STUDIES ON THE BACKWATER OYSTER *CRASSOSTREA MADRASENSIS* (PRESTON) OF COCHIN HARBOUR

Thesis submitted to
THE UNIVERSITY OF COCHIN
in partial fulfilment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY

By

N. UNNIKRISHNAN NAIR, M. Sc.,
Scientist
CENTRAL INSTITUTE OF FISHERIES TECHNOLOGY
(Indian Council of Agricultural Research)
Cochin-682 029

July 1984

DECLARATION

I hereby declare that this thesis is a record of bonafide research carried out by me under the supervision of Professor N. Balakrishnan Nair, B.Sc. (Hons.), M.A., Ph.D., D.Sc., F.Z.S.I., F.Z.S. (London)., F.N.A.Sc., F.A.Sc., F.N.A., Head, Department of Aquatic Biology and Fisheries, University of Kerala, Trivandrum-695007 and that it has not formed the basis for award of any degree, diploma, associateship, fellowship or other similar titles from this or any other University or Society.

N. Unnikrishnan Nair

Cochin-682 029
10.7.1984

N. UNNIKRISHNAN NAIR

UNIVERSITY OF KERALA
DEPARTMENT OF AQUATIC BIOLOGY & FISHERIES

Professor N. Balakrishnan Nair
B.Sc. (Hons)., M.A.,
Ph.D., D.Sc., F.Z.S.I., F.N.A.Sc.,
F.Z.S.(Lond,)., F.A.Sc., F.N.A.,
Head, Department of Aquatic Biology
& Fisheries

Trivandrum-695 007,
Kerala State

This is to certify that this thesis entitled "Studies on the Back Water Oyster, *Crassostrea madrasensis* (Preston) of Cochin Harbour" embodies the results of original work conducted by Mr. N. Unnikrishnan Nair, Scientist, Central Institute of Fisheries Technology, Cochin-682 029, under my supervision and guidance from 15.9.1981 to 10.7.1984. I further certify that no part of this thesis has previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles of this or any other University or Society. He has also passed the Ph.D. qualifying examination of University of Kerala, held in Dec. 1968.

Trivandrum-695 007,
10.7.1984

Dr. N. BALAKRISHNAN NAIR

ACKNOWLEDGEMENTS

It is with profound gratitude that I express my indebtedness to Prof. N. Balakrishnan Nair, B.Sc.(Hons), M.A., Ph.D., D.Sc. F.Z.S.I., F.N.A.Sc., F.Z.S.(Lond.)., F.A.Sc., F.N.A., Professor and Head, Department of Aquatic Biology and Fisheries, University of Kerala, Trivandrum-695 007 for suggesting this problem to me and also for his enlightened guidance and criticism at every stage of this investigation.

I am indebted to Shri. A.G. Radhakrishnan and Dr. P.G. Viswanathan Nair for the help in the biochemical estimations and to Shri. A.K. Kesavan Nair and Shri.H.Krishna Iyer for assistance in the statistical treatment of the data.

I am thankful to Dr. C.C. Panduranga Rao, Director, and Shri. R. Balasubramanyan, Scientist-in-Charge of Craft Division, Central Institute of Fisheries Technology, Cochin-682 029 for providing necessary facilities to carry out this investigation at the CIFT laboratories.

