STUDIES ON SOME ASPECTS OF BIOLOGY AND POPULATION DYNAMICS OF SHORT NECK CLAM *PAPHIA MALABARICA* (CHEMNITZ) IN DHARMADOM ESTUARY, NORTH KERALA, SOUTHWEST COAST OF INDIA

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DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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CERTIFICATE

This is to certify that this thesis entitled "**Studies on some aspects of biology and population dynamics of short-neck clam *Paphia malabarica* (Chemnitz) in Dharmadom Estuary, North Kerala, Southwest Coast of India"** is an authentic record of the bonafide research work carried out by **Smt. Sujitha Thomas**, from December 2003 to November 2004 under my supervision and guidance and that no report of this work has been presented before for any other degree or diploma. It is further certified that **Smt. Sujitha Thomas** passed the Ph. D qualifying examination held in December 2002 conducted by University of Calicut.

DR.M. NASSER

Calicut,
May, 2007.

DECLARATION

I, **Sujitha Thomas**, hereby declare that this thesis entitled "**Studies on some aspects of biology and population dynamics of short neck clam *Paphia malabarica* (Chemnitz) in Dharmadom estuary, North Kerala, Southwest Coast of India**" submitted to the University of Calicut in partial fulfilment of the requirements for the Doctoral degree in Zoology, is a bonafide research work done by me under the supervision and guidance of **Dr. M. Nasser**, Senior Lecturer, Department of Zoology, University of Calicut.

I further declare that the thesis has not previously formed the basis for the award of any other degree, diploma or any other similar title.

C.U. Campus
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Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter I

INTRODUCTION

Fisheries sector plays a vital role in the Indian economy. It addresses various issues like food and nutritional security, employment, livelihood support and socio economic status of fishing communities. The sector provides employment and income to over 5 million fishers and fish farmers, majority of whom live in over 3600 coastal villages, besides fishers hamlets along the major river basins and reservoirs in the country. The fish production in India registered an excellent growth during the past half century and reached 6 million t in the year 2002 from a meager 0.75 million t in 1950. The fishers primarily depend on fisheries in these waters for their livelihoods. The fisheries sector in India contribute to nearly Rs. 220 billion which is 1.4 % of the total national gross domestic products (GDP) and 4.6 % of agriculture GDP (Pillai, 2004), and hence it occupies a very important place in the socio-economic development of the country. The sector has been recognized as a powerful instrument to generate income and employment as it stimulates growth of a number of subsidiary industries and is a cheap and nutritious food besides

being a foreign exchange earner. At the same time it is a means of livelihood for a large section of economically backward coastal population of the country. Indian fish production increased from 3.7 million tonnes in 1990 to 5.3 million tonnes in 1999 and ranks fourth in the fish production in the world. (Fishing Chimes, April 2006).

Fishery experts are of the opinion that to achieve greater production potential of food from the sea in the next few decades it is going to be difficult to rely solely on intensive capture fishery operations alone in the Exclusive Economic Zone and Oceanic zone. These operations are fossil fuel dependent and would be more expensive as time goes on. The current line of thinking is towards promoting production of food resources of inshore forms which remain neglected due to lack of knowledge of these forms and their potentialities. The acceptability of the molluscan meat as an item of diet has caught up amongst the Indian public and present trend indicate very great interest in utilizing molluscan meat as diet, both by exploiting natural beds and trying to evolve suitable technologies in producing them by culture practices. To increase the edible molluscan production, it essential to understand the resource potentiality of all edible species and passing the information to the fishing industry so that greater area coverage results. This will also make good use of the natural stock without allowing them to perish unutilized (Mahadevan 1988).

In India the intake of animal protein is markedly low. If the population growth projection are of any guide, India should in addition to conventional sources of animal protein (fish, beef, pork, chicken etc), explore unconventional areas to increase the present protein level intake as well as to ensure alternative foods at reasonable prices. Among the unconventional sources of animal proteins, molluscs as a group have great prospects. India has a rich variety of edible marine and fresh water molluscs such as oysters, mussels, clams, squid, cuttlefish, and octopuses, apart from this, commercially harvested species such as pearl oysters and sacred conchs. Earlier there was no organized exploitation of these molluscs, due to priority often given to the exploitation of finfishes and crustaceans and also partly due to lack of knowledge about the occurrence and abundance of molluscan resources in various parts of the country. Proper assessment of these resources from Indian coast, except cephalopods in commercial fishing is lacking (Appukuttan, 1993). In recent times molluscan shell fishes are fast emerging as an important component in the marine fisheries of the country. Molluscan research in India was initiated by Madras Fisheries Department and earlier works were mostly confined to the occurrence of important resources along the coast (Hornell, 1922 a, 1949 a, b, c).

The edible oysters, mussels and clams are nutritious sea foods with considerable export potential (Narasimham *et al.*, 1993).The commercially important bivalves along the Indian coast are clams, mussels, edible oysters and pearl oysters. Except for pearl oysters, bivalves have been fished either for their meat or shell since time immemorial and it has a tremendous impact on the Indian economy (Appukuttan and Ramdoss, 2000). The status of bivalve fishery ranges from under exploitation in the northwest and north east coasts to overexploitation in the southern maritime states. Clams and cockles form 73.8 %, followed by oysters (12.5 %), mussels (7.5 %) and window pane oysters (6.2 %). The west coast accounts for 52.3 % of the landings where the catch is utilized for both the meat and the shell (Kripa and Appukuttan, 2003).

Among the exploited bivalve resources of India, clams are by far the most widely distributed and abundant. A number of clam species belonging to the families Arcidae, Veneridae, Tellinidae, Donacidae, Solenidae, Mesodesmatidae, Corbiculidae and Tridacnidae are exploited along the Indian coast (Narasimham, 1991). Due to realization about high nutritive value of clams and their importance in the economy of coastal fishing villages coupled with the development of an export market for the frozen clam meat, research has been initiated on this group during the past decade (Narasimham, 1991). To achieve greater production of marine living resources, intensive fishing of

the presently exploited species in the Economic Exclusive zone (EEZ) alone will not be enough. The need is to exploit resources which are now neglected due to lack of information on the potentialities and availability in new areas. For increased production targets of molluscan resources, a basic understanding of the present status of distribution, abundance, population size and stock, recruitment to fisheries and basic biological features of the resources are essential.

Very little attention has been paid to the studies on molluscan resources during the last century and also in the early part of present century. Since the middle of the present century attempts were made to understand molluscan resource characteristics, biology, biochemical composition, physiology and early development of commercially important bivalves and to develop hatchery and suitable farming techniques for edible oysters, pearl oysters, mussel and clams.

Among the clams, Venerid clams are the most sought after in the clam fisheries of India and three genera namely *Meretrix, Katelysia* and *Paphia* are important. Early studies on the venerid clams from Indian waters include those on the revision of *Meretrix* (Hornell, 1917), the spawning activities of *Meretrix casta* (Hornell, 1922a), distribution of commercially important molluscs

(Hornell, 1922a). *M. casta* was studied for its spawning activities by Panikkar and Aiyar (1939).

In *Paphia* species some studies have been initiated. Nagabhushanam and Mane (1988), studied the neuro-endocrinology of *Paphia laterisulca* from Ratnagiri, and its growth was studied by Mane and Nagabhushanam (1979, 1988). Adaptation of the clam *P. laterisulca* in Kalbadevi estuary was studied by Mane and Dhamne (1980). Growth rate of *Paphia undulata* was studied by Winckworth (1931). *Paphia malabarica* was studied for its infestation of pea-crab and its effect on condition index by Krishnakumari and Rao (1974), calorific value by Vijayaraghavan *et al.*, (1975), ecology and culture under simulated condition by Parulekhar *et al.*, (1984), a brief note on the biology from Mulky estuary by Rao (1988), and population dynamics of *Paphia malabarica* from Ashtamudi estuary by Appukuttan *et al.*, (1999).

Of the fifteen species of *Paphia,* 5 species are found distributed along the Indian coast (Appukuttan, 1993). Of these *Paphia malabarica* is the most important species, on account of its wider distribution and continuous exploitation along the southwest coast for local consumption and also in recent years for clam meat export. *Paphia malabarica* is an important component of the fauna of many estuaries and coastal waters of India (Nayar and Mahadevan, 1974). Till recently its importance as a source of protein–rich food

was not understood. It forms a subsistence fishery along the coast, although there is a growing interest, culturing of clam is yet to take off on a commercial line. There is a great demand for clam meat in international market where contribution by India is negligible. For initiating culture activities or propagation of a particular species, it is essential to have a clear understanding of the biology of the species in a particular environment.

Dharmadom estuary forms a part of Anjarakandy River in North Malabar, Kerala and *P. malabarica* is exploited from the bar mouth area of the estuary. About 80–90 % of clam meat exported from India is contributed by *Paphia malabarica* and of this about 80 % is from Ashtamudi estuary (Appukuttan 1993). There is ample potential for this resource in the export market and it is required to explore the possibilities of exploitation of this resources else where. So far no work has been initiated in this along the Malabar Coast. It is in this context the present study on the ecology, biology and fishery of this species is initiated and the results obtained could be used for evolving suitable fishery management and farming trials in Dharmadom estuary for large scale exploitation and future culture prospects in the Malabar area.

1.1 Systematic Position of *Paphia malabarica* (Chemnitz, 1782).

Paphia malabarica Chemnitz comes under SubFamily Tapetinae Adams and Adams of Family Veneridae Refinesque and Super Family Veneracea Refinesque of Class Bivalvia in the Phylum Mollusca. Important taxonomic characters of Super Family Veneracea, Family Veneridae and Genus *Paphia* Roding with salient features of *Paphia malabarica* Chemnitz are given.

Super family VENERACEA Rafinesque, 1815.

Keen (1969) described the Superfamily Veneracea Rafinesque1815 in Treatise on Invertebrate Paleontology (Ed. Raymond C. Moore) and she has included 12 subfamilies under this family. Vokes (1980) in Genera of Bivalvia – A systematic and Bibliographic Catalogue (Revised and updated) listed *Paphia* under superfamily Veneracea Rafinesque, 1815 of subfamily Tapetinae H & A Adams 1857. The unique characteristics of this Super family are, shell ovate, ornamentation predominantly concentric, but radial also seen in some with spine or lamellae over shell, mostly near posterior slope, beaks anterior, prosogyrate; cardinal hinge teeth generally three in either valve, ligament external, opisthodetic; pallial sinus usually present.

This Superfamily has 5 families, Veneridae Rafinesque 1815; Petricolidae Deshayes, 1839; Cooperillidae Dall 1900; Glauconomidae Gray,

1853 and Rzkakiidae Korobkov 1954. Among these families, Veneridae is most important.

Family VENERIDAE Rafinesque, 1815.

This Family has 12 subfamilies (Keen, 1969, Vokes, 1980). The members of this family have shells ovate usually equivalve, thick, smooth or variously sculptured. Lunules more or less distinctly flattened or depressed and eschutcheon well developed. There are three cardinal teeth in both the valves. The pallial sinus sinuate, varying in size and shape. There are two strong adductor impressions slightly unequal in size. The Subfamilies of this Family are:

Venerinae Refinesque, 1815; Circinae Dall, 1896; Sunettinae Staliozka,1870; Samarangiinae Keen, 1969; Dosiniinae Deshayes, 1853; Cyclininae Frizzel 1936; Gemminae Dall, 1902; Clementiinae Frizzell, 1936; Tapetinae Adams and Adams, 1857 and Chioninae Frizzell, 1936. Genera belonging to most of these subfamilies represent edible and commercially important species.

Subfamily TAPETINAE Adams and Adams.

There are 19 genera under this subfamily. They are *Tapes* Megerle von Muhlfeld, 1811; *Cyclorisma* Dall, 1902; *Cyclorismina* Marwick, 1927;

Eumarcia Iredale, 1924; *Eurhomalia* Cossmann, 1920; *Flaventia* Jukes-Browne, 1908; *Gomphina* Morch, 1853; *Irus* Schmidt, 1818; *Katelysia* Romer, 1857; *Legumen* Conrad, 1858; *Liocyma* Dall, 1870; *Marcia* H. Adams and A. Adams, 1857; ***Paphia*** Roding, 1798; *Paraesa* Casey, 1952; *Psephidia* Dall, 1902; *Sinonia* Stephenson, 1953; *Venerella* Cossmann, 1886; *Veneritapes* Cossmann, 1886 and *Venurupis* Lamarck, 1818.

Fischer–Piette and Metivier (1971) while revising this subfamily have followed the classification by Keen (1951). Among the 19 genera listed above *Paphia* assumes greater importance since it contributes several commercially important species.

Genus *Paphia* Roding, 1798.

Shell regular, not gaping, often well defined lunule. Lunule (of both valve together) much more than twice as long as broad. Hinge with three cardinal teeth, often with an additional tooth in front of the left valve and a depression in the right edge of the hollow being tooth like process. Pallial sinus mostly with more or less definite sinus. Shell usually much more elongate, hinge margin usually thin. Moderately thick and inflated shell with weak concentric grooves, hind margin of shell narrow and rounded. The siphon is often long and separate.

Fischer- Piette and Metivier (1971) while revising the subfamily Tapetinae listed 15 valid species of *Paphia*. They are:

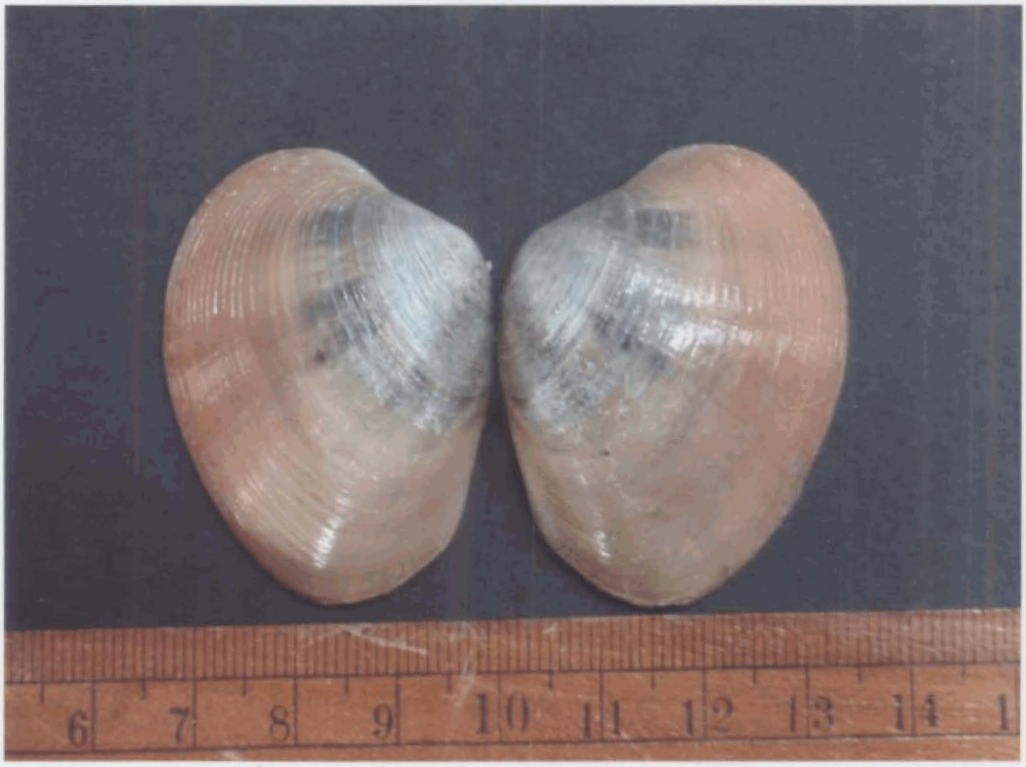
P. schellina Dunker, 1862; *P. inflata* Deshayes, 1852; *P.cor* Sowerby, 1853; *P. malabarica* Chemnitz, 1782; *P. crassisulca* Lamarck, 1818; *P. euglypta* Philippi, 1847; *P. lischkei* Fischer – Piette and Metivier, 1971; *P. amabilis* Philippi, 1847; *P. lirata* Philippi, 1848; *P. exarata* Philippi, 1847; P. *vernicosa* Gould, 1862; *P. semirugata* Philippi, 1847; *P. papilionacea* Lamarck, 1784; *P. undulate* Born, 1780 and *P. textile* Gmelin, 1784. . Jukes–Browne (1914) has discussed the division and subdivision of the genus *Paphia* and assigned the genotype as *Paphia papilionacea* Lamarck, 1847.

From Indian waters Melvill and Standen (1906), Prashad (1932), Chrichton (1941), Gravely (1941), Ray (1949), Satyamurti (1956), Kundu (1965) and Fischer – Piette (1976) have recorded several species of *Paphia* of which only 5 species are valid. They are *P. papilionacea* Lamarck, *P. malabarica* Chemnitz, *P. cor* Sowerby, *P. textile* Gmelin and *P. undulate* Born. Among these, *P. malabarica* is most important since it has got wider distribution and is exploited commercially from Indian waters.

***Paphia malabarica* Chemnitz, 1782**

(Plate I, Photographs)

Venus malabarica Chemnitz 1782, *Conch. Cab* VI p. 323, pl.31, fig 324-325; Lamarck 1818, *Anim.s.vert.*V.p.604 (594); Wood 1828, *Ind. Test,*



A. Shell - External view

B. Shell - Internal view

Paphia malabarica (Chemnitz, 1782)

p.35, No. 36, pl.7. fig.36; Potiez and Michaud 1844, *Galerie de Douai*, 2, p.236, pl.64 fig.3,4; Chenu 1847, *Illustr. Conchl. Tapes*, pl. VI, fig.4, 4a, 4b; Pfeiffer 1870, *Conch.Cab*, ed.2, p175, pl.17, fig.12.

Venus gallus Gmelin 1791, Syst. Nat.ed XIII, p. 3277; 1792 Encyclopedia Methodique, I, pl. 282, fig. 4.

Venus sinosus Lamarck 1818, *Anim.s.vert.*V, p.614 (604).

Venus rhombifera Hanley 1843, *Cat. Rec. Biv. Sh*, p.120, pl.13, fig. 45.

Tapes malabarica Sowerby 1852, *Thes. Conch.* II.p.682, pl.145, fig. 6a,8; Reeve 1864, *Conch. Icon*, pl.VI, fig 27; Romer 1870. Monogr. *Venus* II, p.34, pl.10, fig.3 and pl.17 fig.1; Smith 1884, *Zool.Coll. H.M.S. "Alert" Molluscs*. P.97; Melvill and Ambercrombie 1893, *Mem and Proc. Manchester Liter. Philos. Soc,* p.46; Melvill and Standen 1898, *Jour. Conch*, IX, p. 83; Melvill and Sykes 1898, *Proc. Malac. Soc. Lond*, p.47; Melvill 1899, *J. Linn.Soc. Zool*; XXVIII, p.196; Melvill and Standen 1906, *Proc. Malac. Soc. Lond*, P.382; Braga 1952, *Anais Junt – Invest.* Ultramar, VII, 3. p. 54; Paes Da Franca 1960, *Mem Junt – Ultramar* 2(15) p.96; Barnard 1964, *An.S. Afri. Mus*, 47 (3) p. 509.

Tapes sinosa Sowerby 1852, *Thes. Conch*, II, p.683 pl.145, Fig 10; Reeve 1864 *Conch. Icon* – pl. V,fig 18; Romer 1870, *Monogr. Venus* II, p 35, pl. XI, fig.1.

Tapes rhombifera Deshayes 1853, *Cat. Biv. Sh. Brit. Mus*, p 161.

Pullastra malabarica Chenu, 1862, *Man. Conchyl* II p. 92, fig. 413; Frauenfeld 1869, *Verhandl. Zool. Bot. Ges. Wien* 19, p 883.

Tapes malabaricus Von Martens, 1887, *J. Linn. Soc. Lond., Zool*, XXI, p. 213; Crosse and Fischer, 1889, *Journ. Conchyl.*, 37, p.293; Smith 1891, *Proc. Zool. Soc. Lond.*, p. 424; P. Fischer 1891, *Bull. Soc. Hist. Nat. Autun.*, IV p. 150; Martnes and E.A. Smith 1895, *Madras Government Museum Bull.* No 3, p. 129; Shopland, 1896, *J. Bombay Nat. Hist. Mus.*, X, p. 232; 1902; *Proc. Malac. Soc. Lond.*, p.178; Hidalgo 1903, *Mem. Real Ac. Cienc. Madrid.*, 21, p.250; Hidalgo 1905, *Rev. Real Ac. Cienc. Madrid.*, P. 333; Lynge 1909, *Mem. Acad Roy Danem.*, 7, V. p. 141; Smith 1916, *Proc. Zool. Soc. Lond.*, p. 424; Serene 1937, *Inst. Oceanogr. Indo- Chine*, 30, p.62.

Tapes browniana Preston 1906, *Ann. Soc. Roy. Zool et Malac. Belgigue.*, XLI, p. 73, fig. 6.

Tapes sinuosus Lynge 1909, *Mem. Acad. Roy. Danem.*, 7., V, p. 238.

Paphia gallus Hedley 1918, *Trans. Roy. Geogr. Soc. Austral. Sess.*, 1916 – 1917, p.6; Tomlin 1923, *Proc. Malac. Soc. Lond.*, XV, p.313; Crichton 1941, *J. Bombay Nat. Hist. Soc.* 42 p. 338; Ray 1948, *Rec . Ind. Mus.*, XLVI, p. 119; Chuang 1961, *On Malayan Shores* p.168, pl.74, fig 7.

Paphia malabarica Faustino 1928, *Bureau of Science, Manila Rep.* 25,p.81; Melvill 1928, *Proc Mal Soc Lond.*,18,p 93; Gravely 1941, *Bull. Madras Govt Mus N.S.V* (1), p 52 and 100, fig 20; Satyamurthi 1956, *Bull. Madras Govt Mus (Nat. Hist)*, I (2), pt. 7, p.130, pl xx, fig – 3a: Kundu 1965, *J. Bombay Nat Hist Soc.*, 62 (2), p. 211; Fischer – Piette 1968, *Bull. Mus*, 20 No. 4, p 793; Cheriyan 1973, *Proc. Molluscan Symp.*, Mar Biol Asso India., Pt. I, p.131; Fischer – Piette and Metivier 1971, *N.S. Zool*, LXXX, p.39, pIIX, fig. 7; Fischer – Piette and Metivier 1971, *Mem. Mus Natl Histoire Naturelle* LXXXI, p 31-41, pl 9; Fischer – Piette 1974, *Tethys* 5 (2-4), p. 267 – 316; Fischer – Piette 1976, *Rec. Zool. Surv. India*, 70, p: 235- 257.

Tapes lentiginosus Lamy 1930, *Bull. Mus.*, P 227.

Paphia sinuosa Prashad 1932, *Lamellibr. Siboga*, p.237; Altena 1945, *Zool. Meded.*, XXV, p.151.

Acritopaphia transfuse Iredale 1936, *Rec Austral. Mus.*, 19, p.280, pl 20. Fig 12; Allan 1950, *Australian Sh.*, p 334. col.pl.39, fig 4, pl 37, fig. 18; Iredale and Mc Michael 1962, *Ref. List Mar. Moll. N.S.W., Mem. Austr. Mus.*, XI, p. 23.

Paratapes malabaricus Lamy and Fischer – Piette 1939, *Bull. Mus.*, p.315.

Tapes semirugatus Allan, 1950, *Australian Sh.*, p 334, col. Pl. 39 fig. 11.

Protapes gallus Rippingale and McMichael 1961, *Queensland and Great Barrier Reef Shells*, p 198, pl. 28, fig. 15.

Description

Shell thick, pale yellowish brown with distinct grayish brown bands and concentric sculpture over the shells in the adults; in juveniles the colour is brighter with radiating bands, concentric striation feeble. The front and hind margin are narrowly rounded and the ventral margin almost straight, but slightly inundated towards the hind end. The concentric striation over the shell is close set, slightly raised and rounded with interstitial grooves deeper, especially in adults. The striations are almost parallel to the ventral margin and corresponding inundation is noted in the hind margin (Fig). Hinge bears three short, thick cardinal teeth, the tooth in front of the cardinal in the left valve and the depression in the right being rudimentary. Pallial sinus is 'U' shaped and deep. Inner surface of the shell smooth and the margin is not denticulated. Adductor impressions are deep, the posterior being larger. Lunule is shorter and broader. Long siphon with distal end separated in to exhalent and inhalant siphons. Exhalent siphon has a siphonal membrane and radially arranged small tentacles in the rim of the aperture. In the inhalant siphon there are 24 longer tentacles, radially arranged in the rim of the siphon. The foot is large and wedge shaped adapted to burrowing. Posterior adductor muscle positioned ventral to the hinge margin, larger than the anterior adductor muscle.

The Taxonomic hierarchy of *Paphia malabarica* is

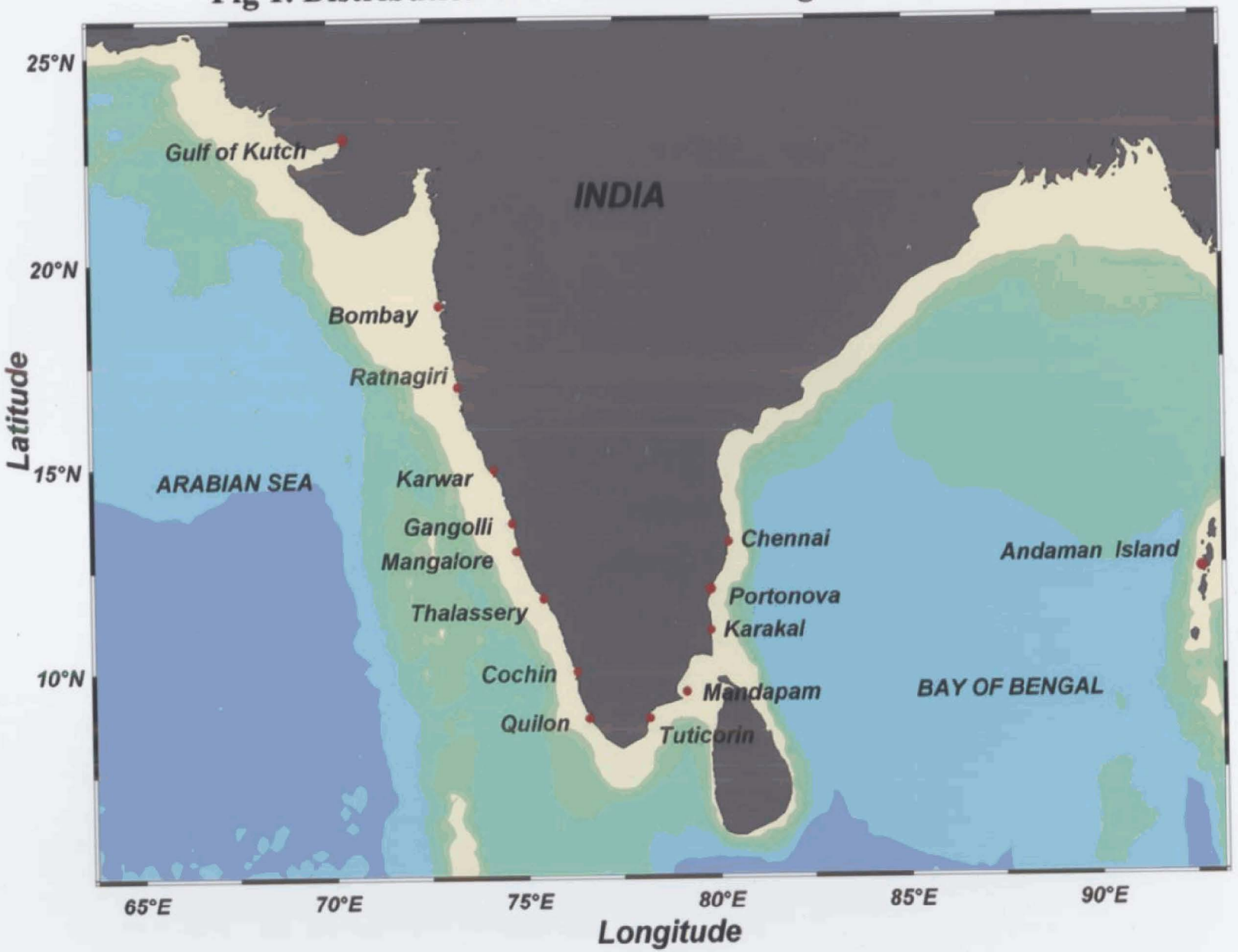
Kingdom	: Animalia
Phylum	: Mollusca
Class	: Bivalvia ,Linnaeus,
Subclass	: Heterodonta ,Neumayr, 1884
Order	: Veneroida, H. Adams and A. Adams, 1856
Superfamily	: Veneroidea, Rafinesque, 1815
Family	: Veneridae ,Rafinesque, 1815
Genus	: *Paphia* (Chemnitz, 1782)
Species	: *malabarica*

1.2 Distribution

The *Paphia malabarica* has wide range of distribution in Durban, Mosambique, Aden, Muscat, Persian Gulf, Pakistan, India, Sri Lanka, Mergui Archipelago, Malaysia, Hong Kong, China, Thailand, Philippines, Java, Western Astralia, Queensland and New south Wales.

From India, this species is recorded (Fig.1) from Gulf of Kutch, Bombay, Ratnagiri, Karwar, Gangoli, Mangalore, Thalassery, Cochin, Quilon along the west coast. Tuticorin, Mandapam, Karakal, Porto Novo, Madras along the east coast and also from Andaman Island (Appukuttan, 1993). *Paphia malabarica* seems to be one of the important species among family Veneridae with a wide range of distribution from Durban to New South Wales.

Fig 1. Distribution of *P. malabarica* along the coast of India



In India it is recorded from both east and west coast with commercially exploitable beds in the west coast (Kripa and Appukuttan, 2003).

The results of the present study are documented in six chapters. **First** chapter includes general introduction, review of the work carried in India, scope of study , systematic position of the *P. malabarica* and its distribution in world and along the coast of India . Each chapter has an introduction, materials and methods, results and discussion. Relevant work done in India and abroad are reviewed and discussed in each chapter

Second chapter includes ecology of the study area, covering hydrographic parameters (Dissolved oxygen, pH, Salinity, nutrients (nitrate, phosphate and silicate), turbidity), productivity, sediment texture and organic carbon.

Third chapter deals with allometric relationships of clam in the estuary in which all relationships viz. length- weight, length- depth, length- width, total weight to flesh weight and total weight to shell weight are done and the results are statistically tested and compared between sexes.

Fourth chapter deals with reproductive biology which includes maturity, spawning sex ratio and condition index of the clams, over a period of one year 2003-2004.

Fifth chapter deals with the biochemical changes in carbohydrate, lipid and protein in adductor, digestive gland and gonad with maturation of the clams. All the results are treated statistically and compared between groups.

Sixth chapter comprise of growth and population dynamics of the *P. malabarica* in Dharmadom estuary, with age, growth, fishery and stock assessment. Salient findings of the work are given in **Summary** after the sixth chapter.

References are given after summary and tables and figures are provided together in the text under each chapter at appropriate places.

Ecology of the Study Area

Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter II

Ecology of the Study Area

Distribution and abundance of natural resources are governed by several factors such as physico-chemical, biological or anthropogenic. One of the most important preliminary aspects, which ultimately determine the very existence of the resources, is the ecology of the environment in which it thrives. The estuarine ecosystem reveals the complexity of the operating forces of both marine and fresh water origin, induced mainly by tidal incursion, current patterns and the magnitude of fresh water discharge at different periods and seasons (Cameron and Pritchard, 1963). The abiotic factors vary from habitat to habitat and are constantly under fluctuations within a habitat. They interact with each other and also influence greatly on the biota. The climatic, physical and chemical factors are the three major determining factors apart from the topography. The type, rate of growth and reproduction of organisms at any locality is determined by climatic and other physical characters (Vink, 1983).

Abiotic factors including climatic, physico-chemical, biological and sedimentological energetics and dynamics of the ecosystem synergistically act to hold the life processes. All factors along with anthropogenic activities permanently interact; constantly change and their action upon the flora and fauna are complex and multidimensional. The hydrographical condition of the estuarine system depends on the interaction of sea and fresh water, the former dominating in summer and latter during the monsoon months. There are thus seasonal variations in water parameters.

Water quality reflects the collective influence of various physico-chemical characters, which is under the influence of meteorological conditions. This would determine the type and growth rate and reproduction of organisms in any locality (Vink, 1983). Monsoon is the most significant among the climatological factors which bring about drastic changes in the topography itself. Rainfall tends to be a characteristic of the tropics, where wet and dry seasons give periods alternately dominated by precipitation and evaporation (Payne, 1986). The environmental characteristics of tropical estuaries undergo short as well as long term variations caused by tidal rhythm and monsoon cycle (Chandran and Ramamoorthi, 1984).

The physical characteristics are the basic determining factors of a habitat. Turbidity is an important parameter as turbidity maximum has a

significant role in determining transparency, sediment transport and estuarine fronts (Uncles and Stephens, 1993). The various environmental and biological characteristics in a water body have a dynamic equilibrium with one another, while the physical and chemical parameters in themselves, collectively determine the water course favorable for aquatic organisms. The nature and distribution of flora and fauna in an estuary are mainly controlled by fluctuations in the physical and chemical characteristics of the water, such as temperature, transparency, pH salinity, dissolved oxygen and nutrients (Murugan and Ayyakkannu, 1991).

Nutrient loading to aquatic systems may happen from internal or external loading. Major chunk of nutrient input is from adjoining terrestrial environment and internal loading happens as regeneration of epilimnetic sediments and mixing with the bottom water entrainment (Caraco *et al.*, 1988). Nutrients are rapidly removed to environmental sinks such as outflows or profoundal sediments (Moeller and Wetzel, 1988) as part of the nutrient cycle. Emery *et al.*, (1957) reported that concentrations of nutrients are relatively high in estuarine systems as a result of close proximity to land drainage. Estuaries are considered as nutrient sinks or traps, where nutrient dynamics are unpredictable and significant as it make estuary a highly productive ecosystem

(Odum, 1971). During its course, it plays a vital role in the productivity of the biotope without which, it is unstable.

The productivity of the ecosystem differs significantly and the annual productivity indicates the trophic status of the system. Primary productivity is an important biological phenomenon in nature on which an entire diverse array of life depends directly or indirectly and it indicates the health of a system.

The recognition and description of spatial pattern and their temporal dynamics are fundamental to understand ecological processes that structure biological assemblages (Andrew and Mapstone, 1987; Jones et al., 1990). Thus the distribution characteristics of infaunal assemblages inhabiting many types of marine soft sediments have recently received considerable attention (McArdle and Blackwell, 1989) and the ecology of these systems is widely studied (Estes and Peterson, 2000).

Influence of environmental parameters especially temperature and salinity are studied in relation to the distribution; reproduction and condition of bivalves world wide. The relative importance of biotic versus abiotic factors in determining the spatial distribution of intertidal calms was studied by Schoeman and Richardson (2002) and in their study they observed that a mixture of biotic and abiotic factors mediates abundance of clams. Abiotic variables such as temperature and salinity were observed to cause mortality of

bivalves *Donax trunculus* and *Donax semistriatus* along the Mediterranean coast. It was found that these species were susceptible to environmental stresses (Cywiak *et al.*, 1989). Study on the influence of temperature and salinity on reproduction of *Ostrea edulis* shows that oyster is an opportunistic organisms which concentrates its reproductive efforts during a short period of favourable condition and it is directly dependent on nutritive availability in the environment (Ruiz *et al.*, 1992). Marin *et al.* (2003) has observed that condition index and total energy content of the clam *Tapes phillipinarum* was influenced by environmental factors. The relationships between gametogensis and environmental parameters have also been described in other bivalve groups (Ruiz *et al.*, 1992; Cano *et al.*, 1997; Ceballos-Vazquez *et al.*, 2000 and Luna-Gonzalez *et al.*, 2000). For *Donax denticulatus* populations in Puerto Rico, it was observed that higher population density and bigger clams were found in water having high concentrations of total organic carbon, particulate organic carbon and nitrates. This study indicated the relationships between water, sediment quality and density of this species (Sastre, 1984).

The ecology of clam beds in India has been studied by several authors. Some of them are on *Anadara granosa* by Narasimham *et al.*, 1984; Narasimham, 1985, *Meretirx casta* by Parulekar *et al.*, 1973; Harkantra, 1975a, b; Rao *et al.*, 1980 and Sreenivasan, 1983 a, b; 1985; *Paphia malabarica* by

Parulekar *et al.*, 1984 and *Villorita cyprinoids* by Parulekar *et al.*, 1984 and Rao *et al.*,1989. Reports on the habitat preferences, density, biomass and distribution are available for *A. granosa* (Radhakrishna and Ganapathi, 1968), *Meretrix ovum* (Desai, 1971 and Kurian, 1972), *Donax cuneatus* (Victor and Subramanian, 1988), *D. incarnates* (Ansell *et al.*, 1972a, 1973), *M. casta* (Balasubramanyan and Natarajan, 1987 and Modassir, 1990) .

Seasonal variations in the ecological parameters are studied in estuaries along the west coast of India. Seasonal variations in hydrographic parameters in Kali estuary (Karnataka) were studied by Harkantra, (1975) and Bhat and Neelkantan (1988). Detailed studies of hydrographic parameters were conducted in Mandovi-Zuari estuary in Goa (Dehadrai and Bhargava, 1972; Paulekar *et al.*, 1973; Qasim 1979; Qasim and Gupta, 1981 and Alagarswamy, 1991). Major work in this aspects carried out in Kerala were that of Qasim and Gopinath (1959), Josanto (1971) and Lakshmanan (1987) in Cochin back waters and in Ashtamudi estuary by Nair *et. al.* (1983) and Nair *et. al.*, (1984 a, 1984 b). Along Malabar coast seasonal ecological variations were studied in Korapuzha Estuary (Rao and George, 1959; George and Kartha, 1963) and Beypore Estuary (Premchand *et. al.*, 1987). Proper understanding of the ecology of clam bed is very essential in order to evaluate the influence of

different environmental factors and their interactions. This will help in future management of fishing and farming of clams in an area.

A number of estuarine systems are found along the east and west coasts of India. Along the west coast the estuaries are smaller compared to the east coast. One of the major estuaries transecting north Kerala is Dharmadom. The area around the Dharmadom estuary is categorized under ecologically important zones by the Institute of Coastal Management because of its mangrove vegetations. Dharmadom estuary lies in the 11°77' N latitude and 75° 47' E longitude. The estuary lies perpendicular to the coast line. On the eastern side of the estuary, there is mangrove vegetation which forms the nursery ground for a variety of fishes and shellfishes. This estuary has good tidal influence and influx of freshwater is found during monsoon.

2.1 MATERIALS AND METHODS.

Present study of biology of *Paphia malabarica* was done in Dharmadom estuary during the period December 2003–November 2004. A preliminary survey was carried out in the estuary during October-November 2003, to select the site for sample collection. In the survey it was observed that, *P. malabarica* was concentrated towards the marine zone (barmouth area) of the estuary. Hence three sampling sites were identified toward the barmouth

area (Fig 2.0) for the study. Station I was located towards the southern side (lat. 11°765' N and long. 75°473' E), Station II on the northern side (lat. 11°766'N and long. 75°471E) and Station III (lat. 11°757' N and long. 75°473' E) toward the eastern side. Station I is at a distance of 556 m from the sea, Station II 461 m and Station III at a distance of 668 m. Distances between these three Stations were approximately 250 m. Further, the estuary bifurcates into two.

Twelve months observations were carried out and observations were grouped into three seasons, pre-monsoon (February to May), monsoon (June – September) and post-monsoon (October – January) (George and Kartha, 1963; Azis and Nair, 1987 and Pisharody, 1987).

2.2 Hydrographic features of Clam bed.

Regular fortnightly sampling was carried out from three Stations I, II and III for a period of one year from December 2003- November 2004. Surface and bottom water samples and sediments were collected invariably in the forenoon (between 8.00 Hrs and 10 Hrs) from the three Stations. *In situ* readings were taken for temperature and transparency measurements. Surface water samples were taken using a 1000 ml plastic bottle and oxygen bottle. Before sampling, the bottles were thoroughly washed using the ambient water. Sampling was done by carefully dipping the bottles in the water and taking

Fig 2.0

MAP SHOWING STUDY AREA

caution to avoid entry of air bubbles. Bottom water sampling was done using 'casscella' type sampling bottle. Sub-samples were siphoned into 100 ml bottles from the main sample and kept intact in an ice box. The water and sediment samples in replicate were collected, preserved and transported to the laboratory in clean polythene bottle for further analysis.

Following hydrographical and sediment characters were studied from the clam bed:

1. Temperature
2. pH
3. Dissolved oxygen
4. Salinity
5. Transparency
6. Nitrate nitrogen
7. Phosphate phosphorus
8. Silicate
9. Primary productivity
10. Sediment Texture
11. Organic carbon.
12. Rainfall

1. Water temperature was measured *in situ* with precision centigrade thermometer of ± 0.5 ° C accuracy. The bottom water temperature was read within the sampler itself as soon it was collected.
2. The hydrogen ion concentration (pH) was measured using an Elico model LI- 120 pH meter. The instrument was calibrated using standard buffers before use.
3. Dissolved oxygen was measured using Winkler's method (Strickland and Parson, 1972). The water samples taken in 125 ml air tight oxygen bottle, fixed with 1ml each of Winkler's 'A' and Winkler's 'B' solution at the time of collection. These were then brought to the laboratory, where the precipitate in the bottle was dissolved in 2 ml of concentrated hydrochloric acid. After thorough mixing, titrated against 0.01 N sodium thiosulphate using starch as indicator. The oxygen content was expressed in milliliter per liter.
4. Salinity was estimated by Mohr's titration method (Strickland and Parson, 1972), which was carried out by silver nitrate

titration method using potassium chromate as the indicator. The values are expressed in terms of parts per thousand.

5. Transparency or the light penetration of the water was measured using the conventional 'Secchi' disc of 20 cm diameter (Golterman *et al.*, 1978). The usual precautions were taken while immersing the disc into the water as given by Welch (1948). The light penetration was recorded in centimeters.
6. Nutrients in the samples were analysed colorimetrically based on the method by Parson *et al.* (1984). Nitrate Nitrogen was estimated (Morris and Riley, 1963) by reducing the nitrate completely to nitrite using hydrazine catalyzed copper ions, kept in dark for 20 hrs and then treated with sulphaniamide and NNED and absorbance was measured at 530 µm using spectrophometer.
7. Phosphate phosphorus was estimated according to Murphy and Riley (1962). Samples were allowed to react with a mixed reagent containing 5 N sulphuric acid, ammonium molybdate and fresh ascorbic acid solution to estimate phosphate phosphorus spectrophotometrically at 620 nm.

8. Concentration of silicate silicon was determined spectrophotometrically using acid molybdate, oxalic acid and ascorbic acid as reductant at 810 nm wave length. Concentrations of all the nutrients were expressed in terms of microgram nutrient per litre.
9. Measurement of primary productivity was made using light and dark bottle method described by Gaarder and Gran, (1927). It was found out in terms of 'Net primary productivity' and 'Gross primary productivity' (Selvaraj, 2000).
10. Samples of sediments from the clam bed were collected using Peterson grab (0.08 m^2). A portion of the fresh mud sample was transferred to a plastic bag and air dried and stored for further granulometric and organic carbon content analysis. Textural studies to understand particle size was done using pipette analysis method (Krumbein and Pettijohn, 1938; Carver, 1971 and Lewis, 1984). Known quantities of the dried samples were dispersed overnight with sodium hexamethaphosphate solution of 0.025 N. Washing the dispersed sediment through a 230 standard sieve separated the

silt and clay fractions. The coarse fraction retained in the sieve were dried and weighed which gave the weight of material coarser than 0.63 mm. The dried materials were analysed using a set of standard sieves. The washings collected in a measuring jar of one litre were anlaysed for silt and clay by pipette method and displayed in percentage of each fraction.

11. Organic carbon in the sediment was determined with fair accuracy by the method described by Jhingran *et al.* (1988), which was proposed by El- Wakeel and Riley (1957). A known quantity of dried soil sample was treated with 1 N dichromate solution, concentrated sulphuric acid and phosphoric acid and titrated with ferrous ammonium sulphate solution using diphenylamine as indicator. The values are expressed as milligram per gram soil.
12. Rainfall data for the study area was collected for the period from Meteorological Department, Government of India.

Statistical Analysis: The climatological, physicochemical, biological and sedimentological data were subjected to different statistical analysis to check

the consistency, to compare and elucidate relationships within and among Stations and seasons. Mean values of the various parameters are given in the graphical form. Seasonal mean and annual mean of all parameters at the three Stations with standard deviation are given in tabular form. Analysis of variance using one way ANOVA comparing different Stations and seasons, including their interactions were executed (Snedecor and Cocharan, 1967). To find similar groupings of data among Stations and seasons, Duncan's multiple Range (DMR) was performed (Steel and Torrie, 1980). To find out the relationship between various factors, multiple correlation analysis was done (Snedecor and Cocharan, 1967).

2.3 RESULTS

Dharmadom estuary receives the full benefit of the south west monsoon. Fluctuations in the hydrographic parameters were more during the monsoon season. Average depth during the study period is given in Table 2.1. The depth ranged from 180 to 250 m in the estuary. Analysis of variance for the three Stations showed that there was no significant difference between the three Stations (Table 2.2). Hence the parameters were pooled for the three Stations and analysis was done for three seasons (Table 2.3).

2.3 a. Temperature: Spatial and temporal variations during the study period are presented graphically on a monthly basis (Fig 2.1) and seasonal means are given in the Table 2.4 a. Surface temperature in the estuary varied from 27.5°C to 29.5°C and bottom temperature from 27.0°C to 29.3°C. There was significant difference in the temperature between the three seasons. High temperature was observed during the pre-monsoon period (29°C). The temperature showed positive correlation with nitrate and organic carbon. The 'r' value is given in Table 2.5.

