.

ia) <u>Comparison of relative growth of various body parts with reference to total length</u>

Results of *t*-test showed that relative growth of second cheliped in relation to total length differed significantly between SM and all other morphotypes barring SM and WOC. On the contrary, the relative growth of rostrum was found significantly different between SM and WOC only. Growth of ischium of first cheliped was found to be different between SM and SOC and between SM and OBC. Similarly, growth of merus of second cheliped was also found to be significantly different between SM and WOC, SM and SOC and SM and WBC. However, the same in respect of dactylus differed only between SM and SOC. Growth pattern of second cheliped, rostrum, ischium(I), merus(II) and dactylus(II) in relation to total length were found to differ between WOC and SOC while between WOC and t-SOC only cheliped, rostrum and ischium (I) showed variation. In WOC and WBC, merus (II) only showed variation while between WOC and SBC, significant difference could be noticed in cheliped, rostrum and dactylus(II). Growth of cheliped, ischium (I) and dactylus(II) were found to be significantly different between WOC and OBC.

Significant difference could also be noticed between SOC and t-SOC in the growth of dactylus (II) while in SOC and WBC, cheliped, rostrum and ischium (I) were also found to be different significantly, besides dactylus (II). No significant variation could be observed in the growth pattern between SOC and SBC while between SOC and OBC, growth of cheliped and dactylus (II) differed significantly.

The relative growth of merus(II) in relation to total length showed variation between t-SOC and WBC while between t-SOC and SBC dactylus (II) showed significant difference. Between t-SOC and OBC, the difference was found significant in the cheliped length and dactylus (II) length.

The growth of rostrum (I) and dactylus (II) showed significant difference between WBC and SBC while between WBC and OBC, that of second cheliped, ischium (I) and dactylus (II) showed variation. Similar difference could also be noticed between SBC and OBC in the growth pattern of second cheliped and dactylus(II).

ib) Comparison of the growth of various body parts with reference to carapace length

The growth of second cheliped, rostrum and ischium(I) with reference to carapace length showed significant variations between the combinations of SM with SOC, SBC and OBC while between SM and WOC, only the growth of rostrum differed significantly. Between SM and WBC, relative growth of rostrum and merus (II) showed significant differences whereas no significant variation could be noticed in the relative growth of any of the body parts between SM and t-SOC.

The growth pattern of second cheliped in WOC differed significantly between SOC, SBC and OBC while the same of rostrum varied only between WOC and OBC. Similarly, relative growth of ischium (I) in WOC varied only with SOC while the same of ischium(II) varied with SBC and OBC.

Growth of merus (II) and carpus (II) in WOC varied with t-SOC and WBC while propodus showed variation only with OBC. The growth pattern of dactylus (II) in relation to carapace length was found to be different with SOC, t-SOC and OBC.

Between SOC and t-SOC, the growth of second cheliped only showed variation while between SOC and WBC, growth of second cheliped and ischium varied significantly. No variation could be observed in the growth of any body parts between SOC and SBC whereas the relative growth of second cheliped, rostrum, propodus(II) and dactylus (II) differed significantly between SOC and OBC.

The relative growth of rostrum in relation to carapace length was found to be different in t-SOC and WBC and t-SOC and OBC whereas growth of second cheliped and ischium (II) varied between tSOC and SBC and also between t-SOC and SBC. Besides, the growth of merus(II), carpus(II), propodus(II) and dactylus (II) were also differed significantly between t-SOC and OBC.

Between WBC and SBC, the growth of second cheliped and ischium were found to be significantly different while between WBC and SBC, the same of all podomeres were found to be significantly different.

The regressions of second cheliped length, propodus length (II) and dactylus length (II) were found to be different between SBC and OBC.

### 3.1.1.3. Distance Function analysis

Morphometric measurements such as total length, length of carapace, second cheliped, rostrum, ischium (II), merus (II), carpus (II), propodus (II) and dactylus (II) of various male morphotypes and their transitional stages were subjected to distance function analysis since these measurements were found to be largely helpful in differentiating the morphotypes and their transitional stages. The variance covariance matrices of pair wise analysis between various male morphotypes are given in Table 2.13 to 2.33. The $D_9^2$-values thus arrived at were statistically tested and the results are given in Table.2.34. All $D_9^2$values derived from various combinations except that of WOC and t-SOC and SOC and t-SOC were found to be significantly different at 1% level. Square root of $D_9^2$ values between pairs of morphotypes indicated approximate distance between them and are given in Table 2.35. Mutual relationship of various morphotypes based on the distances between them is illustrated in Fig.2.2. Highest distance is found between SM and OBC as they occupy the initial and terminal positions respectively in the transformation pathway. The positions of Orange clawed males (WOC, SOC and t-SOC) are relatively nearer to SM while distances of WBC, SBC and OBC were found relatively higher from SM. Among OC males, WOC and t-SOC occupy positions closer to SM, in contrast, SOC occupies a place which is glaringly distant from that of SM.

3.1.1.4 Size characterisation of male morphotypes

Percentage length and weight frequency distribution of various male morphotypes and their transitional stages are shown in Fig.2.3. Among the three male morphotypes, SM, SOC and SBC males exhibit perceptible differences with regard to both length and weight profiles. SM, SBC and OBC appeared in distinctly different length groups whereas in the case of WOC, SOC, t-SOC and WBC such difference could not be seen as there was some degree of overlapping among them. Weight frequency distributions also showed a similar pattern, however, the SOC showed distinct weight difference from that of WOC, t-SOC and WBC. It appears that weight frequency distribution pattern of the morphotypes and their transitional stages provide more precise characterisation. WOC, t-SOC and WBC males predominantly belonged to lower weight groups (30 - 150 g), in contrast, SOC, SBC and OBC can be demarcated due to their position in higher weight groups. Minimum and maximum of total length and weight of various morphotypes studied and their modal values also are given in Table 2.60. SM represented in the lowest size group ranging from 71 - 125 mm in total length and 6-18g in weight. A gradual increase in length and weight ranges could be discernible from SM to SOC whereas in t-SOC and WBC very wide length and weight ranges could be observed. Both t-SOC and WBC include individuals having size lesser than SOC. Minimum length and weight of t-SOC observed were 131 mm and 22 g respectively while the same of WBC was 105 mm and 12 g respectively. Similarly, OBC group is also characterised with a length less than 204 mm and weight of 86 g and this in comparison with its preceding morphotype SBC was far less. A gradual increase in modal values of length and weight from SM to SOC and from WBC to OBC could also be observed. However, both in t-SOC and WBC, modal lengths and weights were found lower than that of SOC. It is interesting to note that 88% of WOC morphotypes were identical with that of the SOC, in size. On the contrary, WOC males were distinctly smaller when compared to SOC, when weights of the two groups were compared.

Fig.2.4 shows monthly variations in length frequency distribution of male morphotypes and their transitional stages. t-SOC with total length lower than SOC appeared in most of the months except in January and April. Similarly, during November to January and April to July, WBC males smaller than WOC were found from the lake. There exist a very complex pattern of transformation as evident from Fig.2.4 in the developmental pathway of morphotypes. The length frequency of male morphotypes showing possible transformation pathways are schematically illustrated in Fig.2.5.

### 3.1.2. FEMALE MORPHOTYPES

An indepth study of exploited stock of *M.rosenbergii* in Vembanad lake brought out the existence of three morphologically distinguishable forms in female population similar to that of male population. Even though females did not exhibit perceptible size heterogeneity identical with that of male morphotypes, however, on closer examination distinct differences could be discernible in second cheliped characteristics . Based on colour and pattern of spination of the second cheliped podomeres, three morphotypes such as Small Female (SF), Strong Orange clawed Female (SOF) and Strong Blue clawed Female (SBF) could be distinguished in the exploited stock. Two transitional stages of Strong Orange clawed Female *viz.* Weak Orange clawed Female (WOF) and Transforming Orange clawed Female (TOF) and one transitional stage of Strong Blue clawed Female *viz.* Weak Blue clawed Female (WBF) could also be identified and differentiated. However, only four numbers of Small Females could be encountered in the exploited stock from the lake during the period of this study.

### 3.1.2.1. Description of female morphotypes and their transitional stages

i) SMALL FEMALE (SF) (Plate 5 A)
(I female morphotypic stage)

Having very small body size (98 mm total length) and translucent body colour. Podomeres are translucent, propodus being suffused with faint blue pigments. Morphologically they resemble Small Males but are distinguishable by the absence of appendix musculina.

ii) WEAK ORANGE CLAWED FEMALE (WOF) (Plate 5 B)

(Transitional stage between SF and SOF)

Ischium : Inner and medial face white, outer distal portion white suffused with blue pigments, outer proximal area yellow to orange.

Merus and Carpus: Inner and medial face orange yellow, outer face slightly bluish.

Propodus : Orange at the sides and dorsally, the tip of the fixed finger slightly bluish.

Dactylus : pale orange coloured and the tip ending in bluish spine.

iii) STRONG ORANGE CLAWED FEMALE (SOF) (Plate 6 A)

(II female morphotypic stage)

Ischium : Inner and medial face white, outer proximal area orange suffused with bluish pigments.

Merus and Carpus: Inner and medial face orange to yellow , outer face slightly blueish in colour.

Propodus : Orange at the sides and dorsally, inner and ventral sides white suffused with orange. Prominent spines present.

Dactylus : Orange coloured

iv) TRANSFORMING ORANGE CLAWED FEMALE (TOF)(Plate 6B)

(Transformed stage between SBF and WBF)

Ischium : Inner and medial face white, outer proximal area bluish

Merus and carpus: Inner and medial face with slight blue, outer face bluish.

Propodus : Blue at the sides and dorsally, inner and ventral sides white suffused with orange pigments.

Dactylus : Bluish black coloured.

v) WEAK BLUE CLAWED FEMLAE (WBF) (Plate 6C)

(Transition stage between TOF and SBF)

Ischium : Dorsal blue black and inner side and ventral portion whitish.

Merus and Carpus: Deep blue black dorsally and at the sides.

Propodus : Proximally bluish black on all sides, a faint orange ring at the point of articulation of the movable finger with propodus which pales to the median and outer sides of propodus, the middle portion of propodus deep blue and propodus ends in a reddish claw spine.

Dactylus naked,deep blue coloured, ending in reddish spine.

vi) STRONG BLUE CLAWED FEMALE (SBF). (Plate 7)

(III female morphotypic stage)

Ischium : dorsal blue black and sides white.

Merus and carpus : deep blue black and small spines

Propodus : The orange ring at the junction of the movable finger and propodus reduced to a small patch, prominent but small spines, deep bluish black colour.

Dactylus : covered fully with thick grey hairs, the terminal portion being naked forming the claw spine.

3.1.2.2 Allometrical characterisation

i) Regression analysis in female morophotypes

Fourteen morphometric measurements of

two female morphotypes such as SOF and SBF and their transitional stages (WOF and TOF of SOF and WBF of SBF) were subjected to detailed regression analysis in order to bring out the variations in allometrical relationship among various female morphotypes. Regression of various body measurements on total length and carapace length were worked out separately and the coefficients thus estimated were tested statistically using ANACOVA and results are given in Table 2. 36 to 2.47. It could be seen that significant difference exists among the two female morphotypes and their transitional stages in the growth of rostrum, ischium (II) and carpus(II) in relation to total length. The coefficients derived from the regression of cheliped length, pleural length, rostral length, ischium, merus, carpus, propodus, dactylus and telson on carapace length also showed significant variations among the two morphotypes and their transitional stages of females. The relationship between second cheliped podomeres on carapace length are shown in Fig. 2.6

ia) <u>Comparison of relative growth of various body parts with reference to total length</u>

A comparison of regression coefficients so arrived at using *t*-test showed that relative growth of rostrum and carpus with reference to total length showed significant variations between WOF and SOF. The growth of ischium (II) varied significantly between WOF and TOF while between WOF and WBF and WOF and SBF, the same of ischium

(II) and carpus (II) showed significant differences. The growth of rostrum and ischium (II) in relation to total length showed significant variation between SOF and TOF, SOF and WBF and SOF and SBF while that of carpus differed only between SOF and WBF. No variation could be noticed in the relative growth of any of the body parts with reference to total length between TOF and WBF, TOF and SBF and WBF and SBF.

ib) Comparison of relative growth of various body parts with reference to carapace length

The relative growth of propodus (II) and dactylus (II) with reference to carapace length were found to be significantly different between WOF and SOF while between WOF and TOF, the growth of only pleura showed variation. Between WOF and WBF, the growth of pleura, merus (II) and carpus (II) showed significant variations while between WOF and SBF, the same of telson, ischium (II), merus (II) and carpus (II) were found to be different.

Significant variation could be noticed in the relative growth of telson and all podomeres of second cheliped between SOF and TOF, SOF and WBF and SOF and SBF. Growth of rostrum also showed variation between SOF and TOF and SOF and SBF whereas the same in regard to second cheliped could be noticed only between SOF and SBF.

The relative growth of dactylus was found to be significantly different between TOF and WBF and TOF and SBF while the same of cheliped length showed variation between

TOF and SBF only. Similar difference could also be noticed between WBF and SBF in the growth of telson in relation to carapace length.

The cheliped length in Orange Clawed females showed allometrical growth in relation to total length (b= 0.86, r=0.8188) while in Blue clawed females nearly isometric growth (b=0.97 r= 0.8264) could be seen. However, the regression of each segment of the second cheliped on carapace length revealed allometrical growth except that of propodus length.

### 3.1.2.3. Distance function analysis

Distance function analysis was carried out based on nine morphometric characters of the female morphotypes and their transitional stages such as total length, carapace length, second cheliped length, rostral length, lengths of ischium, merus, carpus, propodus and dactylus of second cheliped since these body measurements were found largely helpful in morphotypic differentiation. The variance covariance matrices of the pair wise analysis between them are given in Table 2.48 to 2.57. The $D_9^2$ values thus arrived at were statistically tested and the results are given in Table 2.58. No significant difference could be noticed between the pair wise analysis between WOF and TOF, SOF and TOF, SOF and WBF and TOF and WBF. The combination of WOF, SOF, TOF and WBF with SBF and also that of WOF with WBF showed significant variations at 1% level while the same of WOF with SOF differed at 5% level. Square roots of

$D_9^2$- values estimated between pairs indicated approximate distance between morphotypes and are given in Table 2.59. Based on this, the probable mutual relationships existing among female morphotypes is depicted in Fig.2.7. The distance is found to be high between WOF and SBF as they occupy the initial and terminal positions respectively while TOF occupies a position closer to WOF when compared to SOF whereas the position of WBF was found almost closer to WOF rather than SBF.

3.2 *Macrobrachium idella*

The commercial catches of *M.idella* in the lake were found to comprise both large and small males. Small males were having translucent body colour and relatively small and translucent chelipeds while large males possessed grey or greenish blue body colour and long second chelipeds characterised by exceptionally long carpus. The males collected were sorted out into two categories such as Small males (M1) and Large males (M2) while taking morphometric measurements. Though females exhibited variation in body sizes, no difference could be noticed in body colour and second cheliped characteristics and therefore, were treated as a single population for morphometric studies. Results of allometry have shown that no significant difference exist between M1 and M2 males in the relative growth of second chelipeds in relation to both total length and carapace length (Table 2.61 and 2.62). However, both these males showed distinct difference with females (F= 12.72) (Table 2.63). The regression of second cheliped on total length and carapace length showed positive allometry in both males and females.

## 4. DISCUSSION

Results of the present study fully support the earlier findings that there exist morphologically distinguishable forms in the population of *M.rosenbergii* from natural habitats. Tazelaar (1930) noted a bimodality in claw size of males of *M.rosenbergii* (= *Palaemon carcinus*) collected from a natural habitat. Kuris *et al.* (1987) observed that the samples used for allometrical analysis by Tazelaar (1930) could have been SM, WOC, SOC and BC males. The description of second cheliped characteristics of male morphotypes given in the present study are in full agreement to those of Kuris *et al.*(1987) and Sagi and Ra'anan (1988). However, range of body size observed in the present study are much higher when compared to the specimens described from pond populations by Telecky (1984), Kuris *et al.* (1987) and Sagi and Ra'anan (1988). The presence of multi-aged populations in the natural habitat and their faster growth in natural systems when compared to their counterparts in grow-outs can be attributed as the reason for the size disparity. Nevertheless, the pattern of variation in body size and cheliped lengths among morphotypes of the natural habitat was found to be identical when compared to that of pond raised populations.

Kuris *et al*. (1987) recognized only SM, WOC, SOC and BC as adult male morphotypes. Sagi and Ra'anan (1988) identified t-SOC morphotype as large OC males having SOC morphology with the first appearance of BC colouration and spination. However, in t-SOC morphotypic stage encountered in the present study comprised of animals with WOC morphology and body size since they exhibited first appearance of blue colouration on propodus of second pereiopods. Sagi and Ra'anan (1988) hypothesized that t-SOC animals would transform to BC males at the next moult. One transformation stage of Blue clawed males could also be recognized in the present study, which has not been previously reported. Interestingly, heterogeneity with respect to relative body size, claw size and spination could be observed among Blue Clawed males also. WBC morphotypes had small and weak second chelipeds with feeble spines on them and mostly comprised of animals of 150 mm in total length. On the contrary, SBC morphotypes were large and had strong peacock blue second peraeopods ornamented with stout and prominent spines on them. Therefore, it can be reasonably presumed that WOC animals might have bypassed SOC during its course of transformation in natural habitat and attained WBC through t-SOC stage.

Sagi and Ra'anan (1988) recognized OBC morphotypes as males with BC morphology but with relatively small body size and the samples collected by them were also characterised with less body weight, carapace length and small propodus length when compared to BC males. Besides, body of these individuals were also covered with algae and therefore were assumed to be the earliest BC males which had metamorphosed in the process of social hierarchy. The body size was also small in view of the fact that once becoming a BC male, further growth was largely inhibited while the other males continued growing(Ra'anan and Cohen, 1985). Most of OBC morphotypes identified in the natural system had body size more or less similar to that of SBC males, however, were characterised by the presence of exceptionally long chelipeds. In SBC males, extended cheliped length was almost equal to its total length whereas in OBC, it extended to about 50% more than total length. Spineation in these two morphotypes did not vary significantly. Animals fully conforming with the descriptions of Sagi and Ra'anan (1988) were also encountered during the present study both from Vembanad lake and a monoculture grow-out system of *M.rosenbergii* in Kuttanad. It would appear that in culture ponds, being confined areas, resulted in higher population density where social hierarchy is established even in the early stages of growth and the BC males thus becoming dominant will have comparatively small body size. In contrast, in natuaral system, growth is not being affected by the act of such limiting factors as seen in grow-outs and therefore, the growth rate will be comparatively faster when compared to their counterparts in the culture ponds. Ra'anan

(1982) reported that some individuals in culture ponds reach BC status in the early stages of morphotypic differentiation at a smaller body size. On the contrary, in natural system, individuals are blissful in getting dispersed over wide areas and therefore would be less prone to competition for establishing territorial dominance. It appears that individuals which are becoming BC males may also get further chance to grow to much higher sizes regardless of their social dominance inherent with this group.

Results of allometric studies fully support and substantiate the existence of the morphotypes in male population of *M.rosenbergii* inhabiting Vembanad lake. Statistical comparison of regression coefficients of SM, OC and BC males showed significant variations. The relative growth of second chelipeds in relation to total length in SM was found to be isometric whereas the same in pooled data of OC and BC males showed strong positive allometry. However, Kuris *et al.* (1987) observed that cheliped length showed a positively allometric slope in all the above three morphotypes. In the present study, relative growth of second cheliped in relation to total length was found to be isometric in SM, WOC, WBC and OBC. Relative growth of SM, WOC and WBC may be slow owing to their subordinate status in the social hierarchy. OBC, on the other hand, occupies the terminal stage of the developmental pathway (Cohen *et al.*, 1981) and therefore, would have already attained maximum growth so as to perform the dominance. The strong positive allometrical growth in SOC, t-SOC and SBC indicate their rapid development for attaining the dominant positions. Results of *t*-test also fully corroborate this findings.

According to Kuris *et al.* (1987), carpus length is the best discriminator of BC from OC males as the growth of carpus is isometric in BC males. Similarly, in the present study also, regression of carpus length on carapace length were found to be isometric in t-SOC, WBC and SBC males. However, growth of propodus was reported to be negatively allometric in SM, isometric in WOC and positively allometric in SOC (Kuris *et al.*,1987), conversely in the present study, it was found to be positively allometric in all morphotypic forms barring OBC. Pair wise comparison of regression coefficients between various morphotypes showed that no significant variation exists in the growth pattern of various body parts between SOC and SBC which would suggest that these two morphotypes are different only on the basis of morphological characters. Similarly, much allometrical variations could not be observed between SM and WOC, SM and t-SOC, WOC and WBC, SOC and t-SOC and t-SOC and WBC.

The results of $D^2$ analysis also showed that no significant variation exists between the combinations of WOC and t-SOC and SOC and t-SOC. It appears that SM, WOC, SOC, t-SOC and also WBC are closely related. The morphotypes of *M.rosenbergii* represent various stages in the developmental pathway and may transform from SM to BC in an irreversible manner (Cohen *et al*, 1981; Ra'anan and

Sagi, 1985; Kuris *et al*, 1987). The results of $D^2$ analysis arrived at in the present study also support this hypothesis.

It is known that the growth and transformation of morphotypes are governed by social interactions prevalent with in the population. In grow-outs, the presence of BC male may suppress the growth of SM males (Ra'anan and Sagi,1985). The available literature also suggest that OC males can transform to BC males only after becoming larger than the largest BC males at its vicinity and as a result of this 'leap frog' growth pattern prevalent in *M.rosenbergii*, a series of differently sized BC males will be developed (Karplus *et al.*,1991). During the early phases of development, some of the SM males may transform to BC males after becoming OC males, but once the dominant BC male occupies the alpha position in the social hierarchy, the OC males may be following 'leapfrog' growth pattern and therefore, subsequent transformation is delayed till they grow to become larger than the largest BC male (Kurup, 1996). The noticeable size heterogeneity among WOC, t-SOC and WBC morphotypes as observed during present study may be explained on the basis of the above described phenomenon. The relative distance between the male morphotypes as reflected in the distance function analysis of the study also suggest the possibility of two or more transformation pathways undergone by the male morphotypes in the natural habitat. On evaluating the relative positions of various morphotypes with distance function analysis, it could be seen that SOC is far distant to SM than t-SOC which would suggest that they are following 'leapfrog' growth pattern since BC males have already established the dominance. Their transformation to SBC through t-SOC would take place only after they grow bigger than the BC males. Results of present study also support the view that male morphotypes of *M.rosenbergii* from a natural population also exhibit clear size hetergoneity similar to that of a pond population as is shown by length and weight profiles of SM, SOC and SBC males.

The rate of transition from one morphotype to another is controlled by social organisational set up prevalent in their habitat (Cohen *et al.*, 1981). The growth of SM was found to be suppressed by the presence of BC males with strong second chelipeds in their vicinity and the removal of these large individuals stimulates SM to grow at an increased rate to become OC and eventually BC males (Ra'anan and Cohen, 1985; Karplus *et al.*,1992a). As per normal developmental pathway, SM transforms to SOC through WOC and SOC transforms to BC through t-SOC (Kuris *et al.*, 1987; Sagi and Ra'anan,1988). Sagi and Ra'anan (1988) recognized t-SOC animals as individuals with SOC morphology but showing first appearance of blue colouration as in BC animals. The carapace length and weight ranges of t-SOC identified by them were higher than that of SOC. However, in addition to such t-SOC morphotypes, some individuals (2.99%) with morphology and size ranges similar to WOC except for the appearance of blue colouration on propodus of second chelipeds could also be encountered in the present study. Similar heterogeneity was also observed in BC population where some WBC morphotypes(8%) showed morphology similar to WOC except for the blue coloured second pereiopods. This observation would also manifest the possibility of by-pass transformation in addition to the existence of usual developmental pathway.

It seems that SM transforms to OBC following three developmental pathways. The observation of small sized SBC and OBC males in the present study would also support the possibility of by- pass transformation. Ra'anan (1982) observed that some individuals of *M.rosenbergii* reach BC status in the early stages of morphotypic differentiation at a smaller body size. The urge for acquiring hierarchical dominance might make some SM morphotypes to transform to BC status by by-passing SOC stage through SM- WOC- WBC- SBC- OBC or SM- WOC- t-SOC- WBC- SBC-OBC pathways during early stages of population development. It is now known that BC males show clear dominance over OC males irrespective of their size. But once such dominating BC are formed, rest of the WOC may undertake normal transformation pathway through SOC since SOC represents a stage of high somatic growth (Sagi and Ra'anan, 1988). This is required because the largest BC becomes the most dominant, occupying the  position and having a clear advantage in access to resources (Barki,

1989) and is achieved through a "leap frog" growth pattern (Ra'anan and Cohen, 1985) in which an OC will metamorphose in to a BC only after it has become larger than the largest BC in its vicinity. The "leapfrog" growth pattern results in the gradual decrease in the social rank of BC males when new and larger BC males appear in their vicinity (Karplus *et al.*, 1991).

According to "leap frog" growth pattern, a wide heterogenity among morphotypes with regard to size is caused by delayed transition from fast growing OC morphotype in to the slow growing BC. This might be the reason for the wide range of size groups in t-SOC and WBC since large sized individuals of these morphotypes might have formed by transition from SOC stage, following the normal transformation pathway.

The disparity in length and weight ranges between WOC and SOC as observed in the present study indicate difference in somatic growth in terms of stoutness. There is not much differences in lengths of WOC and SOC while perceptible variation could be observed in weight gain during transformation to SOC. The growth rate of WOC is reported to be that of a rapidly growing population in grow out systems (Cohen and Ra'anan, 1983; Ra'anan and Cohen, 1985; Kuris *et al.*,1987). Kuris *et al.*(1987) reported that animals intermediate between WOC and SOC may also be present. This may explain the presence of large sized WOC prawns resembling SOC except for claw characteristics in the natural population.

The complex nature of population profile development in *M.rosenbergii* is reflected in the size frequency distribution. Morphotypic transformation does not take place by strictly adhering to normal SM- WOC- SOC- t-SOC- WBC- SBC- OBC only as evidenced from lack of sequential pattern and the extend of overlapping seen in monthly size frequency distribution of various morphotypes. Besides, the appearance of WBC having size lesser than smallest WOC in most of months also supports this view . Abiding normal developmental pathway, t-SOC and WBC must have had sizes higher than SOC, however, the results of the size characterisation are at variance with this view.

The female population of *M.rosenbergii* is reported to exhibit no morphotypic differentiation and they appeared as rather homogenous with regard to body size and weight in culture systems (Cohen *et al.*, 1981; Ra'anan and Sagi, 1985). Based on maturity stages, three morphotype among females such as Virgin Female (VG or VF), Open Female (OP or OF) and Berried Female (BE or BF) were identified (Ra'anan, 1982; Ra'anan and Cohen, 1985; D'Abramo *et al.*, 1991; Daniels and D'Abramo, 1994; Daniels *et al.*, 1995). However, no morphotypic differentiation among females similar to that of males has so far been reported. A close examination on the morphology of females of *M.rosenbergii* in Vembanad lake revealed that morphologically distinguishable forms of females in par with males exist in natural system. However, size and spination of second chelipeds in females were not found to be so glaring as in the case of males and therefore, did not contribute much for the easy differentiation of female morphotypes as they seldom attain the size and stoutness of their male counterparts. In males, remarkable variations in relative size and surface sculpture of the second chelipeds provide definite criteria for easy differentiation of morphotypes. Among various allometric relationships studied by Kuris *et al.*(1987), relative variations of cheliped length with carapace length were used to diagnose the male morphotypes. Female counterparts of all morphotypic stages except that of OBC could be encountered in the present study. However, allometrical studies and $D^2$ analysis could not be conducted in Small Females as only four specimens were able to be collected from the lake. Small Males and Small Females of *M.rosenbergii* were not adequately represented in the exploited stock of Vembanad lake and it may either be due to their non availability to fishing in view of their small size or due to their rare occurrence in the natural population.

Comparison of regression coefficients between both pooled data of Orange clawed Females and Blue clawed Females and also between individual morphotypes showed significant differences and therefore, it could be concluded that the female morphotypes of *M. rosenbergii* are also distinctly different both in terms of morphological as well as morphometric characters. In females, apart from coloration, the Orange Clawed females and Blue clawed females differed significantly in relative growth of ischium and carpus in relation to carapace length. In males, on the contrary, lengths of carpus and propodus were found best suitable for differentiating OC and BC morphotypes (Kuris *et al.*, 1987). Similarly in BC males, carpus showed isometric growth while propodus followed a positively allometric growth (Kuris *et al.*, 1987). On the contrary, in the present study, the carpus showed an allometric growth in both orange and Blue clawed females whereas the regression of propodus was isometric. The regression of rostral length and telson to carapace length were significantly different between males and females in *M.dayanus*(Koshy,1971) and *M.idella* (Jayachandran and Joseph,1988b). Regression of rostral length and telson length were significantly differed among female morphotypes of *M.rosenbergii*. Among Blue clawed females, the relative growth of cheliped on carapace showed significant difference between WBF and SBF. However, they could readily be differentiated by noticing the relatively strong second cheliped and also by the presence of thick hairs on the dactylus in the latter. Among Orange Clawed females, SOF and TOF differed with regard to the relative growth of rostrum and ischium in relation to total length and the growth of rostrum, telson and the podomeres in relation to carapace.

The results of $D^2$-statistic indicated definite allometric differences between WOF, SOF and SBF, therefore, confirm their morphotypic status. WBF morphotype showed no significant difference on F value in $D^2$ analysis with SOF and TOF and therefore, occupies a position closer to these morphotypes. Similarly, TOF showed no significant difference with WOF, SOF and WBF and occupies a position closer to them. Interestingly, it could be observed that the relative positions of SOF and TOF are just similar to that of SOC and t-SOC in males. In males, t-SOC was closer to WOC than SOC. The distance between WOF and SOF is higher than that of between WOF and TOF. This would manifest the possibility of females following 'leapfrog' growth pattern in their developmental pathway as reported in males (Karplus *et al.*,1991). From the distance function analysis it may be inferred that SBF morphotype occupies a terminal position in the population while SOF has a distinct entity characteristically different from WOF, TOF and SBF. However, it was observed in $D^2$ analysis that WBF showed no significant difference between SOF and TOF whereas it varied significantly with SBF. It would, therefore, be inferred that WBF occupies a position closer to Orange Clawed females, which is manifested by its closeness to WOF and TOF. It is quite possible that a fraction of WOF population would have undertaken by-pass transformation avoiding SOF-TOF pathway and attained WBF morphotypes by directly passing through TOF. The delay imparted in the transformation of Orange Clawed males by the presence of BC male following "leapfrog" growth pattern appears to be applicable in female population also. The high distances of SOF from WOF morphotype may be explained by the above phenomenon, giving it a distinctly different status in the organisational hierarchy. It appears that the female population of *M.rosenbergii* exhibits morphotypic differentiation, though not as conspicuous as that of males and these morphotypes undergo transformation either in WOF- SOF- TOF- WBF- SBF pattern or by by-pass pathway as WOF- TOF- WBF- SBF.

Though male population of *M.idella* from Vembanad lake exhibited two types of males, differing in size and colour, allometric studies ruled out the possibility of morphotypic existence among them. According to Kuris *et al.* (1987), morphotypic differentiation may be present in other species of *Macrobrachium*. The existence of "dimorphic males", "older male stages", "mixture of juvenile and adult males", and "hypertrophied male secondary sex characters" in other species of *Macrobrachium* have been reported (Henderson and Matthai,1910; Holthuis, 1950; Thampy and John, 1973 and Koshy, 1973). Similarly, Ahmed (1967) reported "males feminises" in *M.birmanicus* and *M.malcolmsonii* from Perschbacher et al. (1989) reported the occurrence of similar 'faminises male' forms in *M.malcolmsonii* from Bangladesh. However, in the case of *M.idella*, the large males (M2) are most likely belonging to a second year brood. In Vembanad lake, *M.idella* males attain a size of 75 mm and 110 mm at the end of I and II years respectively (Kurup *et al.*, 1992b). All the M2 males encountered in the present study had total length more than 100 mm. Therefore, it can reasonably be asserted that the morphological difference observed in male population of *M.idella* may not be due to population profile development as seen in *M. rosenbergii* but can be taken as a manifestation of age or maturation process of this species.

Table 2.1. Comparison of regressions of TOTAL LENGTH X CHELIPED LENGTH of various male morphotypes and transitional stages of *M acrobrachium rosenbergii*

| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | DEVIATIONS FROM REGRESSION df | SS {d y.x2 | MS | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | 34 | 9001 242424 | 7877.03 | 8904.879 | 0.875105 | 33 | 2011.652 | 64.892 | |
| 2 | WOC | 29 | 17259 46667 | 16855 13 | 19442 97 | 0.976573 | 28 | 2982 694 | 106.5248 | |
| 3 | SOC | 23 | 36939 33333 | 54619 33 | 84587 33 | 1 478623 | 22 | 3825 952 | 173 8069 | |
| 4 | t-SOC | 21 | 14739 31818 | 18963 82 | 26257.82 | 1.286614 | 20 | 1858 698 | 92 93489 | |
| 5 | WBC | 29 | 22939.86667 | 27642 27 | 40497.47 | 1.204988 | 28 | 7188.864 | 258.7451 | |
| 6 | SBC | 33 | 34945 88235 | 53158 29 | 98626.26 | 1.52116 | 32 | 17763.97 | 555.1241 | |
| 7 | OBC | 32 | 14470.54545 | -3797.36 | 39038.24 | -0.26242 | 31 | 38041.74 | 1227 153 | |
| 8 | WITH IN | | | | | | 194 | 73673.57 | 379.7607 | |
| 9 | Reg.Coeff. | | | | | | 6 | 39173.96 | 6528.993 | |
| 10 | COMMON | 201 | 150295.6551 | 175318.5 | 317355 | 1.166491 | 200 | 112847.5 | 564.2376 | 17.1924 * |
| 11 | Adj.Means | | | | | | 6 | 931273.4 | 155212 2 | 275.083 * |
| 12 | TOTAL | 206 | 667153 6019 | 1244269 | 3364734 | 1.865041 | 206 | 1044121 | | |

Comparison of slopes F= 6528.993 (6,194) 17.19239

Comparison of elevation F= 155212.2 (6,200) 275.0831

*=Significant at 1% level (p=<0.01)

Table 2.2. Comparison of regressions of TOTAL LENGTH X ROSTRAL LENGTH of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | DEVIATIONS FROM REGRESSION df | SS {d y.x2 | MS | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | 34 | 9651.394737 | 3982.263 | 1691.842 | 0.41261 | 33 | 48.72002 | 1.353334 | |
| 2 | WOC | 78 | 60926.86076 | 17057.67 | 8435.949 | 0.27997 | 77 | 3660.319 | 47.53662 | |
| 3 | SOC | 18 | 26760 | 10826 | 4742 | 0.404559 | 17 | 362.2438 | 21.30846 | |
| 4 | t-SOC | 82 | 83876 6506 | 30818.64 | 14356.87 | 0.367428 | 81 | 3033.234 | 37.44733 | |
| 5 | WBC | 90 | 77208.13187 | 24115 42 | 10854.99 | 0.312343 | 89 | 3322.708 | 37.33379 | |
| 6 | SBC | 41 | 19800.5 | 8047 | 4434.571 | 0.406404 | 40 | 1164.239 | 29.10599 | |
| 7 | OBC | 31 | 12826.96875 | 3993.063 | 2221.875 | 0.311302 | 30 | 978.8262 | 32.62754 | |
| 8 | WITH IN | | | | | | 367 | 12570.29 | 34.25147 | |
| 9 | Reg.Coeff. | | | | | | 6 | 601.9597 | 100.3266 | |
| 10 | COMMON | 374 | 291050.5067 | 98840.05 | 46738.09 | 0.339598 | 373 | 13172.25 | 35.31434 | 2.92912 * |
| 11 | Adj.Means | | | | | | 6 | 332.3826 | 55.39711 | 1.56869 |
| 12 | TOTAL | 384 | 1030945.333 | 372079.7 | 147792.3 | 0.360911 | 379 | 13504.63 | | |

Comparison of slopes F= 100.3266 (6,367) 2.929119

Comparison of elevation F= 55.39711 (6,373) 1.568686

*=Significant at 1% level (p=<0.01)

Table.2.3. Comparison of regressions of TOTAL LENGTH X ISCHIUM OF FIRST CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 4681.6 | 601.6 | 89.6 | 0.128503 | 33 | 12.29255 | 0.323488 | |
| 2 WOC | 51 | 38162.69 | 4533.423 | 776.9808 | 0.118792 | 50 | 238.4463 | 4.768926 | |
| 3 SOC | 19 | 34689.8 | 2213.6 | 227.2 | 0.063811 | 18 | 85.94739 | 4.774855 | |
| 4 t-SOC | 77 | 77984.72 | 6604.692 | 1097.846 | 0.084692 | 76 | 538.4807 | 7.085272 | |
| 5 WBC | 74 | 67822.48 | 6969.48 | 1258.48 | 0.102761 | 73 | 542.2919 | 7.428656 | |
| 6 SBC | 40 | 18049.22 | 1421.415 | 481.561 | 0.078752 | 39 | 369.6215 | 9.477475 | |
| 7 OBC | 32 | 12826.97 | 588.0909 | 374.7273 | 0.045848 | 31 | 347.7645 | 11.21821 | |
| 8 WITHIN | | | | | | 320 | 2134.845 | 6.67139 | |
| 9 Reg.Coeff. | | | | | | 6 | 102.8868 | 17.1478 | |
| 10 COMMON | 327 | 254217.5 | 22932.3 | 4306.395 | 0.090207 | 326 | 2237.732 | 6.864208 | 2.570349 ** |
| 11 Adj.Means | | | | | | 6 | 55.76554 | 9.294256 | 1.354017 |
| 12 TOTAL | 339 | 854000.4 | 80501.26 | 9881.847 | 0.094264 | 332 | 2293.497 | | |

Comparison of slopes F= 17.1478 (6,320) 2.570349 **=Significant at 5% level (p=<0.05)
Comparison of elevation F= 9.294256 (6,326) 1.354017

Table.2.4. Comparison of regressions of TOTAL LENGTH X DACTYLUS OF SECOND CHELIPED of various male morphotypes and transitional stages of Macrobrachium rosenbergii

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 8511.875 | 1609.813 | 339.9688 | 0.189125 | 33 | 35.51218 | 1.183739 | |
| 2 WOC | 76 | 54404.31 | 13168.66 | 4227.532 | 0.242052 | 75 | 1040.034 | 13.86712 | |
| 3 SOC | 18 | 26760 | 10006 | 4222.526 | 0.373916 | 17 | 481.1199 | 28.30117 | |
| 4 t-SOC | 91 | 94786.91 | 32338.5 | 17123.25 | 0.341171 | 90 | 6090.307 | 67.67008 | |
| 5 WBC | 82 | 72407.88 | 21596.87 | 11134.55 | 0.298267 | 81 | 4692.925 | 57.93735 | |
| 6 SBC | 54 | 23738.11 | 7846.855 | 8155.527 | 0.330559 | 53 | 5561.676 | 104.9373 | |
| 7 OBC | 72 | 32831.89 | 8629.384 | 5204.658 | 0.262835 | 71 | 2936.55 | 41.35986 | |
| 8 WITHIN | | | | | | 420 | 20838.12 | 49.61458 | |
| 9 Reg.Coeff. | | | | | | 6 | 657.6109 | 109.6018 | |
| 10 COMMON | 427 | 313441 | 95196.08 | 50408.02 | 0.303713 | 426 | 21495.74 | 50.45947 | 2.209065 ** |
| 11 Adj.Means | | | | | | 6 | 34486.03 | 5747.672 | 113.9067 * |
| 12 TOTAL | 431 | 1123262 | 474976.7 | 256827.9 | 0.422855 | 432 | 55981.77 | | |

Comparison of slopes F= 109.6018 (6,420) 2.209065 *= Significant at 1% leve(p=<0.01)
Comparison of elevation F= 5747.672 (6,426) 113.9067 **=Significant at 5% level (p=<0.05)

Table 2.5. Comparison of regressions of CARAPACE LENGTH X CHELIPED LENGTH of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 719 | 1913 | 8904.879 | 2.66064 | 33 | 3815.075 | 123.0669 | |
| 2 WOC | 29 | 1632.8 | 4756.2 | 19442.97 | 2.91291 | 28 | 5588.583 | 199.5922 | |
| 3 SOC | 23 | 4523.333 | 19447.33 | 84587.33 | 4.299337 | 22 | 976.698 | 44.39536 | |
| 4 t-SOC | 21 | 3039.818 | 6046.818 | 26257.82 | 1.989204 | 20 | 14229.46 | 711.4732 | |
| 5 WBC | 29 | 3221.867 | 9307.067 | 40497.47 | 2.888719 | 28 | 13611.97 | 486.1417 | |
| 6 SBC | 33 | 4104.735 | 18136.56 | 98626.26 | 4.418448 | 32 | 18490.83 | 577.8383 | |
| 7 OBC | 32 | 1795.636 | 113.1818 | 39038.24 | 0.063032 | 31 | 39031.11 | 1259.068 | |
| 8 WITHIN | | | | | | 194 | 95743.72 | 493.5243 | |
| 9 Reg.Coeff. | | | | | | 6 | 34267.56 | 5711.26 | |
| 10 COMMON | 201 | 19037.19 | 59720.16 | 317355 | 3.137026 | 200 | 130011.3 | 650.0564 | 11.5724 * |
| 11 Adj.Means | | | | | | 6 | 690353.7 | 115059 | 176.9984 * |
| 12 TOTAL | 206 | 80186.98 | 451691.5 | 3364734 | 5.632979 | 206 | 820365 | | |

Comparison of slopes F= 5711.26 (6,194) 11.5724 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 115059 (6,200) 176.9984

Table.2.6. Comparison of regressions of CARAPACE LENGTH X ROSTRAL LENGTH of various male morphotypes and transitional stages o *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 711.3158 | 1038.947 | 1691.842 | 1.460599 | 33 | 174.3563 | 4.84323 | |
| 2 WOC | 78 | 4885.468 | 4932.722 | 8435.949 | 1.009672 | 77 | 3455.518 | 44.87685 | |
| 3 SOC | 18 | 3823.684 | 4023 | 4742 | 1.052127 | 17 | 509.2945 | 29.9585 | |
| 4 t-SOC | 82 | 9875.06 | 10337.39 | 14356.87 | 1.046817 | 81 | 3535.512 | 43.64829 | |
| 5 WBC | 90 | 8689.538 | 7124.385 | 10854.99 | 0.819881 | 89 | 5013.844 | 56.33532 | |
| 6 SBC | 41 | 2970.119 | 2735.143 | 4434.571 | 0.920887 | 40 | 1915.815 | 47.89537 | |
| 7 OBC | 31 | 2195.719 | 1349.188 | 2221.875 | 0.614463 | 30 | 1392.849 | 46.42832 | |
| 8 WITHIN | | | | | | 367 | 15997.19 | 43.58907 | |
| 9 Reg.Coeff. | | | | | | 6 | 732.0679 | 122.0113 | |
| 10 COMMON | 374 | 33150.9 | 31540.77 | 46738.09 | 0.95143 | 373 | 16729.26 | 44.85055 | 2.799127 ** |
| 11 Adj.Means | | | | | | 6 | 1620.681 | 270.1135 | 6.022524 * |
| 12 TOTAL | 384 | 121306.6 | 125308.5 | 147792.3 | 1.03299 | 379 | 18349.94 | | |

Comparison of slopes F= 122.0113 (6,367) 2.799127 *= Significant at 1% level (p=<0.01)
Comparison of elevation F= 270.1135 (6,373) 6.022524 **=Significant at 5% level (p=<0.05)

Table 2.7. Comparison of regressions of CARAPACE LENGTH X ISCHIUM OF FIRST CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | | DEVIATIONS FROM REGRESSION | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 470.4 | 196.8 | 89.6 | 0.418367 | 33 | 7.265306 | 0.191192 | |
| 2 WOC | 51 | 3342.673 | 1102.7885 | 776.9808 | 0.329912 | 50 | 413.1575 | 8.263149 | |
| 3 SOC | 19 | 4856.2 | 819.2 | 227.2 | 0.168692 | 18 | 89.00787 | 4.944881 | |
| 4 t-SOC | 77 | 9121.949 | 1881.5385 | 1097.846 | 0.206265 | 76 | 709.7507 | 9.338825 | |
| 5 WBC | 74 | 7206.987 | 1848.56 | 1258.48 | 0.256496 | 73 | 784.3326 | 10.74428 | |
| 6 SBC | 40 | 2412.488 | 260.07317 | 481.561 | 0.107803 | 39 | 453.5243 | 11.62883 | |
| 7 OBC | 32 | 2202.242 | 295.54545 | 374.7273 | 0.134202 | 31 | 335.0645 | 10.80853 | |
| 8 WITHIN | | | | | | 320 | 2792.103 | 8.725321 | |
| 9 Reg Coeff. | | | | | | 6 | 129.1651 | 21.52752 | |
| 10 COMMON | 327 | 29612.94 | 6404.5055 | 4306.395 | 0.216274 | 326 | 2921.268 | 8.960944 | 2.467247 ** |
| 11 Adj.Means | | | | | | 6 | 197.0904 | 32.8484 | 3.665729 * |
| 12 TOTAL | 339 | 107433.4 | 26955.979 | 9881.847 | 0.250909 | 332 | 3118.358 | | |

Comparison of slopes F= 21.52752 (6,320) 2.467247 — *= Significant at 1% level (p=<0.01)
Comparison of elevation F= 32.848397 (6,326) 3.665729 — **= Significant at 5% level (p=<0.05)

Table 2.8. Comparison of regressions of CARAPACE LENGTH X ISCHIUM SECOND CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | | DEVIATIONS FROM REGRESSION | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y x2 | MS | |
| 1 SM | 34 | 611.875 | 329.5625 | 198.7188 | 0.538611 | 33 | 21.21282 | 0.707094 | |
| 2 WOC | 76 | 4877.169 | 2443.2208 | 2104.519 | 0.500951 | 75 | 880.5865 | 11.74115 | |
| 3 SOC | 18 | 3823.684 | 1477.1053 | 842.6316 | 0.386304 | 17 | 272.0196 | 16.00115 | |
| 4 t-SOC | 91 | 10800.21 | 5528.9783 | 4782.739 | 0.511933 | 90 | 1952.275 | 21.69194 | |
| 5 WBC | 82 | 7714 | 4538 | 4366.41 | 0.588281 | 81 | 1696.79 | 20.94803 | |
| 6 SBC | 54 | 3411.927 | 1027.2909 | 1852.836 | 0.301088 | 53 | 1543.531 | 29.12323 | |
| 7 OBC | 72 | 6997.37 | 2071.7534 | 4356.164 | 0.296076 | 71 | 3742.768 | 52.71504 | |
| 8 WITHIN | | | | | | 420 | 10109.18 | 24.06948 | |
| 9 Reg.Coeff. | | | | | | 6 | 462.2042 | 77.03404 | |
| 10 COMMON | 427 | 38236.23 | 17415.911 | 18504.02 | 0.455482 | 426 | 10571.39 | 24.81546 | 3.200486 * |
| 11 Adj Means | | | | | | 6 | 1467.43 | 244.5716 | 9.855614 * |
| 12 TOTAL | 431 | 146011.2 | 84952.937 | 61466.54 | 0.581825 | 432 | 12038.82 | | |

Comparison of slopes F= 77.034035 -6420 3.200486 — * = Significant at 1% level (p=<0.01)
Comparison of elevation F= 244.57162 -6426 9.855614

Table 2.9. Comparison of regressions of CARAPACE LENGTH X MERUS OF SECOND CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | Deviations from regression | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 611.875 | 242.6875 | 143.4688 | 0.396629 | 33 | 47.2118 | 1.573727 | |
| 2 WOC | 76 | 4877.169 | 2511.104 | 2022.987 | 0.514869 | 75 | 730.097 | 9.734627 | |
| 3 SOC | 18 | 3823.684 | 2280.105 | 1594.632 | 0.596311 | 17 | 234.9795 | 13.82233 | |
| 4 t-SOC | 91 | 10800.21 | 7660.533 | 10283.16 | 0.709295 | 90 | 4849.585 | 53.88428 | |
| 5 WBC | 82 | 7714 | 5894 | 6558.867 | 0.764065 | 81 | 2055.466 | 25.37613 | |
| 6 SBC | 54 | 3411.927 | 1522 | 8162 | 0.446082 | 53 | 7483.063 | 141.1899 | |
| 7 OBC | 72 | 6997.37 | 2457.904 | 8348.877 | 0.351261 | 71 | 7485.511 | 105.4297 | |
| 8 WITHIN | | | | | | 420 | 22885.91 | 54.49027 | |
| 9 Reg.Coeff. | | | | | | 6 | 907.4777 | 151.2463 | |
| 10 COMMON | 427 | 38236.23 | 22568.33 | 37113.99 | 0.590234 | 426 | 23793.39 | 55.85303 | 2.775657 ** |
| 11 Adj.Means | | | | | | 6 | 25811.35 | 4301.892 | 77.02164 * |
| 12 TOTAL | 431 | 146011.2 | 145488.1 | 194571.6 | 0.996417 | 432 | 49604.75 | | |

Comparison of slopes F= 151.2463 (6,420) 2.775657    * = Significant at 1% level (p=<0.01)
Comparison of elevation F= 4301.892 (6,426) 77.02164    ** = Significant at 5% level (p=<0.05)

Table 2.10. Comparison of regressions of CARAPACE LENGTH X CARPUS OF SECOND CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | Deviations from regression | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 SM | 34 | 611.875 | 340.875 | 287.875 | 0.557099 | 33 | 97.97385 | 3.265795 | |
| 2 WOC | 76 | 4877.169 | 2352.727 | 3332.364 | 0.482396 | 75 | 2197.417 | 29.2989 | |
| 3 SOC | 18 | 3823.684 | 2747.632 | 2632.737 | 0.718582 | 17 | 658.3376 | 38.72574 | |
| 4 t-SOC | 91 | 10800.21 | 9057.163 | 16791.08 | 0.83861 | 90 | 9195.647 | 102.1739 | |
| 5 WBC | 82 | 7714 | 6694 | 10021.16 | 0.867773 | 81 | 4212.285 | 52.00352 | |
| 6 SBC | 54 | 3411.927 | 2110.582 | 14623.35 | 0.618589 | 53 | 13317.76 | 251.2785 | |
| 7 OBC | 72 | 6997.37 | 2966.315 | 9897.342 | 0.423919 | 71 | 8639.866 | 121.6883 | |
| 8 WITHIN | | | | | | 420 | 38319.29 | 91.2364 | |
| 9 Reg.Coeff. | | | | | | 6 | 1218.913 | 203.1522 | |
| 10 COMMON | 427 | 38236.23 | 26269.29 | 57585.9 | 0.687026 | 426 | 39538.2 | 92.81268 | 2.226658 ** |
| 11 Adj.Means | | | | | | 6 | 53084.86 | 8847.476 | 95.32616 * |
| 12 TOTAL | 431 | 146011.2 | 183728.8 | 323812.8 | 1.25832 | 432 | 92623.06 | | |

Comparison of slopes F= 203.1522 (6,420) 2.226658    * = Significant at 1% level (p=<0.01)
Comparison of elevation F= 8847.476 (6,426) 95.32616    ** = Significant at 5% level (p=<0.05)

Table.2.11. Comparison of regressions of CARAPACE LENGTH X PROPODUS OF SECOND CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | DEVIATIONS FROM REGRESSION df | SS {d y.x2 | MS | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | 34 | 611.875 | 903.6875 | 1387.469 | 1.476915 | 33 | 52.79893 | 1.759964 | |
| 2 | WOC | 76 | 4877.169 | 6705.143 | 18585.43 | 1.374802 | 75 | 7367.183 | 98.2291 | |
| 3 | SOC | 18 | 3823.684 | 6724.474 | 12777.79 | 1.758637 | 17 | 951.8792 | 55.9929 | |
| 4 | t-SOC | 91 | 10800.21 | 18331.83 | 69351.3 | 1.697359 | 90 | 38235.62 | 424.8402 | |
| 5 | WBC | 82 | 7714 | 13557 | 43656.87 | 1.757454 | 81 | 19831.06 | 244.8279 | |
| 6 | SBC | 54 | 3411.927 | 5729.909 | 49065.64 | 1.679376 | 53 | 39442.96 | 744.2069 | |
| 7 | OBC | 72 | 6997.37 | 5363.205 | 23383.78 | 0.76646 | 71 | 19273.1 | 271.4521 | |
| 8 | WITHIN | | | | | | 420 | 125154.6 | 297.9872 | |
| 9 | Reg.Coeff. | | | | | | 6 | 5139.42 | 856.5699 | |
| 10 | COMMON | 427 | 38236.23 | 57315.24 | 216208.3 | 1.498977 | 426 | 130294 | 305.8545 | 2.87452 * |
| 11 | Adj.Means | | | | | | 6 | 159340.6 | 26556.77 | 86.82812 * |
| 12 | TOTAL | 431 | 146011.2 | 364228.1 | 1198209 | 2.494521 | 432 | 289634.7 | | |

Comparison of slopes F= 856.5699 (6,420) 2.87452

Comparison of elevation F= 26556.77 (6,426) 86.82812

* = Significant at 1% level (p=<0.01)

Table.2.12. Comparison of regressions of CARAPACE LENGTH X DACTYLUS OF SECOND CHELIPED of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | DEVIATIONS FROM REGRESSION df | SS {d y.x2 | MS | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | 34 | 611.875 | 441.8125 | 339.9688 | 0.722063 | 33 | 20.95215 | 0.698405 | |
| 2 | WOC | 76 | 4877.169 | 3832.377 | 4227.532 | 0.785779 | 75 | 1216.132 | 16.21509 | |
| 3 | SOC | 18 | 3823.684 | 3719.789 | 4222.526 | 0.972829 | 17 | 603.8086 | 35.51815 | |
| 4 | t-SOC | 91 | 10800.21 | 11156.75 | 17123.25 | 1.033013 | 90 | 5598.186 | 62.20207 | |
| 5 | WBC | 82 | 7714 | 7335 | 11134.55 | 0.950869 | 81 | 4159.933 | 51.3572 | |
| 6 | SBC | 54 | 3411.927 | 3068.127 | 8155.527 | 0.899236 | 53 | 5396.557 | 101.8218 | |
| 7 | OBC | 72 | 6997.37 | 3223.507 | 5204.658 | 0.460674 | 71 | 3719.672 | 52.38974 | |
| 8 | WITHIN | | | | | | 420 | 20715.24 | 49.322 | |
| 9 | Reg.Coeff. | | | | | | 6 | 1594.936 | 265.8227 | |
| 10 | COMMON | 427 | 38236.23 | 32777.36 | 50408.02 | 0.857233 | 426 | 22310.18 | 52.37131 | 5.389536 * |
| 11 | Adj.Means | | | | | | 6 | 21381.83 | 3563.639 | 68.04564 * |
| 12 | TOTAL | 431 | 146011.2 | 176409.3 | 258827.9 | 1.20819 | 432 | 43692.01 | | |

Comparison of slopes F= 265.8227 (6,420) 5.389536

Comparison of elevation F= 3563.639 (6,426) 68.04564

* = Significant at 1% level (p=<0.01)

Table.2.13. Variance covariance matrix of D square analysis between SM and WOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 393.0142 | 112.0986 | 388.4503 | 56.91983 | 13.87292 | 11.24558 | 16.16314 | 35.7132 | 16.65991 | -82.9549 |
| CL | | 38.59169 | 113.5374 | 20.17006 | 6.575911 | 5.609801 | 7.912078 | 13.88341 | 7.457846 | -22.1529 |
| CHL | | | 460.9457 | 35.73509 | 5.535073 | 5.277378 | 7.479307 | 25.48806 | 8.661793 | -70.7157 |
| RL | | | | 90.38273 | 22.30872 | 21.05833 | 28.39144 | 47.19915 | 32.20343 | -34.148 |
| I | | | | | 16.06531 | 12.50328 | 16.41711 | 28.18391 | 18.10367 | -13.952 |
| M | | | | | | 12.95698 | 14.86961 | 20.88045 | 16.79213 | -14.4402 |
| C | | | | | | | 20.66484 | 27.97209 | 21.81993 | -15.9618 |
| P | | | | | | | | 92.51818 | 32.31491 | -32.0716 |
| D | | | | | | | | | 27.26609 | -17.6353 |
| | 1 | 0.285228 | 0.988387 | 0.144829 | 0.035299 | 0.028614 | 0.041126 | 0.09087 | 0.04239 | -0.21107 |
| | | 6.618065 | 2.740649 | 3.934942 | 2.61897 | 2.402249 | 3.301901 | 3.697009 | 2.705979 | 1.5081 |
| | | | 77.00644 | -20.5237 | -8.17674 | -5.83761 | -8.49614 | -9.81042 | -7.80465 | 11.27588 |
| | | | | 82.13909 | 20.29952 | 19.42965 | 26.05055 | 42.02685 | 29.79059 | -22.1338 |
| | | | | | 15.57561 | 12.10633 | 15.84657 | 26.92328 | 17.5156 | -11.0238 |
| | | | | | | 12.6352 | 14.40712 | 19.85856 | 16.31542 | -12.0666 |
| | | | | | | | 20.00012 | 26.50335 | 21.13478 | -12.5502 |
| | | | | | | | | 89.27292 | 30.80102 | -24.5335 |
| | | | | | | | | | 26.55988 | -14.1188 |
| | | | | | | -D2 = | | | | -17.5096 |
| | | 1 | 0.414116 | 0.594576 | 0.39573 | 0.362984 | 0.498922 | 0.558624 | 0.408878 | 0.227876 |
| | | | 75.8715 | -22.1533 | -9.2613 | -6.83242 | -9.86351 | -11.3414 | -8.92524 | 10.65136 |
| | | | | 79.79947 | 18.74234 | 18.00133 | 24.08732 | 39.8287 | 28.18168 | -23.0305 |
| | | | | | 14.53921 | 11.15568 | 14.53991 | 25.46026 | 16.44476 | -11.6206 |
| | | | | | | 11.76323 | 13.20858 | 18.51661 | 15.3332 | -12.614 |
| | | | | | | | 18.35272 | 24.65883 | 19.7847 | -13.3026 |
| | | | | | | | | 87.20768 | 29.2894 | -25.3759 |
| | | | | | | | | | 25.45346 | -14.7355 |
| | | | | | | -D2 = | | | | -17.8532 |
| | | | 1 | -0.29198 | -0.12207 | -0.09005 | -0.13 | -0.14948 | -0.11764 | 0.140387 |
| | | | | 73.33107 | 16.03819 | 16.00637 | 21.20733 | 36.51719 | 25.57565 | -19.9204 |
| | | | | | 13.40872 | 10.32168 | 13.33591 | 24.07586 | 15.3553 | -10.3204 |
| | | | | | | 11.14795 | 12.32035 | 17.49529 | 14.52946 | -11.6548 |
| | | | | | | | 17.07044 | 23.18441 | 18.6244 | -11.9179 |
| | | | | | | | | 85.51235 | 27.95523 | -23.7837 |
| | | | | | | | | | 24.40353 | -13.4825 |
| | | | | | | -D2 = | | | | -19.3486 |
| | | | | 1 | 0.218709 | 0.218275 | 0.2892 | 0.497977 | 0.34877 | -0.27165 |
| | | | | | 9.901019 | 6.820936 | 8.697673 | 16.08921 | 9.76166 | -5.96361 |
| | | | | | | 7.654154 | 7.691311 | 9.524482 | 8.946922 | -7.30665 |
| | | | | | | | 10.93729 | 12.62365 | 11.22792 | -6.15689 |
| | | | | | | | | 67.32763 | 15.21915 | -13.8638 |
| | | | | | | | | | 15.48352 | -6.53483 |
| | | | | | | -D2 = | | | | -24.7599 |
| | | | | | 1 | 0.688913 | 0.878462 | 1.625006 | 0.985925 | -0.60232 |
| | | | | | | 2.955125 | 1.699376 | -1.55958 | 2.221992 | -3.19824 |
| | | | | | | | 3.296708 | -1.51012 | 2.652674 | -0.91808 |
| | | | | | | | | 41.18257 | -0.6436 | -4.17292 |
| | | | | | | | | | 5.859257 | -0.65516 |
| | | | | | | -D2 = | | | | -28.352 |
| | | | | | | 1 | 0.57506 | -0.52775 | 0.751911 | -1.08227 |
| | | | | | | | 2.319464 | -0.61327 | 1.374894 | 0.921098 |
| | | | | | | | | 40.35949 | 0.52906 | -5.86081 |
| | | | | | | | | | 4.188516 | 1.749631 |
| | | | | | | | | -D2 = | | -31.8133 |
| | | | | | | | 1 | -0.2644 | 0.592764 | 0.397117 |
| | | | | | | | | 40.19735 | 0.892582 | -5.61727 |
| | | | | | | | | | 3.373529 | 1.203638 |
| | | | | | | | -D2 = | | | -32.1791 |
| | | | | | | | | 1 | 0.022205 | -0.13974 |
| | | | | | | | | | 3.353709 | 1.328369 |
| | | | | | | | | | | -32.9641 |
| | | | | | | | | | 1 | 0.39609 |
| | | | | | | | | -D2 = | | -33.4902 |

Table.2.14. Variance- covariance matrix of D square analysis between SM and SOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 664.067 | 238.7434 | 258.2703 | 241.6764 | 87.94224 | 124.7953 | 161.1356 | 370.7154 | 206 2689 | -122.488 |
| CL | | 89.8739 | 91.96627 | 88.87732 | 31.74925 | 45.60614 | 57.59569 | 138.895 | 76.69365 | -38 6898 |
| CHL | | | 1648.512 | 43.67076 | 24.87036 | 41.68258 | 49.10199 | 109 1952 | 63.57719 | -118.714 |
| RL | | | | 117.9757 | 40.53348 | 52.43693 | 67.63665 | 162 6781 | 90.31985 | -46.1147 |
| I | | | | | 19.54538 | 22.76801 | 31.15785 | 66.07277 | 38.16793 | -21.3063 |
| M | | | | | | 32.22152 | 40.4452 | 89.74699 | 51.36958 | -24.1946 |
| C | | | | | | | 56.84622 | 114.4848 | 65.51876 | -28.2881 |
| P | | | | | | | | 269.1873 | 152.2302 | -63.733 |
| D | | | | | | | | | 87 93576 | -33 0932 |
| | 1 | 0.359517 | 0.388922 | 0.363934 | 0.13243 | 0.187926 | 0.24265 | 0.55825 | 0.310615 | -0.18445 |
| | | 4.041608 | -0.88628 | 1.990556 | 0.132521 | 0.740111 | -0.33529 | 5.616514 | 2.536471 | 5.346818 |
| | | | 1548.065 | -50.3225 | -9.33231 | -6.85305 | -13.5672 | -34.9842 | -16.6453 | -71.0756 |
| | | | | 30 02154 | 8.528328 | 7.019709 | 8.993971 | 27.76221 | 15.25163 | -1.5371 |
| | | | | | 7.899206 | 6.241396 | 9.818702 | 16 97901 | 10.85179 | -5 08526 |
| | | | | | | 8 769278 | 10.16367 | 20 08002 | 12.60634 | -1.17589 |
| | | | | | | | 17.74673 | 24.53081 | 15.4677 | 1.433641 |
| | | | | | | | | 62.23537 | 37.08057 | 4.646088 |
| | | | | | | | | | 23.86563 | 4.953447 |
| | | | | | | -D2 = | | | | -22.5932 |
| | | 1 | -0.21929 | 0.492516 | 0.032789 | 0.183123 | -0.08296 | 1.389673 | 0.62759 | 1.322943 |
| | | | 1547.87 | -49.886 | -9.30325 | -6 69076 | -13.6407 | -33.7525 | -16 0891 | -69.9031 |
| | | | | 29.04116 | 8.463059 | 6.655193 | 9.159104 | 24.99598 | 14.00238 | -4 17049 |
| | | | | | 7.894861 | 6.217128 | 9.829695 | 16.79485 | 10.76862 | -5 26058 |
| | | | | | | 8.633746 | 10.22507 | 19 05151 | 12.14186 | -2 15501 |
| | | | | | | | 17.71892 | 24.99675 | 15.67812 | 1.877204 |
| | | | | | | | | 54.43025 | 33.55571 | -2.78424 |
| | | | | | | | | | 22.27377 | 1.59784 |
| | | | | | | -D2 = | | | | -29.6667 |
| | | | 1 | -0.03223 | -0.00601 | -0.00432 | -0.00881 | -0.02181 | -0 01039 | -0.04516 |
| | | | | 27.43339 | 8.163227 | 6.439558 | 8.71948 | 23.90818 | 13.48385 | -6.42339 |
| | | | | | 7.838945 | 6 176914 | 9 74771 | 16 59199 | 10 67192 | -5 68072 |
| | | | | | | 8 604825 | 10 16611 | 18 90561 | 12 07231 | -2 45717 |
| | | | | | | | 17 59871 | 24 6993 | 15 53633 | 1 261178 |
| | | | | | | | | 53 69425 | 33.20487 | -4 30853 |
| | | | | | | | | | 22.10653 | 0.871243 |
| | | | | | | -D2 = | | | | -32.8236 |
| | | | | 1 | 0.297565 | 0.234734 | 0.317842 | 0.871499 | 0.491512 | -0.23414 |
| | | | | | 5.409852 | 4.260725 | 7.153095 | 9.477742 | 6.659592 | -3.76934 |
| | | | | | | 7,09324 | 8.119347 | 13.29354 | 8.907189 | -0.94938 |
| | | | | | | | 14.82729 | 17.10028 | 11.2506 | 3 302799 |
| | | | | | | | | 32.85829 | 21.45371 | 1 289443 |
| | | | | | | | | | 15 47906 | 4 028415 |
| | | | | | | -D2 = | | | | -34.3276 |
| | | | | | 1 | 0.787586 | 1.322235 | 1.751941 | 1.231012 | -0.69675 |
| | | | | | | 3.737551 | 2.485668 | 5.829003 | 3 662186 | 2.019296 |
| | | | | | | | 5.369223 | 4.56848 | 2 445057 | 8.286753 |
| | | | | | | | | 16.25385 | 9.7865 | 7.893106 |
| | | | | | | | | | 7.281019 | 8 668518 |
| | | | | | | -D2 = | | | | -36.9539 |
| | | | | | | 1 | 0.665052 | 1.559578 | 0.979836 | 0.540272 |
| | | | | | | | 3.716124 | 0.691887 | 0.009512 | 6.943815 |
| | | | | | | | | 7.163064 | 4.075036 | 4.743856 |
| | | | | | | | | | 3.692679 | 6 68994 |
| | | | | | | | | -D2 = | | -38.0449 |
| | | | | | | | 1 | 0.186185 | 0.00256 | 1.868564 |
| | | | | | | | | 7.034245 | 4.073285 | 3.45102 |
| | | | | | | | | | 3.692655 | 6.672167 |
| | | | | | | | -D2 = | | | -51 0198 |
| | | | | | | | | 1 | 0 579062 | 0.490603 |
| | | | | | | | | | 1.333982 | 4 673812 |
| | | | | | | | | | | -52.7129 |
| | | | | | | | | | 1 | 3.503655 |
| | | | | | | | | -D2 = | | -69.0883 |

Table. 2 15. Variance covariance matrix of d square analysis between SM and t-SOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 505.8873 | 156.2459 | 300.4296 | 190.8975 | 82 33831 | 99.38043 | 128.7236 | 259.2319 | 148.6463 | -95.3542 |
| CL | | 57.28184 | 85.55454 | 58.06132 | 22.96224 | 32.4027 | 39.32645 | 87 81112 | 48.94743 | -28.825 |
| CHL | | | 828 3909 | 139.7266 | 47.93891 | 51.59485 | 60.40819 | 85.96623 | 58.96834 | -85 0188 |
| RL | | | | 86.78605 | 26.03882 | 33.64743 | 43.45882 | 84.85717 | 50 00717 | -33.675 |
| I | | | | | 18.21923 | 19.02128 | 25.2198 | 41.57448 | 27 41334 | -15.7542 |
| M | | | | | | 25.1909 | 30.45424 | 56 86729 | 36 0165 | -16 6688 |
| C | | | | | | | 41.04625 | 76.12516 | 45.2178 | -19.3125 |
| P | | | | | | | | 224.9049 | 95.69976 | -40.1021 |
| D | | | | | | | | | 57.2981 | -22.1354 |
| | 1 | 0.308855 | 0.593867 | 0.377352 | 0.16276 | 0.196448 | 0.254451 | 0.51243 | 0.293833 | -0.18849 |
| | | 9.024474 | -7.23472 | -0.89837 | -2.46838 | 1.708533 | -0.43051 | 7.745987 | 3.037247 | 0.625632 |
| | | | 649.9757 | 26.35896 | -0.95907 | -7.42388 | -16.0365 | -67.983 | -29.3078 | -28.3911 |
| | | | | 14.75053 | -5.0317 | -3.85396 | -5.11528 | -12.9645 | -6.08479 | 2.307073 |
| | | | | | 4.817832 | 2.846105 | 4.268721 | -0.61815 | 3.219642 | -0 2343 |
| | | A | | | | 5.66784 | 5.166775 | 5.941752 | 6.81526 | 2.063364 |
| | | | | | | | 8.292371 | 10.16329 | 7.394566 | 4 950482 |
| | | | | | | | | 92 06667 | 19 52891 | 8.760273 |
| | | | | | | | | | 13.62093 | 5.882772 |
| | | | | | | -D2 = | | | | -17.9732 |
| | | 1 | -0.80168 | -0.09955 | -0 27352 | 0.189322 | -0.04771 | 0.858331 | 0.336557 | 0 069326 |
| | | | 644.1758 | 25.63875 | -2 93792 | -6.05419 | -16 3816 | -61.7732 | -26.8729 | -27.8895 |
| | | | | 14 66109 | -5.27742 | -3.68387 | -5.15814 | -12.1934 | -5.78244 | 2.369353 |
| | | | | | 4.142679 | 3.313424 | 4.150966 | 1.500534 | 4.050392 | -0.06318 |
| | | | | | | 5.344377 | 5.248281 | 4.475264 | 6.240242 | 1.944918 |
| | | | | B | | | 8.271833 | 10 53282 | 7.539458 | 4 980328 |
| | | | | | | | | 85.41805 | 16.92194 | 8.223274 |
| | | | | | | | | | 12.59872 | 5.672211 |
| | | | | | | -D2 = | | | | -18 0166 |
| | | | 1 | 0.039801 | -0.00456 | -0.0094 | -0.02543 | -0.09589 | -0.04172 | -0.04329 |
| | | | | 13 64065 | -5.16049 | -3.44291 | -4.50614 | -9.73475 | -4.71287 | 3.47938 |
| | | | | | 4.12928 | 3.285812 | 4 076254 | 1.218802 | 3.927832 | -0.19038 |
| | | | | C | | 5.287478 | 5.09432 | 3.894698 | 5.987682 | 1.682803 |
| | | | | | | | 7.855243 | 8.961901 | 6.856072 | 4.271087 |
| | | | | | | | | 79 49431 | 14.34497 | 5 548809 |
| | | | | | | | | | 11.47767 | 4.508753 |
| | | | | | | -D2 = | | | | -19 2241 |
| | | | | 1 | -0.37832 | -0.2524 | -0.33035 | -0.71366 | -0.3455 | 0.255074 |
| | | | | | 2.176978 | 1.9833 | 2.371505 | -2 46402 | 2.144871 | 1 125932 |
| | | | | | | 4.418484 | 3 956968 | 1.43764 | 4.798149 | 2.561001 |
| | | | | D | | | 6 366658 | 5.746065 | 5 299192 | 5.420487 |
| | | | | | | | | 72.54704 | 10 98159 | 8.031894 |
| | | | | | | | | | 9.849368 | 5.710886 |
| | | | | | | -D2 = | | | | -20 1116 |
| | | | | | 1 | 0.911034 | 1.089357 | -1.13185 | 0.985252 | 0 5172 |
| | | | | | | 2.611631 | 1 796447 | 3.682445 | 2.844099 | 1 535239 |
| | | | | | | | 3.783243 | 8.430262 | 2.962662 | 4 193945 |
| | | | | | | | | 69 75813 | 13.40928 | 9.306285 |
| | | | | | | | | | 7.736129 | 4.601559 |
| | | | | | | -D2 = | | | | -20 6939 |
| | | | | | | 1 | 0.687864 | 1.410017 | 1.089012 | 0 587847 |
| | | | | | | | 2.547532 | 5.897241 | 1.006309 | 3.13791 |
| | | | | | | | | 64.56582 | 9.399047 | 7.141572 |
| | | | | | | | | | 4.638871 | 2.929665 |
| | | | | | | | | -D2 = | | -21 5964 |
| | | | | | | | 1 | 2.314884 | 0.395013 | 1.231745 |
| | | | | | | | | 50.91439 | 7.069557 | -0.12232 |
| | | | | | | | | | 4.241365 | 1.690148 |
| | | | | | | | -D2 = | | | -25.4615 |
| | | | | | | | | 1 | 0.138852 | -0.0024 |
| | | | | | | | | | 3.259744 | 1.707133 |
| | | | | | | | | | | -25.4618 |
| | | | | | | | | | 1 | 0 523702 |
| | | | | | | | | -D2 = | | -26.3558 |

Table 2.16. Variance covariance matrix of D square analysis between SM and WBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 484.4771 | 142.4233 | 291.9857 | 13.2634 | 41.2240 | 52.6542 | 73.8669 | 38.7175 | 22.2750 | -99.3216 |
| CL | | 47.9444 | 70.0450 | -3.8321 | 11.6092 | 15.9646 | 22.8454 | 12.4705 | 7.5363 | -27.6196 |
| CHL | | | 800.5345 | -4.1375 | 26.9501 | 21.3365 | 27.9578 | 17.5015 | 7.2516 | -91.9490 |
| RL | | | | 78.4860 | 5.7899 | -2.1890 | 5.6457 | 13.4578 | 7.2126 | -34.6814 |
| I | | | | | 8.0508 | 6.4764 | 9.5101 | 8.2624 | 4.3725 | -6.2520 |
| M | | | | | | 8.6559 | 10.7244 | 6.0525 | 3.3566 | -11.7735 |
| C | | | | | | | 19.0869 | 10.7624 | 6.7113 | -14.7284 |
| P | | | | | | | | 18.3865 | 8.7133 | 5.5618 |
| D | | | | | | | | | 5.0656 | 2.9980 |
| | 1 | 0.2940 | 0.6027 | 0.0274 | 0.0851 | 0.1087 | 0.1525 | 0.0799 | 0.0460 | -0.2050 |
| | | 6.0757 | -15.7910 | -7.7312 | -0.5095 | 0.4857 | 1.1305 | 1.0886 | 0.9881 | 1.5783 |
| | | | 624.5598 | -12.1311 | 2.1052 | -10.3972 | -16.5605 | -5.8329 | -6.1731 | -32.0897 |
| | | | | 78.1228 | 4.6613 | -3.6305 | 3.6235 | 12.3978 | 6.6028 | -31.9623 |
| | | | | | 4.5431 | 1.9961 | 3.2248 | 4.9679 | 2.4771 | 2.1993 |
| | | | | | | 2.9333 | 2.6964 | 1.8446 | 0.9357 | -0.9790 |
| | | | | | | | 7.8246 | 4.8593 | 3.3151 | 0.4149 |
| | | | | | | | | 15.2923 | 6.9332 | 13.4992 |
| | | | | | | | | | 4.0414 | 7.5646 |
| | | | | | | -D2 = | | | | -20.3617 |
| | | 1 | -2.5990 | -1.2725 | -0.0839 | 0.0799 | 0.1861 | 0.1792 | 0.1626 | 0.2598 |
| | | | 583.5186 | -32.2246 | 0.7809 | -9.1348 | -13.6222 | -3.0036 | -3.6050 | -27.9877 |
| | | | | 68.2852 | 4.0130 | -3.0124 | 5.0621 | 13.7830 | 7.8601 | -29.9540 |
| | | | | | 4.5003 | 2.0368 | 3.3196 | 5.0592 | 2.5600 | 2.3316 |
| | | | | | | 2.8945 | 2.6060 | 1.7575 | 0.8568 | -1.1052 |
| | | | | | | | 7.6142 | 4.6567 | 3.1313 | 0.1212 |
| | | | | | | | | 15.0973 | 6.7561 | 13.2164 |
| | | | | | | | | | 3.8807 | 7.3079 |
| | | | | | | -D2 = | | | | -20.7717 |
| | | | 1 | -0.0552 | 0.0013 | -0.0157 | -0.0233 | -0.0051 | -0.0062 | -0.0480 |
| | | | | 66.5056 | 4.0561 | -3.5169 | 4.3098 | 13.6171 | 7.6610 | -31.4996 |
| | | | | | 4.4993 | 2.0490 | 3.3378 | 5.0633 | 2.5648 | 2.3691 |
| | | | | | | 2.7515 | 2.3928 | 1.7105 | 0.8003 | -1.5433 |
| | | | | | | | 7.2962 | 4.5866 | 3.0471 | -0.5322 |
| | | | | | | | | 15.0818 | 6.7376 | 13.0723 |
| | | | | | | | | | 3.8584 | 7.1350 |
| | | | | | | -D2 = | | | | -22.1141 |
| | | | | 1 | 0.0610 | -0.0529 | 0.0648 | 0.2048 | 0.1152 | -0.4736 |
| | | | | | 4.2519 | 2.2635 | 3.0750 | 4.2328 | 2.0976 | 4.2902 |
| | | | | | | 2.5655 | 2.6207 | 2.4306 | 1.2054 | -3.2091 |
| | | | | | | | 7.0169 | 3.7042 | 2.5507 | 1.5091 |
| | | | | | | | | 12.2937 | 5.1690 | 19.5219 |
| | | | | | | | | | 2.9760 | 10.7635 |
| | | | | | | -D2 = | | | | -37.0335 |
| | | | | | 1 | 0.5324 | 0.7232 | 0.9955 | 0.4933 | 1.0090 |
| | | | | | | 1.3605 | 0.9837 | 0.1773 | 0.0888 | -5.4930 |
| | | | | | | | 4.7931 | 0.6430 | 1.0337 | -1.5936 |
| | | | | | | | | 8.0800 | 3.0809 | 15.2510 |
| | | | | | | | | | 1.9412 | 8.6471 |
| | | | | | | -D2 = | | | | -41.3624 |
| | | | | | | 1 | 0.7230 | 0.1303 | 0.0653 | -4.0374 |
| | | | | | | | 4.0819 | 0.5148 | 0.9695 | 2.3780 |
| | | | | | | | | 8.0569 | 3.0693 | 15.9668 |
| | | | | | | | | | 1.9354 | 9.0055 |
| | | | | | | | | -D2 = | | -63.5399 |
| | | | | | | | 1 | 0.1261 | 0.2375 | 0.5826 |
| | | | | | | | | 7.9920 | 2.9470 | 15.6669 |
| | | | | | | | | | 1.7051 | 8.4407 |
| | | | | | | | -D2 = | | | -64.9252 |
| | | | | | | | | 1 | 0.3687 | 1.9603 |
| | | | | | | | | | 0.6184 | 2.6636 |
| | | | | | | | | | | -95.6375 |
| | | | | | | | | | 1 | 4.3072 |
| | | | | | | | | -D2 = | | -107.1102 |

Table.2.17. Variance covariance matrix of D square analysis betwen SM and SBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 342.0678 | 105.5789 | 70.24627 | 8.917496 | 25.45715 | 27.04413 | 47.45325 | 30.1553 | 14.97784 | -154.194 |
| CL | | 44.49023 | 23.18901 | 1.788449 | 6.192344 | 7.023824 | 15.43559 | 10.3484 | 5.495517 | -50.4824 |
| CHL | | | 1632.757 | -62.1185 | 2.839127 | 4.199813 | -4.36338 | 6.80016 | 12.52151 | -145.229 |
| RL | | | | 82.2473 | 3.141288 | 0.426306 | 8.514684 | 13.44463 | 5.994483 | -57.3206 |
| I | | | | | 8.27906 | 3.609737 | 6.064559 | 7.657553 | 3.77992 | -10.2971 |
| M | | | | | | 7.292179 | 7.0366 | 4.24004 | 2.008378 | -19.5088 |
| C | | | | | | | 16.5594 | 10.87378 | 5.053574 | -25.2618 |
| P | | | | | | | | 16.38942 | 8.274697 | 0.985294 |
| D | | | | | | | | | 4.579198 | 0.682353 |
| | 1 | 0.308649 | 0.205358 | 0.026069 | 0.074421 | 0.079061 | 0.138725 | 0.088156 | 0.043786 | -0.45077 |
| | | 11.90342 | 1.507574 | -0.96393 | -1.66498 | -1.32332 | 0.789191 | 1.041002 | 0.872621 | -2.8905 |
| | | | 1618.331 | -63.9498 | -2.3887 | -1.35391 | -14.1083 | 0.607536 | 9.44569 | -113.564 |
| | | | | 82.01482 | 2.477636 | -0.27872 | 7.277607 | 12.6585 | 5.60402 | -53.3008 |
| | | | | | 6.384504 | 1.597077 | 2.533023 | 5.413355 | 2.665248 | 1.178276 |
| | | | | | | 5.154051 | 3.284911 | 1.85594 | 0.824219 | -7.31813 |
| | | | | | | | 9.97646 | 6.690498 | 2.975777 | -3.87123 |
| | | | | | | | | 13.73105 | 6.954311 | 14.57842 |
| | | | | | | | | | 3.923375 | 7.433925 |
| | | | | | | -D2 = | | | | -69.5062 |
| | | 1 | 0.12665 | -0.08098 | -0.13987 | -0.11117 | 0.066299 | 0.087454 | 0.073308 | -0.24283 |
| | | | 1618.14 | -63.8277 | -2.17783 | -1.18631 | -14.2082 | 0.475692 | 9.335172 | -113.198 |
| | | | | 81.93676 | 2.342808 | -0.38588 | 7.341515 | 12.7428 | 5.674684 | -53.5349 |
| | | | | | 6.151617 | 1.411979 | 2.643411 | 5.558964 | 2.787305 | 0.773971 |
| | | | | | | 5.006936 | 3.372647 | 1.971669 | 0.921229 | -7.63947 |
| | | | | | | | 9.924137 | 6.62148 | 2.917923 | -3.67959 |
| | | | | | | | | 13.64001 | 6.877997 | 14.83121 |
| | | | | | | | | | 3.859405 | 7.645823 |
| | | | | | | -D2 = | | | | -70.2081 |
| | | | 1 | -0.03945 | -0.00135 | -0.00073 | -0.00878 | 0.000294 | 0.005769 | -0.06996 |
| | | | | 79.41907 | 2.256903 | -0.43267 | 6.78107 | 12.76156 | 6.042911 | -58 |
| | | | | | 6.148686 | 1.410382 | 2.624288 | 5.559604 | 2.799869 | 0.621619 |
| | | | | | | 5.006066 | 3.36223 | 1.972018 | 0.928073 | -7.72245 |
| | | | | | | | 9.79938 | 6.625657 | 2.999891 | -4.67354 |
| | | | | | | | | 13.63987 | 6.875253 | 14.86448 |
| | | | | | | | | | 3.805549 | 8.298873 |
| | | | | | | -D2 = | | | | -78.127 |
| | | | | 1 | 0.028418 | -0.00545 | 0.085383 | 0.160686 | 0.076089 | -0.7303 |
| | | | | | 6.08455 | 1.422678 | 2.431586 | 5.196951 | 2.628144 | 2.269844 |
| | | | | | | 5.003709 | 3.399173 | 2.041543 | 0.960995 | -8.03844 |
| | | | | | | | 9.22039 | 5.536031 | 2.483927 | 0.278698 |
| | | | | | | | | 11.58926 | 5.904239 | 24.1843 |
| | | | | | | | | | 3.345751 | 12.71203 |
| | | | | | | -D2 = | | | | -120.485 |
| | | | | | 1 | 0.233818 | 0.399633 | 0.854122 | 0.431937 | 0.37305 |
| | | | | | | 4.671061 | 2.830624 | 0.826402 | 0.346487 | -8.56917 |
| | | | | | | | 8.248648 | 3.459159 | 1.433634 | -0.62841 |
| | | | | | | | | 7.150427 | 3.659483 | 22.24557 |
| | | | | | | | | | 2.210558 | 11.7316 |
| | | | | | | -D2 = | | | | -121.331 |
| | | | | | | 1 | 0.605992 | 0.17692 | 0.074177 | -1.83452 |
| | | | | | | | 6.533313 | 2.958367 | 1.223666 | 4.564439 |
| | | | | | | | | 7.00422 | 3.598182 | 23.76163 |
| | | | | | | | | | 2.184856 | 12.36724 |
| | | | | | | | | -D2 = | | -137.052 |
| | | | | | | | 1 | 0.452813 | 0.187296 | 0.698641 |
| | | | | | | | | 5.664635 | 3.044091 | 21.69479 |
| | | | | | | | | | 1.955668 | 11.51234 |
| | | | | | | | -D2 = | | | -140.241 |
| | | | | | | | | 1 | 0.537385 | 3.829866 |
| | | | | | | | | | 0.319818 | -0.14612 |
| | | | | | | | | | | -223.329 |
| | | | | | | | | | 1 | -0.45689 |
| | | | | | | | | -D2 = | | -223.396 |

Table.2.18. Variance covariance matrix of D square analysis between SM and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 322.8016 | 104.2967 | 108.9476 | 28.73684 | 17.39733 | 26.88909 | 40.49441 | 24.69678 | 17.00476 | -182.381 |
| CL | | 45.71415 | 39.17465 | 8.088583 | 7.517251 | 10.07894 | 13.83331 | 9.121305 | 6.32406 | -61.9172 |
| CHL | | | 735.0016 | 54.82491 | -8.84741 | -1.00703 | 3.566951 | 4.693692 | 5.362662 | -386.439 |
| RL | | | | 56.39366 | 5.505837 | 3.123768 | 11.79115 | 16.58111 | 8.543301 | -68.6861 |
| I | | | | | 8.16733 | 3.623232 | 5.912681 | 7.034723 | 4.225699 | -12.8139 |
| M | | | | | | 5.508722 | 7.34026 | 4.141145 | 2.397101 | -25.7021 |
| C | | | | | | | 14.1945 | 9.681995 | 5.633931 | -33.0118 |
| P | | | | | | | | 16.75731 | 8.914211 | -0.94538 |
| D | | | | | | | | | 5.260437 | -0.79244 |
| | 1 | 0.323099 | 0.337506 | 0.089023 | 0.053895 | 0.083299 | 0.125447 | 0.076508 | 0.052679 | -0.56499 |
| | | 12.01602 | 3.97384 | -1.19625 | 1.896198 | 1.391111 | 0.749626 | 1.141811 | 0.829846 | -2.99015 |
| | | | 698.2311 | 45.12604 | -14.7191 | -10.0823 | -10.1002 | -3.64163 | -0.37655 | -324.885 |
| | | | | 53.83542 | 3.95707 | 0.730015 | 8.186209 | 14.38252 | 7.029483 | -52.45 |
| | | | | | 7.229704 | 2.17405 | 3.730243 | 5.703695 | 3.309231 | -2.98447 |
| | | | | | | 3.268885 | 3.967111 | 2.083925 | 0.980619 | -10.5099 |
| | | | | | | | 9.114612 | 6.583864 | 3.500739 | -10.1326 |
| | | | | | | | | 14.86782 | 7.613218 | 13.00816 |
| | | | | | | | | | 4.364649 | 8.815158 |
| | | | | | | -D2 = | | | | -103.044 |
| | | 1 | 0.330712 | -0.09955 | 0.157806 | 0.115771 | 0.062386 | 0.095024 | 0.069062 | -0.24885 |
| | | | 696.9169 | 45.52166 | -15.3462 | -10.5423 | -10.3481 | -4.01924 | -0.65099 | -323.896 |
| | | | | 53.71633 | 4.145845 | 0.868506 | 8.260837 | 14.4962 | 7.112098 | -52.7477 |
| | | | | | 6.930473 | 1.954524 | 3.611947 | 5.523511 | 3.178276 | -2.51261 |
| | | | | | | 3.107834 | 3.880326 | 1.951736 | 0.884547 | -10.1637 |
| | | | | | | | 9.067846 | 6.512632 | 3.448969 | -9.9461 |
| | | | | | | | | 14.75932 | 7.534363 | 13.2923 |
| | | | | | | | | | 4.307338 | 9.021662 |
| | | | | | | -D2 = | | | | -103.788 |
| | | | 1 | 0.065319 | -0.02202 | -0.01513 | -0.01485 | -0.00577 | -0.00093 | -0.46476 |
| | | | | 50.74291 | 5.148239 | 1.557116 | 8.93676 | 14.75873 | 7.154619 | -31.5912 |
| | | | | | 6.592547 | 1.722381 | 3.384081 | 5.435007 | 3.163941 | -9.64484 |
| | | | | | | 2.94836 | 3.72379 | 1.890937 | 0.874699 | -15.0633 |
| | | | | | | | 8.914194 | 6.452953 | 3.439303 | -14.7554 |
| | | | | | | | | 14.73614 | 7.530608 | 11.42434 |
| | | | | | | | | | 4.30673 | 8.719111 |
| | | | | | | -D2 = | | | | -254.321 |
| | | | | 1 | 0.101457 | 0.030686 | 0.176118 | 0.290853 | 0.140997 | -0.62257 |
| | | | | | 6.070221 | 1.5644 | 2.477381 | 3.937626 | 2.438053 | -6.43968 |
| | | | | | | 2.900577 | 3.449553 | 1.438045 | 0.65515 | -14.0939 |
| | | | | | | | 7.340266 | 3.853669 | 2.179243 | -9.19163 |
| | | | | | | | | 10.44352 | 5.449666 | 20.61274 |
| | | | | | | | | | 3.297947 | 13.17339 |
| | | | | | | -D2 = | | | | -273.989 |
| | | | | | 1 | 0.257717 | 0.40812 | 0.648679 | 0.401642 | -1.06086 |
| | | | | | | 2.497405 | 2.811089 | 0.423251 | 0.026822 | -12.4343 |
| | | | | | | | 6.329196 | 2.246644 | 1.184224 | -6.56347 |
| | | | | | | | | 7.889268 | 3.868152 | 24.79003 |
| | | | | | | | | | 2.318724 | 15.75984 |
| | | | | | | -D2 = | | | | -280.82 |
| | | | | | | 1 | 1.125604 | 0.169476 | 0.01074 | -4.97889 |
| | | | | | | | 3.165023 | 1.77023 | 1.154033 | 7.432639 |
| | | | | | | | | 7.817537 | 3.863606 | 26.89735 |
| | | | | | | | | | 2.318436 | 15.89338 |
| | | | | | | | | -D2 = | | -342.729 |
| | | | | | | | 1 | 0.55931 | 0.364621 | 2.348369 |
| | | | | | | | | 6.827429 | 3.218144 | 22.7402 |
| | | | | | | | | | 1.897652 | 13.18329 |
| | | | | | | | -D2 = | | | -360.184 |
| | | | | | | | | 1 | 0.471355 | 3.330712 |
| | | | | | | | | | 0.380763 | 2.464577 |
| | | | | | | | | | | -435.925 |
| | | | | | | | | | 1 | 6.472725 |
| | | | | | | | | -D2 = | | -451.877 |

Table.2.19. Variance covariance matrix of D square analysis between WOC and SOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 936.5844 | 311.2383 | 485.0667 | 273.522 | 97.04397 | 145.461 | 174.0468 | 408.8028 | 223.9404 | -39.5333 |
| CL | | 116.0954 | 152.4119 | 101.3574 | 37.07884 | 54.93841 | 64.86025 | 153.7462 | 84.90616 | -16.5368 |
| CHL | | | 2008.115 | 66.6461 | 28.86555 | 50.41023 | 55.16775 | 136.1666 | 70.65543 | -47.9982 |
| RL | | | | 192.9993 | 55.91348 | 78.66667 | 88.31489 | 196.4206 | 118.3894 | -11.9667 |
| I | | | | | 35.84039 | 38.79358 | 47.11467 | 93.30586 | 57.26249 | -7.35439 |
| M | | | | | | 49.98507 | 59.71892 | 118.0676 | 74.52632 | -9.75439 |
| C | | | | | | | 77.60717 | 140.8011 | 89.49406 | -12.3263 |
| P | | | | | | | | 373.6842 | 186.7748 | -31.6614 |
| D | | | | | | | | | 120.2303 | -15.4579 |
| | 1 | 0.332312 | 0.51791 | 0.292042 | 0.103615 | 0.15531 | 0.185831 | 0.436483 | 0.239103 | -0.04221 |
| | | 12.66717 | -8.78164 | 10.46279 | 4.829952 | 6.599966 | 7.022391 | 17.89613 | 10.48805 | -3.39944 |
| | | | 1756.894 | -75.0137 | -21.3945 | -24.9255 | -34.9729 | -75.5566 | -45.3256 | -27.5235 |
| | | | | 113.1194 | 27.57256 | 36.18595 | 37.48591 | 77.03297 | 52.98935 | -0.42127 |
| | | | | | 25.7852 | 23.72167 | 29.08085 | 50.94785 | 34.05895 | -3.25815 |
| | | | | | | 27.39351 | 32.6877 | 54.57636 | 39.74611 | -3.61446 |
| | | | | | | | 45.2638 | 64.83271 | 47.8789 | -4.97978 |
| | | | | | | | | 195.2488 | 89.02869 | -14.4058 |
| | | | | | | | | | 86.68545 | -6.00534 |
| | | | | | | -D2 = | | | | -1.66871 |
| | | 1 | -0.69326 | 0.825977 | 0.381297 | 0.521029 | 0.554377 | 1.412797 | 0.827972 | -0.26837 |
| | | | 1750.806 | -67.7603 | -18.0461 | -20.35 | -30.1045 | -63.1499 | -38.0547 | -29.8802 |
| | | | | 104.4774 | 23.58313 | 30.73452 | 31.68558 | 62.25117 | 44.32646 | 2.386586 |
| | | | | | 23.94355 | 21.20513 | 26.40323 | 44.12411 | 30.05989 | -1.96195 |
| | | | | | | 23.95473 | 29.02883 | 45.25195 | 34.28153 | -1.84325 |
| | | | | | | | 41.37075 | 54.9115 | 42.06456 | -3.09521 |
| | | | | | | | | 169.9652 | 74.21121 | -9.60307 |
| | | | | | | | | | 58.00164 | -3.19071 |
| | | | | | | -D2 = | | | | -2.581 |
| | | | 1 | -0.0387 | -0.01031 | -0.01162 | -0.01719 | -0.03607 | -0.02174 | -0.01707 |
| | | | | 101.8549 | 22.8847 | 29.94693 | 30.52046 | 59.80712 | 42.85365 | 1.230151 |
| | | | | | 23.75755 | 20.99537 | 26.09294 | 43.4732 | 29.66765 | -2.26994 |
| | | | | | | 23.7182 | 28.67892 | 44.51795 | 33.83921 | -2.19056 |
| | | | | | | | 40.85311 | 53.82565 | 41.41022 | -3.60899 |
| | | | | | | | | 167.6875 | 72.83861 | -10.6808 |
| | | | | | | | | | 57.1745 | -3.84017 |
| | | | | | | -D2 = | | | | -3.09095 |
| | | | | 1 | 0.224679 | 0.294016 | 0.299647 | 0.58718 | 0.420732 | 0.012077 |
| | | | | | 18.61582 | 14.26691 | 19.23561 | 30.03577 | 20.03931 | -2.54633 |
| | | | | | | 14.91333 | 19.70542 | 26.93371 | 21.23956 | -2.55224 |
| | | | | | | | 31.70776 | 35.90466 | 28.56927 | -3.9776 |
| | | | | | | | | 132.5699 | 47.67581 | -11.4031 |
| | | | | | | | | | 39.14458 | -4.35773 |
| | | | | | | -D2 = | | | | -3.10581 |
| | | | | | 1 | 0.766386 | 1.033294 | 1.613454 | 1.076466 | -0.13678 |
| | | | | | | 3.979371 | 4.963513 | 3.914714 | 5.881712 | -0.60077 |
| | | | | | | | 11.83172 | 4.868881 | 7.862776 | -1.34649 |
| | | | | | | | | 84.10862 | 15.34331 | -7.29476 |
| | | | | | | | | | 17.57294 | -1.6167 |
| | | | | | | -D2 = | | | | -3.4541 |
| | | | | | | 1 | 1.247311 | 0.983752 | 1.478051 | -0.15097 |
| | | | | | | | 5.640671 | -0.01398 | 0.526452 | -0.59715 |
| | | | | | | | | 80.25751 | 9.557167 | -8.70375 |
| | | | | | | | | | 8.879466 | -0.72873 |
| | | | | | | | | -D2 = | | -3.5448 |
| | | | | | | | 1 | -0.00248 | 0.093331 | -0.10586 |
| | | | | | | | | 80.25747 | 9.558472 | -6.70523 |
| | | | | | | | | | 8.830332 | -0.67299 |
| | | | | | | | -D2 = | | | -3.60802 |
| | | | | | | | | 1 | 0.119098 | -0.08355 |
| | | | | | | | | | 7.691941 | 0.125585 |
| | | | | | | | | | | -4.16822 |
| | | | | | | | | | 1 | 0.016327 |
| | | | | | | | | -D2 = | | -4.17027 |