N. UNNIKRISHNAN NAIR

CONTENTS

INTRODUCTION

INTRODUCTION

The edible backwater oyster of India belongs to the genus Crassostrea, which is an important shell fish of commercial value in the country. Different aspects of the biology of oysters have been studied in various parts of the world and innumerable scientific papers are published on the subject (Korringa, 1952; Loosanoff & Davis, 1963; Galtsoff, 1964; Yonge, 1960). However, studies pertaining to the biology of this very important commercial mollusc from the Indian waters are few, even though observations on molluscs date back to the end of the last century. Thus, Melvill & Abercrombie (1893) identified and described the littoral marine molluscs of Bombay. Melvill (1893) separately published descriptions of 25 new species of marine molluscan shells from Bombay in the same year. Nevill (1877) had also listed the molluscs identified and preserved in the Indian museum. Subsequently the systematics of cephalopods in the Indian museum has been worked out by Goodrich (1896), Massy (1916), Adam (1939) and Preston (1909, 1910, 1911, 1914, 1915 & 1916). Annandale & Kemp (1916) studied the oysters from Chilka Lake. Different aspects of the pearl oyster and pearl oyster fisheries such as the systematics, morphology, life history, parasites, predators, pests, pearl formation, location of pearl banks, their ecology and associated flora and fauna of the Gulf of Mannar have been examined and reported by Herdman (1903-1906) to the Government of Ceylon and these are still considered as very important reference works on the subject. Hornell investigated in greater detail the molluscan fauna of the erstwhile Madras State and published very valuable information pertaining to the habits, distribution, fisheries and utilization of oysters. In this connection his contribution pertaining to pearl fisheries in the Gulf of Mannar (Hornell, 1905), report to the Government of Baroda on marine zoology of Okhamandal in Kathiawar (Hornell, 1909a), the prospects of establishing a pearl fishery and other marine industries on the Okhamandal (Honrnell, 1909b), report on the anatomy of Placuna placenta with notes on the distribution and economic uses (Hornell, 1909c), explanation of the principal determining factor in oyster spawning in the Madras Backwaters (Hornell, 1910a), the practice of oyster culture at Arcachon (France) and its lessons for India (Hornell, 1910b), explanation of the cyclic character of pearl fisheries of the Gulf of Mannar (Hornell, 1916a) report on the pearl fishery held at Tondi in 1914 (Hornell, 1916b), the utilization of coral shells for lime making in the Madras Presidency (Hornell, 1916c), records on edible molluscs of the Madras Presidency (Hornell, 1917), the pearl fisheries of the Gulf of Mannar and Palk Bay (1922a), studies on the common molluscs of South India (Hornell, 1922b) and also his studies on Indian molluscs in general (Hornell, 1949a,b,c and Hornell, 1951) deserve special mention. The morphology of the rock oyster *Ostrea* (*Crassostrea*) *cucullata* has been dealt by Awati & Rai (1931). They have also provided a synopsis of eleven species of oysters occurring on Indian coasts and extended their observations to the anatomy, breeding period, early development, pests and fisheries of *Ostrea cucullata*. Rai also described the oyster industry in the Islands of Bombay and Salsette and the shell fisheries of the Bombay Presidency (Rai, 1928; 1932; 1933). Devanesan & Chacko (1955) have published valuable information on the bionomics, early swimming stages, culture and ecology of the Madras edible oyster *Ostrea madrasensis* (Preston).

A new impetus to the study of Indian molluscs particularly oysters has been given consequent on the establishment of the Central Marine Fisheries Research Institute at Mandapam in 1947. The molluscan fisheries of the country have been studied by several workers of the CMFRI and much valuable information on the biology and fisheries of the edible oyster *Crassostrea madrasensis* (Preston) has been published (Rao, 1951, 1953, 1956, 1958, 1969; Rao & Nayar, 1956). Even though Awati &

Rai (1931) have reported 11 species as occurring on the Indian coasts, as Rao (1974) pointed out the occurrence of some of these species has yet to be confirmed. However, four species of oysters which are commercially important and occurring in appreciable quantities all along the Indian coast are *Crassostrea madrasensis* (Preston) *Crassostrea cucullata* (Born), *Crassostrea gryphoides* (Schlotheim) and *Crassostrea discoidea* (Gould). *Crassostrea madrasensis*, the common backwater oyster is confined to the backwaters and estuaries of the southwest and east coasts, *Crassostrea cucullata*, the rock oyster is found on the inter-tidal rocky coasts, *Crassostrea gryphoides* inhabit the muddy creeks while *Crassostrea discoidea* occupy the littoral zone of coastal areas.

The family ostreidae is grouped under the order Anisomyaria (Thiele, 1931) based on the nature of the adductor muscles, the anterior adductor muscle being reduced or totally suppressed in the members of the order. Pelseneer (1906) has included the family Ostreidae in the order eulamellibranchia, which consists of bivalves with gills composed of branchial filaments united at regular intervals by vascular junctions. Members of the sub-order Ostracea (Series according to Thiele) are monomyarian or with very small anterior adductor muscle, with the mantle open, reduced foot, folded gills and inequivalve shells. Ostreidae is characterised by reduced foot and absence of byssus glands, the gills which are fused to the mantle and the shell fixed to the substratum by the left valve which is larger than the right valve.