2.3 b. pH (Hydrogen ion concentration): Spatial and temporal variations during the study period are presented graphically on a monthly basis (Fig 2.2) and seasonal means are given in the Table 2.4 b. The surface pH in the estuary varied from 7.16 to 7.93 and bottom pH from 7.40 to 7.89. There was significant difference in pH between the three seasons. The pH values were low during the monsoon season (7.4 in July), but there was no significant difference in pH between the pre-monsoon and post- monsoon seasons. pH showed significant positive correlation with productivity, organic carbon and salinity and negative correlation with rainfall (Table 2.5).

2.3 c. Salinity: Monthly variations in the salinity in surface and bottom waters are given graphically in Fig 2.3 and seasonal means are given in Table 2.4 c. The surface salinity ranged from 6.3 ppt to 35.0 ppt and bottom salinity from 8.2 to 35.0 ppt. Minimum salinity was observed in the month of July in both surface and bottom waters. There was significant difference in the salinity between the three seasons. The salinity was lowest (6.3 ppt in July) during the monsoon season and there was significant difference in salinity in monsoon when compared with pre and post monsoon seasons. Salinity showed positive correlation with productivity.

2.3 d. Dissolved Oxygen (D.O): The dissolved oxygen values varied from 4.4 to 5.3 ml/l. The spatial and temporal variations in the D.O are given in Fig 2.4 and the seasonal means given in Table 2.4(d). There was no significant difference in the surface dissolved oxygen between seasons. But there was significant difference in bottom dissolved oxygen between the seasons. During monsoon season the D.O in the bottom waters was more (5.6 ml/l in September) when compared to pre and post monsoon seasons. The bottom water dissolved oxygen showed negative correlation with pH (Table 2.5).

2.3 e. Transparency: Seasonal variations in transparency in the estuary are given in the Table 2.4(e) and the spatial and temporal variation in the transparency is graphically represented in Fig 2.5. The values ranged from 95 to 160 cm. The highest value of 160 cm was observed in January. There was significant difference in transparency between the three seasons. There was significant difference between the transparency in post monsoon season when compared with monsoon and pre-monsoon seasons. The average transparency during post-monsoon was 151 cm, whereas during pre-monsoon it was 100 cm and monsoon it was 99 cm.

2.3 f. Nitrate: Monthly variations in nitrate concentration in surface and bottom waters are represented in Fig 2.6 and the seasonal variations given in Table 2.4(f). The nitrate concentrations in surface and bottom waters ranged from 0.69 to 1.54 μ g/l and 0.71 to 1.52 μ g/l. respectively. There was significant difference in nitrate concentrations between pre-monsoon and the other two seasons. The nitrate concentration is low both in surface and bottom waters (0.74μ g/l) during pre- monsoon season, which gradually increased during the monsoon and post-monsoon periods. Nitrate concentration showed positive correlation with temperature in surface waters and negative correlation with transparency (Table 2.5).

2.3 g. Phosphate: Spatial and temporal variations during the study period are presented graphically on a monthly basis (Fig 2.7) and seasonal means are given in the Table 2.4 g. Phosphate in surface waters ranged from 0.35 µg/l to 1.64 µg/l and in bottom waters from 0.39 to 1.70 µg/l. Minimum was recorded in May and maximum in June. There was significant difference in phosphate concentrations between the seasons. Phosphate concentration showed negative correlation with productivity and temperature (Table 2.5).

2.3 h. Silicate: The silicate in the surface and bottom water ranged from 11.21 to 11.63 µg/l and 11.40 to 12.61 µg/l respectively. There was no significant difference in the silicate concentrations between the three seasons. Spatial and temporal variations during the study period are presented graphically on a monthly basis (Fig 2.8) and seasonal means are given in the Table 2.4(h).

2.3 i. Primary productivity: The Gross Primary Productivity (GPP) in the estuary ranged from 0.490 mg $C/m^3/d$ to 1.040 mg $C/m^3/d$. There was significant difference in the GPP during the three seasons. The highest productivity was recorded during the pre-monsoon (1.030 mg $C/m^3/d$) and lowest during the monsoon season (0.570 mg $C/m^3/d$). The GPP showed

significant negative correlation with rainfall and positive correlation with salinity (Table 2.5). The monthly variations in the GPP and NPP are given in the Fig 2.9 and the seasonal variations in Table 2.4(i).

Net Primary Productivity (NPP) in the estuary ranged from 0.49 to 0.83 mg C/m^3/d. There was significant difference in the NPP between seasons. The highest NPP was recorded during pre monsoon (0.83 mg C/ m^3/d) and lowest during monsoon (0.52 mg C/ m^3/d), corresponding to the GPP value. NPP also showed positive correlation to salinity.

2.3 j. Organic Carbon: The spatial and temporal variation in organic carbon is given in Fig 2.10 and seasonal variations are given in Table 2.4 (j). There was no significant difference in organic carbon between seasons. The values ranged from 0.04 to 0.20 mg/g. The organic carbon showed positive correlation with temperature.

2.3 k. Sediment Texture: The spatial and temporal variations in sand, silt and clay are given in the Fig 2.11 and seasonal variations for the three Stations are given in Table 2.4 (k). The sand predominated through out all the seasons and it ranged from 88 to 91 %, this was followed by clay (7.8 to 9.7 %) and then silts (1.3 to 1.4 %). The sand predominated in all Stations and there was no significant difference in the sediment texture between seasons.

2.3 l. Rainfall: The mean values of rainfall for the study period are given in Fig 2.12. Rainfall showed significant difference between seasons with monsoon season recording the highest rainfall. The highest rainfall of 640 mm was received in June and a minimum of 3 mm in February. Rainfall showed negative correlation with salinity and productivity of the estuary.

2.4 DISCUSSION.

Abiosphere is the determining factor of any ecosystem which controls and cycles the entire system properly. The presence and success of an organism or a group of organisms depends upon a complex of conditions. Many factors of the aquatic habitat are interrelated and inter-depended and the variations of any one factor would influence the other. Environmental relations of the organisms are apt to be complex, so that it is fortunate that not all possible factors are of equal importance for a given organism (Odum, 1971). In the present study, marked seasonal as well as spatial variations were observed in all the parameters during the period from December 2003 to November 2004. A number of abiotic factors are related to each other either directly or inversely. Physical, chemical and biological features of this estuary are adapted to a seasonal rhythm induced by the annual cycle of monsoon.

These variations are similar to the characteristics of other open estuaries of west coast of India like Cochin backwaters (Qasim and Gopinath, 1959; Josanto, 1971; Qasim, 1979; and Lakshmanan *et al.*, 1987), Korapuzha estuary (Rao and George, 1959 and George and Kartha, 1963.) and Beypore estuary (Premchand *et. al.*, 1987).

Seasonal variations in temperature were observed in Dharmadom estuary with maximum during the pre-monsoon. Even though a difference in surface and bottom water temperature prevailed, the differences were found to be comparatively less, due to the shallowness of estuary and mixing fronts. Seasonal variations in temperature with maximum during the pre-monsoon were also observed in Beypore estuary (Premchand *et al.*, 1987). The present results were comparable to the results obtained by Nair *et al.* (1983) and Prasanthan and Nayar (2000).

The most important abiotic factor that determines the nature and extent of the estuary is the salinity. Fluctuations of salinity were found to be great temporally. A clear seasonal variation with low salinity during monsoon was observed in Dharmadom estuary. There was no much variation in the surface and bottom salinity in the clam beds. The proximity of the Stations to the sea could be one reason for this. It is a well known fact that salinity is an important factor limiting the distribution of invertebrates in estuarine environment (Gray,

1974). Availability of space, competition, predation and tolerance range to environmental variations are some of the factors which control the distribution and zonation of bivalves (Rao and Sundaram, 1972 and Bayne, 1976). Appukuttan (1993) has observed that *P. malabarica* was abundant in the marine zone of Ashtamudi estuary where the salinity was above 32.0 ppt in all the months except monsoon. Rao and Meiyappan (1988) also observed that salinity for *P. malabarica* bed was above 33.0 ppt. In the present study also in Dharmadom estuary, the salinity was above 33.0 ppt except during monsoon. Hence, it could be assumed that *P. malabarica* prefers higher salinity area in the estuary.

Temperature rather than salinity has been suggested to be the main factor limiting the distribution of temperate bivalves (Manzi and Castagna, 1989). However, in the tropical conditions, where monsoon plays an important role, salinity has been considered as the main factor influencing the distribution of bivalves. The venerid clams *Meretrix meretrix* and *Katelysia opima* coexist in the estuaries of Maharashtra. However, due to the more tolerant nature of *M. meretrix*, it has been found to dominate the typical estuarine zone, while *K. opima* which prefers more salinity is more towards the marine zone (Ranade and Kulkarni, 1969). Narasimham (1985) has also observed salinity restricting the distribution of *Anadara granosa* in Kakinada Bay.

Hydrogen ion concentration or pH forms one of the important chemical characters of the medium which is generally controlled by the carbonate-bi carbonate buffer. The small fluctuations in pH are due to the alkalinity, which assures stability of pH (Huet, 1986). In the present study the pH values were comparatively low during the monsoon season and in other seasons pH was slightly higher. The observations were in accordance with earlier reports (Appukuttan, 1993 and Shibu *et al.*, 1993).

A critical factor for the maintenance of life in water is its dissolved oxygen content which is a regulator of metabolic processes of communities and organisms and as an indicator of the condition of a water body. The surface water dissolved oxygen did not differ significantly between seasons but the bottom water dissolved oxygen was comparatively high during monsoon. Higher solubility of oxygen during monsoon may be due to colder and less saline water, high turbulence and high flow rate. The effect of monsoon on oxygen content has been reported earlier in many water bodies (Saraladevi *et al.*, 1983; Nair and Azis, 1987; Devaraj *et al.*, 1988; and Shibu *et al.*, 1993).

The nutrients are the important life supporting abiotic factor in an ecosystem. The nitrate and phosphate values were significantly different between the seasons, but silicate did not vary much between the seasons but higher values were found during the monsoon. Lowest nitrate and phosphate

concentrations were observed in pre-monsoon. Nair *et al.* (1983) observed that in Ashtamudi estuary along Kerala coast, the phosphates and nitrates were low during pre-monsoon, increased during the monsoon and post-monsoon. Similar observations were also reported by Narasimham (1985) in Kakinada Bay. The nutrient concentrations in the three seasons in Dharmadom estuary are in confirmation with the above observations.

Productivity is the most important biological parameter as far as an ecosystem is concerned. The Gross Productivity and Net productivity determine the biotic life content and quality of any system. The Gross primary productivity and Net primary productivity showed significant difference between seasons. Low values were observed during monsoon season and higher values during pre-monsoon and post-monsoon. This bimodal pattern of productivity was also observed by Rajesh *et al.* (2002) in Nethravathi estuary.

Organic carbon plays an important role in benthic ecology (Gee *et al.*, 1985). Organic carbon did not differ significantly between the seasons. The organic carbon was slightly higher during the pre-monsoon period. The organic carbon (mg/g) was comparatively less when compared to Kakinada bay (Narasimham, 1985) and Ashtamudi estuary (Appukuttan, 1993). The probable reason could be due to the sandy nature of the bed and proximity towards the

marine front. Similar observations were made by Kurian (2002) in Karamana estuary and Appukuttan (1993) in Ashatamudi estuary.

Sediment texture plays an important role in the distribution of clams. The bivalves, especially the clams are substrate specific. The clam bed in Dharmadom where *Paphia malabarica* was distributed was sandy in nature, where more than 80 % of the sediment was constituted of sand in all seasons. The sediment texture did not differ significantly with seasons. Appukuttan (1993) also found that in Ashtamudi estuary *Paphia malabarica* was concentrated more in sandy substratum.

In Dharmadom estuary the distribution pattern and density of the *Paphia malabarica* did not vary much between stations and the distribution was restricted towards the barmouth area where the salinity was high and the sediment was sandy in nature. Schoeman and Richardson (2002), has observed that abiotic and biotic factors influence the distribution of clams and in Dharmadom estuary the two factors influencing the distribution of *P. malabarica* are salinity and sediment texture.

The physico-chemical properties determine the benthic fauna on a spatio- temporal scale. A comparative idea of the bottom ecology is of great significance in any systematic aquaculture programme and optimum management of the clam resources. Although all the ecological factors interact

positively or negatively with each other in the estuary, from the present study it could be inferred that *P. malabarica* distribution is governed mainly by salinity and sediment texture. These two are the basic criteria which have to be taken care of when implementing clam culture or transplantation of this species to other estuaries to augment clam production.

The effect of environmental parameters on reproduction and condition index is discussed in the corresponding chapters dealing with these aspects.

Table 2.1: Average water depth (cm) in *Paphia malabarica* beds in Dharmadom Estuary from December 2003 – November 2004.

Month	Station I	Station II	Station III
December	210	220	220
January	190	200	180
February	190	200	190
March	200	190	230
April	180	180	220
May	200	190	210
June	190	200	250
July	200	210	230
August	180	180	240
September	170	180	230
October	190	180	250
November	180	190	250

Table 2.2: One Way ANOVA comparing hydrographical parameters in three Stations

			Sum of Squares	df	Mean Square	F	Sig.
Surface Salinity* Stations	Between Groups	(Combined)	2.079	2	1.039	0.01	0.99
	Within Groups		3367.96	33	102.06		
	Total		3370.04	35			
Bottom Salinity* Stations	Between Groups	(Combined)	7.58	2.00	3.79	0.04	0.96
	Within Groups		2895.87	33.00	87.75		
	Total		2903.45	35.00			
Surface Temperature* Stations	Between Groups	(Combined)	0.002	2.000	0.001	0.003	0.997
	Within Groups		11.393	33.000	0.345		
	Total		11.396	35.000			
Bottom Temperature* Stations	Between Groups	(Combined)	0.128	2	0.064	0.116	0.891
	Within Groups		18.266	33	0.554		
	Total		18.394	35			
Surface pH* Stations	Between Groups	(Combined)	0.009	2	0.005	0.098	0.907
	Within Groups		1.549	33	0.047		
	Total		1.558	35			
Bottom pH* Stations	Between Groups	(Combined)	0.013	2	0.007	0.148	0.863
	Within Groups		1.47	33	0.045		
	Total		1.483	35			
Surface Dissolved oxygen* Stations	Between Groups	(Combined)	0.001	2	0	0.005	0.995
	Within Groups		2.432	33	0.074		
	Total		2.433	35			
Bottom Dissolved oxygen* Stations	Between Groups	(Combined)	0.024	2	0.012	0.059	0.943
	Within Groups		6.801	33	0.206		
	Total		6.825	35			
Surface Nitrate* Stations	Between Groups	(Combined)	0.004	2	0.002	0.022	0.978
	Within Groups		2.662	33	0.081		
	Total		2.665	35			
Bottom Nitrate* Stations	Between Groups	(Combined)	0.001	2	0.001	0.008	0.992
	Within Groups		2.752	33	0.083		

	Total		2.753	35			
Surface Phosphate* Stations	Between Groups	(Combined)	0.017	2	0.008	0.052	0.95
	Within Groups		5.256	33	0.159		
	Total		5.273	35			
Bottom Phosphate* Stations	Between Groups	(Combined)	0.004	2	0.002	0.011	0.989
	Within Groups		6.48	33	0.196		
	Total		6.484	35			
Surface Silicate* Stations	Between Groups	(Combined)	0.002	2	0.001	0.004	0.997
	Within Groups		7.411	33	0.225		
	Total		7.413	35			
Bottom Silicate* Stations	Between Groups	(Combined)	0.009	2	0.004	0.019	0.981
	Within Groups		7.384	33	0.224		
	Total		7.392	35			
Transparency * Stations	Between Groups	(Combined)	792.167	2	396.083	0.586	0.562
	Within Groups		22308.583	33	676.018		
	Total		23100.75	35			
Organic Carbon * Stations	Between Groups	(Combined)	0	2	0	0.022	0.978
	Within Groups		0.151	33	0.005		
	Total		0.151	35			
Sand * Stations	Between Groups	(Combined)	0.061	2	0.031	0.002	0.998
	Within Groups		619.002	33	18.758		
	Total		619.063	35			
Silt * Stations	Between Groups	(Combined)	0.001	2	0.001	0.001	0.999
	Within Groups		17.358	33	0.526		
	Total		17.359	35			
Clay * Stations	Between Groups	(Combined)	0.047	2	0.023	0.001	0.999
	Within Groups		532.876	33	16.148		
	Total		532.923	35			

Table 2.3: One way ANOVA comparing various hydrographical parameters in the clam beds in three seasons.

			Sum of Squares	df	Mean Square	F	Sig.
Surface Salinity* Season	Between Groups	(Combined)	777.096	2	388.548	9.637	0.006
	Within Groups		362.87	9	40.319		
	Total		1139.966	11			
Bottom Salinity* Season	Between Groups	(Combined)	649.595	2	324.798	8.42	0.009
	Within Groups		347.168	9	38.574		
	Total		996.763	11			
Surface Temperature* Season	Between Groups	(Combined)	2.542	2	1.271	9.114	0.007
	Within Groups		1.255	9	0.139		
	Total		3.797	11			
Bottom Temperature* Season	Between Groups	(Combined)	3.01	2	1.505	5.898	0.023
	Within Groups		2.297	9	0.255		
	Total		5.307	11			
Surface pH* Season	Between Groups	(Combined)	0.435	2	0.218	17.804	0.001
	Within Groups		0.11	9	0.012		
	Total		0.545	11			
Bottom pH* Season	Between Groups	(Combined)	0.445	2	0.223	23.401	0.00
	Within Groups		0.086	9	0.01		
	Total		0.531	11			
Surface Dissolved oxygen* Season	Between Groups	(Combined)	0.307	2	0.153	1.998	0.191
	Within Groups		0.691	9	0.077		
	Total		0.997	11			
Bottom Dissolved oxygen* Season	Between Groups	(Combined)	2.197	2	1.098	14.2	0.002
	Within Groups		0.696	9	0.077		
	Total		2.893	11			
Surface Nitrate* Season	Between Groups	(Combined)	2.365	2	1.182	129.891	0.00
	Within Groups		0.3	33	0.009		
	Total		2.665	35			
Bottom Nitrate* Season	Between Groups	(Combined)	2.476	2	1.238	147.442	0.00
	Within Groups		0.277	33	0.008		
	Total		2.753	35			

Surface Phosphate* Season	Between Groups	(Combined)	1.171	2	0.585	12.273	0.003
	Within Groups		0.429	9	0.048		
	Total		1.6	11			
Bottom Phosphate* Season	Between Groups	(Combined)	1.455	2	0.728	12.308	0.003
	Within Groups		0.532	9	0.059		
	Total		1.987	11			
Surface Silicate* Season	Between Groups	(Combined)	0.409	2	0.205	0.922	0.432
	Within Groups		1.998	9	0.222		
	Total		2.407	11			
Bottom Silicate* Season	Between Groups	(Combined)	0.403	2	0.202	0.869	0.452
	Within Groups		2.088	9	0.232		
	Total		2.492	11			
Transparency * Season	Between Groups	(Combined)	6973.167	2	3486.583	65.136	0.00
	Within Groups		481.75	9	53.528		
	Total		7454.917	11			
Organic Carbon * Season	Between Groups	(Combined)	0.006	2	0.003	0.668	0.537
	Within Groups		0.043	9	0.005		
	Total		0.049	11			
Sand * Season	Between Groups	(Combined)	7.481	2	3.741	0.169	0.847
	Within Groups		198.732	9	22.081		
	Total		206.213	11			
Silt * Season	Between Groups	(Combined)	0.016822	2	0.008411	0.01316	0.987
	Within Groups		5.752244	9	0.639138		
	Total		5.769067	11			
Clay * Season	Between Groups	(Combined)	8.036	2	4.018	0.213	0.812
	Within Groups		169.509	9	18.834		
	Total		177.545	11			
	Within Groups		0.016	9	0.002		

GPP * Season	Between Groups	(Combined)	0.458	2	0.229	126.745	0.00
	Total		0.475	11			
NPP * Season	Between Groups	(Combined)	0.217	2	0.109	267.532	0.00
	Within Groups		0.004	9	0		
	Total		0.221	11			
Rainfall* Season	Between Groups	(Combined)	237785.167	2	118892.583	4.648	0.041
	Within Groups		230199.75	9	25577.75		
	Total		467984.917	11			

Table 2.4: Hydrographical parameters of clam beds in Dharmadom Estuary for three seasons from December 2003- November 2004

2.4 a. Temperature

Temperature (° C)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	29	0.41	29	0.41	29	0.41
	BW	28.6	0.52	28.63	0.63	28.4	0.48
Monsoon	SW	28.38	0.15	28.33	0.13	28.38	0.15
	BW	27.5	0.41	27.13	0.75	27.5	0.41
Post Monsoon	SW	27.9	0.48	27.88	0.48	27.88	0.48
	BW	27.5	0.58	27.38	0.48	27.5	0.58
Annual	SW	28.42	0.59	28.40	0.59	28.42	0.59
	BW	27.85	0.69	27.71	0.89	27.79	0.62

SW= Surface water
BW= Bottom water

2.4 b. pH

pH							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	7.77	0.03	7.69	0.19	7.75	0.03
	BW	7.73	0.05	7.62	0.22	7.72	0.08
Monsoon	SW	7.40	0.17	7.4	0.2	7.46	0.19
	BW	7.34	0.13	7.3	0.1	7.39	0.15
Post Monsoon	SW	7.84	0.08	7.8	0.1	7.74	0.08
	BW	7.76	0.10	7.7	0.1	7.67	0.11
Annual	SW	7.67	0.22	7.6	7.6	7.65	0.18
	BW	7.61	0.22	0.2	0.2	7.59	0.18

2.4 c. Salinity

Salinity (ppt)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	33.6	1.3	33.5	1.1	33.4	0.4
	BW	34.0	1.6	33.9	1.1	32.1	0.9
Monsoon	SW	17.2	10.9	17.38	10.71	16.8	10.9
	BW	18.4	10.6	18.28	10.55	18.0	10.5
Post Monsoon	SW	34.9	0.3	34.9	0.3	34	0.41
	BW	33.9	1.0	34.0	1.0	33.13	0.85
Annual	SW	28.56	10.18	28.58	10.02	28.06	10.11
	BW	28.76	9.52	28.70	9.50	27.76	9.08

2.4 d: Dissolved Oxygen

Dissolved Oxygen (ml/l)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	4.57	0.37	4.59	0.41	4.6	0.27
	BW	4.39	0.32	4.46	0.47	4.38	0.32
Monsoon	SW	4.90	0.22	4.83	0.32	4.81	0.12
	BW	5.30	0.32	5.13	0.33	5.09	0.12
Post Monsoon	SW	4.55	0.21	4.59	0.15	4.65	0.13
	BW	4.40	0.16	4.47	0.16	4.44	0.19
Annual	SW	4.67	0.30	4.67	0.30	4.68	0.20
	BW	4.70	0.51	4.69	0.45	4.64	0.39

2.4 e. Transparency

Transparency (cm)						
Seasons	Station I		Station II		Station III	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	100.00	4.397	96.75	4.99	91.75	12.95
Monsoon	98.75	2.217	98.75	3.30	86.25	16.76
Post Monsoon	150.5	11.68	145	10.6	138.00	14.58
Annual	116.42	26.03	113.5	24.1	105.33	27.71

2.4 f. Nitrate-Nitrogen

Nitrate (μ g/l)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	1.32	0.16	1.29	0.15	1.30	0.16
	BW	1.32	0.15	1.31	0.15	1.32	0.13
Monsoon	SW	1.275	0.077	1.28	0.09	1.23	0.06
	BW	1.283	0.086	1.27	0.11	1.25	0.09
Post Monsoon	SW	0.743	0.046	0.74	0.04	0.73	0.04
	BW	0.740	0.036	0.73	0.04	0.74	0.03
Annual	SW	1.11	0.289	1.10	0.28	1.09	0.28
	BW	1.11	0.290	1.10	0.29	1.10	0.28

2.4 g. Phosphate.

Phosphate (μ g / l)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	0.53	0.156	0.56	0.14	0.52	0.16
	BW	0.54	0.123	0.55	0.11	0.52	0.08
Monsoon	SW	1.24	0.279	1.25	0.29	1.30	0.30
	BW	1.32	0.293	1.37	0.42	1.41	0.30
Post Monsoon	SW	1.14	0.202	1.24	1.24	1.09	0.19
	BW	1.24	0.277	0.33	0.29	1.15	0.24
Annual	SW	0.97	0.381	1.01	0.41	0.97	0.40
	BW	1.03	0.425	1.05	0.46	1.03	0.44

2.4 h. Silicate

Silicate (μ g / l)							
Seasons		Station I		Station II		Station III	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	SW	11.84	0.624	11.88	0.67	11.83	0.63
	BW	11.89	0.666	11.87	0.64	11.84	0.59
Monsoon	SW	12.17	0.338	12.17	0.35	12.17	0.33
	BW	12.18	0.320	12.16	0.35	12.16	0.31
Post Monsoon	SW	11.7	0.40	11.73	0.39	11.79	0.45
	BW	11.73	0.39	11.84	0.51	11.75	0.42
Annual	SW	11.9	0.47	11.93	0.48	11.93	0.47
	BW	11.93	0.48	11.95	0.49	11.92	0.45

2.4 i. Productivity

Productivity (mg $C/m^3/d$)				
Seasons	Gross Primary Productivity		Net Primary Productivity	
	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	1.03	0.009	0.83	0.007
Monsoon	0.57	0.062	0.52	0.029
Post Monsoon	0.92	0.039	0.77	0.017
Annual	0.84	0.208	0.70	0.142

2.4 j. Organic Carbon

Organic Carbon (mg/g)						
Seasons	Station I		Station II		Station III	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pre Monsoon	0.12	0.08	0.10	0.08	0.08	0.07
Monsoon	0.06	0.04	0.11	0.08	0.11	0.07
Post Monsoon	0.09	0.071	0.09	0.072	0.09	0.080
Annual	0.093	0.066	0.098	0.069	0.093	0.068

2.4. k. Sediment Texture: Percentage of Sand, Silt and Clay in three stations for the period December 2003- November 2004

Seasons	Month	Station I			Station II			Station III		
		Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
Pre Monsoon	Feb	91.13	0.74	8.13	91.2	0.8	8	91.15	0.72	8.13
	Mar	88.31	2.54	9.15	88.34	2.56	9.1	88.45	2.57	8.98
	April	94.15	0.92	4.93	94.2	0.86	4.94	94.18	0.9	4.92
	May	89.73	1.06	9.21	89.63	1.05	9.32	89.63	1.06	9.31
Monsoon	June	88.48	1.95	9.57	88.6	1.85	9.55	88.46	1.94	9.6
	July	95.19	1.56	3.25	95.2	1.55	3.25	95.22	1.54	3.24
	Aug	83.66	0.96	15.38	84.2	0.9	14.9	83.55	0.99	15.46
	Sept	88.45	0.66	10.89	88.5	0.65	10.85	88.45	0.65	10.9
Post - Monsoon	Oct	95.39	0.68	3.93	95.78	0.6	3.62	95.42	0.64	3.94
	Nov	95.49	0.44	4.07	95.45	0.45	4.1	95.47	0.45	4.08
	Dec	82.98	2.2	14.82	83.12	2.1	14.78	82.95	2.22	14.83
	Jan	87.76	2.1	10.14	87.52	2.3	10.18	87.73	2.12	10.15

ble 2.5 :Correlation between hydrographic parameters in the surface waters of the clam bed.

	GPP	Rainfall	Diss.oxy	Nitrate	NPP	Org.carb	Phos	pH	Silicate	Salinity	Temp	Transparency
PP	1	-.716(**)	-0.522	-0.204	.966(**)	0.321	-.701(*)	.772(**)	-0.382	.732(**)	0.236	0.308
infall		1	0.45	0.307	-.725(**)	-0.14	0.486	-.662(*)	0.294	-.824(**)	-0.122	-0.428
ss.oxy			1	0.05	-0.497	0.142	0.107	-0.466	0.556	-0.347	0.113	-0.283
rate				1	-0.271	0.049	-0.26	-0.481	0.314	-0.452	.680(*)	-.936(**)
PP					1	0.273	-.618(*)	.858(**)	-0.333	.849(**)	0.204	0.333
g.carb						1	-0.243	0.305	0.075	0.105	.582(*)	-0.094
os							1	-0.298	0.26	-0.442	-0.549	0.215
								1	-0.32	.876(**)	-0.07	0.556
icate									1	-0.302	0.193	-0.342
linity										1	0.017	0.469
mp											1	-.727(**)
ansparency												1

Correlation significant at 0.01 level
Correlation is significant at 0.5 level

orrelation between various hydrographic and sediment parameters in the clam bed (bottom)

	Salinity	D.O	pH	Temp	Silicate	Phosphate	Nitrate	NPP	Org. carb	GPP	Rainfall	Transparency
linity	1	-0.554	.852(**)	0.442	-0.288	-0.417	-0.417	.843(**)	0.122	.732(**)	-.845(**)	0.42
O		1	-.696(*)	-0.298	0.449	0.447	0.245	-.820(**)	-0.067	-.856(**)	.610(*)	-0.411
H			1	0.313	-0.374	-0.351	-0.467	.896(**)	0.335	.846(**)	-.733(**)	0.534
mp				1	-0.04	-.578(*)	0.377	0.532	0.36	0.502	-0.441	-0.46
licate					1	0.182	0.333	-0.308	0.067	-0.352	0.288	-0.361
osphate						1	-0.316	-.609(*)	-0.107	-.688(*)	0.433	0.258
trate							1	-0.286	0.048	-0.215	0.328	-.940(**)
PP								1	0.273	.966(**)	-.725(**)	0.333
g. carb									1	0.321	-0.14	-0.094
PP										1	-.716(**)	0.308
ainfall											1	-0.428
ransparency												1

Correlation significant at 0.01 level
Correlation is significant at 0.5 level

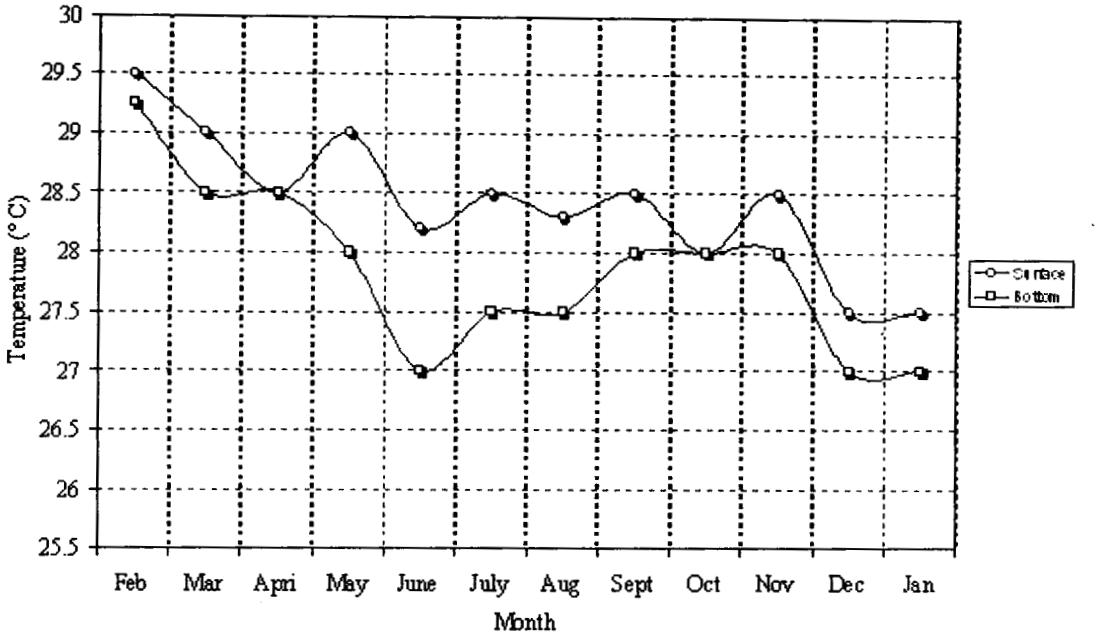


Fig. 2.1: Spatial and temporal variations in surface and bottom water temperature

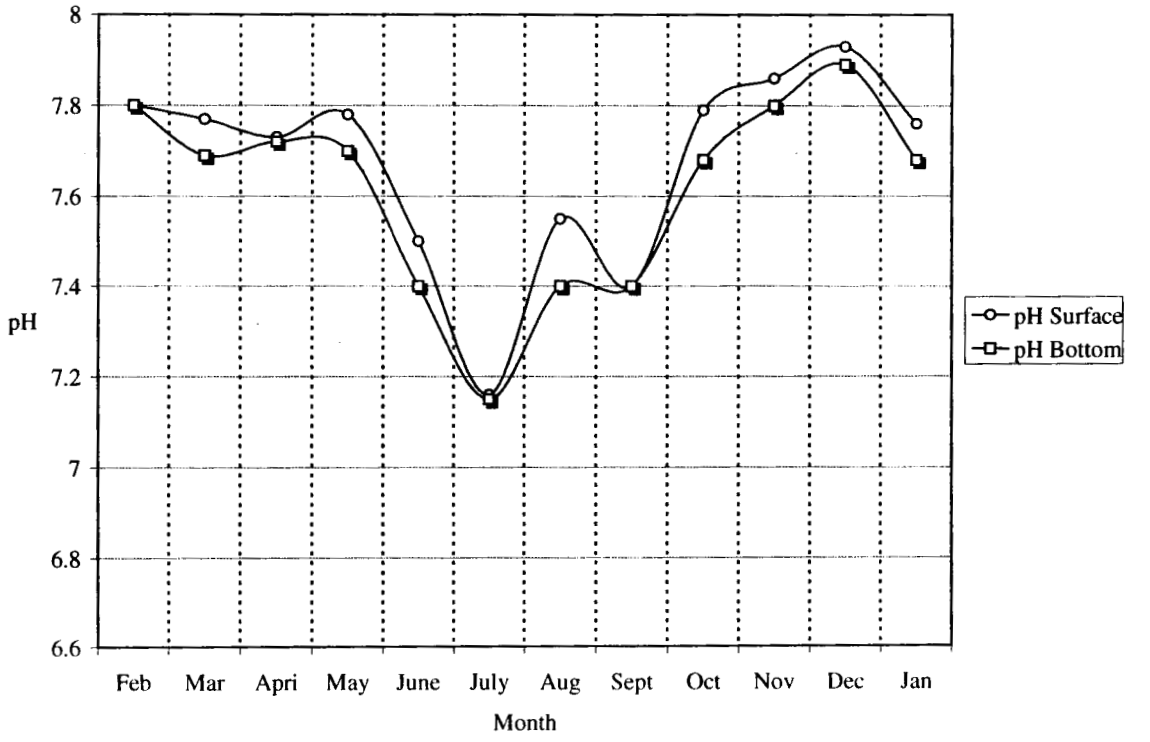


Fig. 2.2: Spatial and temporal variations in surface and bottom water pH.

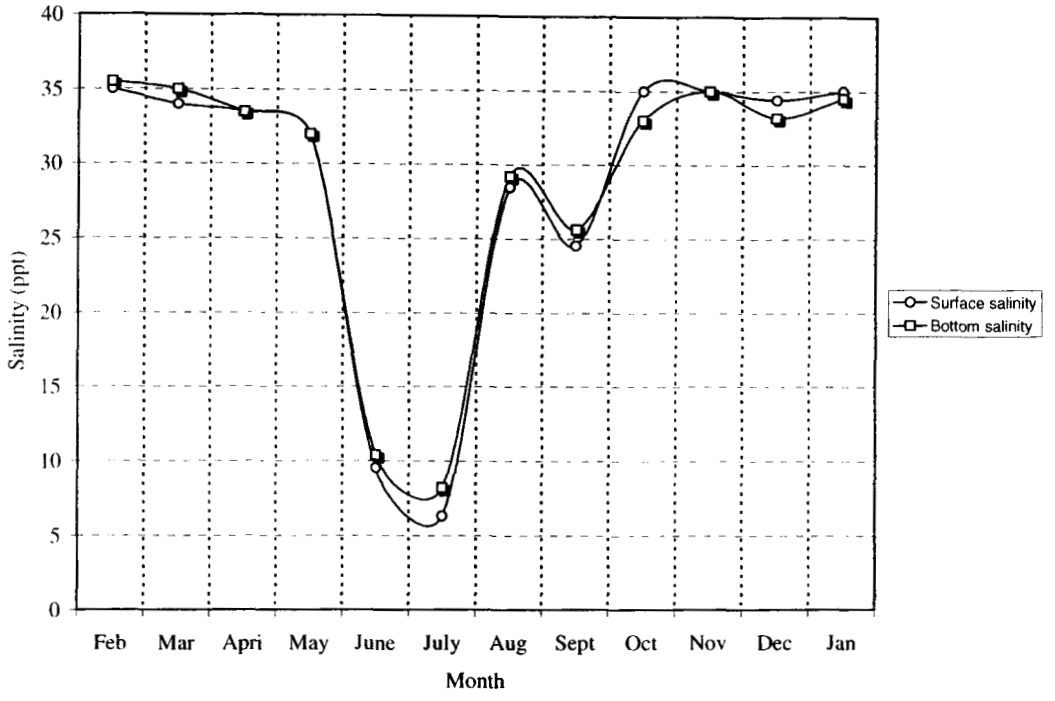


Fig. 2.3: Spatial and temporal variations in surface and bottom water salinity.

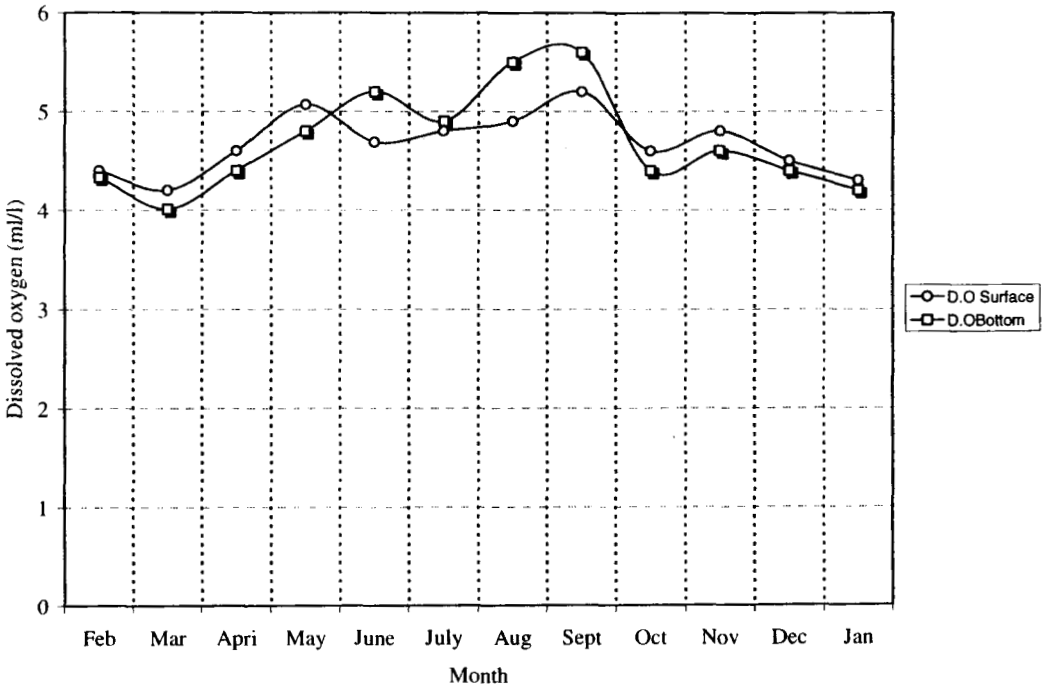


Fig. 2.4: Spatial and temporal variations in surface and bottom water dissolved oxygen.