Table.2.20. Variance covariance matrix of D square analysis between WOC and t-SOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 564.4048 | 165.3922 | 385.5299 | 7.993394 | 44.39042 | 62.00424 | 74.19036 | 153.8283 | 85.01218 | -17.8515 |
| CL | | 61.89327 | 122.8749 | 0.555091 | 14.89564 | 23.11636 | 26.20055 | 56.58745 | 31.23327 | -8.02727 |
| CHL | | | 914.0157 | 42.47097 | 2.540121 | 12.42121 | 6.045818 | 24.18952 | 18.74491 | -13.4576 |
| RL | | | | 133.6457 | 15.63321 | 15.89212 | 18.20418 | 15.58715 | 17.72509 | -3.37576 |
| I | | | | | 25.81915 | 24.43152 | 29.73927 | 47.52339 | 32.85564 | -3.29697 |
| M | | | | | | 29.55515 | 34.41273 | 54.79394 | 40.29636 | -3.9697 |
| C | | | | | | | 43.55509 | 68.67291 | 48.44055 | -4.75455 |
| P | | | | | | | | 236.9664 | 86.23745 | -11.8121 |
| D | | | | | | | | | 62.52327 | -6.52727 |
| | 1 | 0.293038 | 0.683073 | 0.014163 | 0.07865 | 0.109858 | 0.131449 | 0.27255 | 0.150623 | -0.03163 |
| | | 13.42704 | 9.899897 | -1.78728 | 1.887545 | 4.94675 | 4.459932 | 11.50988 | 6.321453 | -2.7961 |
| | | | 650.6704 | 37.01089 | -27.7818 | -29.9322 | -44.6317 | -80.8865 | -39.3247 | -1.26368 |
| | | | | 133.5325 | 15.00453 | 15.01398 | 17.15346 | 13.40856 | 16.5211 | -3.12294 |
| | | | | | 22.32785 | 19.55488 | 23.9042 | 35.4248 | 26.16943 | -1.89295 |
| | | | | | | 22.7435 | 26.26234 | 37.89471 | 30.95712 | -2.00857 |
| | | | | | | | 33.80285 | 48.45235 | 37.26579 | -2.40798 |
| | | | | | | | | 195.0406 | 63.06742 | -6.9467 |
| | | | | | | | | | 49.71851 | -3.83843 |
| | | | | | | -D2 = | | | | -0.56462 |
| | | 1 | 0.73731 | -0.13311 | 0.140578 | 0.368417 | 0.332161 | 0.857217 | 0.4708 | -0.20824 |
| | | | 643.3711 | 38.32867 | -29.1735 | -33.5795 | -47.92 | -89.3729 | -43.9855 | 0.797912 |
| | | | | 133.2946 | 15.25578 | 15.67245 | 17.74712 | 14.94064 | 17.36256 | -3.49512 |
| | | | | | 22.0625 | 18.85948 | 23.27723 | 33.80677 | 25.28077 | -1.49988 |
| | | | | | | 20.92104 | 24.61923 | 33.65427 | 28.62819 | -0.97844 |
| | | | | | | | 32.32144 | 44.62923 | 35.16605 | -1.47923 |
| | | | | | | | | 185.1741 | 57.64856 | -4.54984 |
| | | | | | | | | | 46.74237 | -2.52203 |
| | | | | | | -D2 = | | | | -1.14689 |
| | | | 1 | 0.059575 | -0.04534 | -0.05219 | -0.07448 | -0.13891 | -0.06837 | 0.00124 |
| | | | | 131.0112 | 16.99379 | 17.67294 | 20.60195 | 20.26501 | 19.98298 | -3.54266 |
| | | | | | 20.73963 | 17.33682 | 21.10431 | 29.75418 | 23.28626 | -1.4637 |
| | | | | | | 19.16842 | 22.11813 | 28.98962 | 26.33244 | -0.93679 |
| | | | | | | | 28.75223 | 37.9725 | 31.88989 | -1.4198 |
| | | | | | | | | 172.759 | 51.53838 | -4.439 |
| | | | | | | | | | 43.73519 | -2.46748 |
| | | | | | | -D2 = | | | | -1.14788 |
| | | | | 1 | 0.129713 | 0.134896 | 0.157253 | 0.154682 | 0.152529 | -0.02704 |
| | | | | | 18.53533 | 15.04442 | 18.43198 | 27.12555 | 20.69422 | -1.00417 |
| | | | | | | 16.7844 | 19.339 | 26.25595 | 23.63681 | -0.4589 |
| | | | | | | | 25.5125 | 34.78576 | 28.7475 | -0.86271 |
| | | | | | | | | 169.6244 | 48.44739 | -3.89101 |
| | | | | | | | | | 40.68721 | -1.92712 |
| | | | | | | -D2 = | | | | -1.24368 |
| | | | | | 1 | 0.811662 | 0.994425 | 1.463451 | 1.116474 | -0.05418 |
| | | | | | | 4.573414 | 4.37846 | 4.239166 | 6.840099 | 0.356145 |
| | | | | | | | 7.183287 | 7.811442 | 8.168665 | 0.135866 |
| | | | | | | | | 129.9275 | 18.1624 | -2.42146 |
| | | | | | | | | | 17.58265 | -0.80599 |
| | | | | | | -D2 = | | | | -1.29808 |
| | | | | | | 1 | 0.957372 | 0.926915 | 1.495622 | 0.077873 |
| | | | | | | | 2.99147 | 3.752982 | 1.620143 | -0.2051 |
| | | | | | | | | 125.9981 | 11.82221 | -2.75157 |
| | | | | | | | | | 7.352446 | -1.33864 |
| | | | | | | | | -D2 = | | -1.32582 |
| | | | | | | | 1 | 1.254561 | 0.541588 | -0.06856 |
| | | | | | | | | 121.2898 | 9.789644 | -2.49427 |
| | | | | | | | | | 6.474997 | -1.22757 |
| | | | | | | | -D2 = | | | -1.33988 |
| | | | | | | | | 1 | 0.080713 | -0.02056 |
| | | | | | | | | | 5.684847 | -1.02625 |
| | | | | | | | | | | -1.39117 |
| | | | | | | | | | 1 | -0.18052 |
| | | | | | | | | -D2 = | | -1.57643 |

Table.2.21. Variance covariance matrix of D square analysis between WOC and WBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 692.9247 | 194.5264 | 478.0943 | 23.31667 | 45.37759 | 64.42529 | 78.31092 | 46.68506 | 23.90575 | -16.3667 |
| CL | | 66.30115 | 117.5149 | -0.11264 | 14.53908 | 21.48276 | 26.33563 | 15.78621 | 9.421839 | -5.46667 |
| CHL | | | 1033.456 | 11.18333 | 30.33103 | 27.00575 | 31.41494 | 33.03391 | 9.102874 | -21.2333 |
| RL | | | | 136.5575 | 15.8569 | 15.29885 | 18.12701 | 30.50977 | 24.22701 | -0.53333 |
| I | | | | | 20.46264 | 18.33908 | 20.9477 | 26.34368 | 17.51494 | 7.7 |
| M | | | | | | 21.42529 | 24.2931 | 23.22989 | 18.81034 | 2.666667 |
| C | | | | | | | 33.30632 | 24.93448 | 22.08391 | 1.233333 |
| P | | | | | | | | 85.76839 | 26.80862 | 37.63333 |
| D | | | | | | | | | 25.52011 | 20.63333 |
| | 1 | 0.280732 | 0.689966 | 0.03365 | 0.065487 | 0.092976 | 0.113015 | 0.067374 | 0.0345 | -0.02362 |
| | | 11.69127 | -16.7016 | -6.65839 | 1.800121 | 3.396491 | 4.351218 | 2.680197 | 2.710721 | -0.87201 |
| | | | 703.5871 | -4.90437 | -0.97794 | -17.4455 | -22.6169 | 0.822822 | -7.39127 | -9.9409 |
| | | | | 135.7729 | 14.32996 | 13.13096 | 15.49188 | 28.93883 | 23.42259 | 0.017399 |
| | | | | | 17.491 | 14.12006 | 15.81935 | 23.28641 | 15.94943 | 8.771805 |
| | | | | | | 15.43529 | 17.01208 | 18.8893 | 16.58769 | 4.188372 |
| | | | | | | | 24.45601 | 19.65837 | 19.3822 | 3.083013 |
| | | | | | | | | 82.62304 | 25.198 | 38.73602 |
| | | | | | | | | | 24.69537 | 21.19798 |
| | | | | | | -D2 = | | | | -0.38658 |
| | | 1 | -1.42855 | -0.56952 | 0.153971 | 0.290515 | 0.372177 | 0.229248 | 0.231859 | -0.07459 |
| | | | 679.728 | -14.4162 | 1.593629 | -12.5934 | -16.401 | 4.65163 | -3.51886 | -11.1866 |
| | | | | 131.9808 | 15.35516 | 15.06533 | 17.96997 | 30.46526 | 24.9664 | -0.47923 |
| | | | | | 17.21383 | 13.5971 | 15.14939 | 22.87374 | 15.53205 | 8.906069 |
| | | | | | | 14.44856 | 15.74798 | 18.11066 | 15.80018 | 4.441705 |
| | | | | | | | 22.83659 | 18.66086 | 18.37333 | 3.407556 |
| | | | | | | | | 82.00861 | 24.57657 | 38.93593 |
| | | | | | | | | | 24.06687 | 21.40016 |
| | | | | | | -D2 = | | | | -0.45162 |
| | | | 1 | -0.02121 | 0.002345 | -0.01853 | -0.02413 | 0.006843 | -0.00518 | -0.01646 |
| | | | | 131.6751 | 15.38896 | 14.79823 | 17.62213 | 30.56391 | 24.89176 | -0.71648 |
| | | | | | 17.2101 | 13.62662 | 15.18784 | 22.86283 | 15.5403 | 8.932297 |
| | | | | | | 14.21524 | 15.44412 | 18.19684 | 15.73499 | 4.234449 |
| | | | | | | | 22.44085 | 18.7731 | 18.28843 | 3.137637 |
| | | | | | | | | 81.97677 | 24.60065 | 39.01248 |
| | | | | | | | | | 24.04865 | 21.34225 |
| | | | | | | -D2 = | | | | -0.63572 |
| | | | | 1 | 0.116871 | 0.112384 | 0.13383 | 0.232116 | 0.189039 | -0.00544 |
| | | | | | 15.41158 | 11.89714 | 13.12833 | 19.29081 | 12.63118 | 9.016032 |
| | | | | | | 12.55215 | 13.46367 | 14.76193 | 12.93754 | 4.31497 |
| | | | | | | | 20.08248 | 14.68272 | 14.95715 | 3.233524 |
| | | | | | | | | 74.88239 | 18.82287 | 39.17879 |
| | | | | | | | | | 19.34313 | 21.4777 |
| | | | | | | -D2 = | | | | -0.63962 |
| | | | | | 1 | 0.771961 | 0.851848 | 1.251709 | 0.819591 | 0.585017 |
| | | | | | | 3.368012 | 3.329103 | -0.12982 | 3.186753 | -2.64506 |
| | | | | | | | 8.89913 | -1.75013 | 4.197296 | -4.44677 |
| | | | | | | | | 50.73592 | 3.012306 | 27.89334 |
| | | | | | | | | | 8.990729 | 14.08824 |
| | | | | | | -D2 = | | | | -5.91415 |
| | | | | | | 1 | 0.988447 | -0.03855 | 0.946182 | -0.78535 |
| | | | | | | | 5.608487 | -1.6218 | 1.047358 | -1.83227 |
| | | | | | | | | 50.73092 | 3.135141 | 27.79139 |
| | | | | | | | | | 5.97548 | 16.59095 |
| | | | | | | | | -D2 = | | -7.99144 |
| | | | | | | | 1 | -0.28917 | 0.186745 | -0.3267 |
| | | | | | | | | 50.26194 | 3.438005 | 27.26155 |
| | | | | | | | | | 5.779891 | 16.93311 |
| | | | | | | | -D2 = | | | -8.59003 |
| | | | | | | | | 1 | 0.068402 | 0.542389 |
| | | | | | | | | | 5.544725 | 15.06838 |
| | | | | | | | | | | -23.3764 |
| | | | | | | | | | 1 | 2.717606 |
| | | | | | | | | -D2 = | | -64.3263 |

Table.2.22 Variance covariance matrix of D square analysis between WOC and SBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 527.8794 | 151.9435 | 230.042 | 18.04181 | 28.32555 | 36.40354 | 49.90645 | 37.05642 | 16.03264 | -71.2392 |
| CL | | 61.43985 | 64.57343 | 5.63055 | 8.583681 | 11.60911 | 18.22258 | 13.31328 | 7.127704 | -28.3294 |
| CHL | | | 1904.342 | -51.5268 | 4.446363 | 8.397691 | -3.21452 | 20.64007 | 14.59336 | -74.5137 |
| RL | | | | 136.8149 | 12.38792 | 16.95462 | 20.37581 | 29.39567 | 21.83264 | -23.1725 |
| I | | | | | 19.90487 | 14.52214 | 16.54194 | 24.53327 | 16.03624 | 3.654902 |
| M | | | | | | 19.14976 | 19.49194 | 20.19228 | 16.37808 | -5.06863 |
| C | | | | | | | 29.69839 | 24.13871 | 19.32742 | -9.3 |
| P | | | | | | | | 79.29529 | 25.17429 | 33.05686 |
| D | | | | | | | | | 23.68273 | 18.31765 |
| | 1 | 0.287837 | 0.435785 | 0.034178 | 0.053659 | 0.068962 | 0.094541 | 0.070199 | 0.030372 | -0.13495 |
| | | 17.70484 | -1.64126 | 0.437443 | 0.430527 | 1.130807 | 3.857637 | 2.647059 | 2.512911 | -7.8241 |
| | | | 1804.094 | -59.3892 | -7.89749 | -7.46643 | -24.963 | 4.491434 | 7.606574 | -43.4687 |
| | | | | 136.1983 | 11.41981 | 15.71042 | 18.67011 | 28.12916 | 21.28468 | -20.7377 |
| | | | | | 18.38495 | 12.56876 | 13.864 | 22.54485 | 15.17595 | 7.477537 |
| | | | | | | 16.63929 | 16.05029 | 17.6368 | 15.27244 | -0.15584 |
| | | | | | | | 24.98016 | 20.63534 | 17.81167 | -2.56495 |
| | | | | | | | | 76.69398 | 24.04882 | 38.05776 |
| | | | | | | | | | 23.19579 | 20.48131 |
| | | | | | | -D2 = | | | | -9.61399 |
| | | 1 | -0.0927 | 0.024708 | 0.024317 | 0.06387 | 0.217886 | 0.14951 | 0.141934 | -0.44192 |
| | | | 1803.941 | -59.3486 | -7.85758 | -7.3616 | -24.6054 | 4.736819 | 7.839524 | -44.194 |
| | | | | 136.1875 | 11.40917 | 15.68248 | 18.5748 | 28.06375 | 21.22259 | -20.5444 |
| | | | | | 18.37448 | 12.54126 | 13.77019 | 22.48049 | 15.11484 | 7.667795 |
| | | | | | | 16.56707 | 15.80391 | 17.46774 | 15.11194 | 0.343885 |
| | | | | | | | 24.13964 | 20.05859 | 17.26414 | -0.86018 |
| | | | | | | | | 76.29821 | 23.67311 | 39.22754 |
| | | | | | | | | | 22.83913 | 21.59181 |
| | | | | | | -D2 = | | | | -13.0716 |
| | | | 1 | -0.0329 | -0.00436 | -0.00408 | -0.01364 | 0.002626 | 0.004346 | -0.0245 |
| | | | | 134.235 | 11.15066 | 15.44029 | 17.76529 | 28.21959 | 21.4805 | -21.9984 |
| | | | | | 18.34025 | 12.50919 | 13.66302 | 22.50112 | 15.14899 | 7.475295 |
| | | | | | | 16.53703 | 15.7036 | 17.48707 | 15.14394 | 0.163536 |
| | | | | | | | 23.80402 | 20.1232 | 17.37107 | -1.46298 |
| | | | | | | | | 76.28578 | 23.65253 | 39.34359 |
| | | | | | | | | | 22.80506 | 21.78387 |
| | | | | | | -D2 = | | | | -14.1543 |
| | | | | 1 | 0.083068 | 0.115024 | 0.132345 | 0.210225 | 0.160022 | -0.16388 |
| | | | | | 17.41398 | 11.22659 | 12.18728 | 20.15697 | 13.36464 | 9.302663 |
| | | | | | | 14.76102 | 13.66006 | 14.24113 | 12.67315 | 2.693887 |
| | | | | | | | 21.45288 | 16.38848 | 14.52824 | 1.448389 |
| | | | | | | | | 70.3533 | 19.13678 | 43.96821 |
| | | | | | | | | | 19.36771 | 25.30409 |
| | | | | | | -D2 = | | | | -17.7594 |
| | | | | | 1 | 0.644688 | 0.699856 | 1.157516 | 0.767466 | 0.534206 |
| | | | | | | 7.523361 | 5.803054 | 1.246164 | 4.057127 | -3.30343 |
| | | | | | | | 12.92353 | 2.281504 | 5.174916 | -5.06214 |
| | | | | | | | | 47.02129 | 3.666997 | 33.20023 |
| | | | | | | | | | 9.110807 | 18.16461 |
| | | | | | | -D2 = | | | | -22.7289 |
| | | | | | | 1 | 0.771338 | 0.165639 | 0.539271 | -0.43909 |
| | | | | | | | 8.447419 | 1.32029 | 2.0455 | -2.51407 |
| | | | | | | | | 46.81488 | 2.994978 | 33.7474 |
| | | | | | | | | | 6.922918 | 19.94606 |
| | | | | | | | | -D2 = | | -24.1794 |
| | | | | | | | 1 | 0.156295 | 0.242145 | -0.29761 |
| | | | | | | | | 46.60852 | 2.675276 | 34.14034 |
| | | | | | | | | | 6.427611 | 20.55483 |
| | | | | | | | -D2 = | | | -24.9277 |
| | | | | | | | | 1 | 0.057399 | 0.732491 |
| | | | | | | | | | 6.274053 | 18.59521 |
| | | | | | | | | | | -49.9352 |
| | | | | | | | | | 1 | 2.963827 |
| | | | | | | | | -D2 = | | -105.048 |

Table.2 23. Variance covariance matrix of D square analysis between WOC and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 527.1455 | 155.5374 | 288.6287 | 40.25442 | 19.99736 | 37.24022 | 42.71339 | 31.94741 | 18.31735 | -99.4262 |
| CL | | 64.56722 | 86.13495 | 12.79235 | 10.25944 | 15.37372 | 16.80446 | 12.3162 | 8.190306 | -39.7643 |
| CHL | | | 971.5606 | 74.90451 | -7.90272 | 3.268707 | 5.405357 | 19.86599 | 7.145153 | -315.724 |
| RL | | | | 114.9611 | 15.91207 | 21.61565 | 25.15714 | 34.46522 | 26.26046 | -34.5381 |
| I | | | | | 21.03078 | 15.70578 | 17.50179 | 25.67406 | 17.82704 | 1.138095 |
| M | | | | | | 18.50935 | 21.15179 | 21.79549 | 18.33418 | -11.2619 |
| C | | | | | | | 28.57232 | 24.28304 | 21.47857 | -17.05 |
| P | | | | | | | | 86.42938 | 27.67015 | 31.12619 |
| D | | | | | | | | | 26.45944 | 16.84286 |
| | 1 | 0.295056 | 0.547531 | 0.076363 | 0.037935 | 0.070645 | 0.081028 | 0.060605 | 0.034748 | -0.18861 |
| | | 18.675 | 0.973363 | 0.915043 | 4.359099 | 4.385778 | 4.201626 | 2.889928 | 2.785665 | -10.428 |
| | | | 813.5274 | 52.86395 | -18.8519 | -17.1215 | -17.9816 | 2.37378 | -2.88417 | -261.285 |
| | | | | 111.8872 | 14.38502 | 18.77187 | 21.89542 | 32.02562 | 24.86169 | -26.9456 |
| | | | | | 20.27218 | 14.29307 | 15.88144 | 24.46213 | 17.13217 | 4.909847 |
| | | | | | | 15.87852 | 18.1343 | 19.53857 | 17.04015 | -4.23794 |
| | | | | | | | 25.11135 | 21.69441 | 19.99436 | -8.99372 |
| | | | | | | | | 84.49322 | 26.56004 | 37.15187 |
| | | | | | | | | | 25.82294 | 20.29774 |
| | | | | | | -D2 = | | | | -18.753 |
| | | 1 | 0.052121 | 0.048998 | 0.233419 | 0.234848 | 0.224987 | 0.154749 | 0.149165 | -0.55839 |
| | | | 813.4767 | 52.81626 | -19.0791 | -17.3501 | -18.2006 | 2.223154 | -3.02936 | -260.741 |
| | | | | 111.8424 | 14.17143 | 18.55697 | 21.68955 | 31.88402 | 24.7252 | -26.4347 |
| | | | | | 19.25468 | 13.26934 | 14.90071 | 23.78757 | 16.48194 | 7.34394 |
| | | | | | | 14.84853 | 17.14755 | 18.85987 | 16.38595 | -1.78895 |
| | | | | | | | 24.16604 | 21.04421 | 19.36762 | -6.64756 |
| | | | | | | | | 84.04601 | 26.12896 | 38.76559 |
| | | | | | | | | | 25.40742 | 21.85323 |
| | | | | | | -D2 = | | | | -24.5759 |
| | | | 1 | 0.064927 | -0.02345 | -0.02133 | -0.02237 | 0.002733 | -0.00372 | -0.32053 |
| | | | | 108.4132 | 15.41017 | 19.68346 | 22.87125 | 31.73968 | 24.92188 | -9.50561 |
| | | | | | 18.80721 | 12.86242 | 14.47383 | 23.83971 | 16.41089 | 1.228569 |
| | | | | | | 14.47848 | 16.75937 | 18.90729 | 16.32134 | -7.35011 |
| | | | | | | | 23.75883 | 21.09396 | 19.29984 | -12.4813 |
| | | | | | | | | 84.03993 | 26.13724 | 39.47817 |
| | | | | | | | | | 25.39614 | 20.88224 |
| | | | | | | -D2 = | | | | -108.151 |
| | | | | 1 | 0.142143 | 0.18156 | 0.210964 | 0.292766 | 0.229879 | -0.08768 |
| | | | | | 16.61676 | 10.06455 | 11.22285 | 19.32814 | 12.86842 | 2.579725 |
| | | | | | | 10.90476 | 12.60687 | 13.14465 | 11.79653 | -5.62428 |
| | | | | | | | 18.93382 | 14.39804 | 14.04223 | -10.476 |
| | | | | | | | | 74.74764 | 18.84096 | 42.26109 |
| | | | | | | | | | 19.66713 | 23.06738 |
| | | | | | | -D2 = | | | | -108.984 |
| | | | | | 1 | 0.605687 | 0.675393 | 1.163171 | 0.774424 | 0.155248 |
| | | | | | | 4.808789 | 5.809339 | 1.437843 | 4.002292 | -7.18678 |
| | | | | | | | 11.35399 | 1.343939 | 5.350983 | -12.2183 |
| | | | | | | | | 52.2657 | 3.872782 | 39.26042 |
| | | | | | | | | | 9.701508 | 21.06958 |
| | | | | | | -D2 = | | | | -109.385 |
| | | | | | | 1 | 1.208067 | 0.299003 | 0.832287 | -1.49451 |
| | | | | | | | 4.335917 | -0.39307 | 0.515946 | -3.53621 |
| | | | | | | | | 51.83578 | 2.676083 | 41.4093 |
| | | | | | | | | | 6.370452 | 27.05105 |
| | | | | | | | | -D2 = | | -120.125 |
| | | | | | | | 1 | -0.09066 | 0.118994 | -0.81556 |
| | | | | | | | | 51.80014 | 2.722857 | 41.08872 |
| | | | | | | | | | 6.309058 | 27.47183 |
| | | | | | | | -D2 = | | | -123.009 |
| | | | | | | | | 1 | 0.052565 | 0.793216 |
| | | | | | | | | | 6.165932 | 25.31202 |
| | | | | | | | | | | -155.602 |
| | | | | | | | | | 1 | 4.10514 |
| | | | | | | | | -D2 = | | -259.511 |

Table.2.24. Variance covariance matrix of Dsqare analysis between SOC and t-SOC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 967.1993 | 346.0361 | 214.4709 | 235.7984 | 149.8578 | 224.8089 | 280.1364 | 625.2226 | 352.2413 | 21.68182 |
| CL | | 135.5269 | 97.30009 | 84.87063 | 50.16121 | 80.35701 | 96.32971 | 232.1089 | 128.4783 | 8.509569 |
| CHL | | | 2594.775 | 54.74825 | 26.98 | 62.04294 | 60.07116 | 133.2865 | 93.4013 | 34.54067 |
| RL | | | | 181.9312 | 37.58275 | 55.46853 | 66.65152 | 157.6818 | 89.63986 | 8.590909 |
| I | | | | | 33.12109 | 41.21899 | 52.77316 | 102.5251 | 63.25432 | 4.057416 |
| M | | | | | | 59.42878 | 73.36989 | 154.4155 | 92.14244 | 5.784689 |
| C | | | | | | | 97.32542 | 193.2846 | 113.0935 | 7.57177 |
| P | | | | | | | | 508.737 | 258.2587 | 19.84928 |
| D | | | | | | | | | 151.8049 | 8.930622 |
| | 1 | 0.357771 | 0.221744 | 0.243795 | 0.15494 | 0.232433 | 0.289637 | 0.646426 | 0.364187 | 0.022417 |
| | | 11.72508 | 20.56857 | 0.508746 | -3.45361 | -0.07314 | -3.89503 | 8.422189 | 2.456479 | 0.752438 |
| | | | 2547.218 | 2.461325 | -6.2501 | 12.19287 | -2.04746 | -5.35304 | 15.29383 | 29.73285 |
| | | | | 124.4448 | 1.048164 | 0.661253 | -1.64433 | 5.255662 | 3.765197 | 3.30499 |
| | | | | | 9.902128 | 6.387119 | 9.368843 | 5.65313 | 8.678082 | 0.698036 |
| | | | | | | 7.175826 | 8.257009 | 9.093279 | 10.27001 | 0.745123 |
| | | | | | | | 16.18766 | 12.19718 | 11.07157 | 1.291921 |
| | | | | | | | | 104.577 | 30.56083 | 5.833595 |
| | | | | | | | | | 23.52324 | 1.034389 |
| | | | | | | -D2 = | | | | -0.48604 |
| | | 1 | 1.754237 | 0.04339 | -0.29455 | -0.00624 | -0.3322 | 0.718306 | 0.209506 | 0.064173 |
| | | | 2511.136 | 1.568864 | -0.19165 | 12.32118 | 4.785344 | -20.1276 | 10.98459 | 28.4129 |
| | | | | 124.4227 | 1.198014 | 0.664426 | -1.47533 | 4.890227 | 3.658612 | 3.272342 |
| | | | | | 8.88487 | 6.365575 | 8.221565 | 8.13388 | 9.401637 | 0.919666 |
| | | | | | | 7.175369 | 8.232712 | 9.145817 | 10.28533 | 0.749817 |
| | | | | | | | 14.89375 | 14.99501 | 11.8876 | 1.541878 |
| | | | | | | | | 98.52728 | 28.79633 | 5.293115 |
| | | | | | | | | | 23.00859 | 0.876749 |
| | | | | | | -D2 = | | | | -0.53433 |
| | | | 1 | 0.000625 | -7.6E-05 | 0.004907 | 0.001906 | -0.00802 | 0.004374 | 0.011315 |
| | | | | 124.4217 | 1.198134 | 0.656728 | -1.47832 | 4.902802 | 3.651749 | 3.254591 |
| | | | | | 8.884855 | 6.366516 | 8.22193 | 8.132344 | 9.402475 | 0.921835 |
| | | | | | | 7.114914 | 8.209232 | 9.244575 | 10.23143 | 0.610405 |
| | | | | | | | 14.88463 | 15.03336 | 11.86667 | 1.487733 |
| | | | | | | | | 98.36595 | 28.88437 | 5.520853 |
| | | | | | | | | | 22.96054 | 0.752461 |
| | | | | | | -D2 = | | | | -0.85582 |
| | | | | 1 | 0.00963 | 0.005278 | -0.01188 | 0.039405 | 0.02935 | 0.026158 |
| | | | | | 8.873317 | 6.360192 | 8.236166 | 8.085131 | 9.36731 | 0.890494 |
| | | | | | | 7.111448 | 8.217035 | 9.218697 | 10.21216 | 0.593227 |
| | | | | | | | 14.86706 | 15.09162 | 11.91006 | 1.526403 |
| | | | | | | | | 98.17275 | 28.74048 | 5.392607 |
| | | | | | | | | | 22.85336 | 0.656939 |
| | | | | | | -D2 = | | | | -0.94095 |
| | | | | | 1 | 0.716777 | 0.928195 | 0.911173 | 1.055672 | 0.100356 |
| | | | | | | 2.552607 | 2.313539 | 3.423459 | 3.497886 | -0.04506 |
| | | | | | | | 7.222298 | 7.58704 | 3.215372 | 0.699851 |
| | | | | | | | | 90.8058 | 20.20523 | 4.581212 |
| | | | | | | | | | 12.96456 | -0.28313 |
| | | | | | | -D2 = | | | | -1.03031 |
| | | | | | | 1 | 0.906343 | 1.341162 | 1.370319 | -0.01765 |
| | | | | | | | 5.125437 | 4.48421 | 0.045086 | 0.74069 |
| | | | | | | | | 86.21438 | 15.514 | 4.641644 |
| | | | | | | | | | 8.17134 | -0.22139 |
| | | | | | | | | -D2 = | | -1.03111 |
| | | | | | | | 1 | 0.874893 | 0.008796 | 0.144513 |
| | | | | | | | | 82.29118 | 15.47456 | 3.993619 |
| | | | | | | | | | 8.170943 | -0.2279 |
| | | | | | | | -D2 = | | | -1.13815 |
| | | | | | | | | 1 | 0.188046 | 0.04853 |
| | | | | | | | | | 5.261008 | -0.97889 |
| | | | | | | | | | | -1.33196 |
| | | | | | | | | | 1 | -0.18606 |
| | | | | | | | | -D2 = | | -1.5141 |

Table.2.25. Variance covariance matrix of Dsquare analysis between SOC and WBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 1057.238 | 351.2411 | 357.8156 | 215.9326 | 133.1241 | 200.0851 | 250.1667 | 412.766 | 231.3475 | 23.16667 |
| CL | | 128.433 | 95.03882 | 69.69504 | 43.71855 | 68.59798 | 84.55954 | 151.8824 | 85.00971 | 11.07018 |
| CHL | | | 2456.083 | 14.04823 | 57.11519 | 71.59462 | 82.18193 | 125.6311 | 68.79515 | 26.76491 |
| RL | | | | 177.3057 | 34.1227 | 48 | 58.30993 | 151.9106 | 85.4227 | 11.43333 |
| I | | | | | 25.26805 | 30.84323 | 38.00332 | 67.02643 | 39.14901 | 15.05439 |
| M | | | | | | 44.31131 | 54.25084 | 98.50728 | 56.80291 | 12.42105 |
| C | | | | | | | 75.52561 | 118.099 | 69.56357 | 13.55965 |
| P | | | | | | | | 275.8934 | 155.6408 | 69.29474 |
| D | | | | | | | | | 90.94453 | 36.09123 |
| | 1 | 0.332225 | 0.338444 | 0.204242 | 0.125917 | 0.189253 | 0.236623 | 0.390419 | 0.218823 | 0.021912 |
| | | 11.74179 | -23.8366 | -2.04326 | -0.50865 | 2.124639 | 1.447827 | 14.7511 | 8.150194 | 3.373621 |
| | | | 2334.982 | -59.0329 | 12.06015 | 3.877043 | -2.48545 | -14.067 | -9.50301 | 18.9243 |
| | | | | 133.2031 | 6.933122 | 7.13416 | 7.215317 | 67.60637 | 38.17175 | 6.70172 |
| | | | | | 8.505468 | 5.649122 | 6.503103 | 15.0522 | 10.01844 | 12.13731 |
| | | | | | | 6.444656 | 6.906114 | 20.39019 | 13.01976 | 8.036698 |
| | | | | | | | 16.33043 | 20.4291 | 14.82144 | 8.077884 |
| | | | | | | | | 114.7416 | 65.31823 | 60.25002 |
| | | | | | | | | | 40.32046 | 31.02184 |
| | | | | | | -D2 = | | | | -0.50764 |
| | | 1 | -2.03007 | -0.17402 | -0.04332 | 0.180947 | 0.123306 | 1.256291 | 0.694119 | 0.287318 |
| | | | 2286.592 | -63.1808 | 11.02755 | 8.190199 | 0.453738 | 15.87872 | 7.042421 | 25.77297 |
| | | | | 132.8475 | 6.844608 | 7.503881 | 7.467262 | 70.1733 | 39.59001 | 7.288784 |
| | | | | | 8.483433 | 5.741162 | 6.565823 | 15.69122 | 10.37151 | 12.28346 |
| | | | | | | 6.06021 | 6.644134 | 17.72103 | 11.54501 | 7.426252 |
| | | | | | | | 16.15191 | 18.61021 | 13.81647 | 7.661898 |
| | | | | | | | | 96.20992 | 55.07921 | 56.01177 |
| | | | | | | | | | 34.66326 | 28.68014 |
| | | | | | | -D2 = | | | | -1.47694 |
| | | | 1 | -0.02763 | 0.004823 | 0.003582 | 0.000198 | 0.006944 | 0.00308 | 0.011271 |
| | | | | 131.1018 | 7.14931 | 7.730184 | 7.479799 | 70.61205 | 39.7846 | 8.000917 |
| | | | | | 8.43025 | 5.701663 | 6.563635 | 15.61464 | 10.33754 | 12.15916 |
| | | | | | | 6.030874 | 6.642509 | 17.66415 | 11.51978 | 7.333937 |
| | | | | | | | 16.15182 | 18.60705 | 13.81508 | 7.656784 |
| | | | | | | | | 96.09965 | 55.03031 | 55.8328 |
| | | | | | | | | | 34.64157 | 28.60077 |
| | | | | | | -D2 = | | | | -1.76744 |
| | | | | 1 | 0.054533 | 0.058963 | 0.057053 | 0.538605 | 0.303463 | 0.061028 |
| | | | | | 8.040381 | 5.280117 | 6.155742 | 11.76399 | 8.16799 | 11.72285 |
| | | | | | | 5.575077 | 6.201476 | 13.50064 | 9.173956 | 6.862177 |
| | | | | | | | 15.72507 | 14.5784 | 11.54523 | 7.200305 |
| | | | | | | | | 58.06767 | 33.60213 | 51.52347 |
| | | | | | | | | | 22.56839 | 26.17278 |
| | | | | | | -D2 = | | | | -2.25572 |
| | | | | | 1 | 0.6567 | 0.765603 | 1.463114 | 1.015871 | 1.457997 |
| | | | | | | 2.107626 | 2.159001 | 5.775227 | 3.810039 | -0.83622 |
| | | | | | | | 11.01221 | 5.571847 | 5.291791 | -1.77475 |
| | | | | | | | | 40.85561 | 21.65143 | 34.3716 |
| | | | | | | | | | 14.27077 | 14.26388 |
| | | | | | | -D2 = | | | | -19.3476 |
| | | | | | | 1 | 1.024376 | 2.740158 | 1.80774 | -0.39676 |
| | | | | | | | 8.800586 | -0.34416 | 1.38888 | -0.91815 |
| | | | | | | | | 25.03058 | 11.21132 | 36.66297 |
| | | | | | | | | | 7.383211 | 15.77554 |
| | | | | | | | | -D2 = | | -19.6704 |
| | | | | | | | 1 | 0.03911 | 0.157817 | 0.10433 |
| | | | | | | | | 25.01712 | 11.26564 | 36.62706 |
| | | | | | | | | | 7.164022 | 15.92044 |
| | | | | | | | -D2 = | | | -19.7752 |
| | | | | | | | | 1 | 0.450317 | 1.46408 |
| | | | | | | | | | 2.090912 | -0.57336 |
| | | | | | | | | | | -73.4001 |
| | | | | | | | | | 1 | -0.27421 |
| | | | | | | | | -D2 = | | -73.5573 |

Table.2 26. Variance covariance matrix of Dsquare analysis between SOC and SBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 828.0208 | 287.1822 | 65.6955 | 194.4129 | 105.5121 | 155 3795 | 202.1569 | 372.3483 | 205.5063 | -31 7059 |
| CL | | 117.6501 | 32.44139 | 71.20185 | 34.19007 | 52.89941 | 70.13003 | 138.2019 | 76.2923 | -11.7926 |
| CHL | | | 3403.229 | -62.4123 | 23.54683 | 45 4759 | 36.10165 | 103 3016 | 70 78811 | -26 5155 |
| RL | | | | 174.4227 | 28.4729 | 47 4481 | 57.89216 | 141.0346 | 77.71223 | -11 2059 |
| I | | | | | 24 21308 | 25.2223 | 31 3096 | 61.63474 | 35 65459 | 11.00929 |
| M | | | | | | 39.74998 | 46 0645 | 88.9104 | 50 86624 | 4 685759 |
| C | | | | | | | 67.82817 | 109 8246 | 62.48865 | 3.026316 |
| P | | | | | | | | 253.1124 | 143 5494 | 64.71827 |
| D | | | | | | | | | 83.57952 | 33.77554 |
| | 1 | 0.34683 | 0.07934 | 0.234792 | 0.127427 | 0.187652 | 0.244145 | 0.449685 | 0 24819 | -0.03829 |
| | | 18.04675 | 9 656234 | 3.773661 | -2.40467 | -0.99081 | 0.016016 | 9.060427 | 5.016582 | -0.79603 |
| | | | 3398.017 | -77.8371 | 15.17546 | 33.14803 | 20.06244 | 73.75932 | 54.48315 | -23.9999 |
| | | | | 128.7761 | 3.699461 | 10.96619 | 10.42728 | 53.61007 | 29 46091 | -3.76158 |
| | | | | | 10.768 | 5.422781 | 5.549377 | 14.18755 | 9.467552 | 15.04947 |
| | | | | | | 10.59277 | 8.129429 | 19.03862 | 12 30263 | 10.63542 |
| | | | | | | | 18.47265 | 18.9177 | 12 31537 | 10.76714 |
| | | | | | | | | 85 67299 | 51.13637 | 78.97592 |
| | | | | | | | | | 32 57494 | 41.64462 |
| | | | | | | -D2 = | | | | -1.21406 |
| | | 1 | 0.535068 | 0.209105 | -0 13325 | -0 0549 | 0.000887 | 0.502053 | 0.277977 | -0.04411 |
| | | | 3392.85 | -79.8563 | 16.46212 | 33.67818 | 20.05387 | 68 91137 | 51.79894 | -23.574 |
| | | | | 127.987 | 4 20229 | 11.17337 | 10.42393 | 51.7155 | 28.41192 | -3 59513 |
| | | | | | 10.44758 | 5.290758 | 5.551511 | 15.39482 | 10.136 | 14.9434 |
| | | | | | | 10.53837 | 8.130308 | 19.53606 | 12.57805 | 10.59172 |
| | | | | | | | 18.47264 | 18 90966 | 12.31092 | 10.76784 |
| | | | | | | | | 81.12418 | 48 61778 | 79.37557 |
| | | | | | | | | | 31.18044 | 41 8659 |
| | | | | | | -D2 = | | | | -1.24917 |
| | | | 1 | -0 02354 | 0.004852 | 0.009926 | 0.005911 | 0.020311 | 0.015267 | -0.00695 |
| | | | | 126.1074 | 4.589753 | 11.96605 | 10.89593 | 53.33744 | 29.6311 | -4.14998 |
| | | | | | 10.36771 | 5.127351 | 5.45421 | 15 06046 | 9.884667 | 15.05778 |
| | | | | | | 10.20407 | 7.931249 | 18.85203 | 12 06388 | 10.82572 |
| | | | | | | | 18.35411 | 18 50235 | 12.00475 | 10.90718 |
| | | | | | | | | 79.72453 | 47.5657 | 79.65437 |
| | | | | | | | | | 30.38962 | 42 2258 |
| | | | | | | -D2 = | | | | -1.41296 |
| | | | | 1 | 0.036396 | 0.094888 | 0 086402 | 0.422952 | 0.234967 | -0.03291 |
| | | | | | 10.20066 | 4.69184 | 5.057646 | 13.11921 | 8 806226 | 15 20882 |
| | | | | | | 9 068644 | 6 897359 | 13.79096 | 9.252258 | 11.2195 |
| | | | | | | | 17.41268 | 13 89389 | 9.444566 | 11.26575 |
| | | | | | | | | 57.16534 | 35 03316 | 81.60962 |
| | | | | | | | | | 23.42729 | 43.20091 |
| | | | | | | -D2 = | | | | -1.54953 |
| | | | | | 1 | 0.459955 | 0 495816 | 1.286114 | 0.8633 | 1 490965 |
| | | | | | | 6.91061 | 4 571072 | 7.756718 | 5.201794 | 4.224131 |
| | | | | | | | 14.90502 | 7.389179 | 5.078303 | 3.724977 |
| | | | | | | | | 40.29253 | 23.70735 | 62.04933 |
| | | | | | | | | | 15 82488 | 30.07114 |
| | | | | | | -D2 = | | | | -24 2254 |
| | | | | | | 1 | 0 661457 | 1.122436 | 0.752726 | 0 611253 |
| | | | | | | | 11.88145 | 2.258443 | 1 63754 | 0.930896 |
| | | | | | | | | 31 58611 | 17.86867 | 57.30802 |
| | | | | | | | | | 11 90936 | 26.89153 |
| | | | | | | | | -D2 = | | -26 8074 |
| | | | | | | | 1 | 0.190081 | 0.137823 | 0 078349 |
| | | | | | | | | 31.15682 | 17.5574 | 57.13107 |
| | | | | | | | | | 11.68366 | 26 76323 |
| | | | | | | | -D2 = | | | -26 8803 |
| | | | | | | | | 1 | 0.563517 | 1 833662 |
| | | | | | | | | | 1.789768 | -5.43111 |
| | | | | | | | | | | -131.639 |
| | | | | | | | | | 1 | -3.03453 |
| | | | | | | | | -D2 = | | -148.12 |

Table.2.27. Variance covariance matrix of Dsquare analysis between SOC and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 867.1262 | 309 6865 | 116 6905 | 245.5714 | 105.4397 | 172.2841 | 213 5056 | 410.696 | 233 6127 | -59 8929 |
| CL | | 129 0366 | 54.98922 | 88 85714 | 39 68964 | 63.08964 | 75.28626 | 153 6129 | 86 83659 | -23 2274 |
| CHL | | | 2442.286 | 93.47302 | 10.72581 | 44 03693 | 52.07076 | 113.3598 | 69 01186 | -267.726 |
| RL | | | | 152.2413 | 35.00317 | 57.31429 | 68 84444 | 162 2286 | 90 67302 | -22.5714 |
| I | | | | | 26.18864 | 28.12197 | 34 4731 | 68 00125 | 40 49891 | 8 492481 |
| M | | | | | | 41.69975 | 51 6731 | 100.0679 | 57 89891 | -1.50752 |
| C | | | | | | | 71.51082 | 121 4289 | 70.92047 | -4.72368 |
| P | | | | | | | | 285.166 | 162 4388 | 62.78759 |
| D | | | | | | | | | 95.02122 | 32 30075 |
| | 1 | 0.357141 | 0 134572 | 0.283201 | 0.121597 | 0 198684 | 0.246222 | 0.473629 | 0 26941 | -0.06907 |
| | | 18.43482 | 13.31424 | 1.153463 | 2 032784 | 1.559877 | -0 96538 | 6 936424 | 3 403867 | -1 83724 |
| | | | 2426 582 | 60 4261 | -3 46336 | 20.85239 | 23 339 | 58 09183 | 37 57425 | -259 666 |
| | | | | 82 69508 | 5.142499 | 8.523164 | 8 379353 | 45 91884 | 24 51355 | -5 60968 |
| | | | | | 13.36752 | 7.17279 | 8 511529 | 18 06197 | 12 09238 | 15.77525 |
| | | | | | | 7.469645 | 9.252955 | 18 46918 | 11.4838 | 10.39224 |
| | | | | | | | 18.94105 | 20 30654 | 13.39988 | 10.02326 |
| | | | | | | | | 90 64844 | 51.79304 | 91.15458 |
| | | | | | | | | | 32 08356 | 48 4365 |
| | | | | | | -D2 = | | | | -4 13683 |
| | | 1 | 0 722234 | 0 06257 | 0.110269 | 0.084616 | -0.05237 | 0.376268 | 0 184643 | -0.09966 |
| | | | 2416.966 | 59.59303 | -4.93151 | 19 7258 | 24 03622 | 53 08211 | 35 11586 | -258 339 |
| | | | | 82.6229 | 5.015309 | 8 425563 | 8 439757 | 45 48483 | 24 30057 | -5 49473 |
| | | | | | 13 14337 | 7 000785 | 8.61798. | 17.2971 | 11 71704 | 15.97784 |
| | | | | | | 7 337654 | 9 334641 | 17 88225 | 11.19578 | 10 54769 |
| | | | | | | | 18 8905 | 20 66978 | 13 57813 | 9.927045 |
| | | | | | | | | 88 03849 | 50 51227 | 91.84587 |
| | | | | | | | | | 31 45506 | 48.77574 |
| | | | | | | -D2 = | | | | -4.31993 |
| | | | 1 | 0.024656 | -0.00204 | 0.008161 | 0 009945 | 0.021962 | 0 014529 | -0.10689 |
| | | | | 81 15357 | 5.1369 | 7.939201 | 7 847116 | 44 17603 | 23.43475 | 0.874907 |
| | | | | | 13.13331 | 7.041033 | 8 667022 | 17.40541 | 11 78869 | 15.45074 |
| | | | | | | 7.176664 | 9.138472 | 17.44902 | 10 90919 | 12.6561 |
| | | | | | | | 18.65146 | 20 14189 | 13 22891 | 12 49617 |
| | | | | | | | | 86 87269 | 49 74105 | 97 51959 |
| | | | | | | | | | 30 94486 | 52.52911 |
| | | | | | | -D2 = | | | | -31 9326 |
| | | | | 1 | 0.063299 | 0 097829 | 0 096695 | 0.544351 | 0 28877 | 0 010781 |
| | | | | | 12.80815 | 6.538493 | 8 170312 | 14 60913 | 10 30531 | 15 39536 |
| | | | | | | 6.399977 | 8.370794 | 13.12731 | 8 61658 | 12 57051 |
| | | | | | | | 17.89269 | 15 87031 | 10 96289 | 12.41157 |
| | | | | | | | | 62 82541 | 36 98431 | 97.04333 |
| | | | | | | | | | 24 1776 | 52.27647 |
| | | | | | | -D2 = | | | | -31.942 |
| | | | | | 1 | 0.510495 | 0 6379 | 1.140612 | 0 80459 | 1.201997 |
| | | | | | | 3 062111 | 4.199892 | 5.669424 | 3 355775 | 4.711256 |
| | | | | | | | 12.68085 | 6 55115 | 4 389145 | 2.59088 |
| | | | | | | | | 46 16206 | 25.22996 | 79 4832 |
| | | | | | | | | | 15.88606 | 39.88952 |
| | | | | | | -D2 = | | | | -50.4472 |
| | | | | | | 1 | 1.371568 | 1.851476 | 1.095902 | 1 538565 |
| | | | | | | | 6.920413 | -1.22485 | -0 21353 | -3.87093 |
| | | | | | | | | 35.66526 | 19.01682 | 70.76042 |
| | | | | | | | | | 12 20846 | 34.72644 |
| | | | | | | | | -D2 = | | -57 6958 |
| | | | | | | | 1 | -0.17699 | -0.03085 | -0.55935 |
| | | | | | | | | 35.44847 | 18.97903 | 70.0753 |
| | | | | | | | | | 12 20187 | 34.60701 |
| | | | | | | | -D2 = | | | -59.861 |
| | | | | | | | | 1 | 0 535398 | 1 976821 |
| | | | | | | | | | 2 04054 | 2 91114 |
| | | | | | | | | | | -198 387 |
| | | | | | | | | | 1 | -1 42665 |
| | | | | | | | | -D2 = | | -202.541 |

Table.2.28. Variance covariance matrix of Dsquare analysis between t-SOC and WBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 677.8188 | 202.9948 | 265.9139 | -46.1406 | 78.30576 | 113.3509 | 145.743 | 157.5536 | 91.97485 | 1.484848 |
| CL | | 73.49061 | 68.94424 | -29.2076 | 21.13697 | 35.95636 | 44.71788 | 54.83545 | 31.33061 | 2.560606 |
| CHL | | | 1335.106 | -6.97103 | 29.09479 | 32.33455 | 31.43915 | 14.28618 | 16.99624 | -7.77576 |
| RL | | | | 118.8937 | -4.85012 | -12.9345 | -10.0005 | -26.2522 | -13.2636 | 2.842424 |
| I | | | | | 15.88115 | 16.95818 | 21.17461 | 22.82073 | 15.82897 | 10.99697 |
| M | | | | | | 24.22182 | 29.27273 | 36.40727 | 23.63636 | 6.636364 |
| C | | | | | | | 41.59842 | 47.33291 | 29.70588 | 5.987879 |
| P | | | | | | | | 145.0431 | 56.97145 | 49.44545 |
| D | | | | | | | | | 34.99461 | 27.16061 |
| | 1 | 0.299482 | 0.392308 | -0.06807 | 0.115526 | 0.167229 | 0.215018 | 0.232442 | 0.135692 | 0.002191 |
| | | 12.69721 | -10.6923 | -15.3893 | -2.31423 | 2.009753 | 1.070395 | 7.650902 | 3.785751 | 2.11592 |
| | | | 1230.785 | 11.13031 | -1.62521 | -12.134 | -25.737 | -47.5234 | -19.0863 | -8.35828 |
| | | | | 115.7528 | 0.480323 | -5.2185 | -0.07944 | -15.5272 | -7.00265 | 2.943501 |
| | | | | | 6.834793 | 3.863194 | 4.337483 | 4.619171 | 5.203475 | 10.82543 |
| | | | | | | 5.268267 | 4.900277 | 10.05975 | 8.255508 | 6.388054 |
| | | | | | | | 10.26109 | 13.45609 | 9.929659 | 5.66861 |
| | | | | | | | | 108.421 | 35.59263 | 49.10031 |
| | | | | | | | | | 22.51432 | 26.95912 |
| | | | | | | -D2 = | | | | -0.00325 |
| | | 1 | -0.8421 | -1.21202 | -0.18226 | 0.158283 | 0.084302 | 0.602566 | 0.298156 | 0.166645 |
| | | | 1221.781 | -1.829 | -3.57403 | -10.4415 | -24.8357 | -41.0806 | -15.8983 | -6.57646 |
| | | | | 97.10069 | -2.32457 | -2.78264 | 1.217903 | -6.25411 | -2.41424 | 5.508039 |
| | | | | | 6.412994 | 4.229498 | 4.532577 | 6.013648 | 5.893477 | 11.21109 |
| | | | | | | 4.948157 | 4.730851 | 8.848739 | 7.656288 | 6.05314 |
| | | | | | | | 10.17086 | 12.81111 | 9.610514 | 5.490235 |
| | | | | | | | | 103.8108 | 33.31146 | 47.82533 |
| | | | | | | | | | 21.38557 | 26.32825 |
| | | | | | | -D2 = | | | | -0.35586 |
| | | | 1 | -0.0015 | -0.00293 | -0.00855 | -0.02033 | -0.03362 | -0.01301 | -0.00538 |
| | | | | 97.09795 | -2.32992 | -2.79827 | 1.180724 | -6.31561 | -2.43804 | 5.498194 |
| | | | | | 6.402539 | 4.198954 | 4.459926 | 5.893477 | 5.846971 | 11.19185 |
| | | | | | | 4.858922 | 4.518601 | 8.497657 | 7.520419 | 5.996936 |
| | | | | | | | 9.666013 | 11.97604 | 9.287343 | 5.356552 |
| | | | | | | | | 102.4295 | 32.77691 | 47.60421 |
| | | | | | | | | | 21.1787 | 26.24267 |
| | | | | | | -D2 = | | | | -0.39126 |
| | | | | 1 | -0.024 | -0.02882 | 0.01216 | -0.06504 | -0.02511 | 0.056625 |
| | | | | | 6.346631 | 4.131807 | 4.488258 | 5.74193 | 5.788469 | 11.32378 |
| | | | | | | 4.778279 | 4.552629 | 8.315648 | 7.450157 | 6.155389 |
| | | | | | | | 9.651655 | 12.05284 | 9.31699 | 5.289693 |
| | | | | | | | | 102.0188 | 32.61833 | 47.96183 |
| | | | | | | | | | 21.11748 | 26.38073 |
| | | | | | | -D2 = | | | | -0.70259 |
| | | | | | 1 | 0.651024 | 0.707187 | 0.904721 | 0.912054 | 1.784219 |
| | | | | | | 2.088374 | 1.630666 | 4.577515 | 3.681727 | -1.21668 |
| | | | | | | | 6.477616 | 7.992222 | 5.223458 | -2.71834 |
| | | | | | | | | 96.82391 | 27.38138 | 37.71697 |
| | | | | | | | | | 15.83809 | 16.05283 |
| | | | | | | -D2 = | | | | -20.9067 |
| | | | | | | 1 | 0.780831 | 2.191904 | 1.762963 | -0.58259 |
| | | | | | | | 5.204341 | 4.417958 | 2.348653 | -1.76834 |
| | | | | | | | | 86.79044 | 19.31139 | 40.38377 |
| | | | | | | | | | 9.347341 | 18.19776 |
| | | | | | | | | -D2 = | | -21.6155 |
| | | | | | | | 1 | 0.848899 | 0.451287 | -0.33978 |
| | | | | | | | | 83.04004 | 17.31762 | 41.88491 |
| | | | | | | | | | 8.287424 | 18.99579 |
| | | | | | | | -D2 = | | | -22.2164 |
| | | | | | | | | 1 | 0.208545 | 0.504394 |
| | | | | | | | | | 4.675913 | 10.26088 |
| | | | | | | | | | | -43.3429 |
| | | | | | | | | | 1 | 2.194412 |
| | | | | | | | | D2 - | | -65.8595 |

Table 2 29. Variance covariance matrix of Dsquare analysis between t-SOC and SBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 489.4413 | 153.476 | -3.16974 | -47.0519 | 56.28837 | 77.55367 | 108 1355 | 138 286 | 77 8932 | -53 3877 |
| CL | | 67.37656 | 11.75738 | -20.4584 | 13 81056 | 23.54783 | 34.04125 | 49.10363 | 27.07373 | -20 3021 |
| CHL | | | 2312.668 | -77 6268 | -0 53308 | 10.57501 | -8 32239 | 1.44494 | 22.71544 | -61.0561 |
| RL | | | | 120 4977 | -7.29917 | -8.94212 | -5.33502 | -23.3267 | -13.2356 | -19.7968 |
| I | | | | | 15.58011 | 12.67806 | 16.09933 | 21.00307 | 14.25609 | 6.951872 |
| M | | | | | | 21.40201 | 23.39141 | 31.94355 | 20.48628 | -1.09893 |
| C | | | | | | | 36.84175 | 44.7601 | 25.97643 | -4.54545 |
| P | | | | | | | | 133.2203 | 52.86071 | 44 86898 |
| D | | | | | | | | | 32.1832 | 24 84492 |
| | 1 | 0.313574 | -0.00648 | -0.09613 | 0.115005 | 0.158453 | 0.220937 | 0 282539 | 0.159147 | -0.10908 |
| | | 19.25051 | 12.75132 | -5.7041 | -3.84 | -0.77097 | 0.132777 | 5.740751 | 2.64846 | -3.56115 |
| | | | 2312.648 | -77.9315 | -0.16854 | 11.07727 | -7 62208 | 2.340512 | 23.21989 | -61.4019 |
| | | | | 115.9744 | -1.88794 | -1.48657 | 5.060481 | -10.0328 | -5.74741 | -24.9292 |
| | | | | | 9.10665 | 3.758967 | 3.663162 | 5 099434 | 5.297955 | 13.09174 |
| | | | | | | 9.113362 | 6.256966 | 10 03165 | 8.143837 | 7.360536 |
| | | | | | | | 12 95065 | 14.20765 | 8.76697 | 7.249845 |
| | | | | | | | | 94.14915 | 30.85288 | 59.95307 |
| | | | | | | | | | 19.78672 | 33.34142 |
| | | | | | | -D2 = | | | | -5.82347 |
| | | 1 | 0.662389 | -0.29631 | -0.19948 | -0.04005 | 0.006897 | 0.298213 | 0.137579 | -0.18499 |
| | | | 2304.201 | -74.1532 | 2.375037 | 11.58795 | -7.71003 | -1.4621 | 21.46558 | -59.043 |
| | | | | 114.2843 | -3.02577 | -1.71502 | 5.099824 | -8.33172 | -4.96265 | -25 9844 |
| | | | | | 8.340664 | 3.605177 | 3.689648 | 6.244573 | 5.826258 | 12.38138 |
| | | | | | | 9.082485 | 6.262284 | 10.26156 | 8.249907 | 7.217914 |
| | | | | | | | 12.94974 | 14.16805 | 8.748702 | 7.274407 |
| | | | | | | | | 92.43718 | 30 06308 | 61.01505 |
| | | | | | | | | | 19 42235 | 33.83136 |
| | | | | | | -D2 = | | | | -6.48225 |
| | | | 1 | -0.03218 | 0.001031 | 0.005029 | -0.00335 | -0 00063 | 0.009316 | -0 02562 |
| | | | | 111.8979 | -2.94934 | -1.3421 | 4.851702 | -8.37878 | -4.27185 | -27.8845 |
| | | | | | 8.338216 | 3.593233 | 3.697595 | 6.24608 | 5.804133 | 12.44224 |
| | | | | | | 9.024209 | 6.301058 | 10.26892 | 8.141955 | 7.514844 |
| | | | | | | | 12.92394 | 14.16316 | 8 820528 | 7.076845 |
| | | | | | | | | 92.43626 | 30.0767 | 60.97759 |
| | | | | | | | | | 19.22238 | 34 3814 |
| | | | | | | -D2 = | | | | -7.99517 |
| | | | | 1 | -0.02636 | -0.01199 | 0.043358 | -0.07488 | -0.03818 | -0.2492 |
| | | | | | 8.260479 | 3.557859 | 3.825474 | 6.025237 | 5 691538 | 11.70728 |
| | | | | | | 9.008112 | 6.359249 | 10.16842 | 8.090719 | 7.180399 |
| | | | | | | | 12.71358 | 14.52645 | 9.005748 | 8.285868 |
| | | | | | | | | 91.80886 | 29.75683 | 58.88963 |
| | | | | | | | | | 19.0593 | 33.31687 |
| | | | | | | -D2 = | | | | -14.9439 |
| | | | | | 1 | 0.430709 | 0.463106 | 0.729405 | 0.689008 | 1.417264 |
| | | | | | | 7.475711 | 4.711585 | 7.5733 | 5.639324 | 2.137975 |
| | | | | | | | 10.94198 | 11.73613 | 6.369965 | 2 864164 |
| | | | | | | | | 87 41402 | 25 60539 | 50 35028 |
| | | | | | | | | | 15.13778 | 25.25046 |
| | | | | | | -D2 = | | | | -31.5362 |
| | | | | | | 1 | 0.630252 | 1.013054 | 0.754353 | 0.285989 |
| | | | | | | | 7.972491 | 6.963037 | 2.815767 | 1 5167 |
| | | | | | | | | 79.74186 | 19.89245 | 48.1844 |
| | | | | | | | | | 10.88374 | 23.63767 |
| | | | | | | | | -D2 = | | -32.1476 |
| | | | | | | | 1 | 0.873383 | 0.353185 | 0.190242 |
| | | | | | | | | 73.66046 | 17.43321 | 46.85974 |
| | | | | | | | | | 9.889253 | 23.102 |
| | | | | | | | -D2 = | | | -32.4361 |
| | | | | | | | | 1 | 0.23667 | 0.636159 |
| | | | | | | | | | 5.76334 | 12.01171 |
| | | | | | | | | | | -62 2464 |
| | | | | | | | | | 1 | 2 084158 |
| | | | | | | | | D2 | | 87 2807 |

Table 2.30 Variance covariance matrix of Dsquare analysis between t-SOC and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 483.7802 | 157.8605 | 36.0299 | -29.2739 | 50.06751 | 83.67357 | 107.0223 | 144.9792 | 88.29126 | -81.5747 |
| CL | | 71.76725 | 30.31047 | -15.364 | 16.41897 | 29.43222 | 34.36411 | 52.41416 | 30.80668 | -31.737 |
| CHL | | | 1275.463 | 66.61391 | -15.5628 | 4.863366 | 1.095644 | -1.85755 | 15.04113 | -302.266 |
| RL | | | | 92.96199 | -5.64854 | -6.74134 | -2.97064 | -24.0026 | -12.4533 | -31.1623 |
| I | | | | | 16.35308 | 13.82846 | 17.16383 | 21.89272 | 16.12284 | 4.435065 |
| M | | | | | | 20.93642 | 25.81534 | 35.28287 | 23.28193 | -7.29221 |
| C | | | | | | | 36.42093 | 47.50616 | 29.31723 | -12.2955 |
| P | | | | | | | | 148.284 | 59.23336 | 42.93831 |
| D | | | | | | | | | 36.48525 | 23.37013 |
| | 1 | 0.326306 | 0.074476 | -0.06051 | 0.103492 | 0.172958 | 0.221221 | 0.29968 | 0.182503 | -0.16862 |
| | | 20.25641 | 18.55369 | -5.81177 | 0.081632 | 2.129026 | -0.55791 | 5.106551 | 1.996703 | -5.1187 |
| | | | 1272.78 | 68.79411 | -19.2916 | -1.36829 | -6.87492 | -12.655 | 8.465567 | -296.191 |
| | | | | 91.1906 | -2.61891 | -1.67818 | 3.505362 | -15.2298 | -7.11075 | -36.0985 |
| | | | | | 11.17149 | 5.168898 | 6.087852 | 6.888495 | 6.985374 | 12.87741 |
| | | | | | | 6.464422 | 7.305007 | 10.20758 | 8.011264 | 6.816769 |
| | | | | | | | 12.74538 | 15.43373 | 9.785371 | 5.750561 |
| | | | | | | | | 104.8367 | 32.77424 | 67.38461 |
| | | | | | | | | | 20.37185 | 38.25774 |
| | | | | | | -D2 = | | | | -13.7551 |
| | | 1 | 0.915942 | -0.28691 | 0.00403 | 0.105104 | -0.02754 | 0.252096 | 0.098571 | -0.2527 |
| | | | 1255.786 | 74.11735 | -19.3664 | -3.31835 | -6.36391 | -17.3323 | 6.636704 | -291.502 |
| | | | | 89.52314 | -2.59549 | -1.06735 | 3.345292 | -13.7646 | -6.53788 | -37.5671 |
| | | | | | 11.17116 | 5.160318 | 6.0901 | 6.867915 | 6.977328 | 12.89804 |
| | | | | | | 6.240653 | 7.363645 | 9.670866 | 7.801403 | 7.354763 |
| | | | | | | | 12.73001 | 15.57438 | 9.840365 | 5.60958 |
| | | | | | | | | 103.5493 | 32.27088 | 68.67501 |
| | | | | | | | | | 20.17503 | 38.7623 |
| | | | | | | -D2 = | | | | -15.0485 |
| | | | 1 | 0.059021 | -0.01542 | -0.00264 | -0.00507 | -0.0138 | 0.005285 | -0.23213 |
| | | | | 85.14868 | -1.45248 | -0.87149 | 3.720894 | -12.7417 | -6.92958 | -20.3624 |
| | | | | | 10.87249 | 5.109143 | 5.991958 | 6.600622 | 7.079677 | 8.402576 |
| | | | | | | 6.231884 | 7.346829 | 9.625066 | 7.81894 | 6.584483 |
| | | | | | | | 12.69776 | 15.48654 | 9.873997 | 4.132342 |
| | | | | | | | | 103.3101 | 32.36248 | 64.65171 |
| | | | | | | | | | 20.13996 | 40.30286 |
| | | | | | | -D2 = | | | | -82.7143 |
| | | | | 1 | -0.01706 | -0.01023 | 0.043699 | -0.14964 | -0.08138 | -0.23914 |
| | | | | | 10.84772 | 5.094277 | 6.055429 | 6.383273 | 6.961471 | 8.055231 |
| | | | | | | 6.222965 | 7.384912 | 9.494655 | 7.748016 | 6.376074 |
| | | | | | | | 12.53516 | 16.04334 | 10.17681 | 5.022155 |
| | | | | | | | | 101.4034 | 31.32554 | 61.60467 |
| | | | | | | | | | 19.57601 | 38.64572 |
| | | | | | | -D2 = | | | | -87.5837 |
| | | | | | 1 | 0.469617 | 0.558221 | 0.588444 | 0.641745 | 0.742574 |
| | | | | | | 3.830604 | 4.541177 | 6.496959 | 4.478788 | 2.593197 |
| | | | | | | | 9.154893 | 12.48006 | 6.290769 | 0.525552 |
| | | | | | | | | 97.64723 | 27.2291 | 56.86462 |
| | | | | | | | | | 15.10852 | 33.47631 |
| | | | | | | -D2 = | | | | -93.5653 |
| | | | | | | 1 | 1.185499 | 1.696067 | 1.169212 | 0.676968 |
| | | | | | | | 3.771331 | 4.777919 | 0.981169 | -2.54868 |
| | | | | | | | | 86.62795 | 19.63278 | 52.46638 |
| | | | | | | | | | 9.87187 | 30.44432 |
| | | | | | | | | -D2 = | | -95.3209 |
| | | | | | | | 1 | 1.266905 | 0.260165 | -0.6758 |
| | | | | | | | | 80.57478 | 18.30973 | 55.69532 |
| | | | | | | | | | 9.616604 | 31.10739 |
| | | | | | | | -D2 = | | | -97.0433 |
| | | | | | | | | 1 | 0.228232 | 0.691225 |
| | | | | | | | | | 5.419482 | 18.39595 |
| | | | | | | | | | | -135.541 |
| | | | | | | | | | 1 | 3.394411 |
| | | | | | | | | D2 = | | 197.985 |

Table 2.31. Variance covariance matrix of Dsquare analysis between WBC and SBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 619.3423 | 182.2682 | 133.5775 | -25.6146 | 55.67663 | 77.81214 | 107.6102 | 40.06072 | 21.64769 | -54.8725 |
| CL | | 70.79254 | 21.08096 | -18.3716 | 13.61701 | 21.96395 | 33.15591 | 11.90038 | 7.206199 | -22.8627 |
| CHL | | | 2243.931 | -91.3994 | 25.86142 | 24.45683 | 17.26398 | 12.65351 | 13.18314 | -53.2804 |
| RL | | | | 124.9182 | -4.1309 | -6.29269 | -2.36989 | -4.34573 | -3.15822 | -22.6392 |
| I | | | | | 11.89035 | 8.495256 | 9.634946 | 4.611765 | 2.30506 | -4.0451 |
| M | | | | | | 14.84867 | 15.34677 | 5.364326 | 2.9426 | -7.73529 |
| C | | | | | | | 28.12043 | 6.929032 | 4.218817 | -10.5333 |
| P | | | | | | | | 5.163567 | 1.572676 | -4.57647 |
| D | | | | | | | | | 1.482195 | -2.31569 |
| | 1 | 0.294293 | 0.215676 | -0.04136 | 0.089896 | 0.125637 | 0.173749 | 0.064683 | 0.034953 | -0.0886 |
| | | 17.15227 | -18.23 | -10.8334 | -2.76823 | -0.93563 | 1.486969 | 0.110785 | 0.835432 | -6.71413 |
| | | | 2215.122 | -85.8749 | 13.85329 | 7.674594 | -5.945 | 4.013361 | 8.514249 | -41.4457 |
| | | | | 123.8588 | -1.82823 | -3.07455 | 2.08063 | -2.68891 | -2.26292 | -24.9086 |
| | | | | | 6.885227 | 1.500227 | -0.03882 | 1.010451 | 0.359011 | 0.887745 |
| | | | | | | 5.072609 | 1.826979 | 0.331229 | 0.222855 | -0.84129 |
| | | | | | | | 9.423245 | -0.03148 | 0.457549 | -0.99927 |
| | | | | | | | | 2.572333 | 0.172445 | -1.02717 |
| | | | | | | | | | 0.725549 | -0.39774 |
| | | | | | | -D2 = | | | | -4.8616 |
| | | 1 | -1.06283 | -0.6316 | -0.16139 | -0.05455 | 0.086692 | 0.006459 | 0.048707 | -0.39144 |
| | | | 2195.746 | -97.389 | 10.91112 | 6.680175 | -4.3646 | 4.131107 | 9.402173 | -48.5817 |
| | | | | 117.0164 | -3.57665 | -3.6655 | 3.019801 | -2.61893 | -1.73526 | -29.1493 |
| | | | | | 6.438457 | 1.349224 | 0.201163 | 1.028331 | 0.493843 | -0.19586 |
| | | | | | | 5.021571 | 1.908091 | 0.337272 | 0.268426 | -1.20753 |
| | | | | | | | 9.294336 | -0.04109 | 0.385123 | -0.41721 |
| | | | | | | | | 2.571617 | 0.167049 | -0.9838 |
| | | | | | | | | | 0.684858 | -0.07072 |
| | | | | | | -D2 = | | | | -7.4898 |
| | | | 1 | -0.04435 | 0.004969 | 0.003042 | -0.00199 | 0.001881 | 0.004282 | -0.02213 |
| | | | | 112.6969 | -3.09271 | -3.36921 | 2.826216 | -2.43571 | -1.31824 | -31.304 |
| | | | | | 6.384238 | 1.316029 | 0.222852 | 1.007803 | 0.447122 | 0.045552 |
| | | | | | | 5.001248 | 1.92137 | 0.324704 | 0.239822 | -1.05973 |
| | | | | | | | 9.285661 | -0.03288 | 0.403813 | -0.51378 |
| | | | | | | | | 2.563845 | 0.14936 | -0.8924 |
| | | | | | | | | | 0.644598 | 0.137308 |
| | | | | | | -D2 = | | | | -8.56469 |
| | | | | 1 | -0.02744 | -0.0299 | 0.025078 | -0.02161 | -0.0117 | -0.27777 |
| | | | | | 6.299366 | 1.223568 | 0.300411 | 0.94096 | 0.410946 | -0.81352 |
| | | | | | | 4.900521 | 2.005863 | 0.251885 | 0.200411 | -1.9956 |
| | | | | | | | 9.214785 | 0.028206 | 0.436872 | 0.271265 |
| | | | | | | | | 2.511202 | 0.120868 | -1.56897 |
| | | | | | | | | | 0.629178 | -0.22886 |
| | | | | | | -D2 = | | | | -17.2601 |
| | | | | | 1 | 0.194237 | 0.047689 | 0.149374 | 0.065236 | -0.12914 |
| | | | | | | 4.66286 | 1.947512 | 0.069116 | 0.12059 | -1.83759 |
| | | | | | | | 9.200458 | -0.01667 | 0.417274 | 0.310061 |
| | | | | | | | | 2.370647 | 0.059484 | -1.44745 |
| | | | | | | | | | 0.60237 | -0.17579 |
| | | | | | | -D2 = | | | | -17.3651 |
| | | | | | | 1 | 0.417665 | 0.014823 | 0.025862 | -0.39409 |
| | | | | | | | 8.387051 | -0.04554 | 0.366908 | 1.077558 |
| | | | | | | | | 2.369623 | 0.057696 | -1.42021 |
| | | | | | | | | | 0.599251 | -0.12827 |
| | | | | | | | | -D2 = | | -18.0893 |
| | | | | | | | 1 | -0.00543 | 0.043747 | 0.128479 |
| | | | | | | | | 2.369376 | 0.059689 | -1.41436 |
| | | | | | | | | | 0.5832 | -0.17541 |
| | | | | | | | -D2 = | | | -18.2278 |
| | | | | | | | | 1 | 0.025102 | -0.50694 |
| | | | | | | | | | 0.581696 | -0.13978 |
| | | | | | | | | | | -19.072 |
| | | | | | | | | | 1 | -0.24029 |
| | | | | | | | | -D2 = | | -19.1056 |

Table.2.32. Variance covariance matrix of Dsquare analysis between WBC and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 628.408 | 189 1112 | 181.8287 | -8.07951 | 50.27891 | 83.08546 | 106 5997 | 35 2736 | 24.53401 | -83 0595 |
| CL | | 74 92198 | 37.98257 | -13.7815 | 15.83206 | 26.83801 | 33 3378 | 10.75191 | 8 277211 | -34.2976 |
| CHL | | | 1347.534 | 30.75986 | 15 8068 | 21.04847 | 28 07798 | 11.02372 | 5 583844 | -294.49 |
| RL | | | | 101.7897 | -2.37662 | -4.12245 | -0 0256 | -2.89133 | -1 40799 | -34 0048 |
| I | | | | | 12.15757 | 9.033163 | 9 854762 | 3.618112 | 2.62466 | -6.5619 |
| M | | | | | | 13.74745 | 16.5625 | 5.378827 | 3 459184 | -13.9286 |
| C | | | | | | | 26.8253 | 5 229464 | 4.75119 | -18.2833 |
| P | | | | | | | | 4 354974 | 1.539796 | -6 50714 |
| D | | | | | | | | | 1.880272 | -3.79048 |
| | 1 | 0.300937 | 0.289348 | -0.01286 | 0.08001 | 0.132216 | 0.169635 | 0.056132 | 0.039042 | -0.13217 |
| | | 18.01144 | -16.7364 | -11.35 | 0.701275 | 1.834524 | 1.258007 | 0.136784 | 0.894019 | -9.30194 |
| | | | 1294 922 | 33.09765 | 1.258694 | -2 99215 | -2.76645 | 0 817376 | -1 51503 | -270 457 |
| | | | | 101.6858 | -1.73017 | -3.05421 | 1.344968 | -2.43781 | -1.09256 | -35.0727 |
| | | | | | 8.134753 | 2.385497 | 1.325721 | 0.795872 | 0.661694 | 0.083687 |
| | | | | | | 2.762239 | 2 468335 | 0.7151 | 0 215399 | -2.94679 |
| | | | | | | | 8.742305 | -0.75416 | 0 589374 | -4.19357 |
| | | | | | | | | 2.375008 | 0.16266 | -1.84487 |
| | | | | | | | | | 0 922426 | -0.5477 |
| | | | | | | -D2 = | | | | -10.9784 |
| | | 1 | -0.92921 | -0.63016 | 0.038935 | 0.101853 | 0.069845 | 0 007594 | 0.049636 | -0.51645 |
| | | | 1279.37 | 22.55109 | 1.910325 | -1.28749 | -1.5975 | 0.944477 | -0.6843 | -279.101 |
| | | | | 94 53352 | -1.28826 | -1.89817 | 2.137711 | -2 35161 | -0.52918 | -40.9344 |
| | | | | | 8.107449 | 2.31407 | 1.276741 | 0.790547 | 0 626885 | 0.445857 |
| | | | | | | 2.575386 | 2.340203 | 0.701168 | 0.124341 | -1.99936 |
| | | | | | | | 8.654439 | -0.76371 | 0.526931 | -3.54388 |
| | | | | | | | | 2.373969 | 0 155871 | -1.77423 |
| | | | | | | | | | 0.878051 | -0.08599 |
| | | | | | | -D2 = | | | | -15.7823 |
| | | | 1 | 0.017627 | 0.001493 | -0.00101 | -0 00125 | 0.000738 | -0.00053 | -0.21815 |
| | | | | 94.13602 | -1.32193 | -1.87548 | 2.165869 | -2.36826 | -0.51712 | -36 0147 |
| | | | | | 8.104596 | 2.315992 | 1.279126 | 0.789136 | 0 627907 | 0.862604 |
| | | | | | | 2.574091 | 2.338595 | 0.702118 | 0 123652 | -2.28023 |
| | | | | | | | 8.652445 | -0.76253 | 0 526077 | -3.89238 |
| | | | | | | | | 2.373272 | 0.156376 | -1.56819 |
| | | | | | | | | | 0 877685 | -0.23527 |
| | | | | | | -D2 = | | | | -76.6695 |
| | | | | 1 | -0.01404 | -0.01992 | 0.023008 | -0.02516 | -0.00549 | -0.38258 |
| | | | | | 8.086033 | 2.289655 | 1.309541 | 0.755879 | 0.620645 | 0.356856 |
| | | | | | | 2.536725 | 2.381746 | 0.654935 | 0.113349 | -2.99775 |
| | | | | | | . | 8.602613 | -0.70804 | 0.537975 | -3.06375 |
| | | | | | | | | 2.313692 | 0.143366 | -2.47424 |
| | | | | | | | | | 0.874844 | -0.43312 |
| | | | | | | -D2 = | | | | -90.4481 |
| | | | | | 1 | 0.283162 | 0.161951 | 0.09348 | 0.076755 | 0.044132 |
| | | | | | | 1.888383 | 2.010934 | 0.440899 | -0.06239 | -3.0988 |
| | | | | | | | 8 390531 | -0.83046 | 0.437461 | -3.12155 |
| | | | | | | | | 2.243032 | 0.085349 | -2.5076 |
| | | | | | | | | | 0 827206 | -0 46051 |
| | | | | | | -D2 = | | | | -90 4638 |
| | | | | | | 1 | 1 064898 | 0.23348 | -0 03304 | -1.64098 |
| | | | | | | | 6.249092 | -1.29997 | 0.503903 | 0.178359 |
| | | | | | | | | 2.140091 | 0.099916 | -1.78409 |
| | | | | | | | | | 0.825145 | -0.56289 |
| | | | | | | | | -D2 = | | -95.5489 |
| | | | | | | | 1 | -0 20803 | 0 080636 | 0.028542 |
| | | | | | | | | 1 869664 | 0 204741 | -1 74699 |
| | | | | | | | | | 0 784512 | -0 57728 |
| | | | | | | | -D2 = | | | -95 554 |
| | | | | | | | | 1 | 0.109507 | -0.93439 |
| | | | | | | | | | 0.762091 | -0.38597 |
| | | | | | | | | | | -97.1863 |
| | | | | | | | | | 1 | -0 50646 |
| | | | | | | | | -D2 = | | -97.3818 |

Table.2.33. Variance covariance matrix of Dsquare analysis between SBC and OBC

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 462.1623 | 145.4698 | -54.741 | -11.4371 | 32.33172 | 52.88564 | 75.3625 | 26.08477 | 16.35658 | -28.187 |
| CL | | 69.32391 | -11.4215 | -6.93557 | 9.591947 | 16.27822 | 24.4875 | 8.532178 | 5.982913 | -11.4349 |
| CHL | | | 2226.512 | -35.3457 | -9.97241 | 2.217297 | -7.48333 | -0.3159 | 11.49195 | -241.21 |
| RL | | | | 104.3736 | -4.74566 | -1.11674 | 3.508333 | -1.81583 | -2.17318 | -11.3655 |
| I | | | | | 12.13487 | 5.709384 | 6.041667 | 3.262395 | 2.089356 | -2.51681 |
| M | | | | | | 11.90791 | 12.11667 | 3.430042 | 1.969258 | -6.19328 |
| C | | | | | | | 23.52917 | 5.720833 | 3.058333 | -7.75 |
| P | | | | | | | | 3.093662 | 1.535574 | -1.93067 |
| D | | | | | | | | | 1.557633 | -1.47479 |
| | 1 | 0.314759 | -0.11845 | -0.02475 | 0.069958 | 0.114431 | 0.163065 | 0.056441 | 0.035391 | -0.06099 |
| | | 23.53598 | 5.808718 | -3.33564 | -0.58476 | -0.36802 | 0.766468 | 0.32176 | 0.83453 | -2.56277 |
| | | | 2220.028 | -36.7004 | -6.14287 | 8.481355 | 1.443003 | 2.773723 | 13.42931 | -244.549 |
| | | | | 104.0906 | -3.94555 | 0.192023 | 5.373327 | -1.17031 | -1.7684 | -12.0631 |
| | | | | | 9.873027 | 2.009636 | 0.769494 | 1.437569 | 0.94509 | -0.54492 |
| | | | | | | 5.856162 | 3.492868 | 0.445139 | 0.097559 | -2.96782 |
| | | | | | | | 11.24018 | 1.46732 | 0.391147 | -3.15369 |
| | | | | | | | | 1.62142 | 0.612397 | -0.33978 |
| | | | | | | | | | 0.97875 | -0.47721 |
| | | | | | | -D2 = | | | | -1.71911 |
| | | 1 | 0.246802 | -0.14173 | -0.02485 | -0.01564 | 0.032566 | 0.013671 | 0.035458 | -0.10889 |
| | | | 2218.594 | -35.8772 | -5.99855 | 8.572182 | 1.253838 | 2.694312 | 13.22334 | -243.916 |
| | | | | 103.6178 | -4.02842 | 0.139865 | 5.481954 | -1.12471 | -1.65013 | -12.4263 |
| | | | | | 9.858499 | 2.000492 | 0.788537 | 1.445564 | 0.965824 | -0.60859 |
| | | | | | | 5.850407 | 3.504853 | 0.45017 | 0.110608 | -3.00789 |
| | | | | | | | 11.21522 | 1.456842 | 0.36397 | -3.07023 |
| | | | | | | | | 1.617021 | 0.600988 | -0.30474 |
| | | | | | | | | | 0.94916 | -0.38634 |
| | | | | | | -D2 = | | | | -1.99816 |
| | | | 1 | -0.01617 | -0.0027 | 0.003864 | 0.000565 | 0.001214 | 0.00596 | -0.10994 |
| | | | | 103.0376 | -4.12542 | 0.278487 | 5.50223 | -1.08114 | -1.43629 | -16.3707 |
| | | | | | 9.84228 | 2.023669 | 0.791927 | 1.452848 | 1.001577 | -1.26808 |
| | | | | | | 5.817286 | 3.500009 | 0.439759 | 0.059516 | -2.06545 |
| | | | | | | | 11.21451 | 1.455319 | 0.356497 | -2.93238 |
| | | | | | | | | 1.613749 | 0.584929 | -0.00853 |
| | | | | | | | | | 0.870346 | 1.067455 |
| | | | | | | -D2 = | | | | -28.8147 |
| | | | | 1 | -0.04004 | 0.002703 | 0.0534 | -0.01049 | -0.01394 | -0.15988 |
| | | | | | 9.677106 | 2.03482 | 1.012225 | 1.409562 | 0.94407 | -1.92353 |
| | | | | | | 5.816533 | 3.485137 | 0.442682 | 0.063398 | -2.0212 |
| | | | | | | | 10.92069 | 1.513052 | 0.433195 | -2.05818 |
| | | | | | | | | 1.602405 | 0.569859 | -0.1803 |
| | | | | | | | | | 0.850324 | 0.839256 |
| | | | | | | -D2 = | | | | -31.4157 |
| | | | | | 1 | 0.210271 | 0.1046 | 0.145659 | 0.097557 | -0.19877 |
| | | | | | | 5.388669 | 3.272295 | 0.146291 | -0.13511 | -1.61674 |
| | | | | | | | 10.81481 | 1.365612 | 0.334445 | -1.85698 |
| | | | | | | | | 1.397089 | 0.432346 | 0.099882 |
| | | | | | | | | | 0.758224 | 1.02691 |
| | | | | | | -D2 = | | | | -31.7981 |
| | | | | | | 1 | 0.607255 | 0.027148 | -0.02507 | -0.30003 |
| | | | | | | | 8.827694 | 1.276776 | 0.416493 | -0.87521 |
| | | | | | | | | 1.393117 | 0.436014 | 0.143773 |
| | | | | | | | | | 0.754836 | 0.986372 |
| | | | | | | | | -D2 = | | -32.2831 |
| | | | | | | | 1 | 0.144633 | 0.04718 | -0.09914 |
| | | | | | | | | 1.208453 | 0.375776 | 0.270358 |
| | | | | | | | | | 0.735186 | 1.027665 |
| | | | | | | | -D2 = | | | -32.3699 |
| | | | | | | | | 1 | 0.310956 | 0.223722 |
| | | | | | | | | | 0.618336 | 0.943596 |
| | | | | | | | | | | -32.4304 |
| | | | | | | | | | 1 | 1.526025 |
| | | | | | | | | -D2 = | | -33.8703 |

Table.2.34.Differences between mean values of various measurements of male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| Pair | Dp | df1 | df2 | F |
|---|---|---|---|---|
| MALE MORPHOTYPES | | | | |
| SM X WOC | 33.4902 | 54 | 9 | 51.65 * |
| SM X SOC | 69.0883 | 43 | 9 | 78.89 * |
| SM X t-SOC | 26.3558 | 30 | 9 | 22.19 * |
| SM X WBC | 107.1101 | 54 | 9 | 165.20 * |
| SM X SBC | 223.3955 | 58 | 9 | 370.82 * |
| SM X OBC | 451.8774 | 52 | 9 | 668.15 * |
| WOC X SOC | 4.1703 | 39 | 9 | 4.47 * |
| WOC X t-SOC | 1.5764 | 42 | 9 | 1.87 |
| WOC X WBC | 64.3263 | 50 | 9 | 92.42 * |
| WOC X SBC | 105.0481 | 54 | 9 | 162.02 * |
| WOC X OBC | 259.5109 | 48 | 9 | 357.95 * |
| SOC X t-SOC | 1.3320 | 31 | 9 | 1.20 |
| SOC X WBC | 73.5573 | 39 | 9 | 78.89 * |
| SOC X SBC | 148.1200 | 43 | 9 | 169.13 * |
| SOC X OBC | 202.5405 | 37 | 9 | 209.45 * |
| t-SOC X WBC | 65.8594 | 42 | 9 | 78.02 * |
| t-SOC X SBC | 87.2806 | 46 | 9 | 110.35 * |
| t-SOC X OBC | 197.9840 | 40 | 9 | 225.85 * |
| WBC X SBC | 19.1056 | 54 | 9 | 29.47 * |
| WBC X SBC | 97.3818 | 48 | 9 | 134.32 * |
| SBC X OBC | 33.8703 | 52 | 9 | 50.08 * |

* = Significant at 1% level

Table.2.35. Approximate distance between various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | WOC | SOC | t-SOC | WBC | SBC | OBC |
|---|---|---|---|---|---|---|
| SM | 5.79 | 8.31 | 5.13 | 10.35 | 14.95 | 21.26 |
| WOC | | 2.04 | 1.26 | 8.02 | 10.25 | 16.11 |
| SOC | | | 1.15 | 5.58 | 12.17 | 14.23 |
| WBC | | | | 8.12 | 9.34 | 14.07 |
| SBC | | | | | 4.37 | 9.87 |
| OBC | | | | | | 5.82 |

Table.2.36. Comparison of regressions of TOTAL LENGTH X ROSTRAL LENGTH of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 1587.2 | 402.2 | 113.2 | 0.253402 | 4 | 11.28163 | 3.760543 | |
| SOF | 6 | 1965.333 | 1121.333 | 729.3333 | 0.570556 | 5 | 89.54953 | 22.38738 | |
| TOF | 20 | 13692.2 | 4785.2 | 1817.2 | 0.349484 | 19 | 144.8508 | 8.047269 | |
| WBF | 12 | 6237.667 | 2130.167 | 908.9167 | 0.341501 | 11 | 181.4636 | 18.14636 | |
| SBF | 15 | 7045.733 | 2461.4 | 976.4 | 0.349346 | 14 | 116.5193 | 8.963025 | |
| WITH IN | | | | | | 53 | 543.6649 | 10.25783 | |
| Reg.Coeff. | | | | | | 4 | 109.3509 | 27.33772 | |
| COMMON | 58 | 30528.13 | 10900.3 | 4545.05 | 0.357058 | 57 | 653.0158 | 11.45642 | 2.665059 ** |
| Adj.Means | | | | | | 4 | 131.8387 | 32.95968 | 2.876962 ** |
| TOTAL | 58 | 48721.12 | 15965.93 | 6016.897 | 0.3277 | 61 | 784.8545 | | |

Comparison of slopes F= 27.33772 (4,53) 2.665059 **=Significant at 5% level (p=<0.05)

Comparison of elevation F= 32.95968 (4,57) 2.876962

Table.2.37. Comparison of regressions of TOTAL LENGTH X ISCHIUM OF SECOND CHELIPED of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| 1 | WOF | 5 | 1587.2 | 10.2 | 7.2 | 0.006426 | 4 | 7.134451 | 2.37815 | |
| 2 | SOF | 6 | 1965.333 | -109.333 | 22.83333 | -0.05563 | 5 | 16.75102 | 4.187754 | |
| 3 | TOF | 20 | 13692.2 | 1955.7 | 352.95 | 0.142833 | 19 | 73.61122 | 4.089512 | |
| 4 | WBF | 12 | 6237.667 | 825 | 135 | 0.132261 | 11 | 25.88468 | 2.588468 | |
| 5 | SBF | 15 | 7045.733 | 1194.467 | 276.9333 | 0.16953 | 14 | 74.43481 | 5.725754 | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | WITH IN | | | | | | 53 | 197.8162 | 3.732381 | |
| 9 | Reg.Coeff. | | | | | | 4 | 104.9763 | 26.24406 | |
| 10 | COMMON | 58 | 30528.13 | 3876.033 | 794.9167 | 0.126966 | 57 | 302.7924 | 5.312148 | 7.031454 * |
| 11 | Adj.Means | | | | | | 4 | 54.84172 | 13.71043 | 2.580958 ** |
| 12 | TOTAL | 58 | 48721.12 | 7242.19 | 1434.155 | 0.148646 | 61 | 357.6341 | | |

Comparison of slopes F= 26.24406 (4,53) 7.031454 *=Significant at 1% level (p=<0.01)

Comparison of elevation F= 13.71043 (4,57) 2.580958 **= Significant at 5% level (p=<0.05)

Table.2.38. Comparison of regressions of TOTAL LENGTH X CARPUS OF SECOND CHELIPED of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 1587.2 | 1.6 | 22.8 | 0.001008 | 4 | 22.79839 | 7.599462 | |
| SOF | 6 | 1965.333 | 300.6667 | 56.83333 | 0.152985 | 5 | 10.83582 | 2.708955 | |
| TOF | 20 | 13692.2 | 2210.6 | 578.8 | 0.16145 | 19 | 221.8995 | 12.32775 | |
| WBF | 12 | 6237.667 | 1552.833 | 420.9167 | 0.248945 | 11 | 34.34722 | 3.434722 | |
| SBF | 15 | 7045.733 | 1508.133 | 382.9333 | 0.214049 | 14 | 60.11865 | 4.624512 | |
| WITH IN | | | | | | 53 | 349.9996 | 6.603767 | |
| Reg.Coeff. | | | | | | 4 | 94.61198 | 23.653 | |
| COMMON | 58 | 30528.13 | 5573.833 | 1462.283 | 0.18258 | 57 | 444.6116 | 7.800204 | 3.581743 * |
| Adj.Means | | | | | | 4 | 101.9161 | 25.47904 | 3.266458 * |
| TOTAL | 58 | 48721.12 | 10506.53 | 2812.224 | 0.215646 | 61 | 546.5278 | | |

Comparison of slopes F= 23.653 (4,53) 3.581743 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 25.47904 (4,57) 3.266458

Table.2.39. Comparison of regressions of CARPACE LENGTH X CHELIPED LENGTH of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 15 | 424.9333 | 719.6 | 7387.6 | 1.693442 | 14 | 6168.999 | 474.5384 | |
| SOF | 38 | 2567.395 | 4348.711 | 15041.08 | 1.693822 | 37 | 7675.136 | 213.1982 | |
| TOF | 149 | 11533.97 | 20769.39 | 80715.36 | 1.800714 | 148 | 43315.62 | 294.6641 | |
| WBF | 136 | 11249.64 | 17587.19 | 80381.74 | 1.563356 | 135 | 52886.7 | 394.6768 | |
| SBF | 129 | 6640.76 | 18973.99 | 88232.81 | 2.857202 | 128 | 34020.28 | 267.8762 | |
| WITH IN | | | | | | 462 | 144066.7 | 311.8327 | |
| Reg.Coeff. | | | | | | 4 | 7580.283 | 1895.071 | |
| COMMON | 467 | 32416.7 | 62398.88 | 271758.6 | 1.924899 | 466 | 151647 | 325.4228 | 6.077203 * |
| Adj.Means | | | | | | 4 | 16411.17 | 4102.791 | 12.60757 * |
| TOTAL | 467 | 39591.49 | 86693.81 | 357892.3 | 2.189708 | 470 | 168058.2 | | |

Comparison of slopes F= 1895.071 (4,462) 6.077203 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 4102.791 (4,466) 12.60757

Table.2.40. Comparison of regressions of CARPACE LENGTH X ROSTRAL LENGTH of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | 83.8 | 113.2 | 1.085492 | 4 | 22.23575 | 7.411917 | |
| SOF | 6 | 790.8333 | 104.6667 | 729.3333 | 0.13235 | 5 | 715.4807 | 178.8702 | |
| TOF | 20 | 1405.2 | 1409.8 | 1817.2 | 1.003274 | 19 | 402.7849 | 22.37694 | |
| WBF | 12 | 832.9167 | 759.9167 | 908.9167 | 0.912356 | 11 | 215.602 | 21.5602 | |
| SBF | 15 | 588.4 | 683.6 | 976.4 | 1.161795 | 14 | 182.1971 | 14.01516 | |
| WITH IN | | | | | | 53 | 1538.301 | 29.02454 | |
| Reg.Coeff. | | | | | | 4 | 502.3996 | 125.5999 | |
| COMMON | 58 | 3694.55 | 3041.783 | 4545.05 | 0.823316 | 57 | 2040.7 | 35.80176 | 4.327369 ** |
| Adj Means | | | | | | 4 | 66.41702 | 16.60425 | 0.463783 |
| TOTAL | 58 | 6363.655 | 4988.034 | 6016.897 | 0.783832 | 61 | 2107.117 | | |

Comparison of slopes F= 125.5999 (4,53) 4.327369 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 16.60425 (4,57) 0.463783

Table.2.41. Comparison of regressions of CARPACE LENGTH X PLEURAL LENGTH of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 15 | 450185.9 | 169.2 | 31904.4 | 0.000376 | 14 | 31904.34 | 2454.18 | |
| SOF | 38 | 2567.395 | 402.7105 | 271.0789 | 0.156856 | 37 | 207.9115 | 5.775319 | |
| TOF | 149 | 11533.97 | 3922.745 | 5870.577 | 0.340104 | 148 | 4536.438 | 30.86012 | |
| WBF | 138 | 17698.15 | 5181.978 | 2612.384 | 0.292798 | 137 | 1095.113 | 8.0523 | |
| SBF | 129 | 6640.76 | 2213.783 | 5798.062 | 0.333363 | 128 | 5060.069 | 39.84306 | |
| WITH IN | | | | | | 464 | 42803.87 | 92.24971 | |
| Reg.Coeff. | | | | | | 4 | 3363.289 | 840.8222 | |
| COMMON | 469 | 488626.2 | 11800.42 | 46456.5 | 0.024334 | 468 | 46167.16 | 98.64777 | 9.114632 * |
| Adj Means | | | | | | 4 | 3411.745 | 852.9363 | 8.646281 * |
| TOTAL | 469 | 495744.8 | 16937.41 | 50157.58 | 0.034166 | 472 | 49578.9 | | |

Comparison of slopes F= 840.8222 (4,462) 9.114632 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 852.9363 (4,466) 8.646281

Table 2.42. Comparison of regressions of CARPACE LENGTH X TELSON LENGTH of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | 36.4 | 20.8 | 0.471503 | 4 | 3.637306 | 1.212435 | |
| SOF | 6 | 790.8333 | 43.33333 | 27.33333 | 0.054795 | 5 | 24.9589 | 6.239726 | |
| TOF | 20 | 1405.2 | 476.2 | 286.95 | 0.338884 | 19 | 125.5734 | 6.976298 | |
| WBF | 12 | 832.9167 | 274.0833 | 96.91667 | 0.329065 | 11 | 6.725563 | 0.672556 | |
| SBF | 15 | 588.4 | 131.4 | 43.73333 | 0.223317 | 14 | 14.38942 | 1.106878 | |
| WITH IN | | | | | | 53 | 175.2846 | 3.307256 | |
| Reg.Coeff. | | | | | | 4 | 50.2635 | 12.56587 | |
| COMMON | 58 | 3694.55 | 961.4167 | 475.7333 | 0.260226 | 57 | 225.5481 | 3.956983 | 3.799487 * |
| Adj Means | | | | | | 4 | 25.34314 | 6.335786 | 1.601166 |
| TOTAL | 58 | 6363.655 | 1644.897 | 676.069 | 0.258483 | 61 | 250.8912 | | |

Comparison of slopes F= 12.56587 (4,53) 3.799487 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 6.335786 (4,57) 1.601166