There existed much confusion in the classification of the family ostreidae. Earlier classification of oysters was based on the shape, size, colour and texture of the adult shell (Korringa, 1952). Accordingly about 100 species of recent oysters and about 500 species of fossil oysters were recognised. It is well known that the nature of the habitat such as rock, gravel, sand, silt and other factors of the habitat such as salinity current velocity, tides, waves and depth etc. contribute considerably to the shape and texture of shells in oysters and creation of species entirely based on the morphology of the adult shell is unreasonable. It was Ranson (1948, 1950 & 1960) who unravelled the taxonomic puzzle pertaining to this highly polymorphic group. He has taken into consideration the structure of the larval shell, which is free from the influence of habitat, for the classification of oysters and distinguished three genera, namely, <u>Pycnodonta</u> (Synonymous with <u>Crassostrea</u>) <u>Gryphaea</u> and <u>Ostrea</u>. <u>Pycnodonta</u> which is larviparous, is characterised by equal larval shell valves, the presence of 5 teeh equally divided on the provinculum and 10 small teeth on the edge of each valve. The rectum traverses through the ventricle, promyal chamber present and chalky deposits are lamellated. *Ostrea* is larviparous, the larval shell valves are unequal with two teeth on each side of the provinculum, the anterior pair reduced and interior ligament placed in the provinculum. The rectum does not traverse through the ventricle, the promyal chamber absent and chalky deposits are lamellated.

Hemming, as cited by Korringa (1952) has included *Gryphaea arcuata* Lamark as the type species of the genus *Gryphaea*. Children's selection of *Gryphaea angulata* as the type species of the genus *Gryphaea* was invalid as in 1801, when Lamarck first published the generic name *Gryphaea* (Korringa, 1952). As pointed out by Korringa (1952) *Gryphaea angulata* was 'nomen nudum' (mere name) when Lamarck first published the generic name *Gryphaea* and does not merit consideration as an originally included species. Hence, Gunter (1950) pointed out that the generic name *Gryphaea* can be used for fossil species only. The generic name *Crassostrea* (Sacco, 1897) is the first valid name for oysters of the type *angulata*, *virginica*, *gigas*, *madrasensis* and *cucullata* (Rao, 1974). The genus *Crassostrea* is distinguished by the following features: the shell is very irregular in shape, the left valve is cemented to the substratum, hinge toothless with linear margin, the ligament is partly external and laminated upon a trigonal area in each valve, only posterior adductor muscle present, adult is oviparous, rectum does not traverse through the ventricle, promyal chamber present and chalky deposits are lamellated.

Notwithstanding the considerable amount of work that has been carried out on oysters from other parts of the world, our information about this very valuable mollusc is still fragmentary and inadequate. This prompted Professor N.Balakrishnan Nair, to suggest this problem to the present author for further investigations. In the present study an attempt has been made among others to study the environment, the nature of biofouling; the settlement, shell dimensions and their inter-relations, the age and growth, the condition index, the percentage edibility, the effect of hydrographical factors on the oysters, the biochemical changes and trace metal content of soft tissue, the parasites and associates of *Crassostrea madrasensis* (Preston).

REFERENCES

Adam, W. (1939) The Cephalopoda in the Indian Museum, Calcutta *Rec. Indian Mus.* **41**, 61-110

Annandale, N. & Kemp, S. (1916) Family Ostreidae from fauna of Chilka Lake. *Mem. Indian Mus.* **5**, 348-349

Awati, P.R. & Rai, H.S. (1931) *Ostrea cucullata* (The Bombay oyster) *Indian Zool. Mem.* **3**, 107 pp.