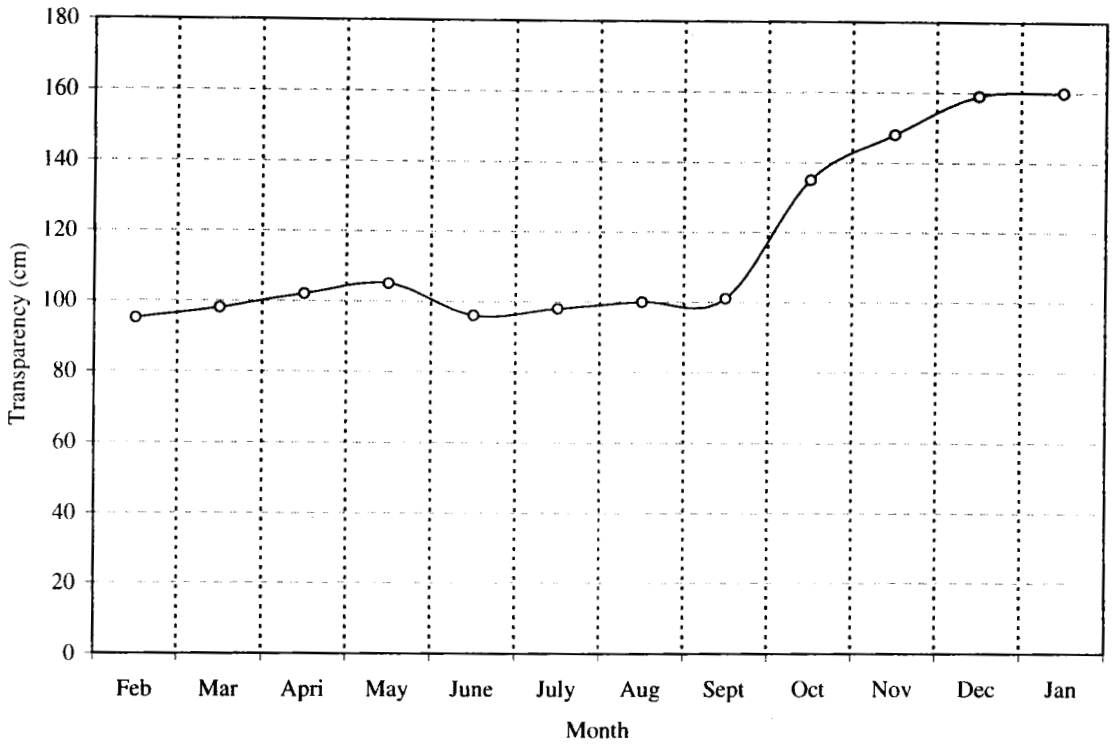


Fig. 2.5: Spatial and temporal variations in water transparency

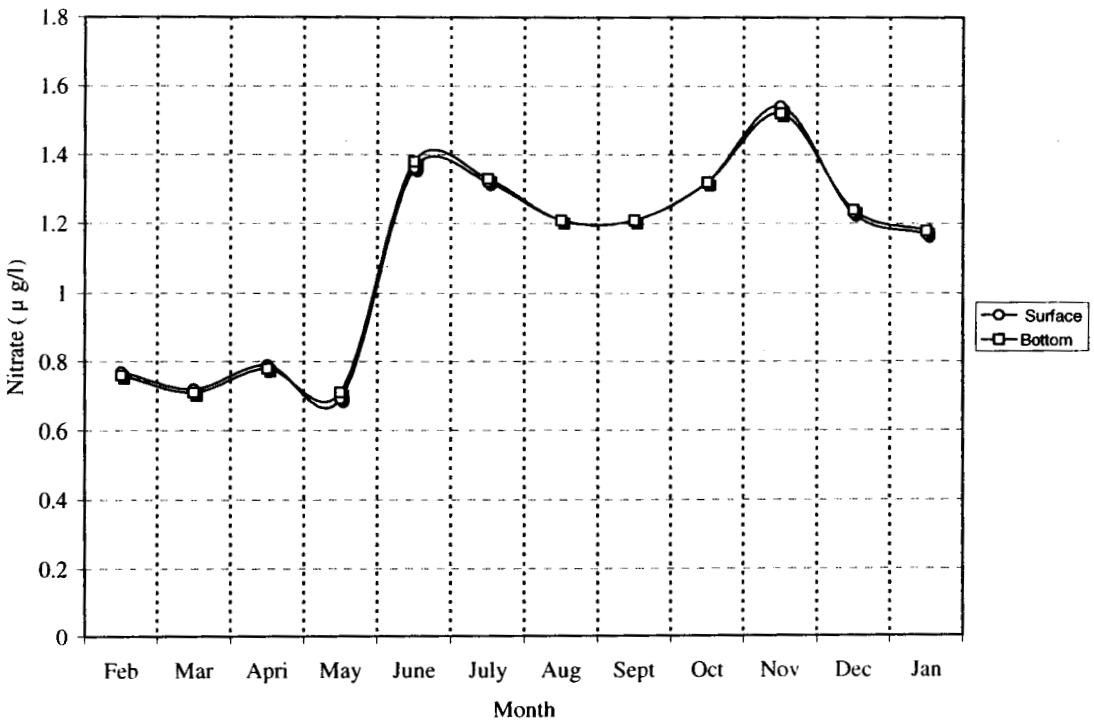


Fig 2.6: Spatial and temporal variations in Nitrate Nitrogen of surface and bottom water

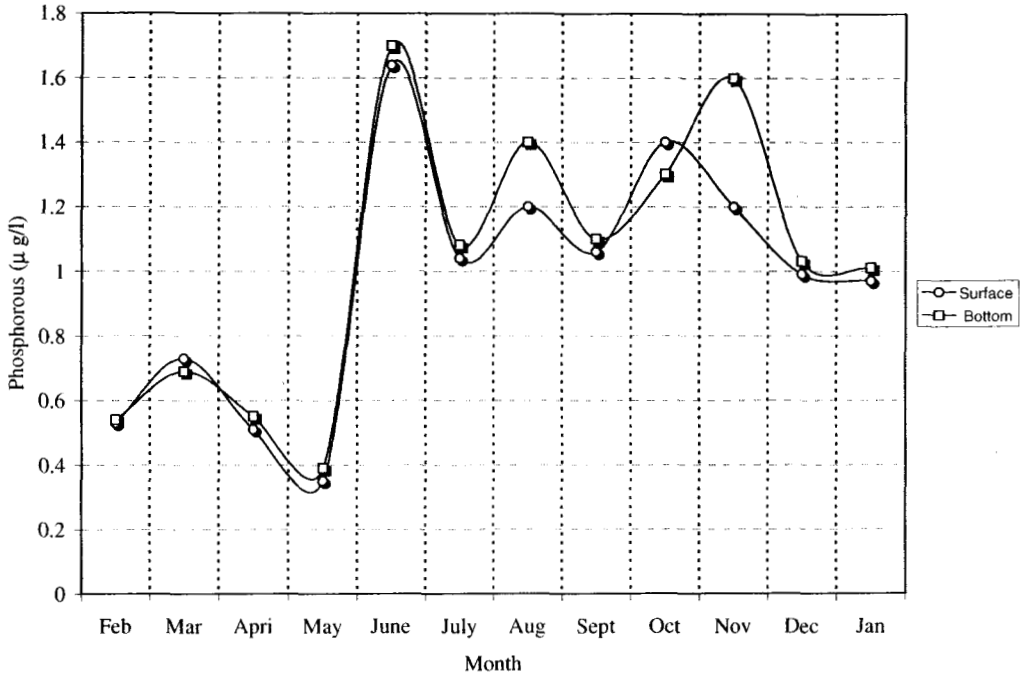


Fig. 2.7: Spatial and temporal variations in surface and bottom water Phosphate Phosphorus

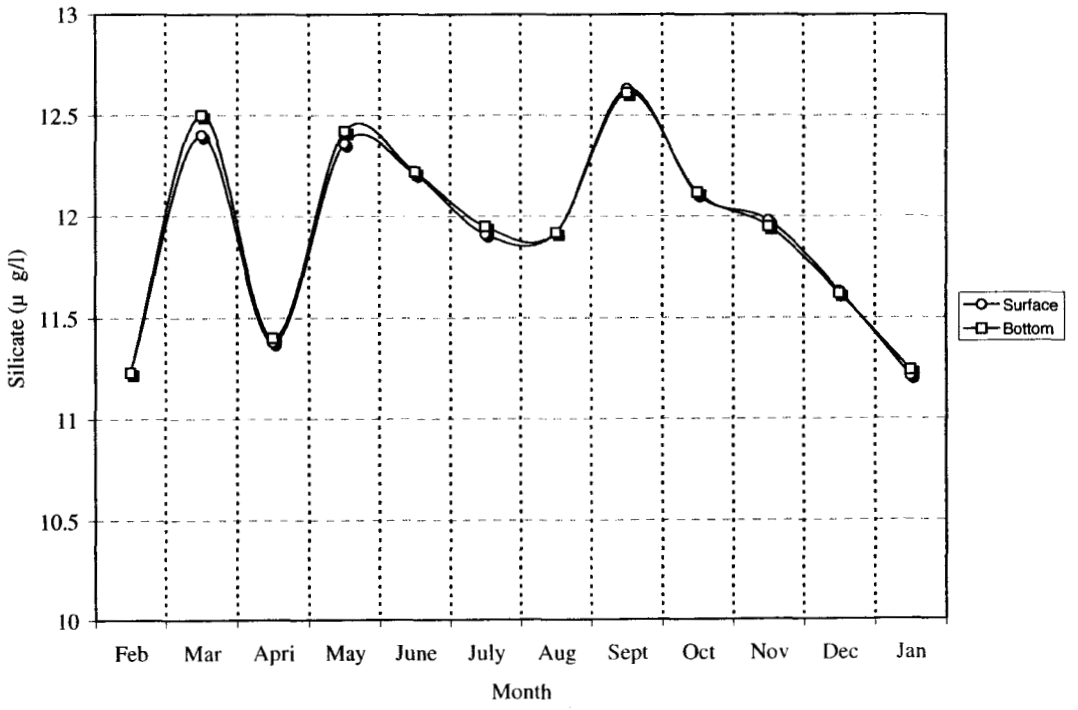


Fig. 2.8: Spatial and temporal variations in surface and bottom water Silicate-Silicon

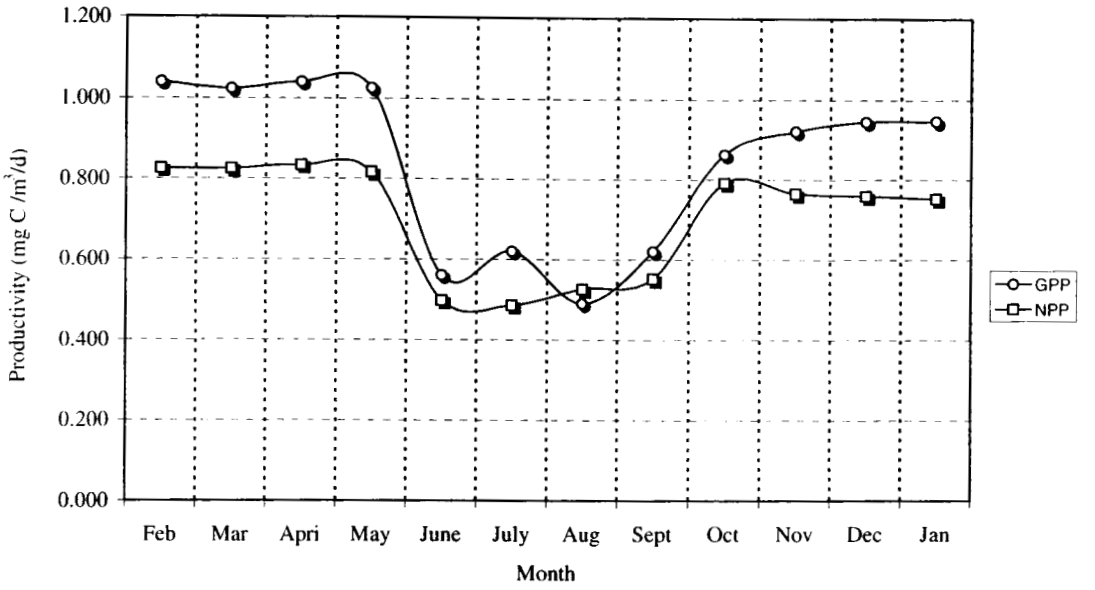


Fig. 2.9: Spatial and temporal variations in Gross and Net Primary productivity

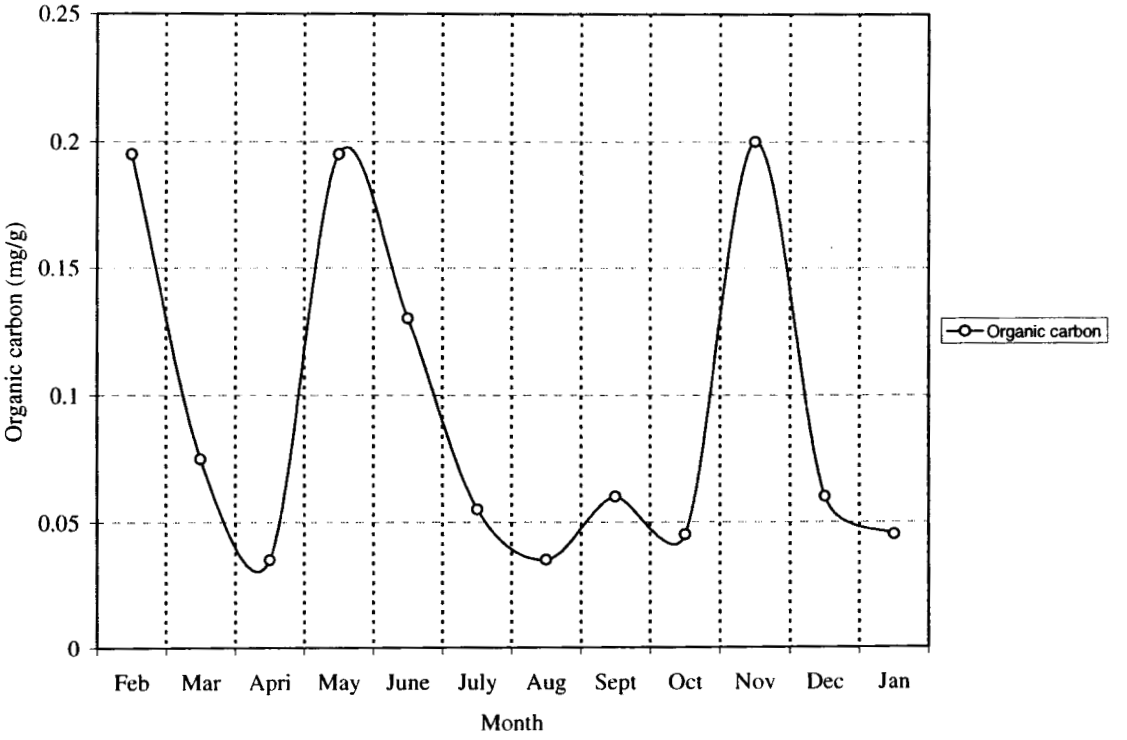


Fig. 2.10: Spatial and temporal variations of sediment organic carbon

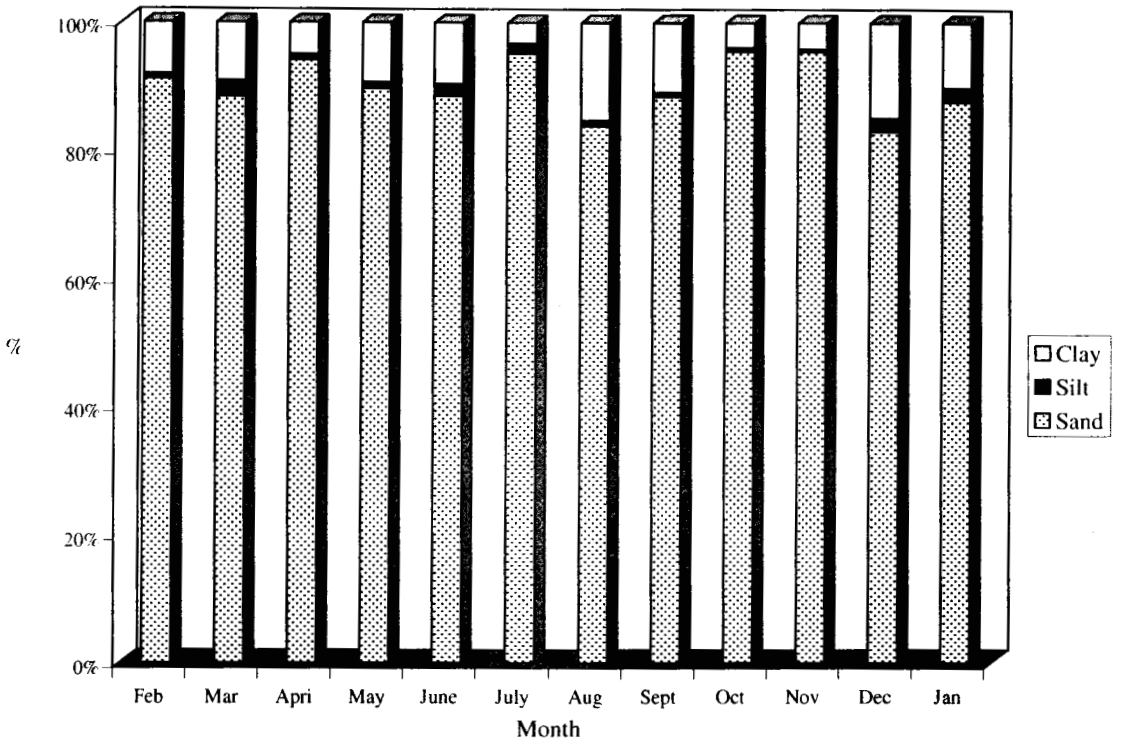


Fig. 2.11: Spatial and temporal variations of sediment texture

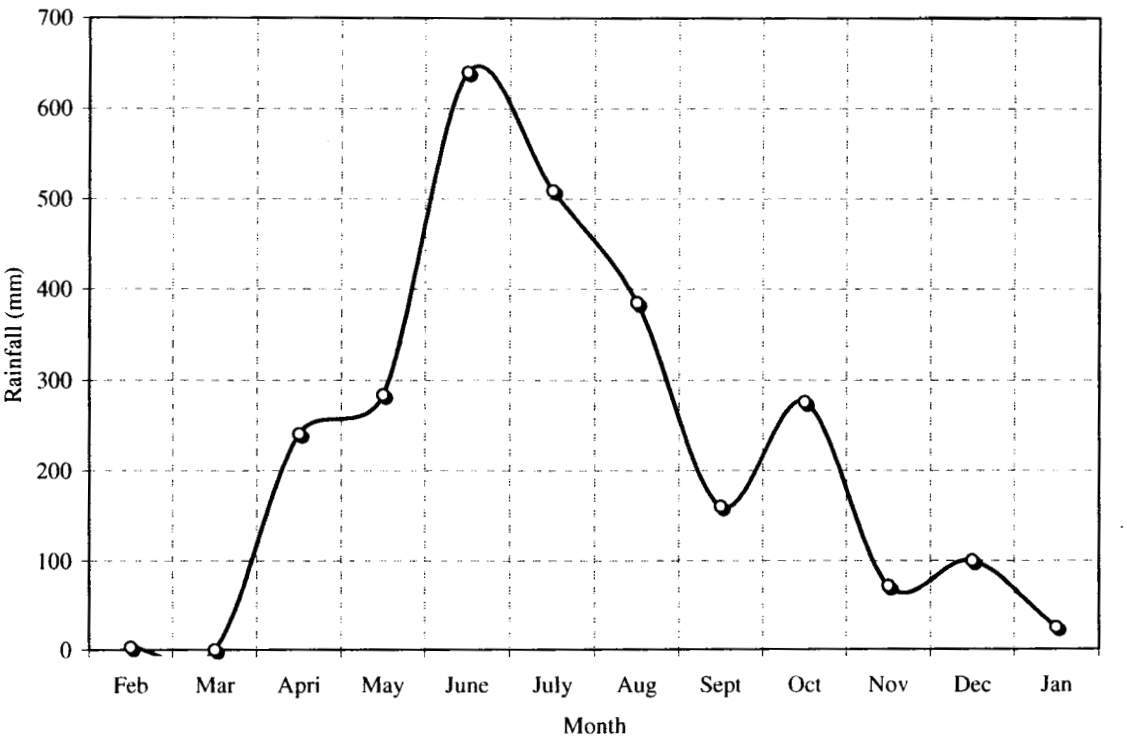


Fig. 2.12: Rainfall Data of Dharmadom area for the period 2003-04

Allometric Relationships of Paphia malabarica

Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter III

Allometric Relationships of *Paphia malabarica*

Growth is a three dimensional process with all dimensions changing over time. The allometric principles of animal morphology have long been recognized, since the concept of allometry was first postulated by Huxley and Tessier (1936). Allometry is the study of the relationship between two measurable variables, or in most general sense, allometry is the study of size and its consequences (Mayrat, 1970; Reiss, 1989). The study of length-weight relationship and dimensional relationships assumes great importance in fishery biology research, as it provides a mathematical relationship between them, enabling the derivations of one variable from other. Often growth is estimated by measuring shell dimensions or the volume of the animal. (Hibbert, 1977; Bailey and Green, 1988) because they are simple, non- destructive methods that can be easily completed in the field. Once the allometric relationship is established, shell measurement is a sufficient surrogate to estimate biomass and total flesh production (Hibbert, 1977;

Rodhouse *et al.*, 1984). Studying bivalve growth and establishing allometric relationships are essential for generating useful information for managing resources and understanding changing environmental conditions and pollution (Palmer, 1990).

Biotic factors such as reproductive state of the animal, population density, physical and biological variables of habitat are known to effect the growth of the bivalves and can change the allometry between the shell and flesh (Thorarrinsdottir and Johnnesson, 1996). Bivalve shell growth and shape are also influenced by abiotic (exogenous/environmental) and biotic (endogenous /physiological) factors (Gasper *et al.*, 2002). A variety of environmental factors such as latitude (Beukema and Meehan, 1985), depth (Claxton *et al.*, 1998), shore level (Franz, 1993), tidal level (Dame, 1972), currents (Fuiman et al., 1999), water turbulence (Hinch and Bailey, 1988), wave exposure (Akester and Martel, 2000), type of bottom (Claxton *et al.*, 1998) and type of sediment (Newell and Hidu, 1982) are known to influence shell morphology and relative proportions of many bivalve species,. Burrowing behaviour, ability and efficiency also affect the relative growth of the bivalve species (Eagar, 1978, Seed, 1980).

Information on allometry helps to understand the ideal conditions under which bivalves show proportionate growth and also to determine the size at

which harvest can be intensified so as to maximize production. Of the different relationships, length-weight is the most important, since it helps inter conversion of variables. Thus, in computation and analysis of catch statistics it helps to convert the sample weight to numbers in order to obtain the abundance of stock in space and time. Moreover, the information would allow for comparison between bivalves species from different geographical areas, and could also be used both in fishery models and in improving fishing gear selectivity. Thus, a thorough knowledge of allometric relationships of commercially important bivalves is imperative for successful exploitation of its fishery potential.

The weight of the animal is considered a function of length and since length is a linear measure and weight is a measure of volume, the relationship between the length and weight of an animal could be expressed by the hypothetical cube law, $W = CL^3$, where W (g) and L (cm) are the weight and length respectively and C a constant. This expression holds good when the specific gravity and the form of the animal remain constant. However, in aquatic organisms the growth is not always isometric and therefore does not exactly follow the cube law. Le Cren (1951) modified the equation into a non- linear equation as $W= aL^b$, where a and b are constants to be derived empirically. This equation explains the relationship between

length and weight of a fish better than cube law. The exponent value of b in the equation varies from 2.5 to 4 (Hile, 1936) depending on the shape of the fish. However, significant variation from the isometric growth ($b = 3$) is not always common in fishes (Beverton and Holt, 1957) and b will be equal to 3 in an ideal situation where the animal maintains its body proportion throughout (Allen, 1938) its life.

This non- linear equation can be transformed into a linear equation of the form, $Y = a + b\,X$ by taking logarithms on both sides as,

$$Log\ W = Log\ a + b\ Log\ L$$

i.e., $Y = A + BX$, where $A = log\ a$, $Y = log\ W$ *and* $X = Log\ L$

Log *a* represents the point at which the regression line intercepts the log *W* axis and *b* represents the slope line.

Newcomb (1950) studied the oysters of different origin and attributed dimensional variations mainly to the environmental changes in different habitat in Virginia. Newell (1983) and Brousseau and Baglivo (1987) observed difference in growth allometry in *Mya arenaria* from different habitats in Long Island Sound. Thorarrinsdottir and Johnnesson (1996), studied the length and meat weight of ocean quahog, *Artica islandica* from

Icelandic waters to find out any significant difference in length- weight relationships of quahogs from different locations. Gaspar *et al.*, (2002) studied the shell morphometric relationship of bivalve species of Algarve coast. Morphometric growth of razor clam *Ensis macha* from Chile was studied by Baron *et al.*, (2004).

In India, allometric relationships of several bivalves have been studied. The important studies are those of Durve and Dharmaraj (1965, 1970), Alagarswami (1966), Parulekar *et al.*, (1973), Alagaraswami and Chellam (1977), Ansari *et al.*, (1979), Shafee (1978), Mohan (1980), Mohan and Damodaran (1981), Sreenivasan (1983), Mohan *et al.*, (1984) and Rao (1988). Studies on *Paphia malabarica* are limited to the length- weight relationship by Rao (1988) from Mulky Estuary in Dakishna Kannada, and dimensional variations by Appukuttan (1993) from Ashtamudi Estuary in south Kerala. The present study gives details of the different allometric relationships *viz.*, length- weight, length-width, length –depth, total weight - flesh weight of male and female clams. The regression equations were calculated separately for male and female clams and the relationships were statistically compared between sexes.

3.1 MATERIAL AND METHODS

Length-weight, length–depth, length–width , total weight -shell weight and total weight - flesh weight relationships were done separately for 383 male and 323 female clams of size ranging from 22–52 mm, collected from the Dharmadom estuary. A total of 706 specimens of various lengths were studied for comparing body parameters of males and females. The clams were weighed in an electronic balance with a sensitivity of 0.1 g and length, width and depth were recorded using digital calipers with 0.01 mm accuracy. Maximum antero–posterior length was taken as total length (APL), maximum length in the dorso–ventral axis (DVL) from umbo as depth (height) and maximum thickness of clam when both valves closed as width. The shells were opened, sex differentiated, and the meat carefully removed. Wet meat weight was taken after draining and blotting the meat off excess water content. Air dried shells were weighed to 0.1 g accuracy. Analysis was carried out separately on them as followed by Appukuttan, (1993).

The linear equation ($log\ W = log\ a + b\ log\ L$) was fitted for males, females and different size groups separately with the log transformed values of length and weight. Regression analysis was performed to determine the constants a and b and the relationship between length and weight using Data

Analysis package in EXCEL software. The correlation coefficient (r) was determined to know the strength and pattern of association between the two variables. Other allometric relationships between body parameters were expressed as $Y = a + bX$, were a and b are constants, Y is the body parameter and X = length or weight.

Analysis of covariance (Snedecor and Cochran, 1967) technique was used to test for significant difference in relationship between sexes at 5 % level. For length-weight, relationship analysis were carried out to confirm if, the values of b obtained in the linear regression were significantly different from isometric value (b = 3), students t test was carried out with a confidence level of ± 95 % expressed by the following equation (Sokal and Rohlf, 1987)

$$t_s = (b - 3)/ S_b$$

Where t_s = test value, b = slope, S_b = standard error of the slope (b)

For length-width and length-depth relationship, analysis of covariance was done to confirm if b values obtained in the linear regressions were significantly different from the isometric value (b= 1), a test with a confidence level of ± 95 % (p=0.05) was applied, expressed by the following equation (Sokal and Rohlf, 1987)

$ts = (b - 1)/S_b$.

Where ts = t-test value; b = slope (relative growth rates of variables); S_b = standard error of the slope (b)

Subsequently, the comparison between the obtained value of the t-test and tabled critical value of the *t*-test, allowed the determination of the statistical significance of the b value and its inclusion in the isometric or allometric ranges (b =3 or b =1 for isometric or $b < 3$ or $b < 1$ for negative allometry or $b>3$ or $b>1$ for positive allometry).

3.2 RESULTS

A total of 323 males with antero- posterior length (APL) ranging from 2.4cm to 5.1 cm and 384 females with APL ranging from 2.2 cm to 5.2 were used to study the total length-weight , length-depth and length-width relationships of *Paphia malabarica*. The raw sums of squares and product of log total length and log total weight for males and females are given in Table 3.1. The regression equation between male and female was tested for equality through analysis of covariance (ANACOVA). The values of slope and elevation differ significantly at 1 % level (Table 3.2). However, as it is a prerequisite in stock assessment studies, a common equation for the species was found out after pooling the data of males and females.

3.2 a. Total length – Total weight relationship

The regression equations for the length-weight relationship of males (n = 323), females (n = 384) and pooled (n = 707) were calculated as:

Males : Log W = -1.06788 + 2.89774 Log L (r = 0.960453)

Females: Log W = -1.35821+ 3.106693 Log L (r = 0.963191)

Pooled: Log W = -1.08686 + 2.98443 Log L (r = 0.961440)

where W is the total weight (g) and L the total length (cm). The calculated curves of total length-total weight relationship for males and females are shown in Figures 3.1-3. 4.

The length–weight relationship for males, females and sexes pooled in the form $W = aL^b$ is as follows:

Females : $W = 0.257121\ L^{3.106693}$

Males : $W = 0.343736\ L^{2.89774}$

Pooled : $W = 0.337274\ L^{2.98443}$

The t test was conducted to test the isometry and the values of t calculated were 0.8357 for females, 0.7615 for males and 0.1179 for pooled

samples. The values did not show significant difference at 95 % confidence level indicating isometric growth.

3.2 b. Length – Depth (height) relationship

The regression equation for length – depth relationship is as follows:

$$Y = 0.69839\,X + 0.19399 \; (r = 0.935600)$$

Where Y is the total depth and X the total length (cm). The calculated curves of total length-total depth relationship for males and females are shown in Figures 3.7 and 3.8.

The raw sums of squares and product of total length and total depth for males and females are given in Table 3.3. The regression equation between male and female were tested for equality through analysis of covariance (*ANACOVA*). The value of slope does not differ significantly at 1 % level (Table 3.4).

As the slope does not differ significantly for both sexes, *t* test was conducted for pooled samples to test the isometry. The value of *t* calculated for pooled samples was 2.0949 which showed significant difference at 95 % confidence level and the *b* value for the same, indicated negative allometric growth.

3.2 c. Length–Width relationship

The regression equation for length–width relationship is as follows:

$$Y = 0.54505\ X - 0.05780\ (r = 0.874880)$$

where Y is the total width and X the total length (cm). The calculated curves of total length-total width relationship for males and females are shown in figures 3.7 and 3.8

The raw sums of squares and product of total length and total width for males and females are given in Table 3.5. The regression equation between male and female were tested for equality through analysis of covariance (ANACOVA). The values of slope do not differ significantly at 1 % level (Table 3.6).

As the slope does not differ significantly for both sexes, t test was conducted for pooled samples to test the isometry. The value of t calculated for pooled samples was 2.6957 which showed significant difference at 95 % confidence level and the b value for the same indicated negative allometric growth.

3.2 d. Total weight –Flesh weight relationship

The regression equation for the flesh weight - total weight relationship of males (n= 323), females (n= 384) and pooled (n= 707) were calculated as:

Males : $Y = 0.10383\,X + 0.38160$ $(r = 0.681681)$

Females : $Y = 0.14032\,X - 0.33853$ $(r = 0.823161)$

Pooled : $Y = 0.11535\,X + 0.14346$ $(r = 0.731258)$

where Y is the flesh weight (g) and X is the total weight (g). The calculated curves of total weight–flesh weight relationship for males and females are shown in figures 3.9 and 3.10.

The raw sums of squares and product of total weight and flesh weight for males and females are given in Table 3.7. The regression equation between male and female were tested for equality through analysis of covariance (ANACOVA). Table 3.8 shows that the values of slope differ significantly at 1 % level.

3.2 e. Total weight -Shell weight relationship

There was no significant difference between b values of male and female, the regression equation for total weight to shell weight therefore are pooled and calculated as:

Pooled : $Y = 0.73878\,X + 0.16246$ $(r = 0.975535)$

where Y is the shell weight (g) and X is the total weight (g). The calculated curves of total weight-total shell weight relationship for males and females are shown in Figures 3.11 and 3.12.

The raw sums of squares and product of total weight and shell weight for males and females are given in Table 3.8. The regression equation between male and female was tested for equality through ANACOVA. The values of slope do not differ significantly at 1 % level.

From the results it is observed that length-weight and total weight -flesh weight relationship in males and females were significantly different ($p < .01$) and the rate of growth in all other relationship studied were not significantly different between sexes. In length- weight relationship it showed isometric growth and in length-width and length-height it showed negative allometric growth.

3.3 DISCUSSION

In allometric relationship involving length and weight the b value lies between 2.5 and 4.5 (Shafee, 1978). Durve and Dharmaraj (1965, 1970) studied dimensional variations in *Meretrix casta* from different localities and observed variations in the body proportion and attributed these observed variations to the environmental conditions and nature of the substratum.

Ansari *et al.*, (1979) found the dimensional variations in mussels from natural bed and cultured mussels and with the latter showing higher proportions. Mohan *et al.*, (1984) noted dimensional variations in allometric relationship of *Meretrix casta*. Alagarswami and Chellam (1977) have also reported on dimensional variations in smaller and larger pearl oysters. Mohan and Dhamodaran (1981) studied the allometric relationship in two size groups of the clam *Sunetta scripta* and found that it varied in the two size groups. Rao (1988) estimated the length-weight relationship of *P. malabarica* from Mulky estuary as $W = 0.000122443L^{3.2640}$ and Appukuttan (1993) observed the length weight relationship of same species from Ashtamudi Estuary as $W= 0.1172L^{3.5176}$ and $W= 0.1975\ L^{3.0682}$ in two stations in the estuary. He also observed that *P. malabarica* from Ashtamudi showed variations in dimensional relationships except length–width for clams from two stations. Although, the precise cause for heterogeneity of shell characters and changes in meat weight proportion from the two stations are not clear, one reason could be the difference in environmental conditions prevailing in two stations.

The length-weight relationship in male and female *P. malabarica* has not been studied from Indian waters and this is the first study of its kind. In the present study, it is seen that the *b* value for male and female lies between

2.989 and 3.107 within the reported range of 2.5 to 4.5 (Shafee, 1978). It is seen that the *b* value of female is higher than that of the male, indicating that at a given length, female is slightly heavier than the male.

Murawski *et al.*, (1982), when comparing the length-weight relationships of bivalve ocean quahogs *Arctica islandica* found difference and has associated this with the sexual development. Firtz (1991) also observed changes in somatic weight of ocean quahogs and attributed it to difference in growth rate, reproductive cycle and lack of synchrony of reproductive cycles of individuals at a given site. In the present study also significant difference was observed between the length-weight relationship and total weight to flesh weight relationship of male and females of *P. malabarica* collected from Dharmadom estuary. Although precise cause for this heterogeneity in male and female clams is not clear, it can be attributed to the difference in weight gain during the reproductive cycles as reported by Murawski (1982) and Firtz (1991). As it is the first study, comparison of the present results with those observed by other authors in related studies using the same species is not available. However, Park and Oh (2002) when, studying the length-weight relationship of 12 species of bivalves observed that of this, eight species showed isometric growth at 95 % confidence limit of *b*. Gaspar *et al.*, (2001) studied six species of clams of Veneridae family and found that

two species showed isometric growth. The present study has revealed that in *P. malabarica* the length-weight relationship showed isometric growth rate. Gaspar *et al.*, (2002), when studying the shell morphometrics of the common bivalve species of Algarve coast, found that, of the six species of family Veneridae, *Venus fasciata* showed negative allometry in length-width relationship and length- depth relationship and *Chamelea galllina* showed negative allometry in shell width-shell length relationship. *Paphia malabarica*, which belongs to family Veneridae, exhibited similar allometric growth pattern. The determination coefficient (r^2) was higher in length-depth than in length-width relationship indicating that the shell growth in depth is less variable than shell growth in width and negative allometry indicates that width and depth increase are inferior to length increase. Gaspar *et al.*, (2002) found similar negative allometric growth in *Donax trunculus* and *Acanthocardia paucicostata* and have attributed it to the substrate which it inhabits and the burrowing nature of the bivalve. Since *P. malabarica* is found near the bar mouth of the estuary, these negative allometry may be an adaptive strategy to improve burrowing efficiency and depth within the substrate, avoiding dislodgement from the bottom sediments by local hydrodynamics.

Of all the allometric relationships length weight relationship is of great importance. Every animal in its life grows both in length and weight, the relationship between these two has both theoretical and practical importance. It has been mathematically proved that there is a fairly constant relationship between total length and weight of the individuals of the species. It helps to establish a direct mathematical relationship between the two variables, namely length and weight, so that if one is known the other could be easily computed. Length-weight relationship is also needed for studies on maturity and yield estimates by analytical models.

Although the species morphometric relationships may vary due to hydrological and sedimentological features in different geographic regions the information on different allometric relationships forms an important input for proposing management measure for bivalve fishery.

Table 3.1. **Total length–total weight** analyses of males and females of *P. malabarica* and their pooled values.

Group	N	Mean X	Mean Y	a	b	r
Female	323	1.398	2.983	-1.35821	3.10669	0.963191
Male	384	1.368	2.896	-1.06788	2.89774	0.960453
Pooled	707	1.381	2.936	-1.18686	2.98443	0.961440

Table 3.2: Regression lines of the **total length–total weight** relationship of *P. malabarica.*

Corrected sum of squares and products					Regression coefficient	Deviation from regression			
Source	DF	SS-X	SP	SS-Y	b	DF	SS	MS	F
Female	322	6.9595	21.6210	72.4017	3.107	321	5.232	0.01630	
Male	383	9.7621	28.2880	88.8608	2.898	382	6.889	0.01804	
Total						703	12.121	0.01724	
Pooled within	705	16.7216	49.9090	161.2625	2.985	704	12.299	0.01747	
Difference between slopes						1	0.177	0.17740	10.29

Comparison of slopes: F = 10.29 (df, 1 and 704), significant at 1 % level

Table 3.3: Total length–total depth analyses of males and females of *P. malabarica* and their pooled values.

Group	N	Mean X	Mean Y	a	b	r
Male	383	4.010	3.000	0.27407	0.67970	0.924075
Female	322	3.992	2.976	0.11128	0.71759	0.947554
Pooled	705	4.001	2.989	0.19399	0.69839	0.935600

Table 3.4: Regression lines of the **total length – total depth** relationship of *P. malabarica.*

Corrected sum of squares and products					Regression coefficient	Deviation from regression			
Source	DF	SS-X	SP	SS-Y	b	DF	SS	MS	F
Male	383	123.0531	83.6389	66.5747	0.680	382	9.726	0.02546	
Female	322	117.9502	84.6394	67.6455	0.718	321	6.909	0.02152	
Total						703	16.635	0.02366	
Pooled within	705	241.0032	168.2783	134.2202	0.698	704	16.721	0.02375	
Difference between slopes						1	0.086	0.08646	3.65

Comparison of slopes: F = 3.65 (df, 1 and 704), not significant at 1% level

Table 3.5: **Total length–total width** analyses of males and females of *P. malabarica* and their pooled values.

Group	N	Mean X	Mean Y	a	b	r
Male	383	3.994	2.104	- 0.01230	0.52985	0.873792
Female	322	4.098	2.194	- 0.14105	0.56977	0.875827
Pooled	705	4.042	2.145	- 0.05780	0.54505	0.874880

Table 3.6: Regression lines of the **total length–total width** relationship of *P. malabarica.*

Corrected sum of squares and products					Regression coefficient	Deviation from regression			
Source	DF	SS-X	SP	SS-Y	b	DF	SS	MS	F
Male	383	159.5428	84.5339	58.6636	0.530	382	13.873	0.03632	
Female	322	73.3436	41.7893	31.0407	0.570	321	7.230	0.02252	
Total						703	21.104	0.03002	
Pooled within	705	232.8863	126.3232	89.7044	0.542	704	21.184	0.03009	
Difference between slopes						1	0.080	0.08009	2.67

Comparison of slopes: F = 2.67 (df, 1 and 704), not significant at 1 % level

Table 3.7: Total weight–flesh weight analyses of males and females of *P. malabarica* and their pooled values.

Group	N	Mean X	Mean Y	a	b	r
Male	383	14.830	1.921	0.38160	0.10383	0.681681
Female	322	16.094	1.920	-0.33853	0.14032	0.823161
Pooled	705	15.408	1.921	0.14346	0.11535	0.731258

Table 3.8: Regression lines of the **total weight–flesh weight** relationship of *P. malabarica.*

Corrected sum of squares and products					Regression coefficient	Deviation from regression			
Source	DF	SS-X	SP	SS-Y	b	DF	SS	MS	F
Male	383	6148.4473	638.4099	142.6499	0.104	382	76.362	0.19990	
Female	322	4145.3300	581.6657	120.4532	0.140	321	38.835	0.12098	
Total						703	115.197	0.16386	
Pooled within	705	10293.7773	1220.0756	263.1031	0.119	704	118.493	0.16831	
Difference between slopes						1	3.296	3.29604	20.11

Comparison of slopes: F = 20.11 (df, 1 and 704), significant at 1 % level

Table 3.9: **Total weight–shell weight** analyses of males and females of *P. malabarica* and their pooled values.

Group	N	Mean X	Mean Y	a	b	r
Male	383	15.622	11.647	0.16925	0.73474	0.976333
Female	322	15.218	11.472	0.10408	0.74702	0.975136
Pooled	705	15.437	11.567	0.16246	0.73878	0.975535

Table 3.10: Regression lines of the **total weight– shell weight** relationship of *P. malabarica.*

Corrected sum of squares and products					Regression coefficient	Deviation from regression			
Source	DF	SS-X	SP	SS-Y	b	DF	SS	MS	F
Male	383	4869.0218	3577.447	2757.4574	0.735	382	128.977	0.3376	
Female	322	3449.876	2577.1116	2024.5692	0.747	321	99.426	0.30974	
Total						703	228.708	0.32490	
Pooled within	705	8318.8977	6154.5587	4782.0266	0.740	704	228.708	0.32487	
Difference between slopes						1	0.304	0.30446	0.94

Comparison of slopes: F = 0.94 (df, 1 and 704), not significant at 1 % level

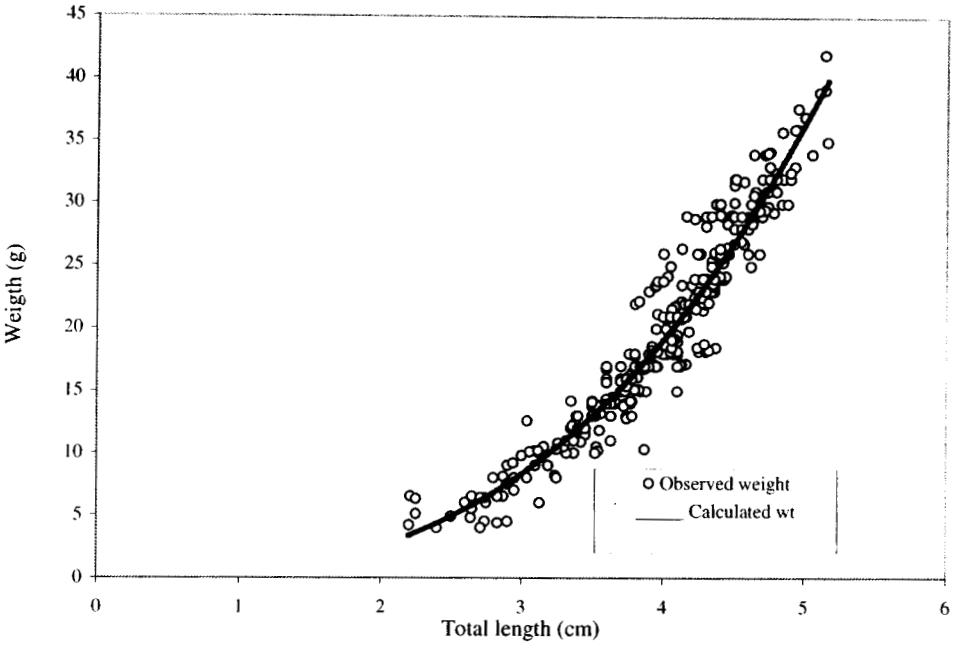


Fig 3.1. Relationship between total length and weight in males of *P. malabarica.*

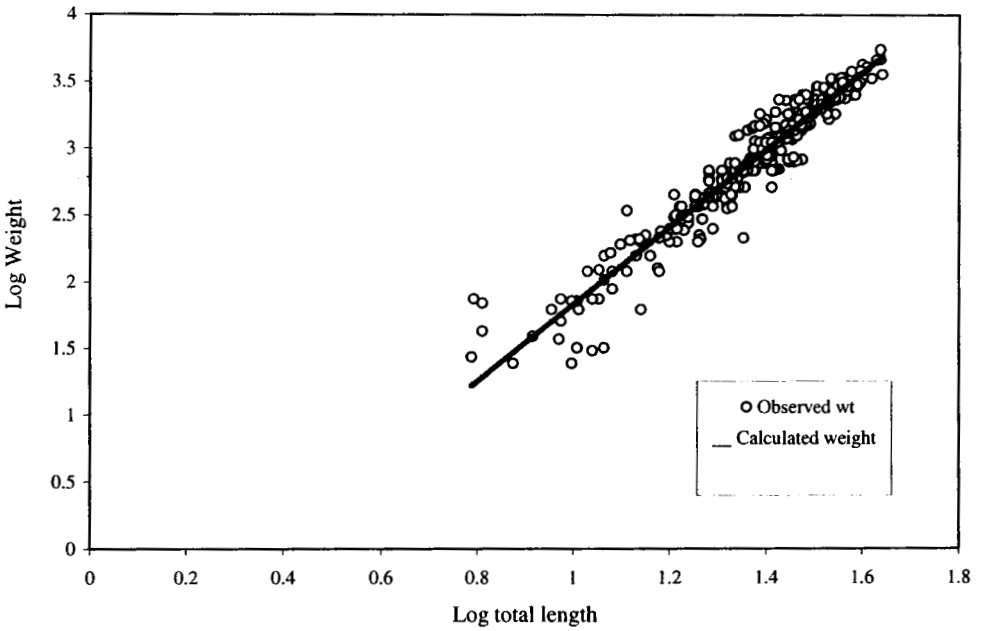


Fig 3. 2: Logarithmic relationship between total length and weight in males of *P. malabarica.*

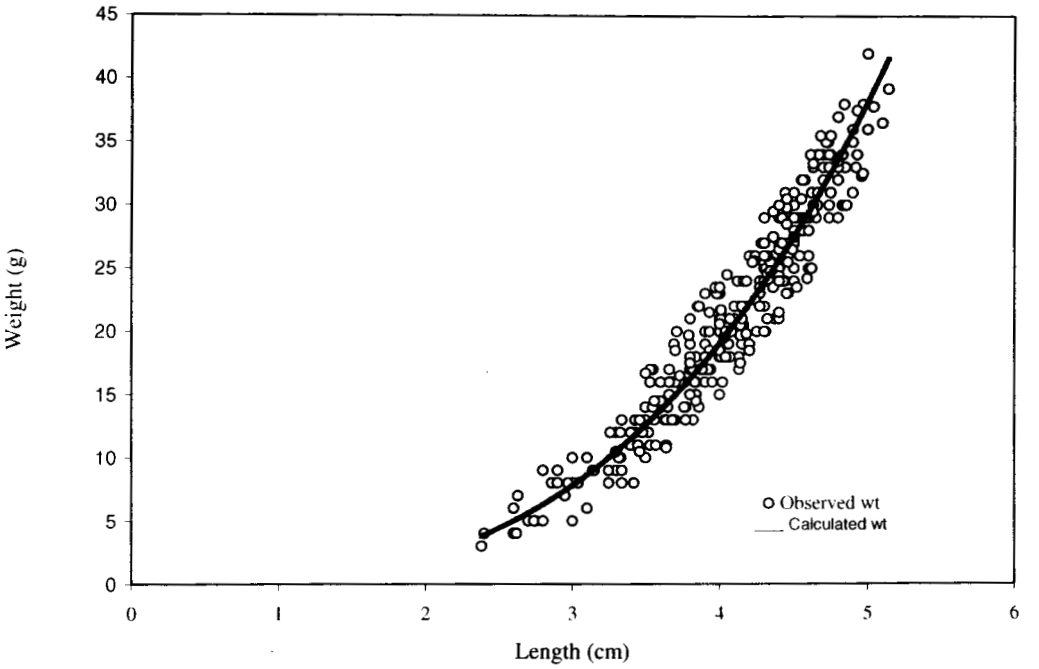


Fig 3.3: Relationship between total length and weight in females of *P. malabarica.*

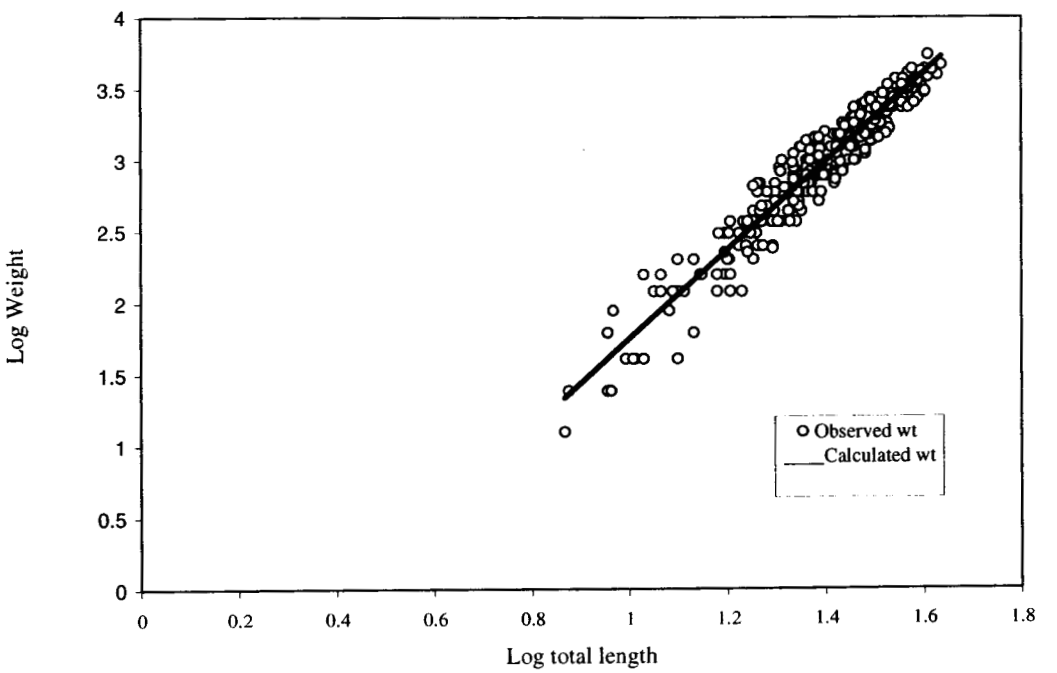


Fig 3.4: Logarithmic relationship between total length and weight in females of *P. malabarica.*

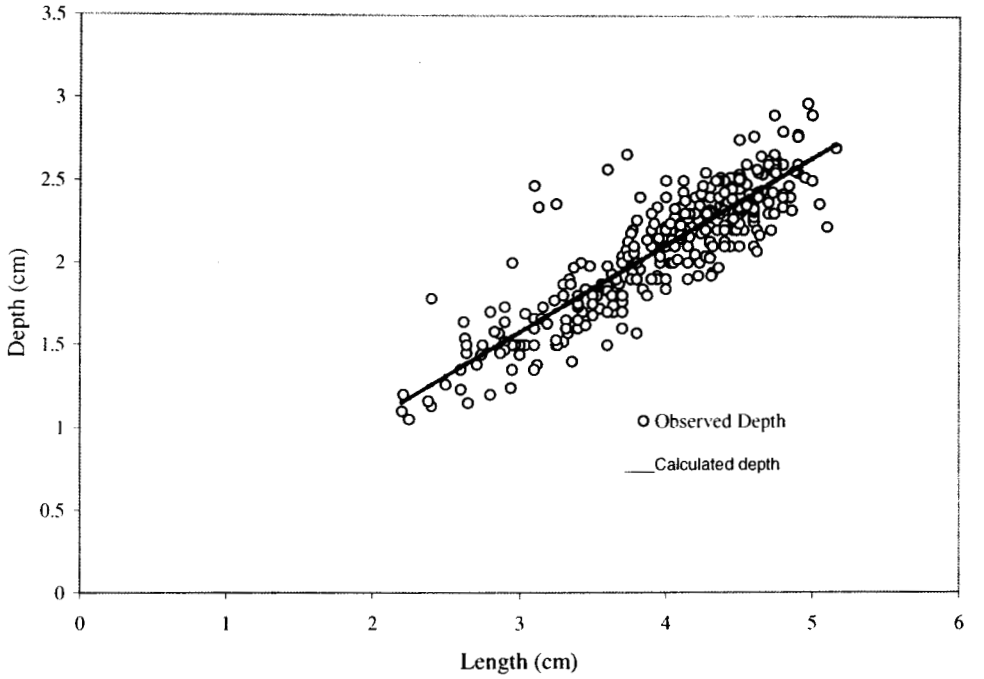


Fig. 3.5: Relationship between total length and total depth in males of *P. malabarica*