Table 2.43. Comparison of regressions of CARPACE LENGTH X ISCHIUM of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | -1.2 | 7.2 | -0.01554 | 4 | 7.181347 | 2.393782 | |
| SOF | 6 | 790.8333 | -5.16667 | 22.83333 | -0.00653 | 5 | 22.79958 | 5.699895 | |
| TOF | 20 | 1405.2 | 604.8 | 352.95 | 0.430401 | 19 | 92.64325 | 5.146847 | |
| WBF | 12 | 832.9167 | 287.5 | 135 | 0.345173 | 11 | 35.76288 | 3.576288 | |
| SBF | 15 | 4696.933 | 2289.933 | 1178.933 | 0.487538 | 14 | 62.50389 | 4.807991 | |
| WITH IN | | | | | | 53 | 220.8909 | 4.167754 | |
| Reg.Coeff. | | | | | | 4 | 183.4432 | 45.8608 | |
| COMMON | 58 | 7803.083 | 3175.867 | 1696.917 | 0.407002 | 57 | 404.3342 | 7.093582 | 11.00372 * |
| Adj.Means | | | | | | 4 | 124.8254 | 31.20634 | 4.399237 * |
| TOTAL | 58 | 9474.345 | 3796.345 | 2050.345 | 0.400697 | 61 | 529.1595 | | |

Comparison of slopes F= 45.8608 (4,53) 11.00372 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 31.20634 (4,57) 4.399237

Table 2 44. Comparison of regressions of CARPACE LENGTH X MERUS of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | -3.6 | 4.8 | -0.04663 | 4 | 4.632124 | 1.544041 | |
| SOF | 6 | 790.8333 | 13.83333 | 32.83333 | 0.017492 | 5 | 32.59136 | 8.14784 | |
| TOF | 20 | 1405.2 | 836 | 1067 | 0.594933 | 19 | 569.6359 | 31.64644 | |
| WBF | 12 | 832.9167 | 444.6667 | 262.6667 | 0.533867 | 11 | 25.27384 | 2.527384 | |
| SBF | 15 | 4696.933 | 2380.733 | 1262.933 | 0.50687 | 14 | 56.21167 | 4.323975 | |
| WITH IN | | | | | | 53 | 688.3449 | 12.98764 | |
| Reg.Coeff. | | | | | | 4 | 214.252 | 53.56299 | |
| COMMON | 58 | 7803.083 | 3671.633 | 2630.233 | 0.470536 | 57 | 902.5969 | 15.83503 | 4.124151 * |
| Adj.Means | | | | | | 4 | 155.5476 | 38.8869 | 2.455751 |
| TOTAL | 58 | 9474.345 | 4361.793 | 3066.224 | 0.460379 | 61 | 1058.144 | | |

Comparison of slopes F= 53.56299 (4,53) 4.124151 *=Significant at 1% level (p=<0.01)
Comparison of elevation F= 38.8869 (4,57) 2.455751

Table.2.45. Comparison of regressions of CARPACE LENGTH X CARPUS of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | -3.6 | 22.8 | -0.04663 | 4 | 22.63212 | 7.544041 | |
| SOF | 6 | 790.8333 | 17.83333 | 56.83333 | 0.02255 | 5 | 56.43119 | 14.1078 | |
| TOF | 20 | 1405.2 | 693.4 | 578.8 | 0.493453 | 19 | 236.6398 | 13.14665 | |
| WBF | 12 | 832.9167 | 549.0833 | 420.9167 | 0.65923 | 11 | 58.94467 | 5.894467 | |
| SBF | 15 | 4696.933 | 2958.867 | 1939.733 | 0.629957 | 14 | 75.77416 | 5.828782 | |
| WITH IN | | | | | | 53 | 450.4219 | 8.498527 | |
| Reg.Coeff. | | | | | | 4 | 291.21 | 72.80251 | |
| COMMON | 58 | 7803.083 | 4215.583 | 3019.083 | 0.540246 | 57 | 741.632 | 13.01109 | 8.566486 * |
| Adj.Means | | | | | | 4 | 160.3665 | 40.09164 | 3.081344 ** |
| TOTAL | 58 | 9474.345 | 5263.379 | 3826.017 | 0.55554 | 61 | 901.9985 | | |

Comparison of slopes F= 72.80251 (4,53) 8.566486 * =Significant at 1% level (p=<0.01)
Comparison of elevation F= 40.09164 (4,57) 3.081344 **=Significant at 5% level (p=<0.05)

Table.2.46. Comparison of regressions of CARPACE LENGTH X PROPODUS of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | 125 | 250 | 1.619171 | 4 | 47.60363 | 15.86788 | |
| SOF | 6 | 790.8333 | 60.83333 | 134.8333 | 0.076923 | 5 | 130.1538 | 32.53846 | |
| TOF | 20 | 1405.2 | 1633.2 | 2792.95 | 1.162254 | 19 | 894.756 | 49.70867 | |
| WBF | 12 | 832.9167 | 823.4167 | 1054.917 | 0.988594 | 11 | 240.8916 | 24.08916 | |
| SBF | 15 | 4696.933 | 4691.867 | 5257.733 | 0.998921 | 14 | 570.9279 | 43.91753 | |
| WITH IN | | | | | | 53 | 1884.333 | 35.55345 | |
| Reg.Coeff. | | | | | | 4 | 712.3894 | 178.0974 | |
| COMMON | 58 | 7803.083 | 7334.317 | 9490.433 | 0.939925 | 57 | 2596.722 | 45.55653 | 5.009284 * |
| Adj Means | | | | | | 4 | 840.9789 | 210.2447 | 4.615029 * |
| TOTAL | 58 | 9474.345 | 9367.931 | 12700.41 | 0.988768 | 61 | 3437.701 | | |

Comparison of slopes F= 178.0974 (4,53) 5.009284

Comparison of elevation F= 210.2447 (4,57) 4.615029

*=Significant at 1% level (p=<0.01)

Table.2.47. Comparison of regressions of CARPACE LENGTH X DACTYLUS of various female morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| WOF | 5 | 77.2 | 53.2 | 49.2 | 0.689119 | 4 | 12.53886 | 4.17962 | |
| SOF | 6 | 790.8333 | 48.33333 | 41.33333 | 0.061117 | 5 | 38.37935 | 9.594837 | |
| TOF | 20 | 1405.2 | 1036.8 | 876.95 | 0.737831 | 19 | 111.9669 | 6.220384 | |
| WBF | 12 | 832.9167 | 395.6667 | 326.6667 | 0.475038 | 11 | 138.7102 | 13.87102 | |
| SBF | 15 | 4696.933 | 2452.133 | 1517.733 | 0.522071 | 14 | 237.5453 | 18.27271 | |
| WITH IN | | | | | | 53 | 539.1406 | 10.17246 | |
| Reg Coeff. | | | | | | 4 | 236.4632 | 59.11581 | |
| COMMON | 58 | 7803.083 | 3986.133 | 2811.883 | 0.510841 | 57 | 775.6038 | 13.60708 | 5.811356 * |
| Adj.Means | | | | | | 4 | 268.2955 | 67.07388 | 4.929335 * |
| TOTAL | 58 | 9474.345 | 4981.966 | 3663.603 | 0.525837 | 61 | 1043.899 | | |

Comparison of slopes F= 59.11581 (4,53) 5.811356

Comparison of elevation F= 67.07388 (4,57) 4.929335

*=Significant at 1% level (p=<0.01)

Table.2.48. Variance covariance matrix of Dsquare analysis between WOF and SOF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 373.3495 | 91.6183 | 79.6720 | 64.2258 | 22.1828 | 39.1882 | 47.4839 | 117.2151 | 57.6022 | -17.8333 |
| CL | | 60.4950 | 29.2204 | 7.4853 | 6.4079 | 11.2842 | 14.4161 | 32.2373 | 17.2695 | -10.7444 |
| CHL | | | 734.1237 | 68.2151 | 1.6559 | -4.3065 | 32.0000 | 41.0323 | 8.7097 | -1.5000 |
| RL | | | | 62.3283 | 1.8466 | 6.8251 | 8.0796 | 15.0674 | 6.1964 | -8.3111 |
| I | | | | | 5.8724 | 5.1520 | 5.1376 | 10.5792 | 5.3211 | -2.8444 |
| M | | | | | | 9.5229 | 8.4280 | 15.9663 | 8.6760 | -3.3444 |
| C | | | | | | | 15.7935 | 22.6366 | 10.9591 | -4.0667 |
| P | | | | | | | | 59.2057 | 27.3025 | -6.8222 |
| D | | | | | | | | | 14.3670 | -2.8222 |
| | 1 | 0.2454 | 0.2134 | 0.1720 | 0.0594 | 0.1050 | 0.1272 | 0.3140 | 0.1543 | -0.0478 |
| | | 38.0123 | 9.6693 | -8.2754 | 0.9643 | 1.6676 | 2.7627 | 3.4732 | 3.1342 | -6.3682 |
| | | | 717.1218 | 54.5094 | -3.0779 | -12.6691 | 21.8670 | 16.0188 | -3.5825 | 2.3056 |
| | | | | 51.2798 | -1.9694 | 0.0837 | -0.0889 | -5.0967 | -3.7127 | -5.2433 |
| | | | | | 4.5544 | 2.8236 | 2.3164 | 3.6148 | 1.8987 | -1.7849 |
| | | | | | | 5.4096 | 3.4439 | 3.6630 | 2.6298 | -1.4726 |
| | | | | | | | 9.7544 | 7.7287 | 3.6331 | -1.7986 |
| | | | | | | | | 22.4054 | 9.2180 | -1.2234 |
| | | | | | | | | | 5.4799 | -0.0708 |
| | | | | | | -D2(1)= | | | | -0.8518 |
| | | 1 | 0.2544 | -0.2177 | 0.0254 | 0.0439 | 0.0727 | 0.0914 | 0.0825 | -0.1675 |
| | | | 714.6622 | 56.6144 | -3.3231 | -13.0933 | 21.1643 | 15.1353 | -4.3798 | 3.9255 |
| | | | | 49.4782 | -1.7595 | 0.4468 | 0.5126 | -4.3405 | -3.0303 | -6.6297 |
| | | | | | 4.5299 | 2.7813 | 2.2463 | 3.5267 | 1.8192 | -1.6233 |
| | | | | | | 5.3364 | 3.3227 | 3.5106 | 2.4923 | -1.1932 |
| | | | | | | | 9.5536 | 7.4763 | 3.4053 | -1.3357 |
| | | | | | | | | 22.0881 | 8.9316 | -0.6415 |
| | | | | | | | | | 5.2215 | 0.4543 |
| | | | | | | -D2(2)= | | | | -1.9187 |
| | | | 1 | 0.0792 | -0.0046 | -0.0183 | 0.0296 | 0.0212 | -0.0061 | 0.0055 |
| | | | | 44.9933 | -1.4962 | 1.4840 | -1.1640 | -5.5395 | -2.6834 | -6.9407 |
| | | | | | 4.5145 | 2.7204 | 2.3447 | 3.5971 | 1.7988 | -1.6051 |
| | | | | | | 5.0966 | 3.7104 | 3.7879 | 2.4121 | -1.1213 |
| | | | | | | | 8.9268 | 7.0281 | 3.5350 | -1.4520 |
| | | | | | | | | 21.7676 | 9.0244 | -0.7246 |
| | | | | | | | | | 5.1946 | 0.4783 |
| | | | | | | -D2(3)= | | | | -1.9403 |
| | | | | 1 | -0.0333 | 0.0330 | -0.0259 | -0.1231 | -0.0596 | -0.1543 |
| | | | | | 4.4647 | 2.7697 | 2.3060 | 3.4129 | 1.7096 | -1.8359 |
| | | | | | | 5.0476 | 3.7488 | 3.9706 | 2.5006 | -0.8924 |
| | | | | | | | 8.8967 | 6.8848 | 3.4656 | -1.6315 |
| | | | | | | | | 21.0855 | 8.6940 | -1.5791 |
| | | | | | | | | | 5.0346 | 0.0644 |
| | | | | | | -D2(4)= | | | | -3.0109 |
| | | | | | 1 | 0.6204 | 0.5165 | 0.7644 | 0.3829 | -0.4112 |
| | | | | | | 3.3294 | 2.3183 | 1.8534 | 1.4401 | 0.2465 |
| | | | | | | | 7.7057 | 5.1221 | 2.5826 | -0.6833 |
| | | | | | | | | 18.4767 | 7.3872 | -0.1758 |
| | | | | | | | | | 4.3800 | 0.7674 |
| | | | | | | -D2(5)= | | | | -3.7658 |
| | | | | | | 1 | 0.6963 | 0.5567 | 0.4325 | 0.0740 |
| | | | | | | | 6.0915 | 3.8315 | 1.5799 | -0.8550 |
| | | | | | | | | 17.4450 | 6.5856 | -0.3130 |
| | | | | | | | | | 3.7571 | 0.6607 |
| | | | | | | -D2(6)= | | | | -3.7841 |
| | | | | | | | 1 | 0.6290 | 0.2594 | -0.1404 |
| | | | | | | | | 15.0349 | 5.5918 | 0.2248 |
| | | | | | | | | | 3.3474 | 0.8825 |
| | | | | | | -D2(7)= | | | | -3.9041 |
| | | | | | | | | 1 | 0.3719 | 0.0149 |
| | | | | | | | | | 1.2676 | 0.7989 |
| | | | | | | -D2(8)= | | | | -3.9074 |
| | | | | | | | | | 1 | 0.6302 |
| | | | | | | -D2(9)= | | | | -4.4109 |

Table 2.49 Variance covariance matrix of Dsquare analysis between WOF and TOF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 669.4012 | 204.6874 | 39.4437 | 94.6067 | 87.6321 | 121.6201 | 116.0062 | 267.2231 | 151.8531 | -15.1129 |
| CL | | 72.8373 | 12.5313 | 27.7830 | 27.9516 | 39.2370 | 40.4054 | 93.2312 | 51.4330 | -4.7616 |
| CHL | | | 697.7416 | 25.1741 | -4.3750 | -21.5359 | 17.1338 | 15.6982 | -13.5440 | -0.7796 |
| RL | | | | 67.3227 | 9.9676 | 9.1119 | 20.3539 | 40.5213 | 20.6428 | -3.8208 |
| I | | | | | 15.5432 | 20.6965 | 16.8350 | 36.7487 | 22.0727 | -3.0036 |
| M | | | | | | 37.3539 | 18.6676 | 49.3703 | 30.9105 | -3.9982 |
| C | | | | | | | 32.5834 | 57.0929 | 31.0668 | -3.4409 |
| P | | | | | | | | 164.3581 | 74.1941 | -2.8459 |
| D | | | | | | | | | 42.5613 | -1.8136 |
| | 1 | 0.3058 | 0.0589 | 0.1413 | 0.1309 | 0.1817 | 0.1733 | 0.3992 | 0.2268 | -0.0226 |
| | | 10.2486 | 0.4704 | -1.1456 | 1.1557 | 2.0484 | 4.9334 | 11.5206 | 4.9998 | -0.1405 |
| | | | 695.4174 | 19.5995 | -9.5386 | -28.7022 | 10.2983 | -0.0476 | -22.4918 | 0.1109 |
| | | | | 53.9519 | -2.4175 | -8.0767 | 3.9587 | 2.7546 | -0.8187 | -1.6849 |
| | | | | | 4.0712 | 4.7750 | 1.6485 | 1.7662 | 2.1934 | -1.0251 |
| | | | | | | 15.2573 | -2.4090 | 0.8199 | 3.3210 | -1.2524 |
| | | | | | | | 12.4797 | 10.7835 | 4.7509 | -0.8218 |
| | | | | | | | | 57.6834 | 13.5747 | 3.1872 |
| | | | | | | | | | 8.1135 | 1.6147 |
| | | | | | | -D2(1)= | | | | -0.3412 |
| | | 1 | 0.0459 | -0.1118 | 0.1128 | 0.1999 | 0.4814 | 1.1241 | 0.4879 | -0.0137 |
| | | | 695.3958 | 19.6521 | -9.5916 | -28.7963 | 10.0719 | -0.5763 | -22.7213 | 0.1174 |
| | | | | 53.8238 | -2.2883 | -7.8477 | 4.5102 | 4.0423 | -0.2598 | -1.7006 |
| | | | | | 3.9408 | 4.5441 | 1.0922 | 0.4671 | 1.6296 | -1.0093 |
| | | | | | | 14.8479 | -3.3950 | -1.4827 | 2.3217 | -1.2243 |
| | | | | | | | 10.1049 | 5.2379 | 2.3441 | -0.7542 |
| | | | | | | | | 44.7330 | 7.9544 | 3.3451 |
| | | | | | | | | | 5.6743 | 1.6833 |
| | | | | | | -D2(2)= | | | | -0.3431 |
| | | | 1 | 0.0283 | -0.0138 | -0.0414 | 0.0145 | -0.0008 | -0.0327 | 0.0002 |
| | | | | 53.2684 | -2.0172 | -7.0339 | 4.2255 | 4.0586 | 0.3823 | -1.7039 |
| | | | | | 3.8086 | 4.1469 | 1.2311 | 0.4591 | 1.3162 | -1.0077 |
| | | | | | | 13.6555 | -2.9779 | -1.5065 | 1.3809 | -1.2195 |
| | | | | | | | 9.9590 | 5.2462 | 2.6732 | -0.7559 |
| | | | | | | | | 44.7325 | 7.9355 | 3.3452 |
| | | | | | | | | | 4.9319 | 1.6871 |
| | | | | | | -D2(3)= | | | | -0.3431 |
| | | | | 1 | -0.0379 | -0.1320 | 0.0793 | 0.0762 | 0.0072 | -0.0320 |
| | | | | | 3.7322 | 3.8805 | 1.3912 | 0.6128 | 1.3307 | -1.0722 |
| | | | | | | 12.7267 | -2.4200 | -0.9706 | 1.4313 | -1.4445 |
| | | | | | | | 9.6238 | 4.9243 | 2.6429 | -0.6207 |
| | | | | | | | | 44.4233 | 7.9064 | 3.4750 |
| | | | | | | | | | 4.9292 | 1.6993 |
| | | | | | | -D2(4)= | | | | -0.3976 |
| | | | | | 1 | 1.0397 | 0.3727 | 0.1642 | 0.3565 | -0.2873 |
| | | | | | | 8.6919 | -3.8664 | -1.6078 | 0.0478 | -0.3297 |
| | | | | | | | 9.1053 | 4.6958 | 2.1469 | -0.2211 |
| | | | | | | | | 44.3227 | 7.6879 | 3.6510 |
| | | | | | | | | | 4.4548 | 2.0816 |
| | | | | | | -D2(5)= | | | | -0.7057 |
| | | | | | | 1 | -0.4448 | -0.1850 | 0.0055 | -0.0379 |
| | | | | | | | 7.3854 | 3.9806 | 2.1681 | -0.3677 |
| | | | | | | | | 44.0253 | 7.6968 | 3.5901 |
| | | | | | | | | | 4.4545 | 2.0834 |
| | | | | | | -D2(6)= | | | | -0.7182 |
| | | | | | | | 1 | 0.5390 | 0.2936 | -0.0498 |
| | | | | | | | | 41.8798 | 6.5282 | 3.7883 |
| | | | | | | | | | 3.8180 | 2.1914 |
| | | | | | | -D2(7)= | | | | -0.7365 |
| | | | | | | | | 1 | 0.1559 | 0.0905 |
| | | | | | | | | | 2.8004 | 1.6009 |
| | | | | | | -D2(8)= | | | | -1.0792 |
| | | | | | | | | | 1 | 0.5717 |
| | | | | | | -D2(9)= | | | | -1.9943 |

Table 2.50 Variance covariance matrix of Dsquare analysis between WOF and BF1

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 519.5206 | 164.1150 | 85.0985 | 58.8264 | 60.1990 | 75.9152 | 86.3569 | 168.7646 | 80.2025 | -25.5323 |
| CL | | 61.4111 | 27.5011 | 16.5736 | 20.2803 | 25.9467 | 29.5955 | 57.2134 | 27.6121 | -8.3746 |
| CHL | | | 690.3401 | 36.7726 | 5.3244 | 7.6830 | 36.1256 | 40.9488 | 15.1121 | 2.9624 |
| RL | | | | 56.7228 | 7.2600 | 10.1140 | 10.5434 | 20.5865 | 9.6057 | -7.2724 |
| I | | | | | 10.8980 | 11.1227 | 12.6415 | 24.9986 | 11.7350 | -4.4229 |
| M | | | | | | 15.8302 | 16.4315 | 30.2111 | 15.1198 | -5.0950 |
| C | | | | | | | 25.0089 | 35.2315 | 17.4669 | -5.8925 |
| P | | | | | | | | 87.8791 | 39.8187 | -10.6201 |
| D | | | | | | | | | 20.7699 | -4.0394 |
| | 1 | 0.3159 | 0.1638 | 0.1132 | 0.1159 | 0.1461 | 0.1662 | 0.3248 | 0.1544 | -0.0491 |
| | | 9.5677 | 0.6188 | -2.0094 | 1.2636 | 1.9653 | 2.3156 | 3.9012 | 2.2764 | -0.3090 |
| | | | 676.4008 | 27.1367 | -4.5363 | -4.7520 | 21.9802 | 13.3048 | 1.9748 | 7.1446 |
| | | | | 50.0618 | 0.4435 | 1.5180 | 0.7650 | 1.4770 | 0.5242 | -4.3813 |
| | | | | | 3.9225 | 2.3261 | 2.6350 | 5.4431 | 2.4416 | -1.4644 |
| | | | | | | 4.7371 | 3.8125 | 5.5503 | 3.4002 | -1.3641 |
| | | | | | | | 10.6543 | 7.1788 | 4.1353 | -1.6484 |
| | | | | | | | | 33.0564 | 13.7651 | -2.3260 |
| | | | | | | | | | 8.3884 | -0.0978 |
| | | | | | | -D2(1)= | | | | -1.2548 |
| | | 1 | 0.0647 | -0.2100 | 0.1321 | 0.2054 | 0.2420 | 0.4077 | 0.2379 | -0.0323 |
| | | | 676.3608 | 27.2667 | -4.6180 | -4.8791 | 21.8304 | 13.0525 | 1.8276 | 7.1646 |
| | | | | 49.6397 | 0.7089 | 1.9307 | 1.2513 | 2.2963 | 1.0024 | -4.4462 |
| | | | | | 3.7556 | 2.0665 | 2.3291 | 4.9278 | 2.1409 | -1.4236 |
| | | | | | | 4.3334 | 3.3369 | 4.7489 | 2.9326 | -1.3006 |
| | | | | | | | 10.0939 | 6.2346 | 3.5844 | -1.5736 |
| | | | | | | | | 31.4657 | 12.8369 | -2.2000 |
| | | | | | | | | | 7.8468 | -0.0243 |
| | | | | | | -D2(2)= | | | | -1.2648 |
| | | | 1 | 0.0403 | -0.0068 | -0.0072 | 0.0323 | 0.0193 | 0.0027 | 0.0106 |
| | | | | 48.5405 | 0.8951 | 2.1274 | 0.3713 | 1.7701 | 0.9287 | -4.7351 |
| | | | | | 3.7241 | 2.0332 | 2.4782 | 5.0170 | 2.1534 | -1.3747 |
| | | | | | | 4.2982 | 3.4944 | 4.8431 | 2.9458 | -1.2489 |
| | | | | | | | 9.3893 | 5.8133 | 3.5254 | -1.8049 |
| | | | | | | | | 31.2139 | 12.8017 | -2.3383 |
| | | | | | | | | | 7.8419 | -0.0437 |
| | | | | | | -D2(3)= | | | | -1.3407 |
| | | | | 1 | 0.0184 | 0.0438 | 0.0076 | 0.0365 | 0.0191 | -0.0975 |
| | | | | | 3.7076 | 1.9940 | 2.4713 | 4.9843 | 2.1363 | -1.2874 |
| | | | | | | 4.2049 | 3.4781 | 4.7655 | 2.9051 | -1.0414 |
| | | | | | | | 9.3864 | 5.7998 | 3.5183 | -1.7686 |
| | | | | | | | | 31.1493 | 12.7678 | -2.1656 |
| | | | | | | | | | 7.8241 | 0.0469 |
| | | | | | | -D2(4)= | | | | -1.8026 |
| | | | | | 1 | 0.5378 | 0.6666 | 1.3444 | 0.5762 | -0.3472 |
| | | | | | | 3.1326 | 2.1490 | 2.0849 | 1.7561 | -0.3490 |
| | | | | | | | 7.7391 | 2.4774 | 2.0943 | -0.9105 |
| | | | | | | | | 24.4486 | 9.8959 | -0.4349 |
| | | | | | | | | | 6.5932 | 0.7887 |
| | | | | | | -D2(5)= | | | | -2.2496 |
| | | | | | | 1 | 0.6860 | 0.6656 | 0.5606 | -0.1114 |
| | | | | | | | 6.2649 | 1.0471 | 0.8896 | -0.6711 |
| | | | | | | | | 23.0610 | 8.7270 | -0.2026 |
| | | | | | | | | | 5.6087 | 0.9844 |
| | | | | | | -D2(6)= | | | | -2.2885 |
| | | | | | | | 1 | 0.1671 | 0.1420 | -0.1071 |
| | | | | | | | | 22.8860 | 8.5784 | -0.0905 |
| | | | | | | | | | 5.4824 | 1.0797 |
| | | | | | | -D2(7)= | | | | -2.3604 |
| | | | | | | | | 1 | 0.3748 | -0.0040 |
| | | | | | | | | | 2.2669 | 1.1136 |
| | | | | | | -D2(8)= | | | | -2.3607 |
| | | | | | | | | | 1 | 0.4912 |
| | | | | | | -D2(9)= | | | | -2.9077 |

Table.2.51. Variance covariance matrix of Dsquare analysis between WOF and BF2

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 551.4135 | 164.2131 | 14.5377 | 76.0885 | 79.1249 | 84.4513 | 97.4715 | 184.2121 | 107.5257 | -41.2419 |
| CL | | 61.0528 | -1.7878 | 18.1948 | 25.4073 | 27.1333 | 33.5399 | 58.6485 | 34.9265 | -14.3423 |
| CHL | | | 764.0257 | 55.0368 | -6.3358 | -11.7734 | 4.8737 | -13.8357 | -2.6422 | -24.2634 |
| RL | | | | 50.9548 | 11.8887 | 13.2128 | 16.3567 | 25.9887 | 17.3854 | -15.7563 |
| I | | | | | 17.5926 | 16.2524 | 18.0849 | 33.0672 | 20.0137 | -7.2616 |
| M | | | | | | 18.7334 | 20.3594 | 36.1541 | 22.3422 | -8.4498 |
| C | | | | | | | 28.9595 | 42.6365 | 24.7991 | -10.3118 |
| P | | | | | | | | 105.7857 | 52.5915 | -18.4265 |
| D | | | | | | | | | 35.9710 | -9.3943 |
| | 1 | 0.2978 | 0.0264 | 0.1380 | 0.1435 | 0.1532 | 0.1768 | 0.3341 | 0.1950 | -0.0748 |
| | | 12.1495 | -6.1172 | -4.4647 | 1.8436 | 1.9834 | 4.5125 | 3.7894 | 2.9049 | -2.0603 |
| | | | 763.6425 | 53.0308 | -8.4219 | -13.9999 | 2.3039 | -18.6924 | -5.4771 | -23.1761 |
| | | | | 40.4555 | 0.9704 | 1.5596 | 2.9068 | 0.5696 | 2.5481 | -10.0654 |
| | | | | | 6.2386 | 4.1341 | 4.0982 | 6.6337 | 4.5843 | -1.3436 |
| | | | | | | 5.7994 | 5.4312 | 7.9413 | 5.8742 | -2.1334 |
| | | | | | | | 11.7298 | 10.0739 | 5.7922 | -3.0216 |
| | | | | | | | | 44.2455 | 16.6701 | -4.6487 |
| | | | | | | | | | 15.0035 | -1.3521 |
| | | | | | | -D2(1)= | | | | -3.0846 |
| | | 1 | -0.5035 | -0.3675 | 0.1517 | 0.1633 | 0.3714 | 0.3119 | 0.2391 | -0.1696 |
| | | | 760.5625 | 50.7828 | -7.4937 | -13.0013 | 4.5760 | -16.7844 | -4.0145 | -24.2135 |
| | | | | 38.8148 | 1.6478 | 2.2884 | 4.5650 | 1.9622 | 3.6156 | -10.8225 |
| | | | | | 5.9589 | 3.8331 | 3.4135 | 6.0587 | 4.1435 | -1.0310 |
| | | | | | | 5.4756 | 4.6946 | 7.3226 | 5.3999 | -1.7971 |
| | | | | | | | 10.0538 | 8.6665 | 4.7132 | -2.2564 |
| | | | | | | | | 43.0636 | 15.7640 | -4.0061 |
| | | | | | | | | | 14.3089 | -0.8595 |
| | | | | | | -D2(2)= | | | | -3.4340 |
| | | | 1 | 0.0668 | -0.0099 | -0.0171 | 0.0060 | -0.0221 | -0.0053 | -0.0318 |
| | | | | 35.4240 | 2.1482 | 3.1565 | 4.2595 | 3.0829 | 3.8837 | -9.2058 |
| | | | | | 5.8850 | 3.7050 | 3.4586 | 5.8933 | 4.1039 | -1.2696 |
| | | | | | | 5.2533 | 4.7728 | 7.0357 | 5.3313 | -2.2110 |
| | | | | | | | 10.0262 | 8.7674 | 4.7374 | -2.1107 |
| | | | | | | | | 42.6932 | 15.6755 | -4.5405 |
| | | | | | | | | | 14.2877 | -0.9873 |
| | | | | | | -D2(3)= | | | | -4.2049 |
| | | | | 1 | 0.0606 | 0.0891 | 0.1202 | 0.0870 | 0.1096 | -0.2599 |
| | | | | | 5.7548 | 3.5136 | 3.2003 | 5.7064 | 3.8684 | -0.7113 |
| | | | | | | 4.9721 | 4.3932 | 6.7610 | 4.9853 | -1.3907 |
| | | | | | | | 9.5141 | 8.3968 | 4.2704 | -1.0038 |
| | | | | | | | | 42.4249 | 15.3375 | -3.7393 |
| | | | | | | | | | 13.8620 | 0.0220 |
| | | | | | | -D2(4)= | | | | -6.5972 |
| | | | | | 1 | 0.6106 | 0.5561 | 0.9916 | 0.6722 | -0.1236 |
| | | | | | | 2.8268 | 2.4393 | 3.2769 | 2.6234 | -0.9564 |
| | | | | | | | 7.7344 | 5.2234 | 2.1192 | -0.6082 |
| | | | | | | | | 36.7665 | 11.5016 | -3.0340 |
| | | | | | | | | | 11.2616 | 0.5001 |
| | | | | | | -D2(5)= | | | | -6.6851 |
| | | | | | | 1 | 0.8629 | 1.1592 | 0.9280 | -0.3383 |
| | | | | | | | 5.6295 | 2.3956 | -0.1446 | 0.2171 |
| | | | | | | | | 32.9677 | 8.4605 | -1.9253 |
| | | | | | | | | | 8.8270 | 1.3877 |
| | | | | | | -D2(6)= | | | | -7.0087 |
| | | | | | | | 1 | 0.4256 | -0.0257 | 0.0386 |
| | | | | | | | | 31.9482 | 8.5220 | -2.0176 |
| | | | | | | | | | 8.8233 | 1.3933 |
| | | | | | | -D2(7)= | | | | -7.0171 |
| | | | | | | | | 1 | 0.2667 | -0.0632 |
| | | | | | | | | | 6.5501 | 1.9315 |
| | | | | | | -D2(8)= | | | | -7.1445 |
| | | | | | | | | | 1 | 0.2949 |
| | | | | | | -D2(9)= | | | | -7.7141 |

Table.2.52. Variance covariance matrix of Dsquare analysis between SOF and TOF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 600.6065 | 189.6698 | 62.7429 | 102.7617 | 81.3267 | 115.9086 | 113.5068 | 234.4352 | 141.5174 | -2.7204 |
| CL | | 86.1699 | 17.4108 | 31.2490 | 28.0033 | 37.7286 | 36.5133 | 82.9722 | 47.6878 | -5.9828 |
| CHL | | | 415.8793 | 21.9208 | 3.1904 | -7.4096 | 9.0293 | 13.7080 | -3.8917 | -0.7204 |
| RL | | | | 96.7452 | 8.6553 | 10.5974 | 22.4947 | 42.6776 | 23.1482 | -4.4903 |
| I | | | | | 15.7807 | 20.4445 | 15.2087 | 33.2887 | 21.4983 | 0.1591 |
| M | | | | | | 36.5975 | 16.6207 | 45.3542 | 29.5902 | 0.6538 |
| C | | | | | | | 29.1141 | 53.4189 | 30.1638 | -0.6258 |
| P | | | | | | | | 149.8027 | 68.3775 | -3.9763 |
| D | | | | | | | | | 40.2925 | -1.0086 |
| | 1 | 0.3158 | 0.1045 | 0.1711 | 0.1354 | 0.1930 | 0.1890 | 0.3903 | 0.2356 | -0.0045 |
| | | 26.2727 | -2.3942 | -1.2029 | 2.3206 | 1.1250 | 0.6683 | 8.9383 | 2.9970 | -5.1237 |
| | | | 409.3248 | 11.1857 | -5.3055 | -19.5181 | -2.8282 | -10.7825 | -18.6755 | -0.4362 |
| | | | | 79.1630 | -5.2594 | -9.2342 | 3.0741 | 2.5665 | -1.0649 | -4.0249 |
| | | | | | 4.7685 | 4.7496 | -0.1610 | 1.5443 | 2.3358 | 0.5275 |
| | | | | | | 14.2287 | -5.2845 | 0.1115 | 2.2794 | 1.1788 |
| | | | | | | | 7.6628 | 9.1138 | 3.4189 | -0.1117 |
| | | | | | | | | 58.2954 | 13.1389 | -2.9145 |
| | | | | | | | | | 6.9476 | -0.3676 |
| | | | | | | -D2(1)= | | | | -0.0123 |
| | | 1 | -0.0911 | -0.0458 | 0.0883 | 0.0428 | 0.0254 | 0.3402 | 0.1141 | -0.1950 |
| | | | 409.1066 | 11.0761 | -5.0940 | -19.4156 | -2.7673 | -9.9680 | -18.4024 | -0.9032 |
| | | | | 79.1079 | -5.1532 | -9.1827 | 3.1047 | 2.9757 | -0.9277 | -4.2595 |
| | | | | | 4.5635 | 4.6502 | -0.2200 | 0.7548 | 2.0711 | 0.9801 |
| | | | | | | 14.1806 | -5.3131 | -0.2713 | 2.1510 | 1.3982 |
| | | | | | | | 7.6458 | 8.8864 | 3.3427 | 0.0186 |
| | | | | | | | | 55.2545 | 12.1193 | -1.1713 |
| | | | | | | | | | 6.6057 | 0.2169 |
| | | | | | | -D2(2)= | | | | -1.0115 |
| | | | 1 | 0.0271 | -0.0125 | -0.0475 | -0.0068 | -0.0244 | -0.0450 | -0.0022 |
| | | | | 78.8080 | -5.0153 | -8.6570 | 3.1796 | 3.2456 | -0.4295 | -4.2350 |
| | | | | | 4.5001 | 4.4084 | -0.2545 | 0.6307 | 1.8419 | 0.9688 |
| | | | | | | 13.2591 | -5.4445 | -0.7444 | 1.2777 | 1.3553 |
| | | | | | | | 7.6271 | 8.8190 | 3.2182 | 0.0125 |
| | | | | | | | | 55.0117 | 11.6709 | -1.1933 |
| | | | | | | | | | 5.7779 | 0.1762 |
| | | | | | | -D2(3)= | | | | -1.0135 |
| | | | | 1 | -0.0636 | -0.1098 | 0.0403 | 0.0412 | -0.0054 | -0.0537 |
| | | | | | 4.1809 | 3.8575 | -0.0521 | 0.8373 | 1.8146 | 0.6993 |
| | | | | | | 12.3082 | -5.0952 | -0.3878 | 1.2305 | 0.8901 |
| | | | | | | | 7.4988 | 8.6881 | 3.2355 | 0.1834 |
| | | | | | | | | 54.8780 | 11.6886 | -1.0189 |
| | | | | | | | | | 5.7756 | 0.1532 |
| | | | | | | -D2(4)= | | | | -1.2411 |
| | | | | | 1 | 0.9226 | -0.0125 | 0.2003 | 0.4340 | 0.1673 |
| | | | | | | 8.7490 | -5.0471 | -1.1603 | -0.4437 | 0.2449 |
| | | | | | | | 7.4982 | 8.6985 | 3.2581 | 0.1921 |
| | | | | | | | | 54.7103 | 11.3252 | -1.1590 |
| | | | | | | | | | 4.9880 | -0.1503 |
| | | | | | | -D2(5)= | | | | -1.3581 |
| | | | | | | 1 | -0.5769 | -0.1326 | -0.0507 | 0.0280 |
| | | | | | | | 4.5867 | 8.0291 | 3.0022 | 0.3334 |
| | | | | | | | | 54.5564 | 11.2664 | -1.1265 |
| | | | | | | | | | 4.9655 | -0.1379 |
| | | | | | | -D2(6)= | | | | -1.3649 |
| | | | | | | | 1 | 1.7505 | 0.6545 | 0.0727 |
| | | | | | | | | 40.5012 | 6.0110 | -1.7101 |
| | | | | | | | | | 3.0005 | -0.3561 |
| | | | | | | -D2(7)= | | | | -1.3892 |
| | | | | | | | | 1 | 0.1484 | -0.0422 |
| | | | | | | | | | 2.1083 | -0.1023 |
| | | | | | | -D2(8)= | | | | -1.4614 |
| | | | | | | | | | 1 | -0.0485 |
| | | | | | | -D2(9)= | | | | -1.4663 |

Table 2.53. Variance covariance matrix of Dsquare analysis between SOF and WBF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 440.5068 | 146.3311 | 111.5105 | 64.5418 | 52.0232 | 67.0875 | 81.8358 | 129.2637 | 64.9814 | 7.6989 |
| CL | | 73.9646 | 33.4103 | 19.2754 | 19.8090 | 23.5322 | 24.9664 | 44.4986 | 22.2428 | -2.3699 |
| CHL | | | 407.9731 | 34.3101 | 13.5511 | 23.8016 | 29.3160 | 40.6801 | 26.7182 | -4.4624 |
| RL | | | | 85.4226 | 5.7630 | 11.6677 | 12.0152 | 21.3836 | 11.3587 | -1.0387 |
| I | | | | | 10.8189 | 10.2179 | 10.7292 | 20.7373 | 10.4558 | 1.5785 |
| M | | | | | | 13.6063 | 14.2321 | 24.8886 | 12.7229 | 1.7505 |
| C | | | | | | | 21.0232 | 30.0670 | 15.6367 | 1.8258 |
| P | | | | | | | | 68.1092 | 31.6583 | 3.7978 |
| D | | | | | | | | | 17.0153 | 1.2172 |
| | 1 | 0.3322 | 0.2531 | 0.1465 | 0.1181 | 0.1523 | 0.1858 | 0.2934 | 0.1475 | 0.0175 |
| | | 25.3552 | -3.6322 | -2.1646 | 2.5275 | 1.2465 | -2.2184 | 1.5588 | 0.6567 | -4.9274 |
| | | | 379.7452 | 17.9719 | 0.3818 | 6.8189 | 8.6000 | 7.9581 | 10.2687 | -6.4113 |
| | | | | 75.9661 | -1.8592 | 1.8383 | 0.0249 | 2.4442 | 1.8378 | -2.1667 |
| | | | | | 4.6750 | 2.2950 | 1.0645 | 5.4715 | 2.7816 | 0.6693 |
| | | | | | | 3.3891 | 1.7688 | 5.2023 | 2.8265 | 0.5780 |
| | | | | | | | 5.8200 | 6.0529 | 3.5646 | 0.3955 |
| | | | | | | | | 30.1777 | 12.5900 | 1.5387 |
| | | | | | | | | | 7.4296 | 0.0815 |
| | | | | | | -D2(1)= | | | | -0.1346 |
| | | 1 | -0.1433 | -0.0854 | 0.0997 | 0.0492 | -0.0875 | 0.0615 | 0.0259 | -0.1943 |
| | | | 379.2249 | 17.6618 | 0.7439 | 6.9975 | 8.2822 | 8.1814 | 10.3628 | -7.1171 |
| | | | | 75.7813 | -1.6435 | 1.9447 | -0.1645 | 2.5773 | 1.8938 | -2.5874 |
| | | | | | 4.4230 | 2.1707 | 1.2856 | 5.3161 | 2.7161 | 1.1605 |
| | | | | | | 3.3278 | 1.8779 | 5.1256 | 2.7942 | 0.8203 |
| | | | | | | | 5.6259 | 6.1893 | 3.6221 | -0.0356 |
| | | | | | | | | 30.0818 | 12.5496 | 1.8416 |
| | | | | | | | | | 7.4126 | 0.2091 |
| | | | | | | -D2(2)= | | | | -1.0921 |
| | | | 1 | 0.0466 | 0.0020 | 0.0185 | 0.0218 | 0.0216 | 0.0273 | -0.0188 |
| | | | | 74.9587 | -1.6781 | 1.6188 | -0.5502 | 2.1963 | 1.4112 | -2.2559 |
| | | | | | 4.4216 | 2.1570 | 1.2694 | 5.3001 | 2.6958 | 1.1744 |
| | | | | | | 3.1987 | 1.7251 | 4.9747 | 2.6030 | 0.9516 |
| | | | | | | | 5.4450 | 6.0106 | 3.3958 | 0.1198 |
| | | | | | | | | 29.9053 | 12.3260 | 1.9951 |
| | | | | | | | | | 7.1294 | 0.4036 |
| | | | | | | -D2(3)= | | | | -1.2257 |
| | | | | 1 | -0.0224 | 0.0216 | -0.0073 | 0.0293 | 0.0188 | -0.0301 |
| | | | | | 4.3840 | 2.1933 | 1.2571 | 5.3492 | 2.7274 | 1.1239 |
| | | | | | | 3.1637 | 1.7370 | 4.9272 | 2.5725 | 1.0003 |
| | | | | | | | 5.4410 | 6.0267 | 3.4061 | 0.1033 |
| | | | | | | | | 29.8410 | 12.2847 | 2.0612 |
| | | | | | | | | | 7.1028 | 0.4461 |
| | | | | | | -D2(4)= | | | | -1.2936 |
| | | | | | 1 | 0.5003 | 0.2867 | 1.2202 | 0.6221 | 0.2564 |
| | | | | | | 2.0665 | 1.1081 | 2.2511 | 1.2080 | 0.4380 |
| | | | | | | | 5.0805 | 4.4929 | 2.6241 | -0.2190 |
| | | | | | | | | 23.3140 | 8.9568 | 0.6899 |
| | | | | | | | | | 5.4061 | -0.2531 |
| | | | | | | -D2(5)= | | | | -1.5817 |
| | | | | | | 1 | 0.5362 | 1.0893 | 0.5846 | 0.2120 |
| | | | | | | | 4.4864 | 3.2858 | 1.9763 | -0.4539 |
| | | | | | | | | 20.8618 | 7.6408 | 0.2127 |
| | | | | | | | | | 4.6998 | -0.5092 |
| | | | | | | -D2(6)= | | -D2 = | | -1.6746 |
| | | | | | | | 1 | 0.7324 | 0.4405 | -0.1012 |
| | | | | | | | | 18.4553 | 6.1934 | 0.5451 |
| | | | | | | | | | 3.8293 | -0.3093 |
| | | | | | | -D2(7)= | | | | -1.7205 |
| | | | | | | | | 1 | 0.3356 | 0.0295 |
| | | | | | | | | | 1.7508 | -0.4922 |
| | | | | | | -D2(8)= | | | | -1.7366 |
| | | | | | | | | | 1 | -0.2811 |
| | | | | | | -D2(9)= | | | | -1.8750 |

Table.2.54. Variance covariance matrix of Dsquare analysis between SOF and SBF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 474.5743 | 146.4360 | 36.1388 | 82.9809 | 72.2395 | 76.2055 | 93.7082 | 145.7644 | 94.1676 | -23.4086 |
| CL | | 73.5819 | 2.1244 | 21.0070 | 25.2856 | 24.7998 | 29.1798 | 46.0316 | 30.0558 | -3.5978 |
| CHL | | | 486.6828 | 53.8196 | 1.0958 | 3.0186 | -4.0667 | -17.8397 | 7.7534 | -22.7634 |
| RL | | | | 79.2613 | 10.7073 | 14.9779 | 18.2249 | 27.1541 | 19.6688 | -7.4452 |
| I | | | | | 17.9699 | 15.6974 | 16.5437 | 29.3561 | 19.2989 | -4.4172 |
| M | | | | | | 16.7074 | 18.4279 | 31.2369 | 20.4377 | -5.1054 |
| C | | | | | | | 25.2431 | 37.9768 | 23.4688 | -6.2452 |
| P | | | | | | | | 87.2368 | 45.3020 | -11.6043 |
| D | | | | | | | | | 33.2529 | -6.5720 |
| | 1 | 0.3086 | 0.0761 | 0.1749 | 0.1522 | 0.1606 | 0.1975 | 0.3071 | 0.1984 | -0.0493 |
| | | 28.3972 | -9.0267 | -4.5978 | 2.9952 | 1.2856 | 0.2649 | 1.0541 | 0.9992 | 3.6252 |
| | | | 483.9308 | 47.5007 | -4.4052 | -2.7845 | -11.2026 | -28.9396 | 0.5826 | -20.9809 |
| | | | | 64.7518 | -1.9240 | 1.6531 | 1.8397 | 1.6667 | 3.2032 | -3.3521 |
| | | | | | 6.9736 | 4.0974 | 2.2795 | 7.1679 | 4.9648 | -0.8540 |
| | | | | | | 4.4706 | 3.3805 | 7.8305 | 5.3166 | -1.3465 |
| | | | | | | | 6.7397 | 9.1946 | 4.8747 | -1.6230 |
| | | | | | | | | 42.4655 | 16.3786 | -4.4144 |
| | | | | | | | | | 14.5676 | -1.9272 |
| | | | | | | -D2(1)= | | | | -1.1546 |
| | | 1 | -0.3179 | -0.1619 | 0.1055 | 0.0453 | 0.0093 | 0.0371 | 0.0352 | 0.1277 |
| | | | 481.0615 | 46.0391 | -3.4532 | -2.3758 | -11.1184 | -28.6046 | 0.9002 | -19.8285 |
| | | | | 64.0074 | -1.4390 | 1.8612 | 1.8826 | 1.8374 | 3.3650 | -2.7651 |
| | | | | | 6.6577 | 3.9618 | 2.2515 | 7.0567 | 4.8594 | -1.2363 |
| | | | | | | 4.4124 | 3.3685 | 7.7828 | 5.2714 | -1.5106 |
| | | | | | | | 6.7373 | 9.1847 | 4.8653 | -1.6568 |
| | | | | | | | | 42.4264 | 16.3415 | -4.5490 |
| | | | | | | | | | 14.5325 | -2.0547 |
| | | | | | | -D2(2)= | | | | -1.6174 |
| | | | 1 | 0.0957 | -0.0072 | -0.0049 | -0.0231 | -0.0595 | 0.0019 | -0.0412 |
| | | | | 59.6013 | -1.1086 | 2.0886 | 2.9467 | 4.5749 | 3.2789 | -0.8675 |
| | | | | | 6.6329 | 3.9448 | 2.1717 | 6.8514 | 4.8658 | -1.3787 |
| | | | | | | 4.4007 | 3.3136 | 7.6415 | 5.2758 | -1.6085 |
| | | | | | | | 6.4803 | 8.5236 | 4.8862 | -2.1151 |
| | | | | | | | | 40.7255 | 16.3951 | -5.7280 |
| | | | | | | | | | 14.5308 | -2.0176 |
| | | | | | | -D2(3)= | | | | -2.4347 |
| | | | | 1 | -0.0186 | 0.0350 | 0.0494 | 0.0768 | 0.0550 | -0.0146 |
| | | | | | 6.6123 | 3.9836 | 2.2265 | 6.9365 | 4.9268 | -1.3948 |
| | | | | | | 4.3275 | 3.2104 | 7.4812 | 5.1609 | -1.5781 |
| | | | | | | | 6.3346 | 8.2974 | 4.7240 | -2.0722 |
| | | | | | | | | 40.3744 | 16.1434 | -5.6614 |
| | | | | | | | | | 14.3504 | -1.9699 |
| | | | | | | -D2(4)= | | | | -2.4474 |
| | | | | | 1 | 0.6025 | 0.3367 | 1.0490 | 0.7451 | -0.2109 |
| | | | | | | 1.9275 | 1.8690 | 3.3022 | 2.1927 | -0.7378 |
| | | | | | | | 5.5849 | 5.9617 | 3.0651 | -1.6025 |
| | | | | | | | | 33.0978 | 10.9750 | -4.1982 |
| | | | | | | | | | 10.6794 | -0.9307 |
| | | | | | | -D2(5)= | | | | -2.7416 |
| | | | | | | 1 | 0.9696 | 1.7132 | 1.1376 | -0.3828 |
| | | | | | | | 3.7727 | 2.7598 | 0.9389 | -0.8871 |
| | | | | | | | | 27.4403 | 7.2184 | -2.9342 |
| | | | | | | | | | 8.1850 | -0.0913 |
| | | | | | | -D2(6)= | | | | -3.0240 |
| | | | | | | | 1 | 0.7315 | 0.2489 | -0.2351 |
| | | | | | | | | 25.4215 | 6.5315 | -2.2852 |
| | | | | | | | | | 7.9513 | 0.1295 |
| | | | | | | -D2(7)= | | | | -3.2326 |
| | | | | | | | | 1 | 0.2569 | -0.0899 |
| | | | | | | | | | 6.2732 | 0.7166 |
| | | | | | | -D2(8)= | | | | -3.4380 |
| | | | | | | | | | 1 | 0.1142 |
| | | | | | | -D2(9)= | | | | -3.5199 |

Table.2.55. Variance covariance matrix of Dsquare analysis between TOF and WBF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 654.5054 | 220.3118 | 71.5081 | 88.2559 | 95.3344 | 124.2194 | 126.3511 | 243.5570 | 136.8435 | 10.4194 |
| CL | | 80.0409 | 19.2199 | 32.0312 | 33.1113 | 42.1624 | 42.5118 | 89.0075 | 47.6780 | 3.6129 |
| CHL | | | 466.4473 | 9.6360 | 5.6548 | 2.8097 | 18.3866 | 20.9290 | 4.4839 | -3.7419 |
| RL | | | | 83.1763 | 11.0801 | 12.1677 | 20.5806 | 39.6382 | 21.2984 | 3.4516 |
| I | | | | | 17.0753 | 21.0435 | 18.4011 | 38.5280 | 22.2086 | 1.4194 |
| M | | | | | | 34.3183 | 20.7054 | 48.6758 | 29.0608 | 1.0968 |
| C | | | | | | | 32.7806 | 55.0763 | 30.1403 | 2.4516 |
| P | | | | | | | | 148.1043 | 67.2285 | 7.7742 |
| D | | | | | | | | | 38.3946 | 2.2258 |
| | 1 | 0.3366 | 0.1093 | 0.1348 | 0.1457 | 0.1898 | 0.1930 | 0.3721 | 0.2091 | 0.0159 |
| | | 5.8821 | -4.8503 | 2.3235 | 1.0210 | 0.3491 | -0.0190 | 7.0243 | 1.6153 | 0.1057 |
| | | | 458.6347 | -0.0064 | -4.7609 | -10.7619 | 4.5821 | -5.6808 | -10.4670 | -4.8803 |
| | | | | 71.2756 | -1.7751 | -4.5825 | 3.5430 | 6.7961 | 2.8459 | 2.0466 |
| | | | | | 3.1890 | 2.9499 | -0.0031 | 3.0518 | 2.2761 | -0.0983 |
| | | | | | | 10.7425 | -3.2749 | 2.4508 | 3.0891 | -0.8807 |
| | | | | | | | 8.3888 | 8.0581 | 3.7229 | 0.4402 |
| | | | | | | | | 57.4710 | 16.3058 | 3.8969 |
| | | | | | | | | | 9.7835 | 0.0473 |
| | | | | | | -D2(1)= | | | | -0.1659 |
| | | 1 | -0.8246 | 0.3950 | 0.1736 | 0.0594 | -0.0032 | 1.1942 | 0.2746 | 0.0180 |
| | | | 454.6352 | 1.9096 | -3.9191 | -10.4740 | 4.5664 | 0.1113 | -9.1350 | -4.7932 |
| | | | | 70.3578 | -2.1784 | -4.7204 | 3.5505 | 4.0214 | 2.2078 | 2.0049 |
| | | | | | 3.0118 | 2.8893 | 0.0002 | 1.8326 | 1.9958 | -0.1167 |
| | | | | | | 10.7218 | -3.2738 | 2.0339 | 2.9932 | -0.8870 |
| | | | | | | | 8.3887 | 8.0808 | 3.7281 | 0.4405 |
| | | | | | | | | 49.0828 | 14.3768 | 3.7707 |
| | | | | | | | | | 9.3399 | 0.0183 |
| | | | | | | -D2(2)= | | | | -0.1678 |
| | | | 1 | 0.0042 | -0.0086 | -0.0230 | 0.0100 | 0.0002 | -0.0201 | -0.0105 |
| | | | | 70.3497 | -2.1620 | -4.6764 | 3.5313 | 4.0209 | 2.2462 | 2.0250 |
| | | | | | 2.9780 | 2.7990 | 0.0396 | 1.8335 | 1.9170 | -0.1580 |
| | | | | | | 10.4805 | -3.1686 | 2.0365 | 2.7827 | -0.9974 |
| | | | | | | | 8.3429 | 8.0796 | 3.8199 | 0.4887 |
| | | | | | | | | 49.0827 | 14.3790 | 3.7719 |
| | | | | | | | | | 9.1563 | -0.0780 |
| | | | | | | -D2(3)= | | | | -0.2183 |
| | | | | 1 | -0.0307 | -0.0665 | 0.0502 | 0.0572 | 0.0319 | 0.0288 |
| | | | | | 2.9116 | 2.6553 | 0.1481 | 1.9571 | 1.9861 | -0.0957 |
| | | | | | | 10.1697 | -2.9339 | 2.3038 | 2.9320 | -0.8628 |
| | | | | | | | 8.1656 | 7.8778 | 3.7071 | 0.3870 |
| | | | | | | | | 48.8529 | 14.2507 | 3.6562 |
| | | | | | | | | | 9.0846 | -0.1426 |
| | | | | | | -D2(4)= | | | | -0.2766 |
| | | | | | 1 | 0.9120 | 0.0509 | 0.6722 | 0.6821 | -0.0329 |
| | | | | | | 7.7480 | -3.0690 | 0.5189 | 1.1208 | -0.7755 |
| | | | | | | | 8.1581 | 7.7782 | 3.6061 | 0.3919 |
| | | | | | | | | 47.5374 | 12.9157 | 3.7205 |
| | | | | | | | | | 7.7299 | -0.0773 |
| | | | | | | -D2(5)= | | | | -0.2797 |
| | | | | | | 1 | -0.3961 | 0.0670 | 0.1447 | -0.1001 |
| | | | | | | | 6.9425 | 7.9838 | 4.0500 | 0.0847 |
| | | | | | | | | 47.5026 | 12.8406 | 3.7724 |
| | | | | | | | | | 7.5677 | 0.0348 |
| | | | | | | -D2(6)= | | | | -0.3574 |
| | | | | | | | 1 | 1.1500 | 0.5834 | 0.0122 |
| | | | | | | | | 38.3214 | 8.1831 | 3.6750 |
| | | | | | | | | | 5.2051 | -0.0146 |
| | | | | | | -D2(7)= | | | | -0.3584 |
| | | | | | | | | 1 | 0.2135 | 0.0950 |
| | | | | | | | | | 3.4577 | -0.7993 |
| | | | | | | -D2(8)= | | | | -0.7108 |
| | | | | | | | | | 1 | -0.2312 |
| | | | | | | -D2(9)= | | | | -0.8956 |

Table.2.56. Variance covariance matrix between TOF and SBF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 696.1510 | 226.1930 | 19.2744 | 94.4712 | 112.4462 | 133.3598 | 137.6283 | 261.4049 | 161.1681 | -27.8818 |
| CL | | 81.4374 | -1.5532 | 30.5797 | 37.6865 | 43.7655 | 46.3140 | 91.8169 | 54.3328 | -10.2879 |
| CHL | | | 514.9166 | 23.7145 | -2.0480 | -10.7653 | -4.2223 | -19.9579 | -8.4904 | -23.2939 |
| RL | | | | 78.2218 | 13.3720 | 13.1857 | 23.4924 | 40.9311 | 25.7618 | -11.7091 |
| I | | | | | 22.3307 | 25.1359 | 22.8075 | 45.3814 | 28.9723 | -4.6303 |
| M | | | | | | 36.5999 | 24.0509 | 53.9169 | 35.0001 | -4.8424 |
| C | | | | | | | 36.0336 | 61.3727 | 36.1688 | -7.2788 |
| P | | | | | | | | 162.8902 | 77.8995 | -16.3000 |
| D | | | | | | | | | 50.5606 | -7.9576 |
| | 1 | 0.3249 | 0.0277 | 0.1357 | 0.1615 | 0.1916 | 0.1977 | 0.3755 | 0.2315 | -0.0401 |
| | | 7.9429 | -7.8158 | -0.1158 | 1.1506 | 0.4343 | 1.5958 | 6.8814 | 1.9662 | -1.2285 |
| | | | 514.3829 | 21.0988 | -5.1613 | -14.4577 | -8.0328 | -27.1955 | -12.9527 | -22.5220 |
| | | | | 65.4015 | -1.8875 | -4.9119 | 4.8155 | 5.4572 | 3.8905 | -7.9254 |
| | | | | | 4.1677 | 3.5949 | 0.5770 | 3.1578 | 2.9395 | -0.1267 |
| | | | | | | 11.0525 | -2.3142 | 3.8403 | 4.1256 | 0.4988 |
| | | | | | | | 8.8246 | 9.6932 | 4.3060 | -1.7666 |
| | | | | | | | | 64.7325 | 17.3808 | -5.8304 |
| | | | | | | | | | 13.2480 | -1.5026 |
| | | | | | | -D2(1)= | | | | -1.1167 |
| | | 1 | -0.9840 | -0.0146 | 0.1449 | 0.0547 | 0.2009 | 0.8664 | 0.2475 | -0.1547 |
| | | | 506.6923 | 20.9849 | -4.0291 | -14.0303 | -6.4625 | -20.4242 | -11.0180 | -23.7308 |
| | | | | 65.3998 | -1.8708 | -4.9056 | 4.8388 | 5.5575 | 3.9192 | -7.9433 |
| | | | | | 4.0010 | 3.5320 | 0.3458 | 2.1610 | 2.6547 | 0.0513 |
| | | | | | | 11.0288 | -2.4015 | 3.4640 | 4.0180 | 0.5660 |
| | | | | | | | 8.5040 | 8.3106 | 3.9110 | -1.5198 |
| | | | | | | | | 58.7708 | 15.6774 | -4.7660 |
| | | | | | | | | | 12.7613 | -1.1985 |
| | | | | | | -D2(2)= | | | | -1.3067 |
| | | | 1 | 0.0414 | -0.0080 | -0.0277 | -0.0128 | -0.0403 | -0.0217 | -0.0468 |
| | | | | 64.5307 | -1.7039 | -4.3245 | 5.1064 | 6.4034 | 4.3755 | -6.9605 |
| | | | | | 3.9690 | 3.4204 | 0.2944 | 1.9986 | 2.5671 | -0.1374 |
| | | | | | | 10.6403 | -2.5804 | 2.8985 | 3.7130 | -0.0911 |
| | | | | | | | 8.4216 | 8.0501 | 3.7705 | -1.8224 |
| | | | | | | | | 57.9475 | 15.2332 | -5.7226 |
| | | | | | | | | | 12.5217 | -1.7145 |
| | | | | | | -D2(3)= | | | | -2.4182 |
| | | | | 1 | -0.0264 | -0.0670 | 0.0791 | 0.0992 | 0.0678 | -0.1079 |
| | | | | | 3.9240 | 3.3062 | 0.4292 | 2.1677 | 2.6826 | -0.3212 |
| | | | | | | 10.3505 | -2.2382 | 3.3276 | 4.0062 | -0.5576 |
| | | | | | | | 8.0175 | 7.5434 | 3.4242 | -1.2716 |
| | | | | | | | | 57.3121 | 14.7991 | -5.0319 |
| | | | | | | | | | 12.2250 | -1.2425 |
| | | | | | | -D2(4)= | | | | -3.1689 |
| | | | | | 1 | 0.8426 | 0.1094 | 0.5524 | 0.6836 | -0.0819 |
| | | | | | | 7.5648 | -2.5999 | 1.5012 | 1.7459 | -0.2869 |
| | | | | | | | 7.9705 | 7.3063 | 3.1308 | -1.2365 |
| | | | | | | | | 56.1146 | 13.3171 | -4.8545 |
| | | | | | | | | | 10.3911 | -1.0229 |
| | | | | | | -D2(5)= | | | | -3.1952 |
| | | | | | | 1 | -0.3437 | 0.1984 | 0.2308 | -0.0379 |
| | | | | | | | 7.0770 | 7.8222 | 3.7308 | -1.3351 |
| | | | | | | | | 55.8167 | 12.9707 | -4.7975 |
| | | | | | | | | | 9.9882 | -0.9567 |
| | | | | | | -D2(6)= | | | | -3.2061 |
| | | | | | | | 1 | 1.1053 | 0.5272 | -0.1887 |
| | | | | | | | | 47.1708 | 8.8470 | -3.3218 |
| | | | | | | | | | 8.0213 | -0.2529 |
| | | | | | | -D2(7)= | | | | -3.4580 |
| | | | | | | | | 1 | 0.1876 | -0.0704 |
| | | | | | | | | | 6.3621 | 0.3701 |
| | | | | | | -D2(8)= | | | | -3.6919 |
| | | | | | | | | | 1 | 0.0582 |
| | | | | | | -D2(9)= | | | | -3.7134 |

Table 2.57. Variance covariance matrix of Dsquare analysis between WBF and SBF

| | TL | CL | II CHL | RL | I | M | C | P | D | di |
|---|---|---|---|---|---|---|---|---|---|---|
| TL | 571.5808 | 191.8712 | 52.5293 | 75.1024 | 90.2501 | 96.7782 | 113.7860 | 181.6209 | 103.8698 | -15.6677 |
| CL | | 71.8454 | 8.9924 | 24.6867 | 31.4587 | 33.0827 | 37.6213 | 62.8131 | 35.2918 | -6.0699 |
| CHL | | | 522.7263 | 34.8821 | 5.1590 | 11.4249 | 9.6684 | -1.4436 | 13.4780 | -26.6957 |
| RL | | | | 71.1694 | 12.5148 | 15.4098 | 17.5300 | 28.4996 | 18.9963 | -8.6387 |
| I | | | | | 18.7847 | 17.6868 | 19.5472 | 36.0730 | 20.8936 | -2.9548 |
| M | | | | | | 19.9256 | 22.2725 | 38.8299 | 22.6860 | -3.4495 |
| C | | | | | | | 30.3269 | 44.3607 | 25.6194 | -4.5075 |
| P | | | | | | | | 103.8108 | 51.1169 | -7.9022 |
| D | | | | | | | | | 33.7832 | -5.3828 |
| | 1 | 0.3357 | 0.0919 | 0.1314 | 0.1579 | 0.1693 | 0.1991 | 0.3178 | 0.1817 | -0.0274 |
| | | 7.4370 | -8.6409 | -0.5240 | 1.1631 | 0.5957 | -0.5750 | 1.8456 | 0.4242 | -0.8105 |
| | | | 517.8987 | 27.9801 | -3.1352 | 2.5308 | -0.7887 | -18.1349 | 3.9322 | -25.2558 |
| | | | | 61.3014 | 0.6565 | 2.6938 | 2.5792 | 4.6357 | 5.3484 | -6.5801 |
| | | | | | 4.5346 | 2.4060 | 1.5809 | 7.3959 | 4.4930 | -0.4810 |
| | | | | | | 3.5394 | 3.0067 | 8.0784 | 5.0991 | -0.7967 |
| | | | | | | | 7.6752 | 8.2050 | 4.9418 | -1.3885 |
| | | | | | | | | 46.1004 | 18.1121 | -2.9237 |
| | | | | | | | | | 14.9076 | -2.5356 |
| | | | | | | -D2(1)= | | | | -0.4295 |
| | | 1 | -1.1619 | -0.0705 | 0.1564 | 0.0801 | -0.0773 | 0.2482 | 0.0570 | -0.1090 |
| | | | 507.8591 | 27.3712 | -1.7838 | 3.2229 | -1.4568 | -15.9905 | 4.4251 | -26.1975 |
| | | | | 61.2645 | 0.7384 | 2.7357 | 2.5387 | 4.7657 | 5.3783 | -6.6372 |
| | | | | | 4.3527 | 2.3128 | 1.6708 | 7.1073 | 4.4267 | -0.3542 |
| | | | | | | 3.4917 | 3.0527 | 7.9306 | 5.0651 | -0.7317 |
| | | | | | | | 7.6308 | 8.3477 | 4.9746 | -1.4512 |
| | | | | | | | | 45.6424 | 18.0068 | -2.7226 |
| | | | | | | | | | 14.8834 | -2.4894 |
| | | | | | | -D2(2)= | | | | -0.5178 |
| | | | 1 | 0.0539 | -0.0035 | 0.0063 | -0.0029 | -0.0315 | 0.0087 | -0.0516 |
| | | | | 59.7893 | 0.8346 | 2.5620 | 2.6172 | 5.6276 | 5.1398 | -5.2252 |
| | | | | | 4.3464 | 2.3241 | 1.6657 | 7.0511 | 4.4422 | -0.4462 |
| | | | | | | 3.4712 | 3.0620 | 8.0321 | 5.0371 | -0.5655 |
| | | | | | | | 7.6266 | 8.3018 | 4.9873 | -1.5263 |
| | | | | | | | | 45.1389 | 18.1462 | -3.5474 |
| | | | | | | | | | 14.8448 | -2.2611 |
| | | | | | | -D2(3)= | | | | -1.8692 |
| | | | | 1 | 0.0140 | 0.0429 | 0.0438 | 0.0941 | 0.0860 | -0.0874 |
| | | | | | 4.3348 | 2.2884 | 1.6292 | 6.9725 | 4.3705 | -0.3733 |
| | | | | | | 3.3614 | 2.9498 | 7.7909 | 4.8168 | -0.3416 |
| | | | | | | | 7.5120 | 8.0555 | 4.7623 | -1.2976 |
| | | | | | | | | 44.6092 | 17.6624 | -3.0556 |
| | | | | | | | | | 14.4030 | -1.8119 |
| | | | | | | -D2(4)= | | | | -2.3258 |
| | | | | | 1 | 0.5279 | 0.3758 | 1.6085 | 1.0082 | -0.0861 |
| | | | | | | 2.1534 | 2.0898 | 4.1101 | 2.5096 | -0.1445 |
| | | | | | | | 6.8997 | 5.4350 | 3.1198 | -1.1573 |
| | | | | | | | | 33.3938 | 10.6324 | -2.4552 |
| | | | | | | | | | 9.9965 | -1.4355 |
| | | | | | | -D2(5)= | | | | -2.3580 |
| | | | | | | 1 | 0.9705 | 1.9087 | 1.1654 | -0.0671 |
| | | | | | | | 4.8717 | 1.4463 | 0.6843 | -1.0171 |
| | | | | | | | | 25.5490 | 5.8424 | -2.1793 |
| | | | | | | | | | 7.0718 | -1.2671 |
| | | | | | | -D2(6)= | | | | -2.3677 |
| | | | | | | | 1 | 0.2969 | 0.1405 | -0.2088 |
| | | | | | | | | 25.1197 | 5.6393 | -1.8774 |
| | | | | | | | | | 6.9757 | -1.1243 |
| | | | | | | -D2(7)= | | | | -2.5800 |
| | | | | | | | | 1 | 0.2245 | -0.0747 |
| | | | | | | | | | 5.7097 | -0.7028 |
| | | | | | | -D2(8)= | | | | -2.7203 |
| | | | | | | | | | 1 | -0.1231 |
| | | | | | | D2(9)- | | | | 2.8008 |

Table 2.58. Differences between mean values of various measurements of female morphotypes and transition stages of *Macrobrachium rosenbergii*

| Pair | Dp | df1 | df2 | F |
|---|---|---|---|---|
| WOF X SOF | 4.4109 | 23 | 9 | 2.98 ** |
| WOF X TOF | 1.9943 | 39 | 9 | 2.09 |
| WOF X WBF | 2.9077 | 39 | 9 | 3.05 * |
| WOF X SBF | 7.7141 | 39 | 9 | 8.10 * |
| SOF X TOF | 1.3475 | 36 | 9 | 1.35 |
| SOF X WBF | 1.8750 | 36 | 9 | 1.72 |
| SOF X SBF | 3.5199 | 36 | 9 | 3.23 * |
| TOF X WBF | 0.8956 | 52 | 9 | 1.34 |
| TOF X SBF | 3.7134 | 53 | 9 | 5.63 * |
| WBF X SBF | 2.8068 | 51 | 9 | 4.11 * |

* = Significant at 1% level
** = Significant at 5% level

Table.2.59. Approximate distance between female morphotypes and transitional stages o *Macrobrachium rosenbergii*

| | SOF | TOF | WBF | SBF |
|---|---|---|---|---|
| WOF | 2.1 | 1.41 | 1.71 | 2.78 |
| SOF | | 1.16 | 1.37 | 1.88 |
| TOF | | | 0.95 | 1.93 |
| WBF | | | | 1.68 |

Table.2.60. Minimum, maximum and modal values of length and weight of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| Morphotype | Total Number Observed | LENGTH Minimum (mm) | Maximum (mm) | Mode | WEIGHT Minimum (g) | Maximum (g) | Mode |
|---|---|---|---|---|---|---|---|
| SM | 38 | 71 | 125 | 102 | 6 | 18 | 6.86 |
| WOC | 280 | 107 | 246 | 193 | 8 | 192 | 56.47 |
| SOC | 47 | 186 | 284 | 256 | 48 | 320 | 176.00 |
| t-SOC | 412 | 131 | 310 | 221 | 22 | 378 | 93.57 |
| WBC | 317 | 105 | 289 | 199 | 12 | 292 | 84.14 |
| SBC | 157 | 238 | 308 | 255 | 200 | 442 | 235.38 |
| OBC | 73 | 204 | 393 | 270 | 86 | 510 | 325.83 |

Table.2.61. Comparison of regressions of TOTAL LENGTH and CHELIPED LENGTH between M1 and M2 males of *Macrobrachium idella*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| | f | {x2 | {xy | {y2 | RC | f | SS {d y.x2 | MS | |
| M1 | 79 | 14766.75 | 27798 | 92388.8 | 1.882472 | 78 | 40059.83 | 513.5876 | |
| M2 | 73 | 5746.595 | 13641.14 | 72561.62 | 2.373777 | 72 | 40180.61 | 558.064 | |
| WITH IN | | | | | | 150 | 80240.44 | 534.9362 | |
| Reg.Coeff. | | | | | | 1 | 998.5295 | 998.5295 | |
| COMMON | 152 | 20513.34 | 41439.14 | 164950.4 | 2.020106 | 151 | 81238.97 | 538.0064 | 1.866633 |
| Adj.Means | | | | | | 1 | 986.2891 | 986.2891 | 1.833229 |
| TOTAL | 153 | 31813.64 | 68424.45 | 229391.9 | | 152 | 82225.26 | | |

Comparison of slopes F=441.1789(2,206)= 1.866633
Comparison of elevation F=27399(2,208)= 1.833229

Table.2.62. Comparison of regressions of CARAPACE LENGTH and CHELIPED LENGTH between M1 and M2 males of *Macrobrachium idella*

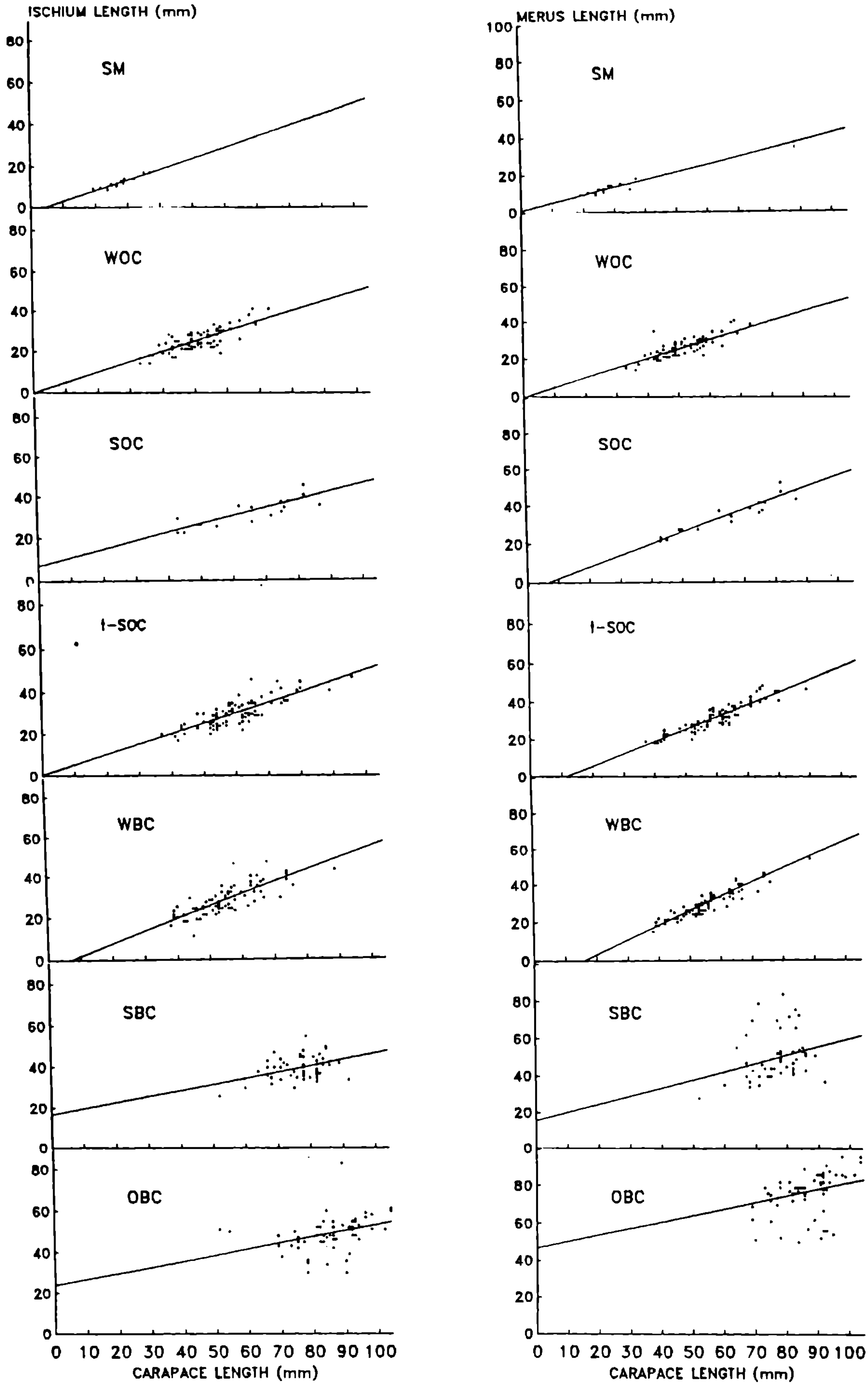
| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| | f | {x2 | {xy | {y2 | RC | f | SS {d y.x2 | MS | |
| M1 | 79 | 1949.8 | 9836.8 | 92388.8 | 5.04503 | 78 | 42761.85 | 548.2288 | |
| M2 | 73 | 878.1622 | 4733.784 | 72561.62 | 5.390558 | 72 | 47043.89 | 653.3873 | |
| WITH IN | | | | | | 150 | 89805.73 | 598.7049 | |
| Reg.Coeff. | | | | | | 1 | 72.28634 | 72.28634 | |
| COMMON | 152 | 2827.962 | 14570.58 | 164950.4 | 5.152326 | 151 | 89878.02 | 595.2187 | 0.120738 |
| Adj.Means | | | | | | 1 | 2544.663 | 2544.663 | 4.275173 |
| TOTAL | 153 | 4219.974 | 24041.77 | 229391.9 | | 152 | 92422.68 | | |

Comparison of slopes F=595.2186(1,150)= 0.120738
Comparison of elevation F=2544.660(1,151)= 4.275173

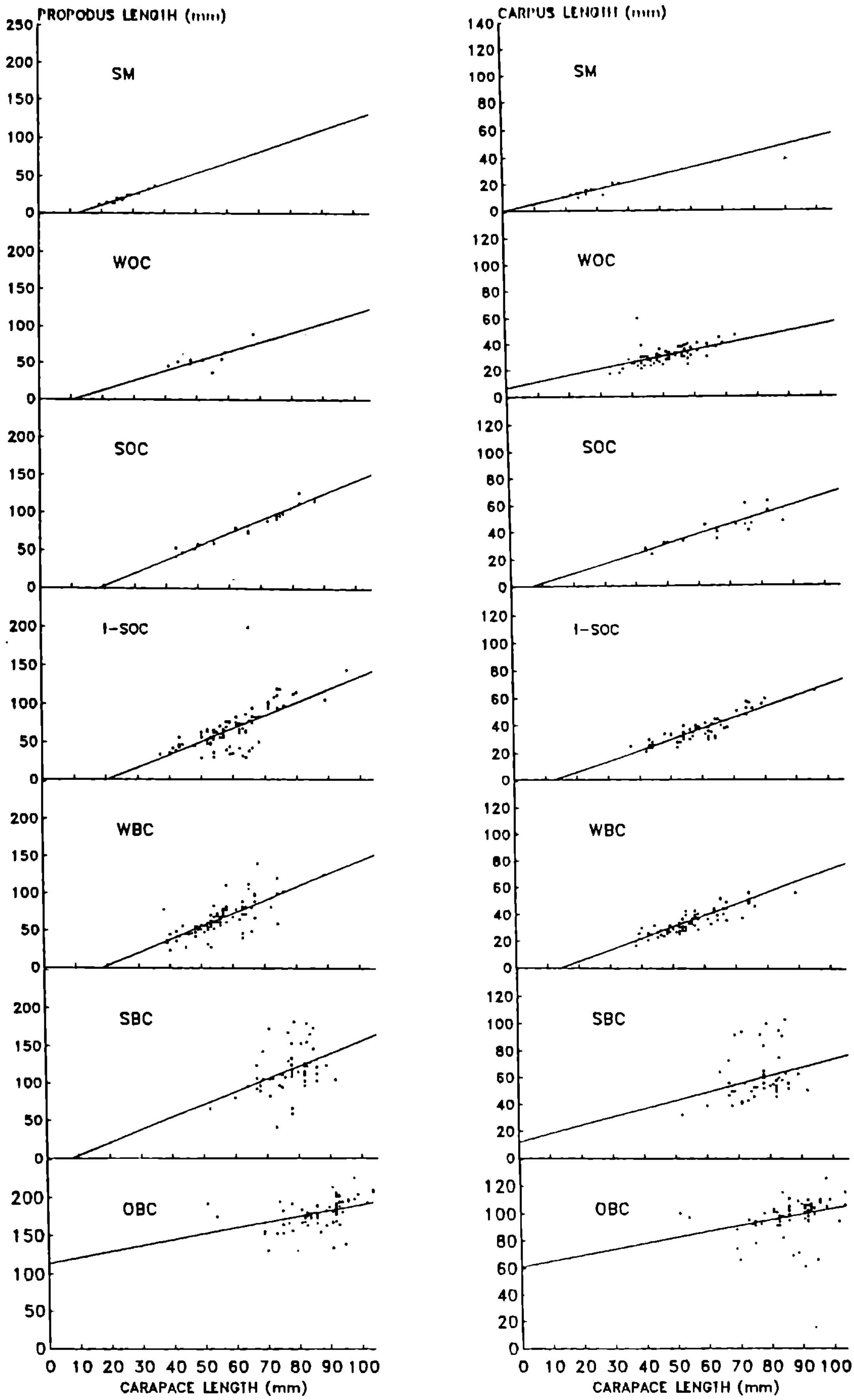
Table.2.63. Comparison of regressions of TOTAL LENGTH and CHELIPED LENGTH between males and females of *Macrobrachium idella*

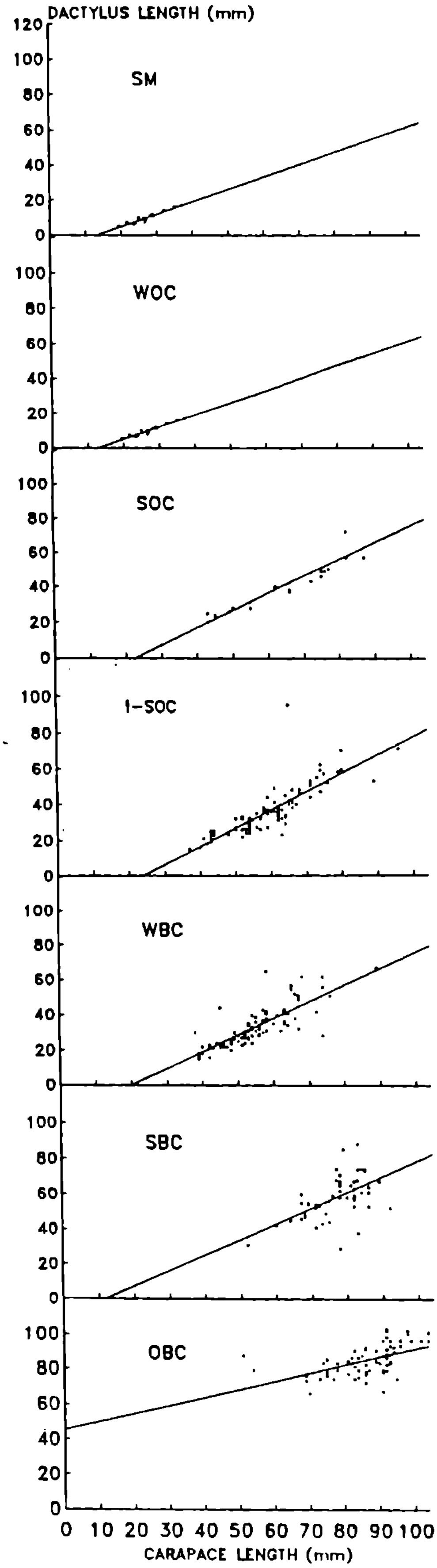
| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| | f | {x2 | {xy | {y2 | RC | f | SS {d y.x2 | MS | |
| POOLED MALE | 153 | 31813.64 | 68424.45 | 229391.9 | 2.15079 | 152 | 82225.26 | 548.1684 | |
| FEMALES | 57 | 5610.483 | 3886.138 | 3374.897 | 0.692657 | 56 | 683.1375 | 12.19888 | |
| WITH IN | | | | | | 208 | 82908.39 | 398.598 | |
| Reg.Coeff. | | | | | | 2 | 10140.43 | 5070.217 | |
| COMMON | 210 | 37424.12 | 72310.59 | 232766.8 | 1.932192 | 210 | 93048.83 | 443.0897 | 12.72013 • |
| Adj.Means | | | | | | 2 | 51434.57 | 25717.29 | 58.04082 • |
| TOTAL | 211 | 38427.83 | 81530.75 | 317463.9 | | 212 | 144483.4 | | |

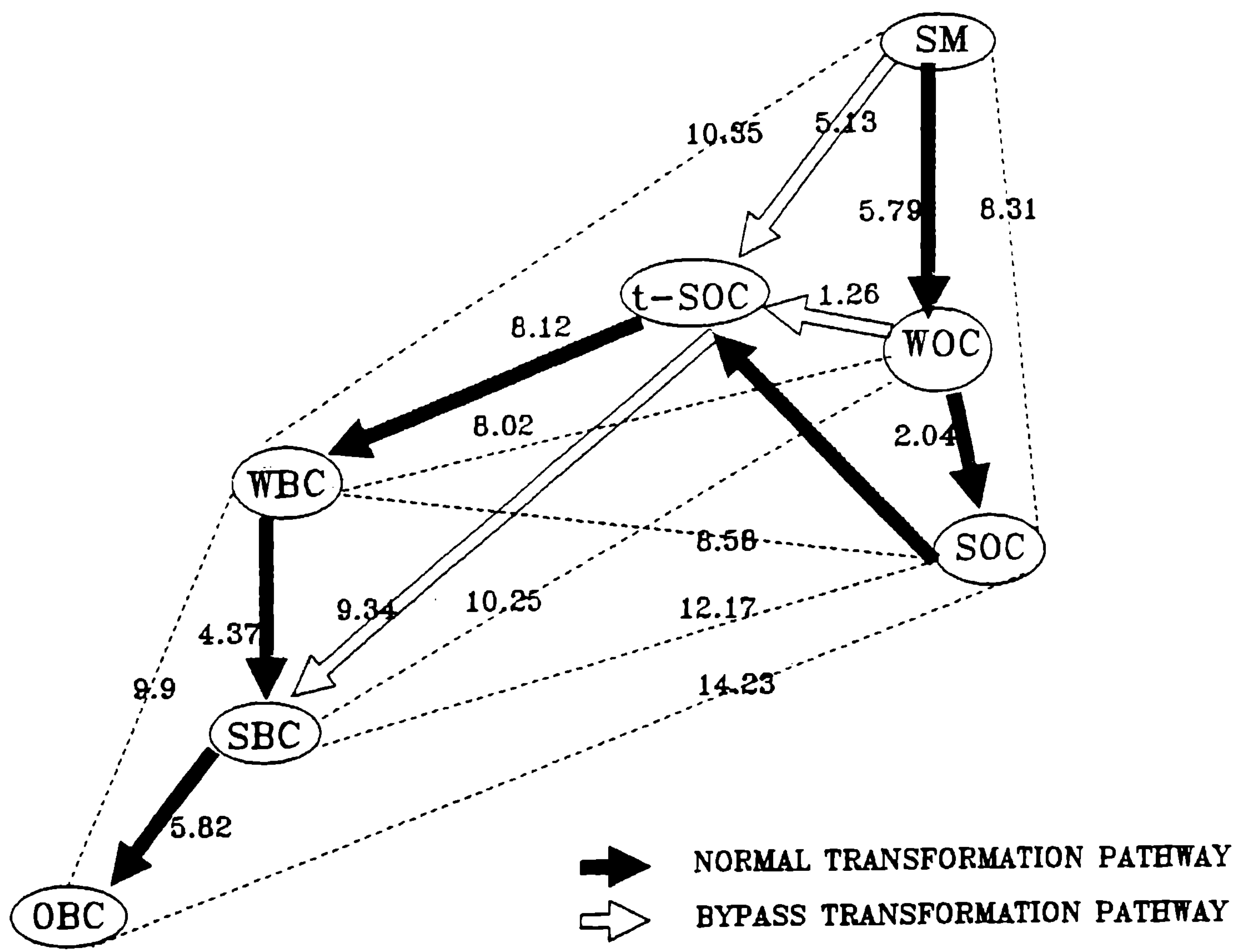
Comparison of slopes F=443.0896(2,208)= 12.72012 •
Comparison of elevation F=25717.28(2,210)= 58.04082 •



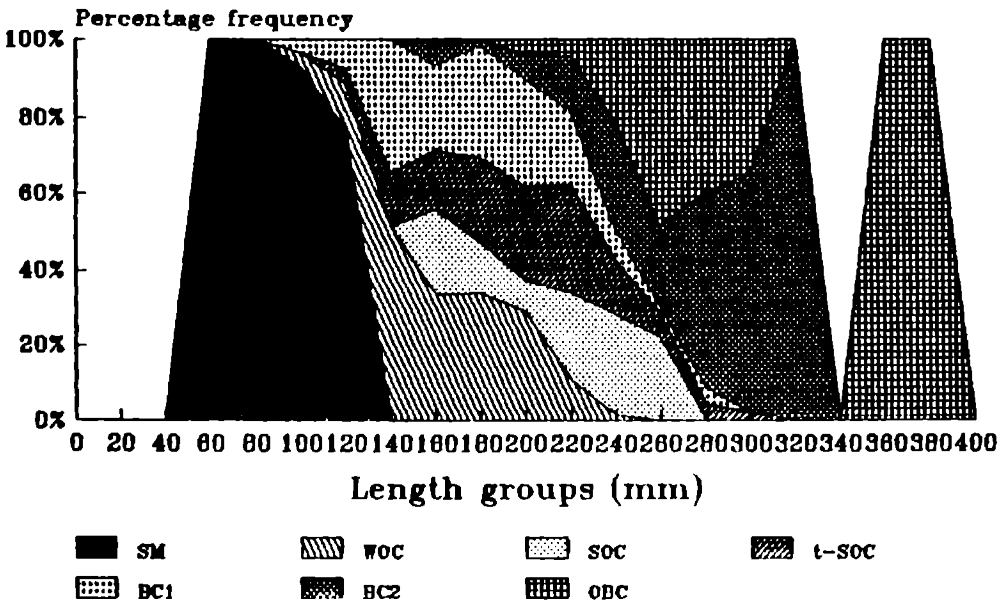
ISCHIUM LENGTH (mm)
MERUS LENGTH (mm)
SM
WOC
SOC
I-SOC
WBC
SBC
OBC
0
10
20
30
40
50
60
70
80
90
100
CARAPACE LENGTH (mm)


PROPODUS LENGTH (mm)
CARPUS LENGTH (mm)
SM
WOC
SOC
I-SOC
WBC
SBC
OBC
CARAPACE LENGTH (mm)
CARAPACE LENGTH (mm)

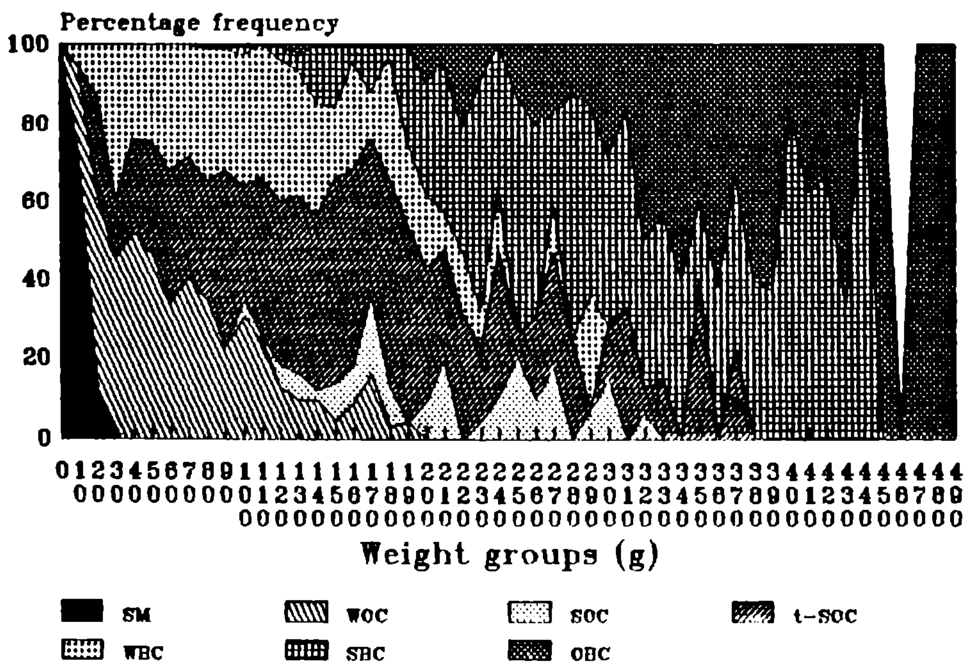

DACTYLUS LENGTH (mm)
SM
WOC
SOC
1-SOC
WBC
SBC
OBC
CARAPACE LENGTH (mm)



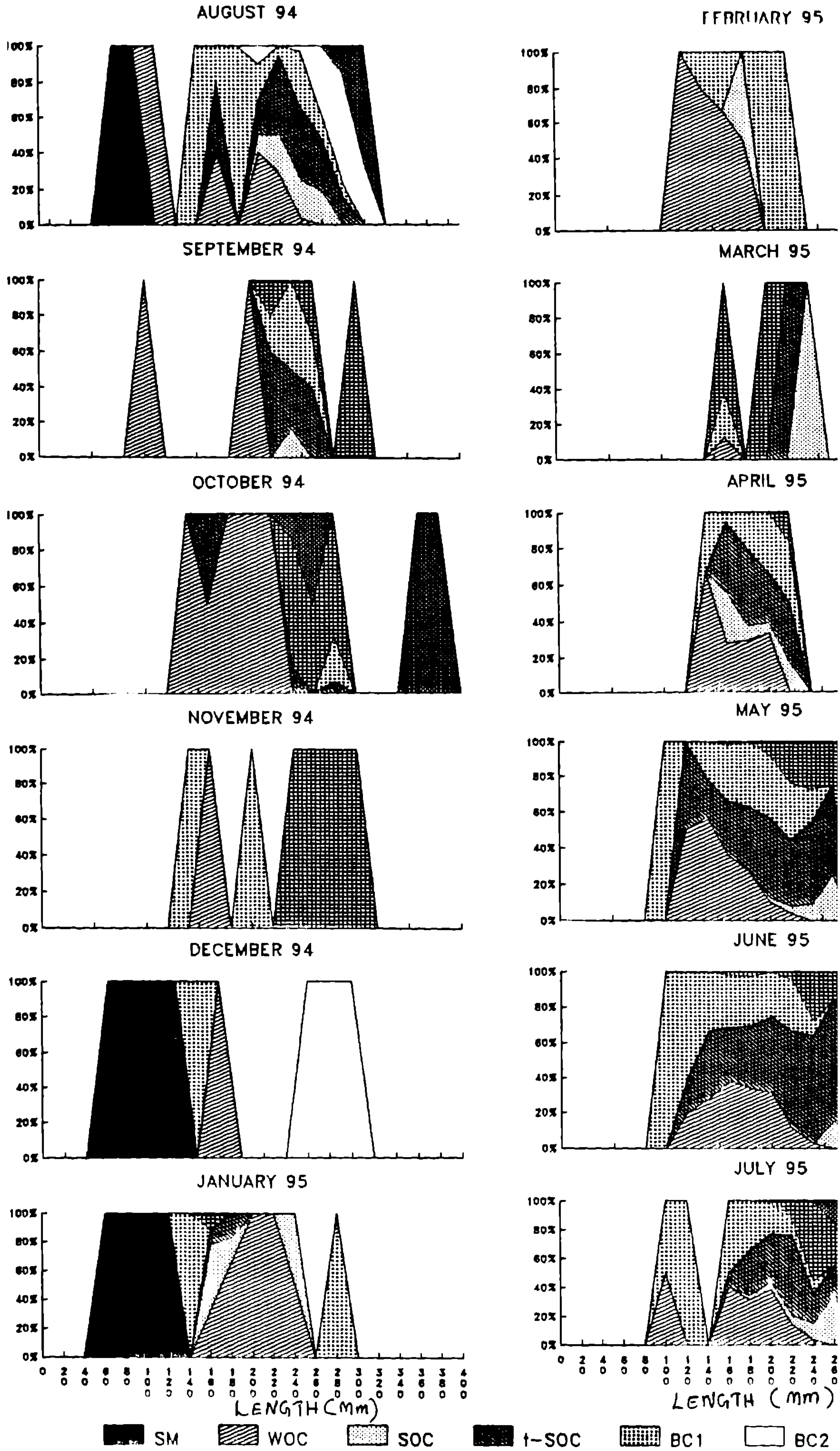
SM
WOC
SOC
t-SOC
WBC
SBC
OBC
5.13
10.35
5.79
8.31
1.26
8.12
8.02
2.04
8.58
9.34
10.25
12.17
4.37
9.9
14.23
5.82
NORMAL TRANSFORMATION PATHWAY
BYPASS TRANSFORMATION PATHWAY