Devanesan, D.W. & Chacko, P.I. (1955) On the Madras edible oyster (*Ostrea madrasensis*). *Contr. Fish. Biol. Stn.* Dept. of Fisheries, Madras, **2**, pp.60

Galtsoff, P.S. (1964) The American Oyster *Crassostrea virginica* (Gmelin) *Fish. Bull. Fish Wildl. Serv.* U.S. **64**, 1-480

Goodrich, E.S. (1896) Report on a collection of Cephalopods from the Calcutta Museum, *Trans. Linn. Soc.* London. **7**, 1-24

Gunter, G. (1950) The generic status of living oysters and the scientific name of the common American species. *Am. Midl. Nat.* **43**, 438-449

Herdman, W.A. (1903 to 1906) *Rep. Govt. Ceylon Pearl Oyster Fish. Gulf Mannar. R. Soc. London.* **1**, 1-307, **2**, 1-300; **3**, 1-384; **4**, 1-326; **5**, 1-452

Hornell, J. (1905) *Rep. Govt Madras Indian Pearl Fish. Gulf Mannar. Govt. Press, Madras*

Hornell, J. (1909a) The Marine zoology of Okhamandal in Kathiawar, *Rep. Govt Baroda*, R. 1, William and Norgate, London. pp.148

Hornell, J. (1909b) The prospects of establishing a pearl fishery and other marine industries on the coast of Okhamandal. *Rep. Govt. Baroda*, William and Norgate, London. pp.1-34

Hornell, J. (1909c) The anatomy of *Placuna placenta* with notes upon the distribution and economic uses. *Rep. Govt. Baroda*, William and Norgate, London, pp.43-97

Hornell, J. (1910a) Note on an attempt to ascertain the principal determining factor in oyster spawning in Madras Backwaters (Madras Fisheries Investigations). *Madras Fish. Bull.* **4**, 25-31

Hornell, J. (1910b) The practice of oyster culture at Arcachon (France) and its lessons for India. *Madras Fish. Bull.* **5**, 1-90

Hornell, J. (1916a) An explanation of the cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.* **8**, 11-22

Hornell, J. (1916b) Report on the pearl fishery held at Tondi in 1914. *Madras Fish. Bull.* **8**, 43-92

Hornell, J. (1916c) The utilization of coral shells for lime burning in the Madras Presidency. *Madras Fish. Bull.* **1**, 105-126

Hornell, J. (1917) The edible molluscs of the Madras Presidency. Madras Fish. Bull. 11, 1-51

Hornell, J. (1922a) The Indian pearl fisheries of the Gulf of Mannar and Palk Bay. Madras Fish. Bull. 16, 1-188

Hornell, J. (1922b) The common molluscs of South India. Madras Fish. Bull. 14, 97-215

Hornell, J. (1949a,b,c) The Study of the Indian mulluscs. Parts i, ii and iii. J. Bombay nat. Hist. Soc. 48, 303-334, 543-569 and 750-774

Hornell, J. (1951) Indian molluscs. Bombay nat. Hist. Soc. pp.96

Korringa, P. (1952) Recent advances in oyster biology. Q. Rev. Biol. 27, 266-308 and 339-365

Loosanoff, V.L. & Davis, H.C. (1963) Rearing of bivalve molluscs. In 'Advances in Marine Biology', Vol.1 (Russel, F.S. Ed.) 1-136 Academic Press, New York

Massy, A.L. (1916) The Cephalopods of the Indian Museum Rec. Indian Mus. 12, 185-248

Melvill, J.C. (1893) Descriptions of 25 new species of marine shells from Bombay. Mem. Proc. Manchr. lit. phil. Soc. Ser. 4, 7, 52-66

Melvill, J.C. & Abercrombie, A. (1893) The marine mollusca of Bombay. Mem. Proc. Manchr. lit. phil. Soc. Ser. 4, 7, 17-51

Nevill, G. (1877) Catalogue of Mollusca in the Indian Museum, Calcutta

Pelsenner, P. (1906) Mollusca. In Lankester's Treatise on Zoology. Adam and Charles Black, London, pp.355

Preston, H.B. (1909) Descriptions of two new shells from South India. Rec. Indian Mus. **3**, 277-278

Preston, H.B. (1910) Description of new shells in the collection of the Indian museum from Burma, Siam and Bay of Bengal. Rec. Indian Mus. **5**, 33-36

Preston, H.B. (1911) Descriptions of six new species of shells from Bengal and Madras. Rec. Indian Mus. **6**, 39-42

Preston, H.B. (1914) Mollusca from the Chilka lake on the east coast of India. Rec. Indian Mus. **10**, 297-310

Preston, H.B. (1915) A further report on a collection of mollusca from the Chilka Lake on the east coast of India. Rec. Indian Mus. **11**, 289-310