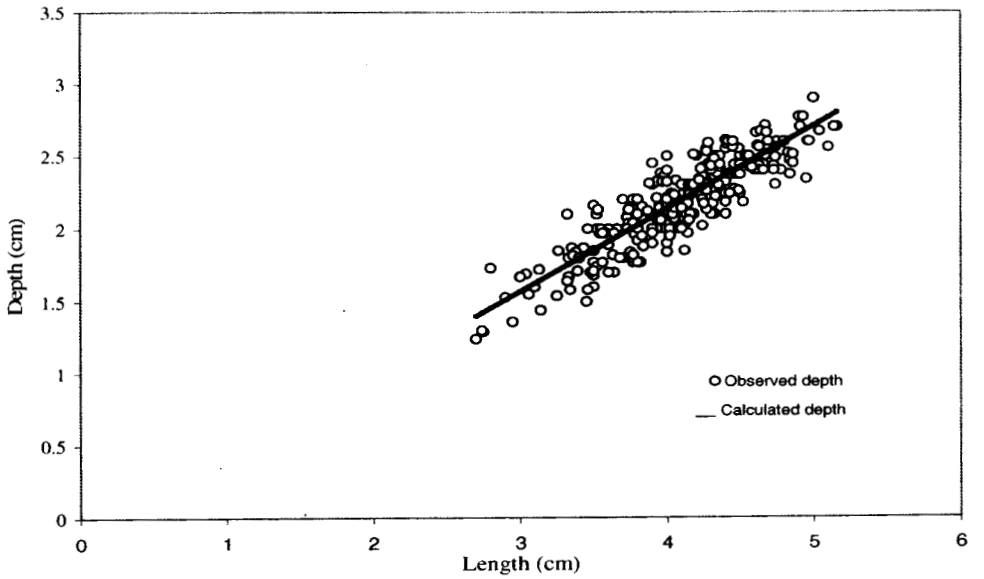


Fig.3. 6: Relationship between total length and total depth in females of *P. malabarica*

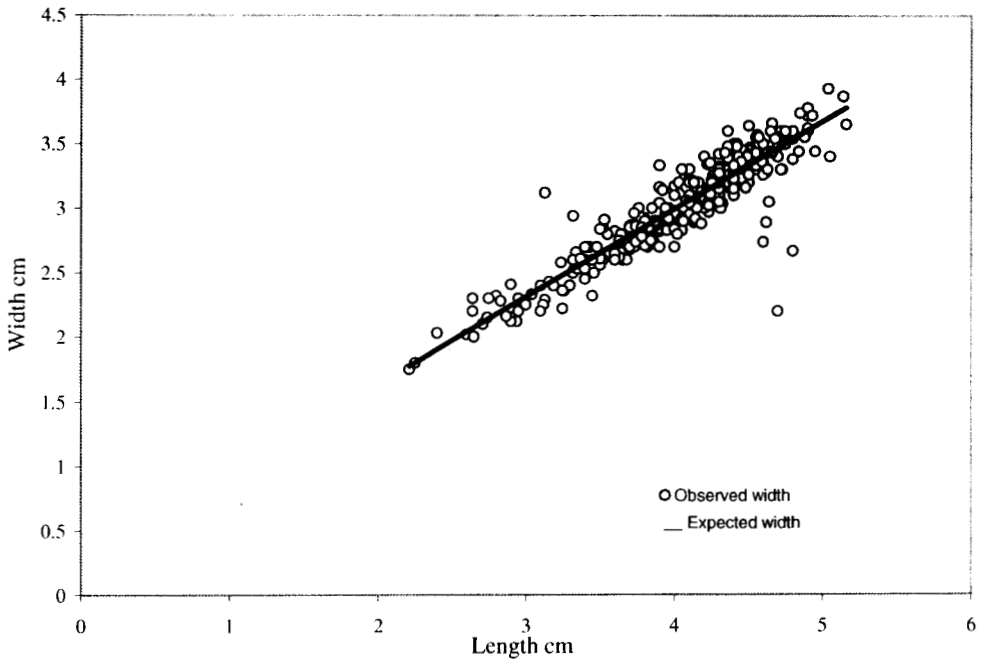


Fig 3.7: Relationship between total length and total width in males of *P. malabarica*

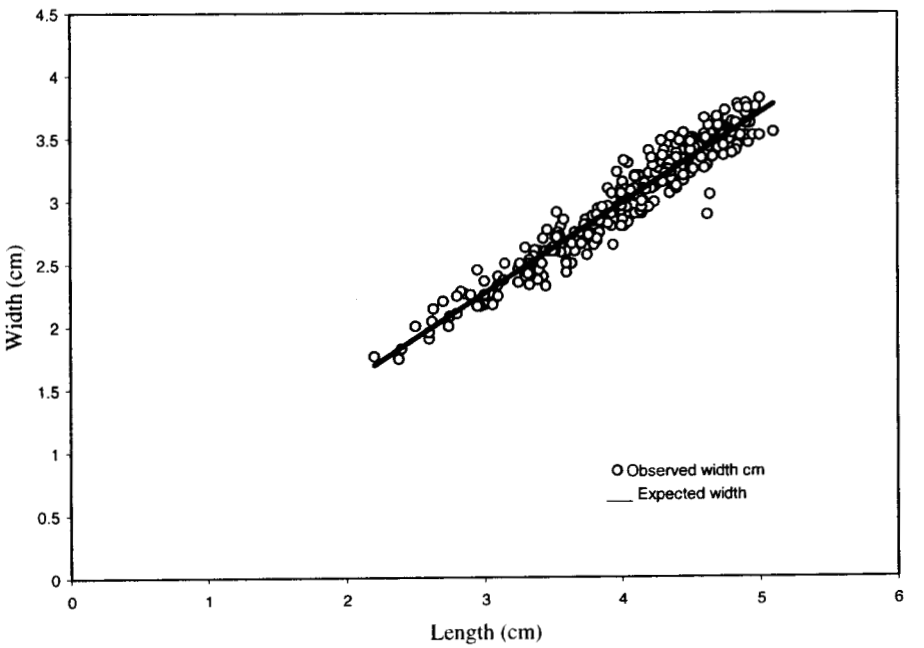


Fig 3.8: Relationship between total length and total width in females of *P. malabarica*

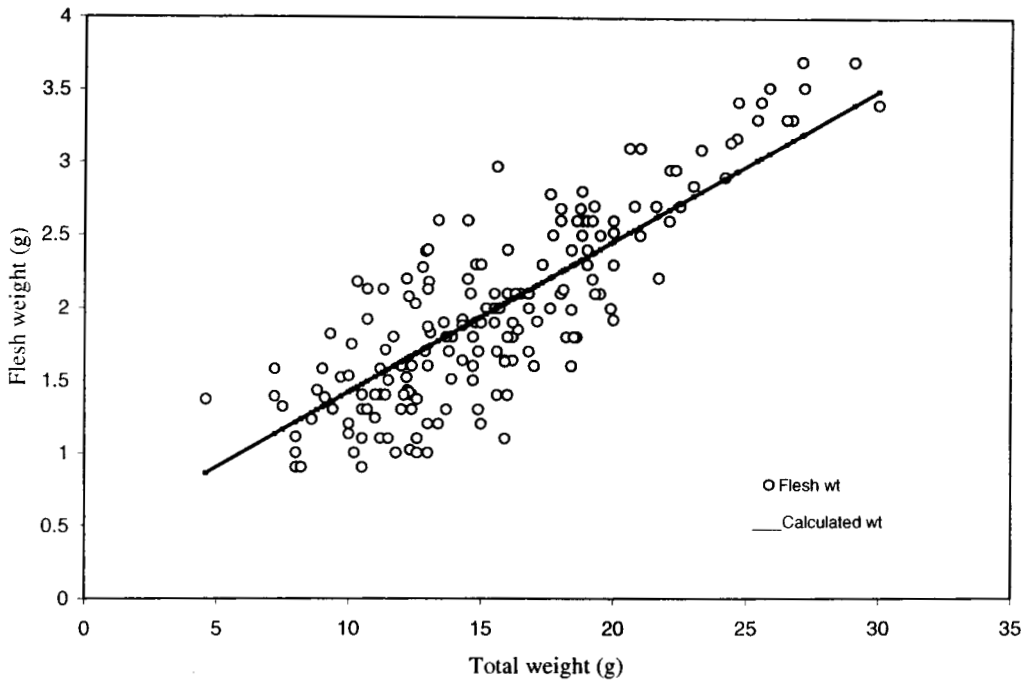


Fig 3.9: Relationship of total weight to flesh weight of male *P. malabarica*

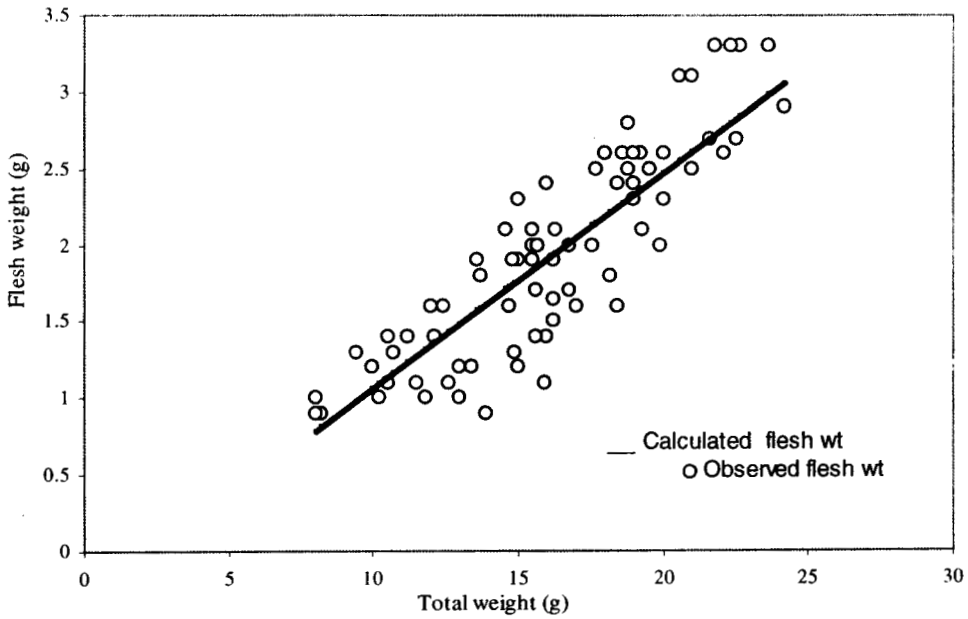


Fig 3.10: Relationship of total weight to flesh weight of female *P. malabarica*

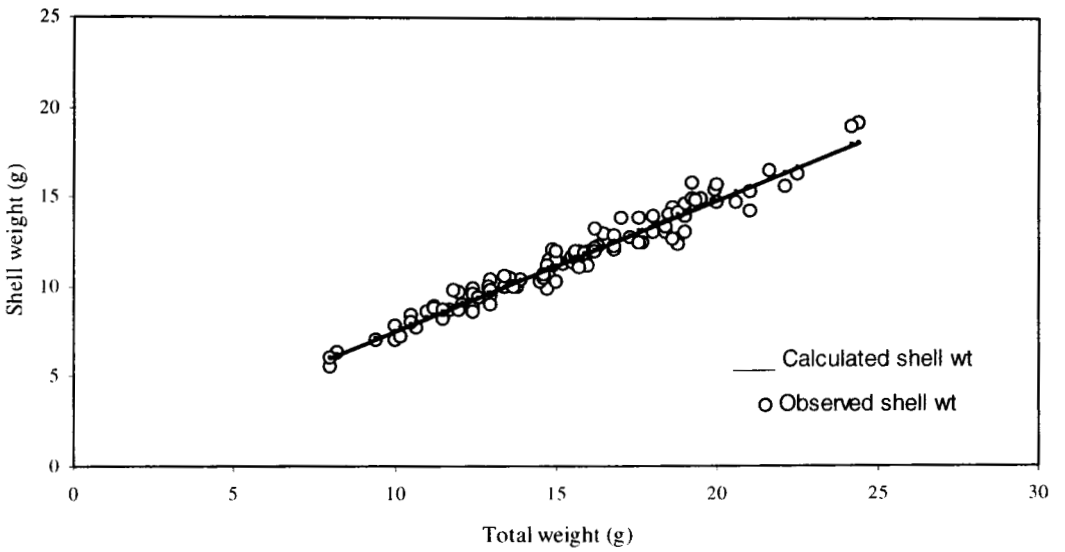


Fig 3.11. Relationship of total weight to shell weight in males of *P. malabarica*

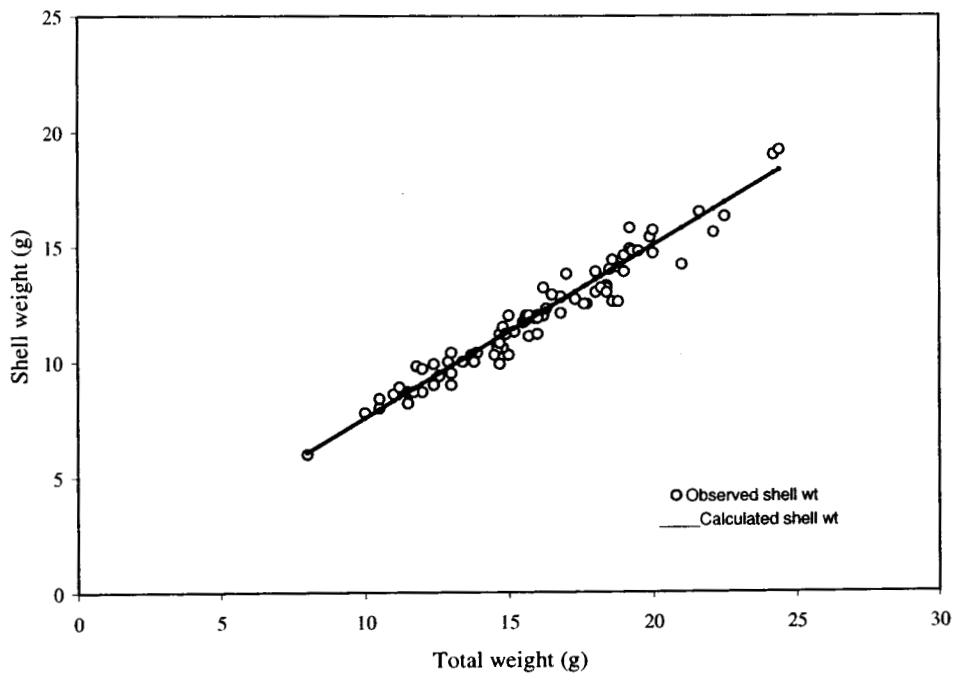


Fig 3.12. Relationship of total weight to shell weight in females of *P. malabarica*

Reproduction and Condition Index of Paphia malabarica

Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter IV

Reproduction and Condition Index of *Paphia malabarica.*

Reproductive activities of molluscs are mainly controlled by an interaction of exogenous and endogenous factors. Exogenous factors like temperature, salinity and food supply act as environmental indicators and synchronise the reproductive activities of the animals in the concerned environment. Endogenous control of reproduction, especially gametogenesis and spawning, is by the endocrine system and is more or less independent of environmental changes (Giese and Pearse, 1974). Often the reproductive activities such as gametogenesis are begun much in advance of favourable conditions. These environmental changes must act as early cues to synchronize reproduction with the favourable conditions (Giese and Pearse, 1974).

There are numerous works on the reproductive biology of bivalves. The cycle of gametogenesis and spawning has been extensively studied from temperate waters. Edible oyster *Crassostrea virginica* is much studied mainly because of its wider distribution. Important works on the reproductive biology of *C. virginica* are those of Coe (1938) and Loosanoff (1942). Sex, gonadal development and seasonal gonadal changes in *Paphia staminea* was studied by Quayle (1941. The reproductive biology of hard clam *Venus mercenaria* was studied by Loosanoff (1936a, 1936 b, 1937 a, 1937 b, 1937 c), Coe and Turner (1938), Davis and Chanley (1956) and Ansell *et al.*, (1964, 1967), reproduction, growth and mortality of *Venus striatula* by Ansell (1961) and Gaspar and Monteiro (1998). Reproductive cycle of soft calm *Mya arenaria* was studied by Rogers (1959), Pfitzenmeyer (1962), Shaw (1964, 1965), Ropes and Stickney (1965) Porter (1974) and Brousseau (1978, 1987). Reproductive cycle of *Mercenaria* spp. was studied by Hesselman *et al.*, (1989) and Heffernan *et al.*, (1988). Reproduction of *Protothaca staminea* was studied by Feder *et al.* (1979) and of Manila clam (*Venerupis japonica*) by Holland and Chew (1974). Observation on the different stages of gonad development *viz.*, maturing, mature , partially spent and spent along with seasonal changes in the gonad are studied in detail in the above studies. Peak spawning season and influence of environmental factors are also discussed. It

is observed that in temperate waters temperature plays an important role in triggering reproduction.

Seasonal gonadal changes in marine clam *Marcia cor* from Pakistan was studied by Barkati and Khatoon (1994). Gametogenic and spawning patterns of Manila clams *Tapes philippinarum* were studied by Bourne (1982), Ponurovsky and Yakovlev (1992) and Sbrenna and Campioni (1994), of red clam *Megapitaria aurantiaca* by Dominguez *et al.* (1994) and of *Spisula solidissima* by Sephton (1987), Jones (1981) and Kanti *et al.* (1993). Investigations on the reproduction stages of the striped venus, *Chamelea gallina* were carried out by Oray and Deval (1991). Annual reproductive cycle of Zebra mussel was studied by Gist *et al.* (1997), influence of environmental parameters on reproduction of European flat oyster (*Ostrea edulis*) by Cano *et al.* (1997), of *Mytilus edulis chilens*is by Gray *et al.* (1997). Gonadal changes during the annual reproductive cycle of pearl oyster were studied by Jamili *et al.* (1999), maturation and sex ratio of *C. madrasensis* from Moheshkhali channel in Bay of Bengal was studied by Alam and Das (1998). Tirado and Salas (1998), Gaspara *et al.* (1999) and Manca *et al.* (2002), studied reproduction and fecundity of *Donax trunculus*. Spawning, settlement, growth of venerid *Ruditapes largillierti* was studied by Kent *et al.* (1999) and Gribben *et al.* (2001). Reproduction of *Corbicula fluminea* was studied by Mouthon

(2001), of *Perna canaliculus* by Buchanan (2001). Investigations on the reproductive cycle of bivalve clams *Semele solida* and *Gari solida* were done by Brown *et al.* (2002), and *Anadara ovalis* by Power and Walker (2002).

From Indian waters, biological studies of bivalves are very recent. Sastry (1979) has studied the reproduction of bivalves from Indian waters. The most important works on the reproductive cycle were in *Crassostrea madrasensis* (Preston), *Ostrea cucullata*, (Born), *Meretrix Meretrix* (Linnaeus), *Meretrix casta* (Chemnitz), *Donax faba* (Gmelin), *Donax cuneatus* (Linnaeus), *Paphia laterisulca*, *Katelysia opima* (Gmelin), *Perna viridis* (Linnaeus), *Perna indica* Kuriakose and Nair, *Anadara rhombea* (Born), *Anadara granosa* (Linneaus), *Solen kempi* Preston, *Pinctada fucata* (Gould), *Villorita cyprinoides* (Gray), and *Placenta placenta* (Linnaeus). Hornell (1910), Paul (1942), Rao (1951, 1956, 1983), Rao and Nayar (1956), Durve (1964 a, 1965), Nayar and Mahadevan (1983), Purushan *et al.* (1983), Joseph and Joseph (1983), Rajapandyan and Rajan (1983, 1987), Samuel (1983), Joseph and Madhystha (1982, 1984) and Narasimham (1989) gave details on the spermatogenesis and spawning cycle of *Crassostrea madrasensis*. Nagabhushanam and Bidaker (1977) gave details of reproduction of *Crassostrea cucullata*, Durve (1965) and Mane and Nagabhushanam (1976) on *C. gryphoides*. Abraham (1953), Durve (1963) and Rao (1988) on *M. casta*,

Jayabal and Kalyani (1987) on *M. meretrix* , Alagarswami (1966) on *Donax faba*, Nayar (1955), Rao (1967), Nagabhushanam and Talikhedkar (1977a) and Victor and Subramaniam (1988) on *Donax cuneatus*; Nagabhushanam and Mane (1988) on *Paphia laterisulca*; Rao (1988) and Appukuttan (1993) on *Paphia malabarica* from Mulky and Ashtamudi estuaries, Mane (1974a), Nagabhushanam and Mane (1975), Appukuttan *et al.* (1985) and Joseph and Joseph (1987) on *Katelysia opima.* Mane and Nagabhushanam (1983, 1988) and Joseph and Joseph (1988) on *Perna viridis*, Kuriakose (1973) and Joseph and Joseph (1987) on *Perna indica*; Narasimham (1985, 1988) and Natarajan and John (1983) on Anadara *granosa* and *A. rhombea.* Information on the reproductive cycle of Indian pearl oysters was also provided by Herdman (1906), Hornell (1922b), Chacko (1970) and Chellam (1987). The details of reproductive cycle of the back water calm *Villorita cyprinodes* were given by Joseph and Joseph (1988) and Achary (1988). Rao *et al.* (1962) described the reproductive cycle of *Solen kempi* and Narasimham (1984) and Pota and Patel (1988) on *Placenta placenta* from Indian waters.

From literature review it is evident that a detailed study on the fishery and biology of *Paphia malabarica* from Indian waters is lacking except for the works from Mulky and Ashtmudi estuaries. Though the occurrence of *P.*

malabarica has been cited in many estuaries, no detailed study has been initiated especially in the Malabar area. Hence an attempt is made to study the reproduction and condition index of *P. malabarica* from Dharmadom estuary.

4.1 MATERIALS AND METHODS

Fortnightly samples of *P. malabarica* from Station I, II and II in Dharmadom estuary were collected from December 2003 to November 2004 using a hand dredge. Samples were pooled from three stations and a total of 1,204 clams was examined for sex and stages of maturity. For classification of the condition of gonad, fresh gonad smears were examined under microscope in 15 x 40 magnifications. The microscopic examination of individual gonad was recorded. Sex and stages of maturity were ascertained from fresh smear of gonad from individual clam.

For exact assessment of gametogenic state of gonad, histological preparations were used. Approximately 25 individuals, arbitrarily selected with respect to visible stage of gonad development were excised, fixed in Bouin's fixative and prepared for sectioning by dehydration in ethanol and embedding in paraffin wax (melting point 60-62° C) (Humason, 1972). The paraffin blocks were cut into 8 micron thickness in hand microtome. Before sectioning, the tissue embedded paraffin blocks were trimmed to suitable size. The sections

were stained in haemotoxylin and counterstained with eosin. Gonadal section were taken of 360 clams of length range of 15-35 mm. Methodology described by Ropes (1968) was followed in the categorisation of the maturity stages except that his 'early active' and 'late active' phases were clubbed under the maturing stage Narasimham (1988). The objective of the study was to observe the occurrence of different reproductive stages in different seasons and also to determine the exact season of spawning.

Histological sections were photographed using a Nikon AFX-DX II microscope fitted with a Nikon Fx-35 camera with photo micrographic attachment.

4.11 Sex ratio

The test of variance of homogeneity (Snedecor and Cochran, 1967) was applied to test the significance of difference in the sex ratio in the monthly samples. It was again ascertained by *Chi-* square test, to find out whether the observed monthly sex ratio differed from the theoretical 1:1 ratio.

4.12 Length at first maturity (L_m)

The mean length at first reproduction or mean length at sexual maturity (L_m) may be defined as the length at which 50 percent of all individuals are

sexually mature *i.e.*, the length at which 50 percent of the female clams are in mature condition

Length at first maturity was studied by examining the gonad sections of 429 clams measuring 11–30mm, collected at peak spawning (Narasimham, 1988).

In the recent studies, logistic model is used for estimating the size at first maturity (Roa *et.al.*, 1999). Hence, the size at maturity for male and female clams was also estimated by fitting the logistic curve. The size at 50 % maturity was estimated by fitting a logistic maturity model with proportion of maturity on length (King, 1995). Logistic curve was fitted to the proportion (P) of sexually mature by length as

$P= 1/(1+ exp[-r(L-L_m)])$, where r is the slope of the curve and L_m is the mean length at sexual maturity or length which corresponds to a proportion of 0.5 (or 50 percent) in reproductive condition (King, 1995).

Statistical analysis was carried out using SPSS 7.5 software and Pearson correlation analysis was carried out to understand the trend and relationships among different parameters.

4.2 RESULTS.

The temporal distribution of maturity stages of *P. malabarica* in different months during 2003-2004 from Dharmadom estuary is given in Table 4.1 and 4.2. Examination of the sections at regular intervals furnished detailed information on the reproductive cycle including spawning. The details of different stages are given below:

Indeterminate:

This stage is unique because of the shrunken follicles, without any differentiation of cells and demarcation of sex. The gonad area is white. The wall of the gonad appears with much connective tissue. The follicles are completely shrunk and collapsed. At this stage the gonad is quiescent without trace of any germinal cells. Differentiation of sex is difficult at this stage.

Stage I. Maturing:

In this stage, gonad of the female is somewhat thick, pale yellowish with underlying genital ductules more prominent. It has small oocytes, which proliferate from genitial cells of the follicle wall, while in male, gonad tissue is thick, firm and white, with follicles occupying the entire area of gonad, and only sperm mother cells and spermatids are present, indicating the commencement of gametogenesis.

In male on the onset of active phase, the follicle increase in size and the periphery contains numerous spermatogonia and a few spermatids radiating towards the lumen of the follicle. As the maturing phase advances, the secondary spermatocytes appear in large numbers along with the primary spermatocytes. The primary and secondary spermatocytes can be differentiated only by size and staining intensity.

In the female gonad, the primary germ cells undergo mitotic division and give rise to oogonia in this stage. The onset of oogenesis is indicated by the appearance, growth and spreading of follicles and the occurrence of oogonia and oocytes in the premeiotic stage. The cytoplasm is small and the nucleus is not distally visible. In the late maturing phase a rapid increase in the size of the follicle is seen along with the secondary oocytes. The follicle occupies more area among the connective tissue.

Stage II. Mature: In Stage II, gonad of the female is full, plumpy, and creamy in colour and free oocytes were more in the follicle. The fully yolked ova was perfectly spherical with round nuclei. As the male gonad attains the ripe condition, the spermatids differentiated into spermatozoa and lie as a core in the lumen of the follicle. A ripe gonad is characterized by bunches of spermatozoa arranged more or less radiating with their tails facing towards the

centre of the follicular lumen. The lumens of the follicle were full of spermatids.

Stage III. Partially Spent: In this stage, some follicles were empty due to the discharge of gametic material. In female clams, the follicle shows varying degree of emptiness. The vesicular tissue, the connective tissue cells and free oocytes are found scattered on the lumen. The ripe ova were present in some follicles and other follicles empty. In male gonad residual sperms and spermatids were seen in the partially empty follicles. The follicle cells ruptures and become empty with a few residual gametes. The vesicular connective tissue increases.

Stage IV Spent: In this stage, the follicles were greatly shrunken with few residual sperms in males and oocytes in females, in addition to the connective tissues. Vesicular and connective tissue increases and occupy the space between the follicle.

The histological sections of gonadal development in male and female *P. malabarica* are given in Plates A to J.

The progress of the reproductive cycle of *Paphia malabarica* in different months could be traced as follows. The indeterminate stage dominated in February with 51 %, and maturing ones in March (53.8 %), April (73 %), May (87 %), June (81 %) and July (88 %). The indeterminates were

found up to July. In August and September maturing clams dominated the population (92 % and 93 % respectively). Mature clams were found in few numbers from June (6 %) onwards and in October it reached 44 %. In November 84 % of the clams were found to be mature and 51 % in December. Partially spent and spent clams were observed from November onwards. In December about 49 % of the clams observed were in partially spent or spent condition and in January 86 % of them were in partially spent or spent condition. (Table 4.1a, b,c)

While examining the male and female clams separately (Tables 4.1 and 4.2), it could be seen that maturing clams dominated from March to September for both sexes. Mature clams started appearing from June onwards. In October 48 % of females and 40 % of the males were in mature condition. In November above 80 % of the female populations were in mature condition and 11 % were in partially spent condition. During this period about 88 % of male were in mature condition and 6 % were in partially spent stage (Fig. 4.1-4.3). The reproductive cycle of the clams thus shows that breeding season commences in October and lasts till February, with a peak spawning in November and December. Sexual activity commences from March onwards and lasts till

September. The peak somatic period could be from February to April when more numbers of indeterminates appear in the population.

4.21. Spawning

More than 80 % of the populations are with fully ripe gonad in spawning condition in November. In December 50 % of the population was in mature stage and remaining in partially spent and spent condition. Hence the peak spawning season for *P. malabarica* seems to be in November-December. In November more than 84 % of the populations are with fully ripe gonads and it is observed that this spawning season coincides with recovered salinity after the monsoon.

4.22 Size at first maturity (L_m)

The gonad was not found developed in size group 11-14 mm in females and 11-19 mm in males. From 15 mm, onwards ovary is found to be developed in females for the first time, whereas in males only above 20 mm size testes are fully developed. In 19 mm size groups 30.8 % of the clams were fully mature and in 20 mm size 53.8 % were mature. In case of male, fully matured appeared from 20 mm (14.3 %) onwards and at 21 mm 54.5 % was in fully mature stage (Fig 4.4). Some clams were indeterminate even up to 24 mm.

Above 30 mm size group, there was no relationship between size and stage of maturity, but spent stages were observed from 30 mm onwards. The observed length range for size at maturity and the values derived logistically were compared. It was found that there was not much difference in the size at maturity for females and males in both cases. L_m observed for females and males were 20 mm and 21 mm respectively and derived logistically was 20 mm and 22 mm respectively (Fig 4.4 and 4.5). Hence for *Paphia malabarica* from Dharmadom estuary, length at first maturity for female is 20 mm and that of male is 22 mm.

4.23 Sex Ratio

The sex ratio of the population studied is given in Table 4.3. Females outnumbered the males in most of the months. Indeterminate was found in the population from February to July. Chi- Square test indicates that only in the month of May, the sex ratio differed significantly at 1 % from the theoretical 1:1 ratio.

Correlation analysis done with reproduction and hydrographic parameters salinity and temperature are given in Table 4.4. Positive correlation

was found with the mature percentage of the clams and salinity and negative correlation with the temperature.

4.3 DISCUSSION

Results of the present study indicated that by estimating the percentage of different maturity stages over a period of time, a reasonably good assessment of the spawning season and spawning frequency could be arrived at. This method of assessing spawning season and spawning frequency has been successfully employed in many other bivalves (Algarswami, 1966; Victor and Subramanian, 1988; Narasimham, 1988; Brousseau, 1987 and Brown *et al.*, 2002). In addition to the maturity stages, condition index has also been used to support and supplement the information regarding spawning season. (Appukuttan 1993 and Barkati and Ahmed, 1994).

Observation and estimation of the different maturity stages of gonad indicated that the clam attains sexual maturity at the size of 15-20 mm in shell length. Fully mature clams start appearing in population from June onwards and the maximum number of mature clams was observed from October–December. The lowest percentage occurrence of mature clams in January and

the highest percentage of spent ones in February indicate that peak spawning occurs before January.

Based on the information available from the literature and from their own investigations, Joseph and Madhystha (1982) have indicated that tropical and subtropical invertebrates in general have mostly semi-annual or annual breeding seasons. According to them, continuous breeding season as reported by several authors is not really continuous. Mane and Nagabhushanam (1988) while discussing the reproduction of edible bivalves from Ratnagiri coast, have reviewed the important works on reproductive biology of Indian bivalves, especially clams and oysters and suggested that many bivalves of tropical waters have continuous spawning and in few cases discontinuous. Important works on the spawning habits of some clams and *Paphia* spp. are summarized in Table 4.5. The literature cited in the table reveals that bivalves in general show three types of spawning periodicity *viz.*, (i) those which spawn only once in a year with comparatively shorter duration (ii) those which spawn twice in a year and (iii) those which spawn for a prolonged period. Certain Species sometimes show two types of spawning periodicity in two different localities. These studies show that bivalves do not possess a definite species specific spawning periodicity, but shows variations according to climatic condition of

the different localities which they inhabit. However, in general the spawning season extends for a few months unlike in temperate waters, where it may be only for a shorter duration.

Joseph and Joseph (1987) studied the reproductive response of bivalves from Mulky estuary, taking into consideration the gametogenic activity, gonadal growth and proliferation, initiation of spawning and gonadal activity or dormancy in relation to their environmental factors and indicated that the effects of salinity on reproduction of bivalves are not well understood, but mostly bivalves respond to salinity changes as far as their spawning habits are concerned (Hornell, 1910; Panikkar and Aiyar, 1939; Paul 1942; Nagabhushanam and Mane, 1975, 1988; Joseph, 1979; Joseph and Madhystha, 1982, 1984). Kripa and Appukuttan (2003) have observed that most of the bivalves from Indian waters have wide spawning period with certain peaks.

In the present study, *P. malabarica* from Dharmadom estuary has a breeding season from November to February with a peak spawning in November- December. Mature clams appeared in the population from June onwards in few numbers. Rao (1988) when studying *P. malabarica* from Mulky estuary has also observed that mature clams were abundant from October to February and considered that as the spawning season although

mature specimens were observed in few numbers in March, June and August. Appukuttan (1993) has observed October to January as breeding season for *P. malabarica* with a peak during November- December from Ashtamudi estuary. In general for *Paphia malabarica* the spawning season is observed from September to February along west coast of India (Kripa and Appukuttan, 2003). Hence *P. malabarica* could be grouped under the category of clams with spawning once in a year with short spawning period. Brousseau (1987) had observed that for *Mya arenaria* from widely separated populations, spawning occurred in different times with varying frequency. Newell *et al.*, (1982), while working on Long Island population of *Mytilus edulis*, has suggested that latitudinal effects on the reproductive cycle of bivalves are secondary to the effects of habitat-specific exogenous factors, such as temperature and food supply. Although for tropical species the temperature difference is not much evident, in Dharmadom estuary the spawning season could be positively correlated with increase in the salinity after the monsoon. Sastry (1979) while reviewing the various exogenous and endogenous factors which influence the reproductive cycles in bivalves showed the importance of temperature and salinity in initiating spawning in bivalves. The condition index and percentage of edibility also increased during pre-spawning season and decreased during spawning season. This is explained in detail in the next

section. The study also reveals that both sexes are showing synchronism in gonadal development. Gaspar *et al.* (1999) has observed that in bivalve *Donax trunculus* gonadal development is synchronized in both sexes.

Sex ratio did not vary from theoretical 1: 1 ratio except in May when males outnumbered females. Rao (1988) found that for *P. malabarica* from Mulky estuary the sexes were almost equally distributed except in August when males outnumbered females. The size at first maturity was observed as 20 mm and 22 mm for female and male respectively. Size at first maturity is determined for the study of the stock and for suggesting management measures for exploitation of the resource. Hence for the clam population in Dharmadom the L_m can be taken as 20 mm and 22 mm for female and male clam. Kripa and Appukuttan (2003) have observed that for *Paphia malabarica* the length at first maturity was 20 mm along west coast of India.

In Dharmadom estuary the peak spawning period is coinciding with the increase in salinity during the post monsoon season. There is a sudden dip in salinity in the monsoon season which increases during the post monsoon season which could be one of the factors which stimulates spawning.

According to Joseph and Joseph (1988), it is quite likely that in our search for a single factor hypothesis to explain reproductive synchronization

with exogenous or endogenous factors, many aspects are overlooked, probably most marine bivalves respond to the net result of all exogenous and endogenous factors and synchronize their reproductive activities. Once the clam population reaches maturity, external factors may induce spawning. If the maturity of the clams of the population react simultaneously to the environmental change, gametes are released profusely for a short spell, giving a short period of spawning and hence the extent of spawning depends mainly on the synchrony of the correct stage of maturity and the factors that induce spawning. Though a number of factors seem to induce spawning, studies so far done in tropical waters and the present study indicate that salinity plays a vital role than the temperature. In Dharmadom estuary also the salinity plays a role in spawning than the temperature.

Table 4.1: Monthly variations in reproductive stages of *Paphia malabarica* in Dharmadom Estuary from December 2003-November 2004

A. MALE

Month	Maturing (%)	Mature (%)	Partially Spent (%)	Spent (%)
Dec	0.0	50	10	40
Jan	0.0	11.5	38.5	50
Feb	0.0	28.6	14.3	57.1
Mar	91.4	0.0	5.7	2.9
Apr	100	0.0	0.0	0.0
May	100	0.0	0.0	0.0
Jun	91.9	8.1	0.0	0.0
Jul	93.3	6.7	0.0	0.0
Aug	92.2	7.8	0.0	0.0
Sept	93.9	6.1	0.0	0.0
Oct	60	40	0.0	0.0
Nov	0.0	88.2	5.9	5.9

B. FEMALE

Month	Maturing (%)	Mature (%)	Partially Spent (%)	Spent (%)
Dec	0	53.3	13.3	33.3
Jan	0	15.8	52.6	31.6
Feb	0	43.8	12.5	43.8
Mar	85	0	5	10
Apr	100	0	0.0	0.0
May	100	0	0.0	0.0
Jun	93.9	6.1	0.0	0.0
Jul	92.7	7.3	0.0	0.0
Aug	91.2	8.8	0.0	0.0
Sept	92.3	7.7	0.0	0.0
Oct	52.4	47.6	0.0	0.0
Nov	0.0	80.6	11.1	8.3

C. POOLED

Month	Maturing (%)	Mature (%)	Partially Spent (%)	Spent (%)
Dec	0.0	51.8	11.8	36.5
Jan	0.0	14.1	46.9	39.1
Feb	0.0	34.1	13.6	52.3
Mar	89.1	0.0	5.5	5.5
Apr	100	0.0	0.0	0.0
May	100	0.0	0.0	0.0
Jun	92.9	7.1	0.0	0.0
Jul	93.0	7.0	0.0	0.0
Aug	91.7	8.3	0.0	0.0
Sept	93.1	6.9	0.0	0.0
Oct	56.3	43.7	0.0	0.0
Nov	0.0	84.3	8.6	7.1

Table 4.2: Monthly variations in male, female and indeterminate *P. malabarica* 2003-2004

Month	Male (%)	Female (%)	Indeterminate (%)
Dec	47.1	52.9	0.0
Jan	40.6	59.4	0.0
Feb	31.5	18.0	50.6
Mar	38.5	22.0	39.6
Apr	43.7	29.4	26.9
May	55.6	31.3	13.1
Jun	46.3	41.3	12.5
Jul	49.2	45.1	5.74
Aug	48.5	51.5	0.0
Sept	51.3	48.8	0.0
Oct	51.7	48.3	0.0
Nov	48.6	51.4	0.0

Table 4. 3: Sex ratio of *Paphia malabarica* in the population from December 2003 to November 2004 with percentage of occurrence of male and female in Dharmadom Estuary with results of test of significance.

Month	Male (%)	Female (%)	Sex Ratio	Chi Square value
Dec	47.1	52.9	1:1.13	0.173
Jan	40.6	59.4	1:1.16	1.758
Feb	63.6	36.4	1:0.57	3.719
Mar	63.6	36.4	1:0.57	3.719
Apr	59.8	40.2	1:0.67	1.909
May	64.0	36.0	1:0.56	3.894*
Jun	52.9	47.1	1:0.89	0.163
Jul	52.2	47.8	1:0.92	0.095
Aug	48.5	51.5	1:1.06	0.046
Sept	51.3	48.8	1:0.95	0.031
Oct	51.7	48.3	1:0.93	0.059
Nov	48.6	51.4	1:1.06	0.041

** Significant at 1 % level*

Table 4.4: Correlation coefficient (Pearson) between reproduction, condition index and hydrographic parameters.