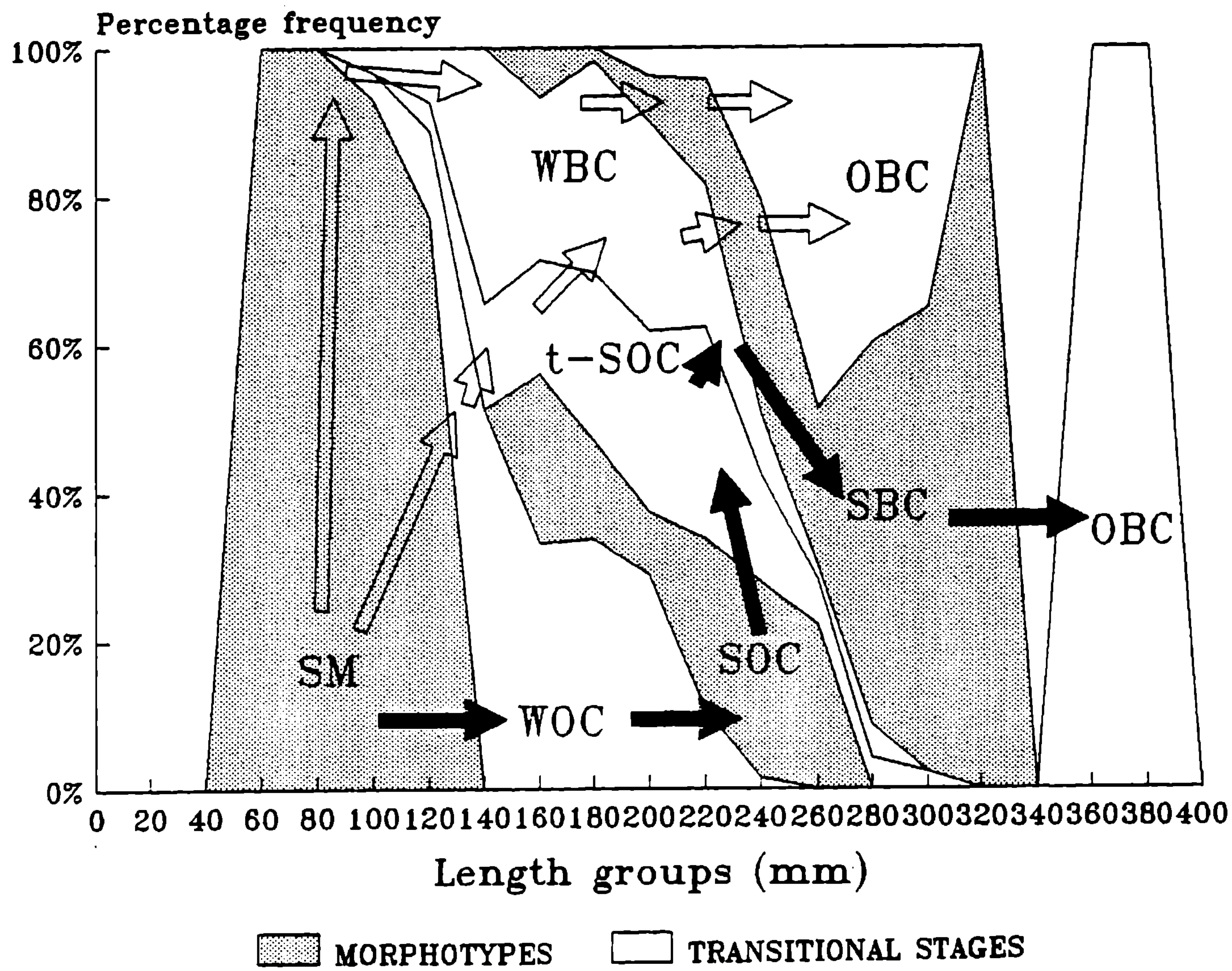

Percentage frequency
100%
80%
60%
40%
20%
0%
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
Length groups (mm)
SM
WOC
SOC
t-SOC
BC1
BC2
OBC

a

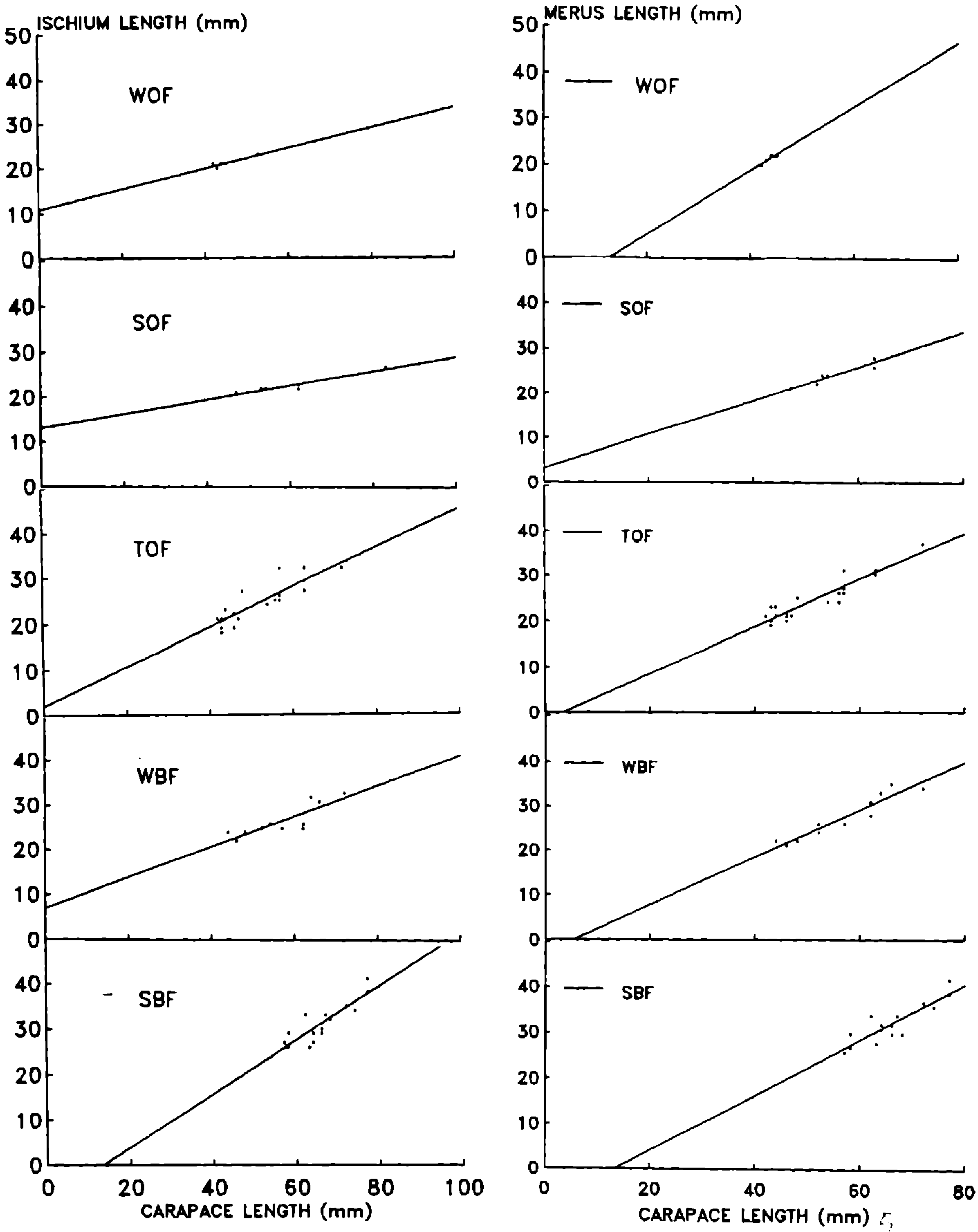

Percentage frequency
100
80
60
40
20
0
Weight groups (g)
SM
WOC
SOC
t-SOC
WBC
SBC
OBC

b

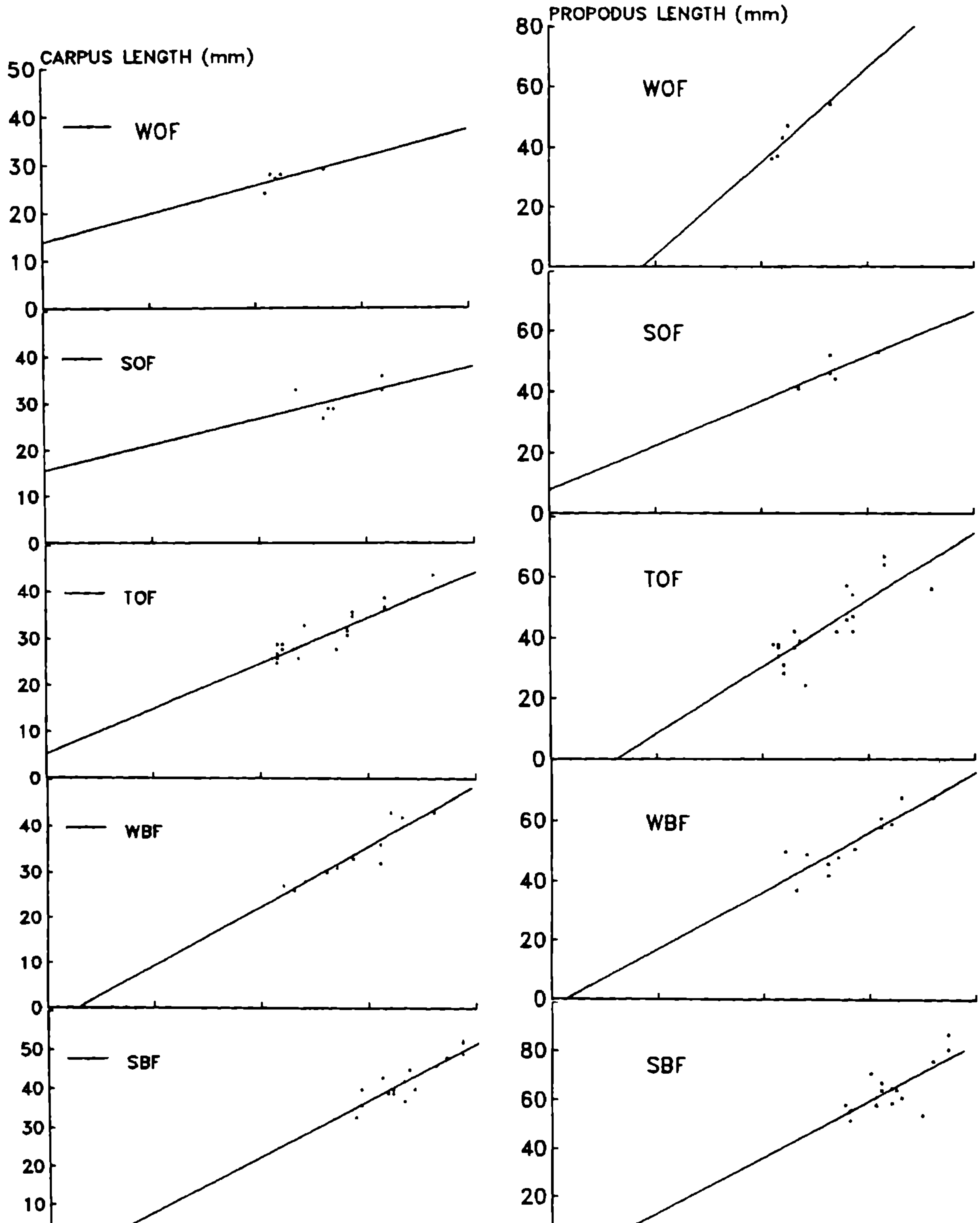

AUGUST 94
SEPTEMBER 94
OCTOBER 94
NOVEMBER 94
DECEMBER 94
JANUARY 95
FEBRUARY 95
MARCH 95
APRIL 95
MAY 95
JUNE 95
JULY 95
100%
80%
60%
40%
20%
0%
LENGTH (mm)
SM
WOC
SOC
t-SOC
BC1
BC2

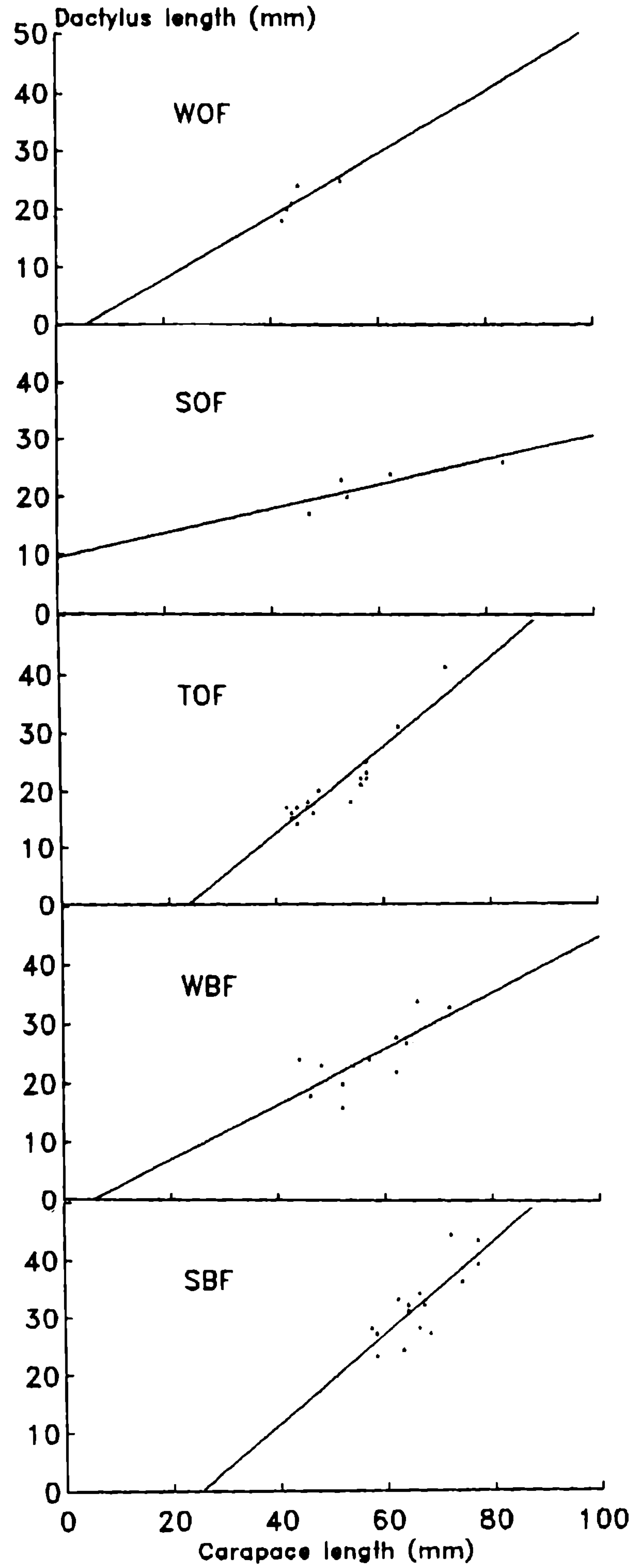


Percentage frequency
100%
80%
60%
40%
20%
0%
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
Length groups (mm)
SM
WOC
SOC
t-SOC
WBC
OBC
SBC
OBC
MORPHOTYPES
TRANSITIONAL STAGES



ISCHIUM LENGTH (mm)
MERUS LENGTH (mm)
WOF
SOF
TOF
WBF
SBF
CARAPACE LENGTH (mm)


CARPUS LENGTH (mm)
WOF
SOF
TOF
WBF
SBF
CARAPACE LENGTH (mm)
PROPODUS LENGTH (mm)
WOF
SOF
TOF
WBF
SBF
CARAPACE LENGTH (mm)



Dactylus length (mm)
WOF
SOF
TOF
WBF
SBF
0
10
20
30
40
50
0
20
40
60
80
100
Carapace length (mm)

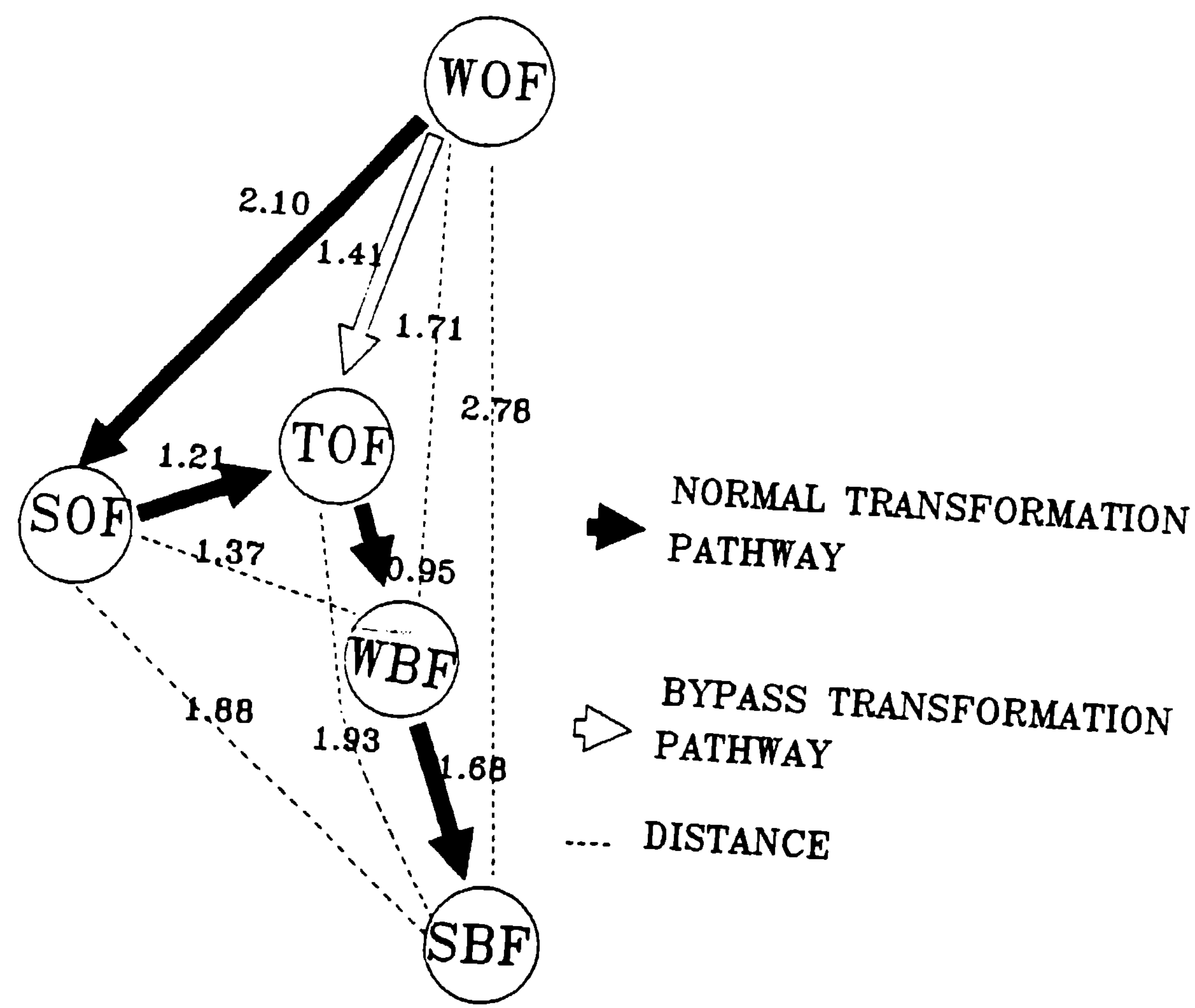
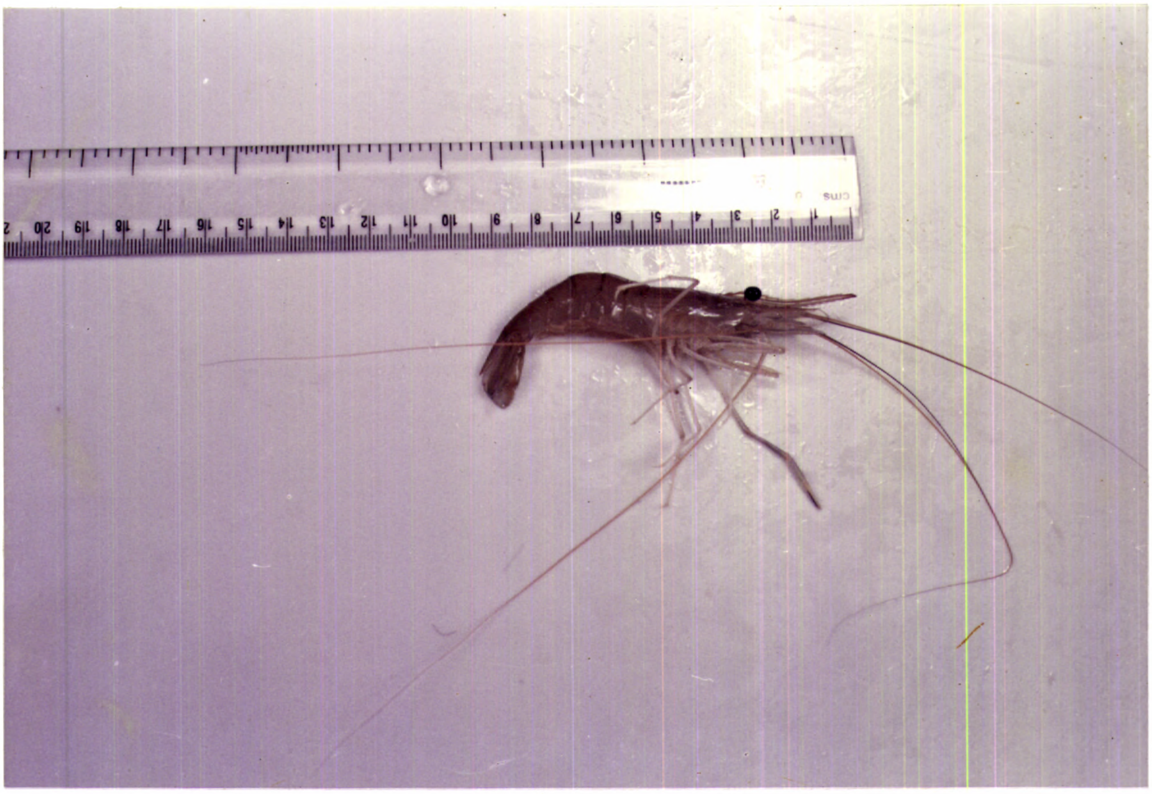

WOF
SOF
TOF
WBF
SBF
2.10
1.41
1.71
2.78
1.21
1.37
0.95
1.88
1.93
1.68
NORMAL TRANSFORMATION PATHWAY
BYPASS TRANSFORMATION PATHWAY
DISTANCE

**PLATE 2.** *Macrobrachium rosenbergii* **(de Man)**

A. **Small Male (SM)**

B. **Weak Orange Clawed Male (WOC)**

**PLATE 2**



A

B

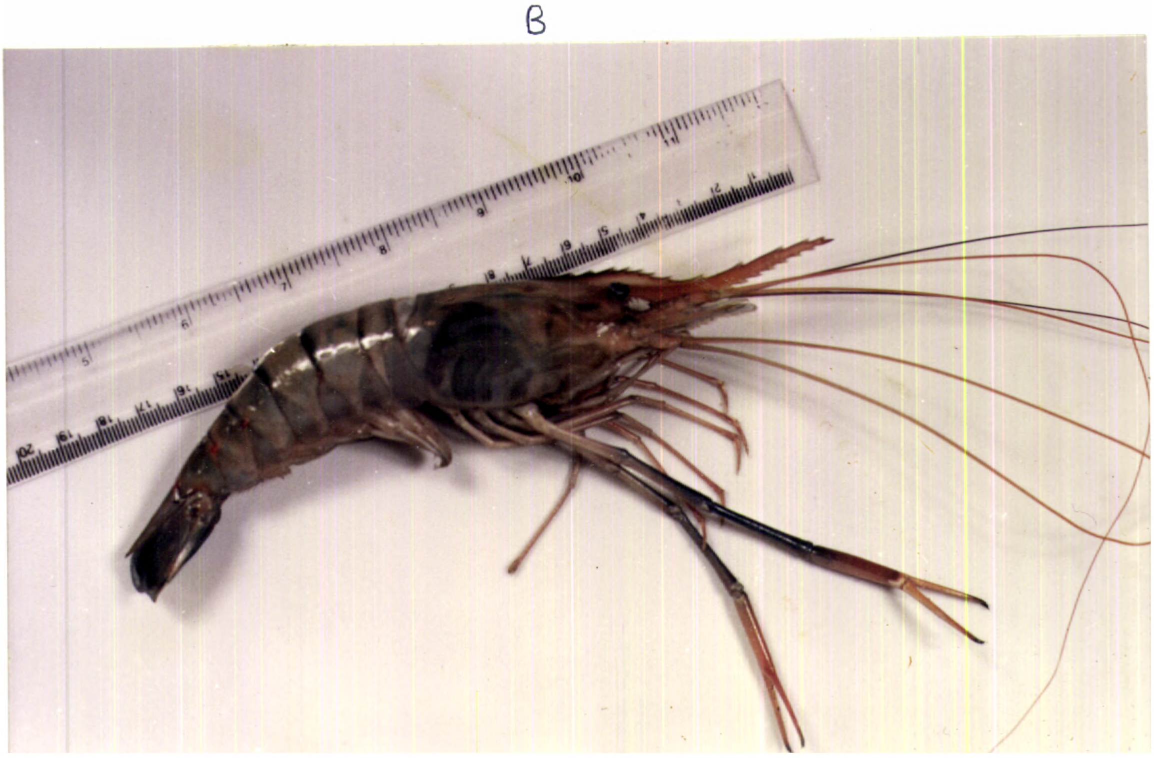
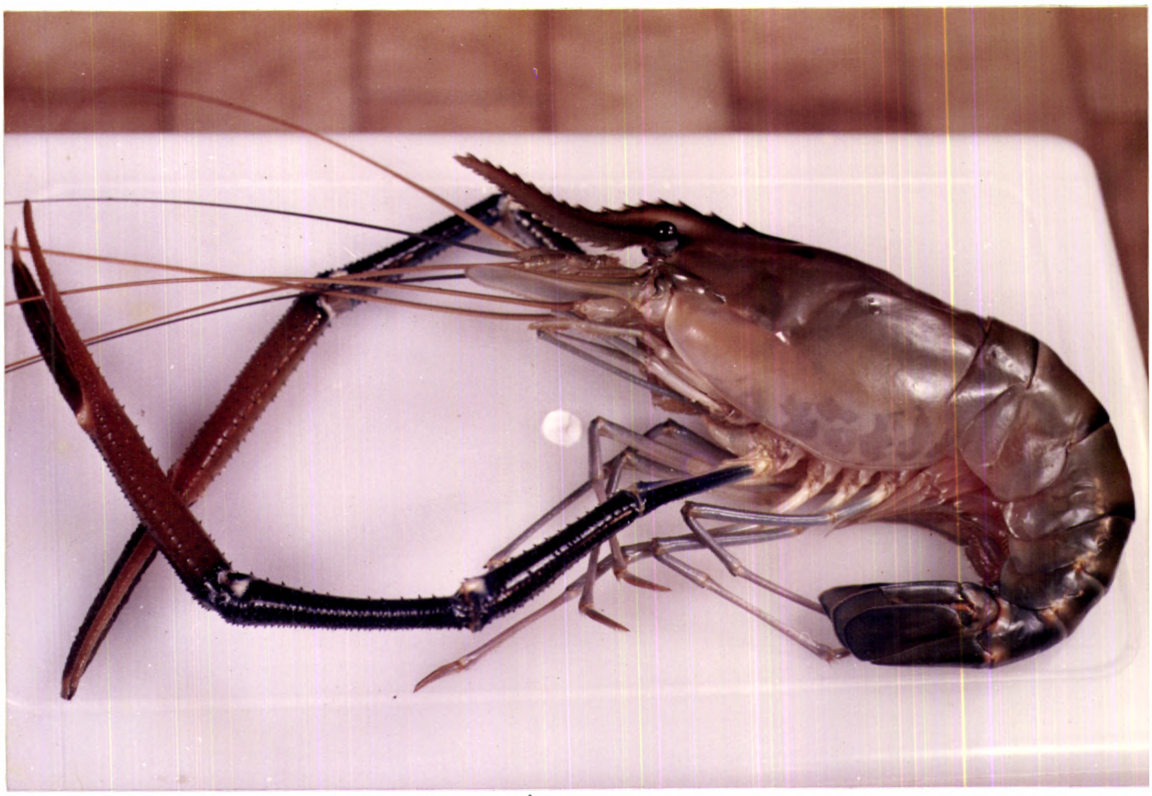


**PLATE 3.** *Macrobrachium rosenbergii* **(de Man)**

A. **Strong Orange Clawed Male (SOC)**

B. **pre- transforming Orange Clawed Male (t-SOC)**

**PLATE 3**



A

B

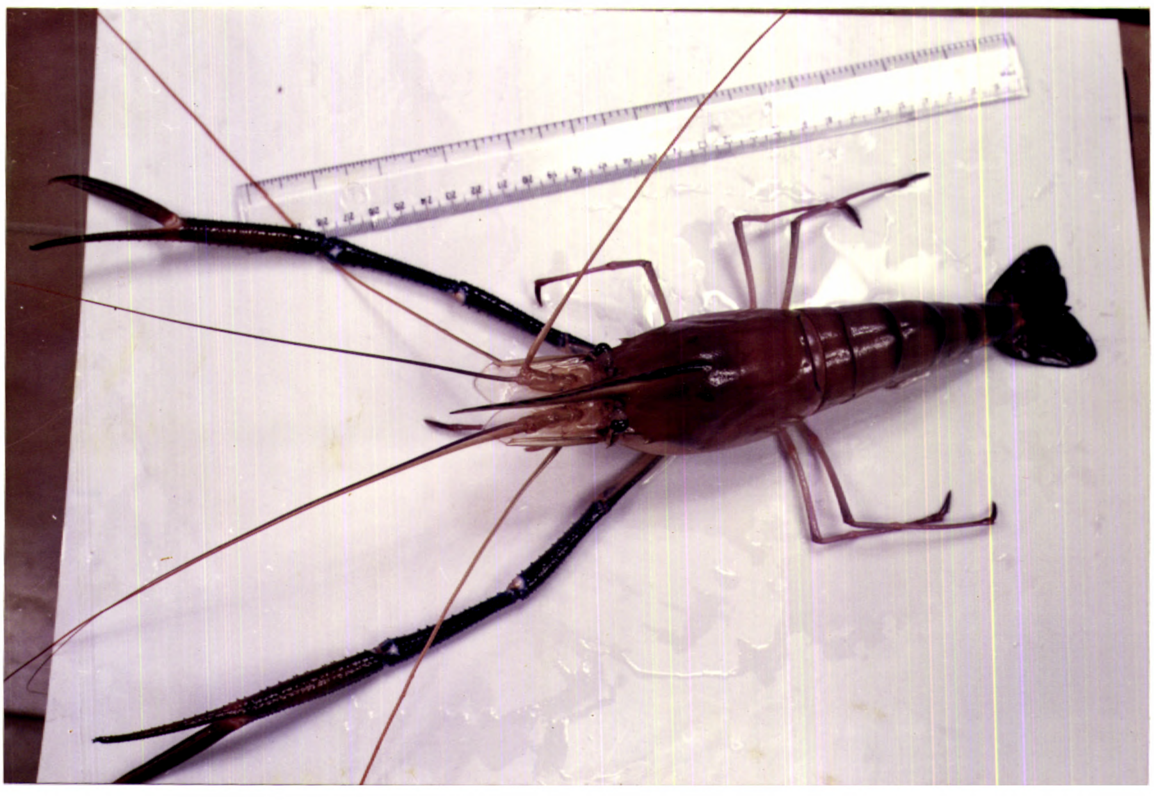


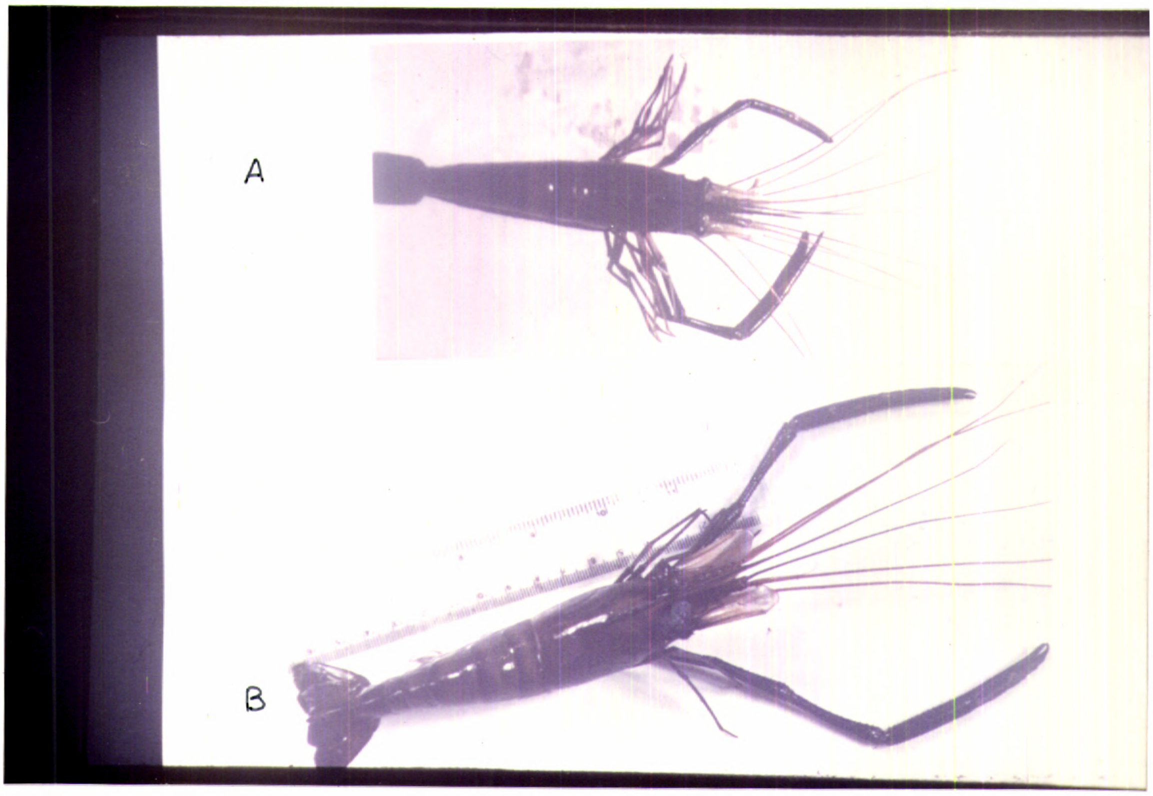
**PLATE 4.** ***Macrobrachium rosenbergii*** **(de Man)**

A. **Weak Blue Clawed Male (WBC)**

B. **Strong Blue Clawed Male (SBC)**

C. **Old Blue Clawed Male (OBC)**

**PLATE 4**



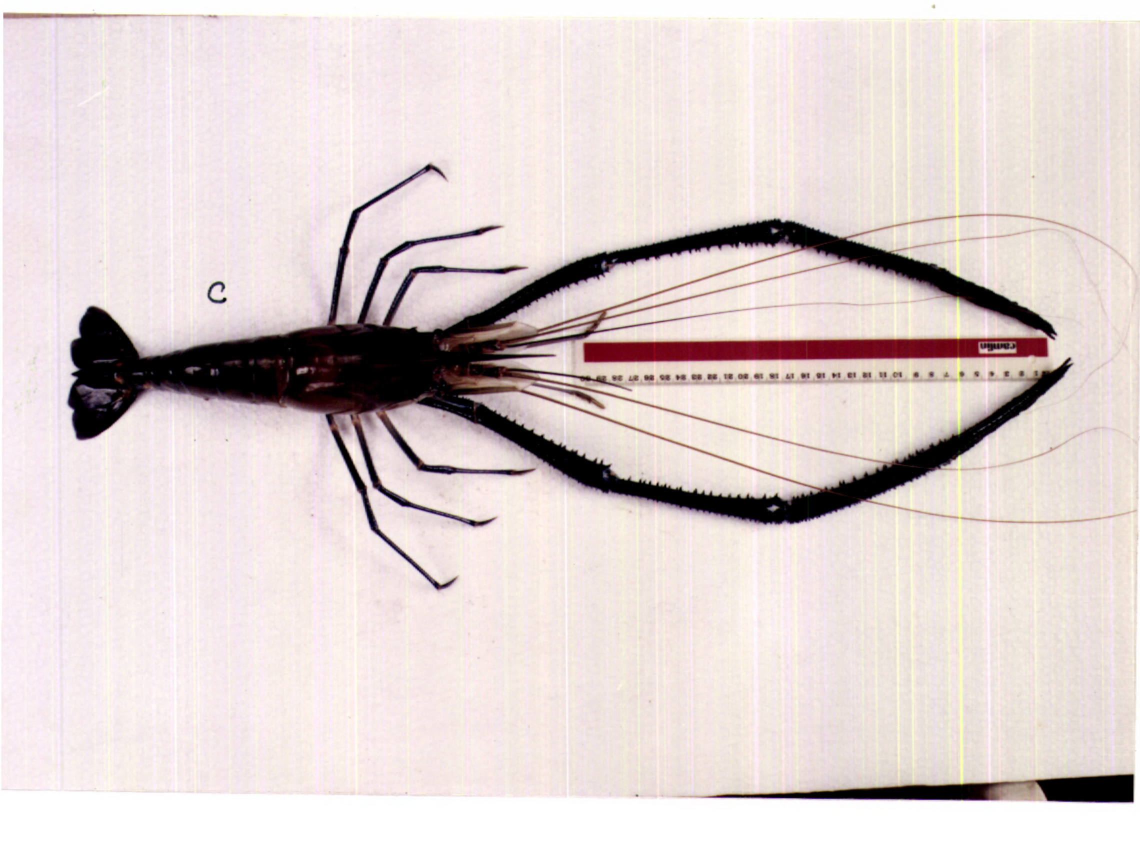
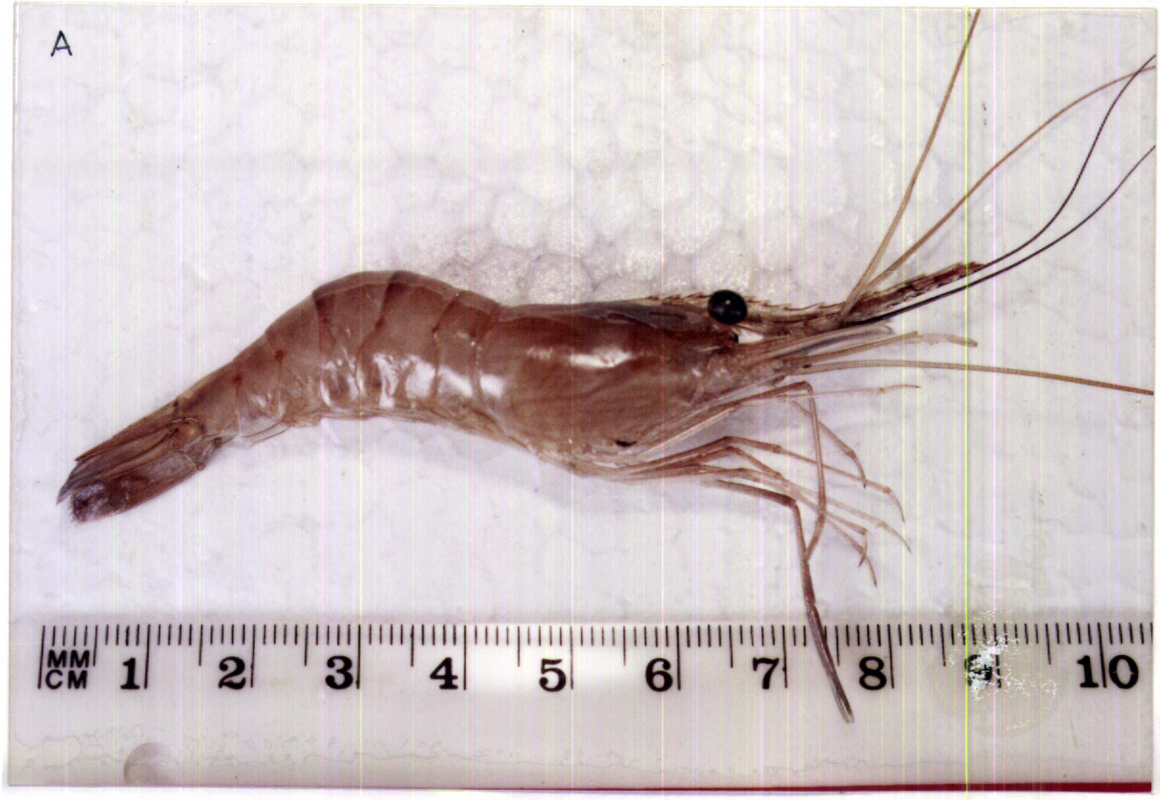



**PLATE 5.** ***Macrobrachium rosenbergii*** **(de Man)**

A. **Small Female (SF)**

B. **Weak Orange clawed Female (WOF)**

**PLATE 5**



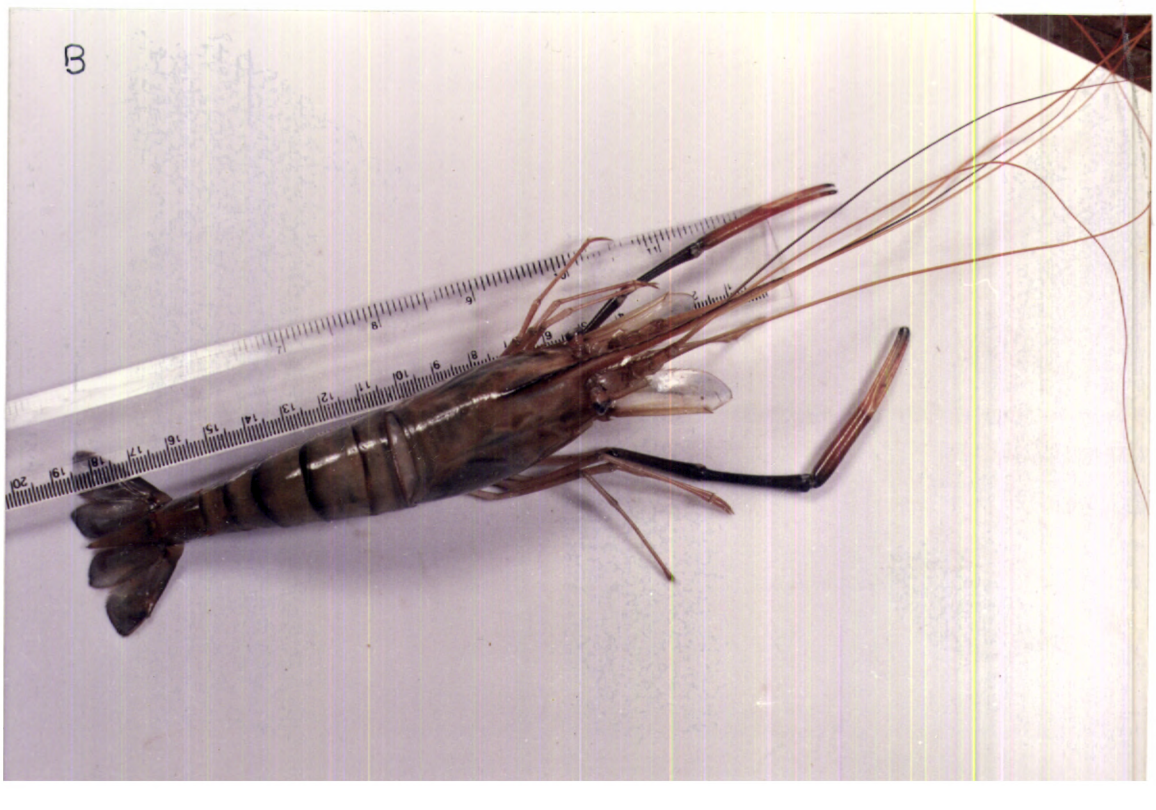



**PLATE 6.** ***Macrobrachium rosenbergii*** **(de Man)**

A. **Strong Orange clawed Female (SOF)**

B. **Transforming Orange clawed Female (TOF)**

C. **Weak Blue clawed Female (WBF)**

**PLATE 6**

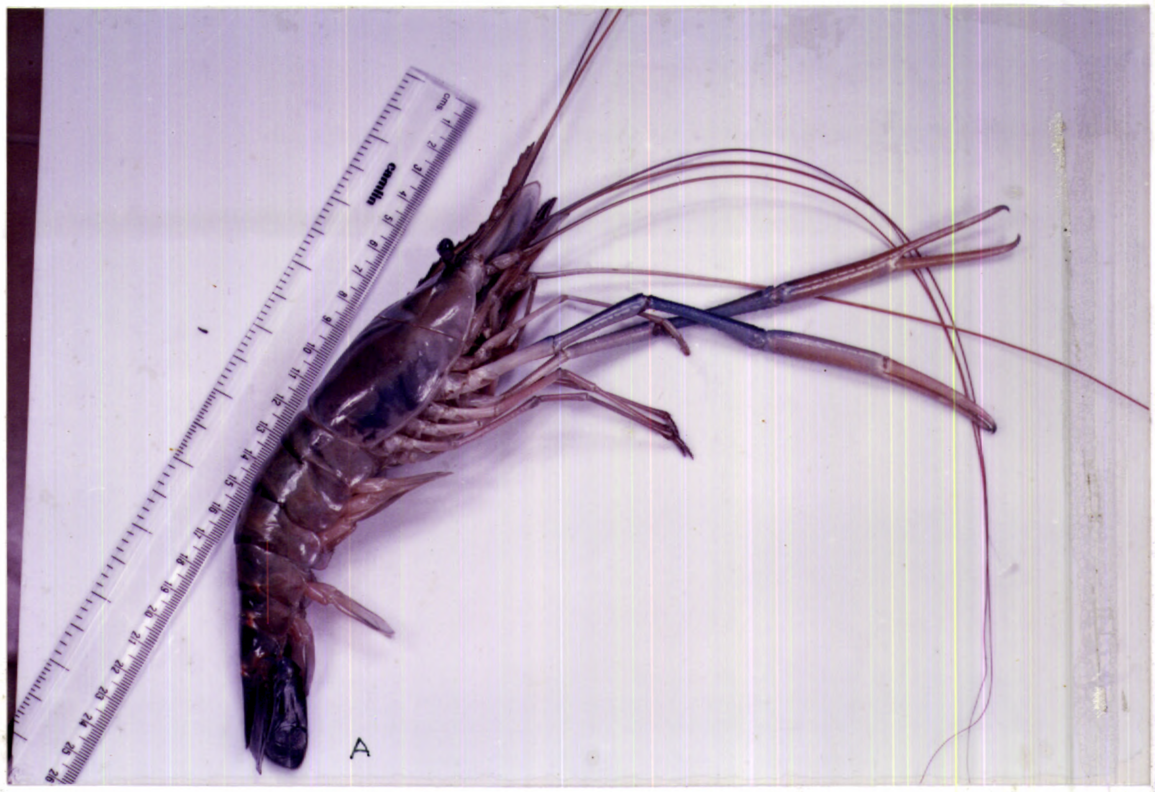
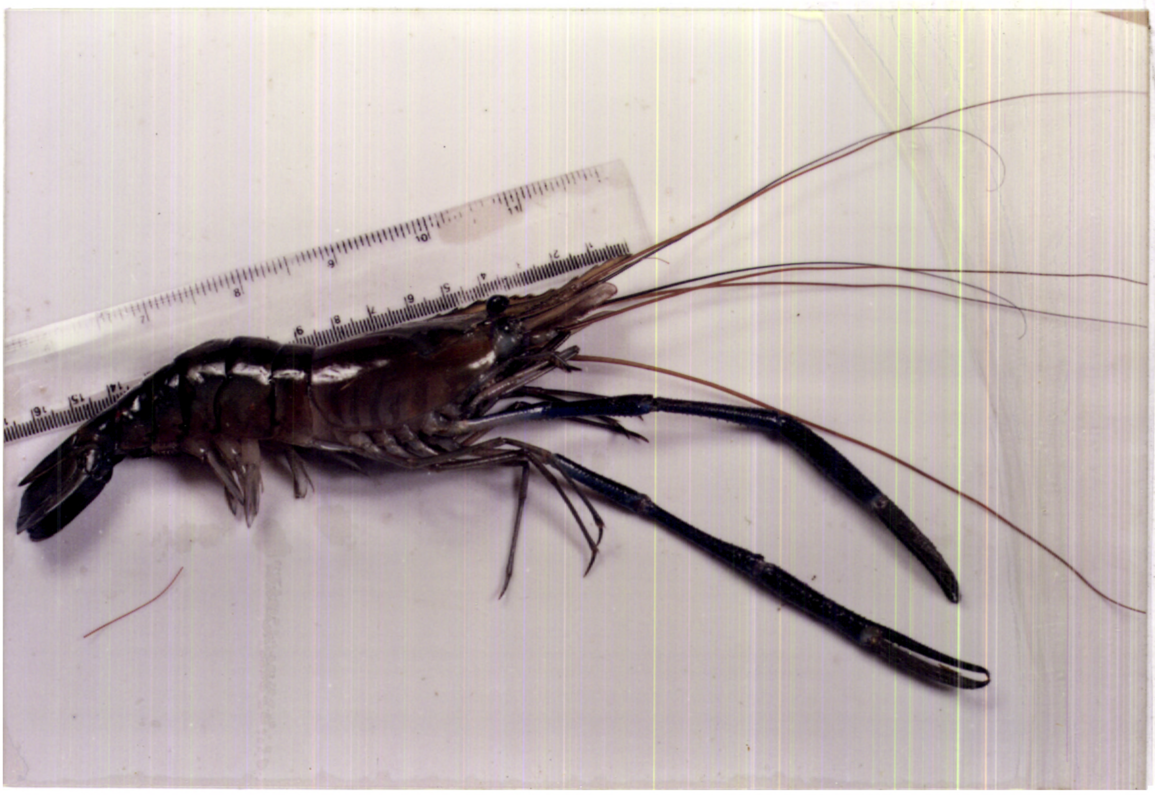



**PLATE 7.** *Macrobrachium rosenbergii* **(de Man)**

**Strong Blue clawed Female (SBF)**

PLATE 7



# CHAPTER 3

## LENGTH WEIGHT RELATIONSHIPS OF MALE AND FEMALE MORPHOTYPES OF *Macrobrachium rosenbergii* (de Man) AND MALE AND FEMALE POPULATION OF *M. idella* (Hilgendorf)

### 1. INTRODUCTION

The study of length- weight relationships is usually undertaken with the objective of working out a mathematical relationship between length and weight measurements so as to enable to find out the other variable when only one is known and also to know whether variations from expected weight for the known length groups are indications of fatness, general well- being, gonadal development and suitability of environment (LeCren, 1951). Like any other morphometric relationship, length-weight relationship can be used as an index in differentiating taxonomic units. Study of length- weight relationship in aquatic animals have wide application in delineating the growth patterns during their developmental pathways (Bagenal, 1978). Weight follows a cubic relationship with length in prawns as in fishes and length- weight relationship is expressed by the hypothetical cube law $W = CL^3$, where 'W' is weight, 'L' is length and 'C' a constant. However, most fishes and prawns change their shape or form as they grow in length and in such cases the exponent may be altered (Martin, 1949). The formula, therefore, is modified as $W = a\ L^n$, where 'W' and 'L' are weight and length respectively, 'a' is a constant equivalent to 'C' and 'n' is another constant to calculated empirically from the data. For an ideal fish which maintains its shape through out, the value of 'n' will be 3 (Allen, 1938).

Study of length-weight relationships has been done only in very few species of the genus *Macrobrachium*, such as *M. rosenbergii* (Rajyalekshmi, 1961; Rao, 1967; Kurup *et al.*, 1992b; Padmakumar *et al.*, 1992; Suresh Kumar and Kurup, 1996a) *M. malcolmsoni* (Rajyalekshmi, 1961; Ibrahim, 1962), *M. mirabilis* (Rajyalekshmi, 1961), *M. idae* (Natrajan *et al.*, 1988) and *M. idella* (Jayachandran and Joseph, 1988a; Kurup *et al.*, 1992b). Length-weight relationship of *M. rosenbergii* inhabiting natural habitats was studied by Rajyalekshmi, (1961); Rao, (1967) and Kurup *et al.*(1992b) whereas Padmakumar *et al.* (1992) and Suresh Kumar and Kurup (1996a) studied length weight relationship of pond reared population of *M. rosenbergii*. Jayachandran and Joseph (1988a) worked out the length- weight relationship of *M. idella* of Vellayani lake while Kurup *et al* (1992b) studied the same from Vembanad lake. In this chapter, length-weight relationships of various male and female morphotypes of *M. rosenbergii* and their transitional stages collected from both wild and grow out habitats were discussed with a view to delineate the variations, if any, in growth patterns of these morphotypic forms in different habitats. Sex wise difference in length-weight relationship of *M. idella* collected from Vembanad is also presented.

## 2. MATERIALS AND METHODS

1286 male and 814 female specimens of *M. rosenbergii* were collected from the exploited stock of the Vembanad lake and adjoining rivers during the monthly fishery survey cruises during March 1994 to February 1996 (refer section 1.4). Besides, 542 male and 391 female prawns were also sampled from commercial monoculture grow-outs in Kuttanad for studying length-weight relationships. The males were classified into three morphotypes such as SM, SOC and SBC and four of their transitional stages viz. WOC, t-SOC, WBC and OBC (refer Chapter 2). Similarly, females were also sorted out in to three morphotypes such as SF, SOF and SBF and three transitional stages viz. WOF, TOF and WBF (refer Chapter 2 for details). The sample number of various morphotypes could not be maintained uniform due to their differential availability in the lake and ponds. In *M. rosenbergii*, total length was measured from tip of rostrum to tip of telson up to nearest millimeter while total weight was recorded to nearest gram using a top loader scale. 292 male and 257 female specimens of *M. idella* were collected from Vembanad lake and were brought into the laboratory and length was measured from tip of rostrum to tip of telson up to nearest millimeter using a vernier caliper while weight was taken with the help of a sartorius electronic top pan balance with 0.01 milligram accuracy. Data on length and weight were analysed separately for each morphotype and male and female of *M. idella* as suggested by Le Cren (1951) in order to unravel the differences, if any, in the dimensional equalities of each group for a better understanding on the growth pattern.

Length weight relationship can be expressed as

$$w = a\ l^{b} \quad ................(1)$$

Logarithmic transformation of the above formula gives a linear equation

$$\log w = \log a + b \times \log l \quad ...........(2)$$

where w = Weight in g, l = total length in mm,
a and b are constants

Regression analysis, ANACOVA on the regression equations,comparison of slopes and calculation of correlation coefficient values and their comparison were done as per standard statistical procedures(Snedecor and Cochran,1967). To test whether the regression coefficient depart significantly from 3, t test (Baily,1959) was employed by using the formula t=b-3/Sb where b the regression coefficient and Sb the standard error of b.

## 3. RESULTS

### 3.1 *Macrobrachium rosenbergii*

#### 3.1.1. MALES

##### 3.1.1.1 Natural population

Various male morphotypes and transitional stages studied and the estimated coefficients of the length-weight relationship are given in Table 3.1. Logarithmic relationship between length and weight of three male morphotypes and their transforming stages are depicted in Fig. 3.1 Logarithmic regression equations in respect of seven morphotypes are given in the respective figures and the exponential equation can be expressed as follows:

SM : $W = 0.121968 \times L^{1.5332}$

WOC : $W = 0.004186 \times L^{3.2226}$

SOC $W = 0.002201 \times L^{3.5014}$

t-SOC : $W = 0.005062 \times L^{3.1517}$

WBC : $W = 0.006121 \times L^{3.0712}$

SBC $W = 0.012770 \times L^{2.8054}$

OBC : $W = 0 .10742 \times L^{1.9472}$

"r" values were found to be highly significant (P< 0.01) in all the treatments which indicate very good correlation between length and weight (Table 3.1). Results of ANACOVA conducted for comparing b values of various morphotypes are given in Table 3.2 and it was found that both the slope (F=15.82053, df=6,1341) as well as the elevation (F=54.0698, df=6,1347) were significantly different at 1% level (P< 0.01)in seven treatments. Therefore, pair wise comparison of b values were carried out using student "t"and the results are given in Table 3.3a. It could be seen that b values were found to be significantly different at 1% level (P <0.01) between SM & WOC, SM & SOC,SM & t-SOC, SM & WBC, SM & SBC, WOC & OBC, SOC & WBC, SOC & SBC, SOC & OBC, t-SOC & OBC, WBC & OBC and SBC & OBC while difference at 5%level (P<0.05) was noticed between WOC & SOC and SOC & t-SOC. Pair wise comparison of correlation coefficient values were also attempted and the results (Table 3.3b) showed significant difference at 1% level ($P<0.01$) between SM & WOC, SM & SOC, SM & t-SOC, SM & WBC, WOC & SBC, WOC & OBC, SOC & SBC, SOC & OBC, t-SOC & SBC, t-SOC & OBC, WBC & SBC, WBC & OBC and SBC & OBC. Regression coefficients of various male morphotypes were tested against the isometric value of 3 and the results are shown in Table 3.4. Statistically significant difference at 1% level($P<.01$) could be seen in respect of SM,WOC,SOC,t-SOC and OBC while the difference to isometric value was found insignificant in the case of WBC and SBC.

3.1.1.2 Grow - out population

Various male morphotypes and transitional stages studied and the estimated coefficients of the length-weight relationship are given in Table 3.5. Logarithmic relationship between length and weight of three male morphotypes and their transforming stages are depicted in Fig. 3.2 and the logarithmic regression equations in regard to the same are given in the respective figures and the exponential equation can be expressed as follows:

SM : $W = 0.015475 \times L^{2.5541}$

WOC $W = 0.005939 \times L^{3.0899}$

SOC : $W = 0.007494 \times L^{3.0055}$

t-SOC : $W = 0.006071 \times L^{3.0910}$

SBC $W = 0.004038 \times L^{3.2923}$

OBC : $W = 0.031454 \times L^{2.4272}$

Only very few specimens of WBC could be collected from the pond and therefore it was not included in the present study. Significant correlation between length and weight of various male morphotypes and transitional stages could be observed at 1% level (Table 3.5). Results of comparison of regression coefficients by ANACOVA are given in Table 3.6. It could be seen that significant difference exists between regression coefficients as shown by both the slope (F= 6.9178, df= 6,500) and elevation (F= 68.6580, df= 6,506). Pair wise comparison of b values of different morphotypes by student t test showed that significant difference at 1% level exists between SM and WOC, WOC and OBC, SOC and OBC, t-SOC and OBC and SBC and OBC whereas regression coefficients of SM and t-SOC varied significantly only at 5% level (Table 3.7). A comparison of correlation coefficients also revealed significant variations between the above pairs, besides WOC and SOC, SOC and t-SOC and t-SOC and SBC (Table 3.7). Results of t-test (Baily, 1959) for finding out whether b values significantly departed from isometric value of 3 are given in Table 3.8 and the results showed that significant difference exists in the case of SM and OBC only.

### 3.1.2 FEMALES

#### 3.1.2.1 Natural population

Small Females were appeared only sporadically in the exploited stock and therefore, length weight relationship could not be established based on sufficient numbers. Details of number of other female morphotypes and their transitional stages collected, their length and weight ranges, regression constants and correlation coefficients are shown in Table 3.9. Logarithmic relationship between length and weight of two female morphotypes(SOF and SBF) and their transforming stages are depicted in Figs 3.3 Logarithmic regression equations in respect of five stages are given in the respective figures and the exponential equation can be expressed as follows:

WOF : $W = 0.044882 \times L^{2.17}$

SOF : $W = 0.017786 \times L^{2.58}$

TOF : $W = 0.005646 \times L^{3.08}$

WBF : $W = 0.008289 \times L^{3.92}$

SBF : $W = 0.025049 \times L^{2.47}$

r values showed significance at 1% level in the correlation of length and weight of all morphotypic stages (Table 3.9). Results of comparison of regression coefficients using ANACOVA are given in Table 3.10. Both slope (F= 6.9013, df= 4,804) and elevation (F= 20.7414, df= 4,808) showed significant variation at 1% level. Hence, pair wise comparison of regression coefficients using t test was carried out and significant variations at 1% level was observed between WOF X TOF, TOF X SBF and WBF X SBF while regression coefficients of WOF X WBF and SOF X TOF differed only at 5% level(Table 3.11). A comparison of correlation coefficients showed that significant variations exist only between TOF X SBF and WBF X SBF (Table 3.11). Regression coefficients of WOF, SOF and SBF were found to depart significantly from isometric value of 3 (Table 3.12).

3.1.2.2 Grow - out population

Only five numbers of SOF morphotype could be collected from the pond and hence the relationship could not be worked out due to inadequacy of sample size. Details regarding number of various morphotypic stages, their length and weight ranges, regression constants and correlation coefficients are given in Table 3.13. Logarithmic relationship between length and weight of two female morphotypes such as SF and SBF and the transforming stages *viz*. WOF, TOF and WBF are depicted in Fig. 3.4.

Logarithmic regression equations in respect of five morphotypic stages are given in the respective figures and the exponential equation can be expressed as follows:

SF $W = 0.015560 \times L^{2.5284}$

WOF : $W = 0.022663 \times L^{2.4979}$

TOF $W = 0.022254 \times L^{2.4937}$

WBF : $W = 0.033607 \times L^{2.2992}$

SBF : $W = 0.016878 \times L^{2.6249}$

r values showed significance at 1% level in all treatments. Results of ANACOVA for comparing regression coefficients of various morphotypes are shown in Table 3.14. Significant difference could only be seen in elevation (F= 32.9275, df= 4,380) whereas slope (F= 0.6590, df = 4,376) showed no significant variation. A comparison of regression coefficients by t-test showed significant difference only between WBF and SBF. However, a comparison of correlation coefficients showed significant variations between WOF X TOF, WOF X WBF, TOF X WBF and WBF X SBF (Table 3.15). Regression coefficients of WBF and SBF showed significant deviations from 3 at 1% level, while that of TOF departed only at 5% level (Table 3.16). Regression coefficient from pooled data of length and weight of female population was also worked out (b= 3.1887, r= 0.9659, df= 389). The results show that b value departed significantly from 3 in t-test (Baily, 1959) which indicated that female population, in general, follows an allometric growth pattern in terms of length and weight in culture systems.

## 3.2 *Macrobrachium idella*

Details regarding the length and weight ranges, number sampled, regression coefficients and correlation coefficients of male and female *M. idella* are given in Table 3.17. Logarithmic relationships between length and weight of the two sexes are depicted in Fig.3. 5 and the exponential equation can be expressed as follows.

MALES $W= 0.062316 \times L^{3.4491}$
FEMALES $W= 0.140061 \times L^{3.0150}$

Values of correlation coefficients of males and females showed significance at 1% level. Results of ANACOVA conducted for comparing regression coefficients of males and females of *M. idella* are shown in Table 3.18. Both slope and elevation showed significant difference at 1% level. In order to test whether b values departed significantly from isometric value of 3, t-test following Baily(1959) was adopted and the results are presented in Table.3.19. The results show that regression coefficient of males showed significant variation from 3 at 1% level whereas in females it did not depart significantly from isometric value, indicating an isometric growth pattern.

## 4. DISCUSSION

The index representing dimensional equality between length and weight and its variation from the hypothetical value could be relied upon for assessing growth pattern of fishes and crustaceans (Beverton and Holt,1957; Alagaraja,1984). In the present study, while examining the regression coefficients of three morphotypes and four of their transforming stages collected from natural system, a definite trend could be discernible in the ascending as well as descending patterns commensurating with the developmental pathway as reported by Sagi and Ra'anan (1988). Regression value was apparently appeared as lowest in SM which occupies the initial stage of hierarchy in the developmental pathway of males (Cohen et al., 1981) and interestingly similar trend could also be discernible in OBC which forms the terminal morphotypic docile. On the contrary, in WOC which occupies the next transition stage of SM, about 100% improvement of b value could be noticed when compared to its predecessor. However, in the true orange clawed male (SOC) further improvement of b values was noteworthy and this morphotype has emerged unique in having the highest b value among the seven. On the contrary, a descending trend in b values could be observed in the successive morphotypic stages from t-SOC onwards and persisted in WBC, SBC and OBC. However, in the former two stages, the values maintained almost around 3 while in the latter two it was well below the hypothetical value of 3. It would thus appear that the weight gain with increase in length was very rapid in WOC and SOC, on the contrary, the process got reversed when the SOC transformed into SBC through the intermediary transition stages of t-SOC and WBC. The b values arrived at in respect of SOC,WOC and t-SOC were definitely well above the value of isometric growth and statistically also found that it was significantly deviating from the isometric value. Though WBC was also found to be maintaining the weight proportional to its cube of length, in its successive stages SBC and OBC, the weight increase was found to be less than cube of length. It may, therefore, be inferred that the orange clawed morphotypes and its transitional stages were characterised with stoutest pattern of growth in contrast to the slender type seen in SM and Blue Clawed Males. Generally it is believed that in shell fishes which maintain the dimensional equality, the weight increase will be proportional to cube of the length increment (Allen, 1938) while slope value less than 3 and its downward deviation indicates that the animal become more and more slender as it increases in length whereas slope greater than 3 denotes stoutness which indicates that growth is allometric(Grover and Juliano,1976). As the increase in weight in regard to SOC,WOC and t-SOC appeared to be a power more than 3 with increase in body length, these groups show typical allometric pattern of growth as defined by Growner and Juliano (1976). The value of b usually varies between 2.5 to 4 (Hile, 1936; Martin, 1949), however, in the present study the b value of SM was apparently lowest and far below from the lowest permissible limit as given above and this would support the fact that the dimensional equality of this group is not properly maintained due to very poor growth.

On analysing the regression coefficients of male morphotypes and their transitional stages collected from culture ponds it could be seen that their growth patterns in respect to length and weight are more or less similar to that of male morphotypes collected from natural system. However, all morphotypes except SM and OBC showed isometric growth as evidenced from lack of significant departure from 3 in t-test (Baily, 1959). Results of pair wise comparison of regression coefficients also showed that b values of SM and OBC differed significantly with all other morphotypes. However, b values of SM and OBC collected from culture ponds are much higher than that of SM and OBC in natural system which indicates that even though they follow allometric growth pattern, they are maintaining a better dimensional equality when compared to their counter parts inhabiting in the natural system. Moreover, in natural system, SOC showed highest b value indicating stoutest growth in relation to increase in length. However, in culture system SOC showed b values more or less close to 3 indicating a clear isometric growth pattern. b values computed in the present study are comparable with that of Suresh Kumar and Kurup(1996a) who have reported a higher b value for BC males than to OC males. It may, therefore, be inferred that BC males maintain dimensional equality in their growth in culture systems when compared to that of the natural systems.

The three morphotypes and their transformation stages of *M. rosenbergii*, probably representing three maturation stages in the process of developmental pathway of male and are developed by transformation of one morphotype to another, following an irreversible order from SM to OC to BC (Cohen et al.,1981; Ra'anan and Sagi, 1985). The demarcation of morphotypes based on the existence of antagonism in energy demands between the somatic growth and reproductive activity have already been attempted (Ra'anan,1982; Sagi and Ra'anan,1988). SM ceases to grow as they invest a large part of their energy in mating attempts, using a sneak copulatory behavior (Ra'anan,1982; Sagi, 1984) and also possesses a well developed reproductive system which is comparable with BC males and are therefore, characterised with an intense sexual activity and reduced growth rate(Sagi and Ra'anan,1988). Low b value obtained for SM in the present study fully conforms to the above characterization. On the contrary, in OC,the next transforming stage of SM, the reproductive system is very small and are corresponds with an ineffective reproductive behavior as they spend only very little energy for reproduction and courtship, the somatic growth is reported to be very fast (Sagi and Ra'anan,1988). In the present study, highest regression coefficient could be arrived at for SOC collected from natural system and this finding strongly corroborates its rapid somatic growth as reported earlier. Sagi and Ra'anan(1985) also reported that in the transitional stages of SOC viz,WOC and t-SOC the reproductive tract do not lengthen even though somatic growth is evident and fully conforming to this observation, in the present study also, the b value computed in respect of these morphotypes were found apparently closer to that of SOC. BC males also spent most of its energy for dominanceship,courtship and reproduction whereby the growth becomes standstill and moulting becomes so infrequent (Ra'anan,1982; Ra'anan and Sagi,1985) and the relatively low b values arrived at for SBC and OBC from natural system and OBC from culture ponds in the present study manifest this possibility. However, WBC from natural system and both WBC and SBC from culture system appear to be maintaining isometric growth and this would suggest that the rapid somatic growth which is characteristics of SOC lasts till it attains WBC or SBC. On the contrary, regression coefficients worked out for OBC collected from both natural and culture system showed lower values, comparable to SM morphotypes. This may support the view that OBC males might have reached the BC status in the early stages of morphotypic differentiation at a smaller body size (Ra'anan, 1982; Sagi and Ra'anan, 1988) in consequence to the leap frog growth pattern (Ra'anan and Cohen, 1985). Ra'anan and Cohen(1985) also reported that although OBC males represented largest males at a given stage, their relative size ranking with in male population decreases since further growth in them was largely inhibited while other males kept growing. The low b values observed in these morphotypic stages in the present study also support the above view.

It would thus appear that the regression coefficient worked out between length and weight of male morphotypes of *M.rosenbergii* show the differential energy demands related to somatic and reproductive growth phases and therefore can very well be taken as an index for their easy demarcation. The results of the present study fully support the earlier finding (Sagi and Ra'anan,1988) that BC and SM males represent the reproductive, slow growing phases,while the OC morphotype represents the non reproductive, fast growing phase. It is quite possible that during the developmental pathway of *M.rosenbergii*, there may be temporary separation of a period of rapid somatic growth phase as represented by SOC and its transforming stages from that of slow growing reproductive phases as shown by SM and BC and this finding is comparable with the conditions seen in brachyura as reported by Adyodi (1978).

However, the growth patterns of female morphotypes collected from natural and grow-out habitats differ significantly as observed in the present study. A comparison of regression coefficients of length and weight of two female morphotypes such as SOF and SBF and their transitional stages collected from the lake showed significant variations at 1% level whereas the same collected from culture system did not vary significantly. Cohen *et al.* (1981) reported that females grown in culture systems did not exhibit apparent morphotypic differentiation owing to rather homogeneous size distribution. The regression coefficients worked out in the present study show that the same in all morphotypes collected from culture system except WOF deviated significantly from isometric value indicating that in these animals dimensional equality was not properly maintained owing to poor growth. This finding is contrary to that of Suresh Kumar and Kurup (1996) who reported isometric growth pattern in female population of *M.rosenbergii* from an extensive culture system in Kuttanad.

Harikrishnan *et al.* (1997) reported clear differentiation of female population based on morphological characteristics and allometrical differences. The relative growth on weight in pooled females collected from natural system was found to be isometric (b= 3.20, r= 0.93). However, it was also reported that irrespective of sexes, *M. rosenbergii* in Vembanad lake followed an isometric form of growth (Kurup *et al.*, 1992b). Form the present findings, it may be inferred that females follow allometrical growth pattern only in certain morphotypic forms such as WOF, SOF and SBF. In the developmental pathway of male morphotypes the orange clawed males represent a stage of faster somatic growth (Ra'anan, 1982; Sagi and Ra'anan, 1988). But the corresponding female morphotype (SOF) does not follow similar trend in natural system, on the contrary TOF, which occupies the successive transitory stage of SOF is characterised by an isometric growth.

Results of present study showed differential growth patterns between males and females of *M.idella* as evidenced from results of ANACOVA. Results of t-test (Baily,1959) has shown that males follow an allometric growth pattern. On the contrary, the growth in terms of length and weight in females was found to be isometric which is quite contrary to the findings of Kurup *et al.* (1992b) and Jayachandran and Joseph(1988b). The b value of female estimated in the present study is far less when compared to the value reported by Kurup *et al.* (1992b) as 3.2113 and Jayachandran and Joseph (1988b) as 3.5142, nevertheless, the same in regard to males is more or less comparable with the estimates of the above authors (3.31 and 3.4773 respectively).

Table 3.1. Coefficients of length- weight relationships of male morphotypes and transitional stages of *Macrobrachium rosenbergii* and details of statistical analysis

| Morphotypes | Minimum length (mm) | Maximum length (mm) | Numbers examined | b | log a | r | Probability |
|---|---|---|---|---|---|---|---|
| SM | 71 | 125 | 35 | 1.5336 | -2.104 | 0.7799 | * P<0.01 |
| WOC | 107 | 246 | 259 | 3.2226 | -5.476 | 0.9528 | * P<0.01 |
| SOC | 167 | 284 | 48 | 3.5014 | -6.119 | 0.9382 | * P<0.01 |
| t-SOC | 131 | 310 | 414 | 3.1517 | -5.286 | 0.9500 | * P<0.01 |
| WBC | 105 | 289 | 329 | 3.0712 | -5.096 | 0.9516 | * P<0.01 |
| SBC | 238 | 354 | 129 | 2.8054 | -4.360 | 0.8045 | * P<0.01 |
| OBC | 204 | 393 | 72 | 1.9472 | -2.231 | 0.6047 | * P<0.01 |

Table.3.2. Comparison of regressions of length and weight of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | MORPHOTYPES | df | {x2 | {xy | {y2 | RC | df | SS (d y.x2 | MS | |
| 1 | SM | 34 | 0 10235 | 0 15692 | 0 394819 | 1 533169 | 33 | 0 154235 | 0 004674 | |
| 2 | WOC | 278 | 1 060343 | 3 382955 | 11 99654 | 3.190435 | 277 | 1 203447 | 0 004345 | |
| 3 | SOC | 56 | 0.215476 | 0.769114 | 3.117328 | 3.569363 | 55 | 0.372081 | 0.006765 | |
| 4 | t-SOC | 437 | 1.832296 | 5.813122 | 20.42391 | 3.172588 | 436 | 1.981261 | 0.004544 | |
| 5 | WBC | 343 | 1.740542 | 5.362302 | 18.25198 | 3.080824 | 342 | 1.731667 | 0.005063 | |
| 6 | SBC | 129 | 0.123764 | 0.353376 | 1.511335 | 2.855246 | 128 | 0.502358 | 0.003925 | |
| 7 | OBC | 71 | 0.111267 | 0.216763 | 1.154423 | 1.948139 | 70 | 0.732139 | 0.010459 | |
| 8 | WITH IN | | | | | | 1341 | 6 677189 | 0 004979 | |
| 9 | Reg Coeff. | | | | | | 6 | 0 472647 | 0.078775 | |
| 10 | COMMON | 1348 | 5.186038 | 16.05455 | 56.85033 | 3.095726 | 1347 | 7.149836 | 0.005308 | 15.82053 * |
| 11 | Adj Means | | | | | | 6 | 1.722006 | 0.287001 | 54.06981 * |
| 12 | TOTAL | 1355 | 12.07525 | 148.1402 | 41.00856 | | 1353 | 8.871842 | | |

Comparison of slopes F=0.078774(6,1341)=15.82053*
Comparison of elevation F=0 2870(6,1347)=54.0698*

*=Significant at 1% level (p=<0.01)

Table 3.3a. Pair wise comparison of slopes of male morphotypes and their transitional stages using t test.

Table.3b. Statistical comparison of correlation coefficients

| | df | t | Probability | z | Probability |
|---|---|---|---|---|---|
| SM X WOC | 310 | 7.65 * | P<0.01 | 4.34 * | P<0.01 |
| SM X SOC | 88 | 6.94 * | P<0.01 | 1.21 | |
| SM X t-SOC | 469 | 7.56 * | P<0.01 | 4.28 * | P<0.01 |
| SM X WBC | 375 | 6.79 * | P<0.01 | 4.33 * | P<0.01 |
| SM X SBC | 161 | 4.90 * | P<0.01 | 0.33 | |
| SM X OBC | 103 | 1.03 | | 1.62 | |
| WOC X SOC | 332 | 2.33 ** | P<0.05 | 3.31 * | P<0.01 |
| WOC X t-SOC | 713 | 0.22 | | 0.37 | |
| WOC X WBC | 619 | 1.29 | | 0.15 | |
| WOC X SBC | 405 | 1.72 | | 6.89 * | P<0.01 |
| WOC X OBC | 347 | 5.28 * | P<0.01 | 8.56 * | P<0.01 |
| SOC X t-SOC | 491 | 2.52 ** | P<0.05 | 3.22 * | P<0.01 |
| SOC X WBC | 397 | 2.94 * | P<0.01 | 3.29 * | P<0.01 |
| SOC X SBC | 183 | 2.90 * | P<0.01 | 1.24 | |
| SOC X OBC | 125 | 4.67 * | P<0.01 | 3.26 * | P<0.01 |
| t-SOC X WBC | 778 | 1.25 | | 0.16 | |
| t-SOC X SBC | 564 | 1.63 | | 5.54 * | P<0.01 |
| t-SOC X OBC | 506 | 5.42 * | P<0.01 | 22.93 * | P<0.01 |
| WBC X SBC | 470 | 1.11 | | 7.03 * | P<0.01 |
| WBC X OBC | 412 | 4.74 * | P<0.01 | 8.66 * | P<0.01 |
| SBC X OBC | 198 | 2.78 * | P<0.01 | 2.74 * | P<0.01 |

* Significant at 1% level (p=<0.01)
** Significant at 5% level (p=<0.01)

Table 3.4 t test(Baily,1959) of regression coefficients of various male morphotypes and transitional stages of *Macrobrachium rosenbergii*

| | | df | b | Std.Err.of b | t |
|---|---|---|---|---|---|
| SM | TL X W | 33 | 1.5336 | 0.2138 | 12.50 * |
| WOC | TL X W | 277 | 3.2226 | 0.0639 | 3.48 * |
| SOC | TL X W | 55 | 3.5014 | 0.1741 | 2.88 * |
| t-SOC | TL X W | 436 | 3.1517 | 0.051 | 2.97 * |
| WBC | TL X W | 342 | 3.0712 | 0.0548 | 1.30 |
| SBC | TL X W | 128 | 2.8054 | 0.1837 | 1.06 |
| OBC | TL X W | 70 | 1.9472 | 0.3065 | 3.43 * |

* = Significant at 1% level (p = <0.01).

Table 3.5. Coefficients of length- weight relationships of male morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from grow out and details of statistical analysis

| Morphotypes | Minimum length (mm) | Maximum length (mm) | Minimum weight (g) | Maximum weight (g) | Numbers examined | b | log a | r | Probability |
|---|---|---|---|---|---|---|---|---|---|
| SM | 71 | 128 | 3 | 20 | 65 | 2.5541 | -4.1685 | 0.8665 | P<0.01 |
| WOC | 89 | 209 | 5 | 114 | 98 | 3.0899 | -5.1262 | 0.9854 | P<0.01 |
| SOC | 165 | 260 | 52 | 184 | 96 | 3.0055 | -4.8936 | 0.8784 | P<0.01 |
| t-SOC | 141 | 242 | 40 | 194 | 65 | 3.0910 | -5.1041 | 0.9388 | P<0.01 |
| SBC | 138 | 243 | 30 | 202 | 33 | 3.2923 | -5.5119 | 0.9248 | P<0.01 |
| OBC | 122 | 288 | 36 | 354 | 185 | 2.4272 | -3.4592 | 0.8915 | P<0.01 |

Table.3.6. Comparison of regressions of total length and weight of various male morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from grow out

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPE: | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| SM | 34 | 0.205926 | 0.526244 | 1.790118 | 2.555503 | 33 | 0.4453 | 0.007068 | |
| WOC | 97 | 0.583669 | 1.803455 | 5.737397 | 3.089861 | 96 | 0.164971 | 0.001718 | |
| SOC | 95 | 0.09787 | 0.294145 | 1.145086 | 3.005467 | 94 | 0.261042 | 0.002777 | |
| t-SOC | 64 | 0.149866 | 0.463237 | 1.62424 | 3.090998 | 63 | 0.192375 | 0.003054 | |
| SBC | 32 | 0.070381 | 0.231716 | 0.892332 | 3.292319 | 31 | 0.129448 | 0.004176 | |
| OBC | 184 | 0.442168 | 1.07322 | 3.277982 | 2.427179 | 183 | 0.673084 | 0.003678 | |
| WITH IN | | | | | | 500 | 1.86622 | 0.003732 | |
| Reg.Coeff. | | | | | | 6 | 0.154922 | 0.02582 | |
| COMMON | 506 | 1.54988 | 4.392018 | 14.46715 | 2.83378 | 506 | 2.021141 | 0.003994 | 6.917798 * |
| Adj.Means | | | | | | 6 | 1.645465 | 0.274244 | 68.65802 * |
| TOTAL | 542 | 8.017791 | 28.24049 | 103.1361 | 3.522229 | 512 | 3.666607 | | |

Comparison of slopes F= 0.02582 (6,500) 6.917798

Comparison of elevation F= 0.274244 (6,506) 68.65802

*=Significant at 1% level (p=<0.01)

Table.3.7. Pair wise comparison of slopes of male morphotypes and trasitional stages of *Macrobrachium rosenbergii* by t-test and values of correlation coefficient comparison

| | df | t | Probability | z | Probability |
|---|---|---|---|---|---|
| SM X WOC | 129 | 3.03 * | P<0.01 | 4.34 * | P<0.01 |
| SM X SOC | 127 | 1.55 | | 1.21 | |
| SM X t-SOC | 96 | 1.94 ** | P<0.05 | 4.28 * | P<0.01 |
| SM X SBC | 64 | 1.78 | | 0.33 | |
| SM X OBC | 216 | 0.67 | | 1.62 | |
| WOC X SOC | 190 | 0.52 | | 3.31 * | P<0.01 |
| WOC X t-SOC | 159 | 0.01 | | 0.37 | |
| WOC X SBC | 127 | 1.05 | | 0.58 | |
| WOC X OBC | 279 | 6.06 * | P<0.01 | 8.56 * | P<0.01 |
| SOC X t-SOC | 157 | 0.39 | | 3.22 * | P<0.01 |
| SOC X SBC | 125 | 1.04 | | 1.24 | |
| SOC X OBC | 277 | 2.82 * | P<0.01 | 3.26 * | P<0.01 |
| t-SOC X SBC | 94 | 0.75 | | 5.54 * | P<0.01 |
| t-SOC X OBC | 246 | 3.74 * | P<0.01 | 22.93 * | P<0.01 |
| SBC X OBC | 214 | 3.48 * | P<0.01 | 2.74 * | P<0:01 |

Table 3.8. t test(Baily,1959) for regression coefficients of various male morphotypes of *Macrobrachium rosenbergii* collected from grow out system

| | | df | b | Std.Err.of b | t |
|---|---|---|---|---|---|
| SM | TL X W | 65 | 2.5555 | 0.1853 | 2.40 * |
| WOC | TL X W | 98 | 3.0899 | 0.0545 | 1.65 |
| SOC | TL X W | 96 | 3.0055 | 0.1685 | 0.03 |
| t-SOC | TL X W | 65 | 3.0910 | 0.1428 | 0.64 |
| SBC | TL X W | 33 | 3.2923 | 0.2433 | 1.20 |
| OBC | TL X W | 185 | 2.4272 | 0.0912 | 6.28 * |

* = Significant at 1% level
p = <0.01.

Table 3.9. Coefficients of length- weight relationships of female morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from Vembanad lake and details of statistical analysis

| Morphotypes | Minimum length (mm) | Maximum length (mm) | Minimum weight (g) | Maximum weight (g) | Numbers examined | b | log a | r | Probability |
|---|---|---|---|---|---|---|---|---|---|
| WOF | 141 | 210 | 34 | 100 | 19 | 2.17 | -3.1037 | 0.7979 | P<0.01 |
| SOF | 141 | 232 | 32 | 134 | 57 | 2.58 | -4.0293 | 0.8702 | P<0.01 |
| TOF | 137 | 258 | 24 | 206 | 210 | 3.08 | -5.1767 | 0.9137 | P<0.01 |
| WBF | 153 | 282 | 36 | 184 | 310 | 2.92 | -4.7928 | 0.8956 | P<0.01 |
| SBF | 142 | 269 | 30 | 228 | 218 | 2.47 | -3.6869 | 0.8469 | P<0.01 |

Table 3.10 Comparison of regressions of total length and weight of various female morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from Vembanad lake

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| MORPHOTYPES | f | {x2 | {xy | {y2 | RC | f | SS {d y.x2 | MS | |
| WOF | 18 | 0.043988 | 0.095728 | 0.325904 | 2.176223 | 17 | 0.117579 | 0.006916 | |
| SOF | 56 | 0.146347 | 0.378004 | 1.288873 | 2.582939 | 55 | 0.312511 | 0.005682 | |
| TOF | 209 | 0.482999 | 1.489724 | 5.503996 | 3.084323 | 208 | 0.909207 | 0.004371 | |
| WBF | 309 | 0.557797 | 1.630311 | 5.940299 | 2.92277 | 308 | 1.175274 | 0.003816 | |
| SBF | 217 | 0.499173 | 1.230223 | 4.227606 | 2.464525 | 216 | 1.19569 | 0.005536 | |
| WITH IN | | | | | | 804 | 3.71026 | 0.004615 | |
| Reg.Coeff. | | | | | | 4 | 0.127391 | 0.031848 | |
| COMMON | 809 | 1.730302 | 4.82399 | 17.28668 | 2.787946 | 808 | 3.837651 | 0.00475 | 6.901281 * |
| Adj.Means | | | | | | 4 | 0.394051 | 0.098513 | 20.74141 * |
| TOTAL | 814 | 2.080916 | 6.179555 | 22.58271 | 2.969633 | 812 | 4.231702 | | |

Comparison of slopes F=0.031847 (4,804) = 6.9013 *
Comparison of elevation F=0.098512 (4,808) = 20.7414 *

*=Significant at 1% level (p= <0.01)

Table.3.11 Pair wise comparison of slopes of female morphotypes and transitional stages using t test and values of correlation coefficient comparison

| | df | t | Probability | z | Probability |
|---|---|---|---|---|---|
| WOF X SOF | 72 | 0.97 | | 0.85 | |
| WOF X TOF | 225 | 2.70 | <P=0.01 | 1.76 | |
| WOF X WBF | 325 | 2.39 | <P=0.05 | 1.39 | |
| WOF X SBF | 233 | 0.77 | | 0.59 | |
| SOF X TOF | 263 | 2.47 | <P=0.05 | 1.41 | |
| SOF X WBF | 363 | 1.81 | | 0.78 | |
| SOF X SBF | 271 | 0.53 | | 0.58 | |
| TOF X WBF | 516 | 1.29 | | 1.11 | |
| TOF X SBF | 424 | 4.36 | <P=0.01 | 3.13 | <P=0.01 |
| WBF X SBF | 524 | 3.50 | <P=0.01 | 2.30 | <P=0.05 |

Table.3.12 t test (Baily, 1959) of regression coefficients of female morphotypes and transitional stages of and transitional stages of *Macrobrachium rosenbergii* collected from Vembanad lake

| morphotypes | n | b | Std.Err | t |
|---|---|---|---|---|
| WOF | 19 | 2.1669 | 0.3969 | 2.10 ** |
| SOF | 57 | 2.5825 | 0.1972 | 2.12 ** |
| TOF | 210 | 3.0843 | 0.0951 | 0.89 |
| WBF | 310 | 2.9230 | 0.0827 | 0.93 |
| SBF | 218 | 2.4650 | 0.1053 | 5.08 * |

* =Significant at 1% level (p=<0.01)
** =Significant at 5% level (p=<0.05)

Table 3.13. Coefficients of length- weight relationships of female morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from grow- out and details of statistical analysis

| Morphotypes | Minimum length (mm) | Maximum length (mm) | Minimum weight (g) | Maximum weight (g) | Numbers examined | b | log a | r | Probability |
|---|---|---|---|---|---|---|---|---|---|
| SF | 60 | 105 | 2 | 12 | 26 | 2.5284 | -4.1630 | 0.8559 | P<0.01 |
| WOF | 102 | 194 | 9 | 84 | 40 | 2.4579 | -3.7870 | 0.8102 | P<0.01 |
| TOF | 115 | 215 | 26 | 172 | 57 | 2.4937 | -3.8052 | 0.8030 | P<0.01 |
| WBF | 121 | 186 | 22 | 70 | 102 | 1.9808 | -2.6958 | 0.7610 | P<0.01 |
| SBF | 138 | 223 | 32 | 134 | 161 | 2.6249 | -4.0817 | 0.9043 | P<0.01 |

Table.3.14. Comparison of regressions of total length and weight of various female morphotypes and transitional stages of *Macrobrachium rosenbergii* collected from grow- out

| Morphotypes | df | {x2 | {xy | {y2 | RC | DEVIATIONS FROM REGRESSION df | SS {d y.x2 | MS | |
|---|---|---|---|---|---|---|---|---|---|
| SF | 25 | 0.107971 | 0.273251 | 0.943153 | 2.530787 | 24 | 0.251612 | 0.010484 | |
| WOF | 39 | 0.125373 | 0.308498 | 1.155284 | 2.460643 | 38 | 0.396179 | 0.010426 | |
| TOF | 56 | 0.138912 | 0.34609 | 1.337656 | 2.491445 | 55 | 0.475391 | 0.008643 | |
| WBF | 101 | 0.183269 | 0.421419 | 1.199556 | 2.29945 | 100 | 0.230524 | 0.002305 | |
| SBF | 160 | 0.389092 | 1.021411 | 3.27892 | 2.625118 | 159 | 0.597595 | 0.003758 | |
| WITH IN | | | | | | 376 | 1.951302 | 0.00519 | |
| Reg.Coeff. | | | | | | 4 | 0.013681 | 0.00342 | |
| COMMON | 381 | 0.944617 | 2.370671 | 7.914569 | 2.509664 | 380 | 1.964982 | 0.005171 | 0.659037 |
| Adj.Means | | | | | | 4 | 0.681074 | 0.170268 | 32.92752 * |
| TOTAL | 386 | 3.270191 | 10.40527 | 35.7541 | 3.181854 | 384 | 2.646056 | | |

Comparison of slopes F= 0.00342 (4,376) 0.659037

Comparison of elevation F= 0.170268 (4,380) 32.92752 *

*=Significant at 1% level

Table.3.15. Pair wise comparison of slopes of female morphotypes and transitional stages using t-test and values of correlation coefficient comparison

| | df | t | Probability | z | Probability |
|---|---|---|---|---|---|
| SF X WOF | 62 | 0.17 | | 0.80 | |
| SF X TOF | 79 | 0.10 | | 0.74 | |
| SF X WBF | 124 | 0.97 | | 1.52 | |
| SF X SBF | 183 | 0.40 | | 1.17 | |
| WOF X TOF | 93 | 0.08 | | 7.23 * | P<0.01 |
| WOF X WBF | 138 | 0.65 | | 7.23 * | P<0.01 |
| WOF X SBF | 197 | 0.71 | | 0.13 | |
| TOF X WBF | 155 | 0.80 | | 1.62 | |
| TOF X SBF | 214 | 0.60 | | 4.40 * | P<0.01 |
| WBF X SBF | 259 | 2.03 * | P<0.01 | 18.04 * | P<0.01 |

Table 3.16. t test(Baily,1959) of regression coefficients of various female morphotypes and and transitional stages o *Macrobrachium rosenbergii* collected from grow-out

| | | df | b | Std.Err.of b | t |
|---|---|---|---|---|---|
| SF | TL X W | 26 | 2.5284 | 0.3119 | 1.51 |
| WOF | TL X W | 40 | 2.4579 | 0.2885 | 1.88 |
| TOF | TL X W | 57 | 2.4937 | 0.2495 | 2.03 ** |
| WBF | TL X W | 102 | 2.2992 | 0.1122 | 6.25 * |
| SBF | TL X W | 161 | 2.6249 | 0.0983 | 3.82 * |

*= Significant at 1% level (p=<0.01)
**= Significant at 5% level (p=<0.01)

Table.3.17. Coefficients of length-weight relationships of male and female *Macrobrachium idella* collected from Vembanad lake

| | Minimum length (mm) | Maximum length (mm) | Minimum weight (g) | Maximum weight (g) | Numbers examined | b | log a | r | Probability |
|---|---|---|---|---|---|---|---|---|---|
| MALES | 30 | 102 | 0.21 | 12.68 | 292 | 3.4491 | -2.7755 | 0.9590 | P<0.01 |
| FEMALES | 32 | 97 | 0.31 | 9.82 | 257 | 3.0150 | -1.9657 | 0.9390 | P<0.01 |

Table.3.18. Comparison of regressions of length and weight of male and female *Macrobrachium idella*

| | | | | | | DEVIATIONS FROM REGRESSION | | | |
|---|---|---|---|---|---|---|---|---|---|
| | df | {x2 | {xy | {y2 | RC | df | SS {d y.x2 | MS | |
| MALES | 290 | 3.12286684 | 10.77091 | 40.39044775 | 3.449046 | 289 | 3.241082 | 0.011176 | |
| FEMALES | 255 | 0.94356148 | 2.844529 | 9.727303979 | 3.014672 | 254 | 1.151981 | 0.004518 | |
| WITH IN | | | | | | 543 | 4.393064 | 0.00809 | |
| Reg.Coeff. | | | | | | 1 | 0.136722 | 0.136722 | |
| COMMON | 545 | 4.06642831 | 13.61544 | 50.11775173 | 3.348255 | 544 | 4.529785 | 0.008327 | 16.89933 * |
| Adj.Means | | | | | | 1 | 4.342057 | 4.342057 | 521.455 * |
| TOTAL | 549 | 12.07525 | 148.1402 | 41.00856 | | 545 | 8.871842 | | |

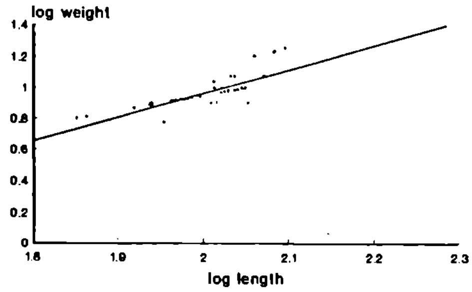
Comparison of slopes F=0.008328(1,543)=16.89932*
Comparison of elevation F=4.341185(1, 544)=521.4549*

* =Significant at 1% level
(Table value 6.63 p= <0.01)

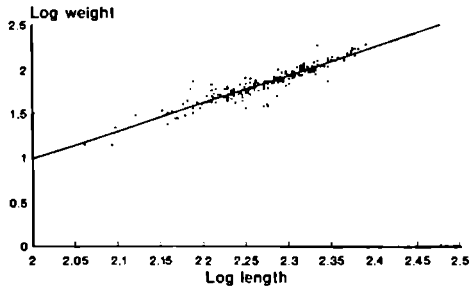
Table 3.19. t test(Baily,1959) for regression coefficients of male and female *Macrobrachium idella* collected from Vembanad lake

| | | df | b | Std. Err. of b | t |
|---|---|---|---|---|---|
| MALE | TL X W | 290 | 3.4412 | 0.0598 | 7.37 |
| FEMALE | TL X W | 255 | 3.0150 | 0.0692 | 0.22 |

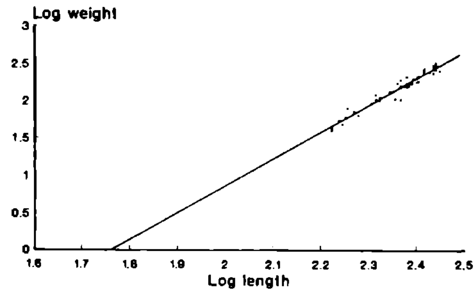
Small Males
Log w = -2.1040 + 1.5337 Log l
(r = 0.7799)



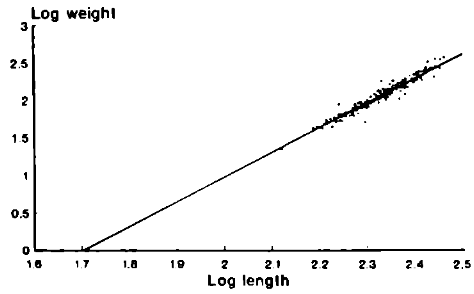

Weak Orange Clawed Males
Log w = -5.476 + 3.2226 Log l
(r = 0.9528)



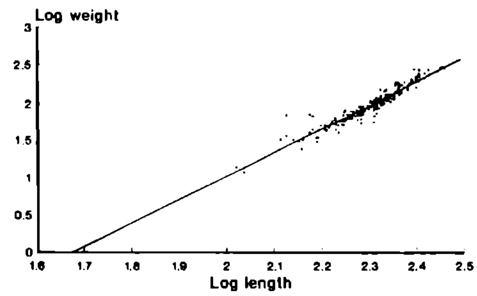

Strong Orange Clawed Males
Log w = -6.119 + 3.5014 Log l
(r = 0.9382)



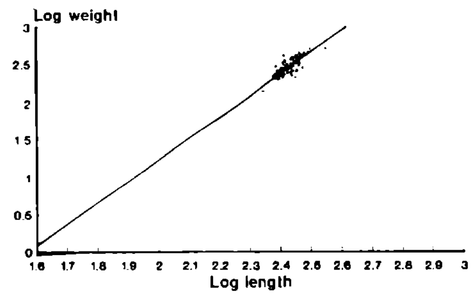

pre- transforming Orange Clawed Males
Log w = -5.286 + 3.1517 Log l
(r = 0.9500)



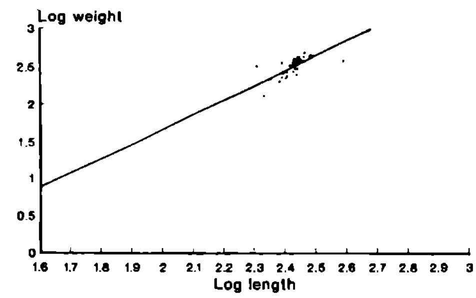

Weak Orange Clawed Males
Log w = -5.096 + 3.0712 Log l
(r = 0.9516)