Preston, H.B. (1916) Report on a collection of mollusca from the Cochin and backwaters. Rec. Indian Mus. **12**, 27-39

Rai, H.S. (1928) A short account of the oyster industry in the Islands of Bombay and Salsette. J. Bombay nat. Hist. Soc. **33**(4), 893-898

Rai, H.S. (1932) The shell fisheries of the Bombay Presidency. J. Bombay nat. Hist. Soc. **35**(5), 826-847

Rai, H.S. (1933) The shell fisheries of the Bombay Presidency. *J. Bombay nat. Hist. Soc.* **36**(4), 884-897

Ranson, G. (1948) Prodissoconques et classification des Ostreides vivants. *Bull. Mus. Hist. nat. Belg.* **24**, 1-12

Ranson, G. (1950) La chambre promyaire et la classification Zoologique des Ostreides. *J. Conchyliol.* **90**, 195-200

Ranson, G. (1960) Les prodissoconques (*Coquilles larvaires*) *des Ostreides vivants. Bull. de l'Istitut Oceanographique*, No.1, **183**, 1-41

Rao, K.S. (1974) Edible bivalves. Mussels and oysters. In '*The Commercial Molluscs of India*' *Bull. Cent. mar. Fish. Res. Inst. Cochin*. **25**, pp.4-39

Rao, K.V. (1951) Observations on the probable effects of salinity on the spawning, development and setting of the Indian backwater oyster *Ostrea madrasensis* (Preston). *Proc. Indian Acad. Sci.* **33B**, 231-256

Rao, K.V. (1953) Sex change in the oviparous Indian backwater oyster *Ostrea madrasensis* (Preston) *Curr. Sci.* **22**, 377-378

Rao, K.V. (1956) Seasonal gonadal changes in the adult backwater oyster, *Ostrea* (*Crassostrea*) *madrasensis* (Preston) from Ennur near Madras. *Proc. Indian Acad. Sci.* **44B**, 332-356

Rao, K.V. (1958) Molluscan Fisheries. In 'Fisheries of the West coast of India' (Jones, S. Ed.,) *Cent. mar. Fish. Res. Inst. Mandapam Camp*, pp.55-59

Rao, K.V. (1969) Molluscs have many uses. *Indian Fmg*. **29**(9), 41-45 and 62

Rao, K.V. & Nayar, K.N. (1956) Rate of growth in spat and yearlings of the Indian backwaters oyster, *Ostrea madrasensis* (Preston). *Indian J. Fish*. **3**, (2), 231-260

Sacco, F. (1897) 1 molluschi dei terreni terziarii del Piemonte e della, Liquria-Part 23 (Ostreidae, Anomidae e Dimydia) *Boll. Musei. Zool. Anat. Comp. R. Univ. Torino*. Vol.12, No.298, 99-100

Thiele (1931) Handbuck der systematis chen weichtierkunde, Zweiter Band (*scaphopoda*, *pelecypoda* and *cephalopoda*)

Yonge, C.M. (1960) *Oysters*, Collins, London. 209 pp.

CHAPTER 1

THE ENVIRONMENT

CHAPTER 1

THE ENVIRONMENT

1.1. Introduction

Cochin (Lat. 9° 58' N, Long. 76° 16' E) is a major port on the south-west coast of India. It is a natural harbour and is continuous with the long stretch of backwaters extending up to Alleppey in the south. The Cochin Backwaters maintain connection with the Arabian Sea on the west through a gut of approximately 450 m wide. To the north and south, Cochin Harbour is continuous with extensive shallow brackish water lagoons, which receive the waters from several rivers. These backwaters extend for the most part parallel to the coast line and are separated from the sea on the west, by low belts of sand. The Cochin Backwaters is the northern extension of the Vembanad Lake (Fig.1). Cochin Harbour receives the full benefit of the south-west monsoon from the middle of May to August and some precipitation from the north-east monsoon during October to December. Of the total rain fall in this region, more than half falls during the four months from May - August. During the south-west monsoon and even after it the salinity of the water is very low