Correlation						
	Mature	Temperature	CI	Dry wt	Edibility	Salinity
Mature	1	-0.002	-0.514	-.718(**)	-.785(**)	0.345
Temperature		1	-0.31	0.178	0.278	0.442
CI			1	0.374	0.226	-0.56
Dry wt				1	.733(**)	-0.464
Edibility					1	0.044
Salinity						1

Table 4.5: Spawning period and spawning frequency of some commercially important clams and three species of *Paphia* spp. in tropic and temperate waters

No	Name of Species	Spawning Season	Spawning Frequency	Locality	Authors
1.	*Donax cuneatus*	Jan- April	Once in a year	Palk Bay	Nayar, (1955)
2.	*Donax cuneatus*	Jan- April	Once in a year	Mirya Bay	Thalikhedkar, (1975)
3.	*Donax cuneatus*	Feb - March	Once in a year	Madras coast	Victor and Subramanian ,(1988)
4.	*Donax trunculus*	March - Aug	Once in a year	South Portugal	Gaspara et al., (1999)
5.	*Donax trunculus*	March - July	Once in a year	South Italy	Zeichena et al., (2002)
6.	*Katelysia opima*	Dec- Jan	Once in a year	Adayar Estuary	Rao, (1951)
7.	*Anadara rhombea*	Jan - April	Once in a year	Kakinada	Narasimham, (1988)
8.	*Paphia malabarica*	Oct - Feb	Once in a year	Mulky Estuary	Rao (1988)
9.	*Paphia malabarica*	Oct - Jan	Once in a year	Ashtamudi estuary	Appukuttan, (1993)
10.	*Paphia malabarica*	Sept- Feb	Once in a year	West coast	Kripa and Appukuttan, (2003)
11.	*Paphia rhombea*	Oct-Dec	Once in a year	Plymouth	Labour, (1938)
12.	*Paphia pullastra*	Feb - March	Once in a year	Plymouth	Labour, (1938)
13.	*Paphia decussata*	Summer	Once in a year	Plymouth	Labour, (1938)
14.	*Meretrix casta*	Apr-May, Sept	Twice in a year	Madras	Hornell (1922)
15.	*Katelysia opima*	Oct-Nov,Mar-Apr	Twice in a year	Ratnagiri	Mane & Nagabhushanam (1988)
16.	Donax cuneatus		Prolonged spawning	West Coast	Nagabhushnam & Talikedkar (1977)
17.	Donax cuneatus		Prolonged spawning	Madras	Rao, (1967)
18.	*Meretrix casta*		Prolonged spawning	Mandapam	Durve, (1964)
19	*Meretrix casta*		Prolonged spawning	Vellar estuary	Jayabal & Kalyani, (1986)
20	*Katelysia opima*		Prolonged spawning	Vellar estuary	Jayabal & Kalyani, (1986)
21	*Meretrix meretrix*		Prolonged spawning	Mandapam	Algarswami (1966)
22	*Paphia laterisulca*		Prolonged spawning	Ratnagiri	Mane & Nagabhushanam (1988)

100

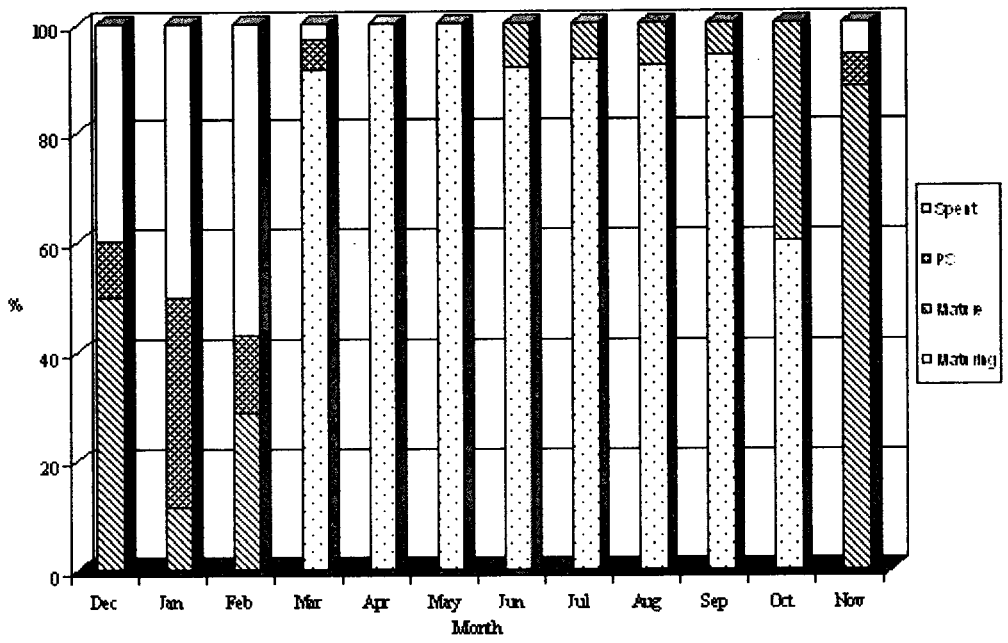


Fig. 4.1: Temporal variations in gonadal stages of male *P. malabarica* (2003-2004)

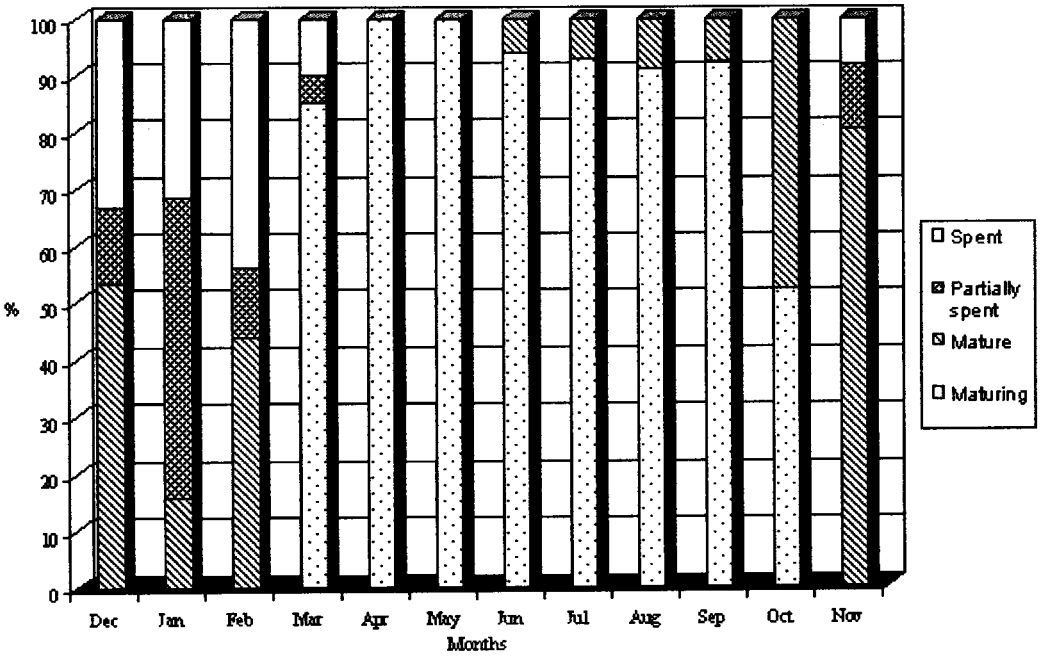


Fig. 4.2: Temporal variations in gonadal stages of female *P. malabarica* (2003-2004)

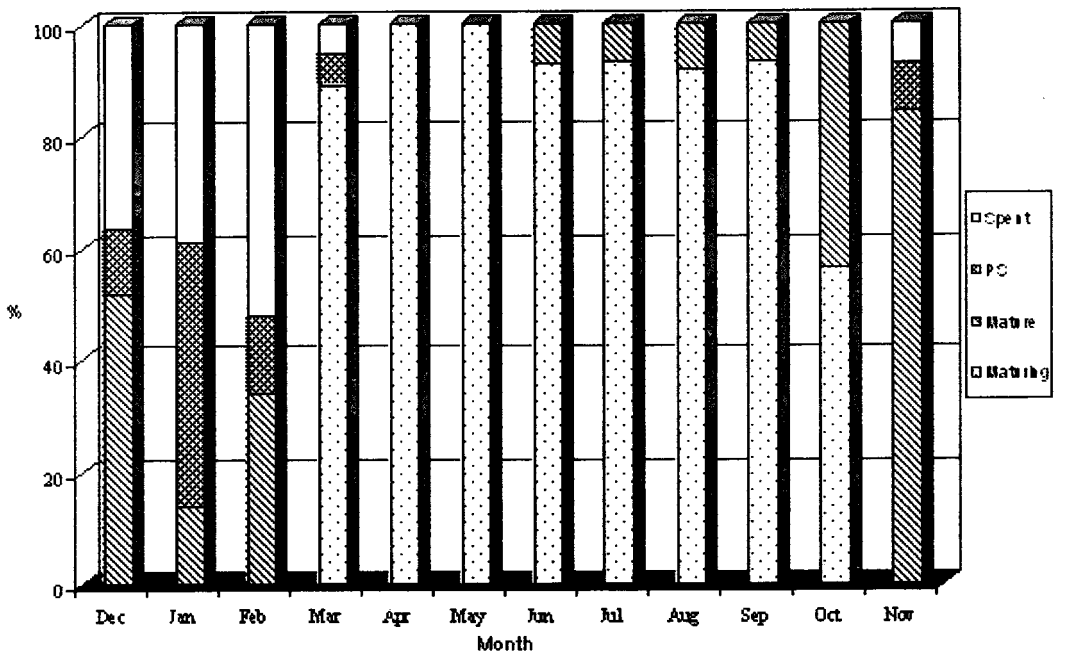


Fig. 4.3: Temporal variations in gonadal stages of *P. malabarica* (pooled) (2003-2004)

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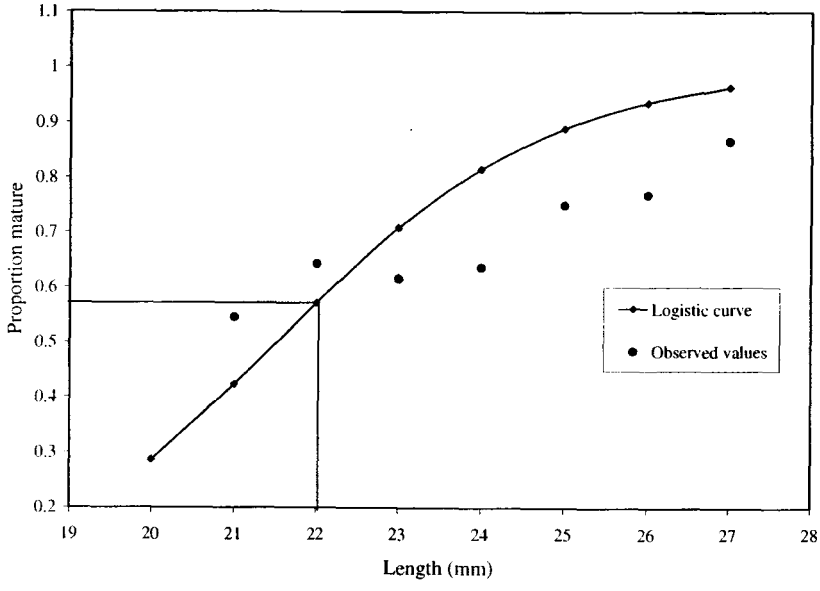

Fig. 4.4: Logistic maturity curve of *Paphia malabarica* (Male), maturity curve with dots and lines to represent the logistic curve for the sample

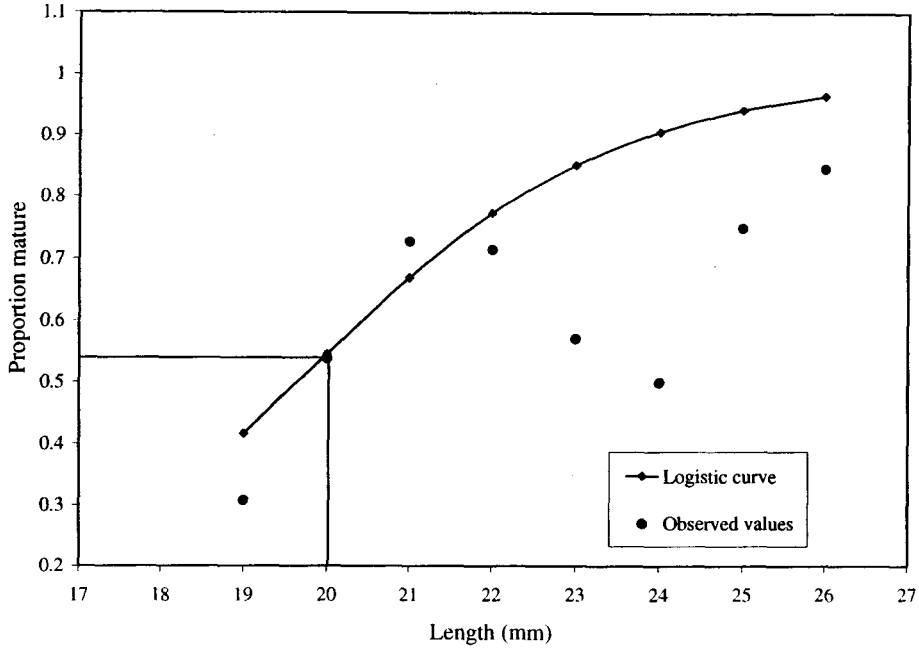

Fig. 4.5: Logistic maturity curve of *Paphia malabarica* (Female), maturity curve with dots and lines to represent the logistic curve for the sample.

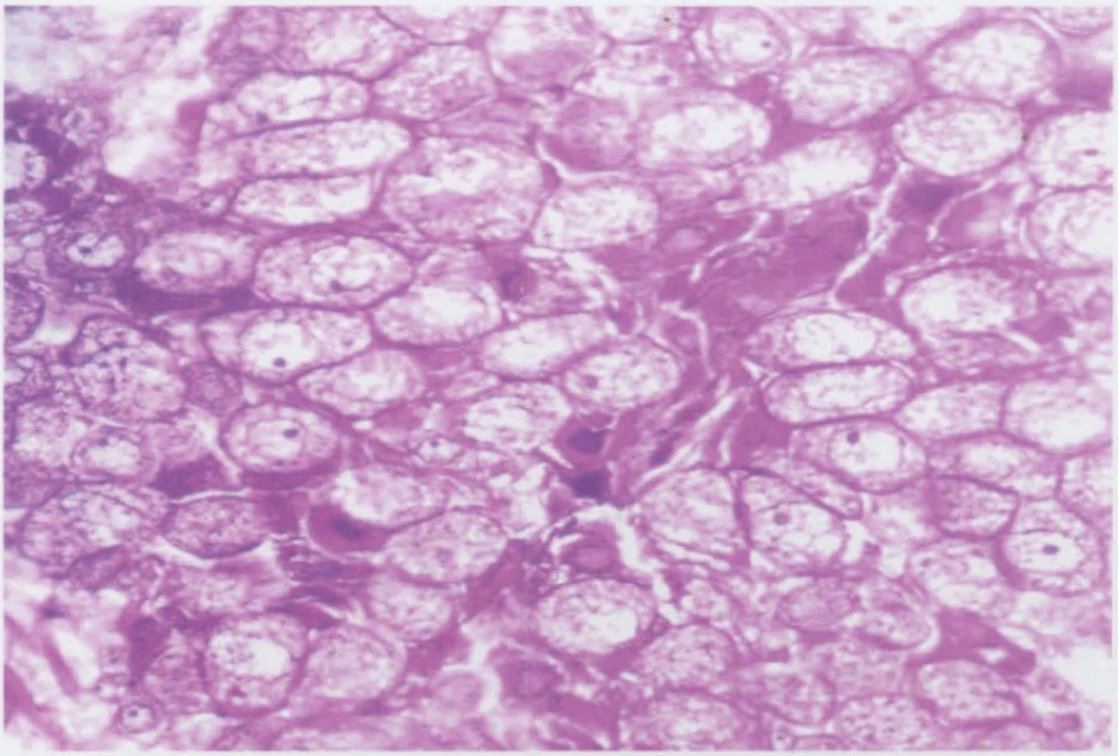

Plate A. Gonadal condition - Female Maturing

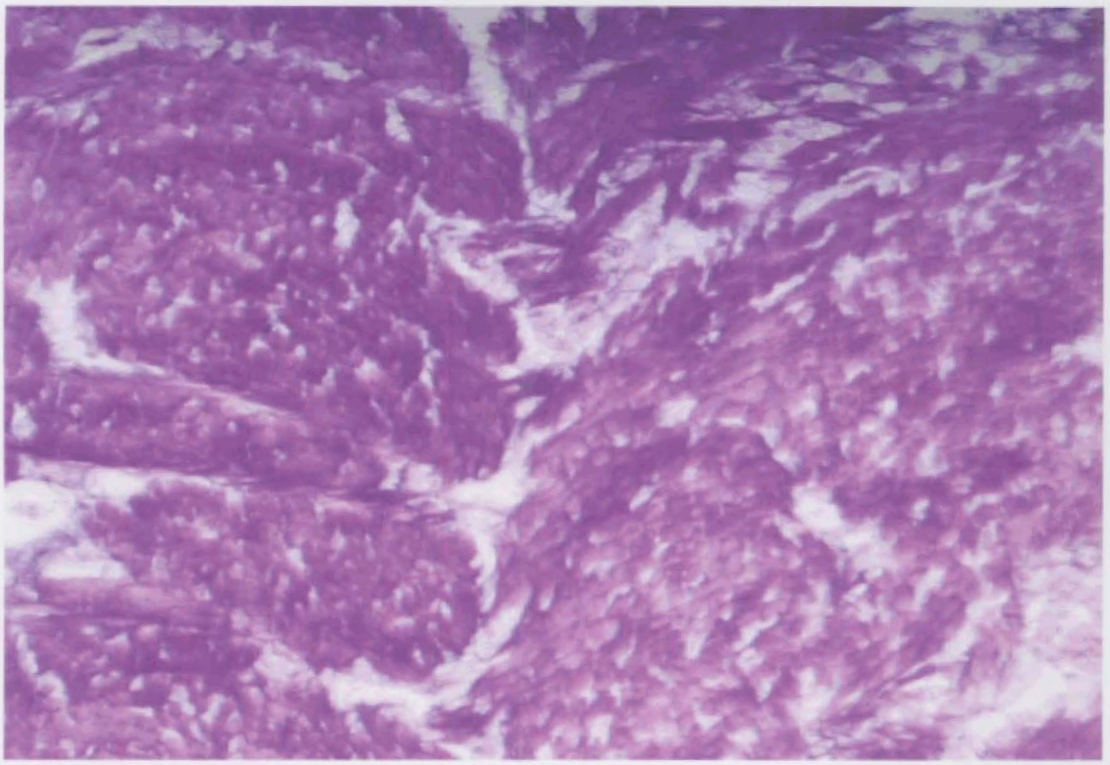

Plate B. Gonadal condition - Male Maturing

Sections of gonads of *P.malabarica* showing different stages of maturity

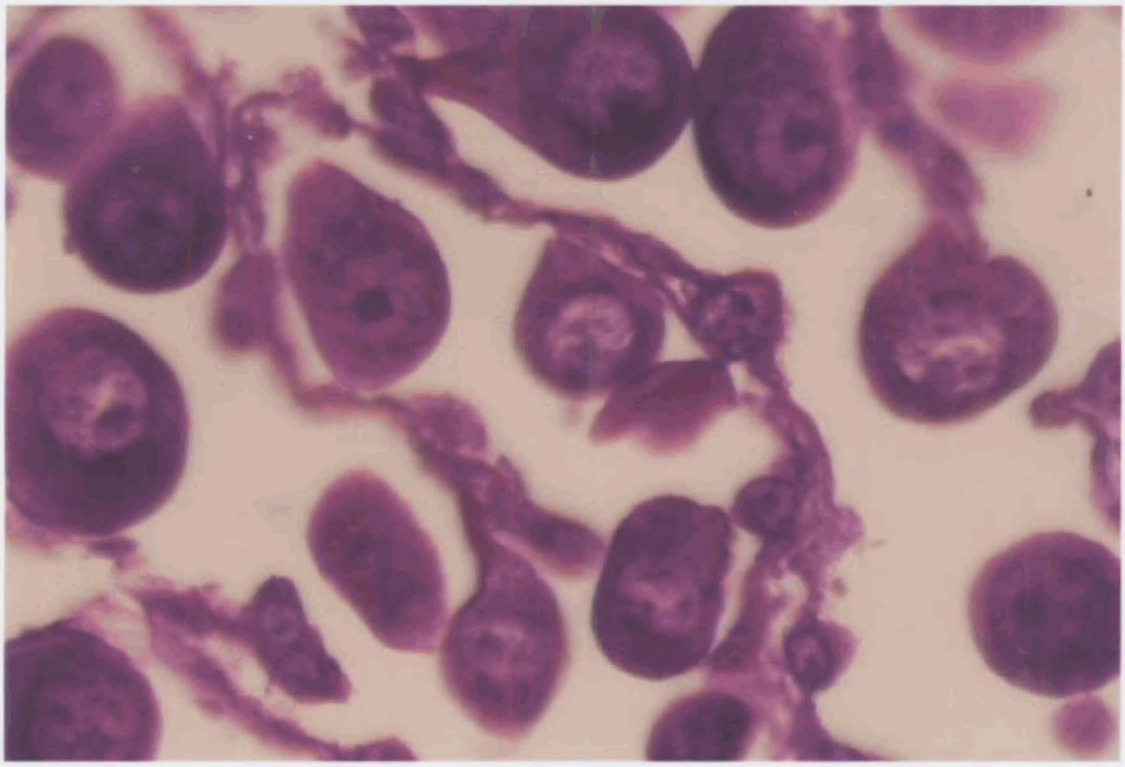

Plate C. Gonadal condition - Female Mature

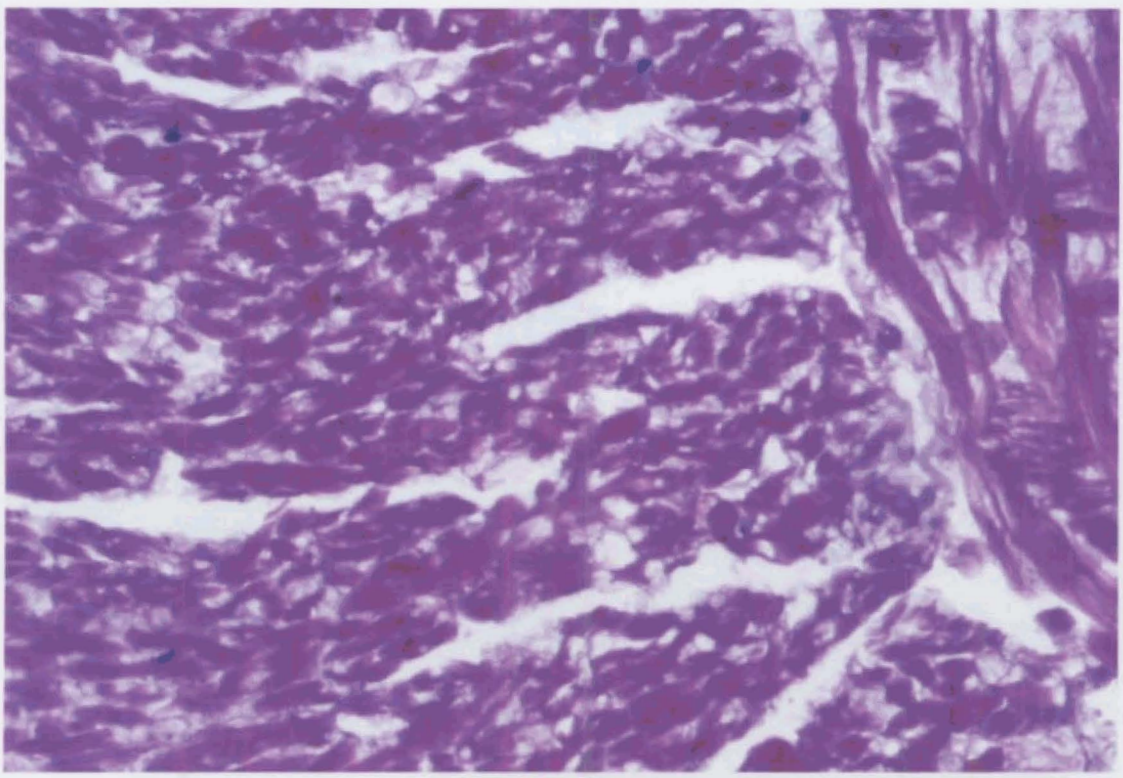

Plate D. Gonadal condition - Male Mature

Sections of gonads of *P.malabarica* showing different stages of maturity

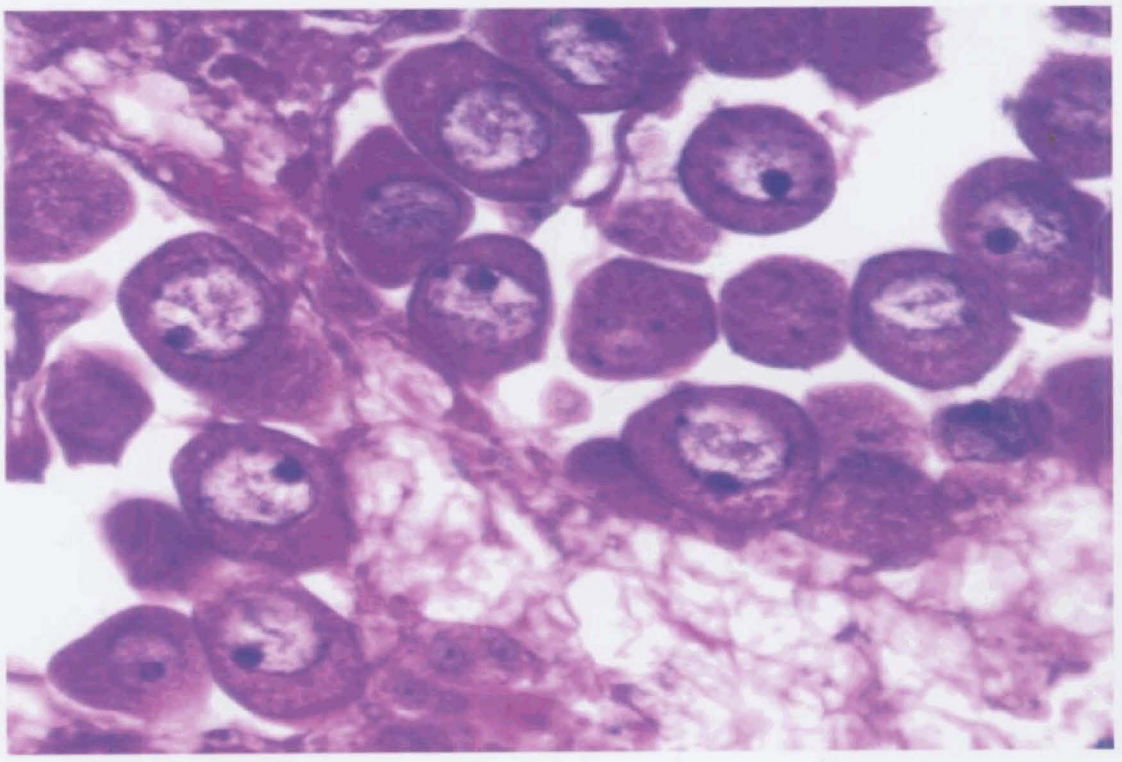

Plate E. Gonadal condition - Female Partially spent

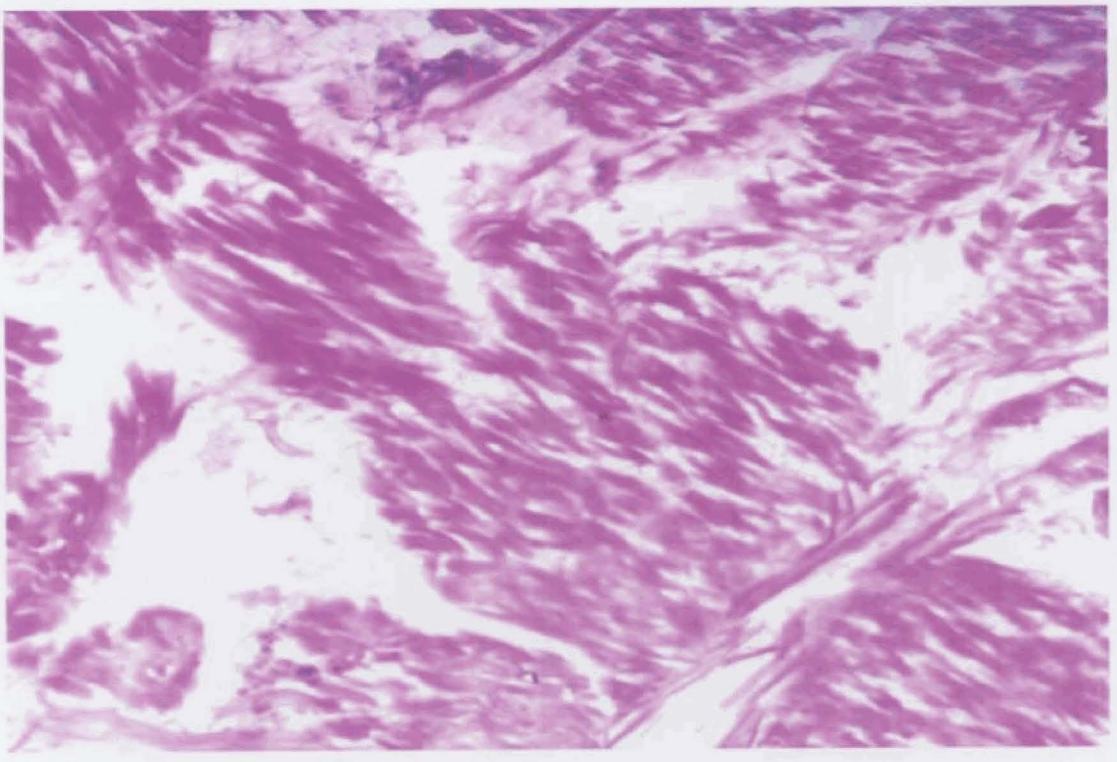

Plate F. Gonadal condition - Male Partially spent

Sections of gonads of *P.malabarica* showing different stages of maturity

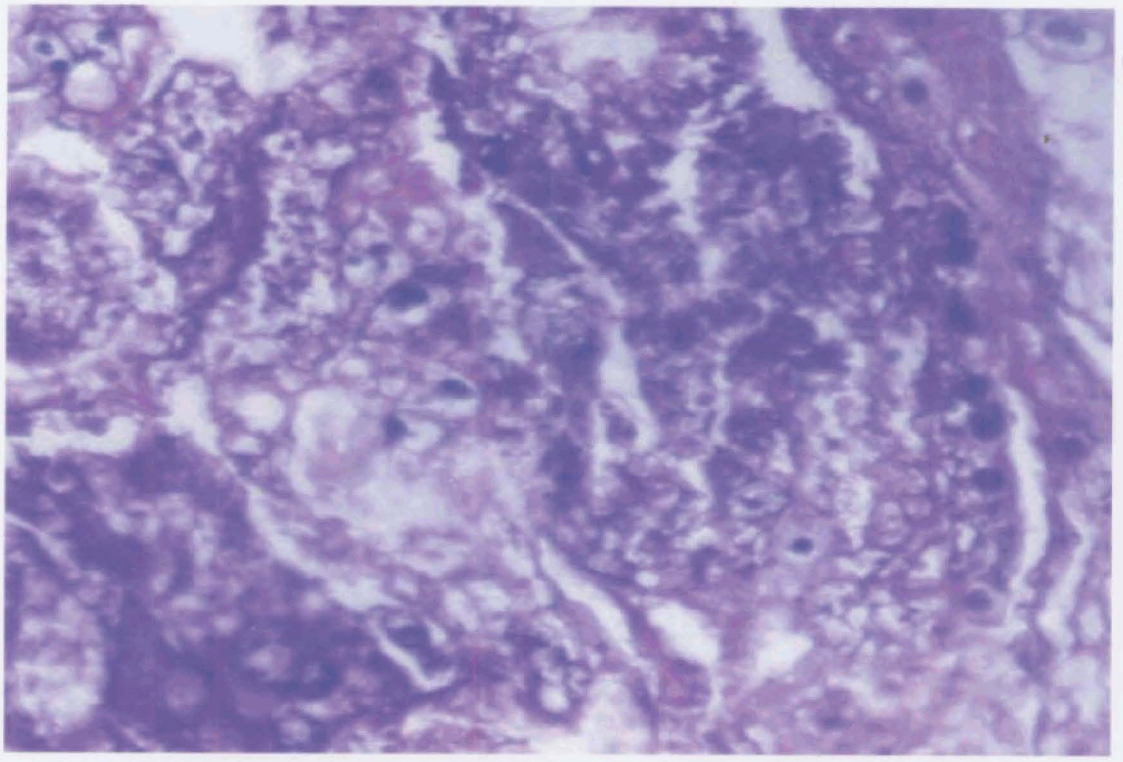

Plate G. Gonadal condition - Female Spent

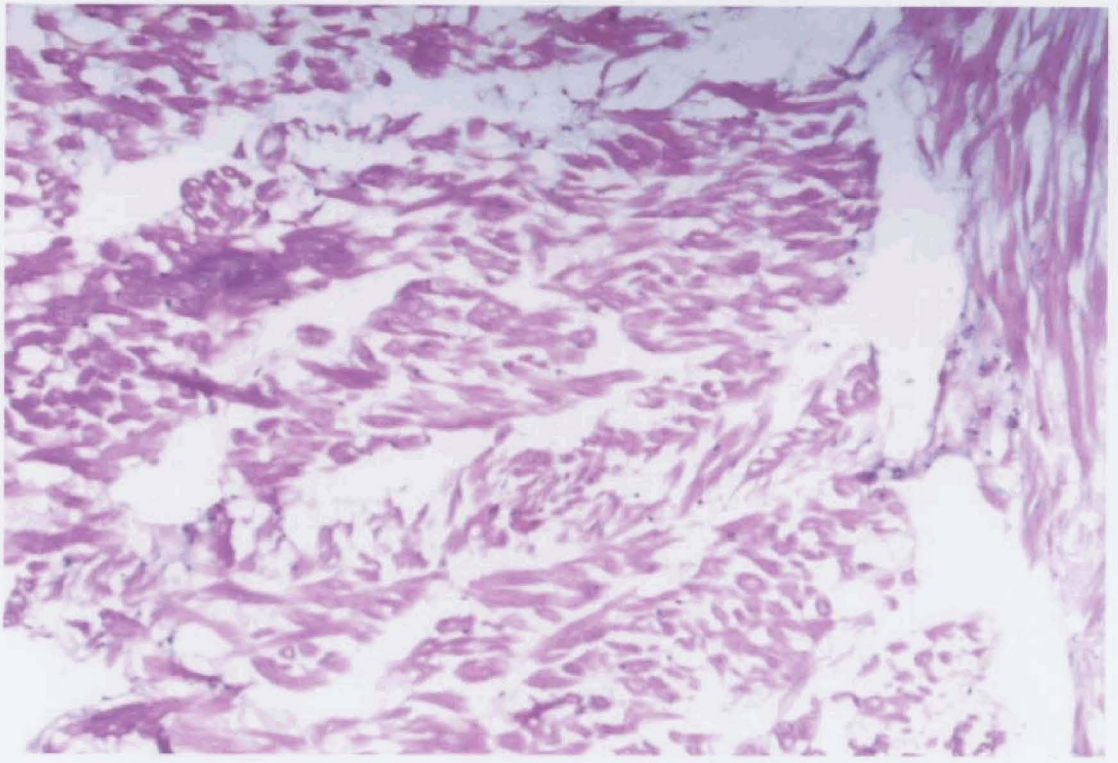

Plate H. Gonadal condition - Male spent

Sections of gonads of *P.malabarica* showing different stages of maturity

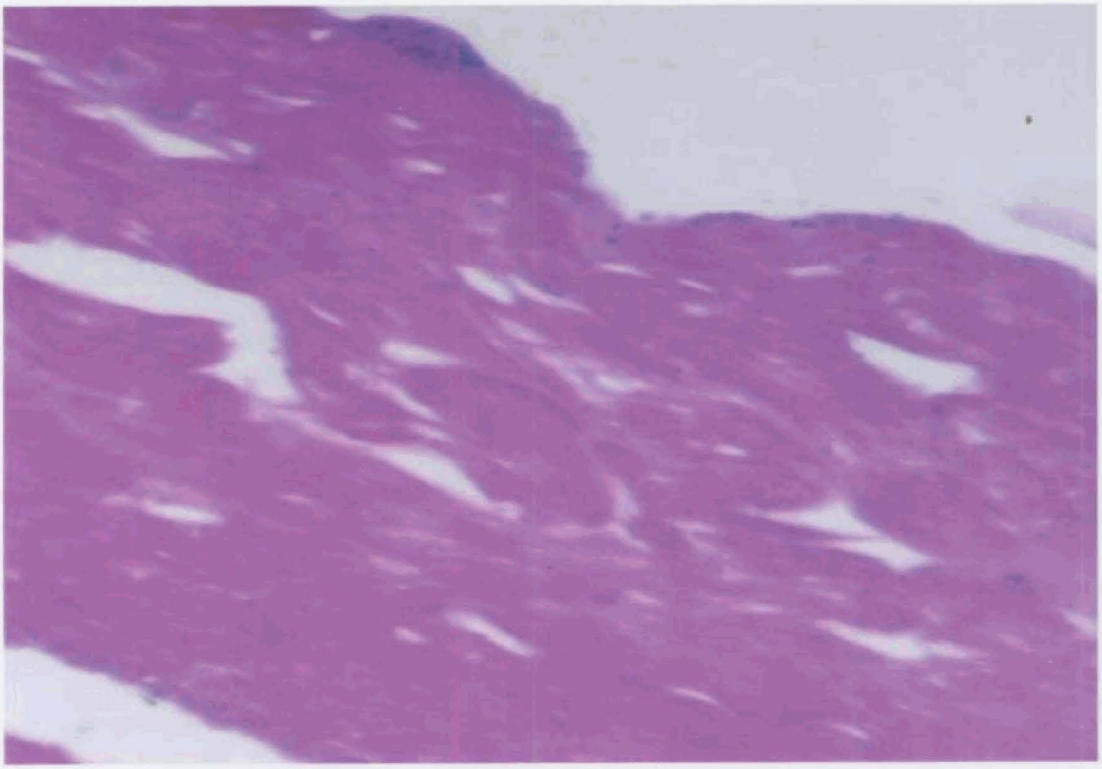

Plate I.

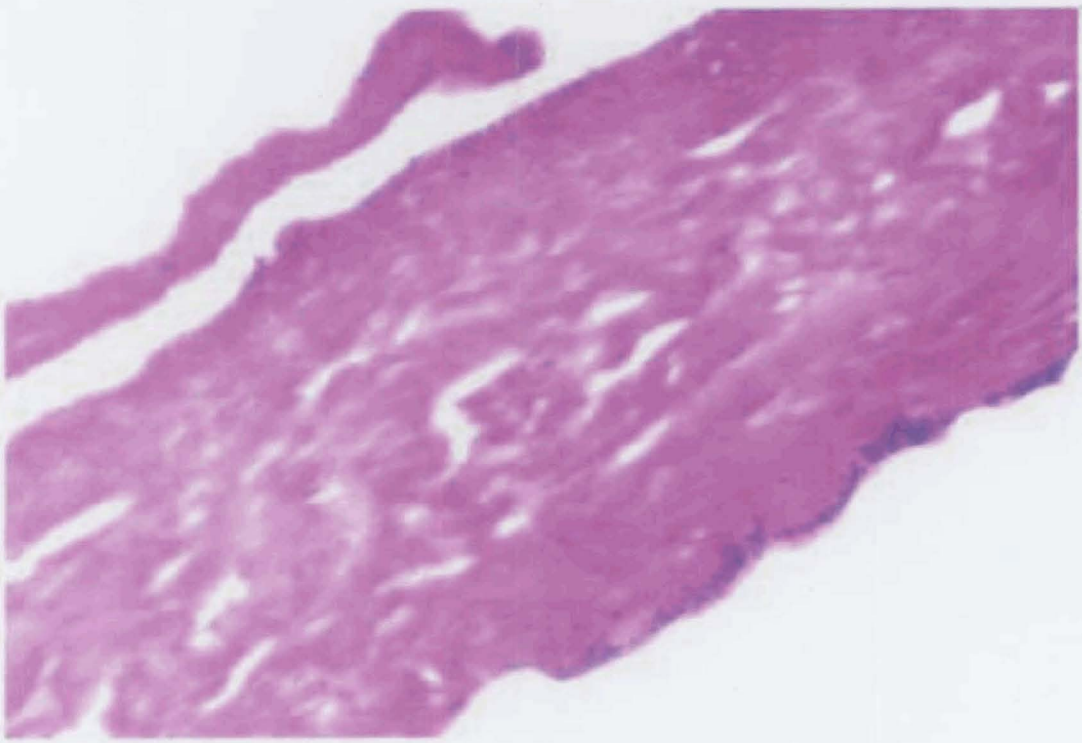

Plate J.

Sections of indeterminate *P.malabarica*

Condition Index of *Paphia malabarica.*

Bivalves are a delicacy at sea food market. Like any commercial food, it is necessary that bivalves present good quality standards, concerning some criteria such as amount of meat and appearance. In bivalves, condition index or fattening index or simply condition, is one of the most satisfactory evaluation methods for estimating the amount of meat related to shell cavity (Nishida, 2006). Variation in meat content is observed in most of the bivalves depending on their physiological condition and also changes in the environmental condition. Condition of bivalves is recognized as the degree of the fatness or the extent to which the meat fills the shell cavity. The body size undergoes changes and such changes are often associated with the breeding cycle. This is accomplished by the development of an increase in size of the reproductive organs followed by a considerable reduction in size after spawning. The meat weight and spawning activity of the bivalves are the two important factors which should be taken into account in any judicious exploitation of the resource. The knowledge of the changes in meat content of the bivalves is also

important for the culturist, as these greatly effect the meat yield and financial returns (Rajapandian and Rajan, 1987). Hence a study on the condition index of *Paphia malabarica* from Dharmadom was taken up, to observe the seasonal changes and to arrive at suitable harvest time of this clam with maximum meat yield.

Reports on the studies on the condition index of the bivalves are available from abroad and India. Schumacker *et al.* (1996) studied the condition index of oysters to monitor the aquatic environment of Willapa Bay in Washington and has observed that gravimetric and volumetric methods produce linearly correlated indices when performed on the same oysters and that less time consuming and more precise gravimetric method can be used as an accurate gauge of oyster. Control of temperature over the condition index was studied by Fisher *et al.* (1996), and they have observed that temperature controls the condition index but it is not known whether the changes resulted directly from the temperature or from the temperature driven reproductive and metabolic cycles. Food limited growth and condition index were studied by Rheault and Rice (1996) in eastern oyster, *Crassostrea virginica.* Seasonal changes in condition index in scallop *Pecten maximas* in relation to environmental condition was studied by Pazos *et al.* (1997). Okumus and

Stirling (1998) studied the meat weight, condition index and biochemical composition of mussels (*Mytilus edulis* L.) in suspended cultures. Seasonal changes in condition index of bivalves *Mytilus edulis* was done by Barkati and Ahmed (1994) and for *Diplodon chilensis chilensis* by Lara and Parade (1991). Seasonal changes in condition index in bivalves were also studied by Hawkins and Rowell (1987), Lleti and Riera (1992), Figueras (1992), Song and Powell (1993), Schluter and Josefsen, (1994) Camacho *et al.* (1995), Etim (1996), Karayuecel and Karayuecel (1997), Almeida *et al* (1997), Pazos *et al.* (1997), Jara *et al.* (1997), Cano *et al.* (1997), Horn and Baker (1997) and Kang-Keun *et al.*(2000). In all the studies it was observed that the condition index varied seasonally and it was correlated with gametogeneis and high condition index was observed during the pre-spawning season.

From Indian waters, seasonal changes in condition index of bivalves were studied by Venketaraman and Chari (1951), Abraham (1953), Nayar (1955), Durve (1964, 1970), Nagabhushanam and Talikhedkar (1977a, 1977b), Krishnakumari *et al.* (1977), Mane and Nagabhushanam, (1979), Joseph (1979), Balasubramaniam *et al.*, (1979), Narasimham (1984, 1988), Rajapandian and Rajan (1987), Joseph and Madhystha (1987), Thippeswamy and Joseph (1988) and Rao (1988). The important species include *Perna viridis* Linnaeus, *Villorita cyprinoides* (Gray), *Katelysia opima* (Gmelin), *Crassostrea*

madrasensis (Preston), *Meretrix meretrix* (Linnaeus), *M. casta* Chemnitz, *Donax fabs* Gmelin, *D. incarnates* Gmelin, *D.cuneatus* Linnaeus, *Placenta placenta* (Linnaeus) and *Anadara rhombea* (Born). In all the studies the condition index was correlated with reproduction and it was observed that high condition index was observed just before the spawning season. In all the studies condition index was low during the spawning season. Except for the studies on condition index of *P. malabarica* from Ashtamudi estuary by Appukuttan (1993), so far no studies have been made from the Indian waters.

4.11 MATERIALS AND METHODS

Three methods were used to find the condition index (CI) of the clams. For objective assessment of condition of bivalves, the volumes of whole shellfish and meat had been found satisfactory. Many have used dry weight or glycogen content of the meat as an index of condition, which is possibly more precise, but because of the time required for the preparation of the material, large samples cannot be used (Baird, 1958). In the first method, index of condition is assessed by measuring the volume of the shell cavity and the volume of the meat contained therein while both are wet; dividing the meat volume by shell cavity volume and multiplying by 100 (Baird, 1958). The index is therefore the percentage of shell cavity occupied by meat

$$\text{Index of condition} = \frac{\text{Meat Volume}}{\text{Shell cavity volume}} \times 100$$

By this method, the degree of fatness of meat is objectively measured, irrespective of shell thickness and to a certain extent the size of the clam, although a significant correlation often exist between length and condition in animals.

Since larger size groups had good export demand and exploited more, the condition index was studied for two size groups (below 30 mm and above 30 mm) for a period of one year (December, 2003 – November, 2004). Thirty specimens in each of the two size groups, 20-29 mm and above 30 mm in total length (anterio-posterior length), were collected every month and the total volume and shell volume were measured by displacement method. Cavity volume was calculated by taking the difference between total volume and shell volume. A total of 720 specimens ranging from 21 to 50 mm were used in the present study.

Condition index was also determined as percentage of wet meat weight in total clam weight (Rao, 1988), which is also called meat edibility (Appukuttan, 1993). For this purpose, excess moisture from the meat was

removed with blotting paper and the meat weight was recorded to an accuracy of 0.01g.

Another method used to find the condition index was, calculating the the index as percentage of dry flesh weight in wet flesh weight (Narasimham, 1989). After the wet flesh weight of the clam was taken, the meat was kept in a hot air oven at 80^0C for 24 hrs and then dry weight taken. Condition index calculated by three methods were statistically treated to find out whether there is significant difference in condition index in different months and also during different seasons (pre-monsoon, monsoon and post-monsoon periods).

Statistical analysis was carried out using SPSS 7.5 software and Pearson correlation analysis was carried out to understand the trend and relationships among different parameters.

4.12 RESULTS

The change in condition index during the different months is given in Fig. 4.11 and 4.12. Condition index, percentage meat edibility, dry weight meat percentage in *Paphia malabarica* for two size groups is given in Table 4.11. The condition index ranged from 30.9 to 55.3, the highest in September (55.3) and the lowest in February (30.9). From March onwards larger size group showed an increase in CI and it ranged between 43 and 53. For size

group less than 30 mm, the CI increased from 32.2 to 41.3 in March. There was a sharp decline in condition index in both size groups after the peak in September. In general the larger size group had higher condition index than the lower size group through out the year.

Results of the statistical analysis are given in the Table 4.12. Results of one way ANOVA shows that there is significant difference in condition index between size groups throughout the year at 1 % significant level. For pre-monsoon, monsoon and post-monsoon season analysis, it is observed that during pre-monsoon and monsoon season there is significant difference in condition index between size groups, but during post-monsoon season there is no significant difference in CI between the two size groups Table 4.13.

Correlation study.

The correlation (Pearson) between condition index and maturing and mature percentages is shown in Table 4.14. Significant positive correlation was observed between the condition index and maturing clams, while negative correlation was observed for mature clams with condition index.

Changes in meat edibility during different months are given in Table 4.11 and Fig 4.11. Meat edibility percentage ranged from 12.5 to 25.6. The percentages was maximum in May (25.6) and minimum in November (12.5).

For size group > 30 mm the meat edibility ranged from 14.7 to 24.6 % and in size group < 30 mm the edibility ranged from 12.5 to 25.6 %.

Results of the statistical analysis are given in Table 4.15. Results of one way ANOVA done show that there is significant difference in meat edibility between size groups throughout the year at 1 % significant level. For pre-monsoon, monsoon and post-monsoon season analysis it is observed that during the three seasons there is significant difference in meat edibility between size groups. The study shows that average meat edibility during pre-monsoon and monsoon season was higher in smaller sized clams, while during post-monsoon average edibility was higher in larger sized clams Table 4.16.

Correlation study.

The correlation (Pearson) between percentage meat edibility and maturing and mature percentages is shown in Table 4.17. Significant positive correlation was observed between the percentage meat edibility and maturing clams, while negative correlation was observed for mature clams with percentage meat edibility.

Results of dry weight percentage for two size groups are given in Table (4.11) and Fig. (4.11). The dry weight percentage ranged from 2.9 to 4.8. The percentage was highest in May and lowest in December for the two size groups.

Results of the statistical analysis are given in the Table 4.18. Results of one way ANOVA show that except in July, August and November there is significant difference in dry weight percentage between size groups throughout the year at 1 % significant level. For pre-monsoon, monsoon and post-monsoon season analysis, it is observed that during pre-monsoon and post monsoon season there is significant difference between size groups but during monsoon there is no significant difference. In the present study it is observed that during pre-monsoon and post-monsoon season, higher dry weight percentage was observed in clams above the size of 30 mm and during the monsoon season the average dry weight percentage for two size groups were almost the same (Table 4.19).

Correlation study.

The correlation (Pearson) between percentage dry weight and maturing and mature percentages is shown in Table 4.20. Significant positive correlation was observed between the percentage dry weight and maturing clams, while negative correlation was observed for mature clams with percentage dry weight.

Results of the statistical analysis for condition index, edibility and dry weight percentage for three seasons are given in Table 4.21. It is observed that

condition index, meat edibility percentage and percentage dry weight were significantly different for the three seasons.

Condition index and salinity showed negative correlation while condition index and temperature showed positive correlation (Table 4.22). Condition index showed positive correlation between pre-spawning clams and negative correlation with spawning clams.