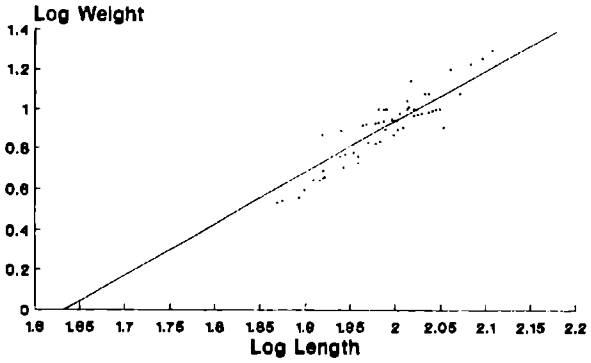

Strong Orange Clawed Males
Log w = -4.360 + 2.8054 Log l
(r = 0.8045)



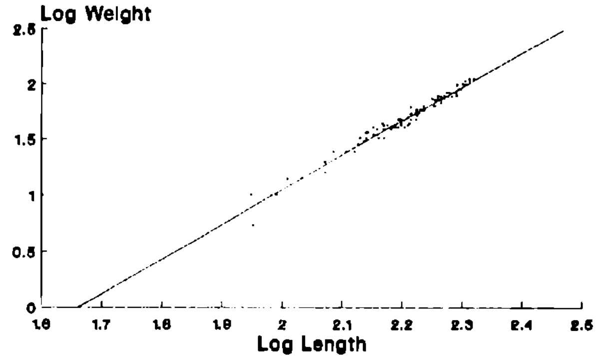

Old Blue Clawed Males
Log w = -2.231 + 1.9472 Log l
(r = 0.6041)



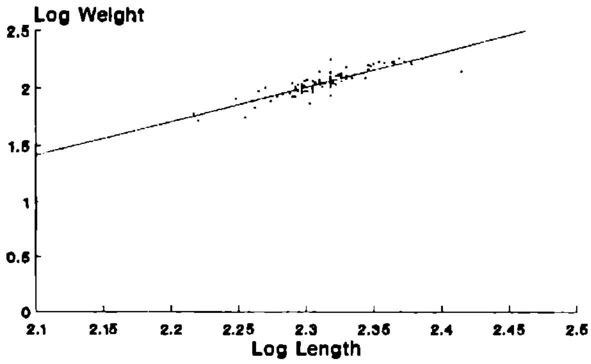
Small Males
Logw = -4.1685 + 2.5541 logl
(r= 0.8665)



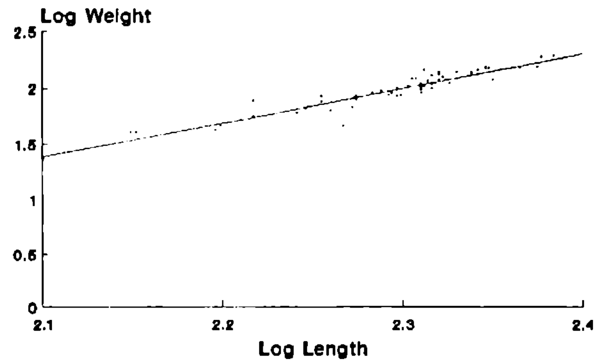

Weak Orange Clawed
Logw = -5.1261 + 3.0889 logl
(r= 0.9854)



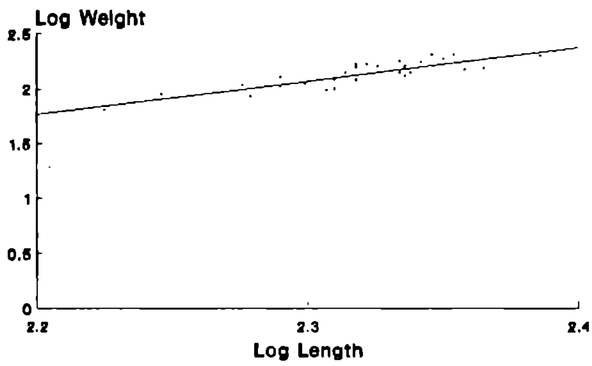

Strong Orange Clawed Males
Logw = -4.8936 + 3.0022 logl
(r= 0.8784)



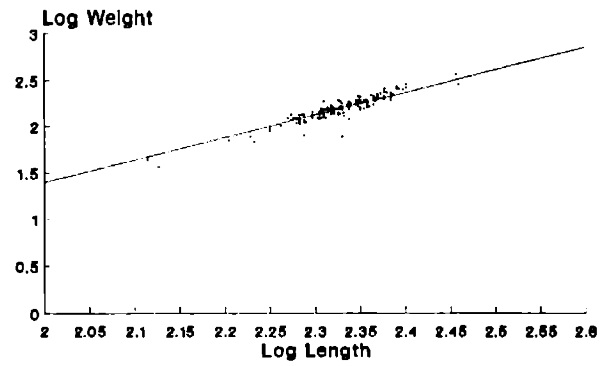

pre- transforming Orange Clawed Males
Logw = -5.1041 + 3.0892 logl
(r= 0.9388)



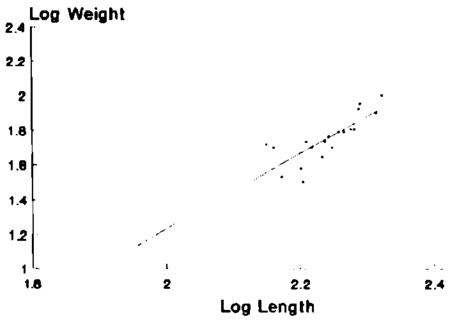

Strong Blue Clawed males
Logw = -5.5119 + 3.2932 logl
(r= 0.9248)



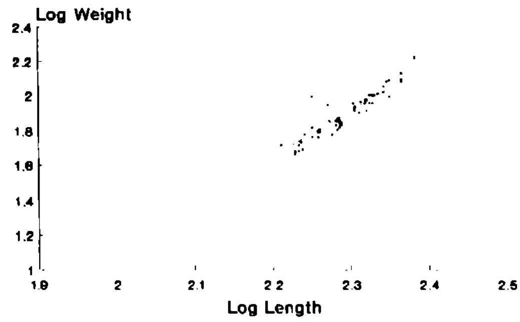

Old Blue Clawed males
Logw = -3.4592 + 2.4276 logl
(r= 0.8915)



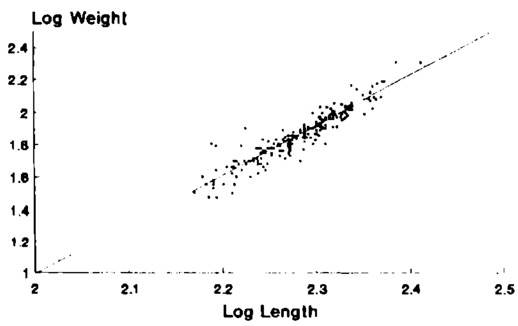
Weak Orange Clawed Female
Log W = -3.1037 + 2.17 Log X
(r = 0.7979)



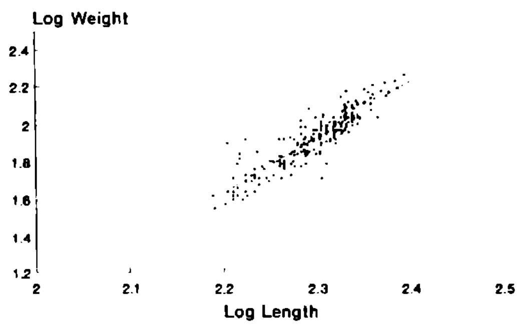

Strong Orange Clawed Female
Log W = -4.0293 + 2.58 Log X
(r = 0.8702)



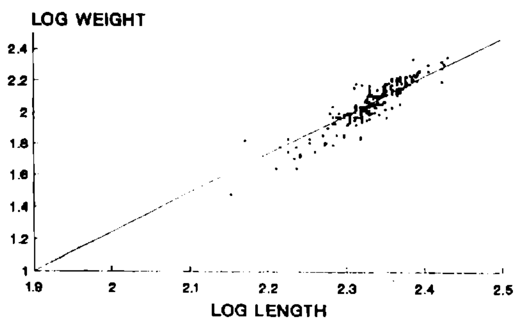

Transforming Orange Clawed Females
Log W = -5.1787 + 3.08 Log X
(r = 0.9137)



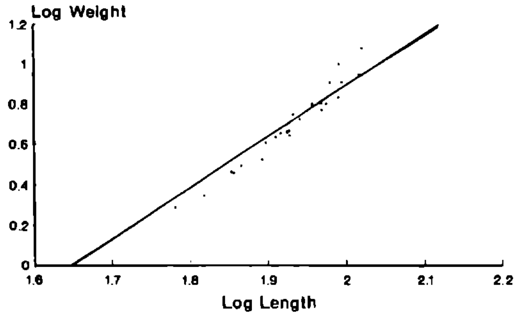

Weak Blue Clawed Female
Log W = -4.7928 + 2.92 Log X
(r = 0.8956)



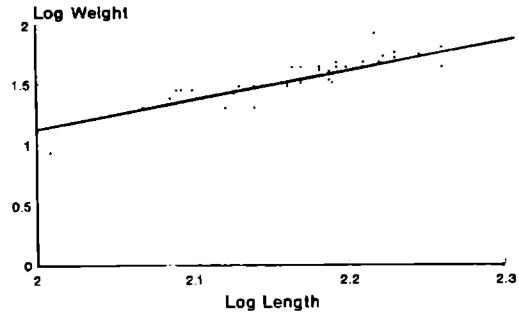

Strong Blue Clawed Females
Log W = -3.6869 + 2.47 Log X
(r = 0.8469)



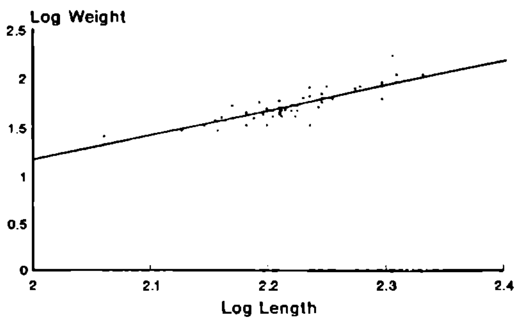
**Small Females**
Logw = -4.1630 + 2.5284 logl
(r= 0.8559)



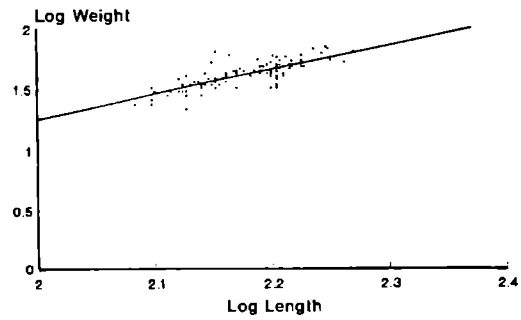

**Weak Orange Clawed Females**
Logw = -3.7870 + 2.4579 logl
(r= 0.8102)



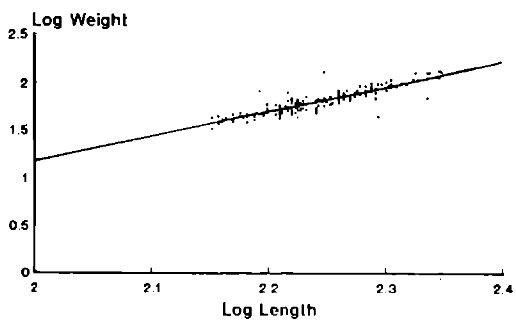

**Transforming Orange Clawed Female**
Logw = -3.8052 + 2.4937 logl
(r= 0.8030)




**Weak Blue Clawed Female**
Logw = -2.6958 + 1.9809 logl
(r= 0.7610)



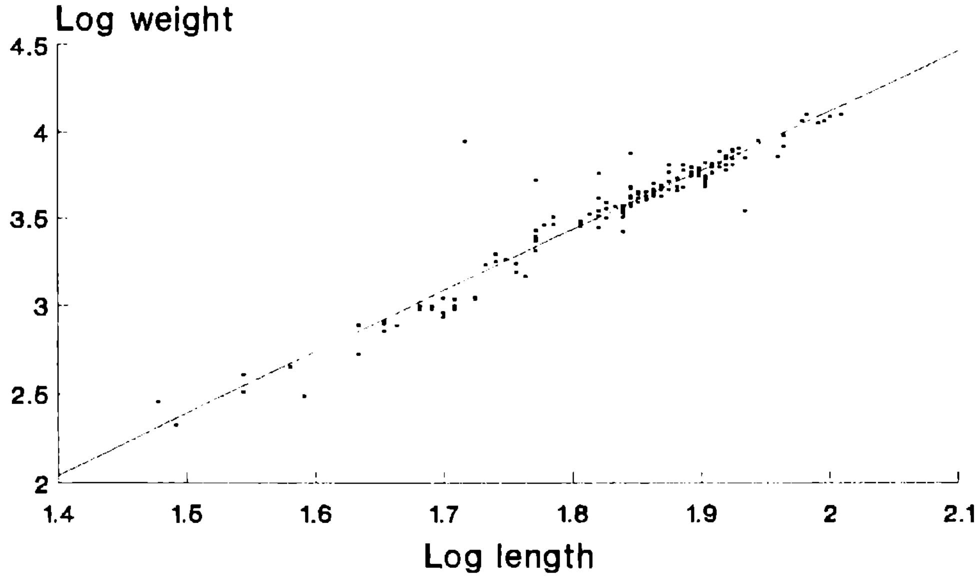

**Strong Blue Clawed Female**
Logw = -4.0817 + 2.6249 logl
(r= 0.9043)



*M.idella* (Males)

Log W = -2.7755 + 3.4491 Log l

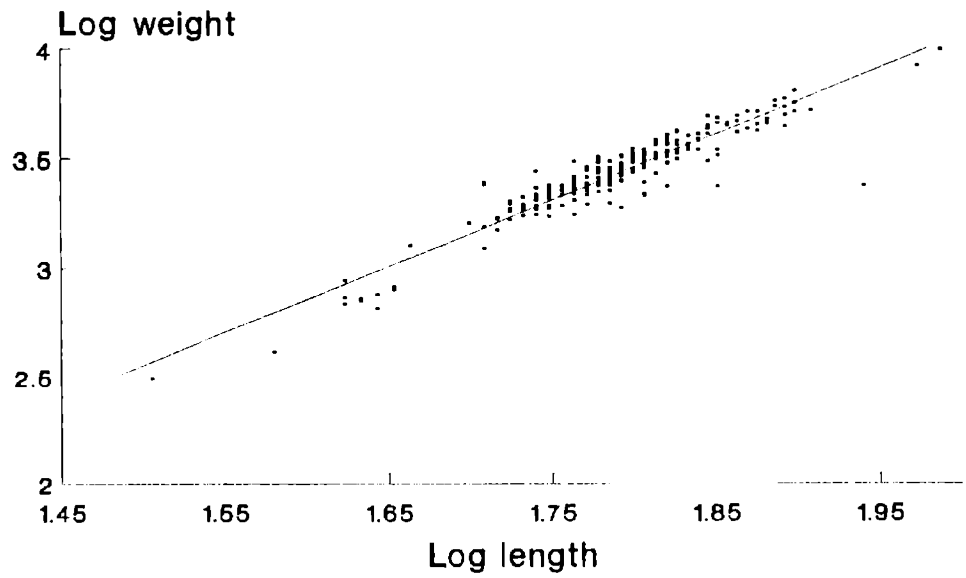
(r = 0.9590)




*M.idella* (Females)

Log W= -1.9657 + 3.0150 Log l

(r = 0.9390)



CHAPTER 4

# TEMPORAL AND SPATIAL DISTRIBUTION OF MORPHOTYPES OF *Macrobrachium rosenbergii* (de Man)

## 1. INTRODUCTION

The fishery of *M. rosenbergii* in Vembanad lake is constituted by the seasonal appearance of male and female stocks differentially, mostly descending from the upper reaches of the lake and parts of the adjoining rivers. The male population of the lake, comprising of three morphotypes such as SM, SOC and SBC, besides the presence of transitional stages such as WOC, t-SOC, WBC and OBC (Harikrishnan and Kurup, 1997a) as reported from the grow out ponds (Sagi and Ra'anan, 1988). Similarly the existence of morphotypes in the female population of this lake could also be established by Harikrishnan *et al.* (1997) (for details refer Chapter 2). Though the differential migration of male and female population in to the lake have been reported (Raman, 1967; Kurup *et al.*, 1992a), hitherto no attempt has been made to analyse the morphotypic composition of male and female populations appearing at different regions of the lake and also to bring out the pattern of temporal changes that take place in accordance with the transformation undergone by these morphotypes. Therefore, the present account encompasses the details of the temporal and spatial variations in the distribution of male and female morphotypes and their transitional stages in the lake.

A review of the literature also shows that very serious attempts were made to bring out the effect of density on population structure of *M. rosenbergii* in grow outs (Karplus *et al.* 1986a; Kurup *et al.* 1996a), however, virtually there is no information on the morphotypic composition of male and female populations in the natural habitat at different levels of population density. Therefore, in the present study an attempt is also made to examine the annual male and female morphotypic composition from four selected zones of the lake, two each of representing zones of highest and lowest population density of *M. rosenbergii* in the lake.

## 2. MATERIALS AND METHODS

The exploited population of *M. rosenbergii* from 13 zones (Fig.1.) was thoroughly examined for a period of 24 months from March 94 to February 96 during the monthly fishery survey cruises (refer Section 1.4). Male morphotypes, SM, SOC and SBC and their transitional stages such as WOC, t-SOC, WBC and OBC and female morphotypes, SF, SOF and SBF and their intermediary stages viz. WOF, TOF, WBF were also identified (for details refer Chapter 2) and classified following Kuris *et al.*(1987), Sagi and Ra'anan (1988), Harikrishnan and Kurup (1997a). The observed catches were apportioned into respective male and female morphotypes by number and the average percentage composition of each morphotype and their transitional stages were worked out. A total of 2299 males and 3055 females were examined to delineate the morphotypic composition of the exploited stock and also to bring out their temporal and spatial variations in the lake. The density of population of *M. rosenbergii* from the four selected zones of the lake was worked out by computing the average number of male and female morphotypes per each fishing unit and multiplying this with total number of units operated in each zone.

## 3. RESULTS

### 3.1 MALE MORPHOTYPES

#### 3.1.1. Percentage composition

Percentage composition of male morphotypes of *M. rosenbergii* viz. SM, SOC and SBC, transitional stages of SOC such as WOC and t-SOC and transitional stages of SBC such as WBC and OBC in the exploited stock of the lake during 1994-95 and 1995-96 are shown in Fig.4.1. Among the various morphotypes, the presence of SM could be registered in 94-95 with an insignificant contribution of 0.13%. In 94-95 and 95-96 blue clawed males (WBC, SBC and OBC) accounted for 64.85 and 51.51% respectively of the total male population, showing a clear cut predominance over the orange clawed males (WOC, SOC and t-SOC) (Fig.4.1). Among orange clawed males, WOC showed highest percentage occurrence during 1994-95 (18.33%), on the contrary, the predominance of t-SOC was worth noticing during 95-96 (25.43%). In contrast, among BC males, WBC emerged as the dominant group with a percentage contribution of 31.08 and 33.11 in first and second years respectively. In 95-96, SOC and SBC showed a remarkable decline in their percentage contribution when compared to its preceding year. Conversely, the percentage of WOC, t-SOC, WBC and OBC showed an increasing trend in 95-96 when compared to 94-95.

3.1.2. Temporal and spatial distribution

Monthly variation in the percentage occurrence of male morphotypes and their transitional stages during 94-95 and 95-96 are shown in Fig.4.2 and 4.3 respectively. Orange clawed males dominated in the catches during Januray to August in 94-95, nevertheless, the predominance of blue clawed males was noteworthy during September to December. During the second year also, the predominance of orange clawed males over a prolonged period could be seen during January to September barring March. The appearance of SM in exploited stock was encountered during 94-95 only in the months of August and December to February in very sparse numbers. In contrast, the appearance of WOC could be noticed almost in all the months except in December during 94-95 whereas during 95-96, it was found represented only in September, October and December. Generally, its availability was relatively high during February to June in both the years, however, it became sparse during July to December. In both the years, SOC and t-SOC appeared in the exploited stock invariably in earlier months of the year commensurating with the onset of fishing season in the lake. The presence of SOC could be noticed in the exploited stock over a prolonged period from January to September during 94-95, on the contrary, in 95-96 its appearance was erratic and was seen only in the months of January, February, April and July. t-SOC appeared in all months except during November to March in both the years. WBC was also present invariably in almost all the months except in December and March during 94-95 and in September, October, December and February during 95-96. The percentage contribution of SBC gradually increased from August onwards and its peak occurrence could be discernible during October to December in 94-95 while in 95-96 its presence could be noticed in all months with a definite peak in December. OBC was also found to be represented in all months except from December to March in the first year while in the second year its percentage composition was glaringly high during September to November.

Percentage occurrence of male morphotypes and their transitional stages in various zones of Vembanad lake and adjoining rivers during 94-95 and 95-96 are depicted in Fig.4.4 and 4.5 respectively. It could be seen that the blue clawed morphotypes predominated in the catches from all the zones during first year, in contrast, the preponderance of orange clawed males could be discernible in zones 2, 4, 8 ,9 and 10 in the second year. SM was encountered only in zone 7 and 10. On the contrary, WOC was represented in almost all zones of the lake except in zone

1 during both the years. SOC and its transitional stages such as WOC and t-SOC were found to be distinctly dominating in zones 7 to 10 during 95-96 which formed the upstream part of the lake, however, they were sporadically represented in the catches from the downstream regions of the lake.

### 3.2. FEMALE MORPHOTYPES

#### 3.2.1. Percentage composition

Percentage composition of female morphotypes and their transitional stages in the exploited stock of Vembanad lake during 1994-95 and 95-96 are shown in Fig.4.6. SF constituted only 0.15% during 1994-95, however, the same could not be observed during 95-96. The preponderance of blue clawed females over others in both the years (75.95 in 1994-95 and 80.04% in 1995-96) was noteworthy. SBF emerged as the single largest female morphotype of the lake in both the years with a percentage contribution of 43.52 and 46.42 in the preceding and succeeding years respectively. Among other morphotypes, SOF and TOF contributed to 2.13 and 20.83% in 94-95 against 0.54 and 17.15% in 95-96 while a corresponding increase of WOF, WBF and SBF could be noticed during 95-96.

#### 3.2.2. Temporal and spatial distribution

Monthly variations in percentage composition of various female morphotypes and their transitional stages during 94-95 and 95-96 are shown in Fig.4.7 and 4.8 respectively. Female population was totally absent in the exploited stock during March and April during both the years. Presence of SF could be noticed only in May 94. During 94-95, orange clawed females (WOF, SOF and TOF) showed distinct preponderance over blue clawed females in February and during May to August except in July. On the contrary, during September to January, the dominance of blue clawed females (WBF and SBF) could be discernible in the exploited stock. Conversely, blue clawed females outnumbered orange clawed females invariably in all the months except in February during 95-96. It could be seen that blue clawed females showed a steady increase in their percentage occurrence from September to January in both the years.

Zone wise variation in percentage occurrence of various female morphotypes and their transitional stages during 94-95 and 95-96 are depicted in Fig.4.9 and 4.10 respectively. SF could be observed only in zone 7 during first year. While examining the trend shown by various female morphotypes it could be seen that blue clawed females dominated in the catches from all zones of the lake during both the years and SBF emerged as the most commonly available morphotype, among females which accounted for a sizeable portion of the exploited female population. However, orange clawed females also made a significant contribution in the exploited stock in all the zones of the lake except zones 1, 4, 11 and 13 during the former year and zones 4 and 13 during the latter year and correspondingly TOF emerged as the most important group in this category while the contribution of WOF and SOF appeared to be comparatively insignificant.

### 3.3 Effect of density on population structure and morphotypic composition

Variations in population density of *M. rosenbergii* (average number for 1994-96, male and female combined) in different zones of Vembanad lake and adjacent rivers is depicted in Fig.4.11. Lowest density could be noticed in zone 6 (0.29/ha), on the contrary, the density was highest in zone 10 (16.18/ha). Population density was found invariably high in zones of the upstream part of the lake and confluent rivers (Fig.4.11) while zones of downstream part of the lake were characterised with relatively lower density. The population structure of *M. rosenbergii* from two each of higher (zones 10 and 11) and lower densities (zones 6 and 5) were examined in order to bring out the implications of prawn density on morphogenesis in the natural habitat. The proportion of males and females were dissimilar at the four levels of densities selected and the ratio between males and females in the zones 10, 11, 5 and 6 were in the order 1:1.31; 1:1.071; 1:8.45 and 1:4.22, respectively. Chi-square analysis of male and female morphotypic composition in higher density and lower density zones revealed that there exist significant differences between zones 10 and 5 ($\chi^2$=

40.88), 10 and 6 ($\chi^2$ = 19.93), 11 and 5 ($\chi^2$= 68.52) and 11 and 6 ($\chi^2$ = 38.19). However, the difference in the sex ratio between zones 5 and 6 ($\chi^2$ = 11.96) was found to be insignificant.

### 3.3.1. Density dependant variations in male morphotypic composition

The composition of male morphotypes in the four selected zones are depicted in Fig.4.12. Blue clawed males (WBC, SBC and OBC combined) dominated in all the four levels of density, however, variation in their proportions at different levels was worth noticing. At higher densities in zone 10 and 11, they formed only 52.28 and 61.69% respectively, on the contrary, at lower densities in zones 6 and 5 they accounted for 76.51 and 73.14% respectively. In contrast, the contribution of orange clawed males was invariably high at higher density zones when compared to that of low density zones. WOC contributed to 20.85 and 16.5% in zones 10 and 11 respectively against 4.76 and 12.16% in zones 6 and 5 respectively. Similarly, t-SOC formed 24.3 and 19.06% in zones 10 and 11 in contrast to 11.79 and 14.7% in zones 6 and 5 respectively. Month wise variation in percentage composition of male morphotypes in the four selected zones is depicted in Fig.4.13 to 4.16. Representation of SM could only be observed in zone 10 during December and January. In zones 10 and 11, the proportion of WOC was found to be appreciably high during

March and April and their occurrence could be discernible till July to August. Similarly high percentage occurrence of t-SOC could also be noticed during May to September in these zones. Blue clawed males (WBC, SBC and OBC) represented in varying proportions in almost all months except March with maximum representation in October and November. On the other hand, in the low density zones (zone 6 and 5) the appearance of orange clawed males could be observed only during May to August period. In zone 6, WOC and t-SOC were observed only in small proportions while blue clawed males dominated in all months from May to November. However, in zone 5, high percentage occurrence of orange clawed males could be observed only in June and August while blue clawed males formed the major portion of the landings in July, September and October.

### 3.3.2. Density dependant variations on female morphotypic composition

Percentage composition of female morphotypes, SOF and SBF and their transitional stages in zones of higher and lower densities of the lake is depicted in Fig.4.17. It could be seen that female morphotypes showed contrasting results when compared to that of their male counterparts with regard to percentage composition at various levels of density. Even though blue clawed females (WBF and SBF) distinctly dominated orange clawed females in all the four zones studied, contribution of SBF in zones 10 and 11 (high density zones) was high when compared to zones

6 and 5 (low density zones). Similarly, though percentage contributions of WOF and SOF were relatively high in zones 10 and 11 when compared to zones 6 and 5, the percentage contribution of TOF was glaringly high in low density zones (zones 6 and 5) than to the high density zones. Month wise variation in percentage composition of female morphotypes in the four selected zones is depicted in Fig.4.18 to 4.21. In high density zones, the presence of orange clawed females could be encountered only during June to October while their prolonged occurrence in low density zones from July to December was quite noteworthy. With regard to the percentage contribution of orange clawed and blue clawed females, significant variation could be noticed among the high density and low density zones. Orange clawed females out numbered blue clawed females in zone 10 during June to August, however, they formed only small proportion in zone 11 during June to September. Similarly, orange clawed females out numbered blue clawed females in zone 6 during August whereas in zone 5, blue clawed females distinctly dominated the other in all the months during June to February.

## 4. DISCUSSION

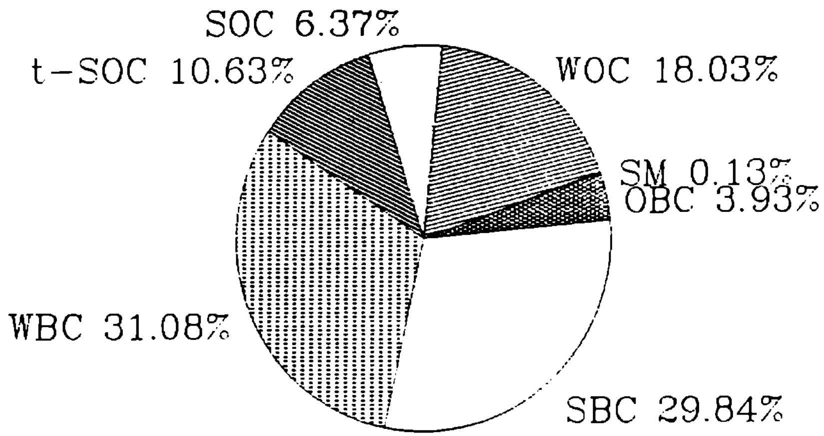
Results of the temporal and spatial variations of male and female morphotypes of *M. rosenbergii* in Vembanad lake showed that both of them exhibit definite trends in their occurrence and availability with regard to space and time. Of the two morphotypic forms of each sex available in the lake, the dominance of blue clawed morphotypes of males and females over the orange clawed ones could obviously be seen in the two years studied. However, the predominance of orange clawed morphotypes during January to July period was noticeable, nevertheless, the quantity of exploited stock worked out during the above period was very less in view of the fact that intensification of fishing activity for *M. rosenbergii* in the lake and riverine areas commences only by the end of June. The fishing season of *M. rosenbergii* in Vembanad lake was demarcated as July to November (Kurup *et al.*, 1992a) and the differential availability of male and female population in the lake have already been reported with a definite trend of predominance of former during March to June and of latter during September to December respectively (Kurup *et al.*,1992a). The results of present study show that males predominated in the catches during February to July and this is in full agreement with that of Kurup *et al.* (1992a). Male morphotypes represent three developmental stages in the maturation process and SM and OC represent earlier stages in the male developmental pathway (Cohen *et al.*, 1981). These morphotypes also undergo transformation in an irreversible pattern from SM to OC and OC to BC (Cohen *et al.*, 1981; Kuris *et al.*, 1987). The spawning season of *M. rosenbergii* in Vembanad lake extends from August to December with a peak breeding in September- November months and after completing the larval life in brackish water the juveniles ascend upstream parts of rivers adjacent to the lake by December onwards (Raman, 1967; Kurup *et al.*,1992a). It has also been reported that river systems associated with the Vembanad lake provide nursery grounds for the juveniles, the sub adults which move down the rivers to lake from March onwards under the influences of currents resulting from occasional showers (Raman, 1964). In the present study it was observed that WOC which represents the early stage of OC male morphotypes (refer Chapter. 2), showed high occurrence in the lake during January to March. Furthermore, it was also observed that OC males (WOC, SOC and t-SOC) predominated in the catches from January to August whereas from September to December, a clear predominance of BC males (WBC, SBC and OBC) could be discernible. This finding clearly indicates that morphotypes in natural habitat also undergo morphotypic transformation similar to that of pond reared population as reported by Kuris *et al.*(1987). However, the pattern of availability of intermediary morphotypic stages do not fully conform to a gradual shifting in their dominance following developmental pathway. Therefore, the population shows a heterogeneous assemblage of various morphotypic stages in almost all months in both years. This was very evident from the percentage occurrence of both WBC and WBF in substantial numbers during earlier months. If the morphotypes had undergone transformation following the normal pathway alone such as SM - WOC - SOC - t-SOC - WBC - SBC - OBC, these stages would have been sequentially appeared in the catches during successive months. In *M. rosenbergii*, the size hierarchy is noticed even in larval stages itself whereby some individuals having higher relative growth rate got differentiated as "Jumpers" from that of smaller individuals known as "laggards". The fast growing jumpers can grow as much as 15 times faster when compared to the laggards within a period of 60 days ( Willis and Berrigan, 1977; Ra'anan, 1982). On size grading juvenile population and growing different fractions separately in earthern ponds, male jumpers were found to be developed mainly to blue clawed and orange clawed males while laggards developed mostly to small males (Karplus *et al.*, 1986b;Karplus *et al.*, 1987). It is quite possible that the WBC and WBF present in the lake during initial months might have developed from jumpers which are capable of growing faster and developed into sexually matured adult population early. The heterogeneous population encountered during early months may also be due to the by-pass transformations of morphotypes as described in Chapter 2.

Results of the present study indicate that OC males predominated in the lake during the period when water temperature of the lake was high. On the contrary, BC males showed higher occurrence in the lake during September to December period during when bottom water temperature ranged between 26-29$^{0}$C. According to Raman (1967) temperature plays an important role in the distribution of these prawns, when summer heat increases these prawns go up the rivers and remain there in deeper basins of rivers where bottom is characterised with low temperatures. Orange clawed females predominated during May to August period during when most part of the lake remained more or less freshwater owing to the influx of monsoonal floods. Blue clawed females, on the other hand, showed highest preponderance in downstream part of the lake during September to December during when salinity reached a maximum of 28ppt (in zone 2). This is because of the downward breeding migration of females in search of breeding ground where optimum environmental conditions for hatching and early metamorphosis are available (Raman, 1967; Kurup *et al.*, 1992a; Harikrishnan and Kurup, 1996a).

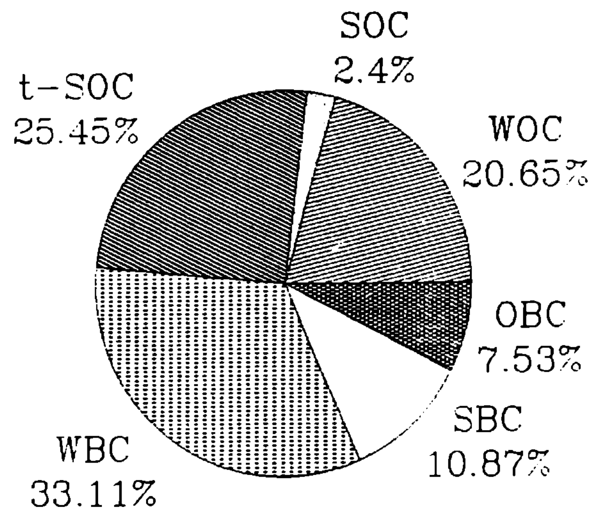
Results of the present study also reveal that there exists a dynamic shift in the proportion of male morphotypes in natural habitat which might be due to variation in population density. A dynamic shift in the proportion of male morphotypes could be observed between high and low density zones. In zones 6 and 5 which were characterised with low population density, the proportion of blue clawed males was found to be quite high which would manifest the possibility of rapid transformation of lower morphotypes to the terminal stages. However, blue clawed males constituted major portion in all the four levels of density. This may be because that in a natural habitat where individuals are dispersed over a wide area, lower morphotypes though prone to social hierarchy may get an advantage of transforming to BC males much progressively over a period of short time at a faster rate. The presence of dominant BC males may not be acting as a constraint for the rapid transformation of the lower morphotypes in to terminal stages in a natural system since these animals are always free to escape from a dominance territory unlike a confined habitat like grow out ponds.

Results of the present study also indicate that density does not influences much on morphotypic development in female population as evidenced from higher percentage occurrence of TOF in low density zones and that of SBF in high density zones. It would thus appear that in females, population structure, dynamics of interaction and transformation of morphotypic forms may not be strongly influenced by socially controlled factors in contrast to their male counterparts. The male morphotypes distinguish themselves by behavioural variations in addition to morphological differences. Large dominant blue males exhibit territoriality and their presence is reported to be inhibiting the growth and development of small males (Barki, 1989; Ra'anan and Sagi, 1985; Karplus *et al.*, 1992b). Such territoriality has not been reported in females and the females in grow out systems have been reported to be constituted by rather homogenous population with regard to size distribution (Cohen *et al.*, 1981). It may, therefore, be inferred that density of the morphotypes does not have any apparent effect on the morphotypes and their transitional stages of female population.

Fig. 4.1 Percentage composition of male morphotypes and their transitional stages in the exploited stock of *Macrobrachium rosenbergii* in Vembanad lake during 1994-1995 and 1995-1996



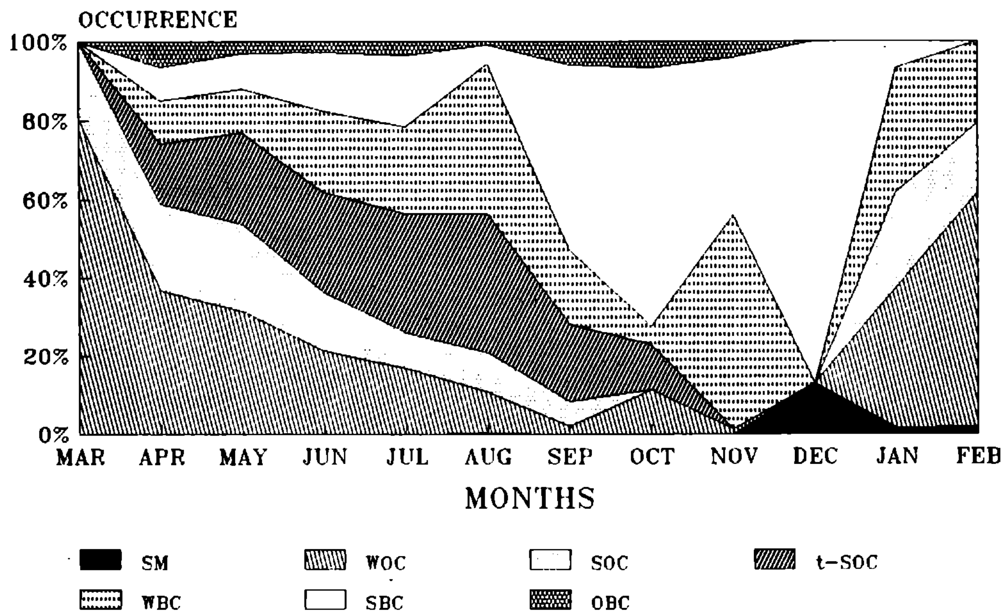

1994–95




1995–96

Fig. 4.2 Monthly variations in the percentage occurrence of male morphotypes and transitional stages during 1994-1995

Fig. 4.3 Monthly variations in the percentage occurrence of male morphotypes and transitional stages during 1995-1996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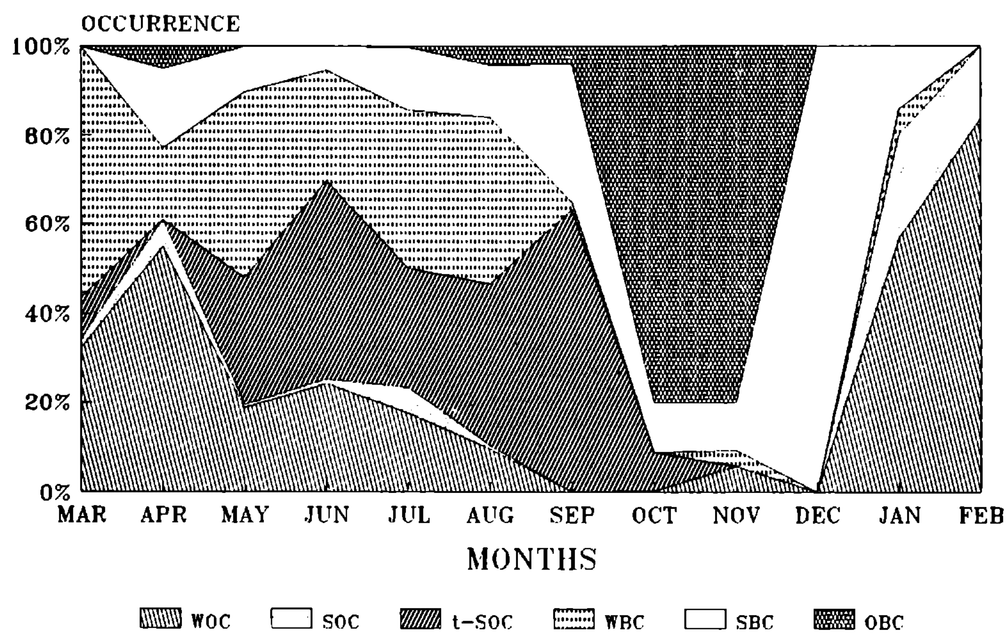
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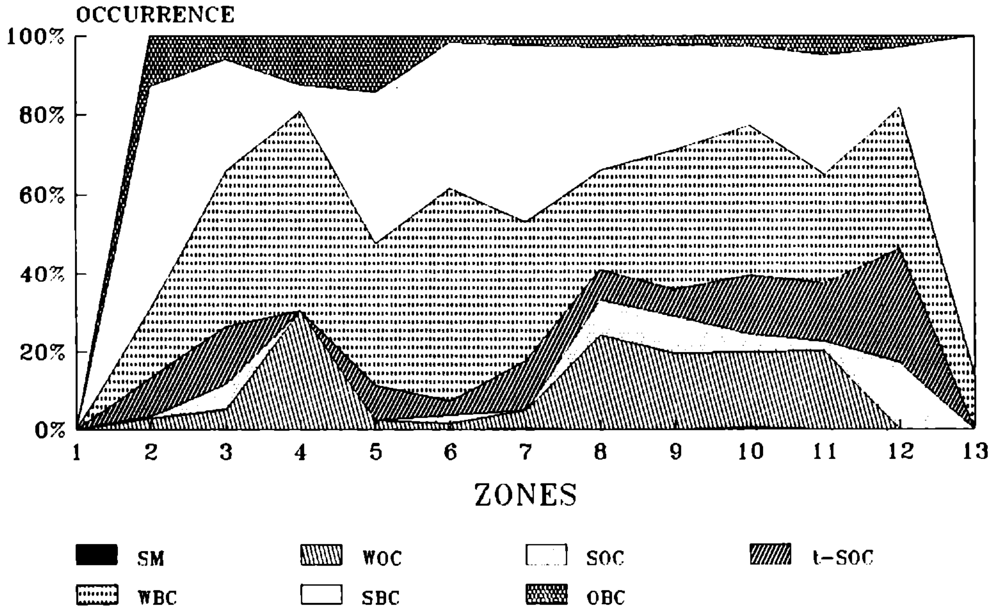
Fig. 4.4 Percentage occurrence of male morphotypes and transitional stages in various zones of the lake during 1994-1995

Fig. 4.5 Percentage occurrence of male morphotypes and transitional stages in various zones of the lake during 1995-1996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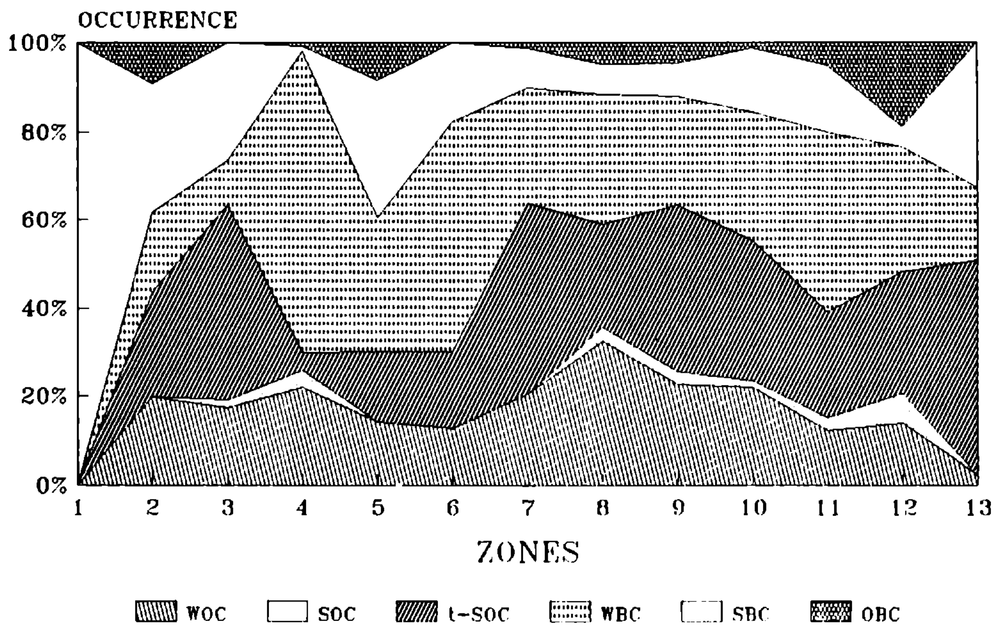
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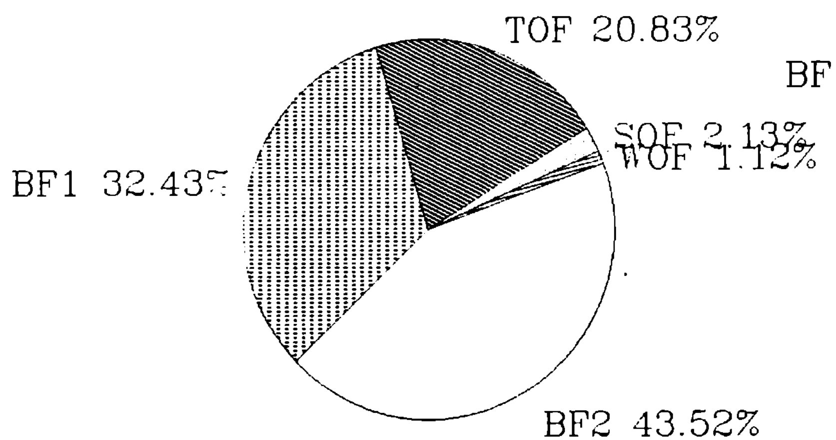
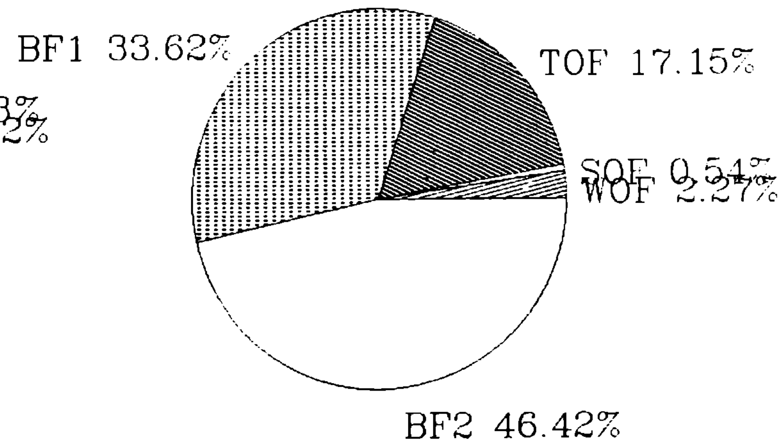
Fig. 4.6 Percentage occurrence of female morphotypes and transitional stages in the exploited stock of *Macrobrachium rosenbergii* during 1994-1995 and 1995-1996



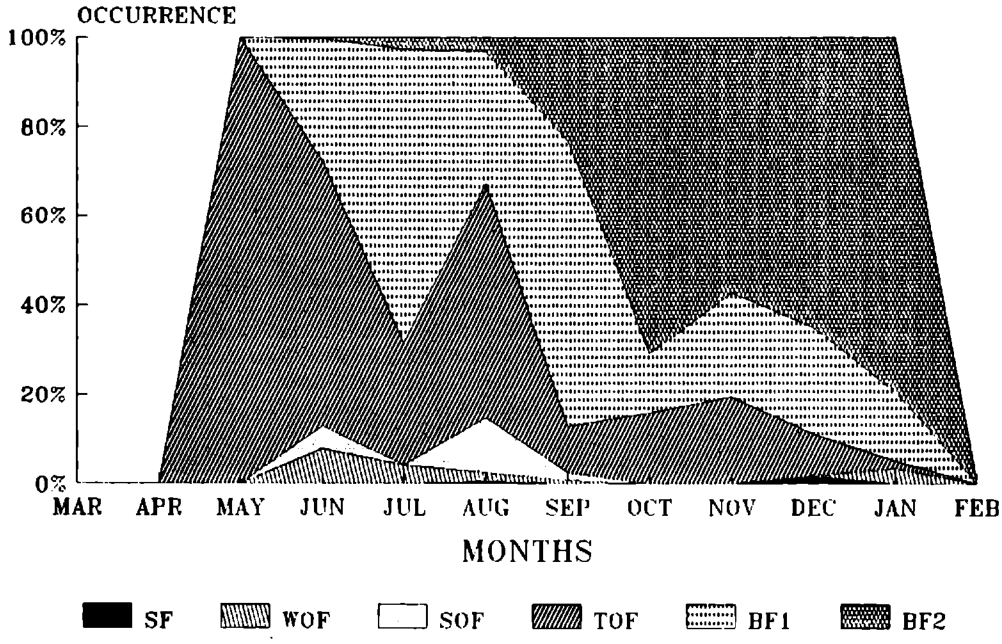
1994–95



1995–96

Fig. 4.7 Monthly variations in the percentage occurrence of female morphotypes and transitional stages during 1994-1995

Fig. 4.8 Monthly variations in the percentage occurrence of female morphotypes and transitional stages during 1995-1996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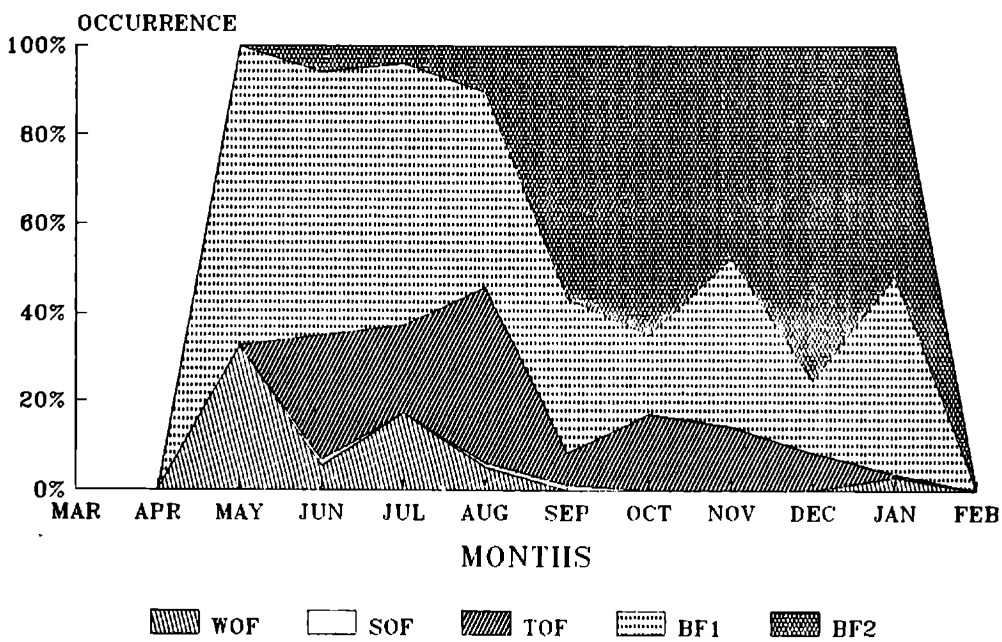
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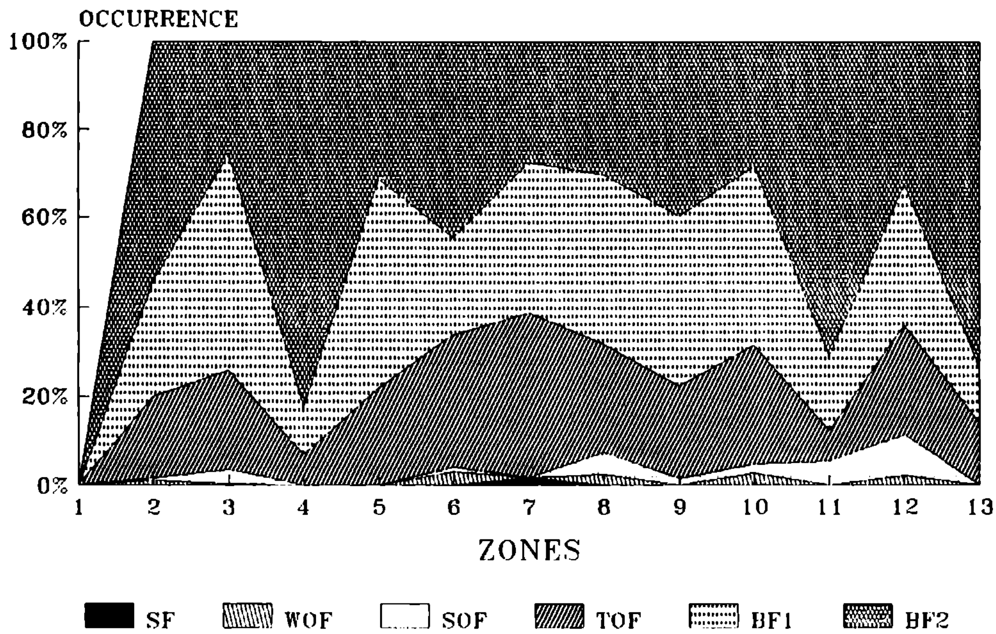
4.8

Fig 4.9 Zone wise variations in the occurrence of various female morphotypes and their transitional stages during 1994-1995

Fig 4.10 Zone wise variations in the occurrence of various female morphotypes and their transitional stages during 1995-1996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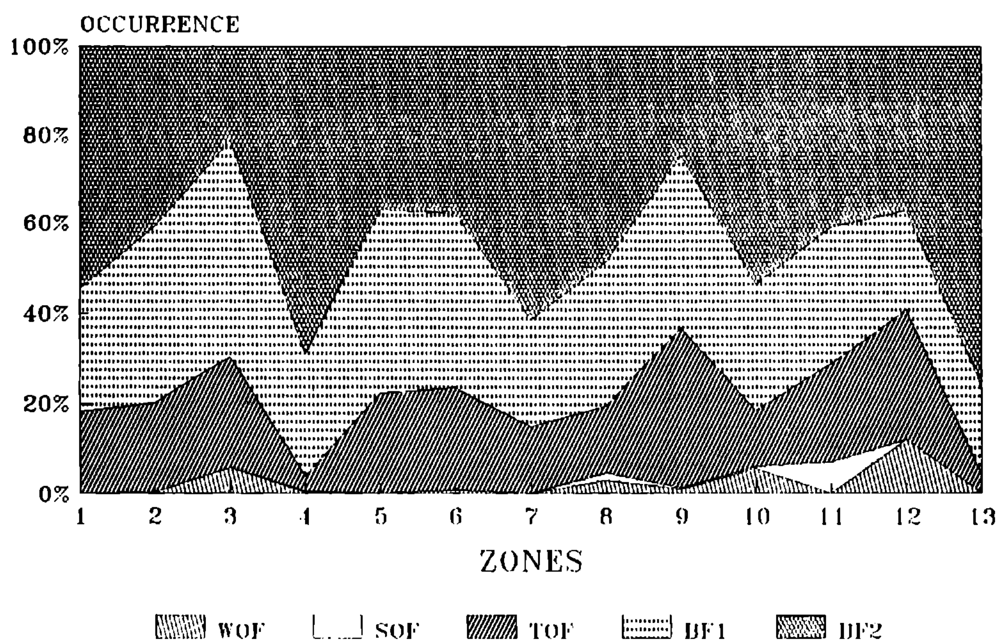
BF2

4.9


OCCURRENCE
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13
ZONES
WOF
SOF
TOF
BF1
BF2

4.10

Fig. 4.11 Variation in population density of *Macrobrachium rosenbergii* in different zones of Vembanad lake and adjacent rivers

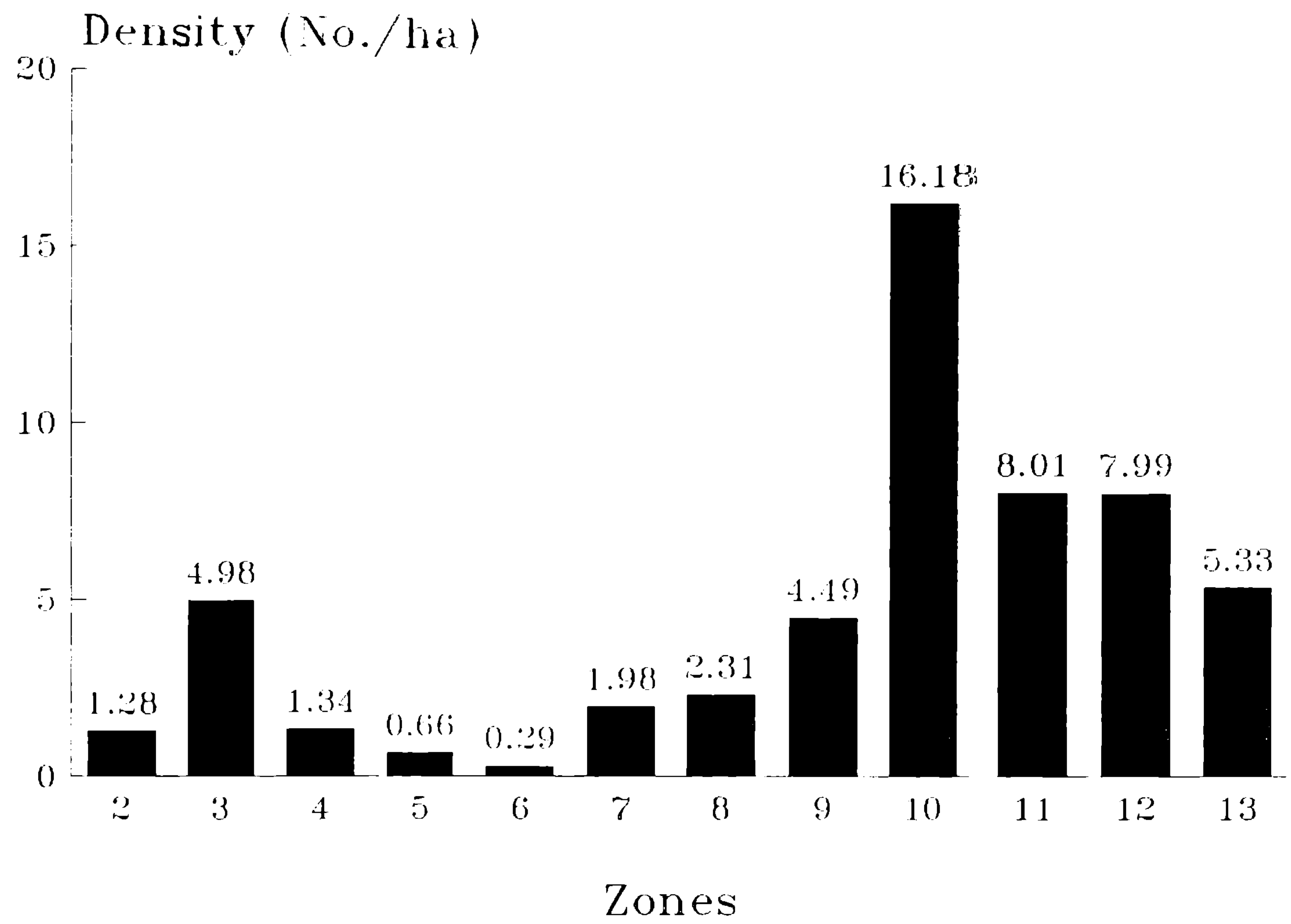
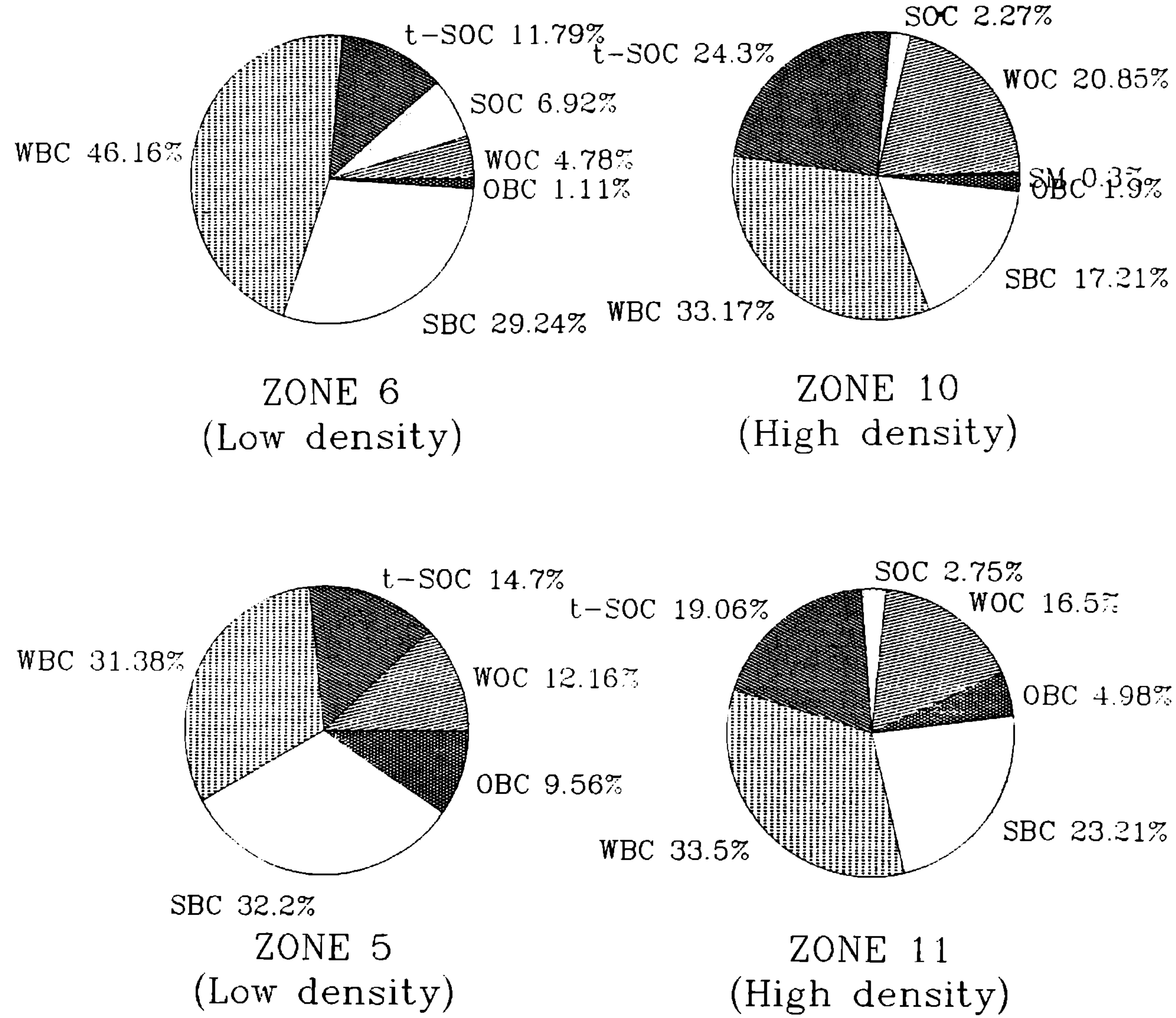

Density (No./ha)
20
15
10
5
0
1.28
4.98
1.34
0.66
0.29
1.98
2.31
4.49
16.18
8.01
7.99
5.33
2
3
4
5
6
7
8
9
10
11
12
13
Zones

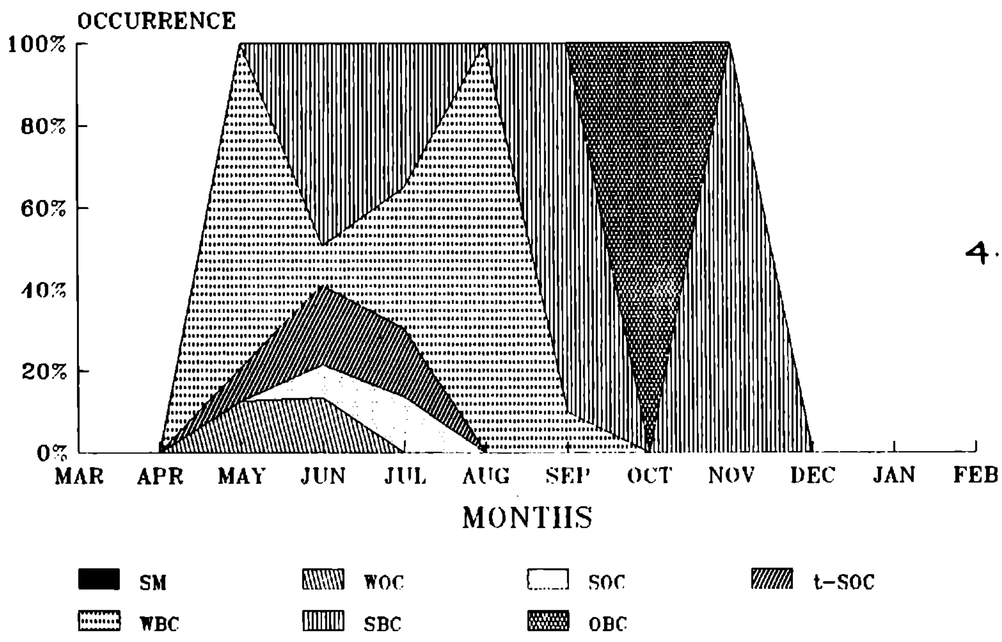
Fig. 4.12 Composition of male morphotypes and transitional stages in two each of high and low density zones



WBC 46.16%
t-SOC 11.79%
SOC 6.92%
WOC 4.78%
OBC 1.11%
SBC 29.24%
ZONE 6
(Low density)
t-SOC 24.3%
SOC 2.27%
WOC 20.85%
SM 0.3%
OBC 1.9%
SBC 17.21%
WBC 33.17%
ZONE 10
(High density)
WBC 31.38%
t-SOC 14.7%
WOC 12.16%
OBC 9.56%
SBC 32.2%
ZONE 5
(Low density)
t-SOC 19.06%
SOC 2.75%
WOC 16.5%
OBC 4.98%
SBC 23.21%
WBC 33.5%
ZONE 11
(High density)

Fig. 4.13 Month wise variation in percentage composition of male morphotypes and transitional stage in zone 6

Fig. 4.14 Month wise variation in percentage composition of male morphotypes and transitional stage in zone 5.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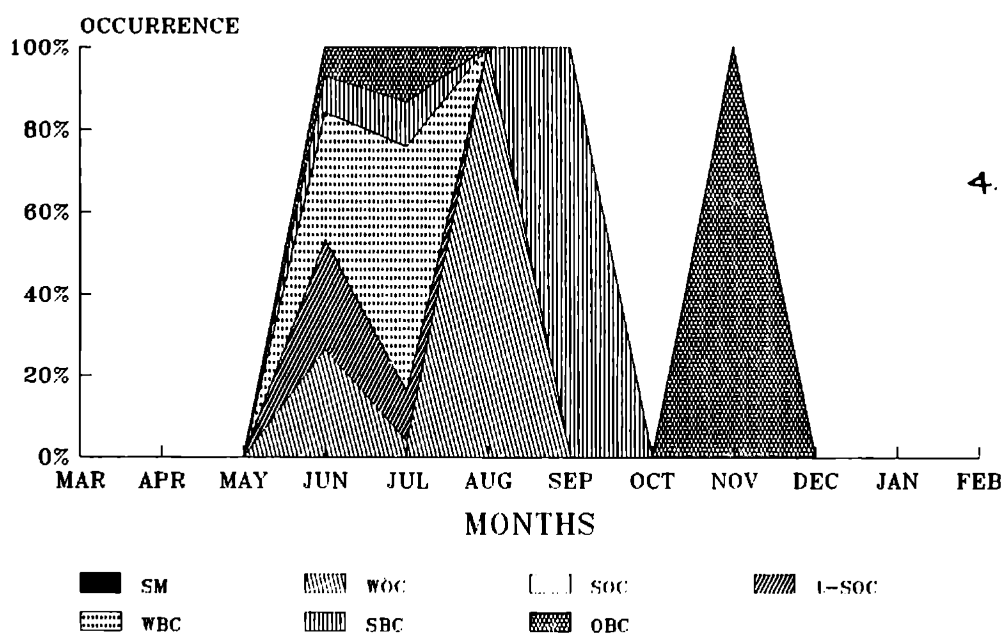
SM
WOC
SOC
t-SOC
WBC
SBC
OBC

4.13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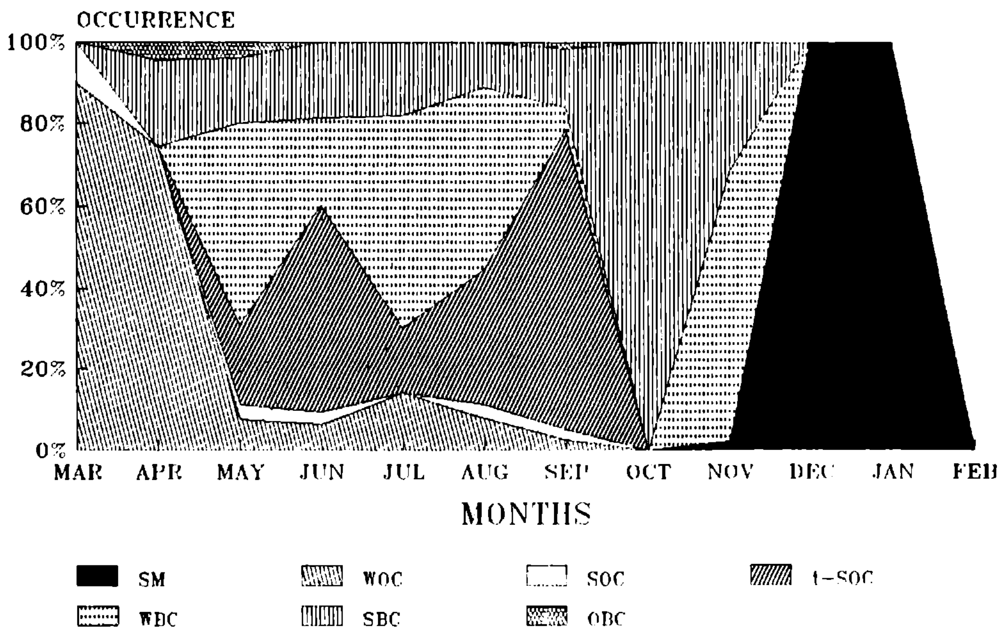
MONTHS
SM
WOC
SOC
t-SOC
WBC
SBC
OBC

4.14

Fig. 4.15 Month wise variation in percentage composition of male morphotypes and transitional stage in zone 10

Fig. 4.16 Month wise variation in percentage composition of male morphotypes and transitional stage in zone 11.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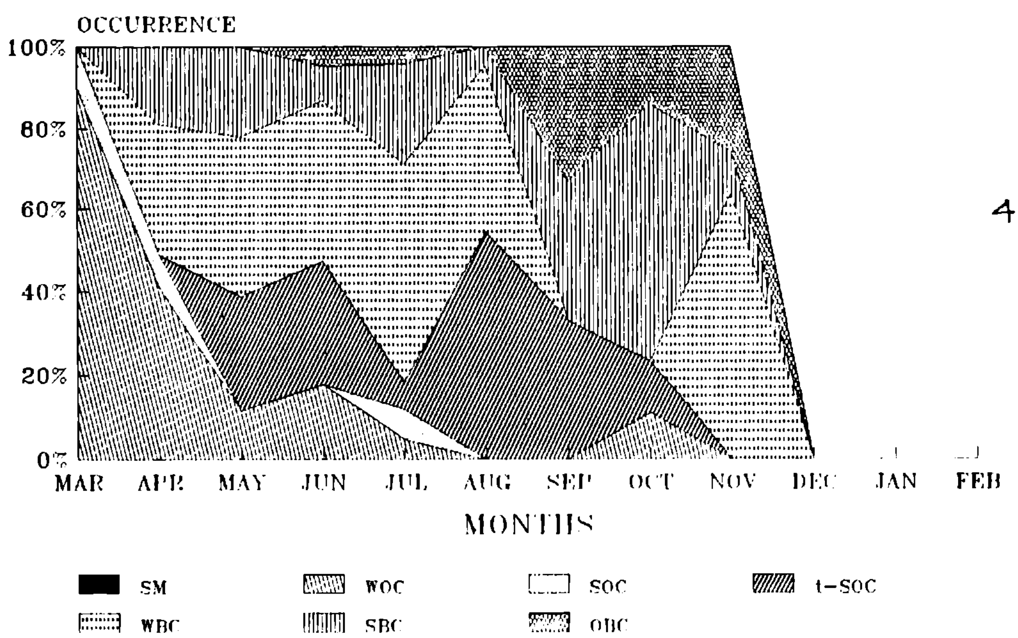
4.15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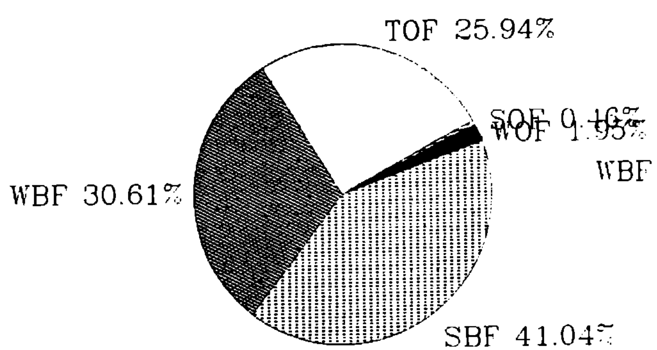
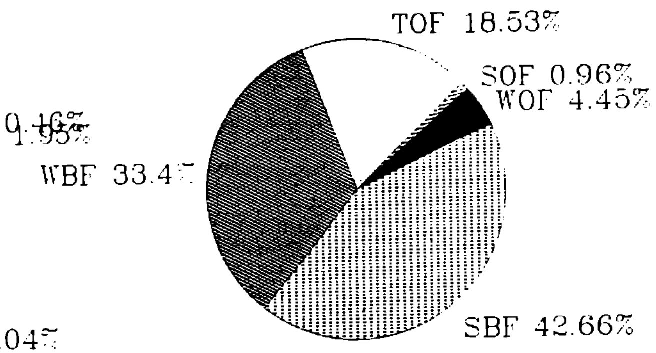
MONTHS
SM
WOC
SOC
t-SOC
WBC
SBC
OBC

4.16

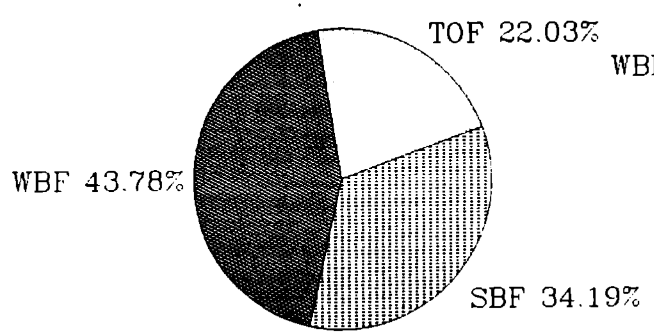
Fig. 4.17 Percentage composition of female morphotypes (SOF and SBF) and their transitional stages in two each of low and high densities.



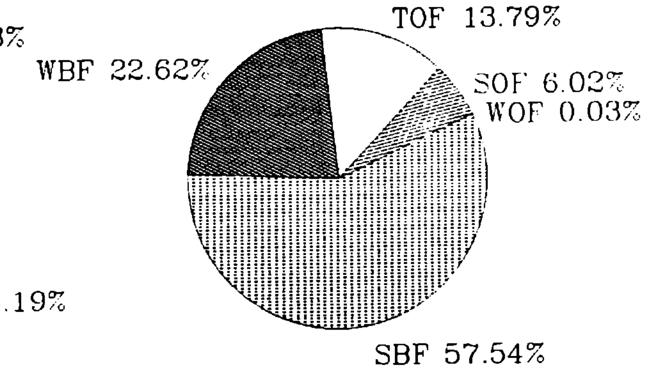

ZONE 6
(Low density)




ZONE 10
(Low density)



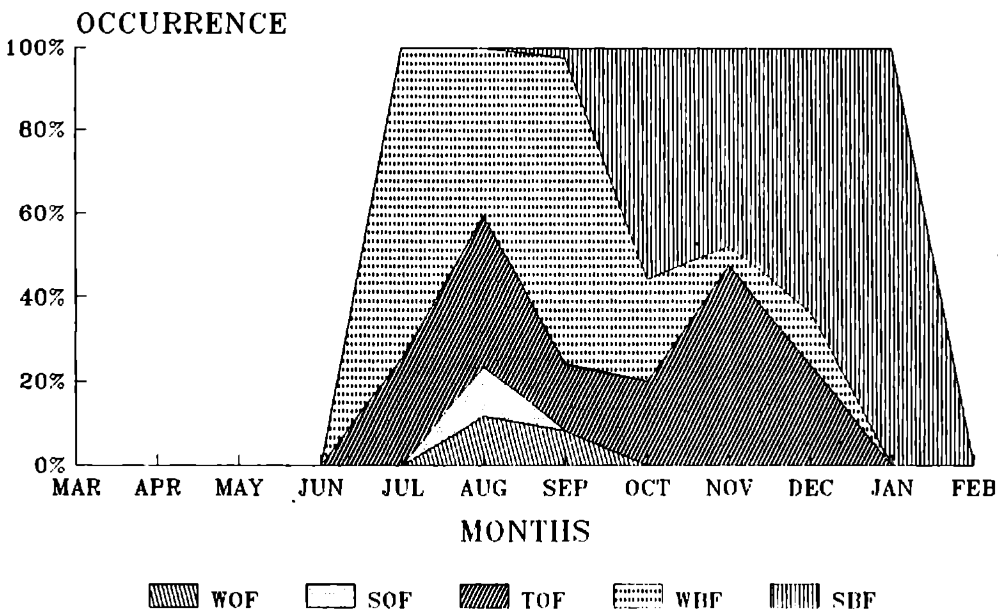

ZONE 5
(Low density)




ZONE 11
(High density)

Fig. 4.18. Month wise variation in percentage composition of female morphotypes and transitional stage in zone 6

Fig. 4.19. Month wise variation in percentage composition of female morphotypes and transitional stage in zone 5.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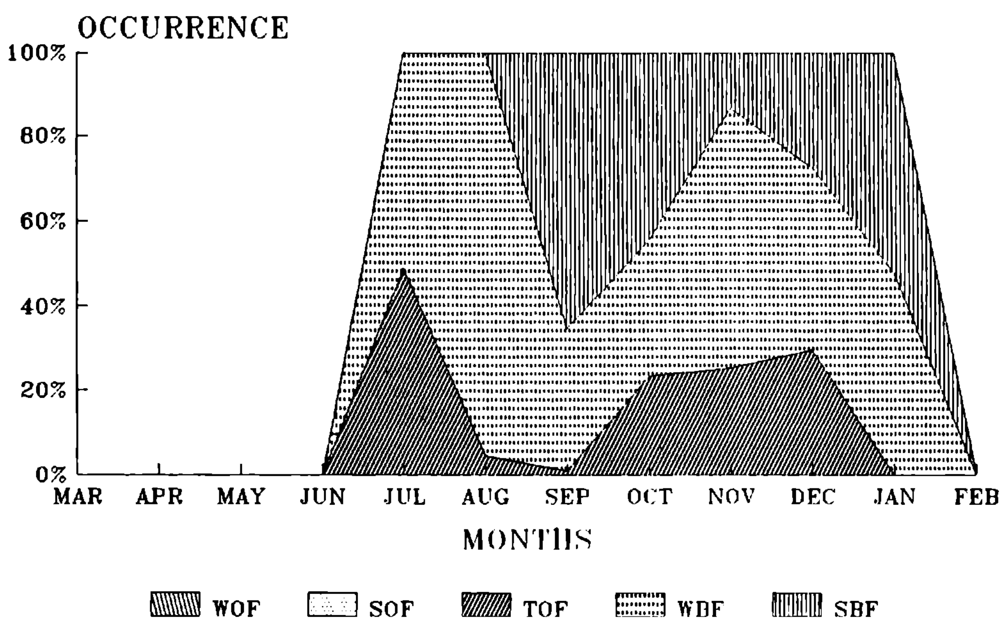
SBF

4.15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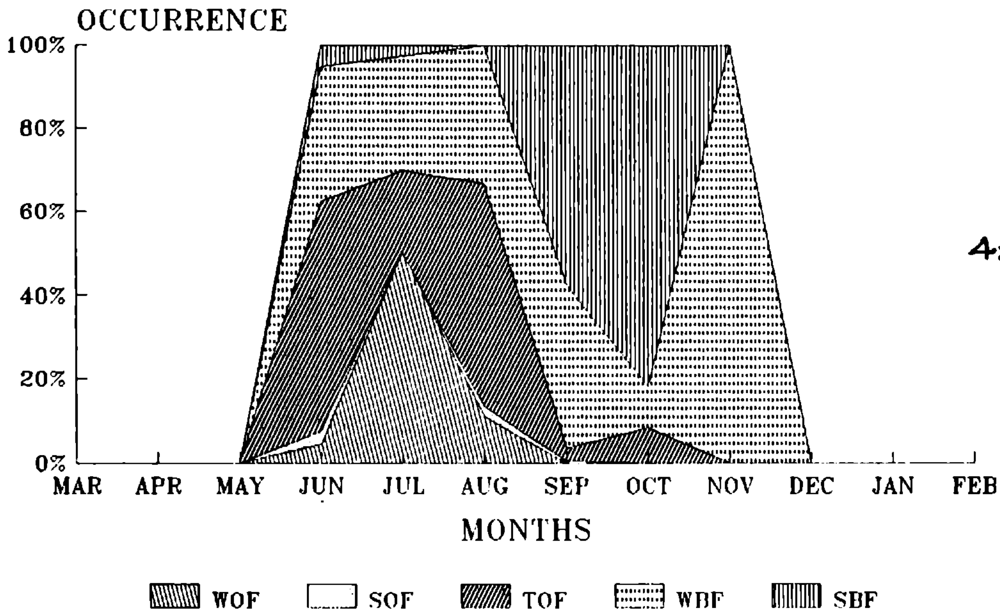
4.16

Fig. 4.20 Month wise variation in percentage composition of female morphotypes and transitional stage in Zone 10

Fig. 4.21 Month wise variation in percentage composition of female morphotypes and transitional stage in Zone 11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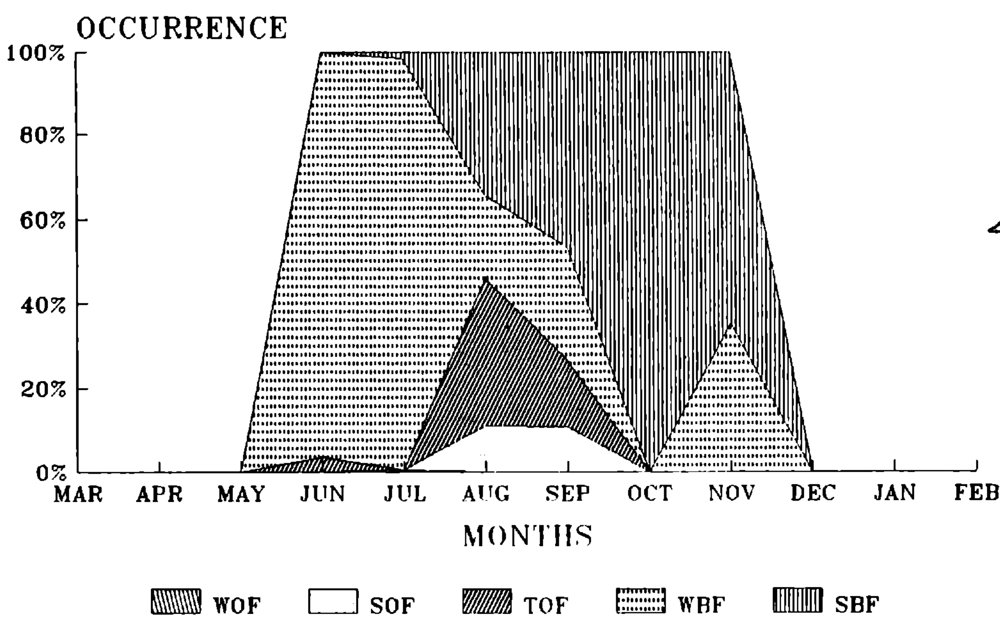
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TOF
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SBF

4.2

# CHAPTER 5

# MORPHOTYPIC DIFFERENTIATION IN GROW- OUT POPULATION OF *Macrobrachium rosenbergii* (de Man) AND ITS RELATIONSHIP WITH DENSITY

## 1. INTRODUCTION

*Macrobrachium rosenbergii* (de Man) locally known as "Kuttanadan Konchu" or "Attu Konchu" is the most important commercial species and has emerged as the best among the cultivable freshwater prawns. In males of *M.rosenbergii*, three morphotypes such as Small Males (SM), Orange clawed males (OC) and Blue clawed males (BC) and two transitional stages (Weak Orange Clawed, WOC and transforming Orange Clawed males, t-SOC) have been established on the basis of relative body size, claw characteristics, hierarchical dominance, differential growth patterns and alternative mating strategies (Cohen *et al.*, 1981; Kuris *et al.*, 1987; Sagi and Ra'anan, 1988). The BC with relatively small body size in terms of carapace length and body weight disproportionate with claw length were differentiated as Old Blue Clawed (OBC) males (Sagi and Ra'anan, 1988). Harikrishnan and Kurup (1997a) distinguished the existence of morphotypes in the female population also inhabiting Vembanad lake and three each of morphotypes and their transitional stages have been described.

The differential growth strategy of various male morphotypes and females of *M.rosenbergii* have been well characterised and documented in culture ponds under different levels of stocking density and management (Smith *et al.*,1978; Brody *et al.*,1980; Cohen *et al.*,1981). Information on the dynamics of the interaction of male morphotypes and the growth strategy of male and female are essentially required for the improvement of the marketable yield of *M. rosenbergii* under captive conditions. Therefore, in the present study an attempt is made to establish the density -population structure-yield characteristics relationships in *M. rosenbergii* reared in the four polders of Kuttanad under extensive commercial monoculture system. Similar studies in *M. rosenbergii* are those of Smith *et al.* (1978), Brody *et al.*(1980), Karplus *et al.*(1986a) and Kurup *et al.*(1996a, 1996b and 1996c).

## 2. MATERIALS AND METHODS

The materials for the present study were collected from commercial modified extensive monoculture farms of Kuttanad during 94-96. These farms are the traditional paddy fields of Kuttanad known as Padasekharams or polders which are the reclaimed portion of the Vembanad lake, lying 1m below the sea level and are separated from the lake with the help of strong peripheral bunds. The present study was conducted in four such polders each of one hectare water spread. After harvesting the punja paddy crop in the month of February these polders were totally dried and scientifically prepared (Padmakumar *et al.*,1992). Liming was done @1000 kg/ha and cow dung was applied for phased manuring @5000 kg/ha. Post larvae of *M.rosenbergii* was procured from two private hatcheries and were directly stocked @ 33,000/ha in polder 1 and 3 and 60,000/ha in polder 2 and 4 with out maintaining in nurseries. Prawns were fed with a locally manufactured commercial feed @ 5% of the body weight on a daily basis in two installments, 40% in the early morning and 60% in the evening. Fresh clam meat was also given @ 1% of the body weight during night. Besides exchanging water by resorting to pumping ten paddle wheel aerators were also erected in each of the polders for facilitating aeration. About 100 earthen pipes of 0.5 m length were kept submerged in each of the polders for providing additional shelters to the prawns.On termination of the culture after seven months, the polders were harvested by pumping it dry and the prawns were hand picked from the bottom. Random samples of 1000 prawns each from the four polders were examined on the day of harvest. All the prawns were sorted according to sex and morphotypes (Ra'anan,1982). The males were then classified into three morphotypes such as SM, SOC and SBC and four of their transitional stages viz. WOC, t-SOC, WBC and OBC. Similarly, females were also sorted into three morphotypes such as SF, SOF and SBF and three transitional stages viz. WOF, TOF and WBF (refer Chapter 2 for details of morphotypes). All the prawns were measured up to nearest millimeter and weighed up to nearest gram. Statistical analysis of the data was done following standard procedures (Snedecor and Cochran, 1967).

3.RESULTS

3.1. Population structure:

Details of population density at stocking and harvesting, mean weight of the prawns at various levels of final density, percentage of survival and contribution of male and female in the harvested population of the four polders are given in Table 1. The population of males and females were dissimilar at the four densities, being 1:0.25 ($\chi^2$= 19.93, $p < 0.05$) at $0.55/m^2$; 1:1.43 ($\chi^2$= 58.84, $p < 0.05$) at $1.3/m^2$; 1:1.7 ($\chi^2$= 37.07, $p < 0.05$) at $1.44/m^2$ and 1:0.42 ($\chi^2$= 29.59, p = <0.05) at $1.56/m^2$ which suggest that in all the four polders studied, the sex ratio showed significant difference from the hypothetical value of 1:1. The structure of male and female population at the four levels of final density is given in Table 2. The percentage contribution by weight of various male and female morphotypes to the respective harvested yield from the four polders are given in Table 2. In polder 1 which represents the lowest density at harvest of $0.55/m^2$, SOC and its successive stages in the transformation pathway viz. t-SOC, WBC, SBC and OBC constituted 97.79% of the male morphotypes and the contribution from SM and WOC was highly insignificant (Table.2) while in polder 2 at a density of $1.3/m^2$, the former category formed 95.92 against 4.08% comprised of SM and WOC. On the contrary, in polders 3 and 4, of still higher density of 1.44 and $1.56/m^2$, reciprocally, the percentage contribution of SOC and its advanced stages showed a declining trend, showing only 84.95 % in former and 81.25% in the latter and a corresponding increase of SM and WOC could also be observed in these polders. It would thus appear that while a direct relationship in the increase of SM and WOC with increase of density at harvesting was apparent, on the contrary, an inverse relationship could be seen with regard to the percentage of SOC and t-SOC (Table.2). However, OBC showed its preponderance in all the polders in appreciable quantities while difference was obvious in regard to BC males, showing high representation at low densities while at higher densities either it was not represented (polder 3) or its percentage became very low (polder 4). The percentage contribution of t-SOC was also relatively higher at low densities when compared to that of higher densities. In female also variations in the morphotypic composition of harvested population was discernible, almost identical with that of their male counterparts. It could be seen that both in polders 1 and 2, SOF and its advanced stages viz. TOF, WBF and SBF accounted for 93.40 and 96.52% respectively, on the contrary, in polders 3 and 4, the percentage contribution of this group was found declined to 92.94 in the former against 76.62 in the latter. In polder 4, the SF and WOF accounted for less than 25% of the harvested population, however, in all other grow outs these group contributed to less than 15% of the total harvested female population. The percentage of berried population in the total female population was in the order of 33.7, 36.24, 20.60 and 37.35% respectively in polders 1,2,3 and 4.

Percentage contribution of male morphotypes to total harvested male population by number in four polders are depicted in Fig.5.1. Though OBC uniformly predominated in all the polders, highest percentage contribution of 35.27 was recorded in polder 1 against 17.22 in polder 4. Similarly, SOC and its successive stages such as t-SOC, WBC, SBC and OBC contributed to 85.48% in polder 1 while in polder 2 it was 83.94%. Conversely, in polders 3 and 4 it was in the order of 40.5 and 43.8% respectively. Similar variations could also be seen in female population (Fig.5.2). In polder 1, 81.66% of the female population was represented by SOF, TOF, WBF and SBF while in polder 2, 93.56% of the female population was constituted by these groups. In contrast, in polder 3 and 4, it was only in the order of 74.52 and 60.85% respectively.

3.2. Yield characteristics:

Stocking densities and yield characteristics of *M. rosenbergii* reared in the four polders are given in Table 1. In polders 1 and 3, the stocking was done @ 3.3/m$^2$ while in polder 2 and 4 the same was @6/m$^2$. However, remarkable difference could be noticed at the time of harvest, especially between polder 1 and 2. The percentage of retrieval varied from 16.59 to 43.65 showing lowest and highest in polder 1 and 3 respectively. The net production varied from 525.41 to 1215.98Kg/ha/7months (Fig.5.3), the lowest was in polder 1 and the highest was in polder 4.

Density dependent variations in mean weight of the population could also be observed in the four polders, showing the highest mean weight of 97.17g in polder 1 against 46.79g registered in polder 3(Table 1). Mean weight, standard deviation, coefficient of variation and skewness in respect of various male and female morphotypes are given in Table 2. Invariably, the mean weight of all male and female morphotypes was highest in polder 1. Similar was the observation in respect of coefficient of variation which would suggest a more heterogeneous nature of the population in polder 1 when compared to that of other polders. The mean weight of male morphotypes in polder 2 was also comparatively higher when compared to their counterpart in polder 3. Similar difference in mean weight could also be observed in female morphotypes of lower and higher densities, the former showing higher values when compared to that of latter. Thus the mean weight of morphotypes showed a remarkable improvement with lowering of density. In order to test the difference, if any, in the weight attained by various morphotypes of *M. rosenbergii* and their yield from four polders studied, the data was statistically analysed using two way ANOVA. The results revealed that there was no significant difference existing between the polders (F= 1.645, df 3,27), however, the weight attained by the various morphotypes showed significant difference (F= 54.779, df 9,27 p=<0.01). From the "t" test it could be seen that the mean weight attained by male and female morphotypes differed significantly between each other except between SOC and t-SOC (t= 1.57).

The weight distribution pattern of prawns in four polders at different levels of final density are depicted in Fig.5.4a to 5.4d. In polder 1 it appeared that the males profoundly influenced the weight distribution pattern, the preponderance of 100-200g weight group was quite discernible. The dominance of weight groups 100-150g and 150-200g was very apparent in polder 1. Whereas in polder 2 and 3, the weight distribution of the total population was found to be much influenced by the female population and 40-70g group showed its distinct predominance. However, in polder 4, though the dominance of small female prawns with a distinct mode at 40-60g could be seen, males having 90-250g were represented in the harvested population in appreciable numbers unlike polders 2 and 3. Density wise difference in the percentage contribution of male and female morphotypes of *M. rosenbergii* to the total yield was also observed (Table 1), showing 90.57% of males in polder 1 while the least was in regard to polders 2 and 3. The marketable weight structure of *M. rosenbergii* at the four levels of final population density is presented in Fig.5.5. A mirror image of the pattern of weight distribution was observed in respect of economic yield configurations in polder 1. At lower density in polder 1, 100-200g emerged as the highest portion of the catch, contributing to 76% of the total harvested population while in higher densities varying from 1.3-1.56/$m^2$, the percentage of the above size group was only in the range of 36-54. Conversely, at higher densities, the percentage of specimens in the weight group of 30-100g was 23, 55 and 37 at 1.3, 1.44 and 1.56/$m^2$ respectively while at lower density of 0.55/$m^2$, it was only 18. It also appeared that out of the total biomass produced from the four polders, 95% of the yield from polder 1 belongs to >50g group and therefore, was marketable whereas in polder 2, only 83% was marketable. While in polder 3, 66% was marketable, however, in polder 4, 88% of the total yield was found marketable. The price packages offered by the seafood processing plants located at Cochin for *M. rosenbergii* per Kg were as follows: >200g- Rs.250/-; 150-200g- Rs.220/-; 100-150g- Rs.200/-; 50-100g- Rs.180/-; <50g- Rs.50/- (mainly for local consumption). While computing the revenue of four polders based on the above tariffs, it would work out to be a total income of Rs.1,04,319/- in polder 1, Rs.1,73,519/- in polder 2, Rs.99,145/- in polder 3 and Rs.2,34,794/- in polder 4. It may, therefore, be seen that though the yield from polder 1 formed only 43.23% of polder 4, income wise it fetches 44.43% of the latter because of large size of prawns. Similarly, the yield from polder 1 comprised only 58.59% of polder 2, it fetched a revenue of 60.35%. Interestingly, though the yield from polder 1 formed only 78.93% of that of polder 3, income wise it fetched 105.65% of the latter and this would suggest the significance of population profile development and their transformation in the grow-outs of *M. rosenbergii*.

## 4. DISCUSSION

In the present study an attempt was made to establish the relationship between population structure-yield characteristics and final population density of *M.rosenbergii* under commercial extensive monoculture system. The results revealed that the morphotypes of this species responded differently in terms of growth and frequency at four levels of density whereby a perceptible variation in population structure and economic yield of the two polders could be noticed. The available reports suggest that females invariably dominated in grow outs of *M.rosenbergii*(Smith and Sandifer,1980;Smith *et al.*,1981), however, in the present study similar trend was noticed at two densities of 1.44 and 1.33/$m^2$. On the contrary, at lowest and highest densities studied, the proportion of male was outnumbering the females and this finding is at variance with earlier reports (Smith *et al.*,1981).The survival percentage in all polders except polder 3 was very low. In polder 1, 90.57% of the total population comprised of males and this would suggest the possibility of selective mortality of female during the earlier phases of farming operation. The selective mortality hypothesis was made applicable in prawn population due to its vulnerability to limb damages and cannibalism during moulting and even under conditions of excess food (Segal and Roe,1975; Peebles,1978), however according to Peebles (1978)the chances of selective mortality in female is less in view of the fact that they used to avoid the above hazards during premating moult as the BC males used to protect them by providing refuge during before and after moulting. The selective mortality of males in natural population of *M.rosenbergii* was reported by Rao(1967)and Langler(1975) based on the declining trend in their frequency over the years and this may be applicable in regard to polders 2 and 3. The percentage of retrieval registered in the present study was also found to be very low when compared to similar reports(Padmakumar *et al.*,1992; Mathew *et al.*,1993).It may be noted that in the present study the post larvae of *M.rosenbergii* were directly stocked in the polders without maintaining in the nurseries against the normal practice of nursery phase. Besides, the postlarvae stocked in polder 1 and 4 were destined to be kept under oxygen packing for about 36 hours as the same were procured from a hatchery which is distantly located from the farming site. This coupled with the poor conditioning of the polders at the time of stocking may be responsible for the low percentages of retrieval rates especially in polders 1 and 4. The growth rate of female being slow when compared to their male counterparts and therefore, the chances of vulnerability to predation in polders 1 and 4 might be high especially during the early phases of culture.