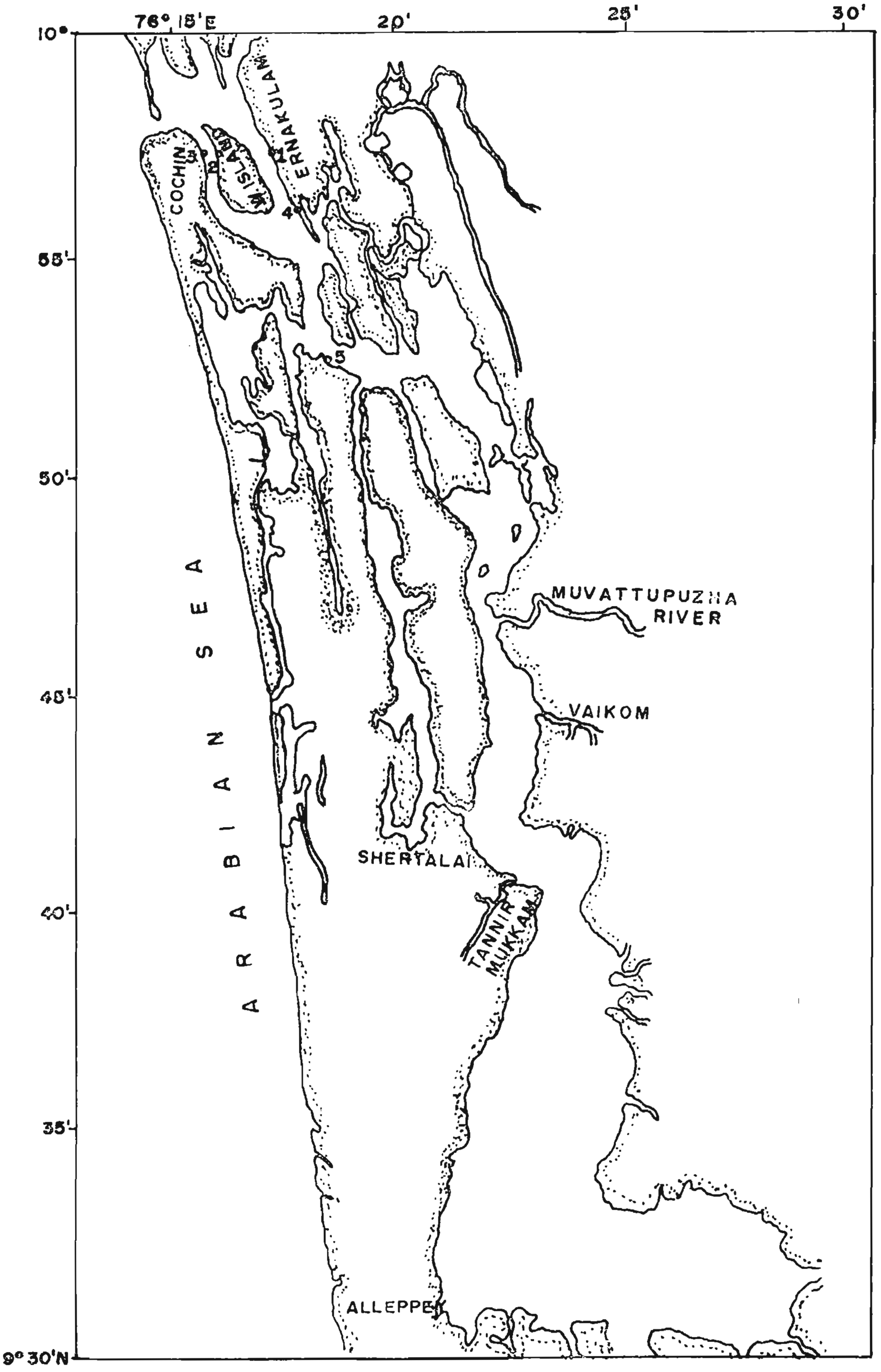


Fig. 1.1. THE VEMBANAD LAKE AND THE COCHIN BACKWATERS

owing to fresh water influx from the rivers. According to Wallershaus (1972) "the tidal currents cause thorough mixture of waters as long as the flow from the rivers does not supply the upper layer with new fresh water. When this occurs the backwater is stratified into a surface layer with low salinity and a bottom layer with high salinity. The strength of the river outflow depends on the rainfall which in turn, depends on meteorological conditions. The higher the fresh water supply, the greater the stability which supports the stratification of the backwater into two layers". The depth in the harbour area varies from 1-5 m except in the dredged shipping channels, namely, the Cochin Approach Channel, the Ernakulam Channel and the Mattancherry Channel where the depth is maintained through dredging at about 12 m for navigation (Fig.1.2). The mean tidal difference is 45 cm varying between 110 and 5 cm.