4.13 DISCUSSION

The condition index in the present study showed seasonal and monthly variations. The trend in the values of the index of condition studied by the three methods was essentially the same except for a few anomalies observed in some values, particularly in the condition index based on dry weight percentage. The anomalies observed could be due to the varying quantities of water retained in the mantle cavity of the clam which could affect the total weight. Similar anomalies were observed by Narasimham (1980) in green mussel *Perna viridis*. Major peak in condition index was observed in September and a minor peak in June. A sudden fall in condition index was observed in October which correlates with the onset of spawning. Similar observations on the fall in condition index with spawning were made by Narasimham (1984), Joseph and Madhystha (1987), Thippeswamy and Joseph

(1988), Narasimham (1988) and Rao (1988). The lowest value of condition index observed in February may be because the clams were in partially spawned or in spent condition. High values in meat edibility and dry weight percentage was observed in May, when 100 % of the clams were in maturing stage. The clams could be in the late maturing stage in May. Etim (1996) also observed increase in CI with sexual maturity, with a peak just before spawning and minimum when the animals are spent. In *P. malabarica* Rao (1988) and Appukuttan (1993) observed similar variations in condition factor in Mulky estuary and Ashtamudi estuary and attributed it to spawning cycles. Moreover, condition index and the size also showed some relationships, where larger sizes showed higher CI during pre-monsoon and monsoon seasons. Percentage meat edibility was higher in smaller size groups during pre-monsoon and monsoon seasons, while during post-monsoon the larger clams had higher meat edibility. Variation in condition index by size has also been observed by Baird (1958), Hickman and Illingworth (1980) and Narasimham (1984).

Correlation study has revealed significant positive relationship for maturing clams and the CI and negative correlation for mature clams with condition index done by the three methods. The reason for the high condition

index for maturing clams could be due to the reserve in nutrients post spawning stage. Similar observations were made by Sastry (1970).

For *P. malabarica*, seasonal variations in condition index are observed and there is significant difference between the seasons. There is significant difference in condition index with salinity and temperatures in the three seasons. It is also observed that during low salinity period (monsoon season) the clams had higher condition index. In Ashtamudi estuary also, during low salinity the condition index of clams were high (Appukuttan, 1993). The reason for high condition index may be due to the fact that during monsoon season the nutrient influx is more into the estuary and food availability could be more and there is an increase in body weight of clams.

Seasonal variations in condition index in other bivalves were observed by Lara and Parade (1991), Barkati and Ahmed (1994), Fisher *et al.*, (1996), Okumus and Sterling (1998). The present study reveals that during pre-spawning season the condition index is high and during the spawning period the condition index is low. Similar observations on the high condition index in oysters were reported by Cano et al. (1997).

The present study shows that variations in the condition index occur with changes in environmental conditions. As in the case of reproduction,

condition index is influenced by salinity and the index is high when the salinity is low. The reproductive activity also plays a role in the variation in condition index of *P. malabarica* in Dharmadom estuary. Just before spawning the condition index is high and that season is best for harvesting of clams, when the yield will be high. This study helps in determining the best time for harvest of the resource and is helpful for future clam culture in the area.

Table 4.11. Condition index, percentage meat edibility, dry weight meat percentage in *Paphia malabarica* for two size groups from Dharmadom Estuary during, December 2003- November 2004.

Months	Condition Index		Meat Edibility %		Dry weight %	
	Small size	Large Size	Small size	Large Size	Small size	Large Size
Dec	45.5	43.8	16.5	17.3	2.9	3.2
Jan	34.3	36.1	18.8	19.5	3.1	3.4
Feb	32.2	30.9	20.8	18.7	3.6	3.8
Mar	41.3	47.0	22.2	20.2	3.7	3.9
April	40.9	43.58	24.3	23.2	4.1	4.5
May	41.4	45.8	25.6	24.6	4.5	4.8
June	44.0	48.5	21.5	19.7	4.2	4.4
July	47.5	49.8	16.3	17.9	4.1	4.3
Aug	43.9	47.3	19.4	16.9	3.9	3.8
Sept	55.3	53.3	21.5	19.1	3.8	3.6
Oct	36.5	45.59	16.6	16.6	3.3	3.5
Nov	38.0	32.5	12.5	14.7	3.2	3.3

Table 4.12: ANOVA table showing the significant difference in condition index between two size groups in *P. malabarica* in different months.

Month		Sum of Squares	df	Mean Square	F	Sig
Dec	Between (Combined)	42.84	1	42.842	11.987	0.001*
	Within Groups	207.29	58	3.574		
	Total	250.13	59			
Jan	Between (Combined)	53.044	1	53.044	15.196	0.00*
	Within Groups	205.949	59	3.491		
	Total	258.993	60			
Feb	Between (Combined)	27.55	1	27.554	5.154	0.027*
	Within Groups	310.07	58	5.346		
	Total	337.63	59			
Mar	Between (Combined)	482.234	1	482.234	131.678	0.00*
	Within Groups	212.408	58	3.662		
	Total	694.642	59			
Apr	Between (Combined)	438.237	1	438.237	98.475	0.00*
	Within Groups	262.565	59	4.450		
	Total	700.802	60			
May	Between (Combined)	288.204	1	288.204	103.294	0.00*
	Within Groups	161.828	58	2.790		
	Total	450.032	59			

Jun	Between (Combined)	299.716	1	299.713	38.257	0.00*
	Within Groups	454.379	58	7.834		
	Total	754.092	59			
Jul	Between (Combined)	75.488	1	75.488	15.662	0.00*
	Within Groups	279.558	58	4.820		
	Total	355.046	59			
Aug	Between (Combined)	176.542	1	176.542	21.688	0.00*
	Within Groups	472.123	58	8.140		
	Total	648.665	59			
Sep	Between (Combined)	60.200	1	60.200	9.994	0.002*
	Within Groups	349.368	58	6.024		
	Total	409.569	59			
Oct	Between (Combined)	1235.788	1	1235.788	461.407	0.00*
	Within Groups	155.342	58	2.678		
	Total	1391.130	59			
Nov	Between (Combined)	461.483	1	461.483	168.987	0.00*
	Within Groups	158.391	58	2.731		
	Total	619.873	59			

* Significant at 0.05 level

Table 4.13: ANOVA table showing the significant difference in condition index between two size groups in *P. malabarica* in three seasons.

Season		Sum of Squares	df	Mean Square	F	Sig
Premonsoon	Between (Combined)	1821.61	1	1821.605	51.146	0.00*
	Within Groups	8512.11	239	35.616		
	Total	10333.71	240			
Monsoon	Between (Combined)	248.514	1	248.514	12.517	0.00*
	Within Groups	4725.278	238	19.854		
	Total	4973.792	239			
Post monsoon	Between (Combined)	55.750	1	55.750	2.102	0.148
	Within Groups	6339.39	239	26.525		
	Total	6395.135	240			

* Significant at 0.05 level

Table 4.14. Correlation coefficient (Pearson) between condition index and maturity stages.

	CI	Mature	CI	Maturing
CI	1.000	-0.462		
Mature	-0.462	1.000		
CI			1.000	0.749**
Maturing			0.749**	1.000

** Correlation is significant at the 0.01 level.

Table 4.1 5: ANOVA table showing the significant difference in meat edibility between two size groups in *P. malabarica* in different months.

Month		Sum of Squares	df	Mean Square	F	Sig
Dec	Between (Combined)	9.842	1	9.842	20.811	0.00*
	Within Groups	27.428	58	0.473		
	Total	37.270	59			
Jan	Between (Combined)	6.734	1	6.734	19.198	0.00*
	Within Groups	20.343	58	0.351		
	Total	27.076	59			
Feb	Between (Combined)	61.125	1	61.125	139.295	0.00*
	Within Groups	25.452	58	0.439		
	Total	86.577	59			
Mar	Between (Combined)	59.601	1	59.601	222.038	0.00*
	Within Groups	15.569	58	0.268		
	Total	75.169	59			
Apr	Between (Combined)	18.704	1	18.704	58.057	0.00*
	Within Groups	18.686	58	0.322		
	Total	37.390	59			
May	Between (Combined)	16.537	1	16.537	47.834	0.00*
	Within Groups	20.052	58	0.346		
	Total	36.590	59			

Jun	Between (Combined)	50.784	1	50.784	133.489	0.00*
	Within Groups	22.065	58	0.380		
	Total	72.849	59			
Jul	Between (Combined)	37.131	1	37.131	187.127	0.00*
	Within Groups	11.509	58	0.198		
	Total	48.639	59			
Aug	Between (Combined)	95.508	1	95.508	415.866	0.00*
	Within Groups	13.320	58	0.230		
	Total	108.828	59			
Sep	Between (Combined)	84.017	1	84.017	414.956	0.00*
	Within Groups	11.743	58	0.202		
	Total	95.760	59			
Oct	Between (Combined)	.067	1	0.067	0.236	0.629
	Within Groups	16.393	58	0.283		
	Total	16.459	59			
Nov	Between (Combined)	71.068	1	71.068	177.658	0.00*
	Within Groups	23.202	58	0.400		
	Total	94.270	59			

* Significant at 0.05 level

Table 4.16 : ANOVA table showing the significant difference in meat edibility between two size groups in *P. malabarica* in three seasons.

Season		Sum of Squares	df	Mean Square	F	Sig
Premonsoon	Between (Combined)	143.160	1	143.160	29.780	0.00*
	Within Groups	1144.132	238	4.807		
	Total	1287.292	239			
Monsoon	Between (Combined)	99.717	1	99.717	31.746	0.00*
	Within Groups	747.578	238	3.141		
	Total	847.295	239			
Post monsoon	Between (Combined)	48.330	1	48.330	10.874	0.001*
	Within Groups	1057.851	238	4.445		
	Total	1106.182	239			

* Significant at 0.05 level

Table 4.17. Correlation coefficient (Pearson) between meat edibility and maturity stages.

	Edibility	Mature	Edibility	Maturing
Edibility Mature	1.000 -0.785**	-0.785** 1.000		
Edibility Maturing			1.000 0.571*	0.571* 1.000

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

Table 4.18: ANOVA table showing the significant difference in dry weight percentage between two size groups in *P. malabarica* in different months.

Month		Sum of Squares	df	Mean Square	F	Sig
Dec	Between (Combined)	1.380	1	1.380	12.655	0.001*
	Within Groups	6.326	58	0.109		
	Total	7.706	59			
Jan	Between (Combined)	1.286	1	1.286	16.407	0.00*
	Within Groups	4.625	59	0.078		
	Total	5.910	60			
Feb	Between (Combined)	0.332	1	0.662	4.652	0.035*
	Within Groups	8.247	58	0.142		
	Total	8.909	59			
Mar	Between (Combined)	0.504	1	0.504	4.427	0.040*
	Within Groups	6.606	58	0.114		
	Total	7.110	59			
Apr	Between (Combined)	2.564	1	2.564	19.688	0.00*
	Within Groups	7.684	59	0.130		
	Total	10249	60			
May	Between (Combined)	2.025	1	2.025	24.899	0.00*
	Within Groups	4.797	59	0.081		
	Total	6.822	60			

Jun	Between (Combined)	0.620	1	0.620	4.582	0.037*
	Within Groups	7.850	58	0.135		
	Total	8.470	59			
July	Between (Combined)	0.561	1	0.561	3.977	0.051
	Within Groups	8.177	58	0.141		
	Total	8.737	59			
Aug	Between (Combined)	0.171	1	0.171	1.032	0.314
	Within Groups	9.589	58	0.165		
	Total	9.759	59			
Sept	Between (Combined)	1.121	1	1.121	6.242	0.015*
	Within Groups	10.413	58	0.180		
	Total	11.534	59			
Oct	Between (Combined)	0.771	1	0.771	4.943	0.030*
	Within Groups	9.043	58	0.156		
	Total	9.814	59			
Nov	Between (Combined)	0.468	1	0.468	2.799	0.100
	Within Groups	9.702	58	0.167		
	Total	10.170	59			

* Significant at 0.05 level

Table 4.1 9: ANOVA table showing the significant difference in dry weight percentage between two size groups in *P. malabarica* in three seasons.

Season		Sum of Squares	df	Mean Square	F	Sig
Premonsoon	Between (Combined)	4.969	1	4.969	17.730	0.00*
	Within Groups	67.261	240	.280		
	Total	72.230	241			
Monsoon	Between (Combined)	.001	1	.001	.005	0.946
	Within Groups	53.937	238	.227		
	Total	53.938	239			
Post monsoon	Between (Combined)	3.747	1	3.747	26.833	0.00*
	Within Groups	33.375	239	.140		
	Total	37.122	240			

* Significant at 0.05 level

Table 4.20. Correlation coefficient (Pearson) between dry weight percentage and maturity stages.

	Dry wt %	Mature	Dry wt %	Maturing
Dry wt % Mature	1.000 -.615*	-.615* 1.000		
Dry wt % Maturing			1.000 .760**	.760** 1.000

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

Table 4.21: ANOVA table showing the significant difference in condition index, meat edibility and dry weight percentage in *P. malabarica* in three seasons.

		Sum of Squares	df	Mean Square	F	Sig
CI Season	Between (Combined)	13918.55	2	6959.275	229.29	0.00*
	Within Groups	21822.77	718	30.352		
	Total	35741.32	721			
Edibility Season	Between (Combined)	4255.420	2	2127.71	469.013	0.00*
	Within Groups	3261.790	719	4.537		
	Total	7517.210	721			
Dry wt % Season	Between (Combined)	112.256	2	56.128	247.603	0.00*
	Within Groups	162.988	719	.227		
	Total	275.244	721			

* Significant at 0.05 level

Table 4.22: Correlation coefficient (Pearson) between condition index, salinity and temperature.

	CI	Salinity	Temperature	Edibility	Dry weight
CI	1.000	-0.560	-0.310	0.226	0.374
Salinity		1.000	0.442	0.044	-0.464
Temperature			1.000	0.278	0.178
Edibility				1.000	0.733
Dry weight					1.000

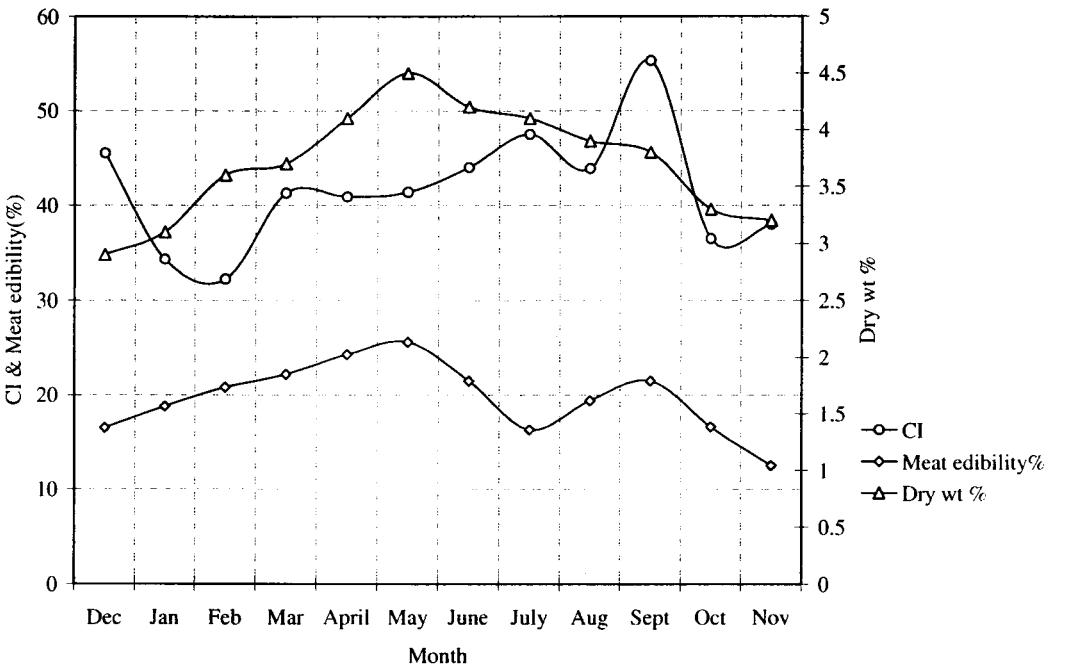

Fig. 4.11 A. Condition index of small sized *P. malabarica* in Dharmadom estuary during December 2003 - November 2004

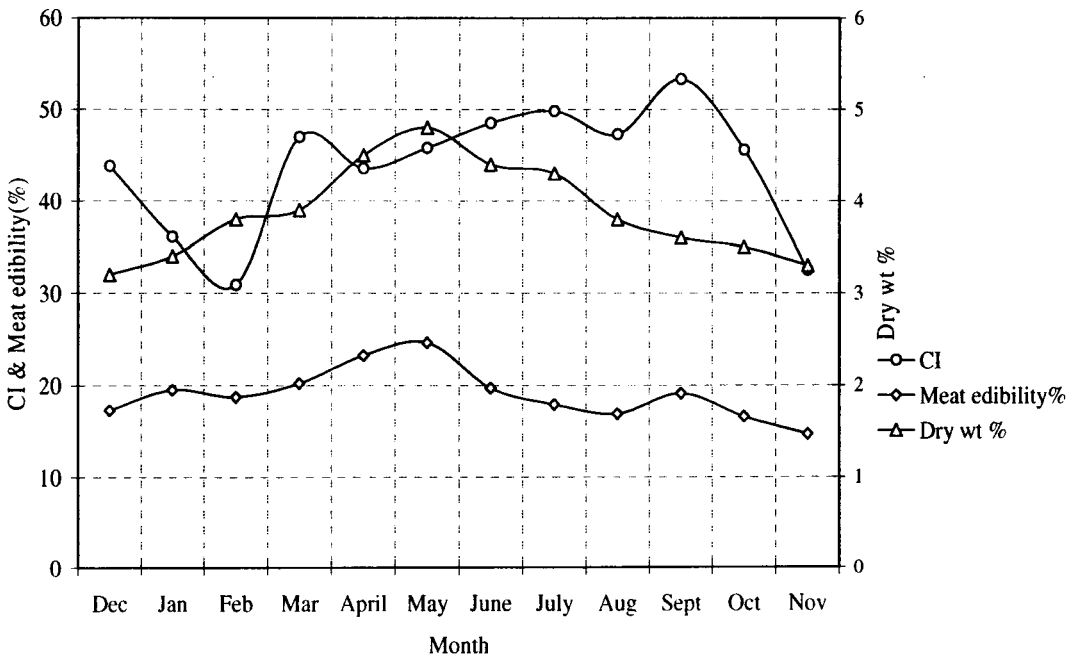

Fig. 4.11 B. Condition index of large sized *P. malabarica* in Dharmadom estuary during December 2003- November 2004

Biochemical changes with maturation in Paphia malabarica

Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter V

Biochemical changes with maturation in *Paphia malabarica*

Studies on biochemical composition of animals are of considerable importance in understanding the physiological mechanism and the chemical constituents of its body. Regardless of the zoological group to which an animal belongs the greatest mass of materials which form the tissue and organs, exclusive of skeleton or shells, consist of three major groups of organic compounds *viz.* protein, carbohydrates and lipids (fats) (Galtsoff, 1964). Studies on the biochemical composition of the meat of many species have been done to understand the constituents of the body and its transformation within the body in different seasons in relation to biological activities (Ansell 1972, Mc Lachlan and Lombard 1980). Fresh water and marine bivalves display marked variations in biochemical content of the soft tissue (Giese *et al.*1967, Trevallion 1971, Ansell 1972, Gabbot and Bayne 1973, Beukema and de Bruin, 1977, Dietz and Stem 1977, Zandee *et al.*, 1980 and Williams and McMahon 1989), that are related to the considerable energetic demands of gametogenesis. Bivalves build up stores of energy in body tissues and then

deplete these stores during production and eventual release of gamete (Nalepa and Joann 1993).

Although the importance of studies on biochemical composition of bivalves was well understood from very early days, few such studies were done in the early part of the century. Compared with other groups of molluscs there is less literature on the bivalves and that too mostly on edible oysters, mussels and clams from temperate waters.

Chipperfield (1953) studied the biochemical composition of *Mytilus edulis* in relation to breeding and has observed that carbohydrate, protein and lipid concentration changed with the reproductive stages. Investigations on the edible mussel *Mytilus edulis* by Williams (1969) showed that variations in biochemical composition are closely related to breeding seasons. Galtsoff (1964) has described the biochemical changes with reproduction in American oyster *Crassostrea virginica* and has observed that in spite of great variability in the composition of meat of several species of *Ostrea* and *Crassostrea*, the order of magnitude of the three components protein, carbohydrate and lipid is common to all the species studied. Lawrence et al., (1965), Sastry (1966), and Vassallo (1973) while studying Chiton *Katharina tunicate*, bivalve *Aequipecten irradians* and scallop *Chlamys hericia* respectively, *have* postulated a flow of reserves from digestive gland into gonad during

gametogensis. Giese (1966) studied the changes in lipid with reference to the reproductive stages in marine molluscs. Other important works during the early days are that of Ansell *et al.* (1964), Ansell and Travellion (1967), Giese *et al.*, (1967), Ansell (1972, 1974 a, 1974 b, 1974 c, 1974 d), Zwaan de and Zandee (1972), Dare and Edwards (1975), Tayler and Venn (1979) , Adachi (1979); Barber and Blake (1981). Thompson *et al.* (1974) and Bayne and Thompson, (1970), observed seasonal changes in carbohydrate, protein and lipid in gonad and digestive gland of *Mytilus edulis* and has suggested that digestive glands serve as an energy reserve and the reserves are transferred from digestive gland to the gonad during gametogenesis . Thompson (1977) studied the seasonal changes of carbohydrate, protein and lipid in the gonad and somatic tissues of giant scallop, *Placopecten magellanicus*. Seasonal changes in protein level in the adductor muscle of the clam *Tapes philippinarum* was studied by Adachi (1979) and he found that the protein level of adductor muscle decreased during the period of gonad maturation. Variations in biochemical components with reproduction of edible gastropod, *Turbo sarmaticus* was studied by McLachlan and Lombard (1980) and in their study it was observed that protein was the major component and it was negatively correlated with carbohydrate and lipid.. Shafee (1981) has studied the seasonal changes in the biochemical composition of black scallop *Chlamys varia*. Seasonal changes in protein, carbohydrate and

lipid in foot, gonad and digestive gland of the Turkey wing *Arca zebra* was examined by Sarkis (1993) and in the study it was observed that first gametogenic cycle in summer derived most of its energy from the utilization of stored total carbohydrate reserves accumulated over the winter months and pedal muscle protein was partially utilized as respiratory substrate as oocytes matured and energy demand increased.. Jeffrey *et al.* (2003) has observed seasonal variations of carbohydrate, protein and lipid in relation to gametogenesis in the Pacific oyster *Crassostrea gigas* and the biochemical composition (glycogen, protein and lipid) of separated gonad and somatic tissue were variable seasonally and annually. He also observed that gametogenesis was associated with increased gonad protein and glycogen and a decrease in lipid concentration. Role of lipid in gonadal development of the clam *Ruditapes decussatus* was studied by Delgado *et al.* (2004) and has found that content of total lipids in the soft tissues increased with sexual maturation.

Earlier studies in India were mainly concerned with the changes that occur in the composition and in calorific value through different seasons. Generally the whole body is subjected to the analysis with no separate consideration on the component body parts. Venkataraman and Chari (1951) studied the biochemical changes in edible oysters, and they found that for the

whole oyster meat the fat and protein content varied during different months. Durve and Bal (1961) studied biochemical changes in *Crassostrea gryphoides* and found that glycogen content was related to gonad development and increased during active gametogenesis, Salih (1975) reported that glycogen and protein content showed a steady fall during premonsoon period and an equally steady raise during the post-monsoon period while the trend was opposite in the case of fat in *Ostrea forskali.* Easterson and Kandaswami (1988) had studied biochemical changes with maturation in *Crassostrea madrasensis* and has found that visceral mass contained high protein and lipid during ripe, spent and indeterminate stages and less carbohydrate in maturing and ripe oysters Other works in oysters are that of Sarvaiya (1977) on *Crassostrea gryphoides*, Desai *et al.* (1979) in *C. cucullata* and Dharmaraj *et al.*, (1987) in *Pinctada fucata.* In all the studies correlation existed between biochemical changes and reproduction.

Biochemical studies on Indian mussels have shown that protein values were high in mature mussels and carbohydrate values were high in immature ones (Salih, 1975; Mane and Nagabhushanam, 1975; and Mohan and Kalyani, 1989). Biochemical composition and their seasonal changes of wood boring bivalves from Indian waters were also studied in detail (Nagabhushanam 1961;

Sreenivasan 1963; Sreenivasan and Krishnaswamy 1964; and Saraswathy and Nair 1969).

Among clams quite a number of works were done in recent years. Venkataraman and Chari (1951) studied the biochemical composition of *Meretrix casta*, Kasinathan (1964) on the fat of marine bivalves and Joshi and Bal (1965) on *Katelysia marmorata*. Rahman (1966) on *Donax cuneatus*, Krishnamurthi (1969) on various bivalve tissues, Suryanarayana and Alexander (1972) on nutritive value of few bivalve clams. Ansell *et al* (1973) on *Donax incarnates* and *D. spiculatum*, Nagabhushanam and Deshmukh (1974) on *Meretrix meretrix*, Salih (1975, 1979) on *Villorita cyprinoides*, *Meretrix meretrix*, *M. casta* and *Sunetta sp.*, Nagabhushanam and Dhamne (1957) on *Paphia laterisulca*, Sarvaiya (1977) on *Pitar erycina*, *Pinna vexillun*, *P. atropurpura*, *Solen truncates* and *Placenta placenta*, Nagabhushanam and Mane (1976) on Katelysia opima, Ansari *et al.* (1981) on *Villorita cyprinoides* and Balasubrahmanyan and Natrajan (1988) on *Meretrix casta*. In the above studies seasonal changes in biochemical composition is associated with reproduction, storage and utilization of reserves. The period of increase in biochemical constituents corresponds to gametogenesis and maturation of the gonad just before breeding.

Biochemical composition of the whole body of *Paphia malabarica* has been studied by Appukuttan (1993). He studied the changes in biochemical composition of *P. malabarica* of two size groups. So far no attempt has been made to study the changes in biochemical composition in different parts of the body in relation to reproduction in *P. malabarica.* In the present study, investigations on the changes in carbohydrate, protein and lipid in three organs *viz.*, gonad, adductor and digestive gland were studied in relation to reproductive stages.

5.1 MATERIALS AND METHODS

Materials for the study were collected during the period 2003- 2004 from Dharmadom estuary at monthly intervals. Microscopic observation was done and the clams were grouped into indeterminate, male and female and classified as maturing, mature and spent. The adductor, gonad and digestive gland from each clam was carefully taken and dried in hot air oven at 60° C for 24 hrs. The dried meat was minced and from this, weighed portions were taken for determination of biochemical constituents. A total of 210 clams were used for the study. The objective of the study was to find out the changes in biochemical constituents with reference to the reproductive stages.

5.11 Quantitative Determination of Protein

To estimate the protein in the gonad, digestive gland and adductor muscle, Folin -Ciocalteau Method (Lowry *et al.* 1951) was followed.

Protein reacts with Folin-Ciocalteau reagent to give a coloured complex. This colour is due to the reaction of carbomyl groups in the protein and potassium ions of the reagent. The colour is intensified by the reduction of phosphomolybdate by tyrosine and tryptophan present in the protein. The intensity of colour is thus related to the amount of protein sample. 10mg of dried and finely powdered tissues of gonad, digestive gland, adductor muscle from different reproductive stages like indeterminate, maturing, mature and spent were precipitated with 2ml deproteinising agent, 10 % tri chloro acetic acid (TCA) by keeping the tubes in ice. All samples were centrifuged at 3000 rpm for 15 minutes. The supernatant obtained in the individual tube was used for carbohydrate estimation. The protein precipitate in each tube was dissolved in 5 ml of 1N NaOH. Three aliquots each with 0.1 ml solution were used as samples. To this 0.4 ml of double distilled water was added and each sample was made upto 0.5 ml. To this 0.5 ml solution, freshly prepared 5 ml alkaline mixture (48 ml of 2 % Na_2CO_3 in 0.1 N NaOH + 1 ml of 0.5 % copper sulphate in 1 % of sodium potassium tartarate) was added and kept at room temperature

for 10 minutes. After 10 minutes, 0.5 ml of Folin reagent (dilute the 2N stock solution with double distilled water) was added and mixed well immediately.

A standard stock solution was prepared using bovine serum albumin crystals at a concentration of 25 mg/ 5 ml 1 N NaOH. Different dilutions in the range of 0.25 to 2.5 mg/ml were prepared from this stock solution and the alkaline mixture and Folin-phenol reagent were added as in the case of tissue samples. A blank was prepared with 0.5 ml double distilled water and treated the same as above.

All the test tubes were kept at room temperature for 30 minutes. After 30 minutes the samples were read for the optical density of the blue colour developed, in a spectrophotometer at 660 nm wavelength against the blank. The protein content of the tissue sample was expressed as mg protein/10 mg dry tissue.

5.12 Quantitative Determination of Carbohydrate

The phenol sulphuric acid method of Dubois *et al.* (1956) was followed to estimate the total carbohydrate in samples.

The supernatant obtained during protein estimation procedure was used for the analysis. From the above supernatant, 0.1 ml was taken and made up to 1 ml with saturated solution of benzoic acid in double distilled water and to

this solution; 1ml of sulphuric acid was added rapidly to each tube and mixed well using a cyclomixer.

A standard solution was prepared using D-glucose (Concentration – 20 mg/100 ml saturated solution of benzoic acid). Different dilutions of the working solution with concentration of glucose ranging from 10 to 100 µg/ ml were prepared and the procedure followed.

All the tubes were kept for 30 minutes at 30°C and the optical density of the orange colour developed was measured at a wave length of 490 nm.

5.13 Quantitative Determination of Total Lipids

The total lipids were quantitatively determined by the sulphophosphovanillin method of Barnes and Blackstock (1973).

About 10 mg of adductor muscle and gonad and 5 mg of digestive gland samples were separately homogenized well in 2 ml of chloroform: methanol (2: 1 V/V) and kept overnight at 4° C for complete extraction. The mixture taken in glass stoppered centrifuge tubes was then centrifuged for 15 minutes at 300 rpm. The clear supernatant containing all lipids was transferred to clean, dry glass tubes. 0.5 ml of the lipid extract of all the tissues were taken separately in clean glass tubes and dried in vacuum over silica gel in a desiccator. To each dried sample, 0.5 ml concentrated sulphuric acid was added and shaken well. The tubes were then plugged with non-absorbent

cotton wool and heated at 100°C in boiling water bath exactly for 10 minutes. The tubes were rapidly cooled to room temperature under running tap water. To 0.1 ml of this acid digest, 2.5 ml of phosphovanillin reagent was added and mixed well by dissolving 80 mg of cholesterol in 100 ml of chloroform : methanol (2:1 V/V) mixture (equivalent to 100 mg of total lipid in 100 ml (2:1 V/V) chloroform : methanol mixture). Working solutions of different concentrations were prepared from stock solution in the range 50 to 500 µg / 0.5 ml and the procedure adopted for the tissue samples were followed. 0.5 ml of 2:1 V/V chloroform: methanol mixture was treated as blank. All the tubes were kept at room temperature for 30 minutes. The intensity of the pinkish red colour developed was measured against the blank at 520 nm.

The optical density of the colour developed for total proteins, carbohydrates and lipids were measured using a UV/VS Spectrophotometer (GBC 911 A) with the samples taken in silica cuvettes. Standard graphs were plotted with the concentration of each biochemical parameter in different dilutions of the working standard solution in the X-axis and optical density (O.D) in the Y- axis. The concentration of different parameters in the samples were calculated (in mg %) by comparing the optical density obtained for the sample with the values in the standard graph and also using the formula,

$$\frac{\text{(O.D. of the sample – O.D. of the blank)}}{\text{(O.D of the standard – O.D of the blank)}} \times \frac{\text{Concentration of Standard X 100}}{\text{Weight of the sample (mg)}}$$

Statistical Analysis

Data on the difference in biochemical constituents such as carbohydrate, protein and lipid with respect to sex, tissue and stage of gonad maturity were analysed through a Multivariate Analysis with SPSS 13.0 computer software.

5.2 RESULTS.

5.21 Biochemical Changes in adductor muscle:

The concentration of protein, carbohydrate and lipid in the adductor muscle of indeterminate, maturing, mature and spent clams are given in Table 5.1. The protein concentration in indeterminate was 13.41 mg %. In male clams the protein concentration ranged from 8.89 to 22.81 mg %, with a low value in the mature stage. In female clam also the values ranged from 6.72 to 27.49 mg %, in maturing, mature and spent, with low values of protein in the mature ones. Higher values of protein in the adductor were observed in both sexes in the spent stage.

The carbohydrate concentration in indeterminate was 9.74 mg % in the adductor muscle. In male clams the carbohydrate value ranged from 12.91 to

38.73 mg % and in female it ranged from 11.91 to 28.28 mg %. In both the sexes lowest value were found in the mature stage. Carbohydrate concentration in adductor was more in the maturing phase of the clam.

The lipid concentration indeterminate was found to be 1.24 mg %. In male clams the lipid concentration varied between 0.81 to 2.11 mg % and in females it ranged from 0.60 to 6.01 mg %. The lipid concentration in the adductor was more in females when compared with the males. In both sexes the lipid concentration was more in the maturing phase.

The protein, carbohydrate and lipid concentration in the samples of adductor tissue were analysed using MANOVA technique. It was found that the stages were significantly different at 1 % level and R^2 was 0.683, 0.740 and 0.607 for protein, carbohydrate and lipid respectively (Table 5.2). Further the data was subjected to Tukey's test to find out the difference between the stages and it was found that in case of protein there was significant difference between indeterminate, maturing, mature and spent clams. In case of carbohydrate, concentration, it was significantly different in indeterminate, maturing, mature and spent stages. Spent stages were significantly different from indeterminate and mature but there was no significant different between

spent and maturing clam carbohydrate concentration in the adductor muscle. In case of lipid concentration, maturing stage was significantly different from indeterminate, mature and spent stages. There were no significant differences in the lipid concentration in adductor muscle in other three stages.

5.22 Biochemical changes in Gonad

The concentration of protein, carbohydrate and lipid in the gonad of indeterminate, maturing, mature and spent clams are given in Table 5.1. The protein concentration in indeterminate was 9.25 mg %. In male clams the protein concentration ranged from 7.35 to 20.19 mg %, with a low value in the maturing stage. In female clam the values ranged from 7.51 to 24.06 mg % in maturing, mature and spent, with low values of protein in maturing stage. Higher values of protein in the gonad were observed in both sexes in the mature stage.

The carbohydrate concentration in indeterminate was 24.78 mg % in the adductor muscle. In male clams the carbohydrate value ranged from 15.52 to 45.86 mg % and in female it ranged from 14.71 to 48.50 mg %. In both the sexes lowest values were found in the mature stage. High values of carbohydrate were observed in maturing stage of both sexes.

The lipid concentration in indeterminate was found to be 1.14 mg %. In male clams the lipid concentration varied between 1.48 to 18.11 mg % and in females it ranged from 1.12 to 10.05 mg %. The lipid concentration in the gonads of both sexes was low during maturing stage and more in the mature phase.

The protein, carbohydrate and lipid concentration in the samples of gonad tissue were analysed using MANOVA technique. It was found that the stages were significantly difference at 1 % level and R^2 was 0.738, 0.892 and 0.796 for protein, carbohydrate and lipid respectively (Table 5.3). Further the data was subjected to Tukey's test to find out the difference between the stages and it was found that in case of protein there was significant difference between indeterminate and mature, indeterminate and spent stages. There was also significant difference between maturing, mature and spent stages. In case of carbohydrate concentration there was significant difference in all the four stages. In case of lipid concentration, indeterminate stage was significantly different from mature and spent stages. There was significant difference between maturing and mature and maturing and spent stages. Lipid concentration in gonad tissues of mature and spent was also significantly different.

5.23 Biochemical Changes in Digestive gland

The concentration of protein, carbohydrate and lipid in the adductor muscle of indeterminate, maturing, mature and spent clams are given in Table 5.1. The protein concentration (mg %) in indeterminate was 10.85. In male clams the protein concentration ranged from 6.89 to 10.05, with a low value in the maturing stage. In female clam the values ranged from 7.37 to 7.99, in maturing, mature and spent. Higher values of protein in the digestive gland were observed in mature stage in male, but not much variation was observed in female tissue.

The carbohydrate concentration in indeterminate was 15.29 mg % in the digestive gland. In male clams the carbohydrate value ranged from 3.01 to 10.98 mg % and in female it ranged from 5.06 to 14.72 mg %. In both the sexes lowest value were found in the mature stage. Carbohydrate concentration in digestive gland was more in the maturing phase of the clam with high values in female clams than the male clams.

The lipid concentration in indeterminate was found to be 1.44 mg %. In male clams the lipid concentration varied between 1.17 to 1.83 mg % and in females it ranged from 1.16 to 1.90 mg %. The lipid concentration in the

digestive gland was more or less same in both sexes. In both sexes the lipid concentration was more in the mature phase.

The protein, carbohydrate and lipid concentration in the samples of digestive gland tissue were analysed using MANOVA technique. It was found that the stages were significantly different at 1 % level and R^2 was 0.389, 0.606 and 0.404 for protein, carbohydrate and lipid respectively (Table 5.4). Further the data was subjected to Tukey's test to find out the difference between the stages and it was found that in case of protein there was significant difference between indeterminate, maturing, mature and spent clams. There was no significant difference between maturing and spent stages. In case of carbohydrate, indeterminate stage was significantly different from mature and spent stages. The maturing stage was significantly different from mature. There was significant difference between the mature all the other three stages. Spent stages were significantly different from indeterminate and mature but there was no significant different between spent and maturing clam carbohydrate concentration in the digestive gland. In case of lipid concentration, mature stage was significantly different from indeterminate, maturing and spent stages. There were no significant differences in the lipid concentration in digestive gland in other three stages.

The mean protein, carbohydrate and lipid concentrations in the four stages in adductor, gonad and digestive gland are given in Fig 5.1, 5.2 and 5.3 respectively.

5.3 DISCUSSION

The present study shows that there is significant difference in the protein, carbohydrate and lipid concentrations in adductor, gonad and digestive gland in indeterminate, maturing, mature and spent stages of clam *P. malabarica*. The protein concentration in adductor muscle showed variations with the maturing stages. The protein level showed a decrease in the mature clams and it increased in the spent and maturing stages. Adachi (1979), also observed that in clam *Tapes phillippinarum*, the protein level decreased in adductor muscle, coincided with the gonad maturation. Nagabhushanam and Mane (1976) observed that increase in protein in gonad free tissues during maturation was due to increase in nonprotein nitrogen. But in *Crassostrea madrasensis* the protein content in adductor muscle did not show much variation with reproduction (Easterson and Kandaswami 1988). Giese *et al.*, (1967) observed that tissue protein level remained constant through out the year in pismo clam *Tivela stultorum* and they concluded that the nutritional reserves are accumulated for gametogenesis independently of other body

components. Hence it appears that adductor muscle protein level is closely related to maturation process than the spawning itself. Sarkis (1993) when studying the biochemical composition of *Arca zebra*, has observed that in pedal muscle the protein level decreased during spawning and suggested utilization of proteins at this time. In *Paphia malabarica* the protein level in adductor has decreased considerably in mature stage and it seems to be that the changes in protein level could be species specific among molluscs (Adachi 1979).

The carbohydrate level of adductor muscle in indeterminate clams were low and it increased to a maximum in the maturing phase, declined in the mature phase or at the time of spawning and again increased in the spent stage. Durve and Bal (1961) in *Crassostrea gryphoides*, Joshi and Bal (1965) in *Katleysia marmorata* and Nagabhushanam and Deshmukh (1974) in *Meretrix meretrix* found that carbohydrate content was related to gonad development and increased during maturation. Thompson (1977) has also observed that carbohydrate content in tissues other than gonad increased during maturation phase. Probable reason for low level of carbohydrate in mature *P. malabarica* could be that the carbohydrate is accumulated in the adductor muscle during pre spawning season and it is utilized during spawning

The lipid concentration in the adductor was found to vary with the maturation. The lipid concentration in the adductor of mature clams was higher than the other three stages. Similar results were obtained by Giese (1966) who observed that in molluscs in general, lipid concentration in the body components is high in mature stage. Easterson and Kandaswami 1988, has observed similar trend in the lipid concentration in oyster *Crassostrea madrasensis*. The accumulation of lipid as energy reserve could be one of the reason for high lipid concentration in mature clams.

The protein concentration in gonad showed fluctuations with the maturity stages. The protein values were high in the mature clams and it was low in the maturing and indeterminate stages. The above results agree with those of Thompson (1977) who has observed that in scallop *Placopecten magellanicus*, the gonad protein is high in the mature stages. High protein concentration in gonad in clam *Meretrix casta* was also reported by Balasubramanyan and Natarajan (1988 a) and by Easterson and Kandaswami (1988) in *C. madrasensis* and Rivonker and Parulekar (1995) in *Perna viridis*. Nagabhushanam and Mane (1976), has observed that in *Katelysia opima*, the gonad protein showed variations with maturation and high values were obtained in the mature gonads. The protein may be accumulated as an energy

reserve in mature gonad when the carbohydrate concentration declines to meet the energy requirement, which could be the probable reason for high protein value in mature gonads.

The carbohydrate concentrations in the gonad of *P. malabarica* also showed fluctuations with the maturation. The highest value was found in the maturing stages and there was a drastic decline in carbohydrate concentration in the mature stage. Galtsoff (1964).has noted that in oysters glycogen is the reserve material and during the rapid proliferation of sex cells the reserve supply is used in the gonad and brings the glycogen content to its minimum. After a short period of relative inactivity during which the unspawned cells are reabsorbed, the oyster begins to accumulate and store glycogen in their tissues. In *Paphia malabarica* also similar trend in the utilization of carbohydrate in gonad is observed. The carbohydrate concentration in gonad tissue in *P. malabarica* reaches its peak in the maturing stage and declines in the mature stage. This conclusion is supported by studies on *K. opima* (Nagabhushanam and Mane 1976), giant scallop, *Placopecten magellanicus* (Thompson 1977), *Crassostrea madrasensis*, (Easterson and Kandaswami 1988) and Pacific oyster *Crassostrea gigas* (Jeffrey et al., 2003). Utilization of carbohydrate in

gametic tissue formation could be the reason for decline in carbohydrate in mature clams.

The lipid concentration in the gonad in indeterminate and maturing stage did not vary much, but gradually increased reaching a high in the mature stage and then it decreased in the spent stage. Nagabhushanam and Mane (1976) has also observed high lipid content in gravid clams. Similar trend in lipid concentration was also reported by Thompson (1977), in *Placopecten magellanicus.* The increase in dry body weight in the mature stage in Scallop *Chlamys varia* is attributed to the accumulation of protein and lipid reserves in the gonad (Shafee 1981). Balasubramanyan and Natarajan (1988) also observed high lipid values in the mature stages of clam *Meretrix casta* and in *Crassostrea madrasensis* by Easterson and Kandaswami, (1988). In *P. malabarica* the lipid was accumulated in the mature gonad as an energy reserve which could be the reason for high lipid concentration that phase.

Only slight variations in the protein concentrations were observed in the digestive gland in different maturation stages. The protein concentration in digestive gland of indeterminate stage was comparatively high when compared to the other three stages. There was no significant difference between the spent and maturing phase. The digestive gland could possible play the role in storage

of metabolic energy reserves (Bayne and Thompson, 1970). Lawrence et al., (1965) and Sastry (1966) have postulated a flow of reserves from digestive gland into gonad during gametogensis in Chiton *Katharina tunicate* and the bivalve *Aequipecten irradians*. More substantial work in support of this hypothesis is provided by Vassallo (1973).

The carbohydrate concentration in digestive gland also showed a similar trend as that of protein in four stages. In *P. malabarica* there could be accumulation of carbohydrate in the digestive gland in maturing phases as an energy reserve and these reserves are transferred to the gonad when the carbohydrate in the gonad is utilized for gamete formation. This could be the reason for decline in carbohydrate in the digestive glands in mature clams. This observation in *P. malabarica* is supported by similar works in bivalve *Mytilus edulis* by Gabbot and Bayne (1973) and Thompson *et al.* (1974).

Lipid in the digestive gland showed significant variation in the mature stage; however there was no significant difference in the other three stages. The probable reason could be that lipid is synthesized and stored in the digestive gland when the carbohydrate content is low. Similar observations were made by Bayne (1976) and Thompson *et al.* (1974) in *Mytilus edulis*.

Marked variations in the biochemical constituents were observed in the four reproductive stages of *P. malabarica*. In conclusion, the biochemical composition of *P. malabarica* follows a cycle of somatic growth and reproduction. In general it can be stated that marine invertebrates store reserves of both lipids and glycogen. In some glycogen may be stored in considerable amounts at least in certain tissues. In others it may be insignificant, in which case lipids may be present in quantity at least in some tissues. Glycogen is generally considered a reserve for immediate use by tissues; while lipid is generally considered reserve for use in adverse condition. Protein is generally present in all tissues and may be used when need arises. Analysis of biochemical composition is useful, for the identification of seasonal patterns of metabolism, to determine the nature, quantity and site of energy reserves and also to understand its role in gametogenesis. In addition to that seasonal and stage wise variations in the biochemical composition of the clam gives a clue of the proximate composition of the meat and helps in the development of management strategies for exploitation from the wild as well as from the farms.

Table 5.1: Protein, Carbohydrate and Lipid (mg %) in different reproductive stages of *P. malabarica*

Sex	Body Part	Stage	Protein (mg %)	Carbohydrate (mg %)	Lipid (mg %)
Indeterminate	Adductor	Id	13.41	9.74	1.24
	Gonad	Id	9.25	24.78	1.14
	Digestive gland	Id	10.85	15.29	1.44
Male	Adductor	Maturing	13.41	38.73	2.11
		Mature	8.89	12.91	0.82
		Spent	22.81	38.36	0.81
Female	Adductor	Maturing	27.49	28.28	6.01
		Mature	6.72	11.91	0.96
		Spent	26.14	26.80	0.60
Male	Gonad	Maturing	7.35	45.86	1.48
		Mature	20.19	15.52	18.11
		Spent	10.22	26.84	10.09
Female	Gonad	Maturing	7.51	48.50	1.12
		Mature	24.06	14.71	10.05
		Spent	20.46	27.65	7.56
Male	Digestive gland	Maturing	6.89	10.86	1.36
		Mature	10.05	3.01	1.83
		Spent	7.85	10.98	1.17
Female	Digestive gland	Maturing	7.99	14.72	1.16
		Mature	7.56	5.06	1.90
		Spent	7.37	10.98	1.17

Id = Indeterminate

Table 5.2: Multivariate analysis (Test of between - subjects effects) of adductor muscle.