A dynamic shift in the proportion of male and female morphotypes with density was also discernible. At higher density the proportion of SM was relatively high in the order of 5.86 and 4.65% while the SOC and its successive transitional stages showed a declining trend in the order of 81.21 and 84.95% in polder 3 and 4 respectively, in contrast, at lower density in polder 1 the contribution of SM was highly insignificant, while the contribution of the latter category showed a significant improvement. Interestingly, in polders 1 and 2 a majority of males had become BC as evidenced by the high percentage occurrence of BC. Similar variation could also be seen with regard to female morphotypes under different levels of density at harvesting. The difference in shift pattern as manifested by the frequency of male morphotypes may be attributed to the complex social organisational hierarchy by *M.rosenbergii*.At high density the percentage of SM and WOC were very high and this would suggest the chances of inhibition of growth of SM by BC due to the proximity of the latter. BC represents the final morphotype in the developmental pathway of males following an irreversible order from SM (Cohen, *et al.*, 1981; Sagi and Ra'anan,1988) while OC are intermediate, fast growing stages where as SM animals may remain SM or further transform into OC and eventually into BC morphotype(Ra'anan and Sagi,1985). It may, therefore, be inferred that in polder 1 the rate of transformation of male morphotype to its successive stages was very rapid on account of low density and high growth rate and this can well be attributed as the reason for the presence of BC morphotypes in appreciably high proportion. The results of the present study revealed that similar density dependent variations also exist in female morphotypes due to difference in the rate of transformation from SF to SBF which is manifested by the high percentage contribution of SOF and its successive stages at low densities in contrast to relatively low percentage of occurrence of this group at higher densities. The presence of SM and WOC in high percentages in polders 3 and 4 further support the above inference.Brody *et al.*(1980) and Cohen *et al.* (1981)reported that the relative proportion of the three male morphotypes SM,OC and BC remain nearly constant at 5:4:1.However, the results of the present study is totally at variance with the above observation since the ratio was found to be varied from 1:1.72:0.67 (polder 3)to 1:9.8:20.3 (polder 2). Male morphotypes of the mature population of *M.rosenbergii* are reported to be stable and not affected by density (Cohen *et al.*,1981; Cohen and Ra'anan,1983).Contrary to this , in the present study, the proportion of morphotypes were found to be unstable and affected by density. This finding is very much in agreement with the observation of Karplus *et al.*(1986a).

The yield of *M.rosenbergii* obtained in polders 1-3 under extensive monoculture farming by providing commercial feed and was found to be very low when compared to similar findings(Padmakumar *et al.*, 1992; Mathew, *et al.*, 1993; Raje and Joshi, 1992). Padmakumar *et al.*(1992)reported a production of 805 kg/ha/ 7 months while Mathew *et al.* (1993)

registered 506 kg/ha./115 days from the pokkali fields of Kerala whereas Raje and Joshi (1992) could be achieved a production of 3125kg/ha/10 months. However, a direct comparison of the results of the present study with the above may not hold good in view of the fact that the above production figures are extrapolated ones based on experimental culture undertaken in 0.1 -0.2 ha.The inverse relationship seen between the prawn density and mean size of different morphotypes observed in this study tallies with earlier findings(Cohen *et al.*,1981; Karplus *et al.*,1986).The reduction in prawn growth with increasing density may be attributed to a variety of reasons such as competition for food,early sexual maturation, hyper activity of subordinate individuals,loss of exuvia and aggressive and social hierarchy(Karplus *et al.*,1986). The results of the present study also revealed that unlike in the case of penaeids, the economic viability of the culture of *M.rosenbergii* is profoundly influenced by the the relative proportion of OC and BC male and female morphotypes in the population and their marketable size structure of the yield rather than the total biomass produced. Therefore, information on effect of various stocking densities and management measures, dynamics of male morphotypes and their interaction,etc., are very much required for improvement of economic yield of *M.rosenbergii*.

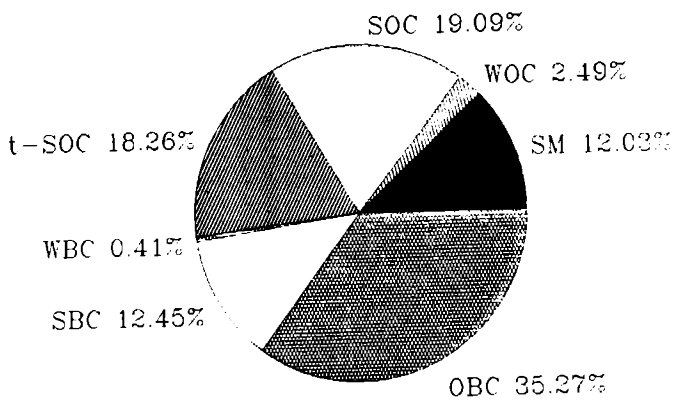
Table 5.1 Stocking density and yield characteristics of *Macrobrachium rosenbergii* reared in polders of Kuttanad under monoculture system

| | POLDERS | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| STOCKING | | | | |
| Numbers per ha. | 33000 | 60000 | 33000 | 60000 |
| Mean weight (g) | 0.2 | 0.2 | 0.2 | 0.2 |
| Biomass per ha. (Kg) | 6.6 | 12 | 6.6 | 12 |
| HARVEST | | | | |
| Numbers per square meter | 0.55 | 1.30 | 1.44 | 1.56 |
| Numbers per ha. | 5475 | 13065 | 14404 | 15683 |
| Mean weight (g) | 97.17 | 69.50 | 46.79 | 78.30 |
| Gross production (Kg/ha) | 532 | 908 | 674 | 1228 |
| Net production (Kg/ha) | 525.41 | 896.02 | 667.36 | 1215.98 |
| Survival (%) | 16.59 | 21.78 | 43.65 | 26.14 |
| Mean Male weight (g) | 109.92 | 89.97 | 56.15 | 102.05 |
| Mean Female weight (g) | 45.94 | 49.62 | 41.28 | 42.69 |
| % by number of Males in population | 90.57 | 44.52 | 44.55 | 70.41 |
| % by number of Females in population | 9.43 | 55.48 | 55.55 | 29.59 |
| Sex ratio | 1:0.25 | 1:1.43 | 1:1.7 | 1:0.42 |

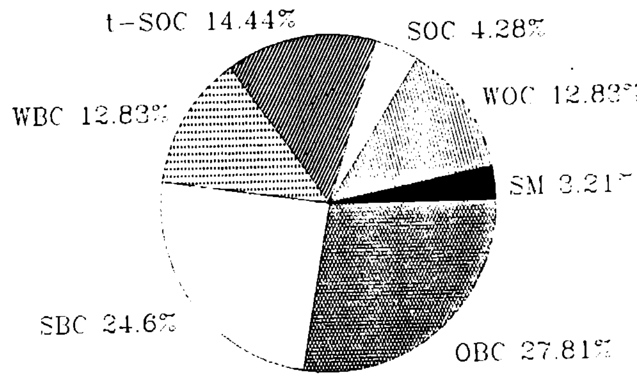
Table 5.2 Number sampled, percentage contribution in sampled weight and mean weight of male and female morphotypes

| pond | | Mean weight of male morphotypes (% of Males) | | | | | | | Mean weight of female morphotypes (% of Females) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SM | WOC | SOC | t-SOC | WBC | SBC | OBC | SF | WOF | SOF | TOF | WBF | SBF |
| | Number sampled | 29 | 6 | 46 | 44 | 1 | 30 | 85 | 4 | 4 | 4 | 24 | 7 | 17 |
| | % by weight | 1.17 | 1.04 | 20.07 | 18.87 | 0.19 | 15.74 | 42.92 | 1.48 | 5.12 | 9.66 | 35.88 | 11.75 | 38.11 |
| | Mean Weight (g) | 9.04 | 47.62 | 113.11 | 116.43 | – | 138.97 | 136.98 | 9.80 | 45.00 | 61.00 | 55.42 | 45.28 | 57.29 |
| 1 | Standard Deviation | 2.82 | 37.05 | 27.27 | 32.07 | – | 35.24 | 48.44 | 2.23 | 16.12 | 12.70 | 18.05 | 10.27 | 14.30 |
| | Coeff. of Variation | 31.22 | 77.81 | 24.11 | 27.55 | – | 25.36 | 30.25 | 22.73 | 35.83 | 20.82 | 32.57 | 22.69 | 24.96 |
| | Standard error | 0.52 | 15.13 | 3.98 | 4.89 | – | 6.43 | 4.55 | 1.11 | 8.06 | 6.35 | 3.68 | 3.88 | 3.47 |
| | Skewness | 0.41 | -1.08 | 0.78 | -0.55 | – | 7.45 | 1.43 | -0.54 | -0.14 | 0.49 | 1.24 | -0.23 | 1.41 |
| | Number sampled | 6 | 24 | 8 | 27 | 24 | 46 | 52 | 3 | 12 | 1 | 20 | 82 | 115 |
| | % by weight | 0.27 | 3.81 | 4.27 | 11.03 | 10.62 | 28.70 | 41.30 | 0.16 | 3.32 | 0.45 | 7.61 | 34.75 | 53.71 |
| | Mean Weight (g) | 10.20 | 19.17 | 108.50 | 65.59 | 92.50 | 149.89 | 174.19 | 7.33 | 23.67 | – | 55.95 | 40.66 | 55.85 |
| 2 | Standard Deviation | 1.51 | 3.82 | 6.30 | 23.52 | 15.12 | 25.76 | 26.31 | 2.31 | 2.67 | – | 17.72 | 9.26 | 13.87 |
| | Coeff. of Variation | 14.78 | 19.92 | 5.81 | 35.18 | 16.35 | 17.18 | 15.10 | 31.49 | 11.30 | – | 31.68 | 22.79 | 24.84 |
| | Standard error | 0.62 | 0.78 | 2.23 | 4.53 | 3.09 | 3.80 | 3.65 | 1.33 | 0.77 | – | 3.96 | 1.02 | 1.29 |
| | Skewness | 0.26 | 4.17 | 0.55 | 0.69 | -2.97 | 0.11 | 0.26 | 0.71 | 0.08 | – | 1.40 | -0.30 | 0.70 |
| | Number sampled | 39 | 40 | 11 | 16 | 0 | 0 | 26 | 40 | 17 | 0 | 19 | 70 | 78 |
| | % by weight | 4.65 | 10.40 | 24.84 | 14.81 | 0.00 | 0.00 | 45.30 | 5.70 | 1.36 | 0.00 | 11.89 | 31.07 | 49.98 |
| | Mean Weight (g) | 11.22 | 45.14 | 89.18 | 88.79 | – | – | 148.64 | 7.83 | 23.56 | – | 51.21 | 43.66 | 57.58 |
| 3 | Standard Deviation | 2.77 | 13.33 | 22.77 | 36.04 | – | – | 26.91 | 2.86 | 11.79 | – | 17.82 | 10.85 | 21.05 |
| | Coeff. of Variation | 24.68 | 29.53 | 25.53 | 40.59 | – | – | 17.79 | 36.53 | 50.04 | – | 34.80 | 24.85 | 36.56 |
| | Standard error | 0.65 | 3.56 | 6.87 | 9.63 | – | – | 5.29 | 0.45 | 2.86 | – | 4.09 | 1.29 | 2.33 |
| | Skewness | 0.70 | 0.83 | 0.30 | -7.54 | – | – | 2.00 | 0.88 | 0.60 | – | 0.49 | 0.13 | 1.72 |
| | Number sampled | 118 | 104 | 39 | 45 | 0 | 21 | 68 | 10 | 55 | 2 | 15 | 41 | 43 |
| | % by weight | 5.86 | 12.93 | 15.19 | 14.23 | 0.00 | 8.54 | 43.25 | 1.47 | 21.92 | 1.92 | 11.73 | 19.84 | 43.13 |
| | Mean Weight (g) | 14.32 | 40.56 | 125.79 | 84.33 | – | 57.00 | 195.47 | 10.40 | 28.11 | 60.00 | 55.44 | 34.29 | 79.67 |
| 4 | Standard Deviation | 4.53 | 27.96 | 25.39 | 21.14 | – | 38.18 | 41.06 | 2.46 | 10.16 | 11.31 | 20.42 | 12.86 | 24.34 |
| | Coeff. of Variation | 31.67 | 68.94 | 20.18 | 25.07 | – | 66.99 | 21.00 | 23.64 | 36.14 | 18.86 | 36.85 | 37.49 | 30.55 |
| | Standard error | 1.04 | 2.74 | 4.06 | 8.63 | – | 27.00 | 4.62 | 0.78 | 1.37 | 8.00 | 5.27 | 2.01 | 3.71 |
| | Skewness | 0.45 | 1.25 | 0.70 | 0.38 | – | 0.00 | 0.14 | -1.15 | 1.83 | 0.00 | 1.33 | 1.59 | 0.30 |

Fig. 5.1 Percentage contribution by number of male morphoytpes to the total harvested male population in grow-outs




POLDER 1

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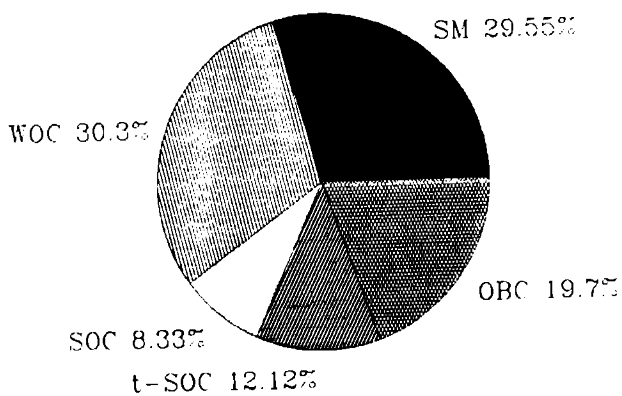
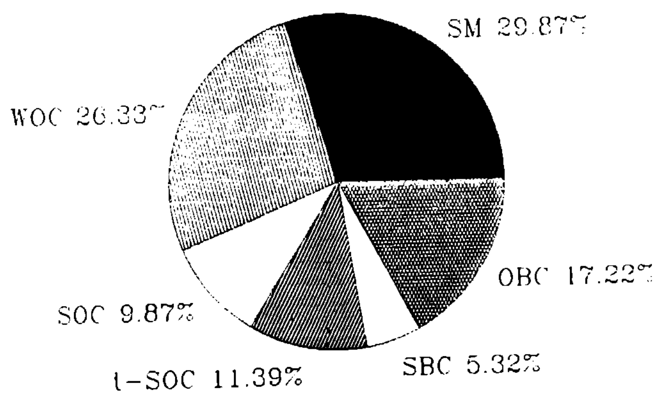
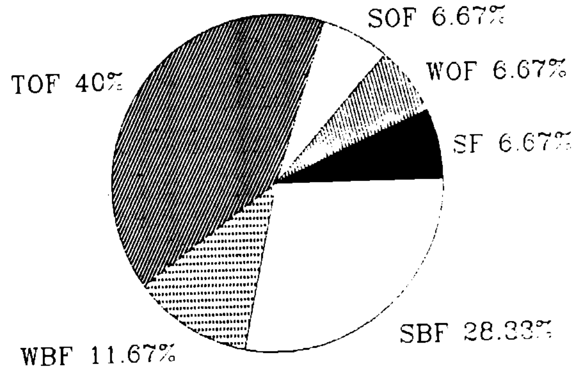



POLDER 3




POLDER 4

Fig. 5.2 Percentage contribution by number of female morphotypes to the total harvested female population in grow-outs

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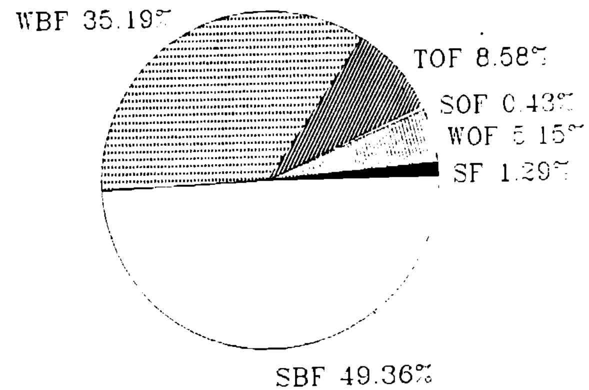


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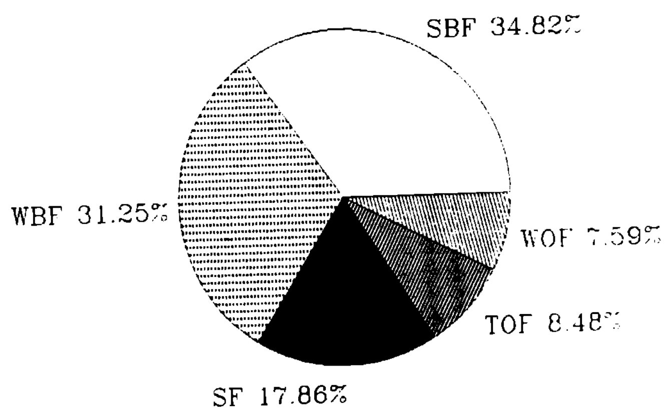


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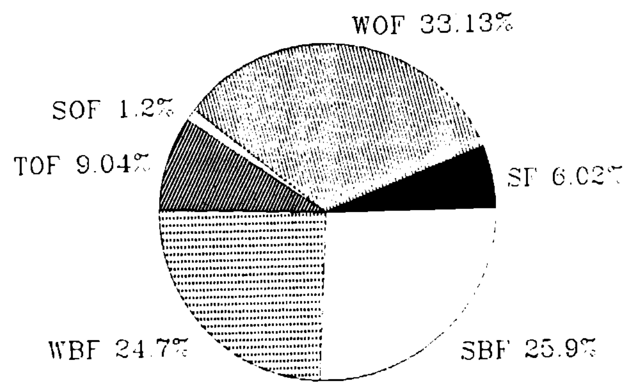



POLDER 4

Fig. 5.3 Production pattern of *Macrobrachium rosenbergii* in polders 1-4

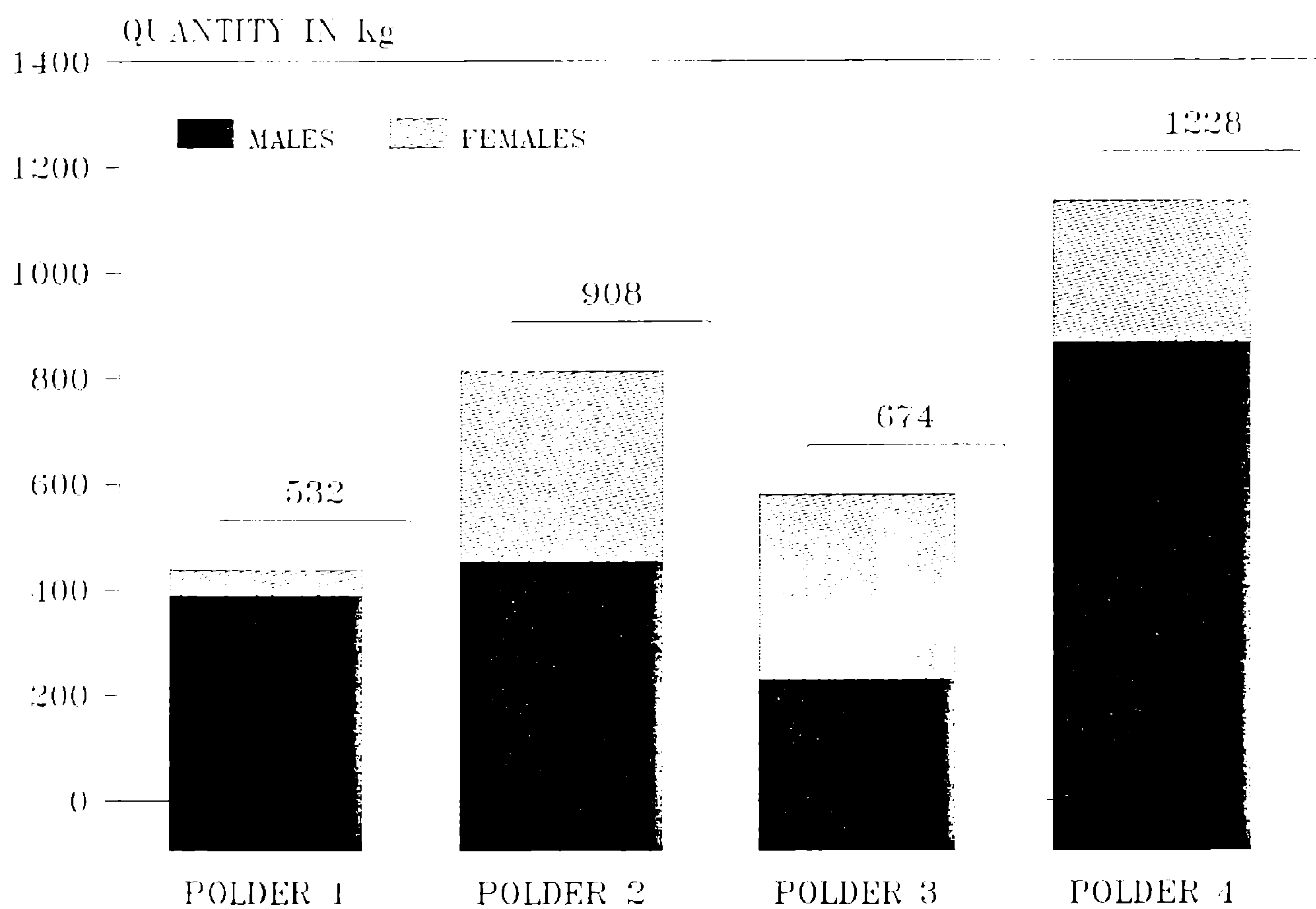
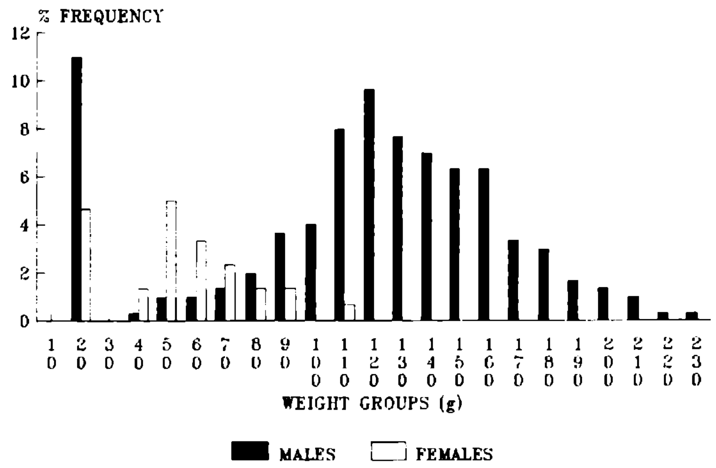
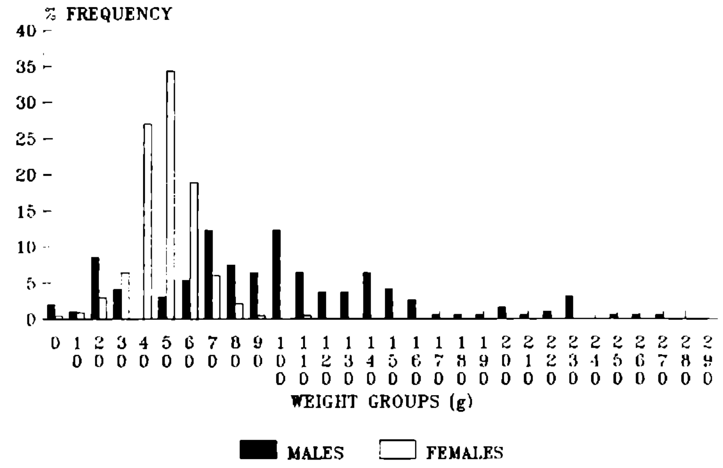

QUANTITY IN kg
1400
1200
1000
800
600
400
200
0
MALES
FEMALES
532
908
674
1228
POLDER 1
POLDER 2
POLDER 3
POLDER 4

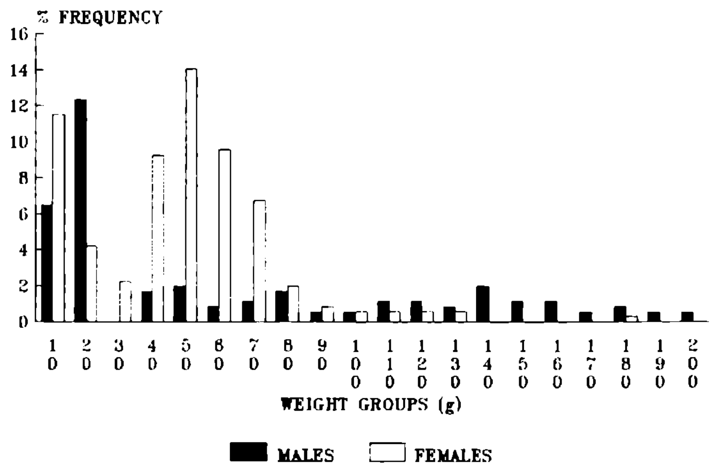
Fig. 5.4 Weight distribution pattern in harvested population of *Macrobrachium rosenbergii* from four polders at different levels of final density




POLDER 1




POLDER 2

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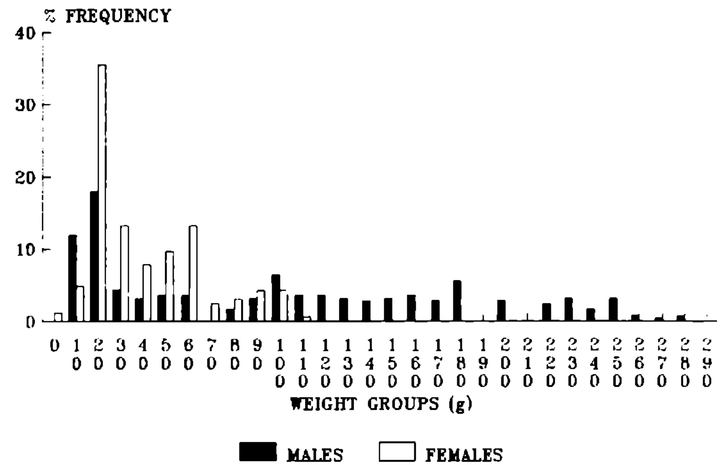
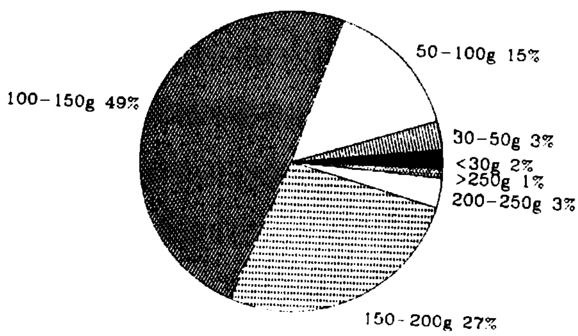
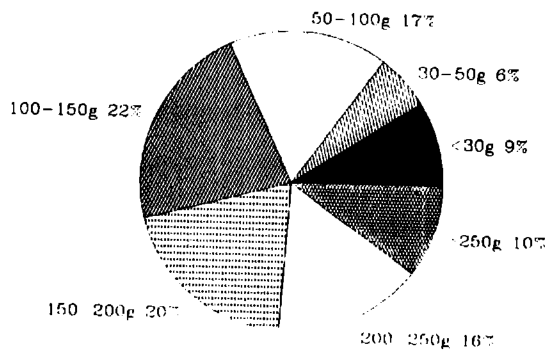



POLDER 4

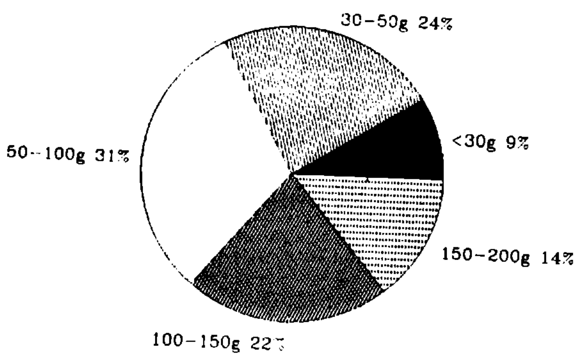
Fig. 5.5 The marketable weight structure of *Macrobrachium rosenbergii* at four levels of final population density



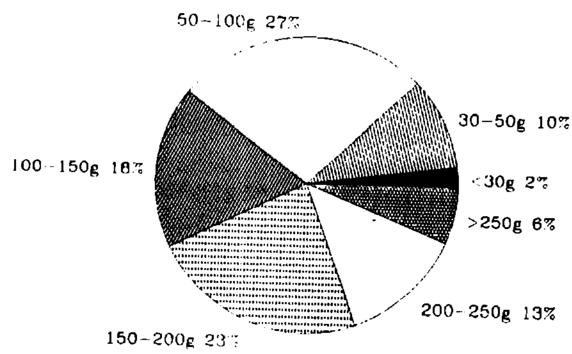
POLDER 1



POLDER 2



POLDER 3



POLDER 4

# Section 4

## Post Larval Distribution And Mark-Recovery Studies

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**Chapter 6 Temporal And Spatial Distribution Of Plaemonid Larvae And Post Larvae of *Macrobrachium rosenbergii* (de Man) And M. idella (Hilgendorf)**

**Chapter 7 Mark-Release-Recovery Studies In *Macrobrachium rosenbergii* (de Man)**

# CHAPTER 6

# TEMPORAL AND SPATIAL DISTRIBUTION OF PALAEMONID LARVAE AND POST LARVAE OF *Macrobrachium rosenbergii* (de Man) AND *M. idella* (Hilgendorf)

## 1. INTRODUCTION

The Vembanad lake ecosystem plays a key role in the life cycle of freshwater prawns, *Macrobrachium rosenbergii* and *M. idella* as the environmental conditions prevalent particularly in downstream part of the lake meet the most essential requirements for the successful completion of larval metamorphosis of these species (Kurup *et al.*, 1992a). However, several man made alterations in the ecosystem such as reclamation of lake and the consequent shrinkage of breeding grounds, construction of bunds, etc., have brought about serious set back in the life cycle of these species inhabiting the lake. Both *M. rosenbergii* and *M. idella* are known to undertake breeding migration to saline areas of the lake and a major shift occurred in the breeding ground of the former species in Vembanad lake consequent to the commissioning of Thanneermukkam salinity barrier is worth mentioning (Kurup *et al.*,1992a). *M. rosenbergii* requires 12+/-2 ppt salinity for the successful completion of larval metamorphosis (New and Singholka, 1985) and therefore the berried females are compelled to undertake lengthy downward breeding migration to reach the breeding grounds. The larvae so produced after attaining the post larval stage ascend upwards by negotiating against the water currents and reach Kuttanad where freshwater habitat is prevalent. The operation of salinity barrier is obstructing both downward migration of berried females and upward migration of post larvae, thereby causing considerable damage in the stock replenishment (Kurup *et al.*, 1992a). The breeding habits and return migration of post larvae and juvenile of *M. rosenbergii* have been studied by Raman (1964; 1967) while Kurup *et al.*(1992a) reported the spawning season of *M. idella* in Vembanad lake.

The first and second larval stages of *M. rosenbergii* of the back waters of Kerala were described quite early by Menon (1938). Ling (1969a) described various larval stages of *M. rosenbergii* while Pillai and Mohammed (1973) published similar information in regard to *M. idella*. Raman (1967) briefly mentioned the distribution of larvae of *M. rosenbergii* in Vembanad lake. Though the distribution of zooplankton (George, 1958; Menon *et al.*, 1971; Rao *et al.*, 1975; Pillai *et al.*, 1975; Silas and Pillai, 1975) and post larvae and juveniles of penaeid prawns (Mohamed and Rao, 1971; Rao, 1972a; Kuttiyamma, 1975; Rao, 1980; Suseelan and Kathiravel, 1982; Jose *et al.*, 1988; Sosamma and Mathew, 1989 a and b;) of Cochin backwaters have been reported, however, hitherto no attempt has been made to study the distribution and abundance of post larvae of *M. rosenbergii* and *M. idella* in Vembanad lake. Therefore, the present study was undertaken with a view to delineate the temporal and spatial availability of post larvae of above two species in this water body. The results of the present study would be useful in delineating the zones of the lake which serve as the nursery ground of these species and also to understand the total number of post larvae that could reach the freshwater habitat from their breeding grounds.

## 2. MATERIALS AND METHODS

Regular monthly collection of plankton samples from 13 stations in the lake and adjoining rivers (Fig.1) (Section 1) were carried out from March 95 to February 96 during the cruise surveys (refer Section 1.4). The samples were collected by horizontal haul using a truncated conical tow net (mesh size of 0.25mm) made of velon cloth and the diameter of the net was 0.5m. The speed of the boat and the total distance covered for each hauling was more or less kept constant during the entire period of study. The net was towed during night hours when the tide was at the receding condition, for a period of 20 minutes, covering a distance of approximately 500m. The volume of water filtered through the net was approximately 60 $m^3$. After each haul, the planktonic samples were collected and preserved in 5% formalin. Qualitative and quantitative enumeration of the larvae and post larvae in the samples so collected were carried out in the laboratory. The samples were diluted in to 250ml and multiple samples of 1 ml each were pipetted out in to a plankton counter. Initial sorting was done with the help of a dissection microscope into larval and post larval forms of palaemonid prawns. The post larvae so segregated were examined in detail for the species level identification using the keys and descriptive accounts published by Ling and Merican (1961), Ling (1969a), Thripathi (1992) and Pillai and Moha med (1973). Besides, the post larvae of the two species were also compared against hatchery produced post larvae of the same by examining the pattern of chromatophores, morphological appearance and morphometric measurements. The number of larvae and post larvae encountered in each collection were taken as an index of abundance in terms of number (Prakash and Agarwal, 1986).

## 3. RESULTS

### 3.1. Palaemonid larvae

Monthly variations in the abundance of Palaemonid larval forms at 13 stations of the study area are depicted in Fig.6.1. The regular occurrence of the larval forms in varying densities round the year in all stations was noteworthy. Highest numerical representation in the order of 160,000 -180,000 larvae/ haul could be observed from stations 5 and 13 respectively in the month of August, on the contrary, during November - April, it declined to less than 1000/ haul in stations 5, 7 and 10. Invariably in all the stations, maximum abundance of larvae could be observed during June to October with a distinct predominance in August and a steep decrease was discernible from October onwards, showing only very sparse occurrence during December - April, especially in the stations representing upstream and riverine regions of the study area. Among the various stations studied, highest concentration of Palaemonid larvae was observed at stations 5, 7, 9 and 13 while stations 8,10,6 and 4 showed moderate level of abundance. While comparing the relative abundance of Palaemonid larvae in the different regions of the study area, it could be seen that the abundance was significantly higher in stations representing the upstream regions of the lake (7,8,9 and 10) when compared to that of downstream part (1-6) and riverine regions (11-13)of the study area.

3.2. Post larvae of *M.rosenbergii* and *M.idella*

Monthly variations in the availability of post larvae of *M.rosenbergii* at 13 stations are shown in Fig.6.2. While examining the trend shown in the appearance of post larvae at different stations of the lake, it could be seen that at stations 1-3, the representation of post larvae of *M.rosenbergii* could be encountered from the month of September while in stations 4-5 and 7 and 13 it appeared in the month of October. On the contrary, its presence was noticed only in December at stations 9,10 and 12. Similarly, the early disappearance of post larvae could also be noticed in stations 1-4 during December- January while its occurrence was observed at station 5-6 till

February. On the contrary, in stations 9 and 10, the presence of post larvae could be registered till April. Highest number of post larvae in the order of 36 and 32 /haul was recorded from stations 5 and 7 respectively in the month of December. In general, a gradual shift in the months representing the peak availability of post larvae in the lake could be discernible while proceeding from downstream to upstream stations of the lake. In the downstream, the highest occurrence of post larvae was recorded during September - December in all stations except station 6, in contrast, in upstream regions, peak availability could be recorded during December - February. However, the trend seen in the distribution of post larvae in station 13 was almost identical with that of stations 3 and 4.

In *M. idella* (Fig.6.3) the occurrence of post larvae could be encountered only at stations 1- 9 and 13, however, the density of post larvae was found relatively high in station 2 when compared to other stations. Though very definite trend could not be noticed in the distribution of post larvae in the lake as observed in the case of *M.rosenbergii*, its occurrence was relatively prolonged in the stations representing downstream part of the lake when compared to that of upstream and riverine regions. Among the various stations studied, in stations 1,2 and 5, the availability of post larvae of *M.idella* could be noticed almost round the year barring one or two months while in stations 8-13, its availability was not only very sparse but also at irregular intervals with out showing any definite trend. Highest number of post larvae/ haul could be registered from zone 2 in the order of 200 and 180/haul in the months of July and September respectively. In almost all stations of the downstream region, its predominance could be seen during July to December, on the contrary, in station 8, its unusual availability during April, June and August was noteworthy. The occurrence of post larvae of *M. idella* was very high in stations representing downstream part of the lake (stations 1-6) in contrast to its sparse availability in the stations representing upstream part of the lake and riverine regions.

## 4. DISCUSSION

Estuaries, despite their frequent changes in environmental parameters are considered as cradles for a variety of marine and freshwater prawns (Kurup *et al.*, 1989). While the larvae of marine prawns immigrate from the sea in to this backwater, as these water bodies provide most congenial habitat apart from offering better refuge and enormous food to the growing prawns (Mohamed and Rao, 1971). In contrast, some of the freshwater prawns descended from the rivers and use part of the estuary as their breeding ground. The marine prawns undertake return migration to the sea while attaining sub adult stage, in contrast, the freshwater prawns desert the estuarine regions upon attaining the post larvae or early juveniles and ascend the rivers. The post larval recruitment of marine prawn into the brackish water environment is acting as the causative factor in bringing about the fluctuation of marine prawn yields, in contrast, the magnitude of fishery of freshwater prawns are mainly governed by the recruitment of post larvae from estuaries in to freshwater habitat (Kurup *et al.*,1989).

In the present study, an attempt is made to delineate the distribution and abundance of larvae of Palaemonid prawns and also to generate adequate knowledge in regard to movement and distribution of post larvae of *M.rosenbergii* and *M.idella* in the Vembanad lake. Mohammed and Rao (1971) reported 8 species under the family Palaemonidae from Cochin backwaters, however, in the present study, a species wise assessment of palaemonid larvae of the lake was not attempted due to the lack of proper keys for identification of larval stage of freshwater prawns. Moreover, the chromatophores of the third abdominal segment of the larvae are being used as a most dependable character for species level differentiation in Palaemonid prawns (Menon, 1938; Ling, 1969a; Uno and Kwon, 1969; Aiyer, 1949; Pillai and Mohamed, 1973). In the present study, as the duration of the cruises invariably exceeded more than a period of 10 days and therefore, while analysing the larval samples, the chromatophores were almost in the verge of disappearance due to the preservative action of formalin. This posed much practical difficulty in their proper species level identification.

The results of the present study revealed that

July - September periods registered the maximum abundance of Palaemonid larvae with a definite peak in August in almost all stations studied. Available reports suggest that the spawning of most of the freshwater prawns are associated with the onset of South-west monsoon ( John, 1957; Rajyalekshmi, 1961; 1980; Jayachandran, 1984; Kurup *et al.*, 1992a). The freshwater prawns are denizens of various rivers influxing into Kuttanad or oligohaline zones of the Vembanad lake and most of them spawn in the place of their inhabitation while species such as *M.rosenbergii* and *M.idella* move out into estuaries for the purpose of breeding. It would thus appear that the peak period of abundance of larvae encountered in the present study strongly coincided with the breeding season of Palaemonid prawns and is therefore, justifiable. In the case of *M.rosenbergii* and *M.idella* the exposure of larval stages to estuarine conditions are obligatory for the first month of non-feeding pre-zoea to the feeding zoel stage. On the other hand, the monsoonal flow water may also wash down huge larval concentrations of freshwater prawns from river proper and adjacent regions and the high density of Palaemonid larvae reported from the lake in the month of August can be attributed to the above reasons. Ling (1969a) reported that all larval stages of *M.rosenbergii* are active swimmers and are planktonic in habit. Individuals of early larval stages tend to swim close together in large groups close to surface waters. George (1958) reported that occurrence of caridean larvae including *Palaemon* spp. in

Cochin backwaters increased from August and reached maximum in December after north east monsoon. In contrast to this, the present findings showed that maximum density of Palaemonid larvae was observed in July and August in stations 1 and 2 respectively which represent one of sampling stations of the above author. Moreover, in most of the stations studied, maximum occurrence of larvae was encountered in August. This may be because that larvae of early broods hatched out in rivers and other freshwater areas of the lake and passively drifted to the estuarine areas along with the flood water caused by south west monsoon.

Physico-chemical parameters of lake water influence profoundly on the distribution of larvae. The preponderance of larvae in almost all stations was encountered during July to September during when both surface and bottom temperatures were particularly low (refer Chapter 1 in Section 2). Temperatures below 24$^{0}$C has been reported to cause retarded development or mortality to the larvae (New, 1990). However, lowest surface temperature recorded during 95-96 from the lake was 25$^{0}$C in July. A close scrutiny of physico-chemical parameters during the study period show that temperature, pH, dissolved oxygen, total hardness, total alkalinity, etc. of surface and sub surface waters from the lake were well within the limits of optimal values preferred by the larval and postlarval stage of *Macrobrachium* spp.(New, 1990), however, the salinity values exceed well beyond the tolerance limit, especially in the stations of downstream part of the lake during January- May. The highest occurrence of larvae in most of the stations was encountered during August 95 during when surface salinity was down to zero even at station 1 which has the direct access to sea.

The occurrence and abundance of post larvae of *M.rosenbergii* and *M.idella* with reference to time and space were investigated in the Vembanad lake. While examining the pattern of appearance of post larvae of *M.rosenbergii* in different stations of the lake, it could be seen that in the downstream part of the lake they appeared from September onwards, on the contrary, the same could be encountered only from December- January months in the upstream stations. The temporal variations so arrived at in the spatial occurrence may indicate the time taken by the post larvae to ascend upwards. The spawning period of *M.rosenbergii* is reported as August to December (Kurup *et al.*, 1992a; Harikrishnan and Kurup, 1996a) and the newly hatched larva may take 16-45 days for completion of larval history and transformation into post larva (New and Singholka, 1985). It may, therefore, be inferred that the post larvae encountered from stations of the downstream part of the lake may represent the zoea produced in the month of August. The gradual shift in the appearance of post larvae of *M.rosenbergii* from August- December at stations 1-4 to October- February at stations 5-7 may manifest the time taken by these for their upward migration negotiating against the strong water currents of the lake.

Furthermore, their presence in the riverine area and confluent portions of the lake (stations 8-11) were also found only during December to April and this finding would also support the above inference and this observation is also well in accordance with that of Raman (1967).

The post larval abundance of *M.rosenbergii* and *M.idella* in the lake are governed by the stock size of migrating mother prawns reaching the breeding grounds and their breeding success of the respective year. In *M.rosenbergii*, the post monsoon peak recorded in the downstream regions and premonsoon peak noticed in the upstream part of the lake would indicate the places of nursery and dwelling grounds of this species respectively. However, this finding is at variance with the observation of Rajyalekshmi (1980) who reported that the peak occurrence of post larvae of *M.malcolmsonii* in river Godavari and Hooghly are during early monsoon and late monsoon respectively. Similar observation had been reported by Prakash and Agarwal (1986) in *M.birmanicum choprai* of the river Ganga. However, Singholka *et al.* (1980) recorded a summer peak in the availability of *M.rosenbergii* and the high post larval abundance of the species noticed in the present study in the upstream part of the lake in premonsoon months shows strong agreement with this finding. The tolerance limit of various physico-chemical parameters of larvae and post larvae of *M.rosenbergii* has been reported (Rao and Thripathi, 1993) and while comparing the values of various physico-chemical parameters observed from the lake, it could be seen that almost all of them except salinity were within the tolerance limit and therefore, these factors may not be acting as limiting factors in the distribution and abundance of post larvae in the lake. However, a decreasing abundance of post larvae with an increasing salinity values could be discernible in stations 1-6. Though the mesohaline conditions prevailing in the lower reaches of the lake during post monsoon season is congenial for the hatching and completion of larval metamorphosis, however, a steady increase of bottom salinity values from November onwards may convert these regions as inhospitable grounds for post larvae, and therefore, they are compelled to migrate to upstream regions of the lake immediately after larval completion. During 1995-96, bottom salinity in zones 1-6 varied from 5-28ppt during November to May and interestingly in zones 1-5, bottom salinity was well above 10ppt in most of months. Though the post larvae of *M.rosenbergii* can tolerate a salinity of 12-15ppt (Proper and Davison,1982), however, it is quite possible that the animals which are destined to be inhabited under such natural conditions over a prolonged period are subjected to long term stress and therefore, are characterised with retarded growth, low defense mechanism and high natural mortalities, apart from predation. The results of the present study would support the above inference as there was no perceptible improvement in the abundance of post larvae in stations 1-6 during January to May period, despite the migration of post larvae to the upstream part of the lake was interrupted due to the lowering of shutters of the Thanneermukkam barrier.

The migratory nature of the post larvae and juveniles of Palaemonid prawns from estuarine regions of India to the confluent rivers are well documented (Ibrahim, 1962; Rajyalekshmi, 1961). The available reports suggest that the larvae of *M.rosenbergii* cease their pelagic mode of life at the instance of metamorphosis in to post larval stage and settle down to the bottom as crawling or clinging to vegetation and submerged objects (Ling, 1969a). Under natural conditions, newly transformed post larvae usually remain in brackish water areas for a week and then start migrating slowly upstream into lesser saline water and as they attain more and more size, they are able to swim against swift current. The juveniles of *M.rosenbergii* are capable of climbing over bunds or dams of 2 to 3 m height, provided there is a little water dripping over the dam (Ling, 1969a). It may, therefore, be inferred that the number of post larval population assessed from the tow net collections in the study may not give realistic picture of the population density of the respective zones as their availability may be mostly associated with either the submerged objects in benthic region of the midstream or fringes and inundated areas of the lake and rivers. However, the results of the present study can be taken as an index of their abundance and availability in different parts of the lake. The mass movement of post larvae and juveniles of *M.malcolmsonii* over the first anicut in the

Godavari and their successful negotiation of the barrier to reach the upper region had been reported by Ibrahim (1962). Though the post larvae and juvenile of *M.rosenbergii* are also reported to be capable of climbing over the bunds or dams of 2 to 3 m in height (Ling, 1969a), however, no such negotiation of this species could be noticed on the Thanneermukkam barrier during the period of closure. It is interesting to note that for facilitating such negotiations by post larvae and juveniles, minimum dripping of water over the barrier is most essential. It may, therefore, be inferred that as the migratory route of post larvae of *M.rosenbergii* is interrupted by way of lowering the shutters of the barrier during December to May periods, they are also deprived of reaching the upstream part of the lake by resorting to climb over the physical structure due to the dry surface of the barrier. It would thus appear that the adverse effect of the barrier in obstructing the upward migration of post larvae and juveniles of *M.rosenbergii* can be minimized substantially by making provisions in the barrier for fish pass, weirs or even oblique pavement with the facilities for continuous dripping of water during December- May periods. This study would strongly recommends for making any one of the above provisions in the barrier as a means for the restoration of the fishery of *M.rosenbergii* and *M.idella* in the Vembanad lake.

*M. idella* is an endemic species of Kerala backwaters and it is known to be completing its entire life cycle in brackish water (Pillai and Mohamed, 1973; Pandian, 1987). It was also reported that newly hatched larvae of *M. idella* become mature and spawn within 120 days and once maturity attains the species continues to spawn at every 20 days. Furthermore, successful larval metamorphosis takes place at a salinity range of 12-18ppt (Pillai and Moham ed, 1973). These may perhaps be the reasons for the continued occurrence of post larvae of *M. idella* in downstream stations of the lake in almost all months. However, large numbers of post larvae were mainly encountered during the months of low salinity (July and September) in stations 1-3. No post larvae of this species could be collected during the present investigation from the rivers influxing to upstream part of the lake whereas only small numbers of post larvae were encountered from stations 8 and 9 which formed part of the upstream part of lake. Therefore, it appears that the post larvae of this species do not perform migration to freshwater rivers similar as seen in *M.rosenbergii*. However, a gradual shift in their preponderance from stations 3 -7 in a successive manner could be seen during July to December which would indicate the performance of short distance migrations by this species commensurating with gradual salinity increase as observed in these regions.

Fig. 6.1 Monthly variation in the abundance of Palaemonid larvae in Vembanad lake

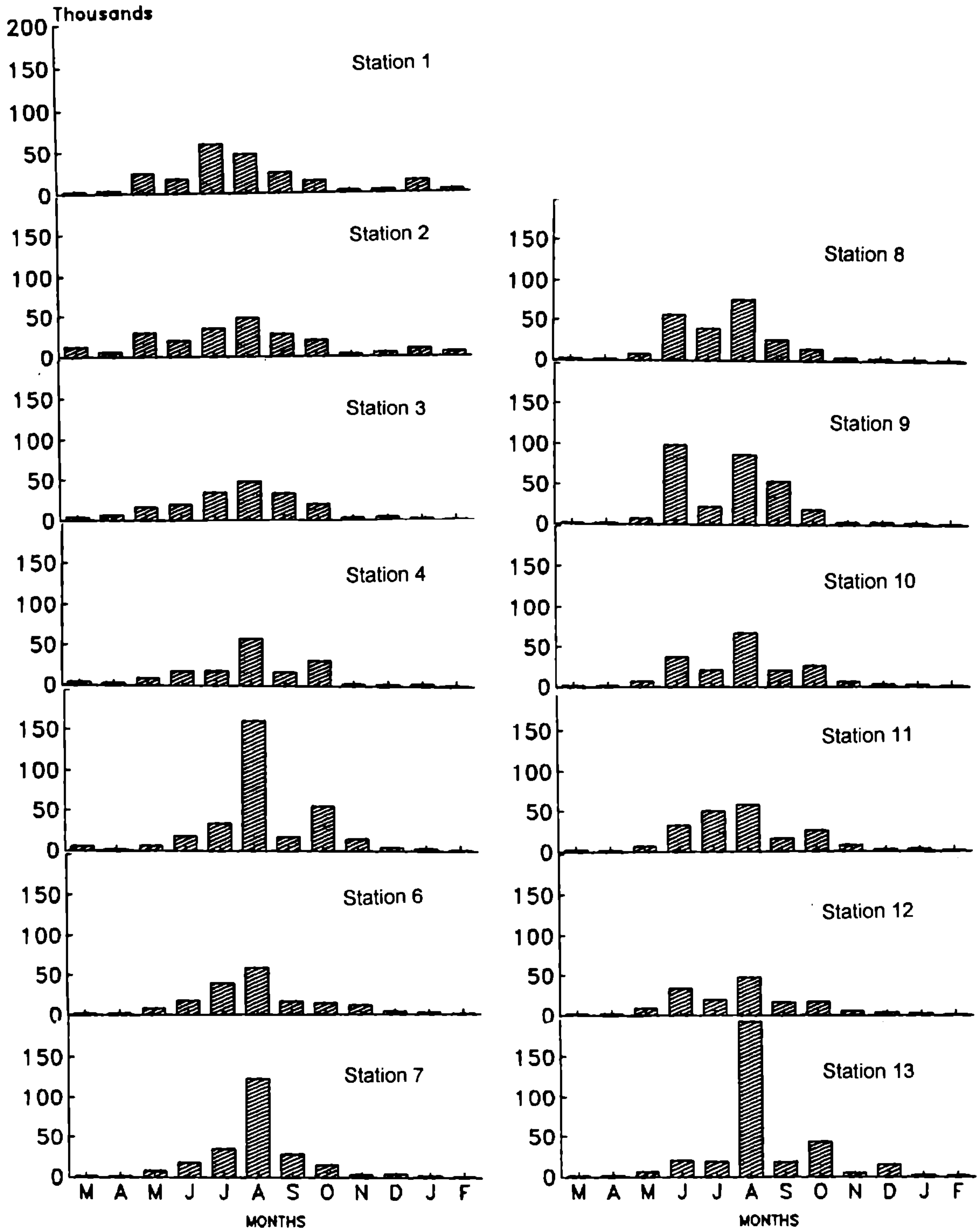
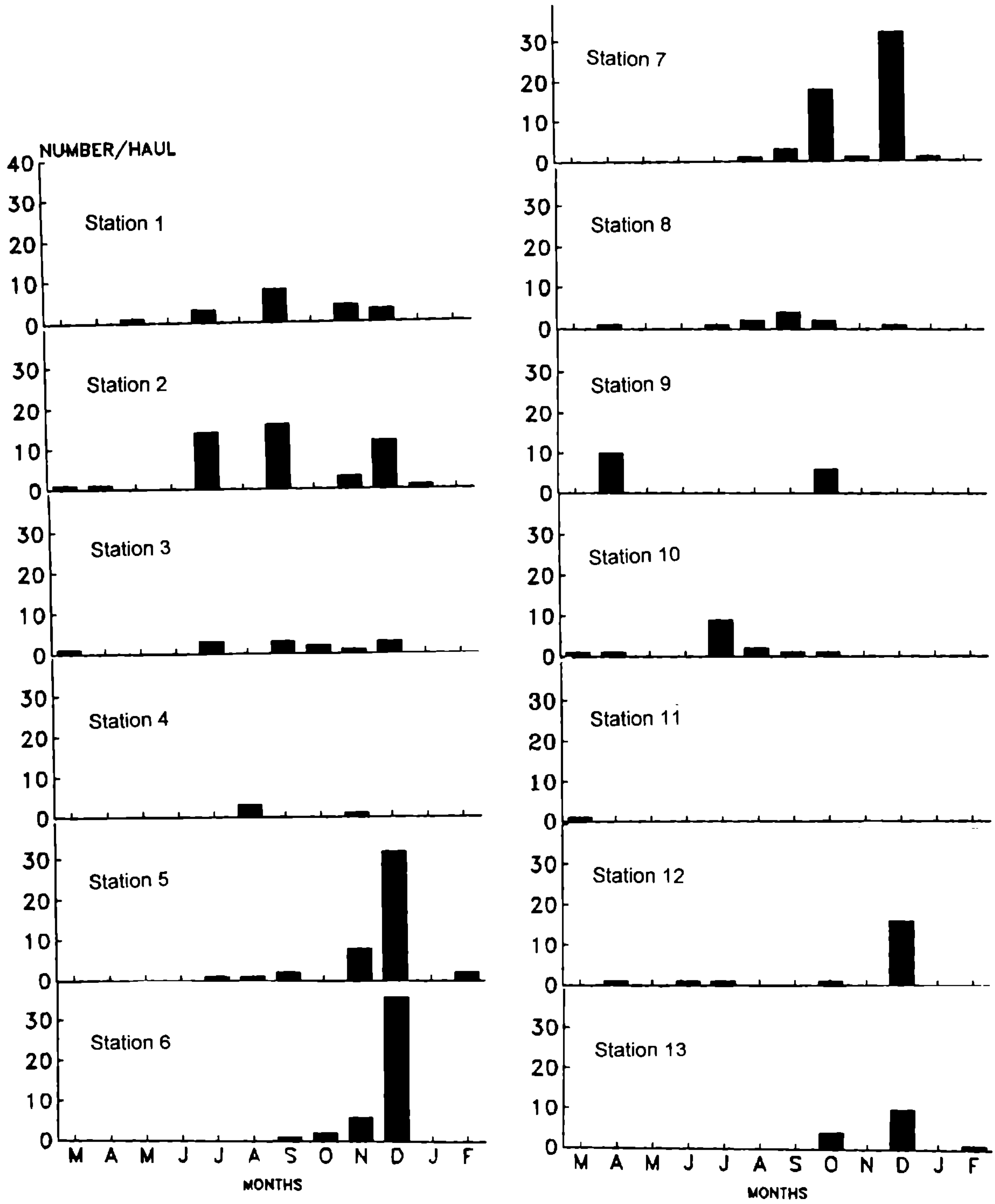
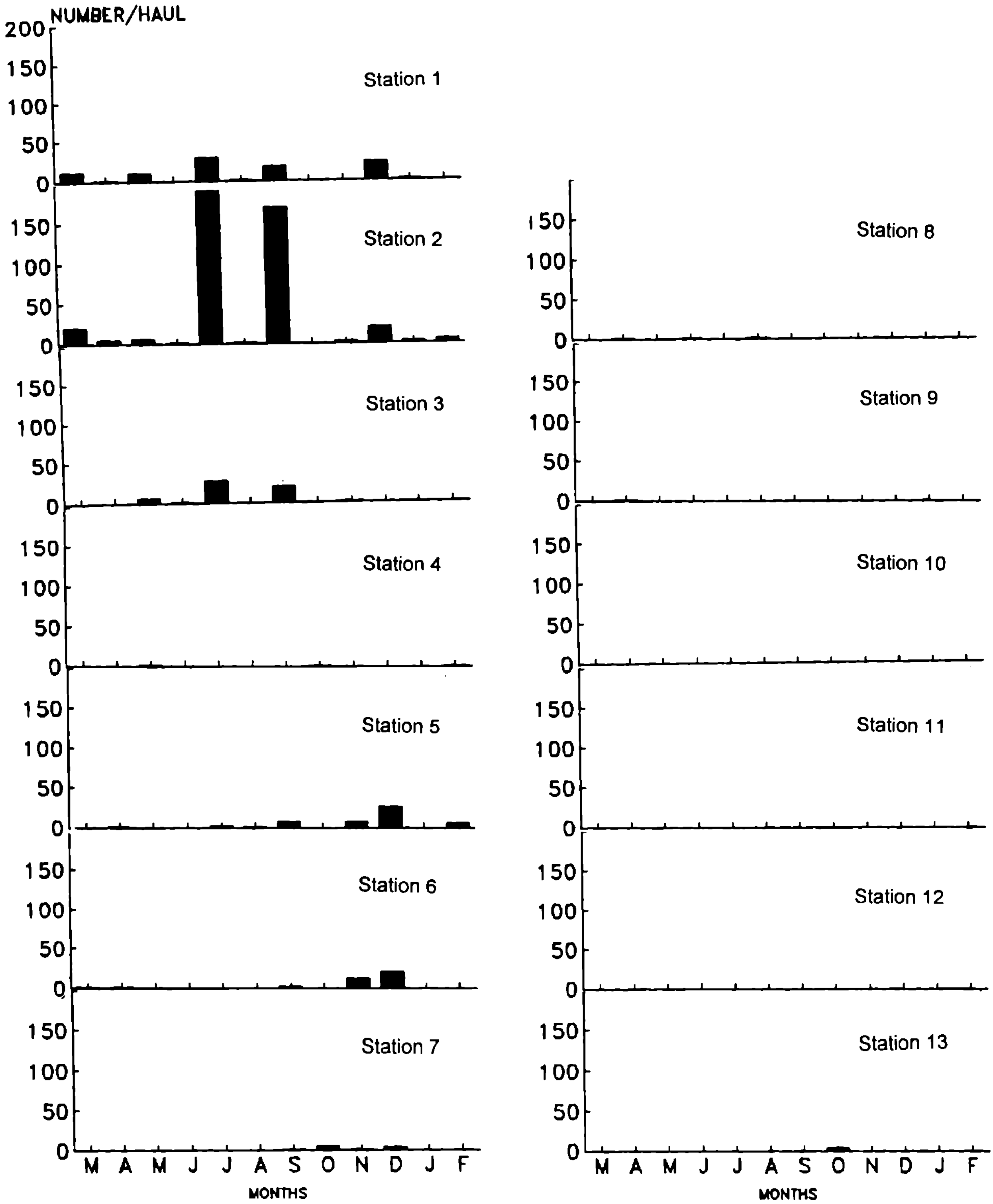

Thousands
Station 1
Station 2
Station 3
Station 4
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
200
150
100
50
0
M A M J J A S O N D J F
MONTHS

Fig. 6.2 Monthly variations in the availability of post larvae of *Macrobrachium rosenbergii* in Vembanad lake



NUMBER/HAUL
40
30
20
10
0
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F
MONTHS

Fig. 6.3 Monthly variations in the availability of post larvae of *Macrobrachium .idella* in Vembanad lake


NUMBER/HAUL
200
150
100
50
0
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
M A M J J A S O N D J F
MONTHS

# CHAPTER 7

## MARK - RELEASE - RECOVERY STUDIES IN *Macrobrachium rosenbergii* (de Man)

### 1. INTRODUCTION

Mark- recovery technique is an important tool in population studies and provides very valuable information on migration and dispersal, age and growth, rate of exploitation and population size. Essentially, this technique involves four stages such as seed production/ procuring of seed from the nature, marking, releasing and recapturing. Marking is a procedure by which an individual or groups of animals can be recognized in the population even after a certain period of time. Use of various chemicals and dyes, mutilation of body parts and use of tags are the various commonly employed methods of marking fishes and shell fishes. Marking with dyes or chemicals are usually carried out either by incorporating them in feeds, immersion or injection. Mutilation or amputation involves clipping of fins or other body parts such as maxillary bone ends or branding. A wide variety of tags have been now used in tagging method which include both internal as well as external tags. A number of methods of marking have been tested in prawns and other crustaceans, however, many of these are found unsuitable for prawns owing to the small size and frequent ecdysis of prawns which render it all the more difficult to device a suitable mark to stay back through the moultings. George (1967) reviewed exhaustively the tagging methods used in crustaceans while Neal (1969) discussed various staining methods administered through injection, feeding and immersion and also summarized external and internal tagging methods used for shrimps. Dawson (1957) first marked shrimps using stains which was subsequently modified by Costello (1959; 1964) and Costello and Allen (1961). Klima (1965) developed a method of marking shrimps by tattooing using fluorescent dyes. Ranade (1967) studied the migration of *Metapeneaus affinis* by staining with Trypan blue while Subramanyam (1967) reported marking experiments with vital dyes on *Metapeneaus monoceros* for studying the immigration and emigration of prawns in Gautami-Godavari estuary. The use of plastic tags for tagging small shrimps *Crangon vulgaris* was studied by Tiews (1967). Marullo *et al.* (1976) experimented with vinyl streamer tags for *Penaeus* spp. while Yano *et al.* (1986) investigated the effects of an internal tag on moult frequency and survival in *Penaeus vannmei*. Rao (1972b) reported mark recapture studies on penaeid prawns in Cochin backwaters using Atkin tags while 16262 penaeid prawns were tagged using loop tags from Cochin area during 1976-82 period as part of the National Tagging Programme (Anon,1982).

Rajyalekshmi (1975) studied the mark recapture techniques, durability of stains and behaviuor of marked prawn *Macrobrachium malcolmsonii* in River Godavari. A more sophisticated electronic tag has been attempted in *M. rosenbergii* by Peebles (1979) while Kuris *et al.* (1987)

reported successful tattooing of the uropods of *M. rosenbergii* with a mounted insect pin. Recently, Schmalbach *et al.* (1994) applied a new method of tagging in *M. rosenbergii*.

Consequent to the major downward shift reported in the breeding ground of *M. rosenbergii* in Vembanad lake (Kurup *et al.*, 1992a), one of the major conjectures attributed in the dwindling nature of the fishery is the obstruction caused to the upwardly migrating postlarvae due to the closure of Thanneermukkam barrier during December- May periods. In Vembanad lake, Thevara, Perumbalam and Arookkutty, regions were demarcated as the breeding ground of *M. rosenbergii* as evident from the high percentage occurrence of berried population in these zones 2-4 (Fig.1, Section I) during October- November period (Harikrishnan and Kurup, 1996a). After completion of the larval metamorphosis, the postlarvae/ juveniles will ascend by swimming against the water currents so as to reach the freshwater habitat. The upward migration of the postlarvae in to Kuttanad region especially belonging to late spawning stock of *M. rosenbergii* is reported to be synchronising with the closure of the barrier in the first week of December which may result in their entrapment in the downstream area (Kurup *et al.*,1992a). The fate of the postlarvae thus entrapped in downstream part of the lake remain unknown and this is attributed one of the factors suspected behind the alarming depletion of the stock of *M. rosenbergii* over the past two decades. The present study was undertaken with the objective of delineating the fate of postlarvae which may be destined to be trapped in the downstream part of the lake during December- March period. Besides, this study also aims at finding out the suitability of marking with dyes and tags on postlarvae of *M. rosenbergii* for mark- release- recovery studies and the data so generated would be useful in assessing the real impact of the Thanneermukkam salinity barrier in the return migration of postlarvae in to the freshwater ecosystems of Kuttanad region.

## 2.1 MATERIALS AND METHODS

Experiments on marking with biological stains were conducted under laboratory conditions during 1994-95 in order to evaluate their suitability for mark- release- recovery studies of postlarvae / juveniles of *M.rosenbergii* in the field. Two series of experiments were carried out separately by way of marking prawns by immersion and administration by injection to the body. Three stains such as Methylene blue, Trypan blue and Fast green FCF were used for immersion/ injecting postlarvae of *M. rosenbergii*. The postlarvae were procured from one of the private hatcheries of Kerala and were acclimatised in 10 litre glass tanks (30 X 30 X 1.5 cm) under laboratory conditions for a week and the animals were fed *ad libitum* with minced and cooked clam and prawn meat during the period of acclimatization. The excess feed and other wastes were removed on a daily basis and water was exchanged @50% in every alternative days. 10

prawns were used in each experiment which was conducted in duplicates and also by maintaining a control.

In the first series of experiments using immersion method of marking, three concentrations each of the above three stains were tried at the rate of 0.1%, 0.5% and 1% (Table.7.1). Postlarvae were immersed in stains at different concentrations kept in 500ml beakers for three minutes and were then immediately released to the glass tanks having 10 litre of aerated water. The animals so kept were observed everyday and the retention of the stain was assessed based on visual and microscopic observations.

The second series of experiments were carried out by resorting to injection method using a 1 ml hypodermic syringe and a needle (no.26). Three different concentration of above stains such as 0.5%, 1% and 2% were prepared using Methylene blue, Trypan blue and Fast green FCF. 0.5ml of the solution so prepared was injected at the dorso-lateral musculature of second abdominal segment of the postlarvae. The injected animals were transferred immediately to aerated water kept in a glass tank under ambient temperatures and daily observations were made in regard to retention of stain in vital parts of the body.

Postlarvae of *M.rosenbergii* were obtained from a private hatchery of Kerala and raised to juveniles in cement cisterns. Tagging of postlarvae/ juveniles was carried out following Schmalbach (1994). A nylon monofilament of 0.25mm diameter carrying a blue coloured small plastic piece at one end is inserted through a hypodermic needle (no.26). The needle is inserted anterior to first abdominal segment passing from dorso posterior cephalothorax to the latero-thoracic abdominal area and terminating between 4th and 5th walking legs. A loop is made on the monofilament after withdrawing the needle ( Plate 8A). The tagged specimens ( Plate 8B) were immediately transferred in to well aerated water kept in glass tanks and the animals were closely observed for a period of six hours. Tagged postlarvae showed signs of irritation and subjected to high mortality. Moreover, the size of the loops of monofilament around the body of postlarvae kept sufficiently large in anticipation of increase in body size, in order to avoid any inconvenience for the animals for its free movements. Tagging could successfully be carried out only on juveniles of sizes above 40mm TL. In advanced postlarvae, mutilation by removing left eye by cutting at the eye peduncle at its base was adopted as a method of marking. The postlarvae and juveniles thus marked by mutilation and tagging were acclimatised in aerated water containing antibiotics for 2-3 days and subsequently got released from Pallipuram, in the downstream part of the lake approximately 10 Km down from the salinity barrier.

## 3. RESULTS

### 3.1 Marking experiments with biological stains

The details of experiments conducted following immersion method and administration of injection, number of retention days observed and percentage of survival are shown in Table 7.1. In the first set of experiments by immersion method, survival up to 7 days could be observed in all treatments except for Fast green FCF and Methylene blue at 1% level. It appeared that the retention period in regard to experiments on immersion at 0.1 and 0.5% levels was very insignificant wherein the stains accumulated in the branchial region started fading from second day onwards. However, the retention period appeared to be prolonged up to 4 days in Methylene blue and 7 days in Fast green FCF when these stains were used at 1% level.

Retention period of stain up to 14 days could be observed in injection method, however, only 30% survival of postlarvae could be noticed when Fast green FCF was administered at 1% level. In Trypan Blue and Methylene Blue, a retention period of 7 days could be observed when these stains were administered at 1% level, however, the percentage survival was only 20% in the latter against 60% in the former. The animals injected with 2% solution showed signs of irritation and did not survive. Among the three stains studied, the retention power of Fast green FCF at 1% level was highest (14 days), in contrast, the minimum was noticed in respect of Trypan blue at 0.5% level (3 days) (Table 7.1.).

3.2 Mark- release- recovery studies

40,000 postlarvae and 10,000 juveniles were marked and were released in 6 batches during January-

February 1996 at Pallipuram (zone 6), approximately 10km down from Thanneermukkam salinity barrier (Fig.7.1) (Plates 9A and 9B). The marked post larvae showed 14.3% mortality between tagging and release while the same in juveniles was 6.8%. The tagging programme was given wide publicity using different media, such as press release in important dailies, distribution of pamphlets, etc. Moreover, such pamphlets were also displayed at major landing centres and markets located at the vicinity of the lake and adjoining rivers of all the zones (Fig.7.1). Awareness among the fishermen of the lake was also created by distributing pamphlets directly to them in the fishing ground itself and better incentive was also offered while returning the recovered specimens. In order to ensure steady recovery of the tagged specimens, half filled containers with 5% formaldehyde were kept in tea shops situated at important fish landing centres and in fish stalls of major landing centres proximal to the lake.

214 eye mutilated and 8 tagged prawns could only be recovered during August 96 to June 1997 period which worked out to be a retrieval percentage of respectively 0.53 and 0.08. The place of retrieval of tagged specimens are shown in Fig.7.1. All the eight tagged prawns were recovered from zones 7 and 8 during the months of August- October. Among the recovered prawns, those marked by eye mutilation showed clear healing marks at one eye stalk and the size ranged from 125 to 205 mm in TL while retrieved tagged specimens were in the size range of

187 mm to 225 mm. On examining the length frequencies of recovered prawns from the lake, it was observed that 58% of total specimens belonged to 140-160mm length group (Fig.7.2).

## 4. DISCUSSION

Rajyalakshmi *et al*. (1968) found that injection of Trypan blue at a concentration of 1% gave retention up to 77 days in *M. malcolmsonii* in River Godavari while Trypan blue was found as the most suitable biological stain showing retention up to 30 days in marking *Metapenaeus affinis* (Ranade, 1967). Similarly, Subra manyam (1967) reported a maximum retention of 55 days in using Trypan blue in *Metapenaeus monoceros* by injection method. However, maximum retention of Trypan blue observed at 1% level during the present study was only 7 days in marking *M. rosenbergii* and this in comparison with the earlier workers is on a very lower side. In the present study, largest retention time was observed in Fast green FCF, giving retention of 14 days on administering at 1% level while for all other dyes tried, the period of retention was less than 8 days.

The release of marked prawns were undertaken in the months of January- February during when practically no fishery for *M. rosenbergii* was prevalent in Vembanad lake and this period also synchronized with the the closure period of the barrier, therefore, the recovery of tagged specimens were expected with the commencement of fishing season by June, after a lapse of 4-6 months. Results of laboratory experiments revealed that marking of *M. rosenbergii* with biological stains is unsuitable for undertaking mark- recovery studies in Vembanad lake in view of their poor period of retention. Besides, in *M. rosenbergii*, the translucent body nature of postlarvae will be lost as the animal grows and therefore, the adoption of tagging method, is justifiable on account of the short retention period of stains as observed and difficulties encountered in easy identification of the stain markings on the branchiae of larger prawns.

The percentage recovery of mutilated and tagged prawns during the present study were very low (0.53% and 0.08% respectively). However, Rao (1972b) recorded only a percentage recovery of 0.3% in Penaeids in Cochin back waters. On the contrary, mark recapture studies on penaeid prawns as part of National Tagging Programme could be recorded a retrieval of 0.86% (Anon, 1982). The low percentage recovery encountered from the upstream part of the lake in the present study would manifest the possibility of negotiating the bund only by a very insignificant portion of the tagged postlarvae / juveniles which were released from the downstream part of the lake during the closure period of the barrier. The bund was closed by 10th December 96 and the shutters were lifted up only by 14th April 96. It is quite possible that the recovery of the tagged specimens from the upstream part of the lake could be encountered due to their negotiation through the locking system during when it is operated for facilitating the water transport. The low percentage recovery recorded in the present study may be due to the physical obstruction caused to the upwardly migrating tagged juveniles and postlarvae due to the closure of the barrier. Therefore, this finding would strongly indicate the possibility of adverse effect of the barrier in the regeneration of the stock of *M. rosenbergii* in Vembanad lake as reported earlier (Kurup *et al.*,1992a) and strongly corroborates with the view that the upstream migration of postlarvae is being significantly hampered by the physical obstruction imposed by the bund. The postlarvae thus trapped in downstream areas can either be migrated into Muvattupuzha river or subjected to high mortality due to the unfavourable environmental conditions prevalent in the downstream part of the lake as well as predation. However, in the present study, no marked prawns could be recovered from Muvattupuzha river and therefore, the chance of bypass migration may also be ruled out. During the closure period of the barrier, surface and bottom water temperatures in the downstream part of the lake show an increasing trend registering a maximum of $31.5^{0}$c whereas salinity varies from 10-28ppt. It is known that *M. rosenbergii* is a highly euryhaline species capable of tolerating wide changes in salinity (Panikker, 1967). However, Venugopal and Thampy (1992a) have found that though some juveniles are capable of tolerating a salinity up to 35 ppt on gradual acclimation, generally salinities above 26.5ppt causes mortality of juveniles. Salinity values recorded from the zones north of Thannermukkam (zones 5 and 6) was in the range of 14-28ppt during January to May. However, juveniles exposed to high saline conditions will be under severe stressed condition as their various body metabolic processes are likely to be adversely affected which would result in growth retardation, reduction in body immunity and these would eventually lead to high mortality. Moreover, during January to May period, there is very strong immigration of many carnivorous fishes into the lake from adjoining sea (Kurup and Samuel, 1985) and therefore, chances of predation on juveniles of prawns may also be high. This inference is further supported by the fact that the fishing of *M.rosenbergii* in the downstream part is not supported by the tagged specimens in the ensuing season.

Table.7.1. Details of experimental protocols of marking of *Macrobrachium rosenbergii* using biological stains by immersion and injection method

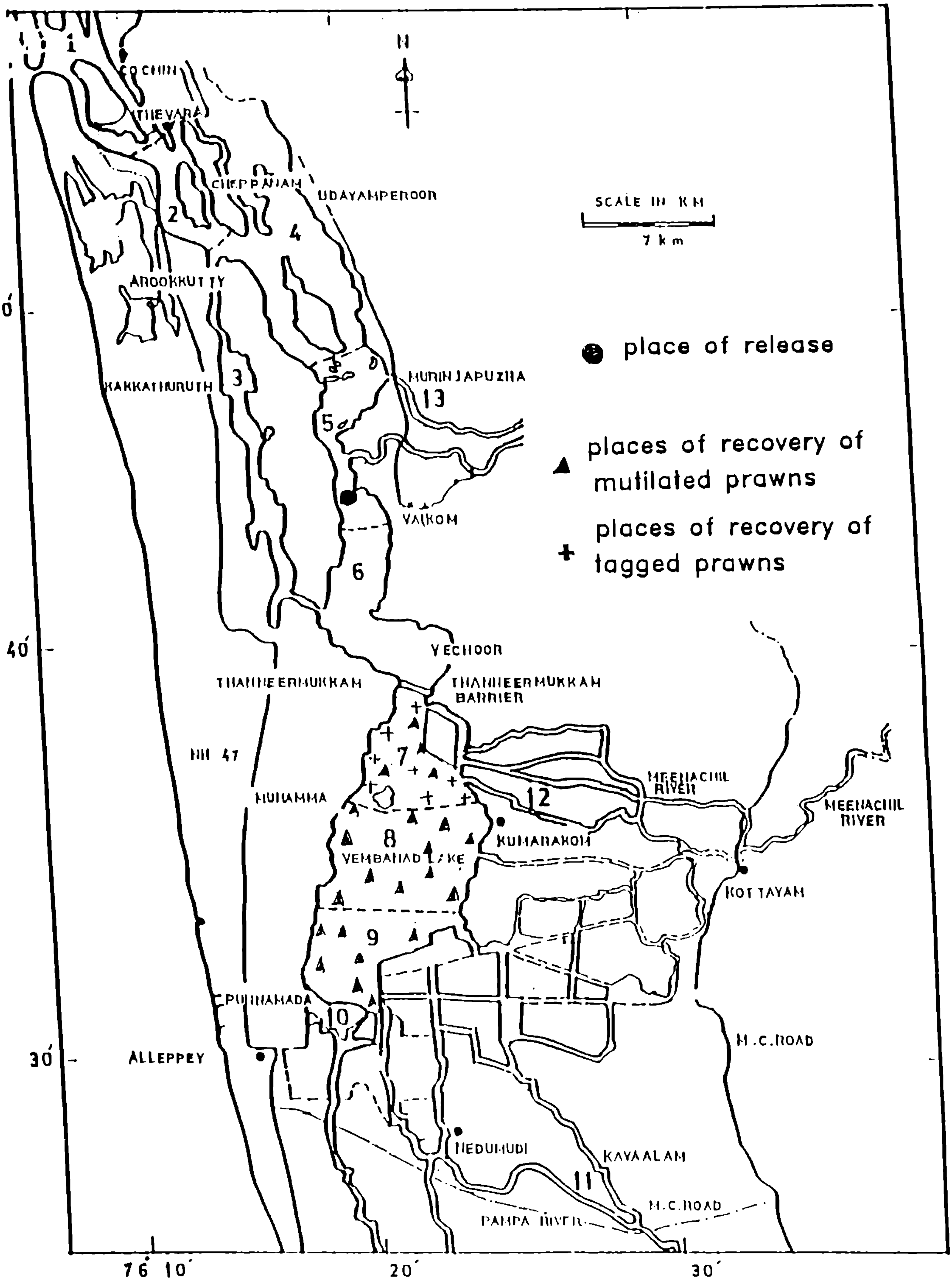
SERIES 1 IMMERSION METHOD

| Experiment no (1) | Stain (2) | Concentration (percentage) (3) | Retention (days) (4) | Survival after retention days given in colum (4) (Percentage) (5) |
|---|---|---|---|---|
| Control | --- | --- | --- | 100 |
| Experiment 1 | Trypan blue | 0.1 | 1 | 100 |
| Experiment 2 | Fast green FCF | 0.1 | 1 | 100 |
| Experiment 3 | Methylene blue | 0.1 | 1 | 100 |
| Experiment 4 | Trypan blue | 0.5 | 1 | 100 |
| Experiment 5 | Fast green FCF | 0.5 | 2 | 100 |
| Experiment 6 | Methylene blue | 0.5 | 1 | 100 |
| Experiment 7 | Trypan blue | 1 | 2 | 100 |
| Experiment 8 | Fast green FCF | 1 | 7 | 80 |
| Experiment 9 | Methylene blue | 1 | 4 | 50 |

SERIES 2 INJECTION METHOD

| Experiment no | Stain | Concentration (percentage) | Retention (days) | Survival after retention days given in colum (4) (Percentage) |
|---|---|---|---|---|
| Control | --- | --- | --- | 100 |
| Experiment 1 | Trypan blue | 0.5 | 3 | 70 |
| Experiment 2 | Fast green FCF | 0.5 | 6 | 50 |
| Experiment 3 | Methylene blue | 0.5 | 4 | 40 |
| Experiment 4 | Trypan blue | 1 | 7 | 60 |
| Experiment 5 | Fast green FCF | 1 | 14 | 30 |
| Experiment 6 | Methylene blue | 1 | 7 | 20 |
| Experiment 7 | Trypan blue | 2 | -- | 0 |
| Experiment 8 | Fast green FCF | 2 | -- | 0 |
| Experiment 9 | Methylene blue | 2 | -- | 0 |

Fig. 7.1 Figure showing locations of release of marked *Macrobrachium rosenbergii* in Vembanad lake and places of its recovery



COCHIN
THEVARA
CHEPPANAM
UDAYAMPEROOR
AROOKKUTTY
KAKKATHURUTH
MURINJAPUZHA
VAIKOM
VECHOOR
THANNEERMUKKAM
THANNEERMUKKAM BARRIER
NH 47
MUHAMMA
MEENACHIL RIVER
KUMARAKOM
VEMBANAD LAKE
KOTTAYAM
PUNNAMADA
ALLEPPEY
M.C.ROAD
NEDUMUDI
KAYAALAM
PAMPA RIVER
SCALE IN KM
7 km
N
place of release
places of recovery of mutilated prawns
places of recovery of tagged prawns
50'
40'
30'
76 10'
20'
30'

Fig. 7.2 Length-frequency distribution of marked and recaptured *Macrobrachium rosenbergii*

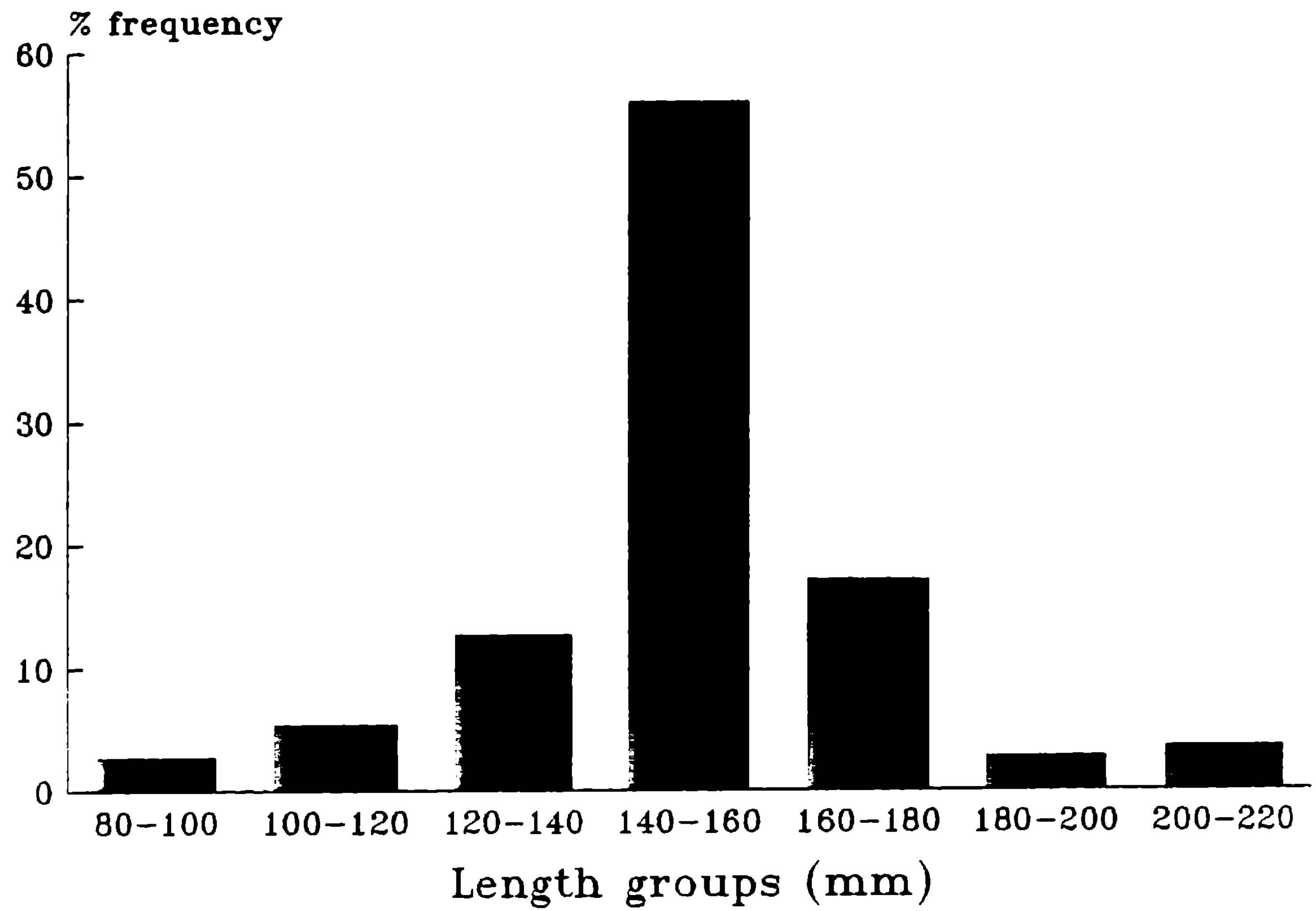

% frequency
60
50
40
30
20
10
0
80–100
100–120
120–140
140–160
160–180
180–200
200–220
Length groups (mm)

**PLATE 8.** ***Macrobrachium rosenbergii*** **(de Man) juveniles**

A. **Tagging procedure using nylon monofilament and plastic tag**

B. **Tagged specimen**

**PLATE 8**


PLATE 9.*Macrobrachium rosenbergii* **(de Man)**

A. **Transportation of marked postlarvae and juveniles for release**

B. **Release of marked prawns at Pallipuram, Vembanad lake**

**PLATE 9**

A

B

# Section 5

# Fishery and Population Dynamics

# CHAPTER 8

# FISHERY OF *Macrobrachium rosenbergii* (de Man) AND *M. idella* (Hilgendorf)

## 1. INTRODUCTION

The freshwater prawns of the genus *Macrobrachium* occupy an important position in the export trade owing to their demand and high market value. The annual landing of freshwater prawns from India is estimated to be around 20,000 tonnes (Thripathi, 1992), however, in recent years the capture fishery of this group showed a declining trend from most of the inland water bodies. Therefore, periodic assessment of the stock size from different aquatic systems is inevitable for proper planning and development of these resources. *Macrobrachium* spp. occur over a wide range of environmental conditions, ranging from estuaries to freshwater lotic and lentic conditions. Commercial capture fisheries exist for individual species in some of the south east Asian countries. More than 40 species were listed under the genus *Macrobrachium* from Indian waters, of which 15 are known to be constituting commercial fisheries (Jayachandran and Joseph, 1992). The giant freshwater prawn *M. rosenbergii* is the most commercially important freshwater species of Indian rivers. The fishery of this species had not gained much significance in Kerala until 1953 when the freezing and packing industry were established at Cochin essentially for the purpose of exporting prawns as a foreign exchange earning commodity. In recent years, it emerged as the prime species in the shrimp packing industry of the state in view of its large size and esteem price it fetches in the international markets.

A detailed survey on the distribution and abundance of Palaemonid prawns of the major rivers, estuaries and lakes of Kerala was conducted by Jayachandran and Joseph (1989a) and of the ten species recorded, *M. rosenbergii* and *M. idella* were reported to be very common in most of the rivers and estuaries of Kerala and constitute commercial level fishery of varying magnitude. According to the authors, *M. idella* is one of two widely distributed species, in almost all inland water bodies from south to north, even in freshwater lakes, however, its good fishery could be recorded only in the estuaries and backwaters of Kerala. On the other hand *M. rosenbergii* evinces very peculiar regional distribution pattern in Kerala by showing a moderate level of fishery in the middle and northern regions of Kerala, in contrast, it is almost absent in southern Kerala (Jayachandran and Joseph, 1989a).

The *Macrobrachium* fishery is a growing industry in the Indo-Pacific region. The fishery resource of *Macrobrachium* spp. with particular reference to that of the giant freshwater prawn *M. rosenbergii* in some Philippine river system was reported by Natividad (1982) while Taw (1983) made a brief account on the fishery of the species in the Irrawaddy delta and associated river systems in Burma. Jinadasa (1985) studied the fishery and biology of *M. rosenbergii* in northern Bolgoda lake, Sri Lanka while

Wanninayake and Costa (1987) made an attempt to assess the magnitude of fishery of this species in Sri Lanka where it supports only on a subsistence level. No concerted attempt has been made so far to quantify the exploited fishery of *Macrobrachium* spp. from different water bodies of the country. Available information on fishery shows that in Ganga river system *M.malcolmsonii* is the predominant freshwater prawn species while in Brahmaputra, Palaemonids contribute to 4-12.05% of the total landings (Thripathi, 1992) whereas in Godavari river, the freshwater prawn fishery is constituted by only one species *viz M. malcolmsonii* which contributes an average of 85 tonnes/ annum forming 32.3% of the total yield. In Kolleru lake, the annual freshwater prawn yield has been estimated to be 143 t and 80 t during 1978-79 and 1979-80 respectively and *M. rosenbergii* and *M. malcolmsonii* contributed to more than 85% of the prawn landings of the lake (Rao, 1992). Species wise stock assessment, landing pattern, size frequency distribution, sex ratio and percentage of berried females in the commercial catches of *Macrobrachium* spp. of river Ganga were studied by Prakash (1989). Fishery and biology of *M. malcolmsonii* of the river Godavari was observed by Ibrahim (1962). Raman (1967) reported that the annual landings of *M. rosenbergii* in the central Kerala rivers varies from 189 t (1962) to 429 t (1960) while Kurup *et al.* (1993) reported that palaemonid prawns contributed to 1.63% of the total exploited fishery resource of the Vembanad lake with a total landings of 117.69 t, constituted by three species viz., *M.*

*rosenbergii*, *M. idella* and *M.scabriculum* with an annual landings in the order of 39.79, 71.45 and 6.78 tonnes respectively. Some of the interesting fishing methods of *M. rosenbergii* in Kerala have been described by Raman (1975) whereas Harikrishnan and Kurup (1997d) have given an account of fishing methods and gear wise intensity of fishing of the giant freshwater prawn in Vembanad lake. Temporal and spatial variations in the intensity of exploitation of berried females from the Vembanad lake and the major gears involved were also reported by Harikrishnan and Kurup (1997b). Monitoring of the stock of *Macrobrachium* spp. of the Vembanad lake is found inevitable from time to time in order to formulate policies for management and exploitation of these species in view of the dwindling nature of the fishery due to ecological transformations brought about by way of constructing barrages, perils from pollution, reclamation of part of the lake for agriculture and other purposes and also due to the severe fishing pressures exerted on the stock. Therefore, in the present study, an attempt was made to quantify the exploited stock and delineating the resource characteristics of two commercially important species of Vembanad lake viz., *M. rosenbergii* and *M. idella*.

## 2. MATERIALS AND METHODS

The quantification of the exploited stock of *M. rosenbergii* and *M. idella* have been made based on the observed catch from the specific and non specific gears and fishing methods operated in the Vembanad lake and confluent rivers coming under the purview of this study. The Vembanad lake was apportioned into ten zones while each of 5km stretch of adjoining rivers influxing into the lake proper viz. Muvattupuzha, Meenachil, Pampa, Achencoil and Manimala were treated as three separate zones (Fig.1, Section 1). The catch was observed from various gears and fishing methods (Harikrishnan and Kurup, 1997d) on a monthly basis during the fishery survey cruises undertaken in the lake and riverine regions from March 1994 to February 1996 with the help of M.B.KING FISHER of the School of Industrial Fisheries (for details of the fishery survey cruises, refer 1.4). In each zone, the prevailing fishing activity of *M. rosenbergii* and *M. idella* were observed for a period of 24 hours continuously (day and night). The gear details such as length, mesh size, twine size, etc. were also registered. Total number of each category of fishing gears and methods in operation were enumerated and the catches of the two species were examined in detail from not less than 30% of each type of gear, giving due emphasis to species wise number and weight of male and female, length composition, sex ratio, etc,. Sexes were differentiated with the help of external manifestations and other secondary sexual characteristics as described by New and Singholka (1985). The fishing hours of the observed catch and the total hours spent for fishing in the ground were also recorded. Daily landings from each category of gears and methods were computed by applying the formula (Kurup *et al.*, 1992a)

$$W = \frac{w}{n} \times N$$

where

W = total weight of *M. rosenbergii* in each zone

w = total weight of *M.rosenbergii* recorded from the gear sampled.

n = number of gears sampled.

N = total number of similar gears engaged in fishing.

Monthly catch was then estimated by multiplying the daily catch with the total number of fishing days of each zone.

# 4. RESULTS

## 3.1 *Macrobrachium rosenbergii*

### 3.1.1. Fishing gears and methods

**(i) Selective gears and fishing methods**

ia) Cast net operations

a) Pongu Veechal:- (**Plate 10A**)

This was appeared as the most common selective fishing method used for the commercial exploitation of *M.rosenbergii* of Vembanad lake. During February to May, this method was restricted in upstream part of the lake especially zones 8, 9 and 10 while from June onwards the operation of this gear could be seen in downstream region also. In this method, baits such as pieces of coconut kernal or boiled tapioca were tied to one end of a long line and pieces of banana stem, thermocol or empty plastic bottles, known as 'Pongu' which serve as floats for demarcating the position of the baits were attached on the other end of the line. Usually a fisherman uses 10-20 such baits. At the instance of biting or holding the bait by *M.rosenbergii*, the float will move and at this time the fisherman casts his net over the bait. Nets used are made of nylon twine (no.0.5 to 1) and mesh sizes usually vary between 22- 36mm. Pongu Veechal has been carried out during both day and night. Night operations in the lake and rivers with the help of petromax lamps accommodated in the canoe were most common especially during June to November in the upstream part of the lake.

b) Koti Kuthi Veechal:- (Plate.10B)

This method is prevalent in upstream areas (zones 8, 9, 10, 11 and 12), mostly from April to October. Baits such as coconut oil cake or boiled and ground tapioca were broadcasted at fixed positions in the lake or rivers at definite intervals and these spots were demarcated by erecting long poles called "Kotis". This is followed by casting net at the vicinity of sites where bait materials are broadcasted near the kotis. Usually a fishing unit consists of two fishermen and operates 15-20 kotis at a stretch (locally called a "nada"). Fishing was carried out mostly during early morning hours or at night during when four to six "nada" were operated. Nets made up of of nylon twine (no 0.5 to 1) and having a mesh size of 18-28mm were employed in this method.

c) Thady Veechal:- (Fig.8.1)

This method was observed exclusively at the north-west end of Perumbalam island (zone 4) of the lake where the lake is relatively shallow and barely influenced by strong currents. About ten units were found engaged in Thady Veechal during July- August to mid November. In this method, pits of about 15-20" diameter and 4-6" depth were dug at the lake bottom wherein a small twig having two or three baits such as pieces of dressed tapioca or coconut kernal was kept fixed. A large coconut tree chunk of approximately 1m length was placed above each pit and its position was demarcated by way of erecting poles (Kotis) which will be visible above water level (Fig.8.1). Usually forty to sixty such pits belonged to one fishing unit. Fishing was usually carried out during low tide and intertidal periods, invariably in the morning hours. Castnets used in this method were usually having a length of 3m with a mesh size of 36-38mm and made up of no.1 nylon twine and a canoe of size 4m OAL was operated with the help of two fishermen. After casting the net over each pit, one of the crew dives into water and scares the sheltered prawns inside the pit to come out and simultaneously releases the entangled net from coconut chunk and returns to the canoe. Thereafter, the net is hauled up obliquely. The catch from 40-60 pits so operated will be around 3-6Kg/day.

ib). Indigenous fishing methods

a) Ottal:- (Plate 11A)

This is a semi-spheroid fishing contrivance having both ends open and made of closely held splinters of bamboo. It is mainly operated in shallow fringes of upstream parts of the lake (zones 8 and 9) during January to May and inside the polders during June- October. Method of operation resembles that of Pongu Veechal except that cast net was replaced by this indigenous gear.

b) Spears:-(Plate 11B)

Trident spears locally called "Muppalli" were widely employed in the fishing of *M. rosenbergii* during June to November period in upstream and riverine areas (zones 8-12). Iron tridents having a length of 15-20cm and fixed on a long wooden pole were usually used along the fringes of lake and rivers during night hours. Coconut oil cake and rice bran were made into balls and broadcasted at definite locations as baits. Prawns preying on the baits were located with the help of light emitted from hand torches and were skillfully caught using the spears.

c) Padal:- (Plate 11C)

This is an indigenous method of catching Palaemonid prawns which are taking shelter in the artificial reef made up of small twigs of shrubs or trees. This method is extensively operated in downstream part of the lake (zones 2,3,4,5 and 6) mostly during June to November. The bunches of twigs were held together with ropes and were placed at shallow banks of the lake for two to three days. Fishing was carried out at low tides mostly during morning hours. A platform made of small meshed webbing was inserted beneath the padal and the same was dragged ashore with the padal. Alternatively, in 'Veeshu padal' the cast net was operated on the submerged Padal and the whole unit will be lifted to the shore and this method will take care in prevent the prawns from escaping during the operation of Padal.