Our knowledge of the different environmental conditions and their temporal and spatial variations in the various estuaries located on the west coast of India is limited. Compared to other estuaries such as the Zuari - Mandovy Estuaries of Goa, the Korapuzha Estuary, the Netravathi - Gurpur Estuary, the Kelwa Backwaters and the Mulki Estuary, the hydrography of the Cochin Backwaters has received better attention. The notable works on Cochin Backwaters are those of George & Kartha (1963)

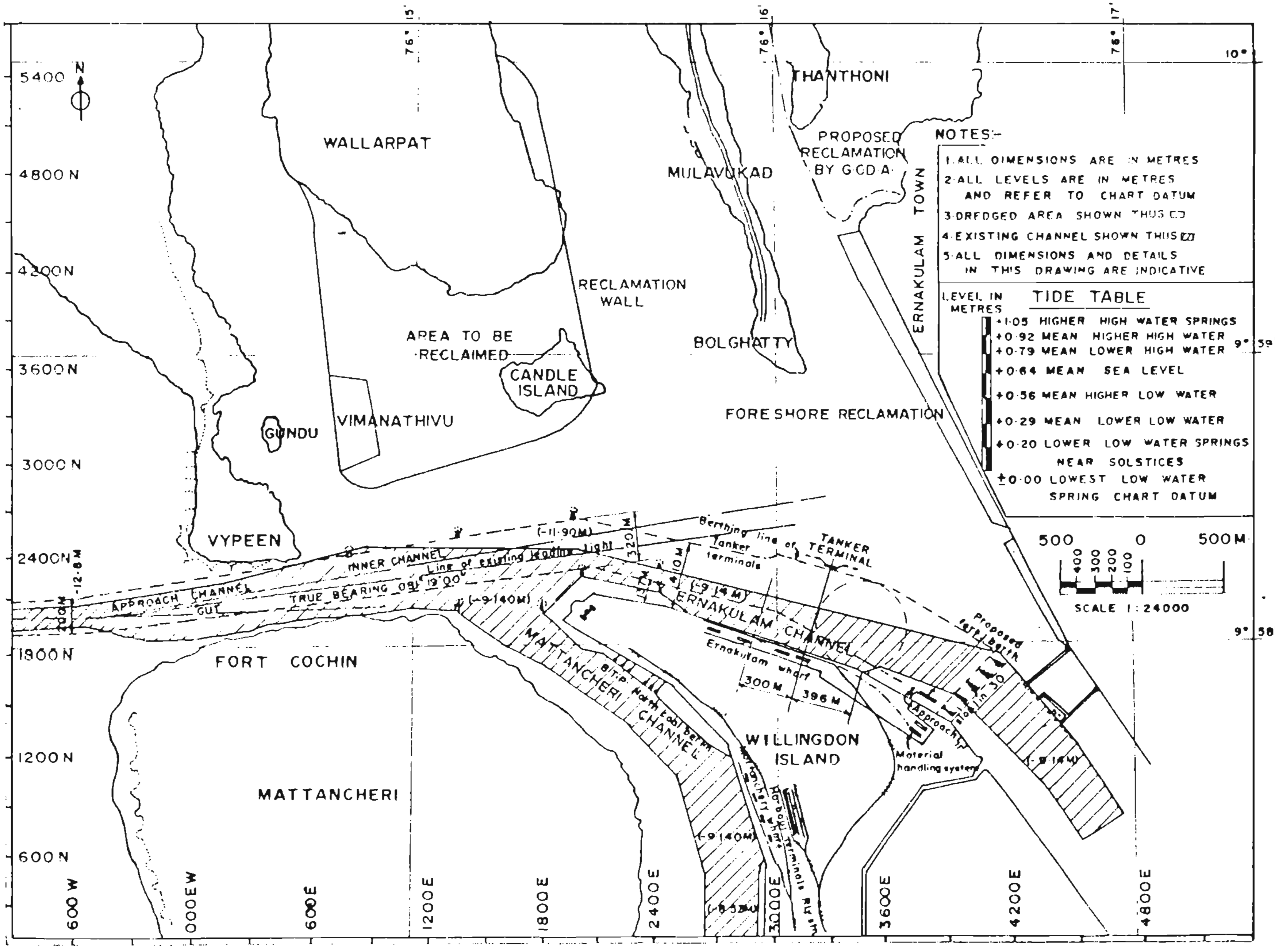


Fig .1.2. THE COCHIN HARBOUR AND COCHIN BACKWATERS on the surface salinity with reference to tide, Ramamirtham & Jayaraman (1963) on some aspects of the hydrographical conditions of the backwaters around Willingdon Island, Qasim & Reddy (1967) on the estimation of plant pigments during the monsoon months, Qasim et al. (1968) on solar radiation and its penetration, Qasim et al. (1969) on organic production, Devassy & Gopinathan (1970) on the hydrobiological features of Kerala Backwaters during the premonsoon and the monsoon, Qasim & Gopinathan (1969) on the tidal cycle and the environmental features, Wallershaus (1972) on the hydrography, Shynamma & Balakrishnan (1973) on the diurnal variation of some physicochemical factors in the Cochin Backwaters during the south-west monsoon, Haridas et al. (1973) on salinity, temperature, oxygen and zooplankton biomass of the backwater from Cochin to Alleppey and Manikoth & Salih (1974) on the distribution characteristics of nutrients in the estuarine complex of Cochin.

Information pertaining to other west-coast estuaries are those of Dehadrai (1970) on the changes in the environmental features of the Zuari & Mandovi estuaries in relation to tide, Dehadrai & Bhargava (1972) on the seasonal organic production in relation to environmental features in Mandovi & Zuari estuaries, benthic studies such as standing crop and faunal composition in relation to bottom salinity, distribution and substratum characteristics of the Mandovi Estuary by Parulekar & Dwivedi