Source	Dependent Variable	Type III Sum of squares	df	Mean Square	F	Significance
Corrected Model	Protein	0.568 [a]	3	0.189	90.79	0.000
	Carbohydrate	1.429 [b]	3	0.476	119.29	0.000
	Lipid	0.026 [c]	3	0.009	65.49	0.000
Intercept	Protein	3.162	1	3.162	1516.6	0.000
	Carbohydrate	5.621	1	5.621	1407.6	0.000
	Lipid	0.031	1	0.031	236.056	0.000
Stage	Protein	0.568	3	0.189	90.79	0.000
	Carbohydrate	1.429	3	0.476	119.29	0.000
	Lipid	0.026	3	0.009	65.49	0.000
Error	Protein	0.254	122	0.002		
	Carbohydrate	0.487	122	0.004		
	Lipid	0.016	122	0.000		
Total	Protein	4.463	126			
	Carbohydrate	9.072	126			
	Lipid	0.080	126			
Corrected Total	Protein	0.822	125			
	Carbohydrate	1.916	125			
	Lipid	0.042	125			

a. R Squared = 0.691 (Adjusted R Squared = 0.683)
b. R Squared = 0.746 (Adjusted R Squared = 0.740)
c. R Squared = 0.617 (Adjusted R Squared = 0.607)

Table 5.3: Multivariate analysis (Test of between - subjects effects) of gonad

Source	Dependent Variable	Type III Sum of squares	df	Mean Square	F	Significance
Corrected Model	Protein	0.444 [a]	3	0.148	114.76	0.000
	Carbohydrate	1.923 [b]	3	0.641	335.52	0.000
	Lipid	0.374 [c]	3	0.125	158.49	0.000
Intercept	Protein	2.093	1	2.093	1621.35	0.000
	Carbohydrate	9.447	1	9.447	4943.72	0.000
	Lipid	0.458	1	0.458	581.70	0.000
Stage	Protein	0.444	3	0.148	114.76	0.000
	Carbohydrate	1.923	3	0.641	335.52	0.000
	Lipid	0.374	3	0.125	158.49	0.000
Error	Protein	0.158	122	0.001		
	Carbohydrate	0.233	122	0.002		
	Lipid	0.096	122	0.001		
Total	Protein	3.114	126			
	Carbohydrate	12.87	126			
	Lipid	1.098	126			
Corrected Total	Protein	0.602	125			
	Carbohydrate	2.156	125			
	Lipid	0.470	125			

a. R Squared = 0.738 (Adjusted R Squared = 0.732)
b. R Squared = 0.892(Adjusted R Squared = 0.889)
c. R Squared = 0.796 (Adjusted R Squared = 0.791)

Table 5.4: Multivariate analysis (Test of between - subjects effects) of Digestive gland

Source	Dependent Variable	Type III Sum of squares	df	Mean Square	F	Significance
Corrected Model	Protein	0.016 [a]	3	0.005	25.86	0.000
	Carbohydrate	0.207 [b]	3	0.069	65.16	0.000
	Lipid	0.001 [c]	3	0.000	29.30	0.000
Intercept	Protein	0.864	1	0.864	4130.06	0.000
	Carbohydrate	1.329	1	1.329	1253.18	0.000
	Lipid	0.022	1	0.022	1688.29	0.000
Stage	Protein	0.016	3	0.005	25.86	0.000
	Carbohydrate	0.207	3	0.069	65.16	0.000
	Lipid	0.001	3	0.000	29.30	0.000
Error	Protein	0.026	122	0.000		
	Carbohydrate	0.129	122	0.001		
	Lipid	0.002	122	0.000		
Total	Protein	0.922	126			
	Carbohydrate	1.624	126			
	Lipid	0.028	126			
Corrected Total	Protein	0.042	125			
	Carbohydrate	0.337	125			
	Lipid	0.003	125			

a. R Squared = 0.389 (Adjusted R Squared = 0.374)
b. R Squared = 0.616 (Adjusted R Squared = 0.606)
c. R Squared = 0.419 (Adjusted R Squared = 0.404)

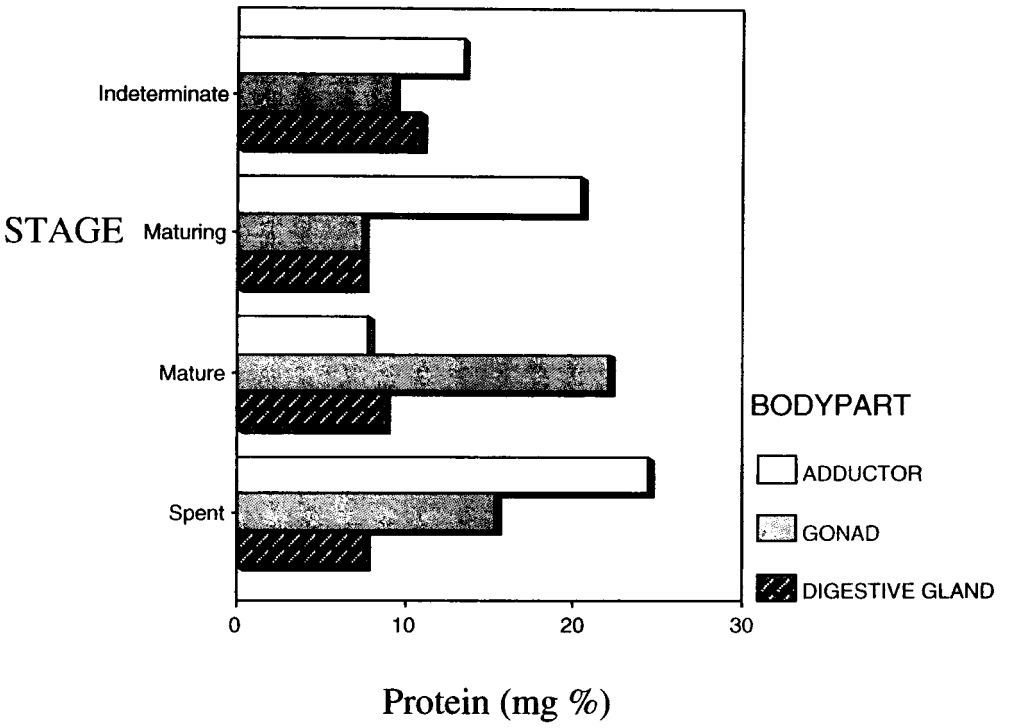

Fig 5.1: Mean Protein (mg %) in different organs in the four reproductive stages of *P. malabarica*

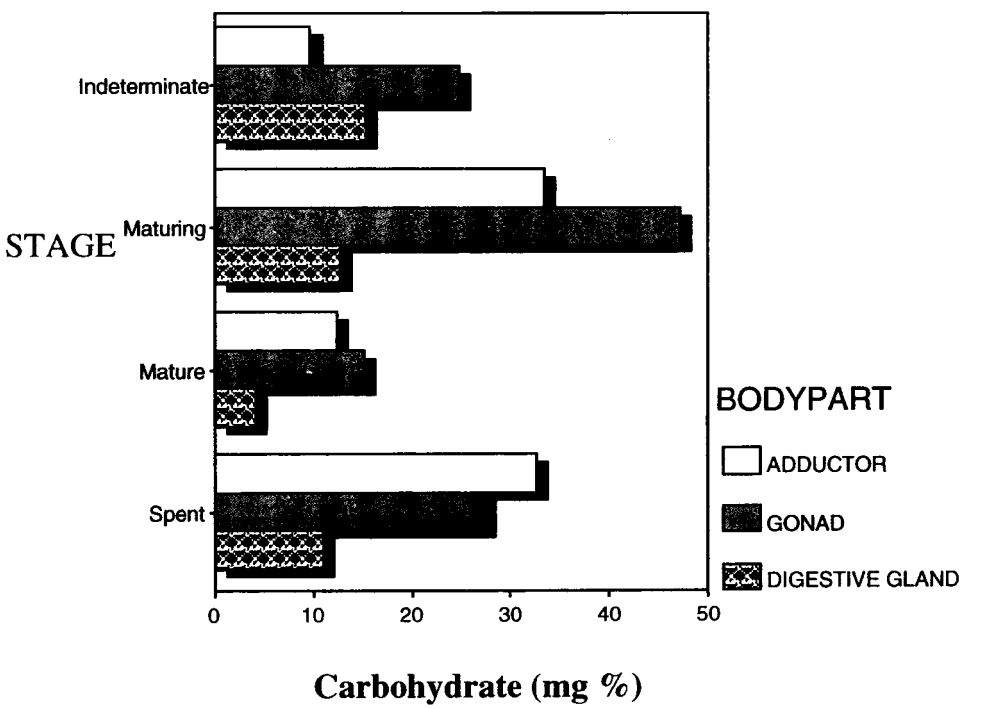

Fig 5.2: Mean Carbohydrate (mg %) in different organs in the four reproductive stages of *P. malabarica*

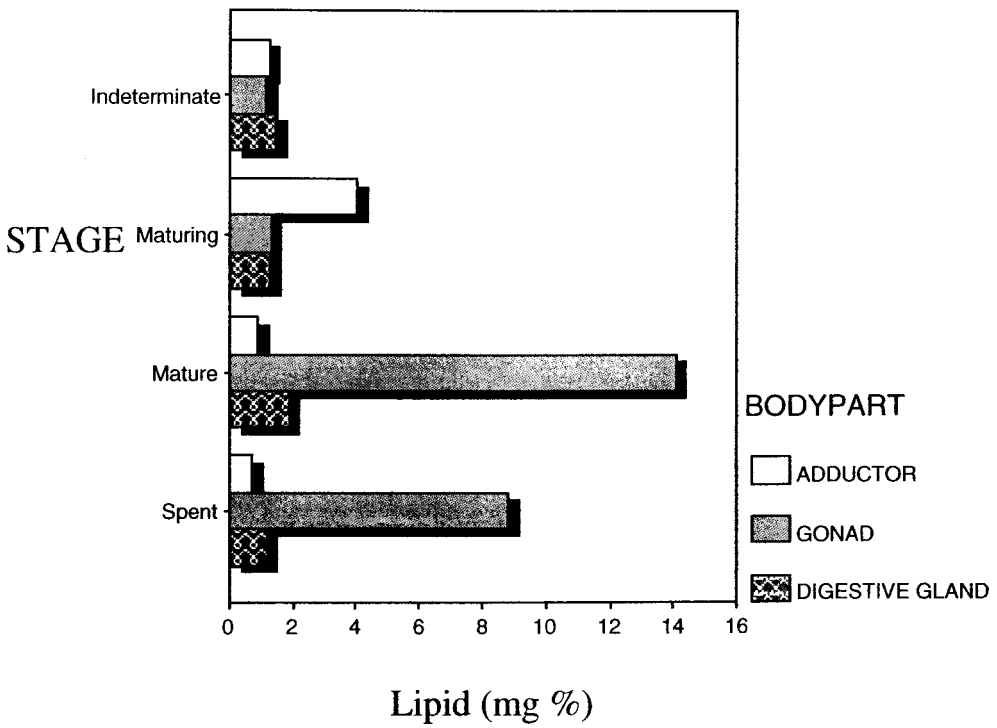

Fig 5.3: Mean Lipid (mg %) in different organs in the four reproductive stages of *P. malabarica*

Fishery and Population Dynamics of Paphia malabarica

Sujitha Thomas “Studies on some aspects of biology and population dynamics of short neck clam paphia malabarica (chemnitz) in Dharmadom Estuary, North kerala, Southwest coast of India ”, Department of Zoology, University of Calicut, 2007

Chapter VI

Fishery and Population Dynamics of *Paphia malabarica*

World clam and cockle production have been increasing steadily, the production of 988 m. t in 1991, showed fluctuations over the years and was estimated at 799 m.t in 2002. In this, *Paphia* spp. contributed 5.4 % to the total production (FAO, 2003) (Fig 6.1). The landings in major clam producing countries, *viz.*, Japan, U.S.A and Europe, remain almost steady and thus it could be assumed that fishery from natural bed alone cannot meet the increasing demand. Suitable farming practices are to be stimulated to augment production. The average annual production of edible bivalves in India during 1996-2000 was estimated as 1.52 lakh tonnes, which is more than the average landings during the period prior to 1996 (Kripa and Appukuttan 2003). Among the exploited bivalve resources of India, clams are by far, the most widely distributed and abundant and they support sustenance fisheries in most of the estuaries and backwaters of Kerala, Karnataka, Goa, Tamilnadu and Andhra Pradesh. One of the major drawbacks in evolving suitable bivalve fishery management is that there is no proper data base for the bivalve resources and

fishery landing. A proper database on the resource availability, fishers and its utilization pattern are required to augment production.

The important works on clam fishery of India are those of Alagarswami and Narasimham (1973), Rasalam and Sebastian (1976), Rao (1984), Rao and Rao (1985), Appukuttan *et al.* (1985, 1988), Joseph *et al.* (1987), Rao *et al.* (1989), Narasimham *et al.* (1993), Kripa and Mathew (1993) and Kripa and Appukuttan (2003).

The status of bivalve fishery ranges from under exploitation in the northwest and northeast coasts to overexploitation in the southern maritime states. The important species of clams that are being exploited from India on sustenance or higher levels are *Villorita cyprinoides*, *Meretrix meretrix*, *M. casta*, *Paphia malabarica*, *Marcia opima*, *Donax cuneatus*, *Mesodema* sp., *Sunetta scripta* and *Anadara granosa*. Bivalves fished along the west coast are utilized for human consumption. Some bivalve products like frozen, smoked, dried and pickled meat are of good demand in metro cities and international market. In Kerala and Andhra Pradesh part of the clam landings are used as major ingredient of shrimp feed. The extensive shrimp farms also use dried and boiled clam meat as shrimp feed. Apart from these, the shells of bivalves are used in manufacture of cement, sand bricks and lime treatments of effluents etc. Along the west coast, with an estimated landing of 52,537 tonnes of clams,

Kerala accounts for 47 % of the total landing of clam and cockles (Kripa and Appukuttan, 2003). Vembanad and Ashtamudi lakes in Kerala are the two main estuarine systems which have well organized clam fishery. Vembanad Lake is known for black clam *Villorita cyprinoides* and Ashtamudi Lake for short neck clam *Paphia malabarica* and their fishery showed wide fluctuations based on the export demand. Along the north Kerala, clams are of great demand in local market. Estuaries where major exploitation is being done are Chaliyar, Korapuzha, Moorad, Dharmadom and Azhithala (Valiaparamba).

Important species exploited are *Meretrix casta*, *Paphia malabarica* and *Villorita cyprinoides*. Of this, *P. malabarica* contribute more than 40 % of the export from India. Indiscriminate fishing of clams in many estuaries along the coast of India has resulted in reduction of these resources. Till now, no work has been initiated along the Malabar Coast (North Kerala) to study the fishery and population dynamics of *P. malabarica*. The present study of fishery and population dynamics of *P. malabarica* is thus essential for stock assessment and to formulate policies for judicious exploitation as well as for the conservation of this resource along the coast.

The *Paphia malabarica* bed extends from the bar mouth up to 700 m from sea. The bed is exploited through out the year, except when the environmental conditions are not favourable to venture into the estuary.

In order to develop appropriate management strategies for exploitation of this species, a need was felt to study its population dynamics (age and growth) and stock assessment in Dharmadom estuary.

Population dynamics of bivalves are studied world wide to suggest management options. The determinate growth model most commonly applied to bivalves is the von Bertalanffy growth curve (Brousseau 1979, Appeldoorn, 1983, Jones *et al.,* 1990). This model which has only three parameters is generally applicable and not computationally difficult and is used world wide for bivalve age and growth studies (Brousseau 1979; Appeldoorn, 1983; Jones *et al.,* 1990; Landry *et al.*, 1993: Walker and Heffernan 1994; Urban, 1996; Devillers *et al.*, 1998). A common characteristic of determinate models is that organisms approach an asymptotic size in a finite period.

Population and fishery dynamics of ocean quahog was studied by Murawski *et al.*, (1989). Growth and mortality of *Mercenaria mercenaria* in Prince Edward Island was studied by Landry *et al.* (1993), and population dynamics of *Venus antique* by Urban (1996). Population dynamics of bivalve *Corbicula fluminea* was studied by Cataldo and Demetrio (1998) in Argentina waters and Lyon waters (France) by Mouthon (2001) and Morgan *et al.* (2003). Juarez and Bernal (1994) studied the growth of Pismo clam (*Tivela stultorum*) based on age length data using von Bertalanffy growth model. Age and growth

studies of *Venus verrucosa* (Bivalvia) was studied by Arneri *et al.*, (1998). Growth and production of the venerid bivalve *Eurohomalea exalbida* were studied by Lomovaskya *et al.*, (2002). Population dynamics of *Donax trunculus* was studied by Zeichena *et al.*, (2002). Population structure, growth and production of surf clam *Donax serra* were studied by Laudien *et al.*, (2003).

From Indian waters, age, growth and stock assessment of clams have been studied by some workers in different estuaries. Important studies on the age and growth of bivalves are of *Paphia undulata* (Winckworth, 1931); *Mytilus viridis* (Paul, 1942); *Ostrea madrasensis* (Paul, 1942); *Katelysia opima* (Rao, 1951a; Mane, 1974a and Kalyanasundaram and Kasinathan, 1983), *Meretrix casta* (Abraham, 1953; Durve, 1970; Salih 1973; Sreenivasan, 1983b; Balasubramayan and Natrajan, 1988a and Rao, 1988), *Pinctada pinctada* (Gokhale *et al.*, 1954); *Donax cuneatus* (Nayar 1955; Talikhedkar *et al.*, 1976); *D. faba* (Alagarswami, 1966); *Perna indica* (Kuriakose, 1973), *Villorita cyprionoides* (Harkantra, 1975 and Nair, 1975) *Donax incarnates* (Nair *et al.*,1978), *Paphia laterisulca* (Mane and Nagabhushanam, 1979), *Meretrix meretrix* (Jayabal and Kalyani, 1986). Maruthamuthu *et al.* (1992) studied the age and growth of estuarine clam *Sunetta scripta* from Vellar estuary. Narasimham (1988) studied the population dynamics of *Anadara granosa* from

Kakinada Bay, Rao (1988) and Appukuttan *et al.* (1999) of *Paphia malabarica* from Mulky and Ashtamudi estuary respectively. However, no information is available about the age and growth or stock of any clam species from North Kerala, and in order to fill this gap, the present study was taken up. Caddy (1989) while studying the population dynamics of scallop fishery, reviewed current developments and future possibilities of research on the dynamics of molluscan population and suggested that the well known yield-per-recruit model of Beverton and Holt (1957) could be used in assessing the likely effect of different size limits and fishing intensities of fishery. It is assumed that self replenishing populations of clams have advantage of free swimming larval life of approximately one to two months, permitting a uniform dispersal and settlement in the fishing area. Considering these factors, in the present study, the stock assessment models used for population dynamics were applied in arriving at basic stock assessment parameters. The study of age, growth, survival and mortality, longevity and maximum sustainable yield are required for the judicious exploitation of the resources. The age and growth of *Paphia malabarica* were studied by continuous sampling of the population and analyzing the changes in size frequency distribution. The growth pattern thus obtained was applied in a mathematical form using von Bertalanffy's growth (VBG) equation (Bertalanffy, 1938).

6.1 MATERIALS AND METHODS

6.11 Fishery: Clam samples were taken at fortnightly intervals from the landings in and around Dharmadom during the period December 2003 to November 2004. Collections were done during the low tide when the fishery was at its peak. On the observation day, the total catch per canoe was recorded. Number of fishermen involved in fishing and number of fishing days also were estimated on that day. Pooling the estimates for the observation days and raising to the total number of fishing days in that month gave catch and effort data for the month. The biomass in three stations was also estimated. Biomass estimation was done by taking random sample of *Paphia malabarica* from 6 substations in three stations, using transect method. A 25 x 25 cm metal square was used to collect sample from unit area in each substations. The mean number and weight per sq. m of samples from each station were calculated, pooled and used in estimating the clam biomass of the bed (Rao *et al.*, 1989).

6.12 AGE AND GROWTH

Age and growth of *P. malabarica* were estimated based on the length-frequency distribution data collected during the period of study. For getting the length-frequency data, the sample collected from an unit area by transect method was pooled and sub-sample was taken for estimation of length frequency. The total number of clams used for the age and growth study was

3,711. Vernier caliper with 0.01mm accuracy was used for measuring the total length of the clam (in anterio-posterior axis). The length-frequency data were grouped into 3 mm class intervals. The length-frequency distribution in the sample was raised to the total catch on the sampling day based on the sample weights. The data thus obtained for different sampling in a month were pooled to get catch in numbers for all the sampling days which in turn, were raised to the monthly catch. The basis of the growth study is the growth equation formulated by von Bertalanffy (1934).

Length frequency of clams coming in the commercial catches was also estimated from the collections made from local market. Fortnightly samples collected were combined for each month and the length frequency estimated.

6.13 Growth equation

von Bertalanffy (1934) developed a mathematical model (von Bertalanffy Growth Formula-VBGF) for individual growth which has been shown to conform to the observed growth of most of the fishery resources. The VBG equation is based on the concept of growth as a net result of the interaction of two opposite processes such as those tending to increase the mass (anabolism), and those tending to decrease it (catabolism), thus letting the growth curve fit well with the growth rates of many species of organisms

(Beverton, 1954; Beverton and Holt, 1957). Bivalves also appear to conform to the typical growth pattern of a sigmoidal growth form as in other fishes (Urban, 1996). This mathematical model expresses the length, L as a function of the age of the fish or clam, t.

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right]$$

where,

L_t = length at age t

L_∞ = asymptotic length, or the maximum length that the clam can theoretically attain

e = base of the Naperian or natural log,

K = curvature parameter (other-wise known as coefficient of catabolism or growth coefficient), the rate at which the fish or clam approaches asymptotic length,

t = age of clam,

t_O = age at which length of fish or clam is theoretically zero.

6.14 Growth parameters

The length-frequency data were analysed using the ELEFAN I module of FiSAT software (2.1) (Gayanilo and Pauly, 1997) without prior

decomposition of data and also through modal progression analysis after decomposition of multi-cohort samples into their component distributions.

The step-wise details of the analysis are given below:

1. Estimate of L_∞ and Z/K were made using the Powell-Wetherall method (Wetherall, 1986; Pauly, 1986)
2. The growth parameters were estimated using the ELEFAN I programme in the FiSAT software by identifying the best fit to the peaks.
3. L_∞ and K were used as input to the catch curve analysis.
4. The resultant catch curve was estimated following the procedure recommended by Pauly (1986). This routine smoothens a set of probability of capture over different length classes so that a resultant length curve is established and the mean size at first capture is derived.
5. Using growth increments data resulting from the linking of means, growth parameters were estimated (Gulland and Holt, 1959).
6. The best fit of growth parameters were selected as representing growth of the species.

In the present study, a preliminary estimate of L_∞ was made using the Powell-Wetherall plot. Based on this, the automatic search routine, response surface analysis and scan of K values provided in the ELEFAN submenus of

FiSAT were run to get the best fit of L_∞ and K. The data were corrected using the selection factors (L_{-50} and L_{-75}) obtained from the catch curve. The growth parameters were re-estimated using the data corrected for selection.

The monthly recruitment value pertains to months of the year when a precise estimate of t_o is available. t_o is also required for the calculation of growth in length using VBG equation. t_o was calculated by

Pauly's empirical equation (Pauly, 1979),

$$Log(-t_0) = -0.392 - 0.275 \log L_\infty - 1.038K$$

6.15 Stock Assessment.

For the purpose of stock assessment studies of *P. malabarica*, L_∞, K and t_0 estimated in the age and growth were used for estimation of stock. Length-weight relationship values obtained in Chapter 3 was used.

The mortality in clams is due to natural causes and fishing which is expressed as total mortality coefficient or instantaneous rate of total mortality and denoted by Z. Natural mortality due to predation including cannibalism and other factors such as disease, parasitic infections, starvation, old age and environmental conditions acting independently is expressed as instantaneous

rate of natural mortality *M*. Fishing mortality caused by fishing activity is expressed as instantaneous rate of fishing mortality *F*.

6.16 Total mortality coefficient (*Z*)

The total mortality coefficient (*Z*) was estimated from the length-frequency data for the year 2003-2004 by using length-converted catch curve method of Pauly (1983).

6.17 Natural mortality coefficient (*M*)

The natural mortality coefficient of *P. malabarica* was calculated by the method of Srinath (1990).

Srinath proposed the following empirical formula to estimate natural mortality

$M = 0.4603 + 1.4573\ K$

where '*K*' is the growth coefficient.

6.18 Probabilities of capture

The probability of capture by length (Pauly, 1983) of *P. malabarica* was calculated by the ratio between the points of the extrapolated descending arm of the length-converted catch curve using the FiSAT software.

6.19 Fishing mortality coefficient (F)

The instantaneous fishing mortality coefficient (F) was computed from the following relationship:

$$F = Z - M$$

6.20 Exploitation rate (U)

This is defined as the fraction of clam present at the start of a year that is caught during the year (Ricker, 1945). This is estimated by the equation given by Beverton and Holt (1957) and Ricker (1945) as

$$U = \frac{F}{Z}\left(1 - e^{-Z}\right)$$

6.21 Exploitation ratio (E)

This refers to the ratio between fish caught and the total mortality (Ricker, 1945) or the exploitation rate or the fraction of deaths caused by fishing (Sparre and Venema, 1992). It is estimated by the equation

$$E = \frac{F}{Z} = \frac{F}{M + F}$$

The E gives an indication of the state of exploitation of a stock under the assumption that the optimal value of exploitation is 0.5 or E $\approx$ 0.5 which in turn is based on the assumption that the sustainable yield is optimised when $F \approx M$ (Gulland, 1971).

6.22 Yield (*Y*)

Yield is the fraction of clam population by weight taken by the fishery and is denoted by *Y*.

6.23 Standing stock (*Y/F*)

This term refers to a concentration of clam population for a given area at a given time. It is measured in terms of numbers or weight and is estimated from the relation *Y/F*.

6.24 Total stock or annual stock or biomass (*Y/U*)

This refers to the total weight or number of clam population available for a given area at a particular time. It is estimated from the relation *Y/U* where *Y* is the yield and *U* is the exploitation rate.

6.25 Maximum sustainable yield (*MSY*)

This refers to the weight of clam that can be taken by fishing without reducing the stock's biomass on a continuing basis. The MSY was calculated by the formula of Gulland (1965) as-

$MSY = Z(Y/F)*0.5$.

The MSY was also calculated from the length-based Thompson and Bell model as given below.

6.26 Virtual population analysis -VPA (Gulland, 1965)

The term virtual population means the part, by number, of a clam stock that is alive at a given time and which will be caught in future. In Virtual Population Analysis (also known as Cohort Analysis), the annual catch obtained from a single cohort during the exploited phase is used to calculate the abundance and fishing mortality rates of the cohort in each year. Managing a fishery by limiting effort requires estimates of annual abundance and total catch at different levels of fishing effort. VPA is a suitable method in such situations.

The basic equations used in this analysis are:

1. $$C(i,t,t+1) = N(i,t)\frac{F(i,t,t+1)}{M+F(i,t,t+1)}\exp[M+F(i,t,t+1)]$$

2. $$\frac{C(i,t,t+1)}{N(i+1,t+1)} = \frac{F(i,t,t+1)}{M+F(i,t,t+1)}\{\exp[M+F(i,t,t+1)]-1\}$$

3. $$N(i,t) = N(i+1,t+1)\exp[M+F(i,t,t+1)]$$

(the notation *exp(x)* is used in place of e^{x})

The terms used in these equations have the following meanings:

$C(i,t,t+1)$	:	Catch in number for year i with ages between t and $t+1$.
$N(i,t)$	:	Number of clam (survivors) of age t in the

sea at the beginning of year i.

$F(i,t,t+1)$: Instantaneous rate of fishing mortality during the year i for those between ages t and $t+1$.

M : Instantaneous rate of natural mortality which is assumed to be the same for all age groups.

$Z(i,t,t+1) = M + F(i,t,t+1)$: Instantaneous rate of total mortality during the year i for those between ages t and $t+1$.

The calculations for VPA are started from the bottom (highest age class in the catch, also known as the terminal class). With an initial guess of the fishing mortality for the terminal class (terminal F value), knowing the estimate of natural mortality M and catch for the terminal class, we can estimate the number of survivors at the beginning of the year for this class from the first equation as:

$$N(i,t) = \frac{M + F(i,t,t+1)}{F(i,t,t+1)} \frac{C(i,t,t+1)}{\exp[M + F(i,t,t+1)]}$$

Since the number of survivors at the beginning of a year is same as the number of survivors at the end of the previous year, we can estimate the fishing mortality for the immediate previous age class from the second equation in which the only unknown factor will be $F(i,t,t+1)$. The number of survivors for this class can be estimated using the third equation. This procedure can be repeated in this fashion starting from the last age class to estimate fishing mortality and number of survivors for each of the age classes.

6.27 Length-based Thompson and Bell model

The Thompson and Bell model is the predictive version of VPA, which can predict the stock size and the catch for various assumptions on the future fishing pattern. The inputs are the same as that of the cohort analysis and the additional inputs required are the parameters of the length-weight relationship The outputs are the number in each lower limit of the length group *N (L1),* the catch in numbers, the yield in weight, the biomass multiplied by Δt, *i.*e. the time required to grow from the lower limit to the upper limit of the length group. Finally, the totals of the catch, yield, mean biomass x *Δt* are obtained. The calculations are repeated for a range of *F* values and the final results are plotted in graphs.

The equation to calculate *F* in length-based VPA is rearranged as:

$$C(L_1, L_2) = [N(L_1) - N(L_2)] * \frac{F(L_1, L_2)}{Z(L_1, L_2)}$$

This gives the equation

$$N(L_1) = \left[N(L_2) * H(L_1, L_2) + \frac{N(L_1) - N(L_2)}{Z(L_1, L_2)} * F(L_1, L_2) \right] * H(L_1, L_2)$$

where

$$H(L_1, L_2) = \left[\frac{L_\infty - L_1}{L_\infty - L_2} \right]^{M/2K}$$

with respect to $N(L_2)$

$$N(L_2) = N(L_1) * \frac{1/H(L_1, L_2) - F(L_1, L_2)/Z(L_1, L_2)}{H(L_1, L_2) - F(L_1, L_2)/Z(L_1 - L_2)}$$

the catch in numbers has to be multiplied by the mean weight of the length group,

$$\overline{w}(L_1, L_2) = q * [L_1 + L_2/2]^b$$

where q and b are the parameters of the length-weight relationship a and b respectively. The yield is given by

$$Y(L_1, L_2) = C(L_1, L_2) * \overline{w}[L_1, L_2]$$

The number of survivors of the length group decreases when a cohort grows from L_1 to L_2 and is calculated as-

$$\overline{N}(L_1, L_2) * \Delta t(L_1, L_2) = [N(L_1) - N(L_2)]/Z(L_1, L_2)$$

and the corresponding mean biomass * Δ_t is

$$\overline{B}(L_1, L_2) * \Delta t(L_i, L_2) = [N(L_1) - N(L_2)]/Z(L_1, L_2)$$

The average biomass during the lifespan of a cohort or all cohorts during a year is given by $\overline{B} = \sum \overline{B_i} * \Delta t_i$

6.28 The relative Y/R model (Y'/R)

Beverton and Holt (1964) based on the realisation that the absolute value of Y/R expressed for example in terms of grams per recruit per year, has no direct relation to fisheries management, proposed the relative yield per

recruit based on the concept that what matters is the relative differences of Y/R for different values of F.

$$\left(Y/R\right)' = E\,U^{M/K}\,[1-\frac{3U}{1+m}+\frac{3U^2}{1+2m}-\frac{U^3}{1+3m}]$$

where

$$m=\frac{1-E}{M/K}=\frac{K}{Z}$$

$$U=1-\frac{L_c}{L_\infty}$$

and

$E=\frac{F}{Z}$ is the exploitation ratio which is the fraction of deaths due to fishing.

The relation between relative yield per recruit $\left(Y/R\right)'$ and the yield-per-recruit $\left(Y/R\right)$ is

$$\left(Y/R\right)' = \left(Y/R\right)\exp[-M(t_r-t_0)]/W_\infty$$

where t_r is the age at recruitment and t_0 is the age corresponding to zero length, which is a parameter in VBGF.

Knowing the relative yield per recruitment, the corresponding yield per recruitment can be calculated using the following equation.

$$\left(Y/R\right) = \left(Y/R\right)' W_{\infty} \exp[M(t_r - t_0)]$$

The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) were obtained from the estimated growth parameters and probabilities of capture by length (Pauly and Soriano, 1986).

The concept of $F_{0.1}$ in the (Y'/R) model is to limit F to the values which correspond to $1/10^{th}$ rate of increase of yield per recruit that can be obtained by increasing F at low levels of F (Gayanilo and Pauly, 1997). $E_{0.1}$ is defined as the exploitation rate at which the marginal increase of relative yield per recruit is $1/10^{th}$ of its value at $E = 0.1$.

6.3 RESULTS.

6.31 Fishery:

The clams are exploited from the barmouth by the traditional method of hand picking during low tide or by using scoop nets. Usually the fishermen reach the area either by swimming or by traditional canoes. Regular fishing was done except when the environment conditions are not favourable to venture into the estuary. The fishing hours lasts for three to four hours depending on the tide. An estimated total of 68.83 t of clams was fished from the estuary during the period. The peak fishing period was from July to

November, with maximum effort in October. The catch was also maximum in this month. The effort was calculated with the number of persons involved in the fishing. Total fishing effort during the period was 3,902 (persons) and catch per effort was 17.6 kg. Average catch for the year was estimated to be 5.74 t at an average effort of 325. (Table. 6.1 and Fig 6.2).

6.32 Length frequency

The month wise size frequency of the clams was raised to the monthly catch and estimated numbers for each month is given in Table 6.2a and Fig. 6.3a. The length ranged from 4.2 mm to 54.0 mm. The length range of 31.0 mm to 40.0 mm contributed maximum to the stock.

In commercial catch the size group 36 mm to 46 mm dominated with the maximum numbers contributed by 36-38 mm size group (Table 6.2 b and Fig 6.3 b).

6.33 Age and Growth.

The data used for fitting regression for the estimation of growth parameters using Powell-Wetherall method are given in Table 6.3. The L_∞ obtained by Powell–Wetherall method was 56.7 mm and $Z/K = 3.096$ (Fig 6.4). Using this estimate, the length-frequency data was subjected to FiSAT routine for the scan of K value, response surface analysis and automatic search routine.

From these analyses the best fitting (with high goodness of fit) growth curve was selected. The values obtained from ELEFAN I with an *Rn* value (0.190) was 59 mm and $K = 0.92.yr^{-1}$ (Fig. 6.5) was best fitting. The values of L_∞ and K obtained by ELEFAN I plot were taken to represent the growth in *P. malabarica.*

By using Pauly's formula (1969), t_0 for *P. malabarica* is calculated as -0.1596. As t_0 calculated by this method has been generally used in the age and growth study of the clams, in the present study also the t_0 obtained from Pauly's equation was used for further analysis.

The life span estimated for clams in Dharmadom estuary was about 2.5 to 3 years. By VBGF, it was estimated that *P. malabarica* in the estuary attains a length of 35.5 mm at the end of first year and 49.6 mm at the end of second year. Since the length at first maturity (L_m) has been estimated at 22 mm (reproduction part), 50 % of the clam mature in 7 months of its life. It was also observed that all the clams above 22 mm were found to be invariably matured and it can be assumed that the clams mature before reaching one year (Fig 6.6).

Stock Assessment.

6.34 Growth parameters

The growth parameters estimated with length-frequency data are L_∞ = 59 mm, K = 0.92 yr $^{-1}$ and t_0 = -0.1596.

6.35 Total mortality coefficient (Z)

The total mortality coefficient (Z) was estimated for 2003-2004 by "linearized length-converted-catch-curve" (Pauly, 1983 a) was 4.53. The result of the mortality estimation by catch curve method for the period is shown in Fig 6.7.

6.36 Natural mortality coefficient (M)

The natural mortality coefficient value estimated by Srinath's formula was 1.82.

6.37 Fishing mortality coefficient (F)

The value of fishing mortality coefficient (F) estimated was 2.83. Fig 6.7.

6.38 Probabilities of capture and length at first capture (l_c)

The results of the length-converted-catch-curve method were used for the estimation of probabilities of capture and l_c (Fig 6.8). The

selection values obtained by the probability of capture were L_{25} = 18.383 mm, L_{50} = 23.421 mm and L_{75} = 27.157 mm. These values were used as inputs in Thompson and Bell prediction analysis and relative *Y/R* of Beverton and Holt (*Y'/R*).

6.39 Exploitation rate (U) and exploitation ratio (E).

The exploitation rate (U) was estimated at 0.59 and exploitation ratio (E) was 0.6. Table 6.4.

6.310 Standing stock and MSY

In Dharmadom estuary *P. malabarica* was taken by the scoop nets. The yield (Y) of *P. malabarica* obtained from the catch was 68.8 t. The estimated stock using Gulland's formula was 115 t and MSY is 57 t. The standing stock for the year was estimated as 25 t. Approximate MSY calculated using Gulland's formula was 80 t and by using length-based Thompson and Bell prediction model, the MSY was estimated at 69.3 t.

Estimated mean numbers and total weight of *P. malabarica* per sq m in three stations and the estimated total stock for the period is given in Table 6.5. The density of the clam was 43 to 209 per sq. m. The estimated stock for the period obtained by random sampling was 120 t.

6.311 Virtual population Analysis (VPA)

Results of the VPA using the pooled length frequency data for the year showed that *F* was maximum in the largest size group. Apart from this, higher value for F was noticed in the size classes 35 mm and 38 mm. The mean numbers, the length-wise catch pertaining to each length class showed that catch constituted mainly of 35-38 mm length group and maximum catch (16.5 t) was obtained in the size class 35 mm. The yield increased from 185 g in the size class 5 mm to the maximum of 16.5 t in the size class 35 mm and gradually reduced to 0.3 t in 5.3mm + size class (Table 6.8 and Fig. 6.9).

6.312 Length- based Thompson and Bell model

Average yield of *P. malabarica* for the period 2003-2004 calculated from the length-based Thompson and Bell prediction model was 115 t, the maximum sustainable yield (*MSY*) calculated from this is 69.3 t. As per Thompson and Bell prediction model, with 80 % of the present effort itself the MSY is reached and with reduction of 20 % of the present effort, maximum yield will be obtained. Subsequent addition of effort from the present level does not increase the yield (Table 6.7 and Fig 6.10).

6.313 The relative Y/R model (Y'/R)

The parameters used as input for Beverton and Holt yield-per-recruit analysis and the different Y/R values obtained against respective F values for *P. malabarica* are presented in Table 6.8 and Fig 6.11. It shows that the present exploitation rate, E (0.59) is little below the optimum exploitation rate ($E_{max} = 0.634$). The $E_{-0.1}$ was 0.5545 and $E_{-0.5}$ as 0.03145. The Y/R of *P. malabarica* was estimated with the present t_c (0.58 years), with a higher t_c (0.75 year) and a lower t_c (0.46 years) (Fig 6.12), showed that the when time at capture is increased the Y/R was high. Thus yield-per-recruitment analysis indicated that the present pattern of exploitation is nearer to the optimum yield.

6.4 DISCUSSION.

Bivalve fishery in India is dominated by venerid clams and mussel. The estimated catch in the Dharmadom estuary for the period 2003-2004 was 68.8 t for an effort of 3902 (persons). Average annual landing of clams and cockles for the period 1996-2000 was estimated at 52,537 t in Kerala (Kripa and Appukuttan, 2003). Although the landing of *P. malabarica* in Dharmadom constituted about 0.13 % of the total bivalve yield, the resource is exploited to the maximum in the estuary. The bivalves are the least managed resource along the Indian coast. Apart from the management measures on the

short neck clam fishery of Ashtamudi estuary in Kerala, there is no regulations for effective utilization and conservation of these sedentary marine resources (Kripa and Appukuttan, 2003). Efforts could be taken for relaying or semiculture of clam in the estuary and restrict fishery during breeding season for ensuring proper recruitment.

The results of the present study indicate that length range of *P. malabarica* within 31-40 mm contributed maximum to the fishery. Since there is a market preference for large sized clams, the exploitation is more for this size group. In Ashtamudi estuary also exploitation is maximum in the size group of 34-36mm (Appukuttan, 1993).

Growth has been defined as a change, either positive or negative in the size of an individual organism or in the mean size of a population (Malouf and Bricelj, 1989). Bivalves exhibit a broad range of growth rates in nature and these growth rates to a certain extent reflect a given species survival strategy (Seed and Brown, 1978). Growth rate and other population parameters obtained for *P. malabarica* during the present study seems to be comparable with that of other species (Winckworth, 1931, Mane and Nagabhushanam, 1979). Winckworth (1931) while evaluating the growth rate of *Paphia undulata* from Indian waters indicated that this species live less than two years, breeding during May- August and the young ones showing rapid growth. Rao

(1951a) observed that *Katelysia opima* reached 22.5 mm in first year, whereas in 2nd and 3rd year it grows to 31.5 mm and 40.5 mm respectively indicating faster growth rate in the 1st year. Abraham (1953) noted 15 mm growth in *Meretrix casta* within 2 months and 29.5 mm in 7 months, also showing rapid growth rate in first two months. Mane (1974a) while studying the growth rate of *Katelysia opima* noted lengths attained by clam in 1st, 2nd and 3rd year as 22 mm, 31 mm and 43 mm respectively. Mane and Nagabhushanam (1979) noted 23 mm, 38 mm and 47 mm as the growth of *Paphia laterisulca* for three consecutive years. Parulekar (1984) while examining the growth and age of bivalves from temperate and tropical estuarine system, noted that annual growth rate in tropical species (*Meretrix casta* and *P. malabarica*) was 10-12 times more than in the temperate environment. No annual or seasonal growth rings were discernible in tropical bivalves. Rao (1988) followed Gulland and Holt (1959) method and growth rate derived at different mean lengths were plotted to fit a regression equation by least square method for *P. malabarica* from Mulky estuary. He estimated that the growth rate as Y = 0.2343, K = 1.4253, L_∞ = 59mm. The estimated length was 36.6 mm in 6 months, 43.1 mm in 9 months and 48.1 mm in one year. The growth rate was higher in the Mulky estuary. In Ashtamudi estuary Appukuttan *et al.* (1999) has observed L_∞ as

44.43 mm and K as 0.8389. The clam attained 30.05 mm in the first year, 38 mm in 2^{nd} year and 41 mm in the third year.

In Dharmadom estuary the clam attained 35.5 mm in the first year, 49.6 mm in the second year and 55.3 in the third year. The K value obtained was 0.92 and L_∞ is 59 mm. The maximum size obtained in the fishery was 52 mm. The K value indicates higher growth rate of the individual. Higher growth rate recorded by Rao (1988) could be due to low population density and the difference in the nature of the substratum of Mulki estuary. The reasons for lower values obtained by Appukuttan *et al.* (1999) may be due to large-scale exploitation of clams in Ashtamudi estuary. It is observed that the growth rate in Dharmadom estuary is higher than the Ashtamudi estuary. The reason for the differences in the growth rate in three estuaries could be attributed to the population density, nature of the substratum and environmental conditions prevailing in the area. Rao *et al.* (1989) observed that *P. malabarica* density in Mulky estuary was 1-85 per sq m while in Ashtamudi estuary (Appukuttan, 1993) estimated as 15-246. In Dharmadom estuary the density was 43-209. Larger size group was more exploited in the estuary due to high market demand. Caddy (1989) has described the plasticity in growth of sedentary molluscs which can produce wide variations in growth rate or meat yield for the population.

The natural mortality is influenced by several biological and environmental factors; it is difficult to get an accurate estimate (Pauly, 1983). The instantaneous growth rate of total mortality of *P. malabarica* are estimated as Z = 4.53, M = 1.82 and F = 2.71. The values of Z, M and F for *P. malabarica* in Ashtamudi estuary was 2.11, 1.17 and 0.94 (Appukuttan *et al.*, 1999). The natural mortality (M) is closely related to age and size, as larger species or groups generally would have less rate of predation. Since M is linked to longevity and longevity to growth coefficient K, M/K ratio is found constant among closely related species and sometimes within the similar taxonomic groups (Beverton and Holt, 1957 and Banerji, 1973). M/K ratio usually ranged from 1 to 2.5 (Beverton and Holt, 1957). In the present study, the M/K ratio obtained for *P. malabarica* fall within the range. F was obtained from the relation $Z = M+F$. The Y'/R estimates shows that with increase in length at capture the yield per recruit can be increased. The present exploitation rate (E) = 0.59 is almost equal to E_{max} of 0.63; hence there is no scope for increasing the effort. As the estimate of *MSY* by Thompson and Bell model is 69.3 t as against the present catch of 68.8 t, it is evident that the stock of *Paphia malabarica* is exploited almost near to *MSY* level. As per Thompson and Bell prediction model, with 80 % of the present effort itself the *MSY* is reached and with reduction of 20 % of the present effort maximum yield will

be obtained. Subsequent addition of effort from the present level does not increase the yield. In the light of the results obtained from Thompson and Bell yield analysis, it is evident that there exists no scope for increasing the fishing effort to result higher economic yield and that the fishery is already operating near biologically optimal level. Beyond MSY, the exploitation is that of the lower size group which will not be economical. In Dharmadom estuary, judicious exploitation coupled with semiculture practice can increase the production in the coming years.

Table 6.1: Catch and Effort of *P. malabarica* from Dharmadom Estuary during December 2003-November 2004.