**ii) Non- Selective gears and methods**

The non selective gears used for the fishery of *M. rosenbergii* include Stakenets ("Oonni vala"), Chinese nets ("Kampa vala"), gill nets ("Neettu vala") and hand lines ("Choonda") and Seines (Vattavala and Thappuvala). The details regarding these gears and methods were given by Kurup and Samuel (1985) and Kurian and Sebastian (1982). All these gears were found extensively operated in downstream part of the lake and *M. rosenbergii* forms a sizeable quantity landed from these gears during September to Janaury. Significant landings of berried females of *M. rosenbergii* could be observed from Neettuvala during October - November months in zones 2- 4. Similarly, moderate numbers of *M. rosenbergii* were also caught by Hand lines in zones 4 and 5 during September to November.

### 3.1.2. Quantification of the exploited stock:

The exploited stock of *M. rosenbergii* from the Vembanad lake and confluent zones of the rivers during March 94 to February 95 was quantified as 112.85 tonnes while in March 95 to February 96, the same was computed at 129.44 tonnes (Fig.8.2). The riverine zones (10, 11, 12 & 13) contributed to 30.2% of the total exploited stock while the share of upper reaches of the lake (zones 7, 8 & 9) was 34.39% whereas 35.39 % of the total catch was registered from the downstream regions of the lake (zones 1-6) during 1994-95 (Fig.8.3). In 1995-96 periods, contributions from the riverine, upper and lower reaches of the lake were in the order of 30.42, 32.27 and 37.31% respectively. The average annual yield / ha of the study area was computed at 4.94Kg/ha in 1994-95 against 5.71 Kg/ha in 1995-96. The riverine regions appeared to be the most productive areas with a production of 54.91Kg/ha in 94-95 and 61.68Kg/ha in 95-96 while in downstream part of the lake, the production was in the order of 20.94 and 24.85Kg/ha in 94-95 and 95-96 respectively whereas the least production could be noticed in the upstream part of the lake which worked out to be 14.73Kg/ha in 94-95 and 16.43Kg/ha in 95-96 (Fig.8.4).

#### i) Month wise landings

Month wise landings of *M. rosenbergii* during 1994-95 and 1995-96 are depicted in Fig.8.2. In 1994-95, the fishery got intensified from July onwards and continued up to December and highest landings could be registered in the month of October, followed by September. On the contrary, in 1995-96 the onset of fishery could be observed somewhat earlier from May onwards and continued up to December with peak landing in the month of September followed by October. The peak fishery in the former year was observed during July to November while in the latter year the same could be noticed during June to November. In both the years, the fishery appeared to be very bleak during January to April.

In 1994-95 and 95-96, the fishery during March- May was exclusively contributed by males while in June and July, though the predominance of male continued in the catches, the appearance of females in stray numbers in the landings was noteworthy. Interestingly, in August, the contribution of male and female in the landing appeared almost in equal proportions while during September to November the major share of the landing was obviously represented by females. Interestingly, in December, the entire catch was exclusively comprised of females alone.

### ii) Zone wise landings

The annual zone-wise distribution of exploited stock of *M. rosenbergii* during 1994-95 and 1995-96 are presented in Fig.8.3. The highest contribution in both 94-95 and 95-96 could be recorded from zone 9 followed by zone 8 in 94-95 and zone 11 in 95-96. In both the years, the production pattern from different zones have shown more or less similar trends, showing a moderate production in zones 2 -4 which was succeeded by a less productive area coming under zones 5-7, thereafter, the magnitude of fishery got intensified in zones 8-11 and further a sizeable decline in the production could be discernible in zones 12 and 13. The annual yield/ha from the 13 zones are shown in Fig.8.4. During 1994-95 zone 10 appeared to be the most productive area ( 19.75 Kg/ ha/ year) while in 95-96 highest production could be registered from zone 11 (18.04 Kg/ha). Zones 6 and 7 were the least productive regions (2.19 Kg/ha and 2.06 Kg/ha in 94-95 and 1.37 Kg/ha and 3.15 Kg/ha in 95-96 respectively) of the study area. The difference observed in the production per hectare was very remarkable between zones 10-13 and 5-7. The rate of diminishment was very glaring from zone 10 to 6, the latter showing only less than one-tenth production of former, however, zones 2-4 were appeared as comparatively more productive among the downstream zones. While examining the percentage contribution of male and female in the exploited stock quantified from different zones of the lake (Fig.8.3), it could be seen that in zones 8-11 which represent the upper reaches of the lake and confluent parts of the river Pampa, the male dominated in the catches in contrast to the preponderance of female in the zones 2-7 which are situated in the downstream part of the lake.

The pattern of fishery prevalent in zones 1-13 during 94 March to 96 February are shown in Fig.8.5. It could be seen that in zones 10 and 11 which formed the parts of river Pampa, the appearance of fishery could be noticed from March and continued till November with intense fishing activity during May- October in the former while in the latter, the fishing intensity was moderate during June to August and the peak period of the fishery could be registered in September-October months. Zone 12 which forms the confluent part of the Meenachil river, very low level fishery could be observed during August to October while in Zone 13 which forms the confluent portion of river Muvattupuzha, only poor catches could be observed during the latter half of the year. Zones 8 and 9 could be demarcated as the regions of the lake where *M. rosenbergii* supported a perennial fishery and the landings from these zones appeared to be very good during June to October. Though the appearance of the stock could be discernible in zone 7 during April to December, however, the contribution was less than one tonnes in most of the months except in September and October. Among the various zones of the downstream regions of the lake, the catch remained lowest during June to December barring October in zones 5 and 6. On the contrary, in zones 3, 4 and 5 the magnitude of fishery was relatively high during June to November with peak landing during October - November in zones 3 and 5 and August to October in zone 3. In zone 2, the appearance of fishery could be encountered from July onwards and lasted till January and landings were invariably high during October-November while in zone 1 only very stray catches could be observed in the month of September during the period of investigation (Fig.8.5).

iii). Gear wise landings

Percentage exploitation of *M. rosenbergii* from various fishing gears and methods during 1994-95 and 1995-96 are depicted in Fig.8.6. Among the three types of cast net operated, in 1994-95, Pongu veechal accounted for 71.28% of the total exploited quantity against 73.97% in 1995-96 whereas Koti kuthi veechal and Thady veechal contributed to 5.22 and 2.13% respectively in 94-95 in contrast to 3.67 and 2.93% registered in 1995-96. Stake net accounted for 6.47% in 94-95 against 8.01% registered in 95-96 while the contribution of Chinese dip net was in the order of 2.97 and 1.83% respectively in 94-95 and 95-96. The contribution of gill net was relatively higher (4.94%) in 94-95 when compared to 95-96 during when it accounted only for 2.46% and similar trend could be seen in regard to hook and line operations. The contribution by other indigenous fishing methods such as Ottal, Padal and Spear worked out to be 4.8% in 95-96 against 3.54% registered in 94-95.

3.1.3. Gear wise size and sex composition

Though length ranging from 60-340mm were represented in the catches from Pongu veechal, prawns above 120mm formed major portion of the landings and size groups 180mm and 200mm appeared as modal classes. On the contrary, catches from Thady veechal comprised mainly of large sized prawns ranging from 160 to 300mm, among them 200mm size group appeared as the modal class. Landings from Koti kuthi veechal comprised mainly of prawns having size ranges 60-260mm and 160mm formed the modal size. Padal, Ottal, Choonda, Seines and Stake nets caught mainly prawns below 160mm while the catches from Neettu vala, Muppalli and Chinese net were represented by comparatively larger specimens.

Males dominated in the catches from Pongu veechal (53.81%), Koti kuthi veechal (87.49%) and Ottal (52.94%), on the contrary, females clearly predominated in Thady veechal (83.87%), Neettu vala (97.67%), Chinese net (85.71%) and Padal (72.73%). Exclusive representation of females could be observed in Choonda and seines. 55.8% of the total female population comprised of berries, of which Pongu veechal accounted for 81.1% in their exploitation. Thady veechal (9.45%), Neettu vala (2.84%) and Stake net (2.27%), Ottal (1.89%) and Choonda (1.70%) were also involved in the exploitation of ovigerous females from the lake.

### 3.1.4. Sex and morphotype wise composition

The representation of male and female in the exploited stock during 1994-95 and 1995-96 are depicted in Fig. 8.7. In both the years, the predominance of female over its counterpart was apparent and contributed to the tune of 59.07 and 54.61% of the exploited stock in 1994-95 and 1995-96 respectively while the contribution of male was only in the order of 40.93 and 45.39%. Among the various female morphotypes, SBF formed the mainstay of the landings in both the years followed by WBF while the contribution of WOF and SOF was highly insignificant (Fig.8.8a and 8.8b). Similarly, among male morphotypes, highest contribution was made by SBC in 1994-95, in contrast, in 95-96 t-SOC and WBC appeared as the most important male morphotypes which formed the mainstay of the catch while SBC occupied only the third position (Fig.8.8a and 8.8b). In both years, the contribution by SOC was found insignificant whereas in 1995-96, WOC contributed to a substantial portion of the exploited stock. The sparse presence of SM could be noticed only during 1994-95, however, it was totally absent in the landings of the second year.

### 3.1.5. Size frequency distribution

Males in the length range 71-393mm TL (4-510g TW) and females of 141-282mm TL (38-228g TW) could be encountered from the lake during the course of the present investigation (Fig.8.9). However, the exploited stock was predominantly represented by specimens in the range 150-270mm TL. In 1994-95, the modal classes of male and female were 180-199mm and 200-219mm respectively (Fig.8.9) followed by 160-179mm in male and 180-199mm in female. In contrast, during 1995-96 the modal values were represented by two size groups of 180-199mm and 200-219mm, both in male and female population, followed by 220-239mm in male and 160-179mm in female (Fig.8.9). The size groups constituted the fishery in 1994-95 was relatively wide in males when compared to that of the succeeding year.

### 3.1.6 Marketable yield structure

In consonance with the different grading system and price tariff packages offered by the seafood export plants of Cochin towards procurement of *M. rosenbergii* for export purposes, the exploited quantities from the lake have been apportioned into different marketable weight groups and the results are shown in Fig.8.10a & 8.10b. In male, 250-300g weight group showed its dominance and contributed to 22% in 1994-95, however, it formed only 7% in the succeeding year. On the contrary, in 1995-96, the dominance of weight group 50-100g was very apparent and contributed to the tune of 24% of the exploited stock. The contribution of weight group 200-250g was almost in the same order in both the years, 14 and 12% in the preceding and succeeding years respectively. Perceptible difference in percentage contribution of specimens weighing more than 400g could also be observed between the two years, in the former year it formed 17% against only 2% in the latter. Similar difference could also be seen in the weight group 350-400g. On the contrary, weight group 100-150g contributed to 24% of the stock exploited in 1995-96 against

7% in the previous year. Similar difference could also be observed in regard to weight group 50-100g between the two years. In general, the predominance of higher weight groups in the exploited stock could be discernible in 1994-95 while in 1995-96, a reverse trend could be noticed in the male population.

The marketable weight structure of the exploited female stock during 1994-95 and 1995-96 are shown in Fig.8.10a and 8.10b. In both the years, the dominance of weight groups 100-150g was very apparent forming 44 and 43% of the exploited stock in 1994-95 and 95-96 respectively. 50-100g emerged as the second dominant group with a contribution of 37 and 39% in 94-95 and 95-96 respectively while prawns having more than 200g were sparsely represented in the catch whereas weight group 150-200g was moderately represented in the exploited stock of both the years.

### 3.1.7. Sex ratio and differential migration

The monthly distribution of two sexes of *M. rosenbergii* in the study area during 1994-95 and 1995-96 are given in Table 8.1. The ratio was tested by Chi-square analysis for the difference from the hypothetical 1:1 ratio (Snedecor and Cochran, 1967). In 1994-95, the sex ratio skewed significantly in all the months at 1% level whereas in January 95 the difference could be noticed at 5% level. The reason for the skewness during January to July was due to the predominance of males while during the period from August to December period, it was due to preponderance of female in the exploited stock. In 1995-96 also, the trend was almost identical, showing significantly skewed, sex ratio at 1% level during Feb-August due to the outnumbering of males over females, in contrast, during September to November, the skewness was due to the dominance of female over its male counterpart. However, in December 95 and January 96, the sex ratio conformed to the hypothetical ratio of 1:1. The Chi-square values for the whole year of 1994-95 and 1995-96 were also found to be not conforming with the expected value of 1:1 and the skewness was found to be statistically significant at 1% level. The reason for the skewness of the sex ratio was due to the preponderance of female in the exploited stock in both the years studied.

## 3.2.. *Macrobrachium idella*

### 3.2.1. Fishing gears and methods

*M. idella* was predominately exploited with the help of "Padal", Koti kuthi veechal and Seines. Landings of this species could also be observed in meagre quantities from Chinese net and Stake net. The description of these gears were given elsewhere. Cast net ("Koona Chemmeen Vala) having small mesh size (18-22mm) was employed in Koti kuthi veechal in zones 3-6 during night hours. Similar operations were also observed in zones 7 and 9 in upstream part of the lake. *M. idella* also formed small proportions in the landings from seines (Koru vala, Kampa ketti koru vala) in zones 3, 5 and 6.

### 3.2.2. Quantification of the explioted stock:

The annual landing of *M. idella* from the study area during the period from March 94 to February 95 was estimated to be 78.5 tonnes, however, in the second year the same was computed at 62.77 tonnes showing a slight plummeting of the exploited stock (Fig.8.11). In 1994-95, males contributed to 56.16% of the landings while in 1995-96, females outnumbered males with a percentage contribution of 60.79% (Fig.8.12). Zones 10-13 which represent the riverine part of the study area contributed only very insignificant potion of the exploited stock while zones 1-6 which formed the downstream part of the lake appeared to be the most productive regions of the lake, contributing to the tune of more than 70% of the total exploited stock in both the years. The contribution from upper reaches of the lake (zones 7-9) was also relatively low, showing only 17.15% in 1994-95 against 22.76% in 1995-96 (Fig.8.13). The average annual yield/ha from the lake was worked out to be 3.46 in 1994-95 while in 95-96 it was only 2.75 Kg/ha. The average annual production /ha in the downstream region of the lake (zones 1-6) worked out be 5.02 in 1994-95, however, in 1995-96, it declined to 3.66 Kg/ha while in the upstream part of the lake (zones 7-9) the production was found to be stabilized around 1.7Kg/ha in both the years. In the riverine part of the study area (zones 10-13) annual yield was found to be only around 1Kg/ha in both the years (Fig.8.14).

**i) Month wise landing**

Month wise landing of *M. idella* during 1994-95 and 1995-96 are depicted in Fig.8.11. In both the years, the onset of fishery could be seen in the month of July and continued till January and July to October period appeared as the peak fishing season. In 1994-95, highest landings could be recorded in the month of August while in 1995-96, the same could be observed in the month of September. The predominance of males could be discernible during most of the months during 1994-95, however, in 1995-96 female predominated in the landings during September to November. Both male and female represented in the landings in all the months during when the fishery was prevalent in the lake.

**ii) Zone wise landings**

The magnitude of exploitation of *M. idella* from the different zones of the lake and confluent rivers during 1994-95 and 1995-96 are shown in Fig.8.13. In both the years, the highest landing could be registered from zone 5. Zones 2 and 4 appeared as the other important regions in 1994-95 while in 1995-96 these positions were occupied by zones 6 and 4. The average annual yield/ha worked out from 13 zones of the study area during 1994-95 and 1995-96 are depicted in Fig.8.14. Zones 5 emerged as the most productive zone of the lake in both the years, showing an annual yield of 20.71 in 1994-95 against 12.240Kg/ha in 1995-96. In 1994-95, an exceptionally good fishery of *M. idella* could be observed in zone 13. Among the zones of downstream part of the lake, lowest yield could be recorded in zone 1, however, in the other confluent regions (zones 2,4,5), a gradual increase in the yield was quite noteworthy, showing the highest production in zone 5 and thereafter, a diminishing trend was discernible in zones 6-12. On examining the catch composition from various zones, it could be seen that the predominance of males was very conspicuous in almost all zones during 1994-95, in contrast, the preponderance of females could be discernible in 1995-96 (Fig.8.12).

The magnitude of fishery of *M. idella* prevalent in zones 1-13 during March 1994 to February 1996 are depicted in Fig.8.15. Among the various zones of the downstream part of the lake, the pattern of appearance and intensification was almost similar in all zones barring zone 6, wherein the commencement of fishery could be observed by May and continued till January showing the peak landings during July- October. On the other hand, in zone 6, the appearance of the fishery was noticed only in the month of June and landings was quite good during August to October in both the years. In the zones of upstream part of the lake, the fishery of *M. idella* was characterised by the late appearance and earlier disappearance of the stock, showing moderate landings during September-October months. The pattern of fishing in zone 13, which forms the confluent portion of River Muvattupuzha was almost similar to that of zones of the downstream part of the lake. During the period of present investigation, no fishery of *M. idella* could be noticed from zones 10 and 11 which form part of the River Pampa and also from zone 12 which forms the confluent portion of the river Meenachil.

**iii) Gear- wise landing**

Percentage contribution of *M. idella* from various fishing gears and methods during 1994-95 and 1995-96 are shown in Fig.8.16. It could be seen that Padal accounted for a major portion of stock exploited from the lake, showing 66.45 and 72.92 % of the total landings estimated during 1994-95 and 1995-96 respectively while contribution from Koti Kuthi Veechal (Cast net) was in the order of 22.18 and 18.33% in the above years. The share from the Seines was 7.24 in 1994-95 against 5.25% in 1995-96 while the contribution from Stake net and Chinese net were highly insignificant in both the years.

**3.2.3.** Gear- wise size and sex composition

The commercial fishery of *M. idella* was constituted by the length groups ranging in size from 12-132mm TL. While examining the size groups constitute the fishery from different fishing gears and methods, it could be observed that the catches from seines was invariably represented by specimens in the range 60-130mm with a modal class at 80-100mm. Similarly, in Koti Kuthi Veechal also, the catch was widely represented by specimens above 80mm and prawns of 100-120mm contributed the modal class. Conversely, catches from Padal comprised mainly of smaller sized prawns ranging between 20-100mm and the modal size class was represented by 60-80mm. The landings from Stake nets were also appeared similarly while the same from Chinese nets were represented by specimens of comparatively large size groups.

The dominance of males could be discernible in the catches from Seines and Koti Kuthi Veechal (Cast net) while females outnumbered in the landings from Padal and Stake nets. On the other hand, no perceptible difference in the sex variation could be noticed in the catches from Chinese nets.

### 3.2.4 Size frequency distribution

The fishery of *M. idella* was constituted by specimens ranging in size from 12-132mm in males and 12-116mm in females, however, specimens below 40mm and above 120mm are barely represented in the commercial landings. The regular fishery was constituted by prawn in the range 40-120mm. The annual combined frequency distribution of *M.*

*idella* exploited from the 13 zones during 1994-95 and 1995-96 for both males and females are depicted in Fig.8.17. In 1994-95, the modal class was found at 60-79mm both in male and female while in 1995-96, the modal class of female remained the same whereas in male, a shift to 80-100mm could be discernible. On examining the size groups representing the fishery of both the years, it could be seen that the size below 40mm was frequently represented in the catches during 1994-95, conversely, in 1995-96, these groups constituted only very insignificant proportion in the exploited stock.

3.2.5. <u>Sex ratio</u>

The monthly distribution of males and females of *M. idella* in the exploited stock of the lake is given in Table.8.2. The Chi-square value revealed that the sex ratio skewed significantly at 1% level in almost all months except in February, May and August. The reason for the skewness during March, April, September, October, November and February was due to the preponderance of females, while in June, July and December it was due to the predominance of males in the catches. The Chi-square values for the whole year is 591, indicating a highly significant variation from the hypothetical value of 1:1 and reason by which it does not conform with the above ratio is due to the outnumbering of females over their male counterparts.

## 4. DISCUSSION

Among the five species of the genus *Macrobrachium* reported from the Vembanad lake (Jayachandran, 1987), *M. rosenbergii* and *M. idella* constituted the majority in the commercial fishery. By virtue of the excellent demand for export, the former species is almost exclusively procured by the sea food processing plants while the latter forms the principal component of the local Palaemonid fishery. With the appearance of the stock of *M. rosenbergii* in the lake, majority of the fishermen of the lake switched over in the exploitation of this species of high value, in recent years and therefore, the prosperity of the fishermen inhabiting in these regions are profoundly influenced by the magnitude of fishery of *M. rosenbergii* of the Vembanad lake.

The fishing gears and methods employed for fishery of *M.rosenbergii* in Vembanad lake as observed in the present study agree well with the observations of Raman(1967, 1975) and Kurup *et al.* (1992a). However, it has been reported that fishing with Ottal has almost disappeared from lake proper(Kurup *et al*,1992a). In contrast to this, in the present study, the use of Ottal could be encountered in the shallow areas of upstream parts of the lake. Raman(1967) reported only occasional landing of freshwater prawns in Chinese dip nets and Stake nets. However, the results of the present study showed that these stationary gears accounted for the substantial portion of landings of *M.rosenbergii*, especially in the downstream part of the lake. It may, therefore, be inferred that the availability of these prawns in downstream area may be associated with the shifting of their breeding ground from Kumarakom to Thevara- Perumbalam areas in downstream part of the lake, consequent to the commissioning of Thannermukkam salinity barrier as reported by Kurup *et al.*(1992a).

Castnet appears to be the principal gear used for the fishery of *Macrobrachium* spp.(Rajyalekshmi and Ranadhir,1969; Ibrahim, 1962; Rao,R.M,1967; Raman,1975). The percentage exploitation by cast nets (78.62%) arrived at in the present investigation was comparable with 72.93% in 1988-89 as reported by Kurup *et al.*(1992a). However, percentage exploitation by hand lines during the present study was only 3.47% in contrast to 19.49% in '88-89. Kurup *et al.*(1992a) pointed out the possibility of growth over fishing on the basis of the declining trend noticed in the modal size classes constituting the exploited fishery of *M.rosenbergii* in Vembanad lake. The results of present study also support the above observation. Moreover, it was worth noticing that Koti kuthi veechal, Muppalli, Choonda and Padal caught mainly small and undersized prawns from the lake.

Males dominated in catches from gears which were predominantly operated in upstream part of the lake whereas catches from gears operated widely in downstream areas were comprised mostly of females. Males dominated catches from Pongu Veechal, Koti kuthi veechal and Ottal whereas females dominated in Thady veechal, Muppalli, Choonda, Neettu vala, Chinese net, Padal, etc,. This can be attributed to the differential availability of males and females in the lake (Raman,1967; Kurup *et al.*, 1992a) as part of breeding migration of *M.rosenbergii* in the lake and also due to the operational peculiarities of the above gears. Pongu veechal was carried out through out the year in almost all zones whereas Koti kuthi veechal and Ottal were mainly employed in riverine regions and upstream part of the lake, mostly during summer months when depth of water column was invariably very low. On the contrary, Thady veechal, Choonda, Muppalli and Padal were mainly operated consequent to the onset of monsoon during when the downward migration of females could be discernible.

The prevailing environmental conditions of the lake and adjoining parts of the river have a distinct bearing on the distribution and abundance of fishes and prawns, among them the most important are salinity and temperature. The penetration of marine and freshwater organisms in to the estuary is often a function of the rate of the changes in salinity, rather than the precise salinity at any point (Mc Lusky, 1974). While elucidating the variations of physico-chemical parameters of the study area it could be seen that a seasonality in the distinct fluctuation shown by the salinity and temperature was quite obvious (refer Chapter 1). Among the various parameters studied, pH, dissolved Oxygen, acidity, alkalinity and hardness recorded from most of the stations during the study period were within the tolerance limit of *M. rosenbergii* and *M. idella* (Chapter 1) and therefore, may not be influencing much in their occurrence and abundance. Based on the stock size of the two freshwater prawn species quantified from the lake during 1994-96, it was very obvious that the stock size showed an inverse relationship with the increasing salinity and temperature profiles of different zones. Highest landing of *M. rosenbergii* was recorded from the typical freshwater and oligohaline zones of the study area and the gradual disappearance of the stock could be observed with the increase in salinity gradient. However, female spawning stock was found to be susceptible to meso or polyhaline conditions of the lake. Conversely, the high abundance of *M. idella* could be encountered from the zones where slightly brackish water conditions were prevalent, however, this species was also found disappeared during when the salinity values showed a steady increase. Similarly, the abundance of the stock of these two species also strongly coincided with the period in which low water temperature could be recorded from the lake. The sudden lowering of temperature and salinity of the lake was brought about due to the heavy freshwater discharge from the adjoining rivers, especially during June - July periods during when about 60% of the annual rainfall is being received in this part of the state. It would thus appear that the descend of the stock of *M. rosenbergii* to the lake was primarily governed by the annual monsoon rain and therefore, the fishery in the lake was fully depended on the intensity of the monsoon prevalent in the respective years. This finding show very much agreement with that of Ibrahim (1962), Rajyalakshmi, (1980) and Prakash, 1989) who have reported that the peak abundance of freshwater prawns in the lake and rivers strongly coincided with the monsoon and post monsoon seasons.

During the past two decades, very serious alterations have been taken place in the ecology of Vembanad lake and the confluent rivers mainly due to human interventions and therefore, periodic monitoring of the stock size and resource characteristics of the Palaemonid prawns, especially of those which are endowed with very complicated life cycles, are very essential for assessing the impacts of various ecological transformations brought about in these regions. Of the two species studied, *M. rosenbergii* is a true denizen of the rivers of Kuttanad, however, the adult population undertakes breeding migration in to the saline region of the lake where the hatching and larval metamorphosis are completed. The post larvae so produced will again ascend to the typical freshwater habitat where it attains adulthood.

The exploited stock of *M. rosenbergii* from Vembanad lake and 5 Km stretch of the confluent rivers viz., Pampa, Manimala, Meenachil and Muvattupuzha was quantified as 112.85 tonnes during 1994-95 and 129.44 tonnes in 1995-96. Based on the figures furnished by the purchasing agent who supplied prawns to the freezing companies located in Kumarakom and Ramankari, the former regions represents zone 8 of the present study and the latter is situated about

20km further upstream in the river Pampa proper, the annual production varied from 189 to 429 tonnes during 1957 to 1962, the lowest was in 1962 while highest in 1960, which would work out to be an annual average of 300 tonnes during 1957-62(Raman, 1967). However, Kurup *et al.*(1992a) quantified the annual production from the lake as 39 tonnes, which accounted for only 13% of the quantity assessed by Raman (1967). A comparison of the estimates of annual production from the lake during 1988-89 (Kurup *et al.*, 1992a) with the data collected during the present study showed that, there is a marked improvement in production from 39 tonnes in 1988-89 to 112.85 in 1994-95 . A further increase in the catch to the tune of 129.44 tonnes could be seen in 1995-96. It would thus appear that the present estimates show a three fold increase over the quantity assessed by Kurup *et al.*(1992a). According to Kurup (1997), *M. rosenbergii* has become a rarity in Kuttanad, the home ground and the depletion of the stock was attributed mainly to the impact of man made changes in the ecosystem such as habitat alteration, reduction in the natural grow-outs due to intensification of paddy cultivation and cropping patterns, reclamation of about 16,000ha of the lake as paddy fields, physical obstruction imposed in the migratory path of the berries and post larvae due to the operation of the Thanneermukkam salinity barrier, over fishing and pollution hazards mainly due to excessive application of pesticides in the paddy fields. As *M. rosenbergii* requires both freshwater and saline area for completion of its life history, the implication of the barrier deserves mention in view of the fact that the operation of this physical structure may obstruct the downward migrating spawning stock as well as the upwardly migrating post larvae and juveniles. While examining the operation schedule of the barrier, it could be seen that prior to 1990, the barrier invariably closed before 10th of December and lifting of the shutters had taken place either by the end of May or by the beginning of June. By the closure of the barrier in December, the downward migration of a sizeable number of berries may be obstructed (Kurup *et al.*, 1992a) and thereafter, are prone to indiscriminate exploitation subsequently in the upstream part of the lake. According to Harikrishnan and Kurup (1997b), highest landing of spawning stock was encountered from the lake in October, followed by September which collectively accounted for 82.11% of the berried population of the lake. The authors also reported that about 30.2% of the total 23.43tonnes of ovigerous female reach the breeding ground located in zone 2,3 or 4 of the lake during September and October, where the environmental conditions are congenial for hatching and completion of larval metamorphosis (Harikrishnan and Kurup, 1997b). A minimum of 16-45 days are required for hatching and completion of larval metamorphosis of *M. rosenbergii* (New and Singholka, 1985). The post larvae begin their upward migration towards freshwater habitat within one or two weeks after metamorphosis and are soon able to swim against rapidly flowing currents or to crawl over the stones at the shallow edges of rivers. It may, therefore, be inferred that bulk of the post larval stock will get ready for upward migration only by the middle of December onwards, which almost synchronises with the closure of the barrier. However, since 1990 onwards, according to the data furnished by the Irrigation Department, Alleppey, the opening of the barrier was made effected relatively earlier, from the middle of April. Interestingly, a steady improvement in the landings of *M. rosenbergii* from the lake could be noticed during 1994-95 and during 1995-96 and the major changes effected in the operation schedule of the barrier can be attributed as one of the reasons for the improvement of the stock of this species in the lake. It can reasonably be asserted that the opening of the barrier by the middle of April may be helpful in minimising the ill effect of the barrier in the upwardly moving post larvae and juveniles to some extent and this is manifested by the steady replenishment of stock of *M. rosenbergii* in recent years. In order to assess the fate of juveniles and post larvae trapped in the downstream regions of the lake, mark release recovery studies have been done and the results are furnished in Chapter.7. The results revealed that only 0.61% of the total marked and released postlarvae and juveniles in the downstream regions of the lake in the month of January- February months could be collected from the upstream part of the lake. This finding would suggest the possibility of heavy mortality of juveniles in the downstream part of the lake, mainly due to the rapid increase of salinity and also due to predation. It may, therefore, be inferred that operation of the barrier has, in fact, adversely affected the stock of *M. rosenbergii* in Vembanad lake and confluent rivers and this finding shows very much agreement with that of Kurup *et al.*(1992a).

The pattern of fishery prevalent in different zones of the study area during 1994-96 are given in Fig.8.5. A critical analysis of the trend shown by the fishery revealed that invariably in the zones of the upstream part of the lake *M. rosenbergii* constitutes almost an year round fishery with peak landing during July to October. In contrast, in the zones of the downstream region (zones 1-6) the fishery was found generally restricted to June to January. It is also pertinent to note that there is an obvious shift in the onset of fishery in different zones of the lake, almost in the descending order from south to north. The appearance of this species could be seen in the months of May- June in zone 6, 5,4 and 3 which are located proximal to the upstream part of the lake, on the contrary, in zones 2 and 1 which form the southern most regions of the lake, the presence of stock could be seen only in the months of July-August. Conversely, in the zones 11 and 12 which form the confluent portions of river Pampa and Meenachil, the occurrence of stock was observed much early in the month of March and continued till October-November. It may, therefore, be inferred that zones 8, 9 and 10 are characterised by the presence of a resident stock which undertakes seasonal migration upwardly and downwardly, the migration towards riverine habitat takes place during summer months or pre monsoon season while the downward migration is performed during the monsoon and post monsoon seasons. According to Raman (1964), the upward migration of *M. rosenbergii* during summer months is mainly for inhabiting the deeper parts of the rivers where the bottom is not only slushy but also very cool. Natividad (1982) reported that *M. rosenbergii* inhabiting some Philippine rivers preferred thriving at a temperature range of 23.5- $25.5^{0}$C. In the present study also, a steep increase of water temperature could be observed from February onwards in the lake proper, attaining peak in April. However, the bottom temperature of riverine areas were relatively lower when compared to similar values obtained from the lake proper. Juveniles and large males of *M. rosenbergii* are fully at home in the river mouths adjacent to the brackish water areas where salinity was nearly 18 ppt indicating that increased salinity alone is not the indicating factor for the ascend of the stock in to the rivers (Raman, 1964). However, in the present study, the salinity values did not exceed beyond 8 ppt in upstream part of the lake and therefore, it can reasonably be asserted that temperature is the only indicating factor responsible for their upward migration. The sojourn of the males in the backwater regions of the lake (zones 6-1) could be observed only by the end of May or early June and this is found to be fully coincided with the onset of monsoon. This may be due to heavy discharge of freshets from the adjoining rivers due to the onset of south- west monsoon which not only rise the water level in the lake, but also results in lowering of the water temperature, sudden rise in turbidity and conversion of whole lake into a freshwater lentic environment by reducing salinity. In the present study also, lowest temperature could be recorded from the lake in the month of June-August during when typical oligohaline conditions in the lake in most of the zones. Invariably, *Macrobrachium* spp. show their peak abundance in the lakes and rivers of India during monsoon and postmonsoon seasons (George, 1969; Ibrahim, 1962; Rajyalekshmi, 1980; Prakash, 1989). The total yield of *M. rosenbergii* in Irrawaddy river in Burma is reported as 1782.2 tonnes and the prime period of landings is from September to January (Taw, 1982). In Pulicat lake, highest landing of *M. rosenbergii* was reported in winter and monsoon seasons which accounted for 62 and 28% respectively (Rao,1992). The distribution and maximum abundance of *M. rosenbergii* in the Vembanad lake and confluent rivers has been observed during the above periods and therefore show full agreement with the above findings. Incursion of saline water into the lake could be noticed from September onwards and shows gradual penetration into the zone of the downstream regions of the lake, making them mesohaline and polyhaline conditions during January to April and the disappearance of the stock of the species during January to May in these zones can be attributed to the sudden increase of salinity.

The breeding season and breeding migration shown by *M. rosenbergii* in Vembanad lake have been well addressed by so many workers (Raman, 1967; Kurup *et* *al.*,1992a; Harikrishnan and Kurup, 1996a). In this species, though the hatching takes place in freshwater, it requires salinity in the ranges 12-14ppt for completion of larval metamorphosis (New and Singholka, 1985). Prior to the commissioning of Thanneermukkam salinity barrier, Kumarakom and adjoining regions of the upstream part of the lake offered ideal brackish water conditions for hatching and larval metamorphosis and the species was reported to breed during August to December with peak intensity in October-November (Raman,1967). During this period, the saline water incursion was reported up to Pulikizh in river Pampa, located about 80 km away from Cochin barmouth and in Kumarakom and adjoining regions of the lake salinity values up to 23 ppt was recorded in the month of April (Josanto, 1971). It would thus appear that the upstream part offered as the ideal spawning ground of *M. rosenbergii* prior to 1976, consequently the stock need not perform lengthy spawning migration for this purpose and therefore, the fishery was well restricted in the upper reaches of the lake (Raman,1967). According to Kurup *et al.*(1992a), with the commissioning of the barrier, the salinity of the upstream part does not go beyond 6 ppt and therefore, a shift in breeding ground was found effected to 40km downward and consequently the berried females are compelled to undertake lengthy breeding migration in order to reach the new breeding grounds. In zones 2, 3 and 4, the salinity varied from 6-22 ppt during when the predominance of black berried female could be observed and therefore, it was inferred that these zones may serve as breeding ground. The slow moving ovigerous females are most vulnerable to heavy fishing pressure and the annual exploitation of berried females from the lake was in the order of 23.43 tonnes, highest being in the month of October and only 30.2% of the spawner stock reaches the breeding grounds (Harikrishnan and Kurup, 1997b). This situation would suggest the possibility of recruitment over fishing as defined by Pauly (1980) which may also be considered as one of the reasons for the alarming depletion of the stock observed in the lake during the past decade.

The results of the present study also show that the seasonal fishery of *M. rosenbergii* in the downstream regions of the lake (zones 1-6) was predominantly contributed by the migratory stock, characterised by the dominance of males during the earlier period of June and July while in latter months of August- October by the female, as a result of their differential breeding migration. Similar situations also prevails in Bolgoda lake, Sri Lanka where the fishery is supported by the spawning stocks. Migratory movement into the lakes for breeding, hatching or both have been reported in many Palaemonids such as *Palaemon carcinus* (Johnson, 1966) and *P. mirabilis* (Rajyalakshmi, 1961).

The modal value of male *M. rosenbergii* constituting the fishery of the lake during the present study was observed as 180-199mm in 1994-95 while in 1995-96, in both the groups, 180-199 and 200-219mm were found equally represented in the catch. This was found similar in comparison to that of Kurup *et al.*(1992a), however, when compared to Raman (1967) was on a lower side. While comparing the modal size frequency of fishery between 94-95 and 95-96 of the lake, there is a shift towards upper class from 180-199 to 200-219 could be discernible and this can be taken as a manifestation of the stock revival. Female also maintained the same modal class as reported by Kurup *et al.*(1992a), however, appeared to be far below when compared to 220-240mm as reported by Raman(1967). In the present study, the maximum size registered in regard to male and female were 393 and 289mm respectively which in comparison with that of Kurup *et al.*(1992a), is on a higher side in the case of male while in female the value is identical. In *M. rosenbergii*, the female outnumbers the male in the commercial catches (Wanninayake and Costa, 1987) and in compliance with their observations, in the present study also, the overall dominance of female in the fishery could be observed with a ratio of 1:1.44. During January to July, males were very abundant, on the contrary, from August to November which formed the breeding season of this species in the lake, the sex ratio between male and female was in the range 1:1.38 to 1:29.33, touching the highest value in the month of November and this finding also shows very much agreement with that of previous workers (Raman, 1967; Smith *et al.*,1978; Kurup *et al.*, 1992a). Data collected on the exploited stock showed that the peak landing of *M. rosenbergii* was in the month of October in 94-95 while in 95-96 the same was in the month of September. This finding is at variance with the result of Kurup *et al.*(1992a) and Raman (1967) who have reported that the peak landing of *M. rosenbergii* was July and August respectively in Vembanad lake.

*M. idella* forms the second most important freshwater prawn species of the lake which constitute a sustenance fishery during May-June to December-January periods. It mainly abounds in the downstream regions of the lake during when meso and polyhaline conditions prevail in various zones of the lake. In 1994-95 and 1995-96, highest landings were recorded in the month of August and September respectively while among various zones of the lake, highest landings was registered from zone 5. Besides, zone 2,4 and 6 were also found to be important fishing grounds of this species in the lake. In the above zones, invariably during July- August to January months typical brackish water conditions were prevalent due to the incursion of sea water from the barmouth and salinity values of 6-18ppt were recorded from this part of the lake. It would thus appear that unlike *M. rosenbergii*, *M. idella* prefers slightly brackish water conditions and therefore, thrive well in the downstream part of the lake. Though the place of abundance of these two species showed slight differences, however, they co-exist in most of the zones and furthermore, the period of peak abundance was also almost identical and strongly corroborative with the period of low temperature and high rainfall and this would suggest the bearing of these two factors in the appearance and abundance of freshwater prawns in the lake as reported earlier (Ibrahim, 1962; Rajyalakshmi, 1980; Prakash, 1989).

In the present study, the exploited stock of *M. idella* from the lake and adjoining rivers was quantified as 78.5 and 62.2 tonnes during 1994-95 and 1995-96 respectively. This is favourably comparable with that of the quantity reported in 1988-89 period (Kurup *et al.*,1992a) from the lake and month and zone showing highest production of this species also showed strong agreement. In the present study, Padal accounted for more than 66% in both the years while the contribution from castnet was less than 22%. In contrast, during 1988-89, castnet accounted for 47.36% and the contribution from Padal was only 6.55%. It may, therefore, be seen that the operation of Padal became so popular and widespread in the lake during the recent years. A sizeable reduction in the landings of *M. idella* from castnet operations could also be noticed and this may be due to the switching over of castnet operators into the fishery of *M. rosenbergii* on account of their abundance as a result of partial revival of the stock of the latter. The modal class contributing the fishery in 1994-95 also showed similarity when compared to 1988-89, however, in 1995-96, the shift to 80-99mm in male population is worth noticing. The sex ratio also showed skewness due to the preponderance of females as reported by Kurup *et al.*(1992a).

During 1988-89 period, the annual production of *Macrobrachium* spp. from the Vembanad lake was estimated to be 117.69 tonnes of which the percentage composition of

*M. rosenbergii* and *M. idella* were in the order of 33.37 and 58.03% respectively. Nevertheless, in 1994-96 period, the stock of *M. idella* remained almost same while that of *M. rosenbergii* showed a remarkable improvement to the tune of more than 300%. *M. rosenbergii* contributed lucrative fishery of the lake in the order of an average 300 tonnes/ annum during sixties (Raman,1967) and showed severe depletion over the past two decades, with a stock size of mere 39 tonnes during 1988-89 (Kurup *et al.*, 1992a). It may therefore, be inferred that the depletion of the former species has eventually resulted in the succession of *M. idella* in the lake by occupying the same ecological niche of the former species whereby the latter could emerge as the next abundant species of freshwater prawns in the lake and this is very much similar to the definition of ecosystem over fishing as defined by Pauly (1980). Nevertheless, the results of the present study show that further provision for succession of the stock of *M. idella* does not exist in the lake possibly due to partial revival of the stock of *M. rosenbergii*. The inference is supported by the fact that a slight declining trend in the stock of *M. idella* was apparent while comparing the exploited quantity of 1994-95 and 1995-96 from the lake. The results of this study also show that the possibility of further revival of the stock of *M.rosenbergii* is possible by imposing regulatory management measures such as

1). reduce the closure period of Thanneermukkam salinity barrier by limiting Punja cropping during November-March period, 2). minimising the recruitment over fishing by imposing a ban on fishery during October- November during when the peak occurrence of spawner stock migrating to downstream part of the lake,

3). reducing fishing pressure at the breeding ground during the breeding season

4). regulation of fishing effort of the gears which are primarily responsible for the exploitation of major part of the spawner stock (Gulland, 1983) and

5). making necessary provision in the Thanneermukkam salinity barrier for the negotiation of postlarvae as described in Chapter 7.

Table 8.1 Sex ratio of *Macrobrachium rosenbergii* of Vembanad lake

a) 1994-1995

| Months | Males | Females | M:F | Chi-square value | Probability |
|---|---|---|---|---|---|
| March 94 | 50 | 0 | 1:0.00 | 50 * | P<01 |
| April | 165 | 0 | 1:0.00 | 165 * | P<01 |
| May | 196 | 1 | 1:0.00 | 193 * | P<01 |
| June | 291 | 41 | 1:0.14 | 188 * | P<01 |
| July | 249 | 172 | 1:0.66 | 14 * | P<01 |
| August | 110 | 285 | 1:2.59 | 78 * | P<01 |
| September | 25 | 313 | 1:12.52 | 245 * | P<01 |
| October | 42 | 450 | 1:6.67 | 338 * | P<01 |
| November | 19 | 343 | 1:5.47 | 290 * | P<01 |
| December | 8 | 120 | 1:4.38 | 98 * | P<01 |
| January 95 | 23 | 10 | 1:0.43 | 5 ** | P<05 |
| February | 24 | 0 | 1:0.00 | 24 * | P<01 |
| Total | 1202 | 1735 | 1:0.88 | 97 * | P<01 |

| | | | |
|---|---|---|---|
| Heterogenity | Sum of Chi-square | 1688.74 df=12 | |
| | pooled Chi-square | 96.73 df=1 | |
| | | 1592.01 df=11 | * P<01 |

b) 1995-1996

| Months | Males | Females | M:F | Chi-square value | Probability |
|---|---|---|---|---|---|
| March 94 | 12 | 0 | 1:0.00 | 12 * | P<01 |
| April | 70 | 0 | 1:0.00 | 70 * | P<01 |
| May | 201 | 5 | 1:0.02 | 186 * | P<01 |
| June | 339 | 105 | 1:0.24 | 123 * | P<01 |
| July | 256 | 116 | 1:0.45 | 53 * | P<01 |
| August | 122 | 168 | 1:0.76 | 7 * | P<01 |
| September | 45 | 399 | 1:8.87 | 282 * | P<01 |
| October | 32 | 424 | 1:6.69 | 337 * | P<01 |
| November | 3 | 88 | 1:3.67 | 79 ** | P<05 |
| December | 5 | 7 | 1:1.40 | 0 | |
| January 95 | 4 | 8 | 1:2.00 | 1 | |
| February | 8 | 0 | 1:0.00 | 8 * | P<01 |
| Total | 1097 | 1320 | 1:0.79 | 21 * | P<01 |

| | | | |
|---|---|---|---|
| Heterogenity | Sum of Chi-square | 1160.08 df=12 | |
| | pooled Chi-square | 20.57 df=1 | |
| | | 1139.51 df=11 | * P<01 |

Table 8.2 Sex ratio of *Macrobrachium idella* of Vembanad lake

a) 1994-1995

| Months | Males | Females | M:F | Chi-square value | Probability |
|---|---|---|---|---|---|
| March 94 | 10 | 33 | 1:3.30 | 12 * | P<01 |
| April | 18 | 22 | 1:1.22 | 0 | |
| May | 0 | 14 | __ | 0 | |
| June | 1025 | 858 | 1:0.84 | 15 * | P<01 |
| July | 718 | 493 | 1:0.69 | 42 * | P<01 |
| August | 697 | 675 | 1:0.97 | 0 | |
| September | 1540 | 938 | 1:0.61 | 146 * | P<01 |
| October | 686 | 795 | 1:1.16 | 8 ** | P<05 |
| November | 434 | 479 | 1:1.10 | 2 | |
| December | 175 | 137 | 1:0.78 | 5 ** | P<05 |
| January 95 | 30 | 14 | 1:0.47 | 6 ** | P<05 |
| February | 125 | 124 | 1:0.99 | 0 | |
| Total | 5458 | 4582 | 1:0.84 | 76 * | P<01 |

| | | | |
|---|---|---|---|
| Heterogenity | Sum of Chi-square | 236.61 df=12 | |
| | pooled Chi-sqare | 76.43 df=1 | |
| | | 160.18 df=11 | * P<01 |

Fig. 8.1 Schematic illustration showing the operation of Thady veechal method

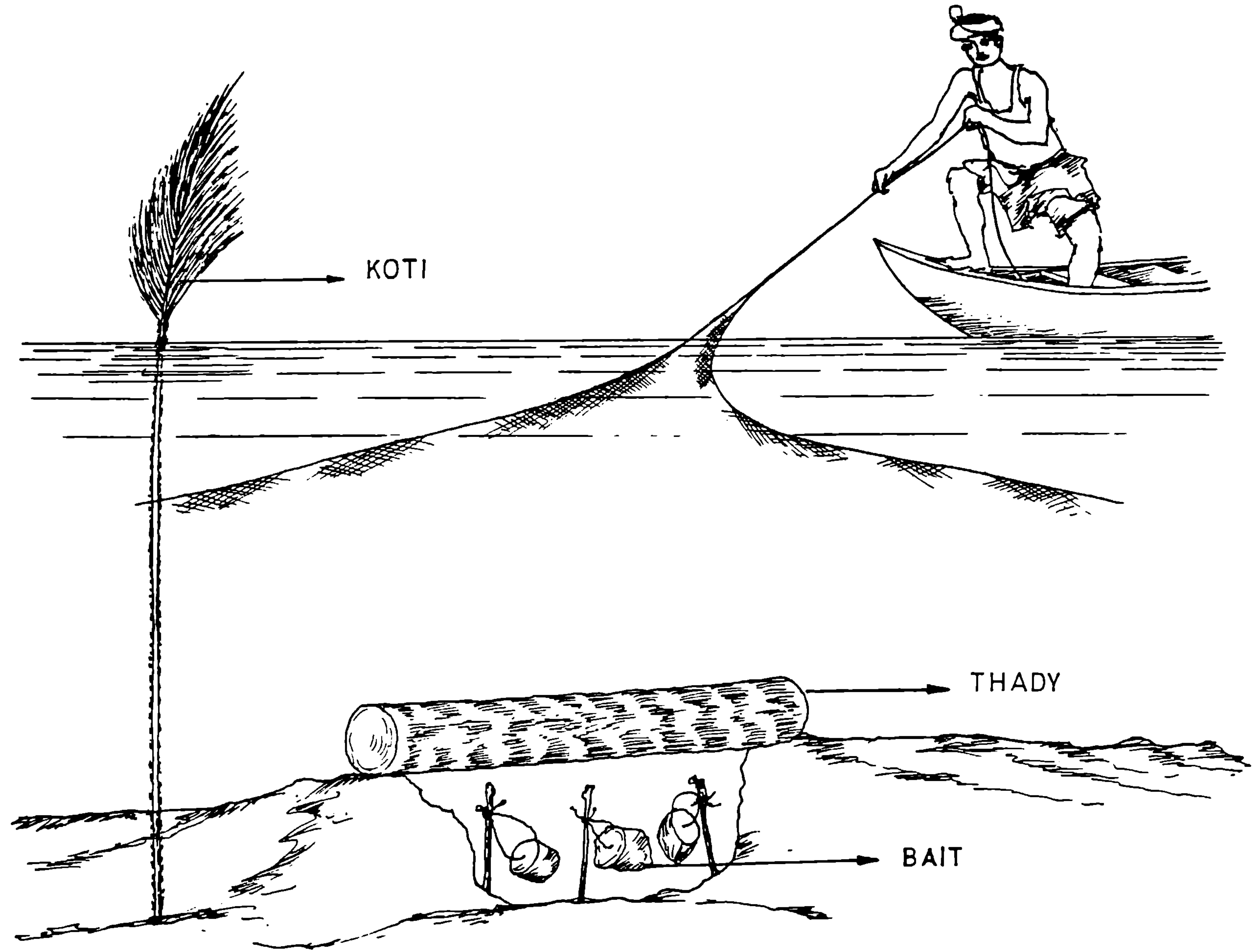
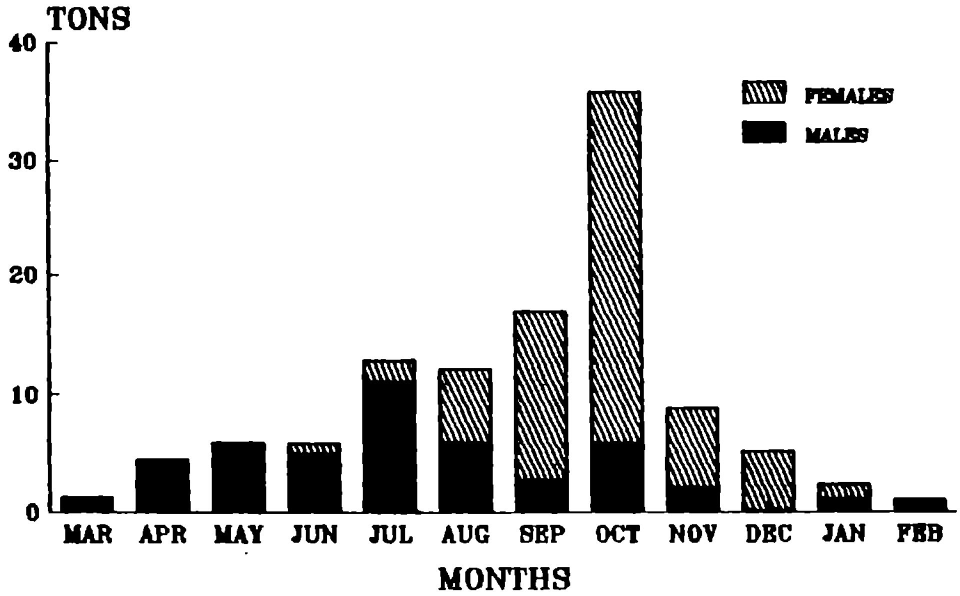

KOTI
THADY
BAIT

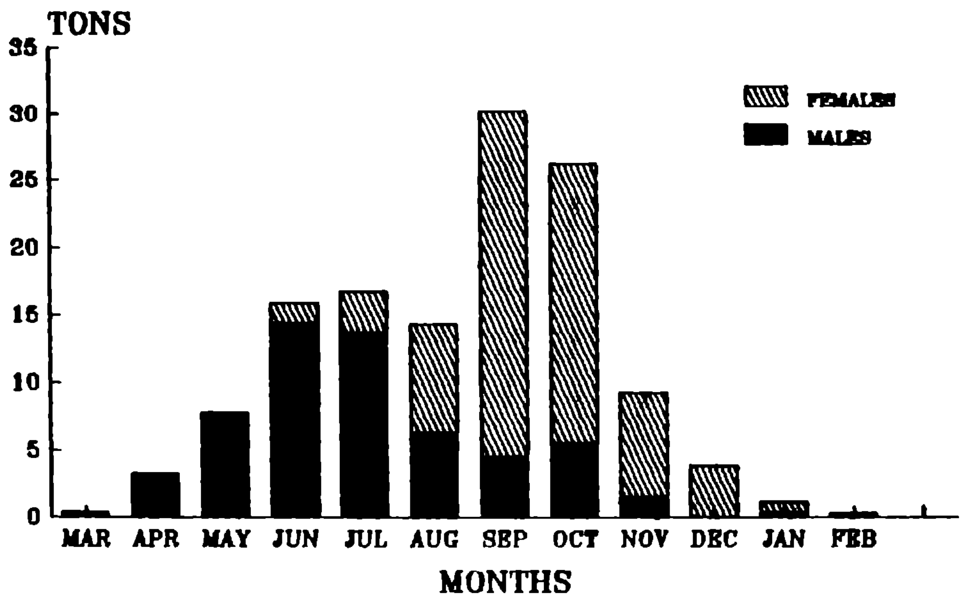
Fig. 8.2a Month wise landings of *M.rosenbergii* in Vemband lake during 1994-95

Fig. 8.2b Month wise landings of *M.rosenbergii* in Vemband lake during 1995-96



TONS
40
30
20
10
0
FEMALES
MALES
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MONTHS


a

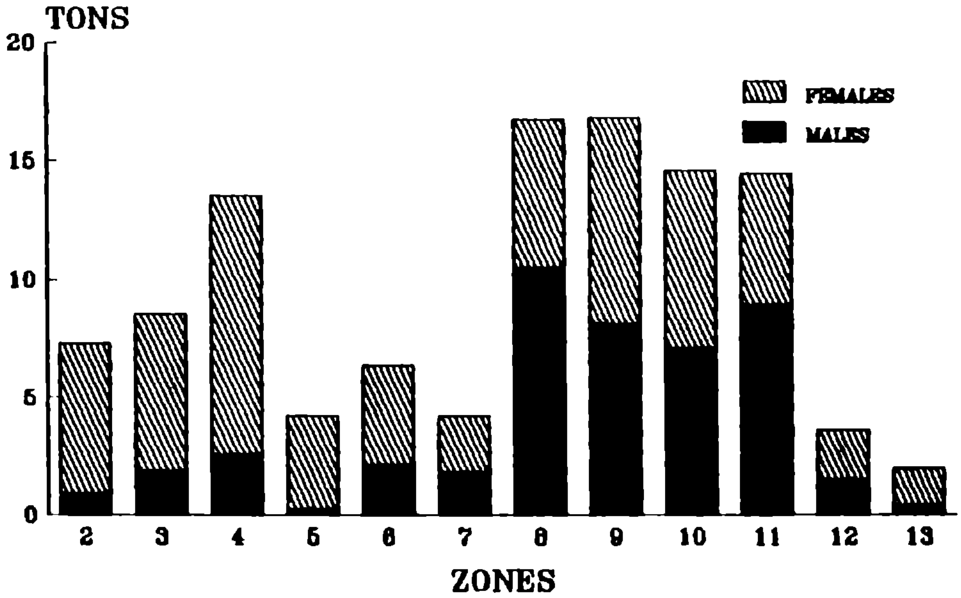


TONS
35
30
25
20
15
10
5
0
FEMALES
MALES
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MONTHS

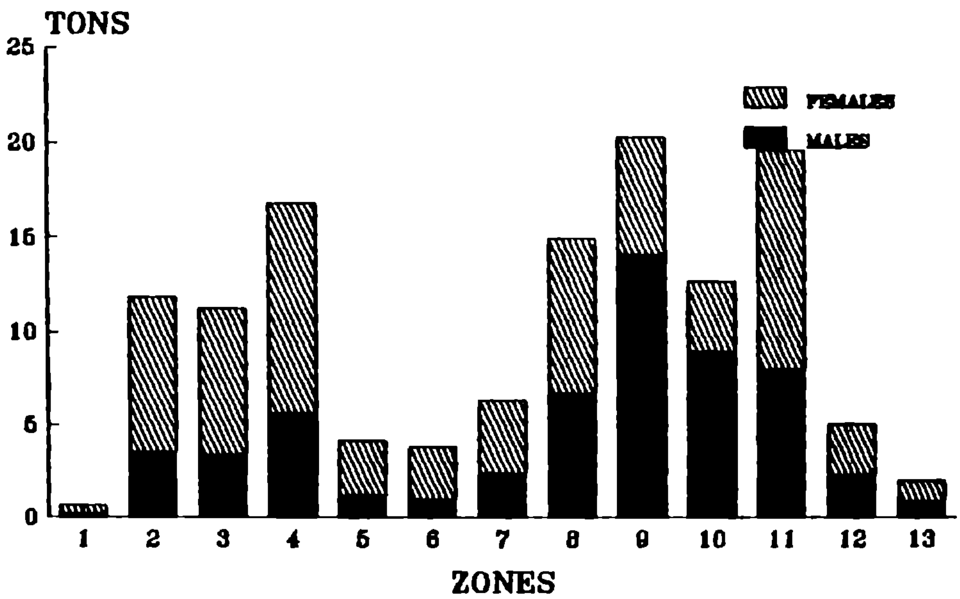

b

Fig. 8.3a Zone wise landings of *Macrobrachium rosenbergii* in Vembanad lake during 1994-95

Fig. 8.3b Zone wise landings of *Macrobrachium rosenbergii* in Vembanad lake during 1995-96

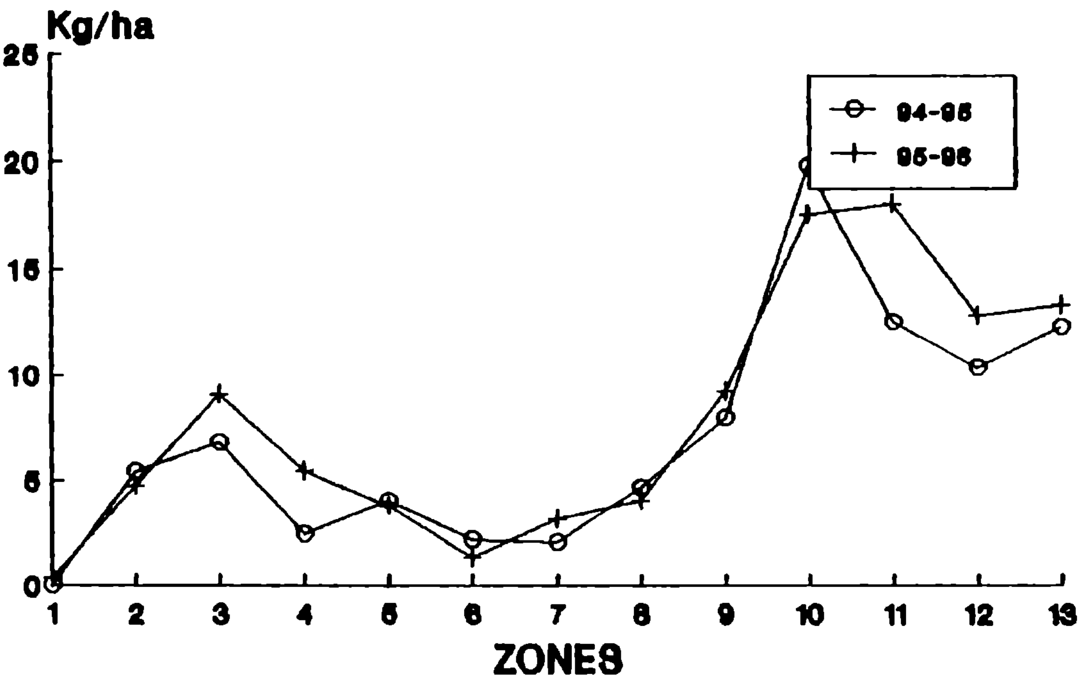

TONS
20
15
10
5
0
FEMALES
MALES
2
3
4
5
6
7
8
9
10
11
12
13
ZONES

a


TONS
25
20
15
10
5
0
FEMALES
MALES
1
2
3
4
5
6
7
8
9
10
11
12
13
ZONES

b

Fig. 8.4 Zone wise production per hectare of *Macrobrachium rosenbergii* in Vembanad lake during 1994-95 and 1995-96



Kg/ha
25
20
15
10
5
0
94-95
95-96
1
2
3
4
5
6
7
8
9
10
11
12
13
ZONES

Fig. 8.5 Fishery of *Macrobrachium rosenbergii* in various zones of Vemband lake during March 94 to February 96

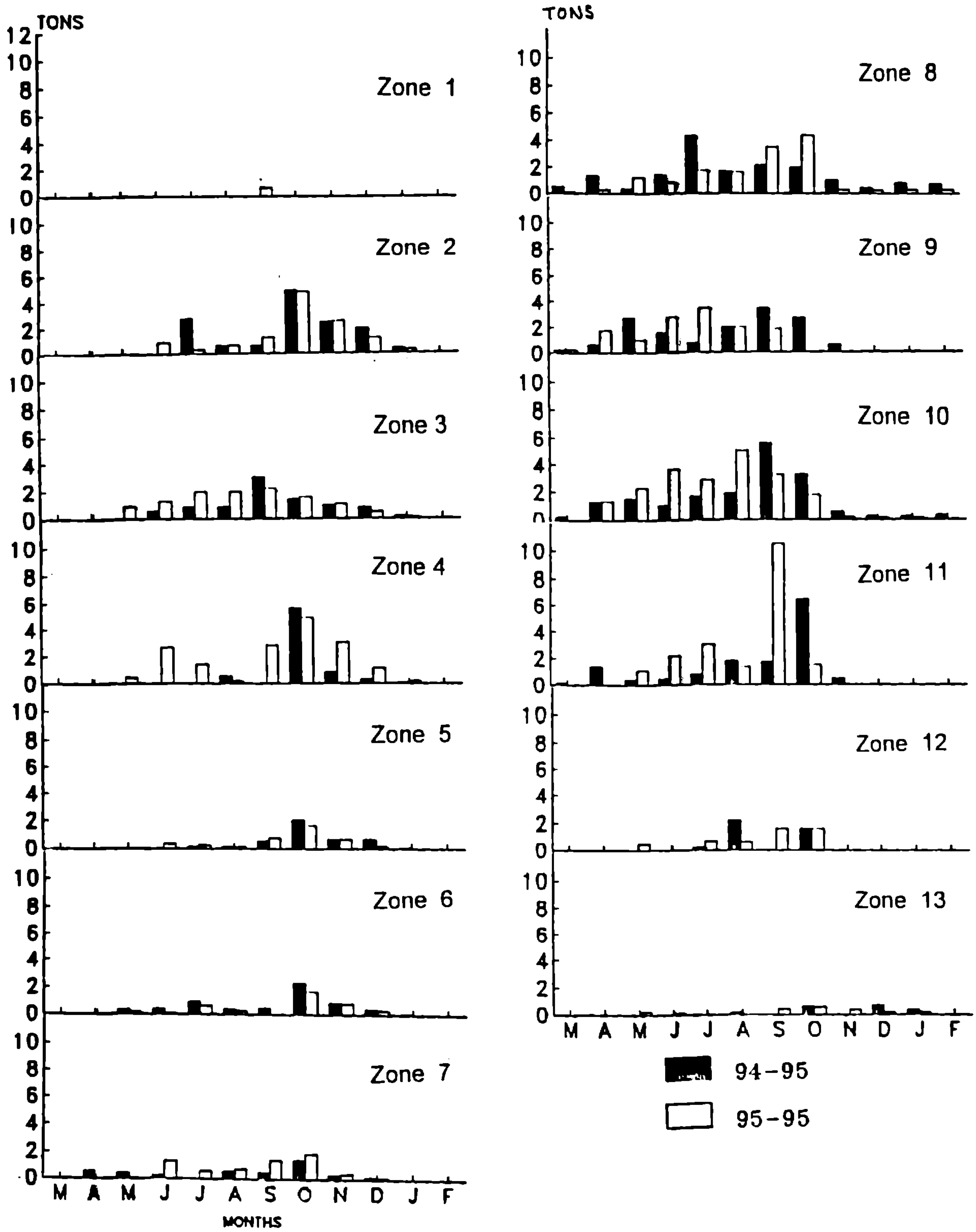
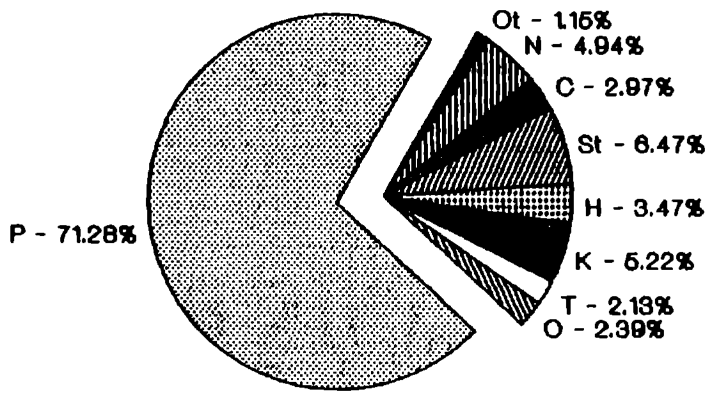

TONS
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
Zone 13
M A M J J A S O N D J F
MONTHS
94-95
95-95

Fig. 8.6 Percentage exploitation of *Macrobrachium rosenbergii* by various fishing gears and methods




1994-95

P = Pongu veechal

K = Koti kuthi veechal

T = Thady veechal

O = Ottal

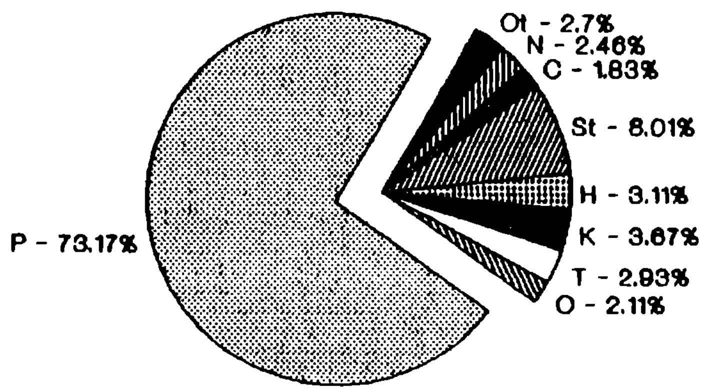
N = Neettu vala

C = Chinese net

St = Stakenet

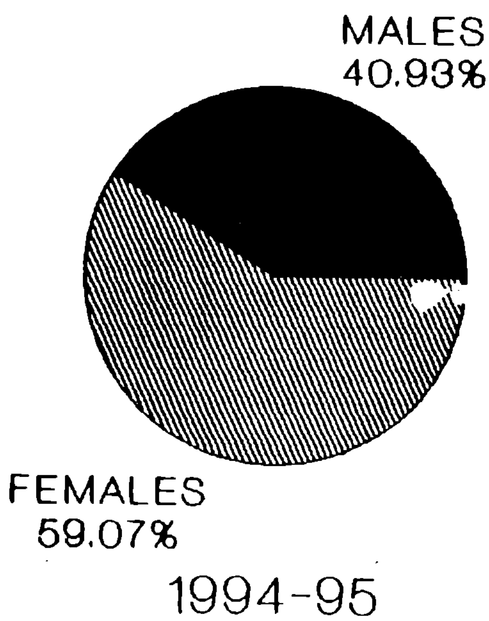
H = Hand lines

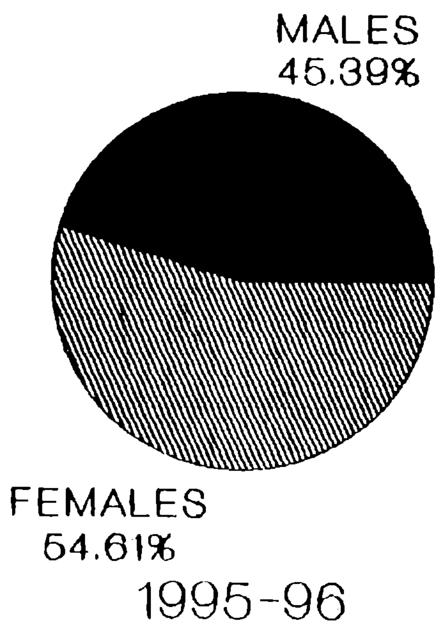
Ot = Other gears (Padal, seines)




1995-96

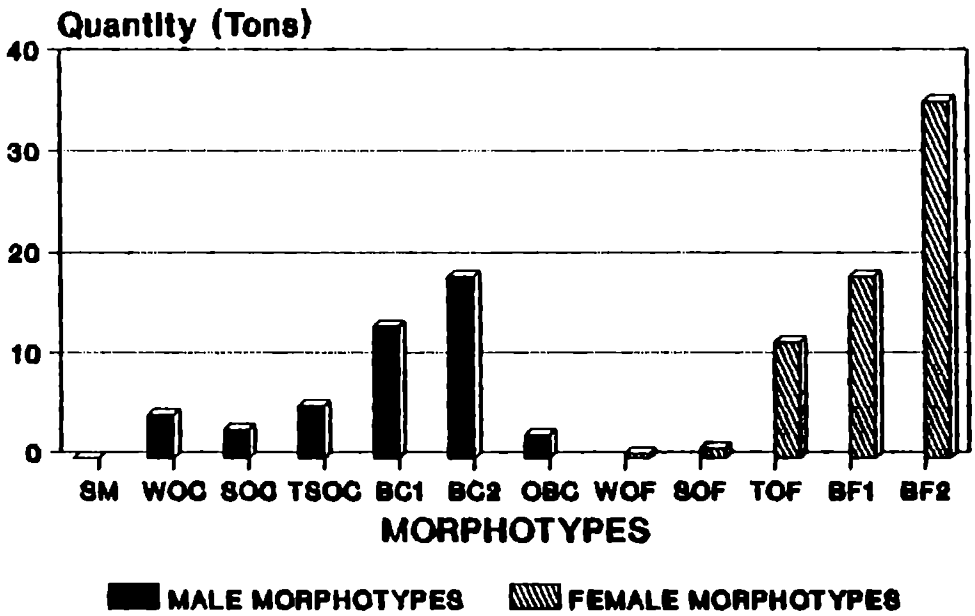
Fig. 8.7 Percentage composition of males and females in the exploited stock of *Macrobrachium rosenbergii*


MALES
40.93%
FEMALES
59.07%
1994-95


MALES
45.39%
FEMALES
54.61%
1995-96

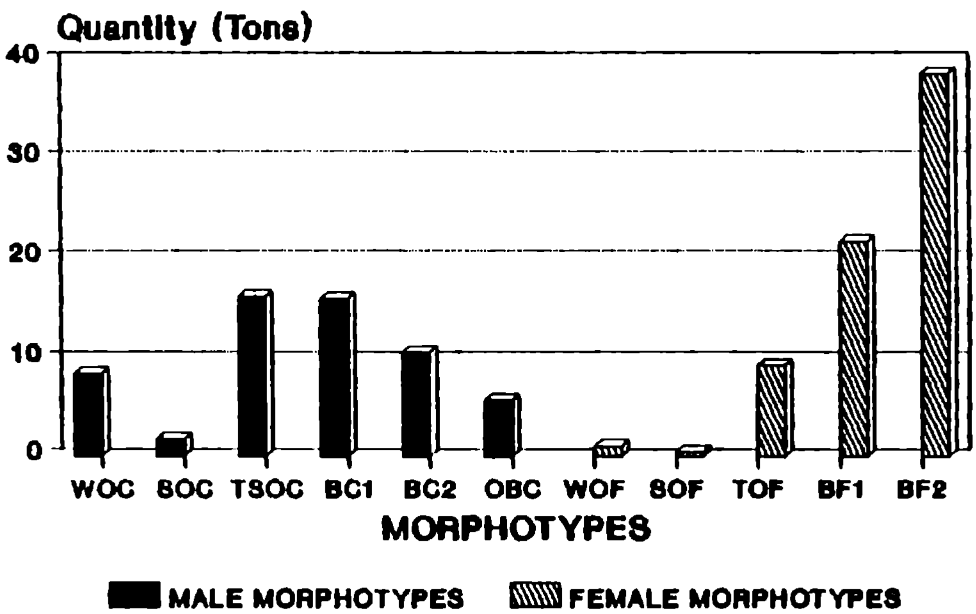
|Fig. 8.8 Contribution of male and female morphotypes in the fishery of *Macrobrachium rosenbergii*in Vembanad lake during

a) 1994-95 b) 1995-96



Quantity (Tons)
40
30
20
10
0
SM WOC SOC TSOC BC1 BC2 OBC WOF SOF TOF BF1 BF2
MORPHOTYPES
MALE MORPHOTYPES
FEMALE MORPHOTYPES


a

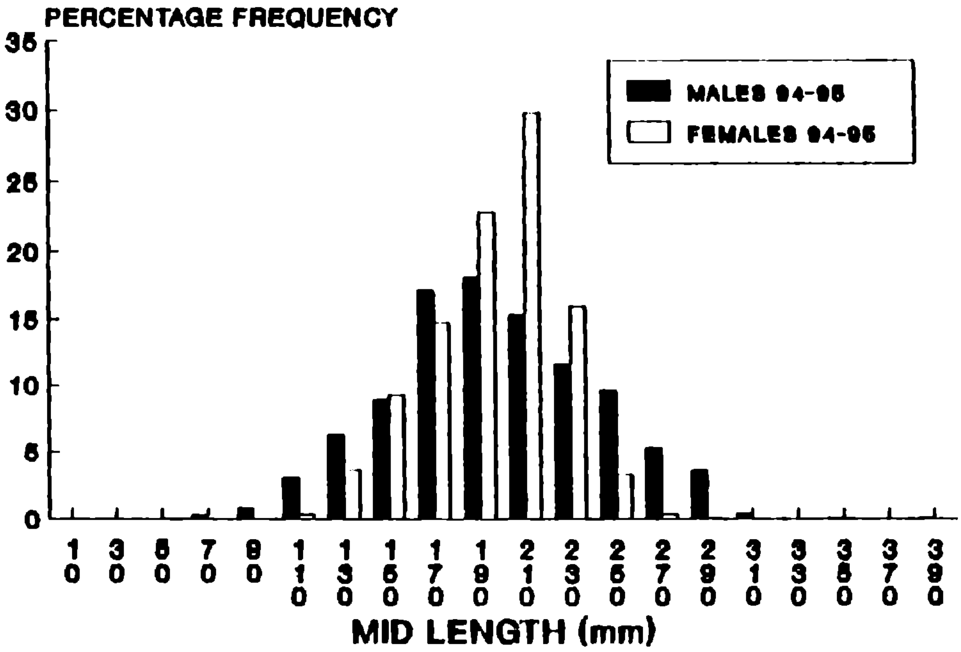


Quantity (Tons)
40
30
20
10
0
WOC SOC TSOC BC1 BC2 OBC WOF SOF TOF BF1 BF2
MORPHOTYPES
MALE MORPHOTYPES
FEMALE MORPHOTYPES

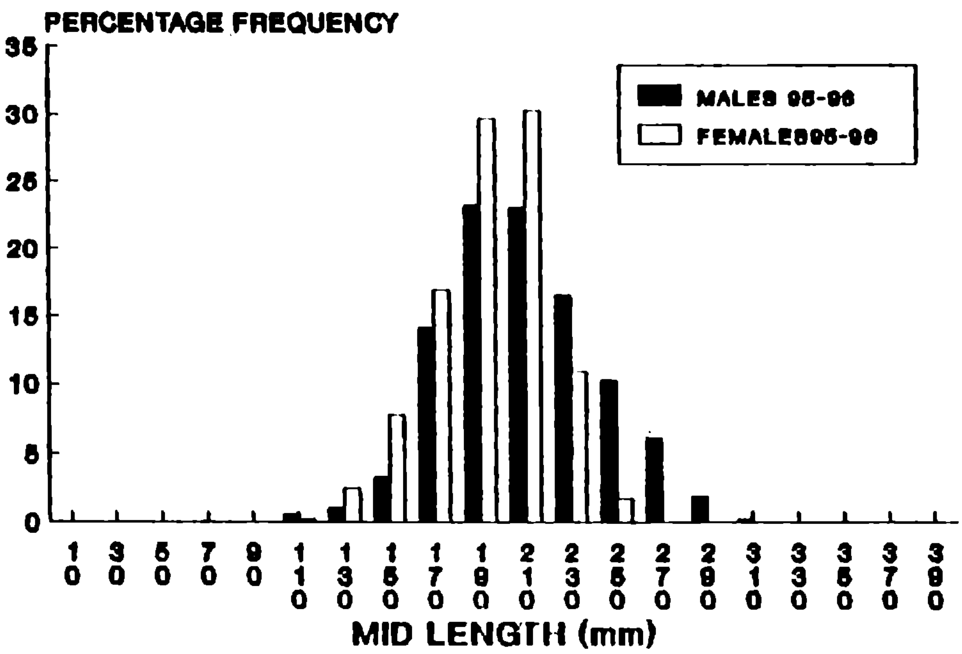

b

Fig. 8.9 Length frequency distribution of males and females in the exploited stock of *Macrobrachium rosenbergii*

a)1994-95 b) 1995-96


PERCENTAGE FREQUENCY
MALES 94-95
FEMALES 94-95
MID LENGTH (mm)

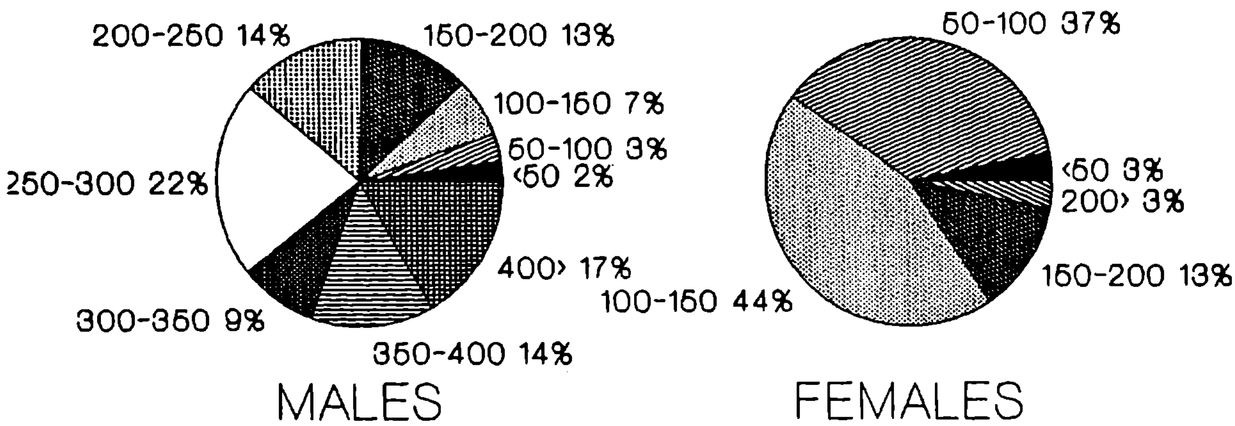
a


PERCENTAGE FREQUENCY
MALES 95-96
FEMALES95-96
MID LENGTH (mm)

b

Fig. 8.10 Marketable weight structure of the exploited stock of *Macrobrachium rosenbergii*

a) 1994-95 b) 1995-96


200-250 14%
150-200 13%
100-150 7%
50-100 3%
<50 2%
250-300 22%
400> 17%
300-350 9%
350-400 14%
MALES
50-100 37%
<50 3%
200> 3%
150-200 13%
100-150 44%
FEMALES

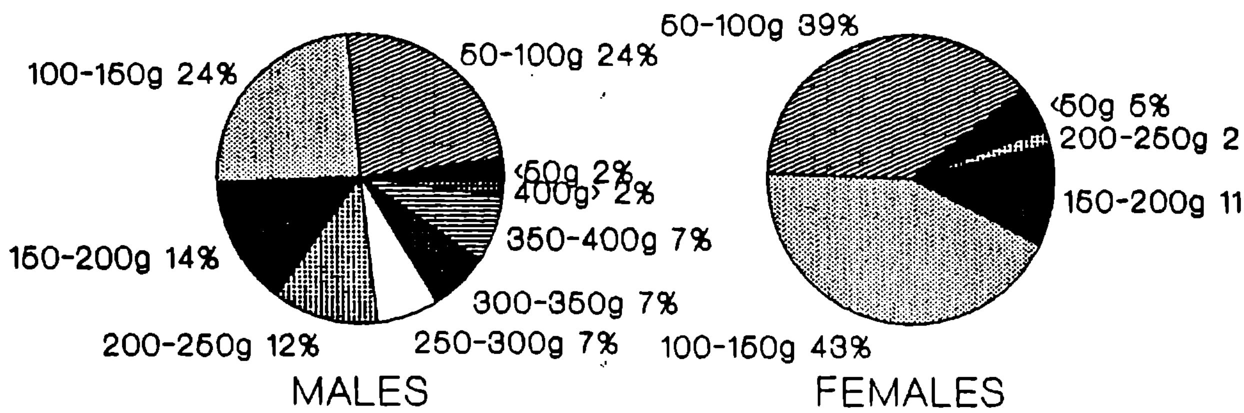
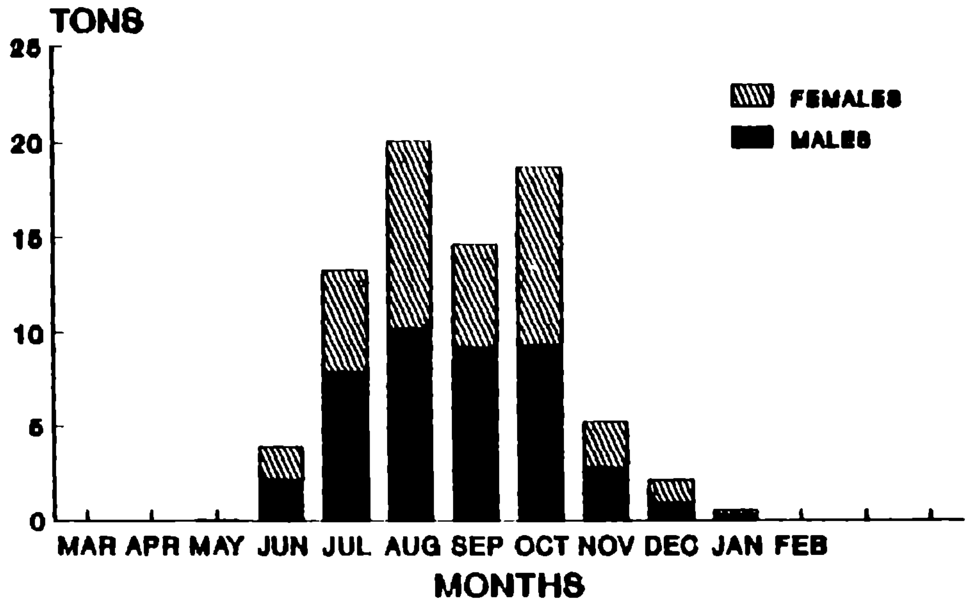
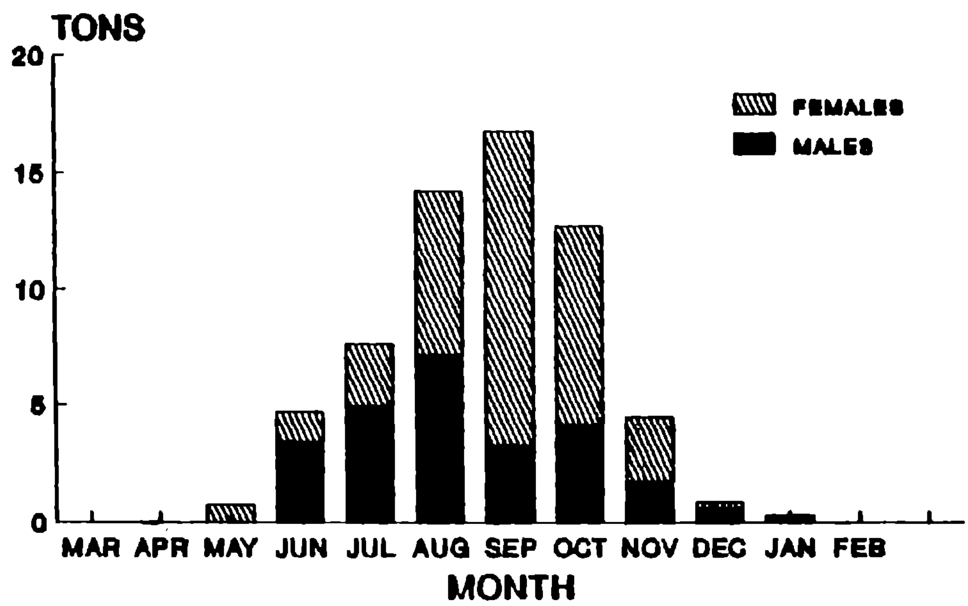

100-150g 24%
50-100g 24%
<50g 2%
400g> 2%
350-400g 7%
150-200g 14%
300-350g 7%
200-250g 12%
250-300g 7%
MALES
50-100g 39%
<50g 5%
200-250g 2
150-200g 11
100-150g 43%
FEMALES

Fig. 8.11 Month wise landings of male and female of *Macrobrachium idella* in Vembanad lake

a) 1994-95 b) 1995-96


TONS
25
20
15
10
5
0
FEMALES
MALES
MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
MONTHS

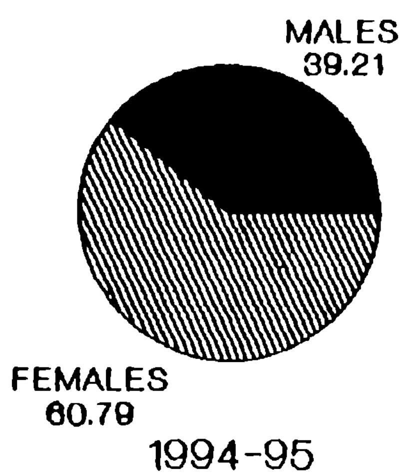
a


TONS
20
15
10
5
0
FEMALES
MALES
MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
MONTH

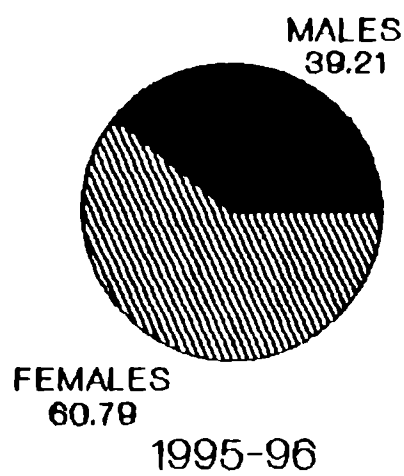
b

Fig. 8.12 Percentage composition of male and female in the exploited stock of *Macrobrachium idella* in Vembanad lake

a) 1994-95 b) 1995-96


MALES
39.21
FEMALES
60.79
1994-95

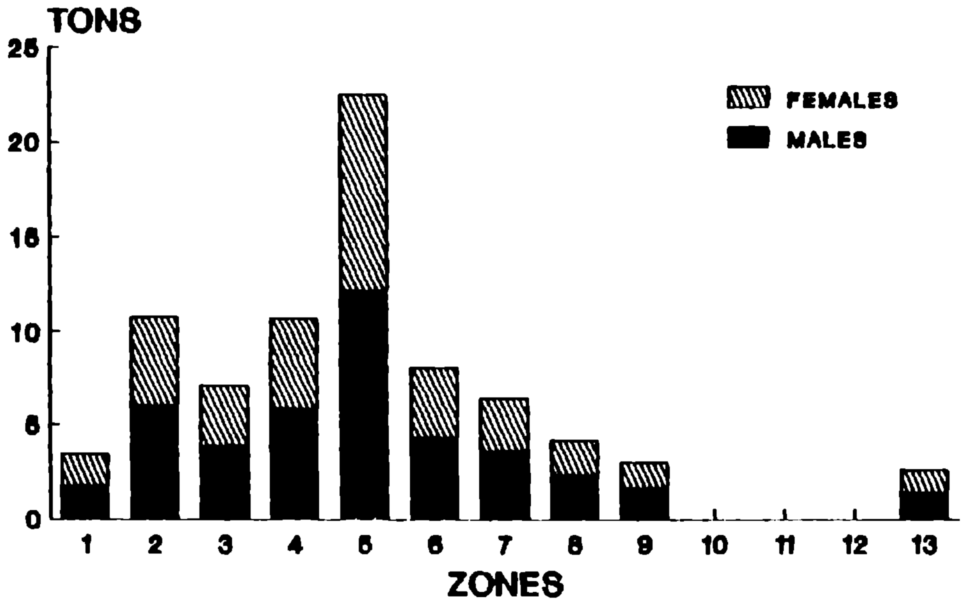
a


MALES
39.21
FEMALES
60.79
1995-96

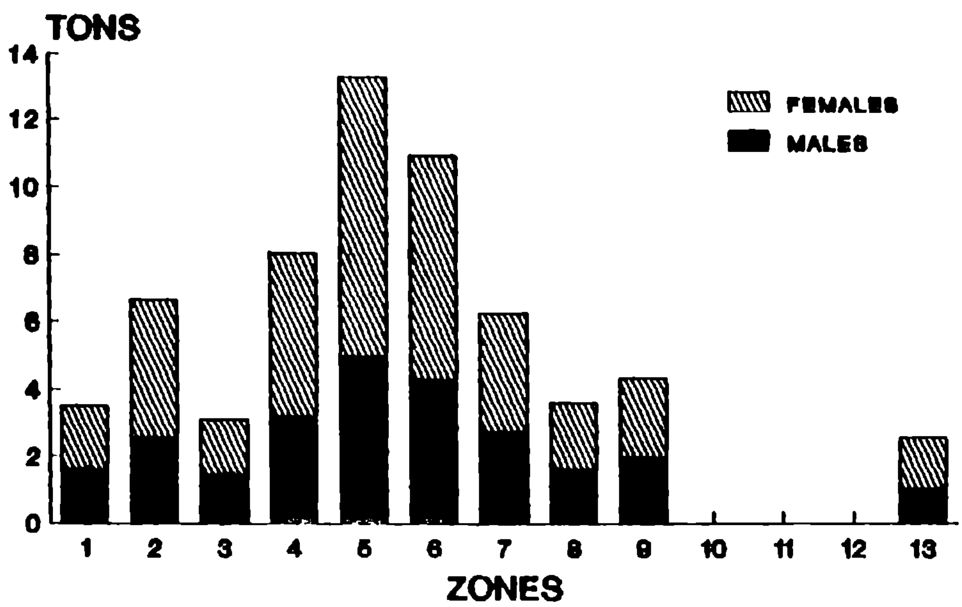
b

Fig. 8.13 Zone wise landings of male and female *Macrobrachium idella* in Vembanad lake during

a) 1994-95 b) 1995-96

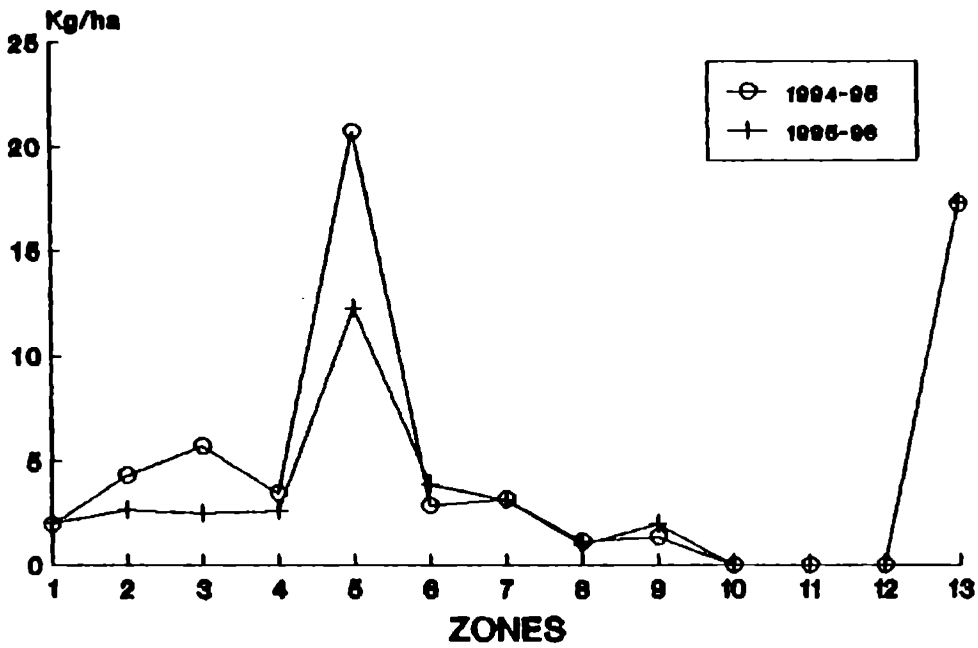

TONS
25
20
15
10
5
0
FEMALES
MALES
1
2
3
4
5
6
7
8
9
10
11
12
13
ZONES

a


TONS
14
12
10
8
6
4
2
0
FEMALES
MALES
1
2
3
4
5
6
7
8
9
10
11
12
13
ZONES

b

Fig. 8.14 Zone wise production per hactare of *Macrobrachium idella* during 1994-95 and 95-96




M.idella total prod/ha zone wise

Fig. 8.15 Fishery of M.idella from various fishing zones during March 94 to February 96

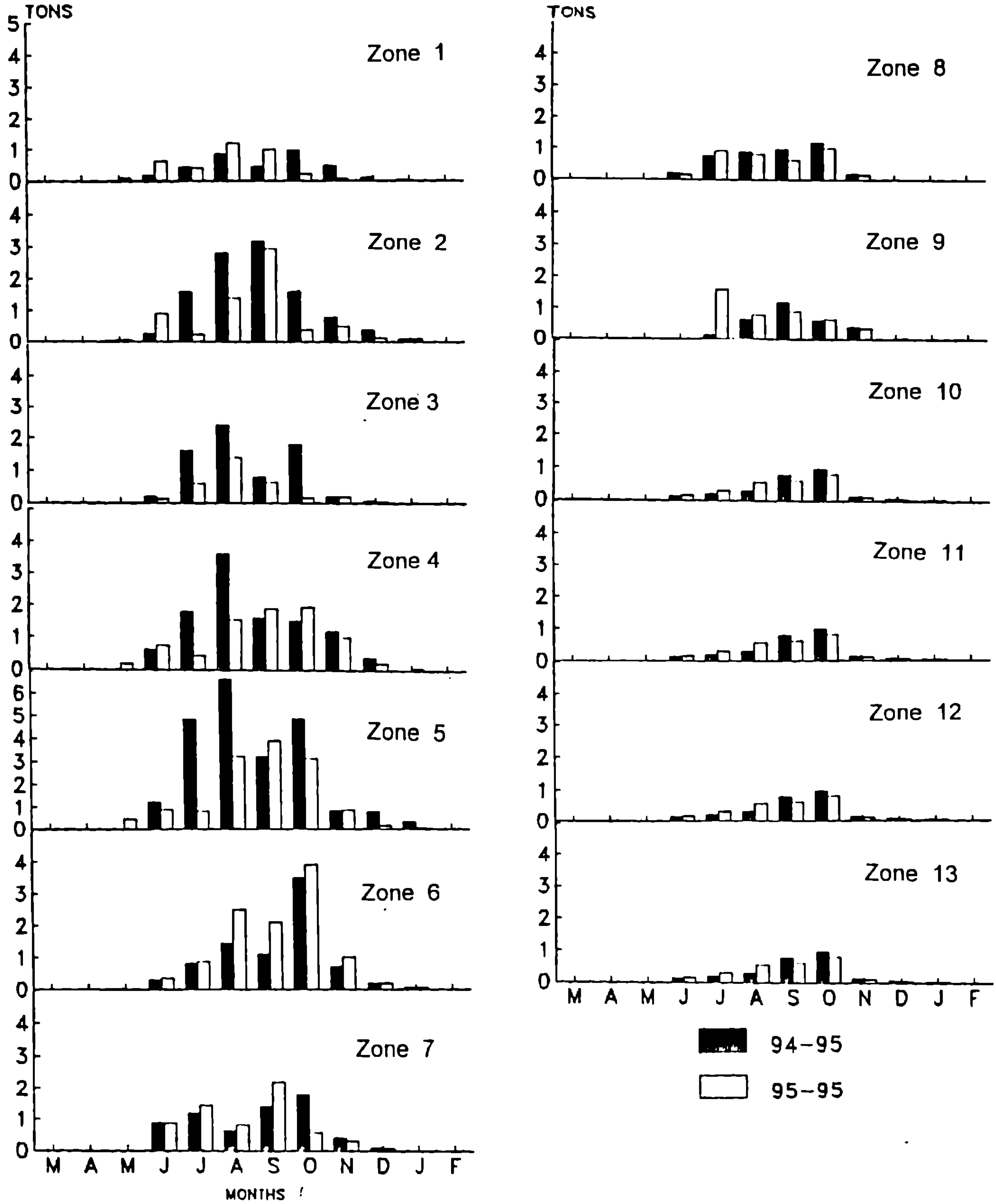
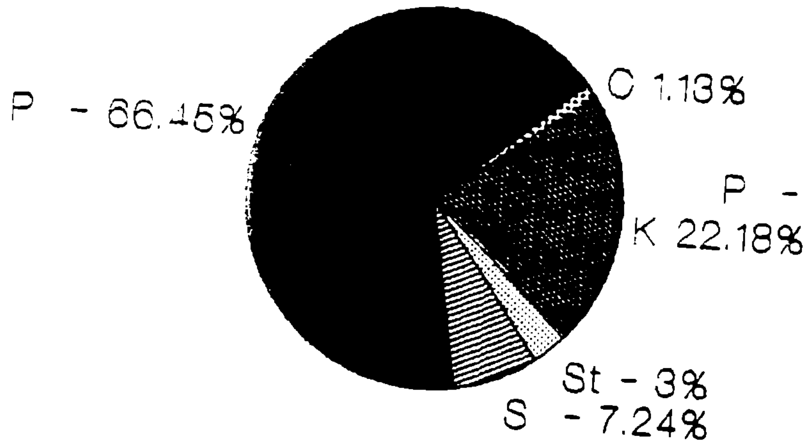
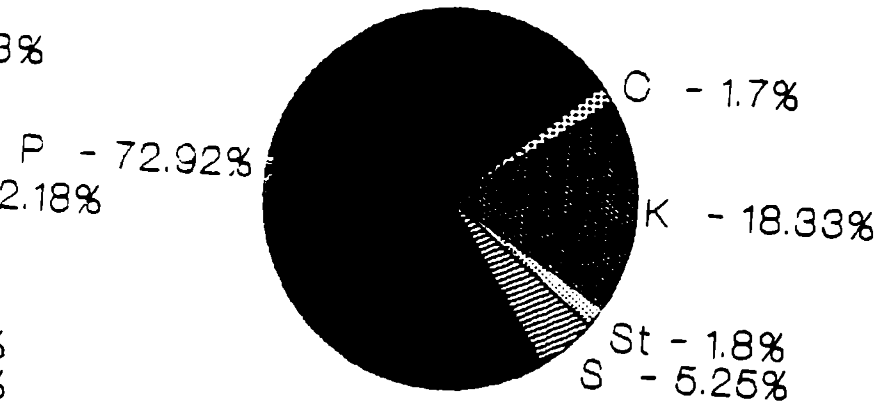

TONS
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
Zone 13
M A M J J A S O N D J F
MONTHS
94-95
95-95

Fig. 8.16 Percentage contribution of *Macrobrachium idella* from various fishing gears and methods

a) 1994-95 b) 1995-96




1994-95
a

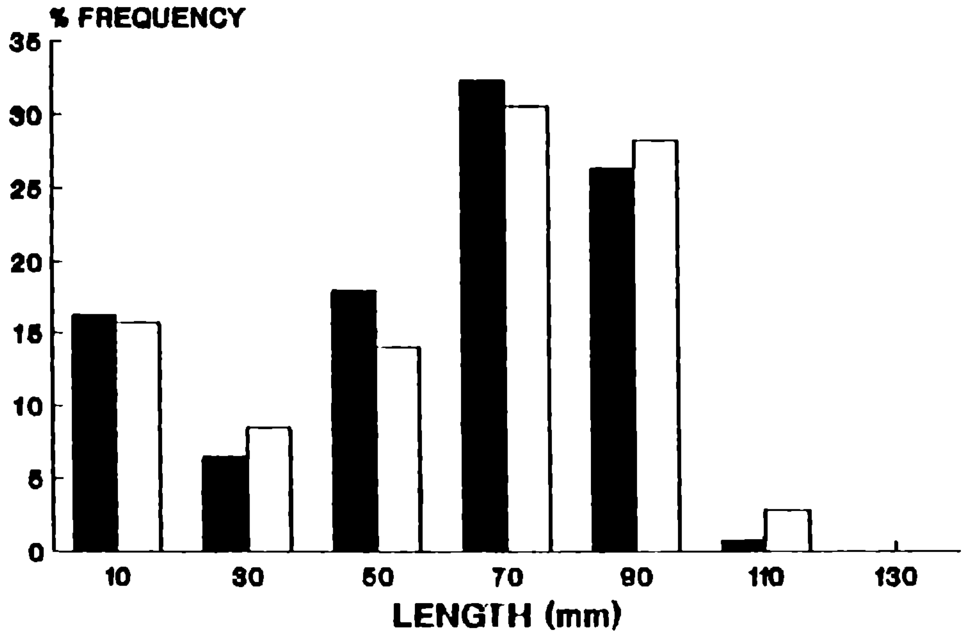



1995-96
b

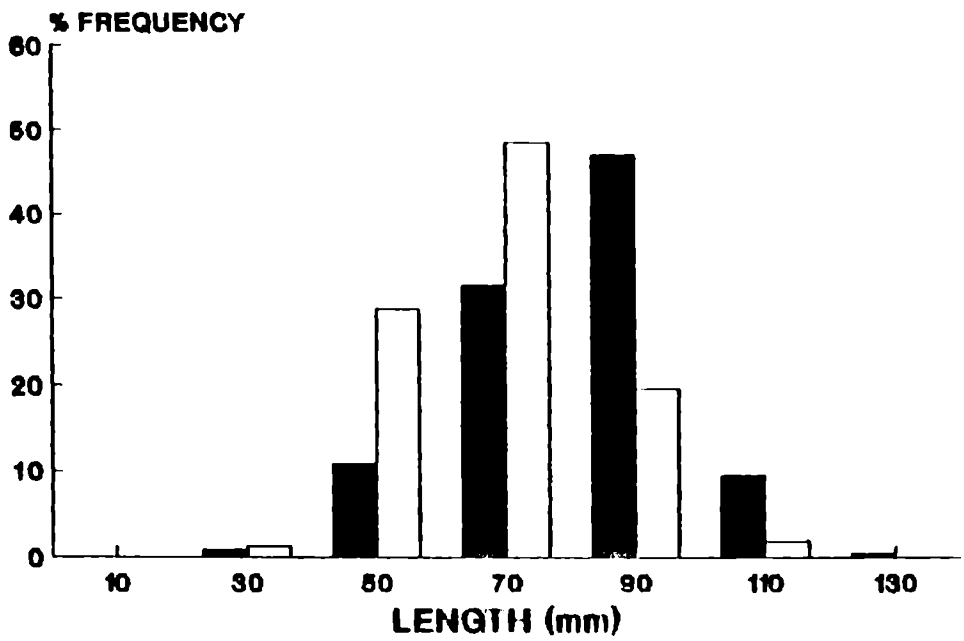
**P- PADAL; S- SEINES; St- STAKE NETS; C- CHINESE NETS**
**K- KOTI KUTHI VEECHAL**

Fig. 8.17 Length frequency distribution of males and females in the exploited stock of *Macrobrachium idella*

a) 1994-95 b) 1995-96




1994-95




1995-96

**PLATE 10 Fishing methods of *Macrobrachium rosenbergii* (de Man)**

A. **Cast net operation - Pongu Veechal**

B. **Cast net operation - Koti Kuthi Veechal**

PLATE 10

A

B

**PLATE 11. Fishing methods of *Macrobrachium rosenbergii* (de Man)**

A. **Ottal**
B. **Spear (Muppalli)**
C. **Padal (Veechu padal)**

**PLATE 11**

A

B

C

# CHAPTER 9

# GROWTH AND POPULATION DYNAMICS

## 1. INTRODUCTION

Fishery resources are renewable and therefore, scientific management for its optimal exploitation is very essential for maintenance of the stock under sustainable level. For successful management practices, a knowledge on the dynamics of the prawn population is highly necessary to understand and quantify the stock, that could be produced in consideration of the losses due to fishing as well as natural causes. These information are also useful to regulate the exploitation level and for proposing conservatory measures. Further, it would also help to understand the status of the stock under the given environmental and fishing conditions.

Males of *Macrobrachium rosenbergii* (de Man) are characterised themselves into distinct morphologically distinguishable forms and three such morhotypes such as small male (SM),orange clawed male (OC) and blue clawed male (BC)have been described from the grow outs (Kuris *et al.*,1987). Recently, Harikrishnan and Kurup (1997a) diagnosed similar morphotypic differentiation in the natural population also and reported the occurrence of above three male morphotypes. Besides, the two transitional stages of OC *viz.* weak orange clawed (WOC) and pre-transforming orange clawed (t-SOC) were also distinguished and therefore the fully differentiated orange clawed males were redesignated as strong orange clawed male (SOC). Similarly, the transitional stages of BC *viz.* WBC were also diagnosed from the fully differentiated BC and therefore the fully differentiated blue clawed males were designated as strong blue clawed males(Kurup, *et al.*1996). BC with relatively small body size in relation to carapace length and body weight disproportionate with claw length has been differentiated as Old blue clawed Males following Sagi and Ra'anan(1988). The existence of morphotypes in the natural female population of *M. rosenbergii* has only been distinguished recently (Harikrishnan and Kurup(1997a) and therefore their dynamics remain unknown.

According to Gulland (1969) a statistical sample of individuals from a stock should be characterised by " homogeneity of natural production characteristics " such as cohort strength (recruitment), growth rate, natural and fishing mortality rates and gain by immigration and loss by emigration shall be negligible. According to him, a stock may be a portion of the population or include more than one population which has to be established on the basis of the above production characteristics. In compliance with the concept of stock as envisaged by Gulland (1969), OC and BC morphotypes inhabiting Vembanad lake can be considered as two separate stocks on the basis of differences observed in regard to growth rate and fishing and natural rates. Moreover, the appearance of these stocks in the lake were also noticed differentially and therefore were also subjected to different levels of fishing pressures.Hence, morphotype wise study on the growth parameters, mortality rate and exploitation ratio would be more meaningful for a proper understanding of the dynamics of the above stocks inhabiting the lake. However, no such differentiation could be seen in the population of *M.idella* and therefore the dynamics of male and female population is studied. These two species formed the mainstay in the exploited stock from the lake and therefore information on dynamics and stock characteristics are highly essential for a judicious exploitation and management of the resources. Kurup *et al* (1992a) made a preliminary attempt to study the stock characteristics of the male and female population of these two species. In the present study an attempt is made to estimate the growth parameters, mortality rates, exploitation rates and stock sizes of the male and female morphotypes of *M.rosenbergii* and male and female populations of *M.idella*. Similar studies in penaeid prawns are those of Lalithadevi (1986), Suseelan and Rajan (1989) and Agasen and Mundo (1988).

## 2. MATERIALS AND METHODS

Materials for the present study were collected from the commercial gears and fishing methods operated in the Vembanad lake and adjoining rivers such as cast nets, (*Ponthu veechal, Koti kuthy veechal*) gill nets (*Odakku vala, Ozhukku vala, Podi vala*), seines (*Vatta vala, Thappuvala*) and lines at monthly intervals during the fishery survey cruises carried out during March 1994 to February 1996 (for details refer Section 1.4). Male and female morphotypes and their transformation stages as detailed in the introduction were identified and classified following Kuris *et al.* (1987), Sagi and Ra'anan(1988) and Harikrishnan and Kurup(1997a). A total of 1664 males and 2056 females were analysed for morphotypic composition and length measurements, the latter was recorded to the nearest mm using a vernier caliper.As there was inadequacy in the sample numbers especially in regard to the intermediary stages of male and female morphotypes of *M.rosenbergii* and therefore, the specimens of designated morphotypes and their transitional stages as mentioned in the introduction were pooled together and treated as a single morphotype for subsequent analysis and discussion. Thus two each of male and female morphotype such as orange clawed male(OC) and Blue Clawed male(BC) of the former and Orange clawed female(OF) and Blue clawed female(BF) of the latter were grouped and the estimation were carried out. Among the morphotypes of *M. rosenbergii*, specimens of small males and small females could not be collected from the lake in appreciable numbers and therefore the dynamics of these morphotypes was not attempted. Among male morphotypes, 1002 and 662 of OC and BC respectively were examined while 589 and 1467 of OF and

BF respectively were used for this study. Similarly, 11,501 of males and 12,800 of females of *M. idella* were also examined for studying the population dynamics.

2.1 Growth

The length frequency data were grouped into 20 mm class intervals and sequentially arranged for two years. The growth parameters were estimated following integrated method of Pauly (1982, 1983) and ELEFAN I (Gayanilo *et al.*,1996).

The von Bertalanffy growth formula (VBGF) (Bertalanffy, 1938) was used to describe the growth. The equation in growth in length is given by

$$L_t = L_\infty (1-\exp^{-k(t-t_0)})$$

where Lt is the length at age t, $L\infty$ is the asymptotic length, K is a growth coefficient and 'to' is the age at which animal would have had zero length if they had always grown according to the above equation. Lengths at age of three months intervals were obtained from the integrated method of Pauly (Pauly, 1983) and estimates of $L\infty$ and K were done using Ford- Walford plot (Ford, 1933; Walford, 1946) which in the linear form is given by

$$L_{t+1} = L_\infty (1-e^{-k}) + e^{k} L_t$$

OR

$$L_{t+1} = a + bLt$$

The lengths at age derived were subjected to linear regression and the results obtained were employed to calculate the growth parameters, $L\infty$ and K as per the following formulae.

$$L_\infty = a / (1-b)$$

$$K = -\log_e b$$

The time interval used was one quarter (3 months) and hence the K value obtained was multiplied by 4 to get the annual growth coefficient or curvature parameter.

Estimate of $t_0$ was also made using von Bertalanffy (1934) plot in which the results of the regression of $-\ln(1-L_t/L_\infty)$ against t was used in order to calculate $t_0$ as:

$$t_0 = -a / b.$$

The growth performance of morphotypes in terms of length were compared using the formula of Pauly and Munro (1984)

$$= \log_{10} K + 2 \log_{10} L_\infty$$

where K is the growth constant ($yr^{-1}$) and $L_\infty$ is the asymptotic length (TL, cm).

2.2) Total mortality coefficient estimation:

The methods employed for the estimation of Z are given below:

(i) **Beverton and Holt method (1966)**

$$Z = K \frac{L_\infty - \bar{L}}{\bar{L} - L'}$$

where $\bar{L}$ is the mean length of the prawn of length L' and larger. L' is the lower limit of the size group from which length upwards, all lengths are under full exploitation.

**(ii) Ssentongo and Larkin method(1973)**

$$Z = K \frac{n}{n+1} \frac{1}{\bar{y} - yc}$$

where $y = -\log(1 - l/l\ )$

$yc = -\log(1 - lc/l\ )$

$\bar{y} = fy / f$ where $n = f$ , $n+1 = f+1$

yc = corresponding to lc value

n = number of prawn caught from yc onwards

l = mid length

**(iii)Length converted catch curve method**
(Gayanilo *et al.*,1996)

$$\ln(N_i / t_i) = a + b\ t_i$$

N is the number in length class i,

t is the time needed to grow through length class i

t is the age corresponding to the midlength of class i (relative age computed with $t_0 = 0$)

b is an estimate of Z when sign changed.

(iv) **Pauly's pile up method (1983)**

$$\log_e(Nt/\ \ t\ ) = a-bt^*$$

$$Z = -(-b)\ \ ,\ t^* = t_1 + 1/2\ \ \ t$$

t = time taken to grow from lower limit of the length class to upper limit

$$t = 1/k \log_e\ (L_\infty - L_1) / (L_\infty - L_2)$$

$$t_1 = {}^1/_K \log_e(1 - {}^1/_{L_\infty})$$

l= lower limit of length class

$t_1$= relative age corresponding to lower limit of length class

$t^*$= relative age corresponding to the mid length of length-class

$N_{t=}$ Number of individual caught at time 't'.

## 2.3 Natural mortality coefficient estimation:

Natural mortality coefficient(M) was estimated using the following methods:

(i) **Sekharans' method(t max method) (1975)**

$$M = -\left(\frac{\log_e 0.01}{t_{max}}\right)$$

where $t_{max}$ = 3/K

$t_{max}$ is the age at $l_{max}$ assuming that 99% of fish in the exploited population die when they reach $t_{max}$ or the longevity of the prawn stock in question (ii)**Pauly's empirical formula (1980)**

Pauly's (1980)empirical formula is given by

$$\log_{10} M = -0.0066-0.279 \log_{10} L_\infty + 0.6543 \log_{10} k + 0.4634 \log_{10} T$$

where M is the natural mortality, $L_\infty$ and K are the parameters of VBGF and T is the annual mean temperature (in C) of water in which the stock lives, is taken as 30 $^{o}$C.

(iii) **Rikhter and Efanov method(1976)**

This method is used to calculate the natural mortality using the relationship

$$M = 1.521\ (t_m^{-0.72})\ -0.155$$

where $t_m$ is the age at which 50% of the population is mature, which was taken as 1.8612 and 1.7635 for OC and BC males while for the whole male population it was computed as 1.2078 years.The above values in respect of OF and BF were 1.4899 and 1.5285 respectively whereas for the whole female population it was estimated as 1.0063.

## 2.4 Fishing mortality estimates

Instantaneous rate of fishing mortality rate (F) was estimated by the subtraction of M from Z as

$$F = Z - M$$

## 2.5 Jones' (1984) length based cohort analysis

Jones' (1984) length cohort analysis was used to estimate stock sizes and fishing mortalities. In this analysis the number of fishes in the river that attain $L_1$ is given by

$$N(L_1) = [ N(L_2) X(L_1,L_2) + C (L_1,L_2)] X(L_1, L_2) \text{ where}$$

$$X(L_1, L_2) = ((L_\infty - L_1)/ ((L_\infty - L_2))^{M/2K}$$

The exploitation rate is determined from the relationship

$$F/Z = C (L_1,L_2)/( N (L_1)-N (L_2))$$

The fishing mortality was calculated using the formula $F= M (F/Z) /(1-F/Z)$. In the above expressions $L_\infty$ and K are growth parameters of VBGE, $L_1$ and $L_2$ are lower and upper limits of a length group considered, N is the stock number, C is the number caught, F and M are fishing and natural mortality coefficients respectively.

2.6 Exploitation rate (U):

The rate of exploitation is defined as the fraction of fish present at the start of the year and that is caught during the year (Ricker, 1975).

The rate of exploitation (U) is estimated by the equation given by Beverton and Holt (1957) and Ricker (1975) as

$$U = F/Z\ (1-e^{-Z})$$

2.6 Exploitation ratio (E)

It refers to the ratio between fish caught and the total mortality (Ricker,1975), estimated by the equation

$$E = \frac{F}{Z} = \frac{F}{M + F}$$

The ratio gives an indication whether a stock is overfished or not, under the assumption that the optimal value of E equals to 0.5 or $E \approx 0.5$which in turn is under the assumption that the sustainable yield is optimised when $F \approx M$ (Gulland,1971).

## 3. RESULTS

### 3.1 *Macrobrachium resenbergii*

i) Growth

The growth parameters computed in respect of male and female population and their respective morphotypes by using ELEFAN I programme and integrated method of Pauly(1983) are shown in Table 1. The restructured length frequency data with super imposed growth curve fitted at highest levels of Rn values in the response surfaces of pooled males, OC and BC and pooled females, OF and BF are depicted in Fig.9.1 and 9.2 respectively. Based on the growth parameters computed by integrated method of Pauly, the growth equations of the above groups can be expressed as follows:

| | |
|---|---|
| OC | : Lt = 318.45 (1-exp-1.2540(t-1.0725) |
| BC | : Lt = 414.08 (1-exp-1.0254(t-1.0988) |
| Pooled males | : Lt = 454.89 (1-exp-0.6780(t-0.1580) |
| OF | : Lt = 291.49 (1-exp-1.1380(t-0.9558) |
| BF | : Lt = 326.50 (1-exp-1.0974(t-0.8889) |
| Pooled females | : Lt = 297.36 (1-exp-1.3660(t-0.2260) |

The computed values of as used to compare the growth performance of the stocks were found to be 3.10, 3.25 and 3.15 for OC, BC and pooled males respectively while that of OF, BF and pooled females were 2.99, 3.07 and 3.08 respectively.

ii) Mortality, Exploitation and stock size:

The total mortality(Z) and natural mortality (M) of male and female population of *M. rosenbergii* and their respective morphotypes were estimated following different methods and the results are given in Table 2. The estimates of total mortality following Beverton and Holt (1957) were found higher in all groups while the values arrived at using length converted catch curve were the lowest. The length converted catch curves for estimating total mortality of pooled males, OC and BC and also of pooled females, OF and BF are shown in Fig.9.3 and 9.4 respectively. Similarly, natural mortality estimate based on Rikhter and Efanov(1976)has given lower values against other two methods as given in Table 2. It would thus appear that the values of Z and M estimated following different methods were not closer and therefore, the average was taken for further computation and analyses.Among the various morphotypes studied, the total mortality was found to be higher in OF followed by BF while in males this coefficient was higher in OC when compared to that of BC. Among the two morphotypes each of male and female, natural mortality values were high in orange clawed morphotypes when compared to blue clawed morphotypes.The natural mortality rate in female population was also found higher when compared to the male.In corollary with the above observations, the fishing mortality coefficients were also high in pooled females and their respective morphotypes when compared to their male counterparts.The exploitation ratio and exploitation rate of the various groups studied are given in Table 2 and it could be seen that the exploitation ratio and exploitation rate were found to be relatively higher in female and its morphotypes when compared to the male counterparts.Among the morphotypes, the above values were glaringly high in BC when compared to that of OC. The estimated F values were found to be slightly higher in comparison with the estimates of average F obtained from cohort analysis in regard to pooled male and female population, in contrast, both the estimated and average of F computed from cohort analysis were found almost similar in the case of OC,BC OF,conversely, the estimated F was very low when compared to the other in respect of BF of *M. rosenbergii*.

Results of the length converted cohort analysis are depicted in Figs.9.5 and 9.6. In male population specimens below 100mm are not vulnerable to exploitation against 80mm in female.Though, a gradual increase in fishing mortality could be seen in 100-230mm in pooled males,a steep increase could be discernible in 230-290mm TL while in OC the fishing mortality was high in 210-270mm TL whereas in BC similar trend could be seen in 270-310mm TL.Conversely, in the pooled females and its two morphotypes OF and BF fishing mortality was invariably high in the size groups 210-230mm.

3.2 *Macrobrachium idella*

i) Growth

The growth parameters estimated in male and female population of by applying ELEFAN I programme and integrated method of pauly (1983) are given in Table 3 . The restructured length frequency data with super imposed growth curve fitted at highest levels of Rn values in the response surface of male and female are shown in Fig.9.7. Based on the growth parameters arrived at by integrated method of Pauly, the growth equations of *M. idella* can be expressed as follows:

Male : Lt = 137.99 (1-exp-0.8450 (t-0.7393)

Female: Lt = 126.94 (1-exp-0.7612 (t+0.0195)

The growth performance of male and female were computed using and the values so arrived at are 2.21 and 2.09 for males and females respectively.

ii) Mortality, Exploitation and Stock size:

Among the mortality rates estimated in male and female population of *M. idella* following different methods(Table 4),the one computed based on Beverton and Holt (1957) appeared as highest in both sexes while lowest values could be observed in length converted catch curve method (Fig.9. 8) whereas the natural mortality estimated based on Rikhter and Efanov (1976) appeared as the lowest (Table 4). As there was disagreement in the values of Z and M arrived at following different methods, further analysis of the data was carried out based on the average values of various methods. Among the two sexes studied, the natural mortality was obviously high in male, on the contrary, high natural mortality could be seen in the femlae population. In compliance with this, the fishing mortality was also apparently high in male population when compared to the female counterpart. The exploitation ratio and exploitation rate were also high in males (Table 4). The estimated F in regard to both male and female were almost similar and therefore comparable.

Results of the length converted cohort analysis revealed that in males and females, specimens in the length group 40-60 mm and above were vulnerable to exploitation, however, heavy exploitation of the length class 60-79 mm was quite discernible (Fig. 9.9). The fishing mortality was found gradually increasing up to 40-59mm and thereafter, it became steep from 60mm onwards in both the sexes.

# 4. DISCUSSION

Of the two species contributing to the commercial fishery of Vembanad lake, *M. rosenbergii* is the most heavily exploited one by virtue of its premium price and good demand for export markets. The stock of this species has undergone an alarming depletion over the past three decades (Kurup *et al.*, 1992b) and therefore, precise assessment of the stock and the resource characteristics of based on length based methods from time to time would be utmost useful in the maintenance of the stock under equilibrium conditions. In Vembanad lake, the peak spawning period of *M. rosenbergii* is reported as September- October months (Kurup *et al.*1992b) and therefore the recruitment of one major mode to the commercial fishery with a distinct modal length arrived at in the present study was very much justifiable on the basis of length frequency data of male and female populations. The growth curves obtained using ELEFAN I also corroborate the possible recruitment of one major brood to the commercial fishery of the lake.

In the present study, an attempt is made to estimate the growth parameters and resource characteristics of both male and female population and their respective morphotypes of *M.rosenbergii*. $L_\infty$ estimated by integrated method of Pauly (1983) and ELEFAN I are similar only in the case of BC males, on the contrary, in pooled males, OF and BF $L_\infty$ computed by the former method have given higher values while in all other groups, the values obtained by using the latter method were higher. Conversely, the K values obtained from Pauly's method (1983) was found higher when compared to ELEFAN I. However, the $L_\infty$ values computed based on the above two methods were distinctly higher than the $L_{max}$ values observed in various groups studied which almost conform to Pauly's equation $L_\infty = L_{max}/ 0.95$. Between two male morphotypes studied, higher $L_\infty$ values were recorded in BC and this observation fully agrees with the hierarchical position occupied by BC in the developmental pathway (Cohen *et al.*,1981; Ra'anan, 1982; Sagi and Ra'anan, 1988). Similar observation could also be seen in regard to BF. The $L_\infty$ of male and female estimated in the present study are distinctly higher when compared to the values reported by Kurup *et al.*, (1992a) and this manifests the representation of higher size classes in the exploited stock in the study period from the lake due to thorough sampling over a period of two years. The K values of male and female estimated in the present study when compared to Kurup *et al.* (1992a) is on a lower side.

Natural mortality M is estimated following three different methods in *M.rosenbergii* in the present study which is inclusive of Pauly's Empirical formula (1980) which is meant only for fishes, however, this method is widely used for shell fishes as well (Suseelan and Rajan,1989; Agasen and Mundo, 1988). Comparison of M by regressing Z against fishing effort is not attempted as the computation of effective effort of *M. rosenbergii* was found practically not feasible and therefore, it may result in unrealistic values of M including negative values as opined by Ricker (1975) and Pauly (1982). Cushing (1981) also opined that the estimation of natural mortality coefficient in exploited population is very difficult. It can reasonably be asserted that natural mortality (M) is related to age and size as the larger fishes are less prone to predations and therefore M can be correlated to longevity of the fish and the latter is highly interrelated to K of VBGF. It would thus appear that M/K ratio can be used as an index for checking the validity of M and K values arrived at following different methods. While working out the ratio of different groups studied by selecting the K arrived at from ELEFAN I, it could be seen that the ratio computed in respect of Blue clawed males, OF and BF by using the M estimated following Rikhter and Efanov method (1976) and Pauly's empirical method (Pauly, 1980) have given values below 1 while ratio was beyond 2.5 in the case of OC when M obtained from the Sekharan's method (Sekharan,1975) was used for the computation. In all other morphotypes, the M/K ratio was found to be with in known limits of 1 to 2.5 (Beverton and Holt, 1959). M/K ratios were also computed based on the K obtained from modal progression analysis (Pauly, 1983) and the results showed that ratios below 1 was observed in regard to OC, BC, OF and BF when M from Ricker and Efanov and Pauly's empirical formula was used whereas in all other estimations using M from Sekharan' method (Sekharan, 1975) the ratios were found to be with in the known limits. It may, therefore, be inferred that the estimation of M following Sekharan's (1975) method appeared to be more reasonable in *M. rosenbergii* when compared to other two methods used for the computation of natural mortality.

The results of the present study revealed that both the total mortality and fishing mortality of *M. rosenbergii* are glaringly high in female population and in its two morphotypes when compared to their male counterparts. In consonance with this exploitation ratio was also found to be relatively high in the female population. In Vembanad lake female contributed to 58.94 % of total exploited stock of which 20.86% forms the berried females (Harikrishnan and Kurup, 1997b). The berried female population is susceptible to heavy fishing pressure during its course of downward breeding migration as a consequence of changes brought about in the ecosystem by human interventions and therefore, high fishing mortality observed in the female population can be attributed to the above reasons. An analysis of the values computed on exploitation ratio of various groups would be helpful in assessing the present level of exploitation of various morphotypes of *M. rosenbergii* in Vembanad lake. While comparing against the values of Ricker (1975), it could be seen that both the male and female population were being well exploited beyond the optimum levels. The results of present study also revealed that the male and female morphotypes of *M. rosenbergii* of Vembanad lake exhibit differences in growth pattern and are also responding and reacting at different levels to various dynamic forces acting on them. The K value which represents the curvature parameter in VBGF, was relatively high in OC and OF which manifests their faster growth when compared to blue clawed morphotypes and this observation strongly corroborates to the earlier findings that the somatic growth in OC was very fast as they spend only very little energy for reproduction and courtship in contrast to intense sexual activity and the consequently reduced growth rate shown by BC males (Sagi and Ra'anan, 1988). The natural mortality coefficients of Orange clawed morphotypes were also found high when compared to that of blue clawed morphotypes. As the three male morphotypes represent three maturation stages in the developmental pathway and are developed by transformation of one morphotypes to another following an irreversible order from SM to OC to BC (Cohen *et al.*,1981), the OC occupies an intermediate stage whose size is distinctly smaller than BC and therefore the natural mortality of this group can normally be expected to be high in comparison with that of BC in view of the fact that smaller prawns are prone to much predation and cannibalism. On the other hand, the fishing mortality, exploitation ratio and exploitation rate were relatively high in Blue clawed morphotypes indicating that the stock of BC are prone to high rate of exploitation. Of the two types of morphotypes studied, Blue clawed morphotypes have emerged as the most heavily exploited group of animals in the lake and this may be attributed to the terminal morphotypic docile occupied by them in the developmental pathway, year round exploitation of the same in view of their prolonged occurrence in the lake when compared to other morphotypes in the exploited stock and also due to their abundance in the lake synchronising with the peak fishing season (Harikrishnan and Kurup, 1997b). The two morphotypes are distinct behaviourally also as BC males are dominant and territorial and characterised with sequestered post moult female prawns to mating exhibiting complex courtship in contrast to subordinate, non territorial and freely moving characters shown by OC males. It may therefore be inferred that BC morphotypes are more vulnerable to fishing pressures due to their sedentary mode of life against the fast moving and widely dispersed conditions of OC males. Harikrishnan and Kurup (1997b) reported the possibility of recruitment over fishing in the stock of *M. rosenbergii* of Vembanad lake and attributed this as one of the reasons for the alarming depletion of the stock observed during the past decade and also proposed different methods for the conservation of the stock such as regulation of fishing effort of the principal gears engaged in the selective fishing of *M. rosenbergii*, especially those involved in the exploitation of berried females, reduction of fishing pressures in breeding stock at the breeding ground and imposition of partial or total ban during the peak period of occurrence of spawner stock etc. The results of the present study revealed that stock of *M. rosenbergii* can not be maintained sustainably by continuing the present level of exploitation rate and therefore, it is highly essential to implement regulatory measures for the rational management of this over exploited stock.

In males and females of *M. idella*, the $L_\infty$ computed by applying ELEFAN I was on a higher side when compared to that of integrated method of Pauly. The Lmax recorded in regard to both the sexes were far below to that of the corresponding $L_\infty$ values and also conform to the equation $L_\infty$ = Lmax / 0.95 as proposed by Pauly (1982). Similarly, the $L_\infty$ value of male was higher in both the methods than the female. Kurup *et al.* (1992b) reported the $L_\infty$ value of male *M. idella* in the range 152.5 to 153.6mm in males and 129mm in females and the present finding when compared against these values show that the values arrived at based on ELEFAN I were well above while the values computed following integrated method of Pauly were far below. The value in respect of other growth parameters such as K and $t_0$ were also found to be low when compared to the estimates of Kurup *et al.* (1992b).

While applying the M/K ratio in order to check the validity of M and K values estimated following different methods, it could be seen that in male of *M. idella*, the M/K ratio was found to be with in known limits of 1-2.5 in all the combinations of M and K arrived at following different methods (Table 2 and 3) while in female also similar results could be observed in all combinaitons barring the combination of M obtained from

Pauly empirical relationship and K estimated following integrated method of Pauly. It may therefore be inferred that the estimates of M following almost all methods appeared to be reasonable and acceptable in *M. idella* and an exception to this inference is with regard to female as mentioned above.

In the present study also, the total mortality and fishing mortality of *M.idella* is glaringly high in males while the natural mortality was high in females and this finding is very much similar to that of Kurup *et al.*(1992b), however, the coefficients estimated at present is far below when compared to values reported by above authors. Both the exploitation ratio and exploitation rate were found to be high in male when compared to their female counterparts. On assessing the state of exploitation by comparing the above values against that of Ricker (1975), it appears that male population of *M. idella* were exploited beyond the optimum levels while female population were exploited more or less at equilibrium level. It may be inferred that the males were more vulnerable to fishery due to their higher size in contrast to the smaller size of females which make them non vulnerable to various types of fishing operations prevalent in the lake.

Table 9.1 Estimated growth paramters of pooled males, orange clawed males, blue clawed males pooled females, orange clawed females and blue clawed females of *Macrobrachium rosenbergii*

| | GROUPS | Lmax | Integrated Modal Progression L inf | K | t0 | ELEFAN I L inf | K | Rn |
|---|---|---|---|---|---|---|---|---|
| 1 | Total Males | 393 | 454.89 | 0.6710 | 0.1580 | 420.00 | 0.9800 | 323 |
| 2 | Orange Males Pooled | 310 | 318.45 | 1.2540 | 1.0725 | 326.00 | 0.5300 | 300 |
| 3 | Blue Males Pooled | 393 | 414.08 | 1.0254 | 1.0988 | 414.80 | 0.9900 | 434 |
| 4 | Total Females | 282 | 297.36 | 1.3660 | 0.2260 | 308.00 | 1.1000 | 541 |
| 5 | Orange females Pooled | 258 | 291.49 | 1.1380 | 0.9558 | 272.00 | 1.2000 | 684 |
| 6 | Blue Females Pooled | 282 | 326.50 | 1.0974 | 0.8889 | 296.00 | 1.0000 | 494 |

Table 9.2 Coefficients of Total Mortality (Z), Natural Mortality (M), Fishing Mortality (F) and Exploitation rate (U) of pooled males, orange clawed males, blue calwed males, pooled females, orange clawed femlaes and blue clawed females of *Macrobrachium rosenbergii*

| | Total Mortality | | | | | Natural Mortality | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pauly's pile up | Beverton & Holt | Ssentongo & Larkins | Length Catch Curve | Average | Rickter Effanov | Sekharan's Method | Pauly's Empirical | Average | Average Z | Average M | Fishing Mortality F | Exploitation rate (U) |
| Total Males | 4.4912 | 6.1946 | 6.1065 | 4.4700 | 5.3156 | 1.5968 | 1.5043 | 1.6000 | 1.5670 | 5.3156 | 1.5670 | 3.7485 | 0.7017 |
| Orange Males Pooled | 3.8576 | 4.7824 | 4.6041 | 3.0000 | 4.0610 | 0.8118 | 1.9249 | 0.9800 | 1.2389 | 4.0610 | 1.2389 | 2.8221 | 0.6830 |
| Blue Males Pooled | 3.6984 | 7.6093 | 1.0205 | 3.4600 | 3.9471 | 0.8503 | 1.5197 | 0.7757 | 1.0486 | 3.9471 | 1.0486 | 2.8985 | 0.7202 |
| Total Females | 3.6621 | 10.5850 | 9.3041 | 5.4600 | 7.2528 | 1.5740 | 1.6886 | 1.8800 | 1.7142 | 7.2528 | 1.7142 | 5.5386 | 0.7631 |
| Orange Females Pooled | 3.9943 | 5.6880 | 5.3564 | 2.4600 | 4.3747 | 0.9807 | 1.8420 | 0.9960 | 1.2729 | 4.3747 | 1.2729 | 3.1018 | 0.7001 |
| Blue Females Pooled | 4.1904 | 7.7309 | 2.7273 | 2.7000 | 4.3372 | 0.9599 | 1.5351 | 0.8623 | 1.1191 | 4.3372 | 1.1191 | 3.2181 | 0.7323 |

Table 9.3 Estimated growth paramters of males and females of *Macrobrachium idella*

| GROUPS | Lmax | Integrated Modal Progression L inf | K | t0 | ELEFAN I L inf | K | Rn |
|---|---|---|---|---|---|---|---|
| Total Males | 126 | 137.99 | 0.8450 | 0.7393 | 156.00 | 0.9100 | 309 |
| Total Females | 118 | 126.94 | 0.7612 | -0.0195 | 132.00 | 0.9400 | 424 |

Table 9.4 Coefficients of Total Mortality (Z), Natural Mortality (M), Fishing Mortality (F) and Exploitation rate (U) of males and females of *Macrobrachium idella*

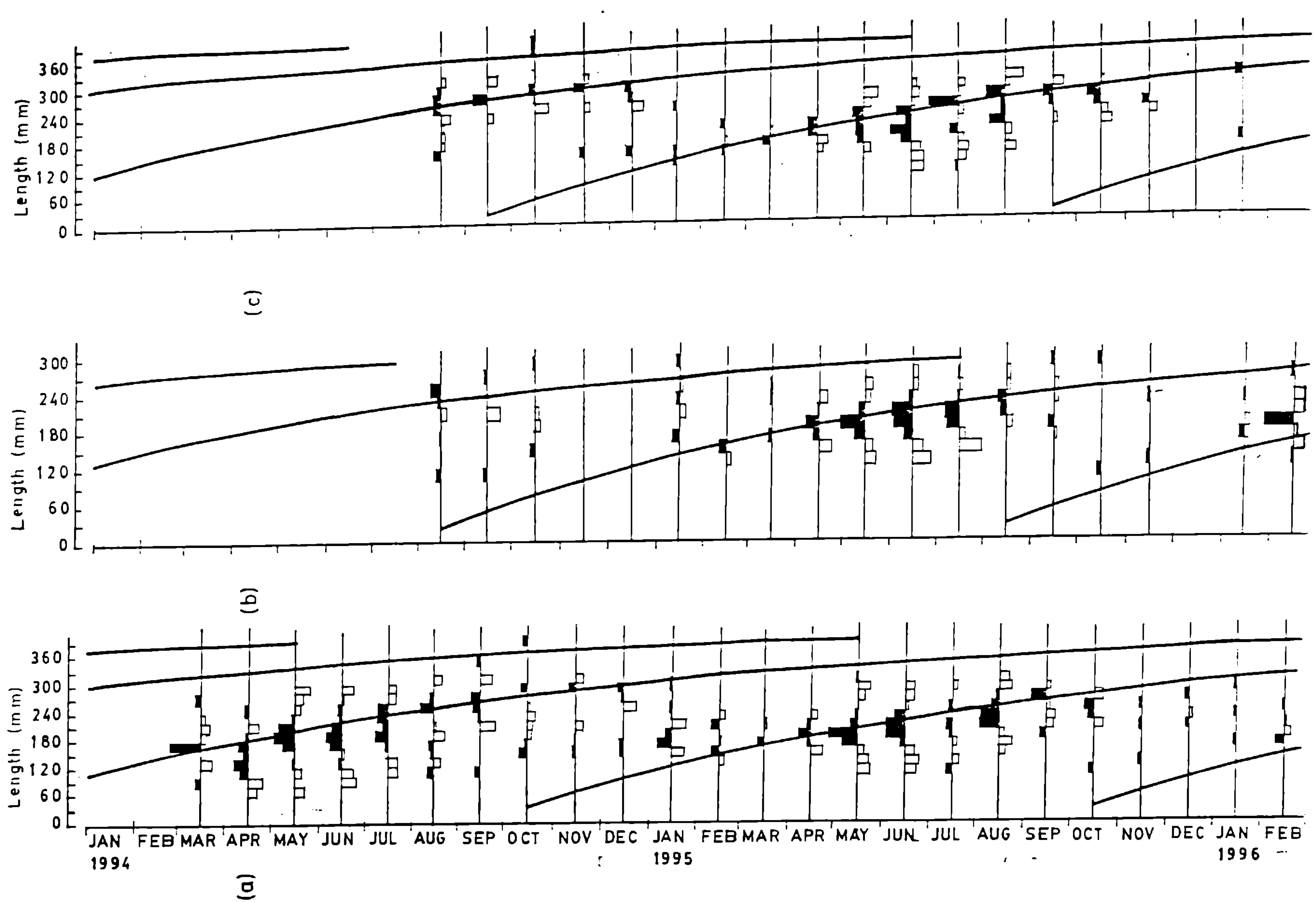
| | Total Mortality | | | | | Natural Mortality | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pauly's pile up | Beverton & Holt | Ssentongo & Larkins | Length Catch Curve | Average | Rickter Effanov | Sekharan's Method | Pauly's Empirical | Average | Average Z | Average M | Fishing Mortality F | Exploitation rate (U) |
| Males | 7.3611 | 10.5080 | 9.9471 | 5.4400 | 8.3141 | 1.2026 | 1.3969 | 0.9788 | 1.1928 | 8.3141 | 1.1928 | 7.1213 | 0.8565 |
| Females | 3.7296 | 6.7321 | 6.0840 | 3.3700 | 4.9789 | 0.9667 | 1.4430 | 4.0855 | 2.1651 | 4.9789 | 2.1651 | 2.8139 | 0.5652 |

Fig. 9.1 Growth curve of pooled males, Orange Clawed males (OC) and Blue Clawed males (BC) of *Macrobrachium rosenbergii* as estimated using the ELEFAN I programme

a) Pooled males (L = 420mm; K= 0.98/year)

b) OC males (L = 320mm; K= 1.20/year)

c) BC males (L = 414mm; K= 0.99/year)



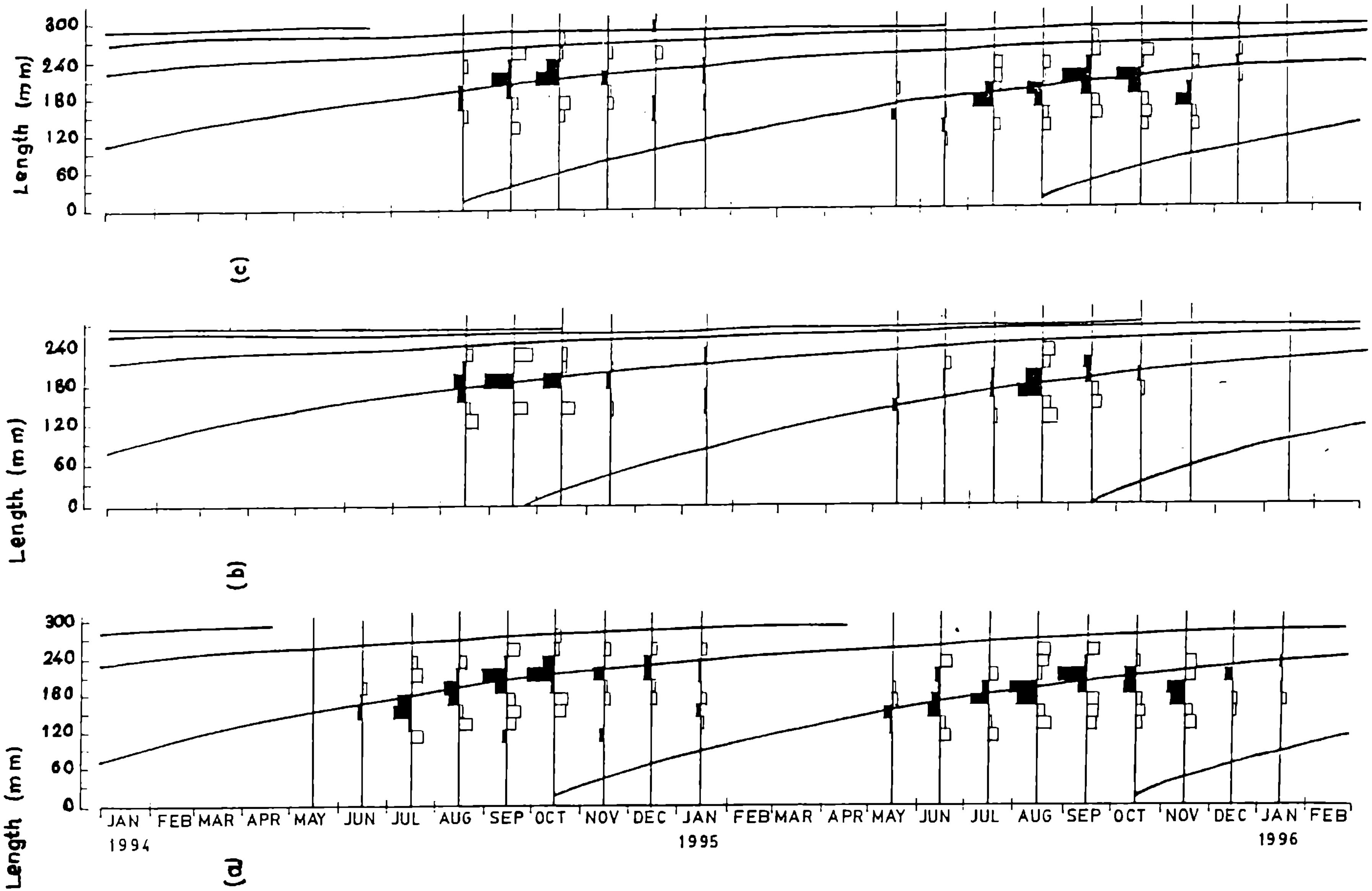
(a)
(b)
(c)
Length (mm)
0
60
120
180
240
300
360
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
1994
1995
1996

Fig. 9.2 Growth curve of pooled females, Orange Clawed females (OF), Blue Clawed females (BF) of *Macrobrachium rosenbergii* as estimated using ELEFAN I programme

a) Pooled female (L = 308mm; K = 1.10/year)

b) OF (L = 272mm; K= 1.2/year)

c) BF (L = 296mm; K= 1.0/year)



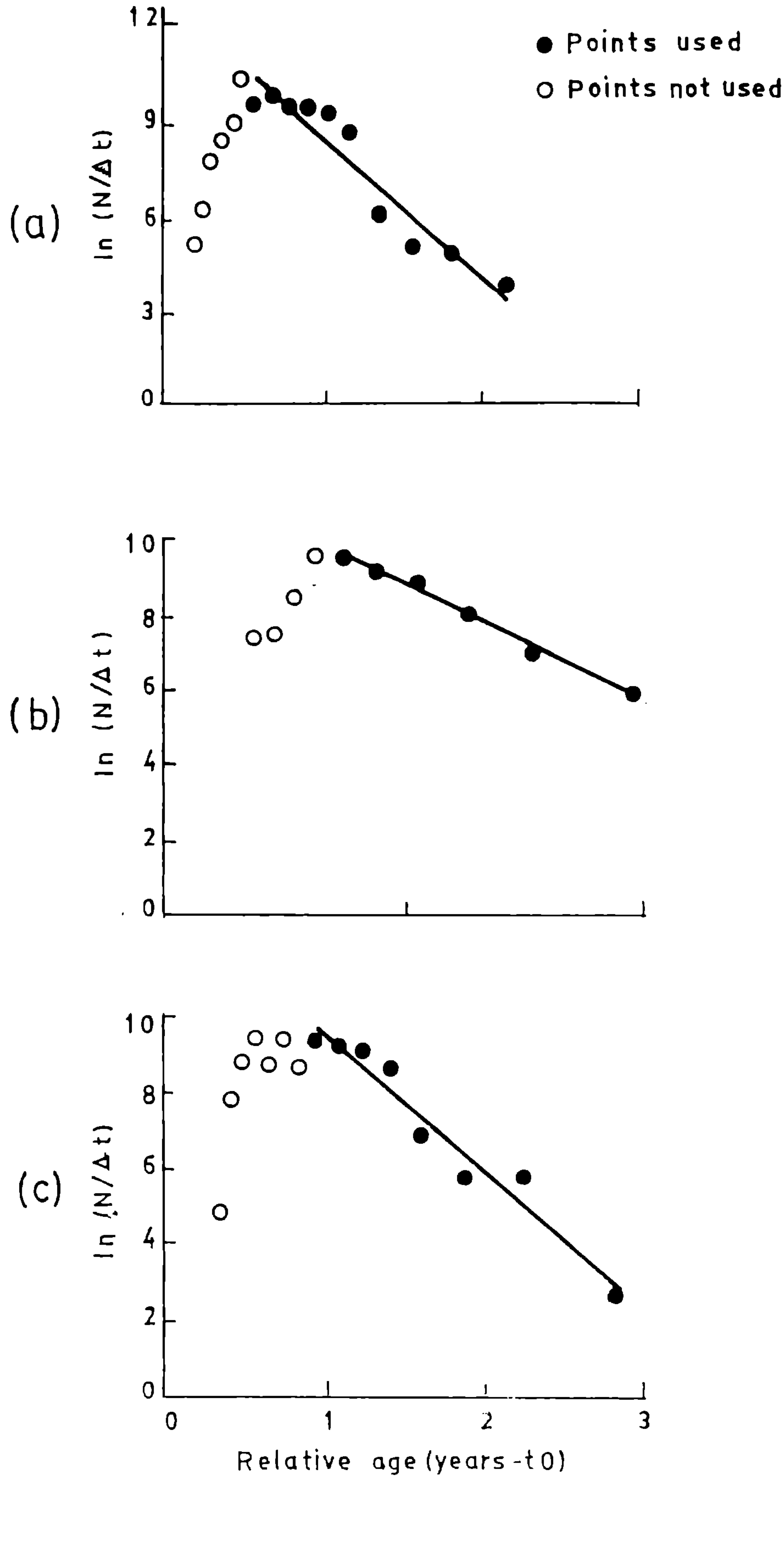
Length (mm)
0
60
120
180
240
300
(c)
Length (mm)
0
60
120
180
240
(b)
Length (mm)
0
60
120
180
240
300
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
1994
1995
1996
(a)

Fig. 9.3 Catch curve of pooled males, OC and BC males of *Macrobrachium rosenbergii* based on length composition

a) Pooled males ($L\infty$= 420mm; K= 0.98/year; Z= 4.47)

b) OC males ($L\infty$= 320mm; K= 1.20/year; Z= 3.00)

c) BC males ($L\infty$= 414mm; K= 0.99/year; Z= 3.46)



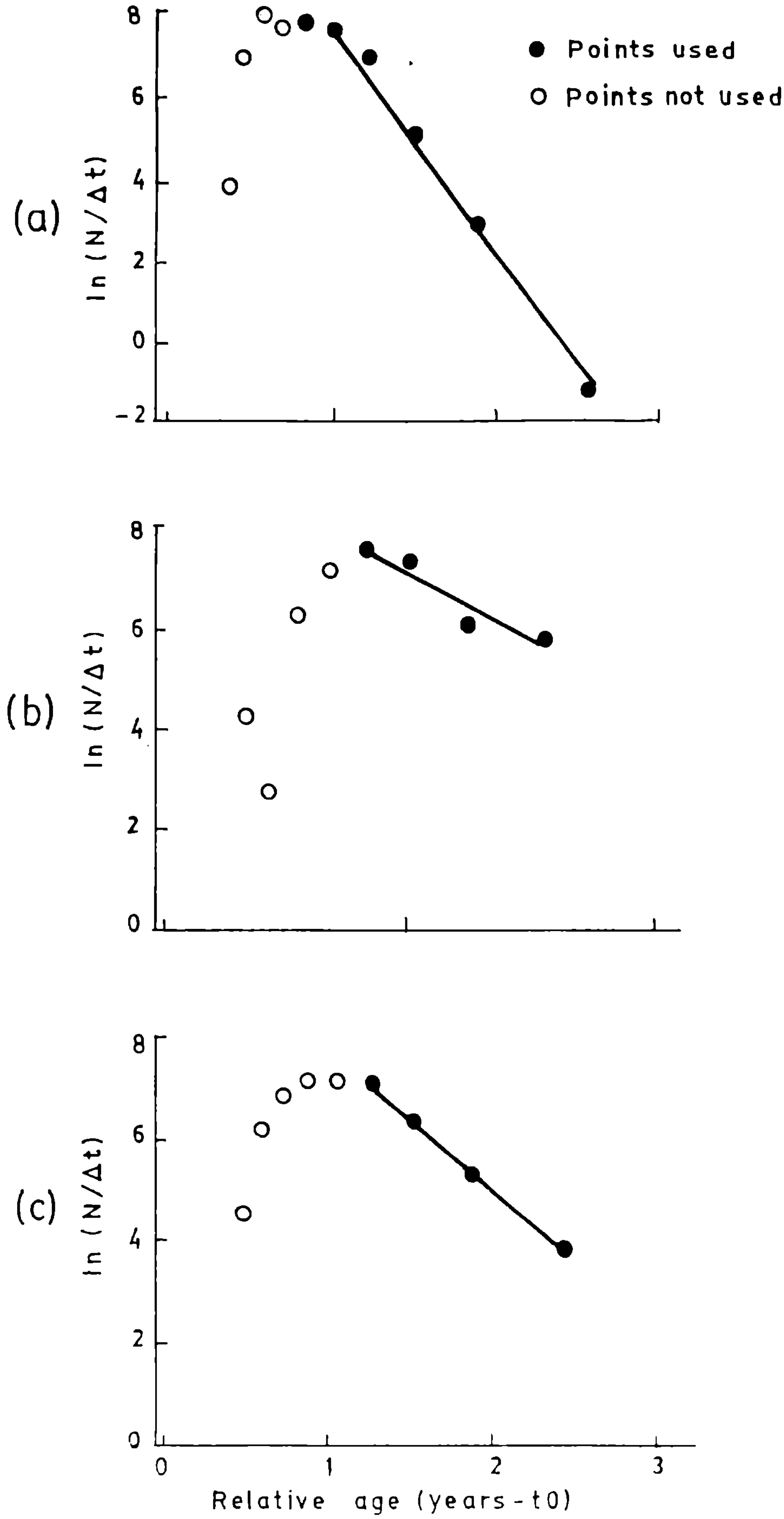
● Points used
○ Points not used
(a)
(b)
(c)
ln (N/Δt)
12
9
6
3
0
10
8
4
2
1
Relative age (years -t0)

Fig. 9.4 Catch curve of pooled females, OF and BF of *Macrobrachium rosenbergii* based on length composition

a) Pooled females ($L_\infty$=308mm; K= 1.10/year; Z=5.46)

b) OF ($L_\infty$= 272mm; K= 1.2/year; Z= 2.46)

c) BF ($L_\infty$= 296mm; K= 1.0/year; Z= 2.70)



Points used
Points not used
(a)
(b)
(c)
ln (N/Δt)
8
6
4
2
0
-2
0
1
2
3
Relative age (years - t0)

Fig. 9.5 Length cohort analysis of pooled males, OC and BC males of *Macrobrachium rosenbergii* of Vembanad lake

a) Pooled males ($L_\infty$= 420mm; K= 0.98/year; Z= 4.47; M=1.5670; Terminal F= 0.4492; Mean F>200mm= 0.5259; Terminal exploitation rate = 0.7565)

b) OC males ($L_\infty$ = 320mm; K= 1.20/year; Z= 3.00; M= 1.2389; Terminal F= 1.20; Mean F>180mm= 0.6171; Terminal exploitation rate = 0.7332)

c) BC males ($L_\infty$= 414mm; K= 0.99/year; Z= 3.46; M= 1.0486; Terminal F= 0.4487; Mean F>240mm= 0.5593; Terminal Exploitation rate = 0.7332)

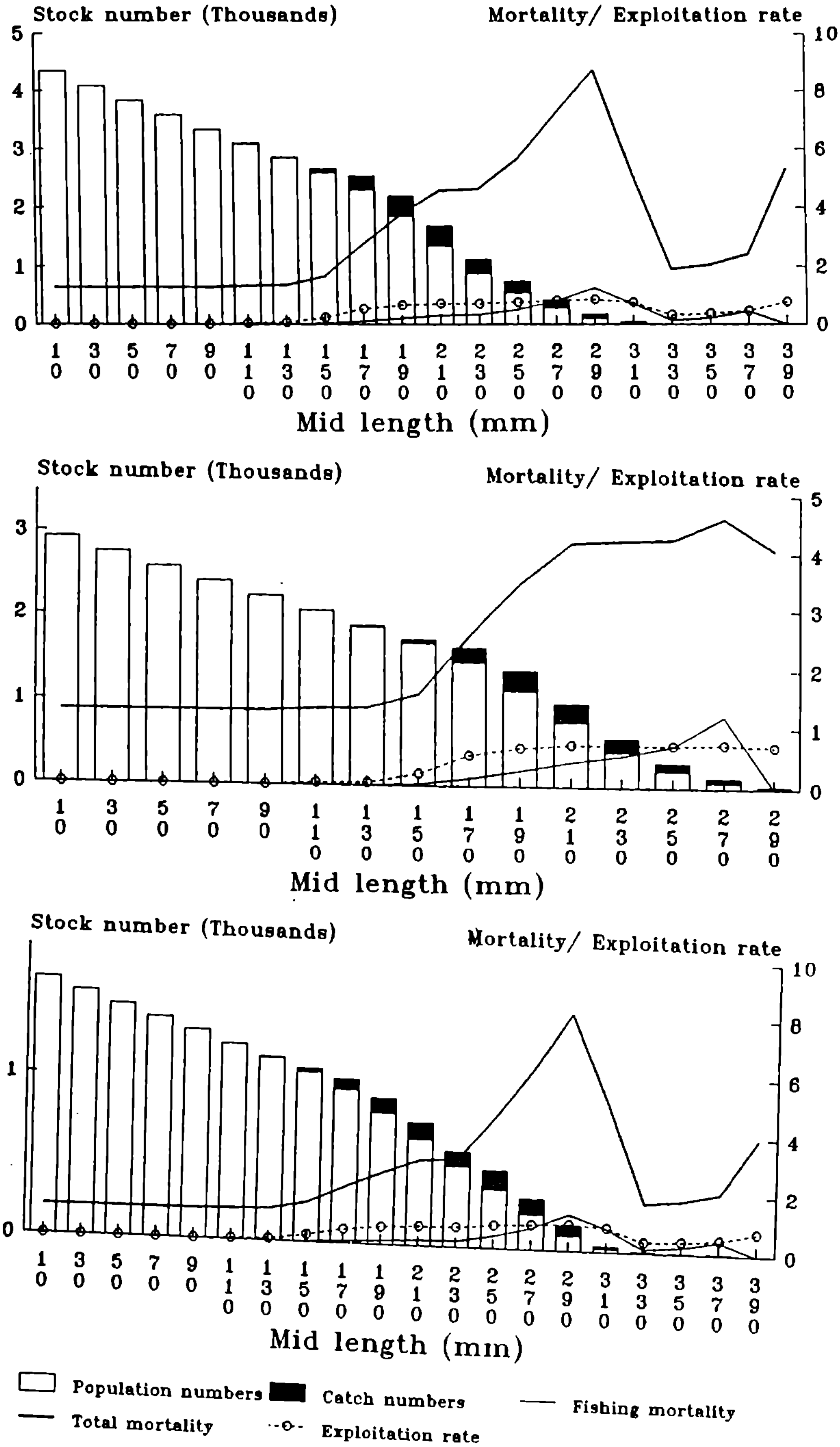

Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
Population numbers
Catch numbers
Fishing mortality
Total mortality
Exploitation rate

Fig. 9.6 Length cohort analysis of pooled females, OF and BF of *Macrobrachium rosenbergii* in Vembanad lake

a) Pooled females ($L_\infty$=308mm; K= 1.10/year; Z=5.46; M= 1.7142; Terminal F= 0.5167; Mean F>200mm= 0.7901; Terminal exploitation rate = 0.8076)

b) OF ($L_\infty$= 272mm; K= 1.2/year; Z= 2.46; M= 1.2729; Terminal F= 1.5178; Mean F>180mm= 0.9443; Terminal exploitation rate = 0.7041)

c) BF ($L_\infty$= 296mm; K= 1.0/year; Z= 2.70; M= 1.1191; Terminal F= 0.3784; Mean F>200mm = 0.6811; Terminal exploitation rate= 0.6265)

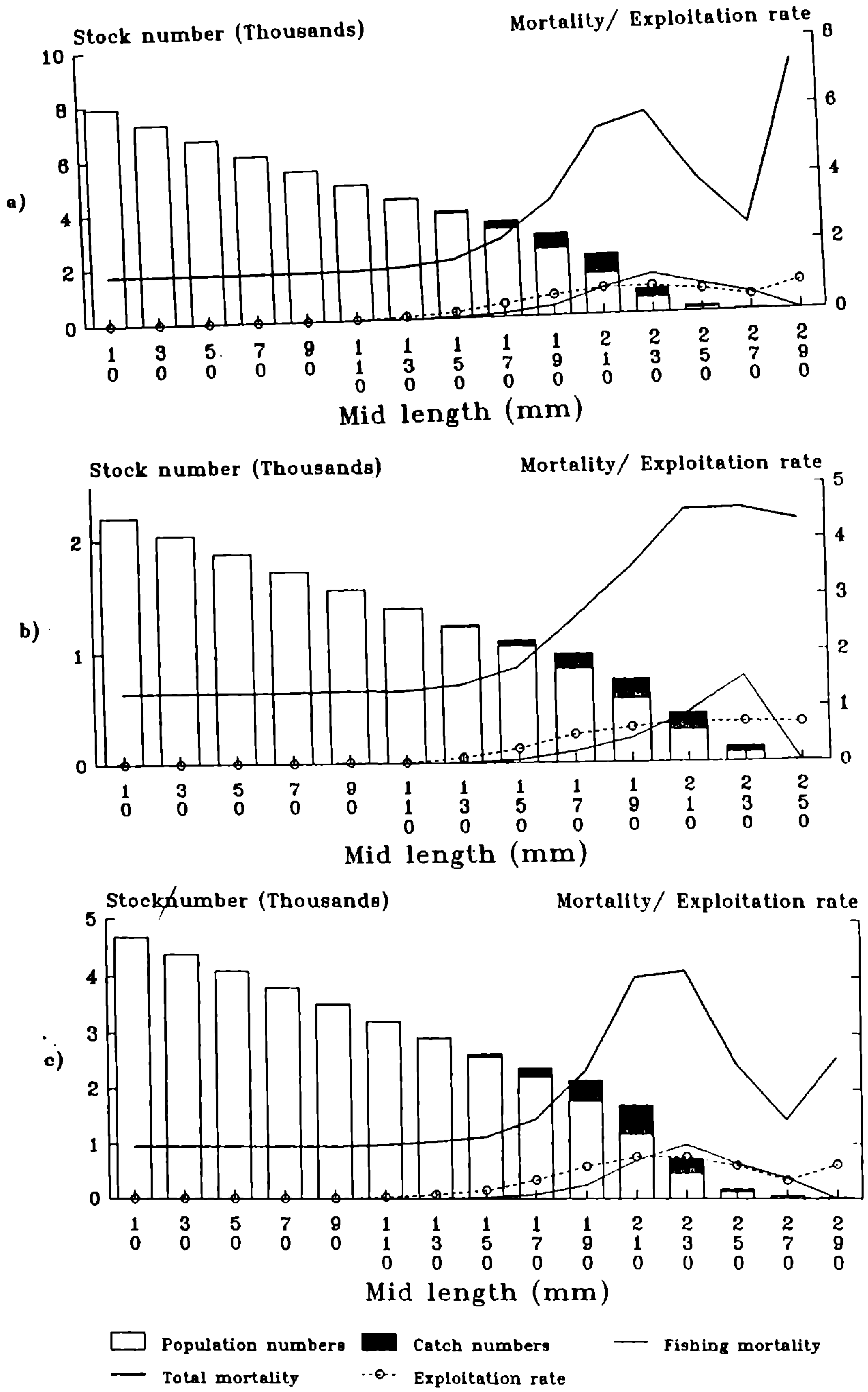
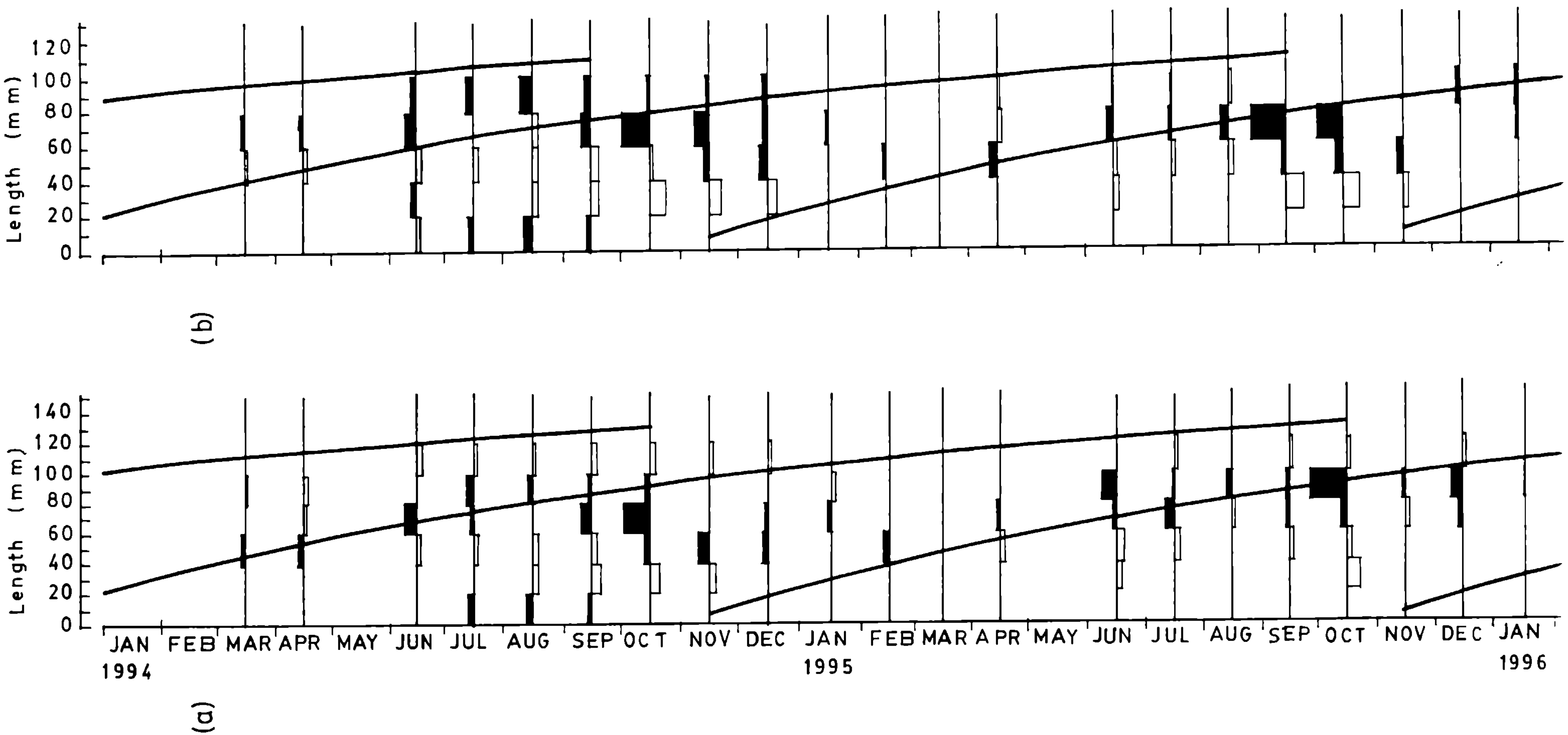

a)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
b)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
c)
Stocknumber (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
Population numbers
Catch numbers
Fishing mortality
Total mortality
Exploitation rate

Fig. 9.7 Growth curve of males and females of *Macrobrachium idella* as estimated using ELEFAN I programme

a) Male = ($L_{\infty}$= 156mm; K= 0.91/year)

b) Female = ($L_{\infty}$= 132mm; K= 0.94/year)



Length (mm)
0
20
40
60
80
100
120
(b)
Length (mm)
0
20
40
60
80
100
120
140
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN
1994
1995
1996
(a)

Fig.9.8 Catch curve of males and females of *Macrobrachium idella* based on length composition

a) Males($L_\infty$= 156mm; K= 0.91/year; Z= 5.44)

b) Females ($L_\infty$ = 132mm; K= 0.94/year; Z=3.37)

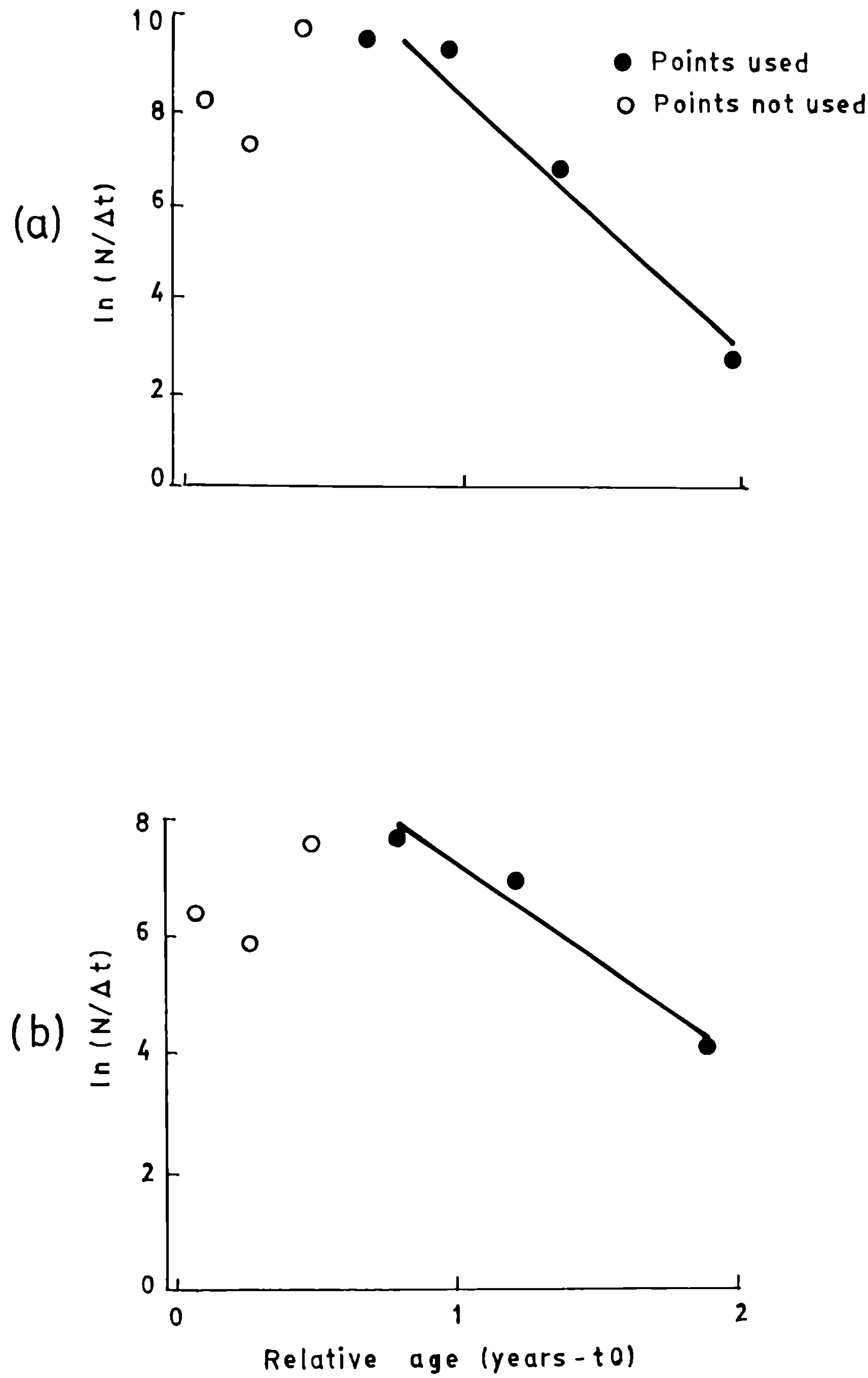
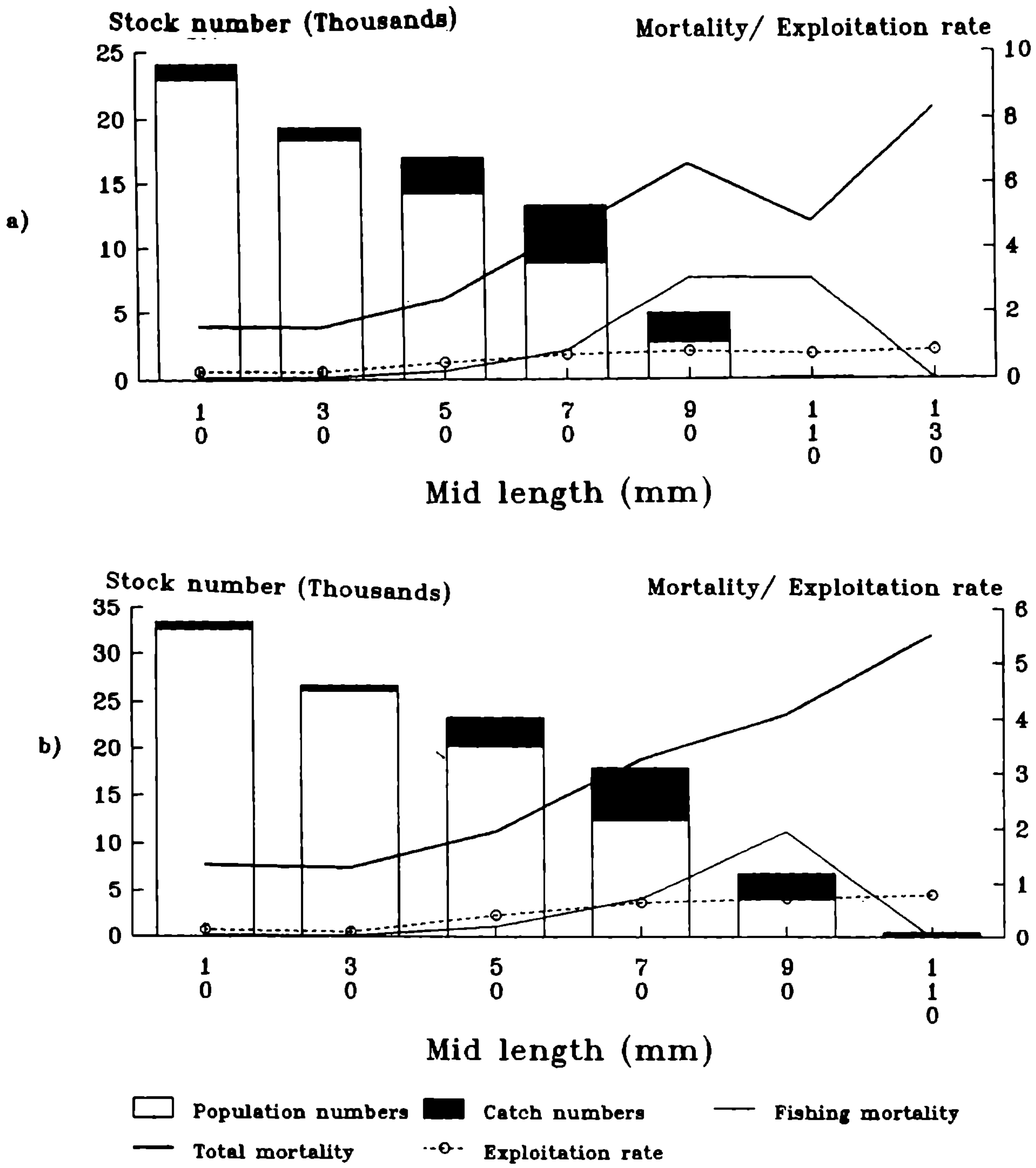

(a)
Points used
Points not used
ln (N/Δt)
10
8
6
4
2
0
(b)
ln (N/Δt)
8
6
4
2
0
0
1
2
Relative age (years - t0)

Fig. 9.9 Length cohort analysis of males and females of *Macrobrachium idella* in Vembanad lake

a) Males ($L_{\infty}$ = 156mm; K= 0.91/year; Z= 5.44; M= 1.1928; Terminal F= 3.0387; Mean F>60mm= 2.3142; Terminal exploitation rate = 0.8585)

b) Females ($L_{\infty}$= 132mm; K= 0.94/year; Z=3.37; M= 1.1651; Terminal F= 1.9440; Mean F>60mm= 1.3287; Terminal exploitation rate = 0.7880)


a)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
b)
Stock number (Thousands)
Mortality/ Exploitation rate
Mid length (mm)
Population numbers
Catch numbers
Fishing mortality
Total mortality
Exploitation rate

# Summary

# SUMMARY

*Macrobrachium rosenbergii* (de Man) and *M. idella* (Hilgendorf) form two commercially important Palaemonid prawns of the Vembanad lake (9 28' and 10 10' N and 76 13' and 76 31' E). Both of them were known to have contributed to a very lucrative fishery during the sixties, however, in recent years these natural resources have badly depleted owing to the impact of many man made alterations brought about in the ecosystem such as habitat reduction, physical obstruction imposed in the migratory pathway of these species, pollution hazards, etc,. Changed environmental conditions and increased fishing pressures caused persistent alterations in the stock size of these prawns during the past so many years, however, no serious attempt was made to monitor the stock size from time to time and also to bring out the resource characteristics. Though, the morphotypic differentiation in grow out male population of *M. rosenbergii* has been documented, no similar studies were conducted with regard to natural male and female population. Based on the data collected during fishery cruise surveys conducted in Vembanad lake from March '94 to February '96, population characteristics, postlarval distribution, fishery and population dynamics of *M. rosenbergii* and *M. idella* of the lake were studied in detail.

Vembanad lake has all the characteristics of a positive type estuary and it receives freshwater from five major rivers. However, the construction of Thanneermukkam salinity barrier has brought about severe alterations in the ecological conditions of the lake as the lake was separated in to two distinctly different ecosystems due to the operation of the barrier. Eight physico-chemical parameters were studied for delineating the role of prevailing hydrological conditions of the lake in the distribution and abundance of larvae, postlarvae and stock size of *M. rosenbergii* and *M. idella*. The annual rainfall was 2940 in 1995-96 against 2710 mm in 1994-95. Monsoon season accounted for major discharge of rainfall during both the years registering 65.36% and 67.35% in 1994-95 and 1995-96 respectively. Surface temperature varied from 25 to 32°C during study period while the bottom water temperature ranged from 24.5 to 31.5°C. A pronounced drop in temperature was noticed during June- July months coinciding with the south -west monsoon whereas a gradual increase was discernible from August onwards. Following a slight fall in temperature during November- December, a steady increase could also be noticed till March.

The onset of south-west monsoon converts the entire lake to freshwater habitat and the saline conditions were retained only at the bottom part of the stations adjacent to bar mouth. Both surface and bottom salinities showed a steep increase from November onwards and high surface and bottom salinities of more than >20 ppt were observed in stations 1 and 2 during March and April. Highest salinity recorded from upstream part of the lake was 8 ppt.

The dissolved oxygen content of surface and bottom waters in most of the stations fluctuated between 4-8 ml/l during both years. Dissolved oxygen content of surface water ranged between 3.16 to 10.64 ml/l while the same of bottom water varied from 2.88 to 9.21 ml/l. Generally, low dissolved oxygen values were noticed in most of the stations during premonsoon period while postmonsoon period registered higher values. pH ranged from 5.1 to 9.9. High pH values were observed in most of the stations during 1994-95 while in 1995-96, it remained more or less close to 7. Total hardness was high in bottom water in most of the stations when compared to surface water.

High levels of total hardness could be recorded in both surface and bottom water samples during April to August in 1994-95 in almost all stations, while in 94-95 high surface and bottom water hardness were 94 and 143.9 mg CaCO3/l respectively, whereas, the same in 95-96 were only 44.92 mg CaCO3/l and 53.44 mg CaCO3/l respectively. Highest alkalinity in surface and bottom water recorded during 94-95 were 160 and 148 mg CaCO3/l respectively, the same during 95-96 were found to be ranging from 22 to 40 mg CaCO3/l. High values of both surface and bottom water acidity could be noticed in most of the months during 95-96 when compared to its preceding year. High values of surface and bottom water acidity recorded during 94-95 were 180 and 200 mg CaCO3/l respectively and the same recorded during 95-96 were 190 and 270 mg CaCO3/l respectively.

Sexually matured male population of *M.rosenbergii* belonging to same age group and raised in culture ponds have been differentiated into three distinct morphologically distinguishable kinds representing three phases in the developmental pathway. A thorough examination of the exploited stock of *M.rosenbergii* in Vembanad lake revealed the existence of similar morphologically distinguishable forms among male and female populations inhabiting the lake. Three male morphotypes such as Small Males (SM), Strong Orange Clawed males (SOC) and Strong Blue Clawed males (SBC) could be differentiated and distinguished based on morphological characteristics and allometric studies. The existence of two transitional stages each of SOC and SBC could also be distinguished, *viz.* Weak Orange Clawed (WOC) and pre-transforming Orange Clawed males (t-SOC) of the former and Weak Blue Clawed (WBC) and Old Blue Clawed males (OBC) of the latter. Three morphotypes could be identified among female populations such as Small Female (SF), Strong Orange clawed Female (SOF) and Strong Blue clawed Female (SBF). Besides, two transitional stages of SOF *viz.* Weak Orange clawed Female (WOF) and Transforming Orange clawed Female (TOF) and one transitional stage of SBF *viz.* Weak Blue clawed Female (WBF) could also be differentiated. Detailed description of male and female morphotypes and their transitional stages are given.

Regression analyses of fourteen morphometric measurements using total length and carapace length as standard dimensions revealed significant variation in the growth patterns of various body parts between the morphotypes and transitional stages of both male and female populations. Besides, the distance function analyses on nine morphometric measurements of male and female morphotypes and their transitional stages also confirmed significant variations among them. The mutual relationship of male and female morphotypes and transitional stages based on the distances between them conformed with their developmental pathway from SM to BC through OC.

A clear size heterogeneity with regard to length and weight of male morphotypes could be noticed similar to that of grow-out population. SM, SBC and OBC can be demarcated as distinct groups based on size characteristics whereas in the case of WOC, SOC, t-SOC and WBC, such difference could not be seen as there was some degree of overlapping in length among them. Weight frequency distribution also showed almost similar pattern, however, the SOC showed strong positive skewness in weight configuration from that of WOC, t-SOC and WBC. Monthly variation in length frequency distribution of male morphotypes and their transitional stages clearly indicated that there is the possibility of a very complex pattern of transformation which might be profoundly influenced by the social hierarchy prevalent in the habitat.

Based on the results obtained in the present study three possible developmental pathways of morphotypes could also be established in the transformation of SM to OBC such as 1) SM=> WOC=> SOC=> t-SOC=> WBC=> SBC=> OBC; 2) SM=> WOC=> WBC=> SBC=> OBC and 3) SM=> WOC=> t-SOC=> WBC=> SBC=> OBC. Similarly, in female population also, a normal developmental pathway could be established such as WOF=> SOF=> TOF=> WBF=> SBF, besides a bypass transformation pathway as WOF=>TOF=>WBF=> SBF.

No similar morphotypic differentiation could be established in male and female populations of *M.idella.* Though male population of this species was found to comprised of two types of individuals which showed difference in size and colouration, however, allometric studies ruled out the possibility of existence morphotypic forms in *M.idella.*

Detailed study on length-weight relationships of male morphotypes and transitional stages of *M.rosenbergii* from natural habitat revealed that SM, WOC, SOC, t-SOC and OBC followed allometric growth pattern while WBC and SBC followed an isometric growth. SOC and its transitional stages showed stoutest growth pattern in contrast to slender growth seen in SM and Blue Clawed males. All morphotypes morphotypes collected from except SM and OBC showed isometric growth. The length weight relationship of male and female morphotype belonging to natural population can be expressed as

SM : $W = 0.121968 \times L^{1.5332}$

WOC $W = 0.004186 \times L^{3.2226}$

SOC $W = 0.002201 \times L^{3.5014}$

t-SOC : $W = 0.005062 \times L^{3.1517}$

WBC : $W = 0.006121 \times L^{3.0712}$

SBC : $W = 0.012770 \times L^{2.8054}$

OBC $W = 0\ .10742 \times L^{1.9472}$

WBF, SOF and SBF collected from natural habitat and TOF, WBF and SBF collected from grow-out systems showed allometric growth pattern. Length-weight relationship of male morphotypes belonging to grow-out population can be expressed as

SM : $W = 0.015475 \times L^{2.5541}$

WOC : $W = 0.005939 \times L^{3.0899}$

SOC $W = 0.007494 \times L^{3.0055}$

t-SOC : $W = 0.006071 \times L^{3.0910}$

SBC : $W = 0.004038 \times L^{3.2923}$

OBC : $W = 0.031454 \times L^{2.4272}$

The length-weight relationship of female morphotypes belonging to natural population can be expressed as

WOF : $W = 0.044882 \times L^{2.17}$

SOF $W = 0.017786 \times L^{2.58}$

TOF : $W = 0.005646 \times L^{3.08}$

WBF $W = 0.008289 \times L^{3.92}$

SBF $W = 0.025049 \times L^{2.47}$

Length-weight relationship of female morphotypes belonging to grow-out population can be expressed as

SF : $W = 0.015560 \times L^{2.5284}$

WOF : $W = 0.022663 \times L^{2.4979}$

TOF : $W = 0.022254 \times L^{2.4937}$

WBF : $W = 0.033607 \times L^{2.2992}$

SBF $W = 0.016878 \times L^{2.6249}$

In *M. idella*, males followed allometric growth pattern in contrast to isometric growth seen in females which can be expressed as

MALES $W = 0.062316 \times L^{3.4491}$

FEMALES $W = 0.140061 \times L^{3.0150}$

While examining the percentage composition of various male and female morphotypes represented in the exploited stock of *M. rosenbergii* in the Vembanad lake, it could be seen that Blue clawed morphotypes showed clear cut predominance over Orange Clawed morphotypes during 1994-95 and 1995-96 whereas contributions of SM and SF were found to be insignificant during the both years. Among Orange Clawed males, WOC predominated during 1994-95 while t-SOC showed distinct dominance during 1995-96 whereas WBC emerged as the dominant group among Blue Clawed males. SBF appeared as the single largest female morphotype of the lake in both years. Monthly variation in the occurrence of male morphotypes and their transitional stages showed that Orange Clawed males dominated in the catches during January to August in contrast to the distinct predominance shown by Blue Clawed males during September to December.

Spatial variation on the percentage

composition of morphotypes of *M.rosenbergii* revealed that Blue Clawed males predominated in the catches from all zones of the lake during 1994-95, in contrast, the preponderance of Orange Clawed males could be discernible in zones 2, 4, 8, 9 and 10. Female population was totally absent in the exploited stock in the months of March and April during both the years and with the appearance of female population in the lake, Orange clawed Females predominated in the catches in February and during May to August except in July. During September to January, Blue clawed Females dominated in the catches.

The morphotypic composition of male and female population in the exploited stock of *M.rosenbergii* from two each of low and high population density zones of the lake were examined where the density varied from 0.29 to 16.18/ha. A dynamic shift in the proportion of male morphotypes could be discernible in the natural habitat. At low densities the percentage composition of WOC was found to be insignificant and their occurrence could be seen only for a short period while BC and OBC males showed their predominance in almost all months. At high densities, the contribution by WOC and t-SOC were relatively high and their representation could also be noticed in almost all months. Percentage composition of various female morphotypes and their transitional stages showed contrasting results when compared to that of males. High contribution of TOF and SBF was encountered in zones irrespective of difference in density which indicate that density does not influence much on morphotypic development and transformation in female population.

Density dependent variations could be noticed in the population structure and yield characteristics of *M.rosenbergii* raised in four polders of Kuttanad under modified extensive monoculture system. On analysing the percentage contribution by weight of various male morphotypes and their transitional stages, it could be noticed that in polders having low population density at the time of harvest ($0.55/m^2$), SOC and its successive stages in the transformation pathway *viz.* t-SOC, WBC, SBC and OBC constituted 97.79% of the male morphotypes whereas in polders with high density at harvest in the order of 1.44, and $1.56/m^2$, SOC and its advanced stages constituted only 84.95 and 81.25%. Similar results could also be observed in the female population.

Density dependant variations in the mean weight of male and female morphotypes and their transitional stages were quite discernible in grow-outs, showing a remarkable improvement at low population density level. In polder 1 with a density of $0.55/m^2$, 100-200g size group constituted the highest portion of the catch, contributing to 76% of the total harvested population while in polders of high densities (1.44 to $1.56/m^2$), the percentage of above size group was only in the range of 41-54%. In polder 1, 95% of the yield was constituted by >50g and therefore marketable while in polder 3 with a density of $1.44/m^2$ only 66% was marketable.

Analysis of plankton samples from 13 stations of the lake during March 95 to February 96 showed the occurrence of Palaemonid larval forms in varying densities round the year. Highest numerical representation in the order of 160,000 and 180,000 larvae/ haul could be observed from stations 5 and 13 respectively in the month of August, on the contrary, during November -April, it declined to less than 1000/haul in stations 5, 7 and 10. Maximum abundance of larvae could be observed during June to October with a distinct predominance in August and very sparse occurrence could only be noticed during December- April period, especially in upstream and riverine regions.

Highest number of postlarvae of *M.rosenbergii* in the order of 36 and 32/ haul were recorded from stations 5 and 7 respectively in the month of December. A gradual shift in the months representing the peak availability of post larave of this species could be observed while proceeding from downstream to upstream stations of the lake. In the downstream stations, the highest occurrence of post larvae of *M.rosenbergii* was recorded during September- December in almost at all stations except 6, while in upstream regions, peak availability could be recorded only during December-February.

Relatively prolonged occurrence of postlarvae of *M.idella* could be noticed in stations representing downstream regions of the lake. Highest number of postlarvae/ haul could be registered from zone 2 in the order of 200 and 180/ haul in the months of July and September respectively. The occurrence of postlarvae of *M.idella* was very high in downstream stations especially in station 2 during July and September. In stations representing upstream part of the lake and riverine regions, sparse availability of the same could only be observed.

Two series of experiments were carried out separately for finding out the suitability of marking postlarvae of *M.rosenbergii* with biological stains by immersion and administration by injection to the body. Retention of the stain was found insignificant by the former method when it was used at low concentration. Among the three stains used, Fast green FCF registered maximum period of retention as 7 days when the stain was used at 1% concentration. Retention up to 14 days could be observed in injection method when Fast green FCF was administered at 1% level. Postlarval survival up to 30% could only be observed in this experiment.

With the objective of verifying the existing conjecture behind the dwindling nature of the fishery and also to delineate the fate of postlarvae of *M.rosenbergii* being trapped in the downstream part of the lake due to the closure of Thanneermukkam salinity barrier, mark- release-recovery studies were undertaken. 40,000 postlarvae and 10,000 juveniles of *M.rosenbergii* were marked by mutilation and tagging respectively and were released in six batches during January - February 1996 at Pallipuram (zone 6), approximately 10 km down from the salinity barrier. 214 eye mutilated and 8 tagged prawns could only be recovered during August 1996 to June 1997 period, registering a retrieval percentage of 0.53 and 0.08 respectively. The size of the recovered mutilated prawns ranged from 125 to 205 mm in TL while the retrieved tagged specimens were in the length range 187 to 225 mm. 58% of total recovered prawns belonged to 140-160 mm TL group. The low percentage recovery of the marked prawn from upstream part of the lake in the present study would manifest the possibility of negotiating the bund only by a very insignificant portion of the marked postlarvae and therefore strongly inclined towards the existing conjecture that upward migration of postlarvae of *M.rosenbergii* might be significantly hampered by the physical obstruction caused by the barrier.

The exploited stock of *M.rosenbergii* from the lake and confluent zones of the rivers during March 94 to February 95 was quantified as 112.85 tonnes while in March 95 to February 96 , it was computed at 129.44 tonnes. This in comparison with the previous estimates of 1988-89 showed a 300% improvement in the stock size. The average annual yield /ha was computed at 4.94 Kg in 1994-95 and 5.76 Kg/ha in 1995-96. The riverine region appeared to be the most productive areas with an annual average yield of 54.91Kg in 1994-95 and 61.68Kg/ha in 1995-96 while down stream and upstream parts of the lake occupy the next order of importance. In 1994-95, highest landing could be registered in the month of October while in 95-96 it was in the month of September, showing peak fishing during July to November in former year and June to November in the latter. Among the various zones of the lake, highest contribution during both year could be registered from zone 9.

Among the three types of cast net operated for *M. rosenbergii*, "Pongu Veechal" accounted for 71.28% and 73.97% of the total exploited stock during 94-95 and 95-96 respectively whereas the contribution from "Koti Kuthi Veechal" and "Thady Veecahal" was less than 5% . The indigenous fishing methods such as Padal and Spears contributed to 4.85% in 1995-96 against 3.5% in 1995-96. Females contributed 59.07 and 54.61% of the exploited stock in 94-95 and 95-96 respectively. Among the various male morphotypes, highest contribution was made by SBC in 94-95 while in 95-96 t-SOC and WBC appeared as the most important male morphotypes. SBF formed the mainstay in the landings in both the years followed by WBF among female morphotypes. The modal class of male and female constituting the fishery was 180-199 mm and 200-219 mm respectively. Marketable yield structures of the exploited stock showed that in males, 250-300 g contributed to 22% in 94-95 while 50-100 g showed the highest percentage contribution in 95-96. The same with regard to the females in the stock was represented by 100-150 g in both the years.

The exploited stock of *M. idella* from the lake and confluent zones of the rivers during 1994-95 was quantified as 78.5 tonnes while the same during 1995-96 was estimated at 62.77 tonnes. Average annual yield/ ha worked out to be 3.46 Kg in 1994-95 while in 95-96 it was only 2.75Kg/ha. Contribution from the downstream part of the lake was highest, in the order or 5.02 Kg/ha in 94-95 and 3.66 Kg/ha in 95-96. Padal, Koti kuthi veechal and seines accounted for the major share of landings of *M. idella* from the lake, the former formed 66.45 and 72.92% of total landings of *M. idella*in Vembanad lake during 94-95 and 95-96 respectively. Highest landings could be recorded during August and September in the first and Second years respectively. Highest landings could be registered from zone 5 in both the years. The commercial fishery of *M. idella* in the lake was constituted by length groups ranging from 12-132 mm in total length. Females predominated in the catches in March, April, September, October, November and February whereas males clearly dominated in June, July and December.

Based on length composition of commercial landings of *Macrobrachium rosenbergii* (de Man) of the Vembanad lake, growth parameters $L\infty$ and K were estimated separately for male and female populations and their respective morphotypes such as orange clawed males (OC) and blue clawed males (BC) of the former and orange clawed females (OF) and blue clawed females (BF) of the latter using ELEFAN I and modal progression analysis. Growth equations of various groups based on the growth parameters computed by integrated method of Pauly(1983), can be expressed as follows:

| | |
|---|---|
| OC | :Lt=318.45 (1-exp-1.2540(t-1.0725) |
| BC | :Lt=414.08 (1-exp-1.0254(t-1.0988) |
| Pooled males | :Lt=454.89 (1-exp-0.6780(t-0.1580) |
| OF | :Lt=291.49 (1-exp-1.1380(t-0.9558) |
| BF | :Lt=326.50 (1-exp-1.0974(t-0.8889) |
| Pooled females | :Lt=297.36 (1-exp-1.3660(t-0.2260) |

Total mortality (Z), natural mortality (M) and fishing mortality (F) were worked out separately for the above groups and results showed that averages of both total mortality and natural mortality were found to be high in orange clawed morphotypes of both males and females when compared to blue clawed morphotypes. Fishing mortality coefficients were found to be high in pooled females and also in orange and blue clawed females when compared to their male counterparts. Exploitation rate was also found high in females.

Length converted cohort analysis in *M.rosenbergii* showed that prawns below 100mm are not vulnerable to exploitation in males against 80mm in females. Fishing mortality in OC males was found to be high in prawns of 210-270mm TL while, in BC males, similar trend could be seen in

270-310mm TL. Fishing mortality was invariably high in prawns of size 210-230mm in both OF and BF. The results of the present study revealed that the male and female morphotypes of *M.rosenbergii* were being exploited well above the optimum levels and therefore can not be maintained sustainably by continuing the present level of exploitation rate and it is highly essential to implement regulatory measures for rational management of this over exploited stock.

Growth parameters were estimated separately for male and female populations of *M.idella* and the growth equations based on growth parameters arrived at by integrated method of Pauly (1983) can be expressed as

Males $L_t$ = 137.99 (1-exp- 0.8450 (t-0.7393)

Females $L_t$ = 126.94 (1-exp- 0.7612 (t-0.0195)

Natuarl mortality was obviously high in female population of *M.idella* whereas fishing mortality was very high in male population. The length converted cohort analysis showed that prawns of size 40-60 mm and above were vulnerable to exploitation, however, heavy exploitation of the length class 60-79 mm was quite discernible. Both the exploitation ratio and exploitation rate were found to be high in males when compared to its female counterpart which would suggest that the male population was exploited beyond optimum levels while female population was exploited more or less at equilibrium level.

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