Month	Catch (kg)	Effort (persons)	C/E (kg)
December	960	80	12
January	1200	120	10
February	970	138	7
March	1320	132	10
April	3360	280	12
May	4275	375	11
June	5100	300	17
July	7000	500	14
August	10120	506	20
September	11000	500	22
October	13230	575	23
November	10296	396	26
Total	68831	3902	17.6

Table 6.2 a: Annual estimated numbers of *P. malabarica* in different size groups in clam bed during December 2003- November 2004.

Size Groups mm	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
4.1-7	0	2519	539	0	0	0	0	0	0	0	0	0	3057
7.1-10	0	3238	1616	968	5157	0	0	0	0	0	0	0	10980
10.1-13	0	10795	4310	4197	10313	2076	867	0	0	2502	0	0	35060
13.1-16	475	7196	5387	9362	25783	6227	10408	8449	0	10009	9547	4598	97443
16.1-19	238	17271	10236	10653	30939	15568	14745	21123	28610	7507	4774	9197	170860
19.1-22	2377	5397	14007	9685	28877	33212	20816	42245	50862	12511	42962	11496	274448
22.1-25	2852	2519	3771	9039	25783	36326	34694	52806	71525	60055	116953	18394	434716
25.1-28	3922	1799	2155	9685	36096	37363	45969	95051	93777	112602	114566	52883	605869
28.1-31	5229	6117	5387	4842	33002	35288	39031	76041	76293	135123	159915	59780	636048
31.1-34	7130	7196	8889	14527	15470	72651	27755	143633	84241	100091	83538	96568	661689
34.1-37	8557	11514	8081	5811	47440	7265	55510	52806	117619	195177	174236	137954	821971
37.1-40	9745	6837	6734	6456	10313	10379	22551	38021	47683	55050	69217	181640	464626
40.1-43	8319	3598	1077	3874	6188	12454	16480	6337	27021	80073	38189	27591	231200
43.1-46	832	720	539	968	11344	7265	3469	0	7947	20018	14321	9197	76621
46.1-49	832	1439	1347	968	8250	0	0	0	1589	17516	2387	2299	36628
49.1-52	119	720	269	0	4125	0	0	0	0	15014	2387	2299	24933
52.4-54	119	720	269	0	1031	0	0	0	0	0	0	2299	4438
Total	50745	89595	74615	91034	300110	276074	292296	536512	607168	823248	832991	616197	4590587

Table 6.2 b: Annual estimated numbers of *P. malabarica* in different size groups in commercial catch during December 2003- November 2004.

Size Groups mm	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Total
10.1-12.0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.1-14	0	289	0	0	0	0	0	0	0	0	0	0	289
14.1-16	0	0	0	0	0	0	0	0	0	0	0	0	0
16.1-18	0	0	0	183	0	0	0	0	0	0	0	2059	2243
18.1-20	231	578	0	183	0	0	0	0	0	0	0	0	993
20.1-22	0	867	255	0	0	0	0	0	0	0	2908	0	4030
22.1-24	0	289	255	550	431	0	0	0	0	0	5815	0	7341
24.1-26	694	0	255	183	431	0	0	0	728	0	2908	2059	7258
26.1-28	463	867	255	1283	431	1336	0	0	728	0	8723	2059	16146
28.1-30	463	289	510	1283	1292	1002	0	667	728	0	23262	0	29496
30.1-32	463	289	255	367	431	668	0	0	1456	0	11631	4118	19678
32.1-34	463	289	510	917	2154	1670	0	0	728	1528	5815	12355	26429
34.1-36	1157	578	1531	1283	431	2004	436	4000	728	4583	17446	12355	46533
36.1-38	925	1157	1531	1283	2154	2004	1308	4667	1456	18333	34892	2059	71770
38.1-40	0	1446	510	917	1292	2672	4795	3333	4368	10694	31985	4118	66131
40.1-42	0	0	1021	367	1723	0	5231	3333	5096	12222	23262	2059	54314
42.1-44	463	867	0	1100	2154	1670	3923	3333	2184	9167	17446	0	42307
44.1-46	694	578	510	917	2585	3006	2179	3333	10921	4583	31985	8237	69528
46.1-48	231	867	255	0	3446	3006	0	4667	6553	0	17446	6178	42649
48.1-50	0	867	255	0	431	1336	0	2000	3640	7639	11631	0	27799
50.1-52	0	0	0	0	0	0	0	667	728	7639	2908	2059	14001
52.1-54	0	0	0	0	0	0	0	0	0	0	0	2059	2059
Total	6246	10120	7911	10817	19385	20373	17872	30000	40043	76389	250062	61776	550993

Table 6.3: Data for estimation of L_∞ and *Z/K* for *P. malabarica* using the method of Wetherall

L(mean)-L'	L'	N (cumulative)
25.503	2.500	21028
22.567	5.500	20971
19.709	8.500	20831
17.107	11.500	20386
14.718	14.500	19617
12.661	17.500	18312
10.742	20.500	16694
8.874	23.500	14873
7.266	26.500	12510
5.676	29.500	10052
4.400	32.500	7115
3.801	35.500	3893
3.424	38.500	1819
3.739	41.500	668 ***
2.950	44.500	336
2.338	47.500	127
1.500	50.500	35
*** regression line is fitted from this point Y = 13.86 + (-0.244) * X, r = - 0.998		
Estimate of L∞ = 56.773 mm Estimate of Z/K = 3.096		

Table 6.4: Estimates of mortalities, exploitation rate (U), exploitation ratio (E), total stock (Y/U) and standing stock (Y/F) of *P. malabarica* in Dharmadom estuary during December 2003- November 2004

Year	Z	M	F	U	E	Yield (Y) t	Total stock (Y/U)	Standing Stock (Y/F) t
2003-04	4.53	1.82	2.71	0.59	0.61	68	115	25

Table 6.5: Estimated total weight of *Paphia malabarica* per sq.m area in kg during December 2003- November 2004 in Dharmadom estuary.

Month	Station I	Station II	Station III	Average
Dec	0.852	0.813	0.71	0.79
Jan	1.159	1.241	1.078	1.16
Feb	1.732	1.809	1.715	1.75
Mar	0.713	0.602	0.586	0.63
Apr	0.997	0.917	0.95	0.95
May	1.424	1.335	1.378	1.38
Jun	1.535	1.445	1.448	1.48
Jul	1.105	1.144	1.03	1.09
Aug	1.266	1.212	1.233	1.24
Sep	1.122	1.056	1.109	1.10
Oct	1.08	0.98	1	1.02
Nov	0.855	0.823	1.021	0.90
Average production per sq m.			1.12	
Total area of Clam bed			10,7146 sq.m	
Estimated total stock			120.5 t	

Table 6.6 : Length- structured VPA results for *Paphia malabarica* (2003-2004) in Dharmadom estuary

Mid-length	Catch (numbers)	Population (N)	Fishing mortality (F)
1.1	49.67	23919.51	0.0325
1.4	138.04	21090.08	0.0967
1.7	242.05	18354.21	0.1833
2.0	388.80	15709.31	0.3232
2.3	615.85	13130.92	0.5757
2.6	858.31	10568.12	0.9385
2.9	901.07	8045.22	1.2084
3.2	937.39	5787.06	1.6395
3.5	1164.46	3809.06	3.0784
3.8	658.22	1956.13	3.0945
4.1	327.53	910.78	2.9636
4.4	108.55	382.11	1.9018
4.7	51.89	169.68	1.7535
5.0	35.32	63.93	3.3752
5.3	6.29 (Ct)	9.56 (Nt)	3.5000 (Ft)

L_∞ = 59 mm K = 0.92.yr $^{-1}$

Table 6.7: Yield, average biomass table derived from length based Thomas and Bell analysis for *P. malabarica* in Dharmadom estuary

	f-factor	Yield (10^5)	Biomass (10^6)
1	0.0	0.000	139.114
2	0.1	314.597	106.589
3	0.2	487.380	85.279
4	0.3	584.955	70.541
5	0.4	640.344	59.897
6	0.5	671.036	51.936
7	0.6	686.792	45.805
8	0.7	693.294	40.967
9	0.8	693.970	37.068
10	0.9	690.947	33.869
11	1.0	685.581	31.205
12	1.1	678.749	28.954
13	1.2	671.031	27.031
14	1.3	662.800	25.370
15	1.4	654.319	23.922
16	1.5	645.765	22.648
17	1.6	637.252	21.520
18	1.7	628.863	20.514
19	1.8	620.640	19.611
20	1.9	612.617	18.796
21	2.0	604.814	18.057

Table 6.8: Yield per recruit and Biomass per recruit for *P. malabarica* with different values of length at capture.

	L_c =23 T_c = 0.58		L_c = 20 T_c = 0.46		L_c = 30 T_c = 0.75	
Effort	Y'/R	B'/R	Y'/R	B'/R	Y'/R	B'/R
0.05	0.004566	0.915413	0.004716	0.909975	0.00406	0.924623
0.1	0.008782	0.833940	0.009012	0.823659	0.007893	0.851417
0.15	0.012639	0.755686	0.01288	0.741170	0.011491	0.780465
0.2	0.01613	0.680757	0.016313	0.662624	0.014847	0.711852
0.25	0.019248	0.609260	0.019306	0.588133	0.017956	0.645665
0.3	0.021987	0.541301	0.021854	0.517812	0.020809	0.581995
0.35	0.024342	0.476986	0.023955	0.451766	0.023402	0.520932
0.4	0.026311	0.416414	0.02561	0.390096	0.025728	0.462568
0.45	0.027891	0.359683	0.026822	0.332893	0.027781	0.406994
0.5	0.029085	0.306881	0.027597	0.280236	0.029559	0.354301
0.55	0.029896	0.258084	0.027946	0.232185	0.031057	0.304576
0.6	0.030332	0.213357	0.027885	0.188779	0.032275	0.257901
0.65	0.030405	0.172743	0.027438	0.150030	0.033212	0.214352
0.7	0.030133	0.136260	0.026634	0.115910	0.033871	0.173994
0.75	0.029541	0.103896	0.02551	0.086351	0.034259	0.136878
0.8	0.028659	0.075597	0.024117	0.061226	0.034385	0.103036
0.85	0.027529	0.051259	0.022514	0.040345	0.034263	0.072474
0.9	0.026202	0.030718	0.020771	0.023435	0.033914	0.045167
0.95	0.024737	0.013737	0.01897	0.010139	0.033364	0.021048
1	0.023207	0.000000	0.017205	0.000000	0.032647	0.000000

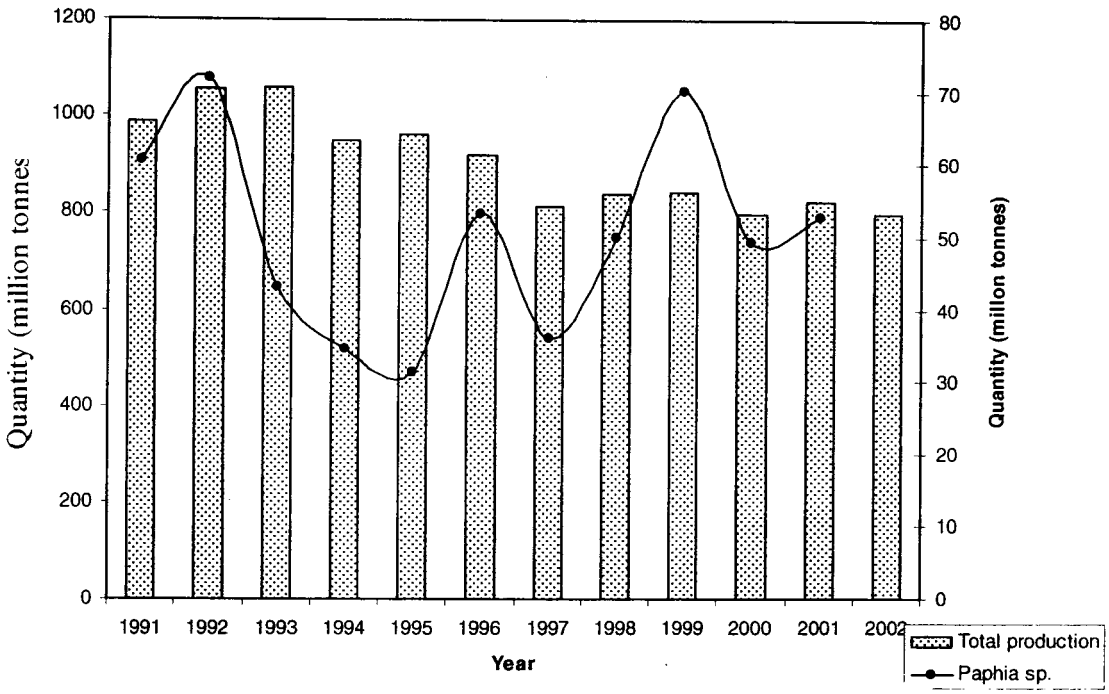

Fig. 6.1: World production of clam and *Paphia* Spp.

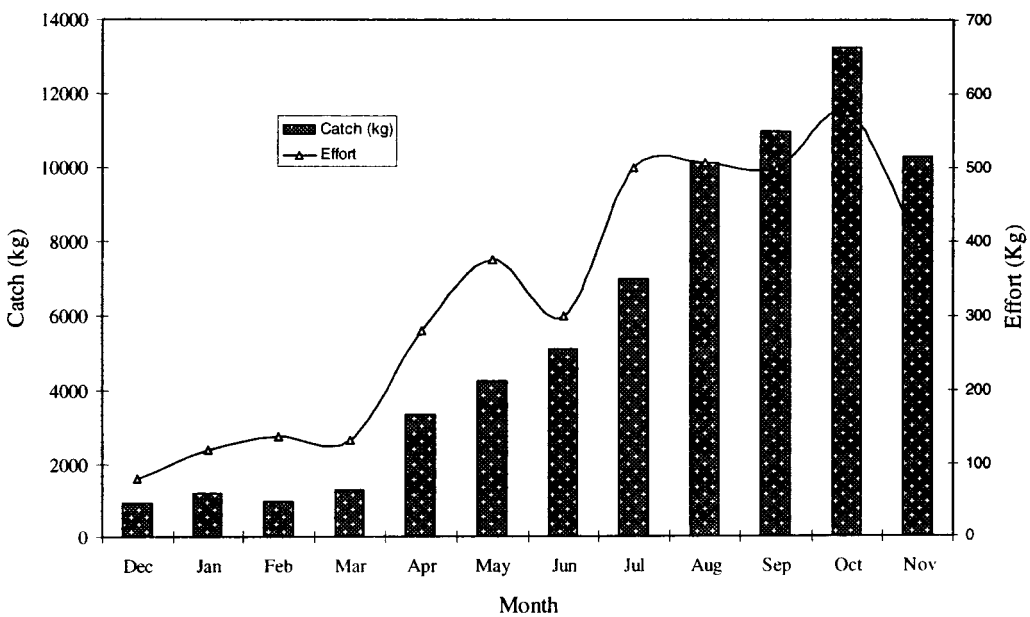

Fig. 6.2: Estimated Catch and Effort of *Paphia malabarica* in Dharmadom estuary during December 2003 – November 2004.

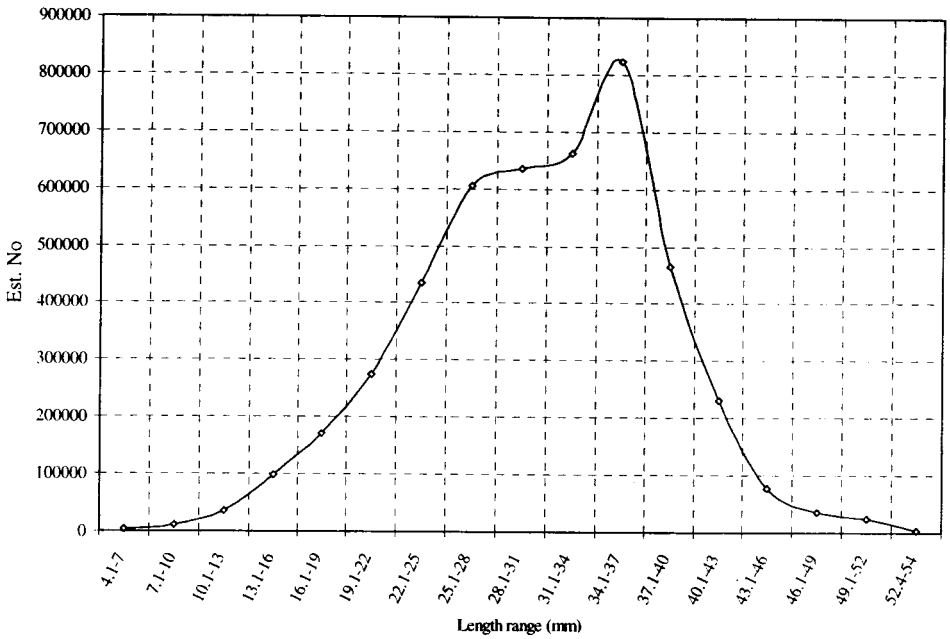

Fig. 6.3 a: Estimated numbers and dominant size group of *P. malabarica* in Dharmadom during December 2003– November 2004.

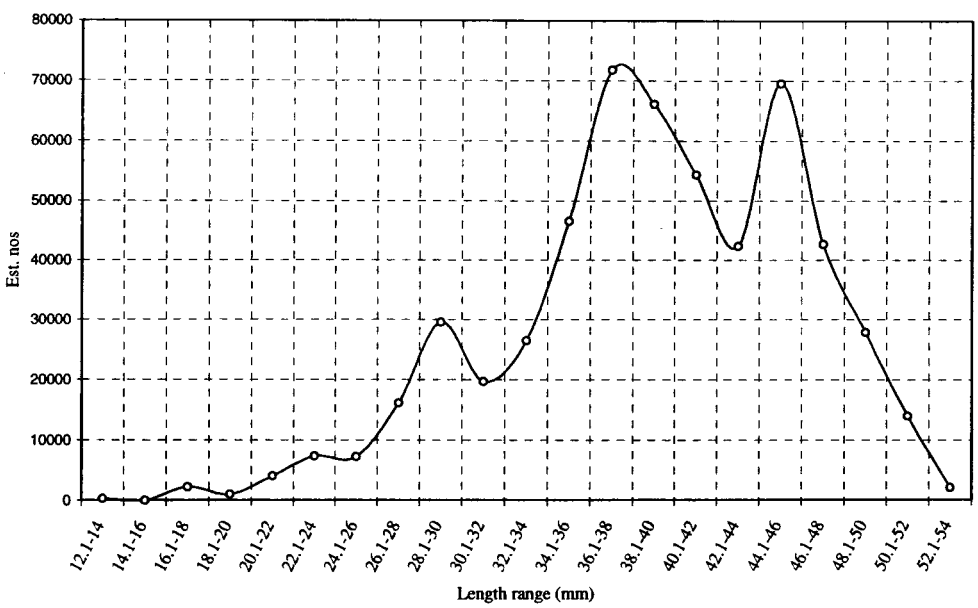

Fig. 6.3 a: Estimated numbers and dominant size group of *P. malabarica* in Dharmadom during December 2003 – November 2004.

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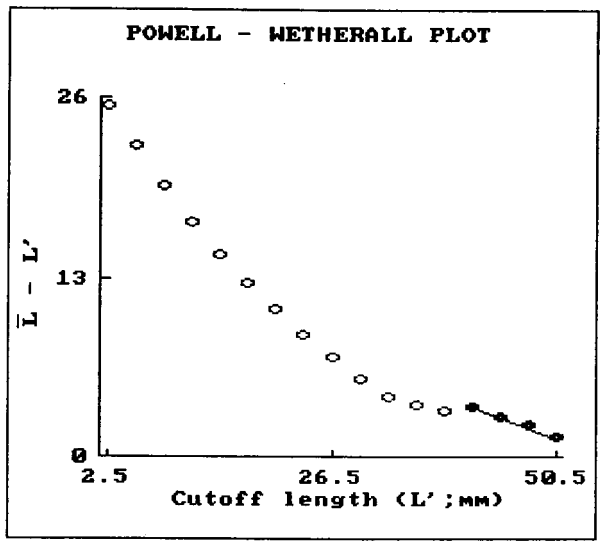

Fig. 6.4: Estimation of L_∞ and Z/K of *Paphia malabarica* using Powell-Wetherall Plot

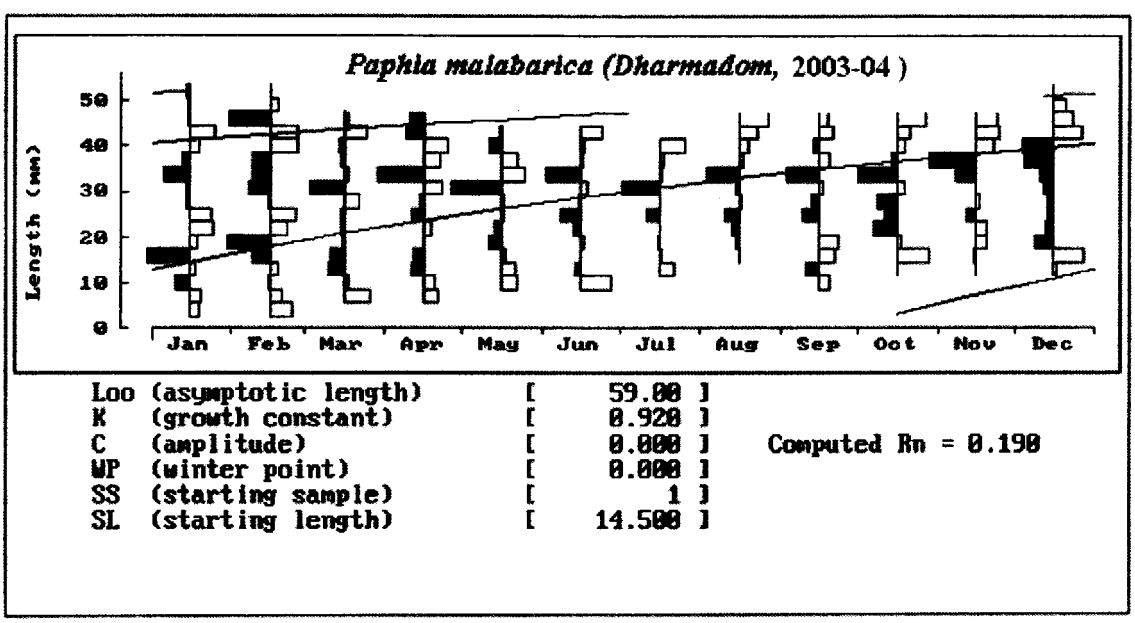

Fig. 6.5: Estimation of L_∞ of *Paphia malabarica* using ELEFAN I method

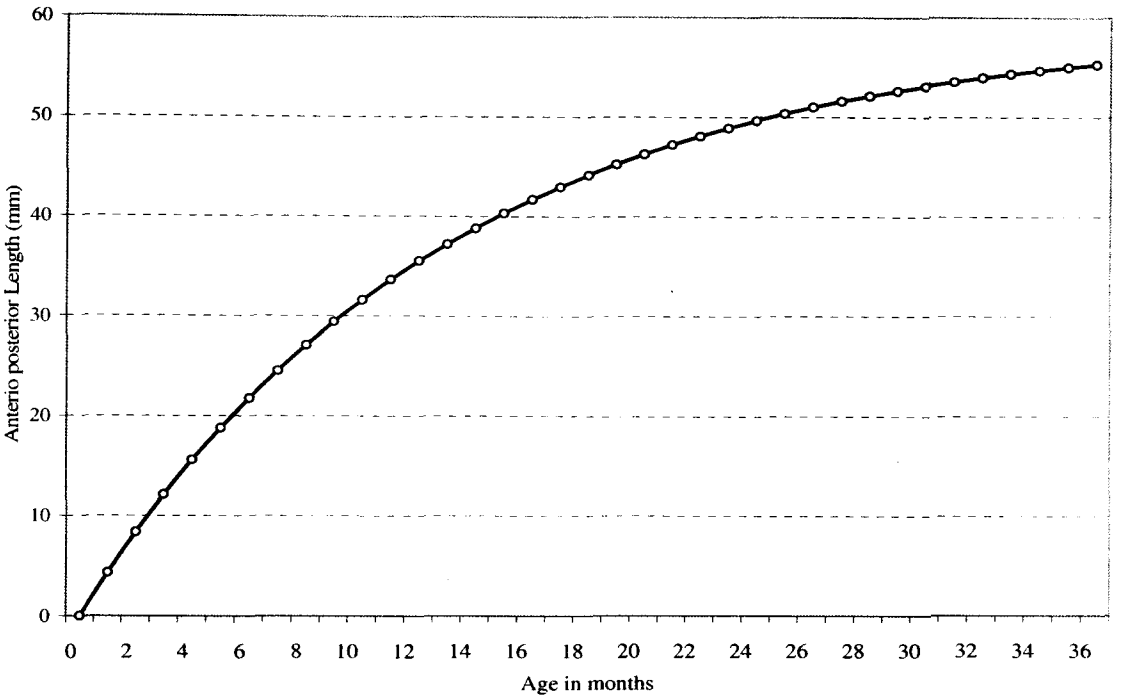

Fig. 6.6: The VBGF curve for *P. malabarica* with selected growth parameters.

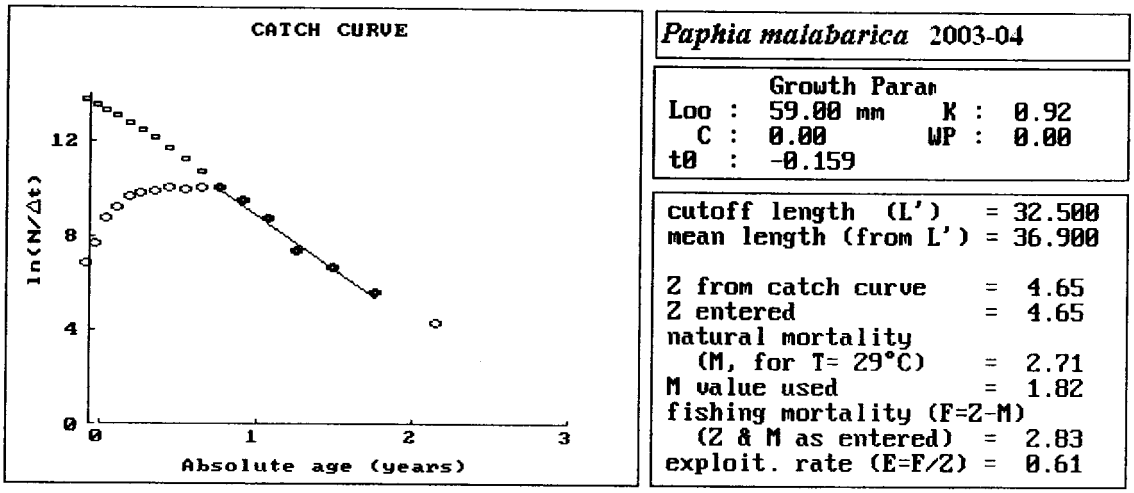

Fig. 6.7: Total mortality estimation of *Paphia malabarica* using Pauly's linearised length converted catch curve method and estimation of exploitation of *P. malabarica* during 2003- 04 in Dharmadom Estuary

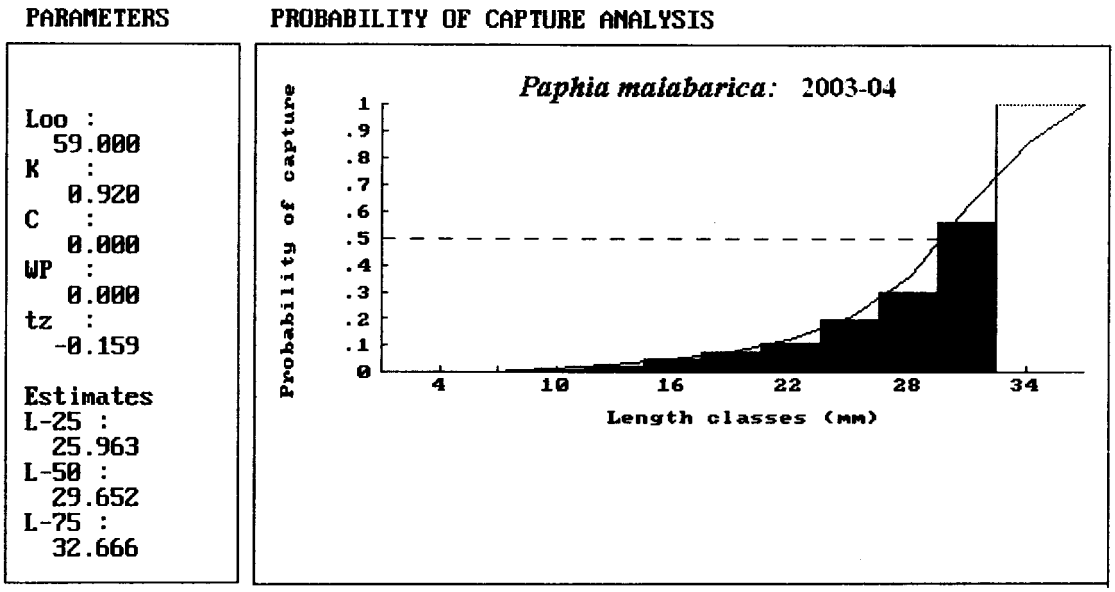

Fig 6.8: Analysis of probability of capture for *P. malabarica* during 2003- 04 in Dharmadom Estuary with length frequency data.

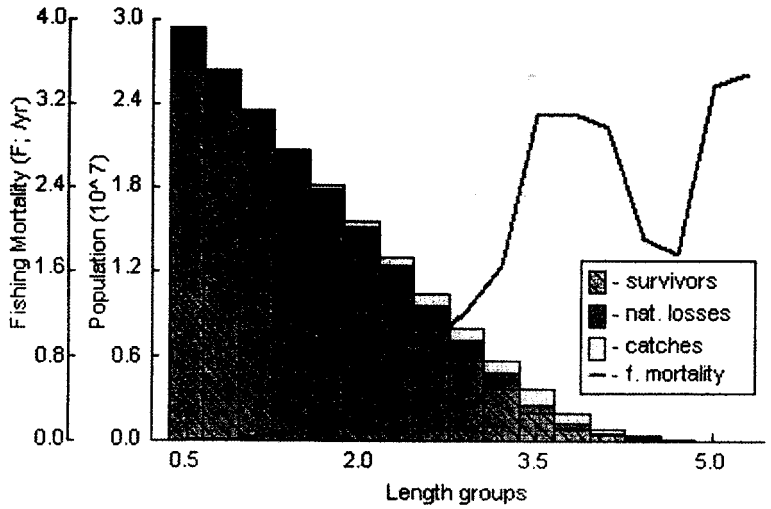

Fig. 6.9: Length- Structured Virtual population analysis of *Paphia malabarica*

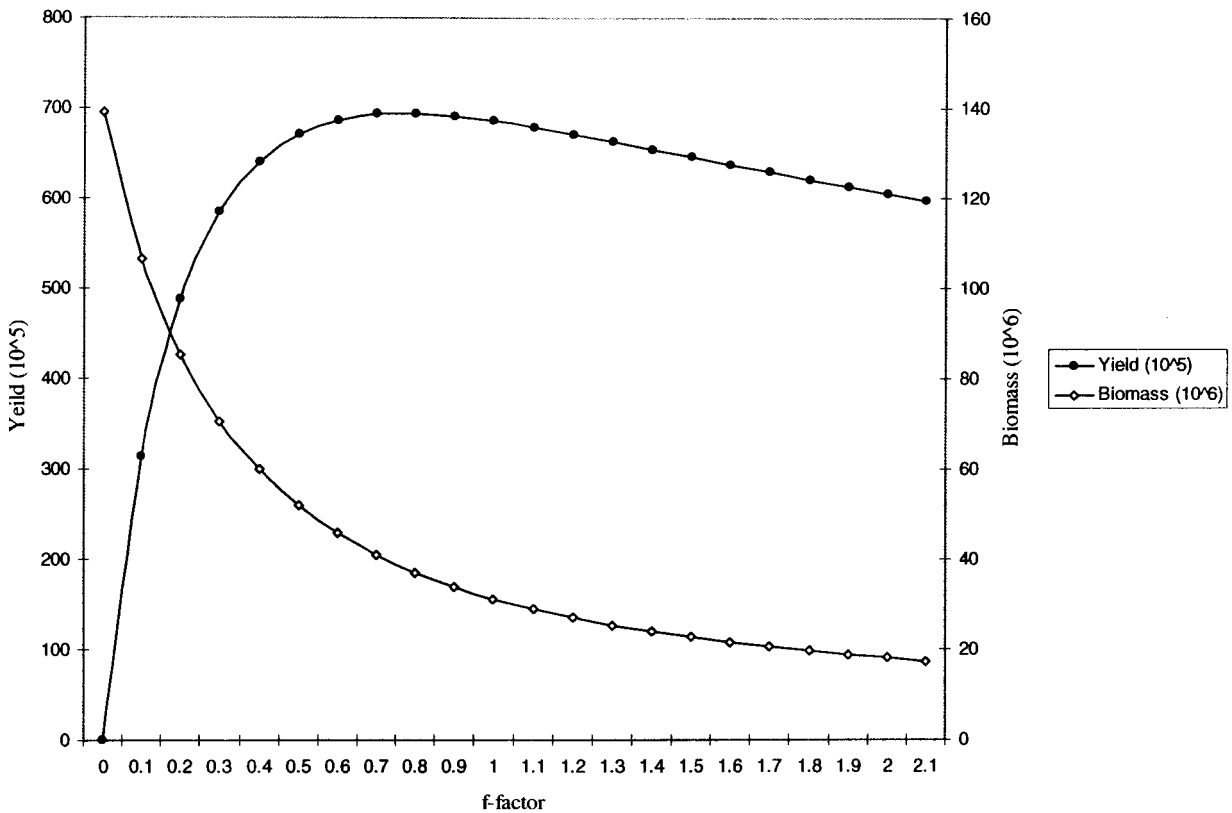

Fig. 6.10: Results of Thompson and Bell analysis for *P .malabarica* in Dharmadom Estuary during December 2003- November 2004.

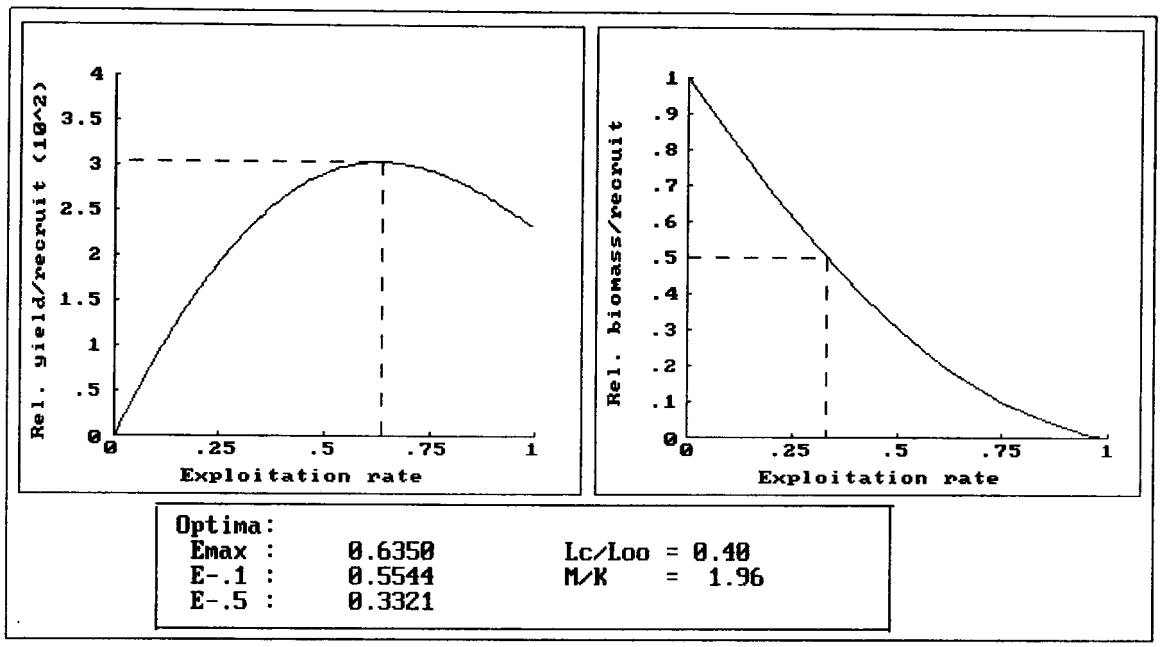

Fig. 6.11: Results of relative yield-per-recruit and biomass –per-recruit analysis for *P. malabarica* indicating $E_{0.1}$ and $E_{0.5}$ (Length-frequency data pooled for 2003-04).

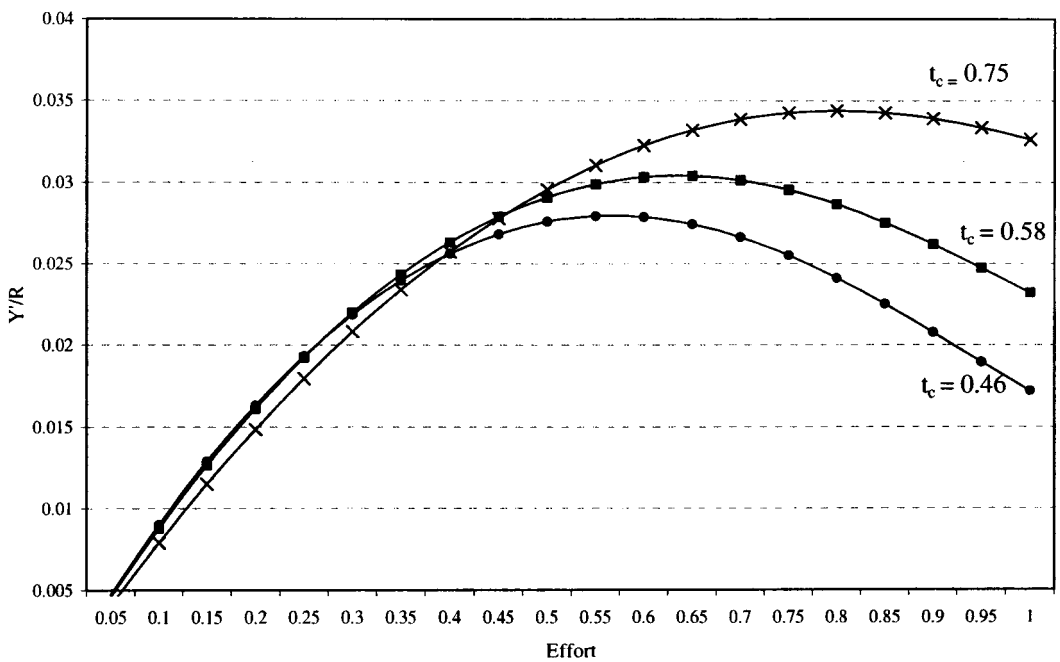

Fig. 6.12: Yield per recruit (Y/R) of *Paphia malabarica* from Dharmadom estuary during December 2003- November 2004.

SUMMARY

The study presents comprehensive account of the biology and population dynamics of *P. malabarica* in Dharmadom estuary along north Kerala coast, Southwest coast of India.

Detailed study on the ecology of the clam bed, allometric relationship, reproduction, condition index, and biochemical changes with maturation and population dynamics of *P. malabarica* is done which is a pioneering effort along the northern part of Kerala. The salient findings of the study are given below.

1. The climatic factor such as rainfall, physical factors such as temperature and turbidity and chemical factors such as pH, dissolved oxygen, salinity, nutrients (nitrate, phosphate and silicate), productivity, sediment texture and organic carbon were analysed for a period one year (2003-2004) from the clam beds (surface and bottom) of Dharmadom estuary and the observations were grouped into pre-monsoon, monsoon and post monsoon seasons. In the present study, marked seasonal variations were observed in all parameters. The physical, chemical and biological features of this estuary are adapted to a seasonal rhythm induced by the annual cycle of monsoon.

2. Although all the ecological factors interact positively or negatively with each other in the estuary, from the present study it could be inferred that *P. malabarica* distribution is governed mainly by salinity and sediment texture. *P. malabarica* prefers high salinity (above 30 ppt) and sandy substratum. These are the two basic criteria which have to be taken care of when implementing clam culture or transplantation of this species to other estuaries to augment clam production.

3. In the present study, relationship between length-weight, length-depth, length-width, total weight-shell weight and total weight–flesh weight of *P. malabarica* are derived and presented.

4. The study shows that b value of female is higher than that of male; indicating that at a given length, female is slightly heavier than the male. There is significant difference in total length- total weight and total weight- flesh weight between the male and female clams. One reason for heterogeneity could be due to difference in weight gain during the reproductive cycles. *P. malabarica* showed isometric growth in length weight relationship. It showed negative allometry in length-width and length-depth relationships. Since *P. malabarica* is found in the bar mouth area these negative allometry maybe an adaptive strategy to improve burrowing efficiency and depth within the substrate avoiding dislodgement from bottom sediment by local hydrodynamics.

5. Detailed study on the reproductive stages along with the histology of gonad was done. The stages were grouped into (1) Indeterminate (2) Maturing (3) Mature (4) Partially spawned and (5) Spent. Spawning season, size at maturity and sex ratio were also investigated in detail.

6. The peak spawning season for *P. malabarica* seems to be in November-December when more than 84 % of the populations are with fully ripe gonads.

7. In Dharmadom estuary the peak spawning period is coinciding with the increase in salinity during the post monsoon season. There is a sudden dip in salinity in the monsoon season which increases during the post monsoon season which could be one of the factors which stimulates spawning.

8. Sex Ratio analysis shows that females outnumbered the males in most of the months. Indeterminate was found in the population from February to July. *Chi- Square* test indicates that only in the month of May, the sex ratio differed significantly at 1 % from the theoretical 1:1 ratio.

9. Length at first maturity (L_m) observed for females and males were 20 mm and 21 mm respectively and derived logistically was 20 mm and 22 mm respectively. Hence for *Paphia*

malabarica from Dharmadom estuary, length at first maturity for female is 20 mm and that of male is 22 mm.

10. The condition index in the present study showed seasonal and monthly variations and it also showed significant difference between the small and large size groups.

11. Major peak in condition index was observed in September and a minor one in June. High condition index (CI) observed in September is just before spawning. A sudden fall in condition index was observed in October which correlates with the onset of spawning. The lowest value of condition index observed in February when the clams were in partially spawned or in spent condition.

12. Condition index and the size also showed relationship, where larger sizes showed higher condition index during pre-monsoon and monsoon seasons.

13. Correlation study has revealed significant positive relationship for maturing clams and the condition index and negative correlation for mature clams with condition index.

14. The present study shows that variations in the condition index occur with changes in environmental conditions. Condition index and salinity showed negative correlation and CI and temperature showed positive correlation.

15. The condition index is high just before spawning (September) and that season is best for harvesting of clams in the estuary, when the yield will be high.

16. The present study shows that there is significant difference in the protein, carbohydrate and lipid concentrations in adductor, gonad and digestive gland in indeterminate, maturing, mature and spent stages of clam *P. malabarica*.

17. The protein concentration in adductor muscle showed variations with the maturing stages. The protein level showed a decrease in the mature clams and it increased in the spent and maturing stages. Decrease in protein level in adductor muscle, coincided with the gonad maturation.

18. Carbohydrate was low in the mature phase and the probable reason could be that the carbohydrate is accumulated in the adductor muscle during pre spawning season and it is utilized during spawning. The lipid concentration in the adductor of mature clams was higher than the other three stages.

19. The protein concentration in gonad of *P. malabarica* was high in the mature clams and it was low in the maturing and indeterminate stages.

20. The carbohydrate concentrations in the gonad of *P. malabarica* also showed fluctuations with the maturation. The carbohydrate concentration in gonad tissue in *P.*

malabarica reaches its peak in the maturing stage and there was a drastic decline in the mature stage.

21. The lipid concentration in the gonad in indeterminate and maturing stage did not vary much, but gradually increased reaching a high in the mature stage and then it decreased in the spent stage.

22. The protein concentration in digestive gland of indeterminate stage was comparatively high when compared to the other three stages. There was no significant difference between the spent and maturing phase. The carbohydrate concentration in digestive gland also showed a similar trend as that of protein in four stages.

23. Lipid in the digestive gland showed significant variation in the mature stage; however there was no significant difference in the other three stages.

24. Growth parameters estimated were $L\infty$ = 56.7 mm, Z/K = 3.096, K = 0.92.yr -1. t_0 for *P. malabarica* is calculated as -0.1596.

25. The life span estimated for clams in Dharmadom estuary was about 2.5 to 3 years. By VBGF, it was estimated that *P. malabarica* in the estuary attains a length of 35.5 mm at the end of first year and 49.6 mm at the end of second year.

26. The total mortality coefficient (Z) was estimated for 2003-2004 was 4.53. The natural mortality coefficient value

estimated was 1.82. The value of fishing mortality coefficient (*F*) estimated was 2.83.

27. The exploitation rate (*U*) was estimated at 0.59 and exploitation ratio (*E*) was 0.6. In Dharmadom estuary *P. malabarica* was taken by the scoop nets. The yield (*Y*) of *P. malabarica* obtained from the catch was 68.8 t.

28. Results of the VPA using the pooled length frequency data for the year showed that F was maximum in the largest size group. Apart from this, higher value for F was noticed in the size classes 35 mm and 38 mm. The mean numbers, the length-wise catch pertaining to each length class showed that catch constituted mainly of 35-38 mm length group and maximum catch (16.5 t) was obtained in the size class 35 mm.

29. Average yield of *P. malabarica* for the period 2003-2004 calculated from the length-based Thompson and Bell prediction model was 115 t, the maximum sustainable yield (*MSY*) calculated from this is 69.3 t.

30. As per Thompson and Bell prediction model, with 80 % of the present effort itself the *MSY* is reached and with reduction of 20 % of the present effort, maximum yield will be obtained. Subsequent addition of effort from the present level does not increase the yield.

The result of the present study will help

- To create knowledge base for this commercially important bivalve along north Kerala, since most of the findings in the present study is first of its kind in that region.
- To understand the biology and population dynamics of *P. malabarica* in that region, which is essential for future clam culture or clam relaying programmes planned in the northern Kerala and to suggest management measures to sustain the fishery.

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