(1974), ecology of clam beds in Mandovi, Cumbarjua Canal and Zuari estuarine system of Goa, (Parulekar et al. 1973), hydrography and suspended sediment load of the oceanic and estuarine waters adjoining Marmagoa Harbour during early summer by Cherian et al. (1974), variations in physical characteristics of the waters of the Zuari Estuary by Cherian et al. (1975), ecology and environmental monitoring of Mandovi, Zuari and Cumbarjua canal complex by Dwivedi et al. (1975). Rao & George (1959) studied the hydrography of the Korapuzha Estuary of Malabar, Kerala State and the seasonal variation in hydrographic conditions of estuarine and oceanic waters adjoining old Mangalore Port was examined by Reddy et al. (1979). Durve & Bal (1961) investigated the hydrology of the Kelwa Backwater and the adjoining sea.

In the aquatic habitat, more particularly in the ecotone, the environment plays a paramount role in the life of the organisms. It is known that the unidirectional stream currents and oscillating tidal currents meet and bring about complicated changes in sedimentation, mixing of water and other physiological features in the estuarine system, thereby greatly influencing the biota. The constant change in the physical and chemical evironment of the estuary, necessitates physiological adjustment of the inhabitants of the estuary. Many of these organisms in these special habitats, through years of acclimatization and physiological adjustments show considerable tolerance to many fluctuating environmental factors.

The qualitative and quantitative structure of the fouling community, their settlement, growth, breeding intensity and survival rate have a great bearing on the several essential physical and chemical factors prevalent in the ambient medium, the more important of which are temperature, salinity, pH, pollution, turbidity, water movements, light penetration, texture and colour of the substratum. Water has a very high latent heat of vapourization or evaporation and its heat carrying capacity coupled with the enormous volume of sea water result in rhythmic changes of temperature throughout the year. Temperature affects nutrition, growth, reproduction and larval development of many invertebrates, (Moore, 1958; Kinne, 1964; 1970; Orton, 1920; Giese & Pearse, 1974). It is known that in tropics (Paul, 1942) where the temperature does not show considerable fluctuations between the maxima and minima, there is apparently no distinct periodicity in fouling organisms including oysters. However, the constant settling down of generations of organisms, production of several offsprings in an year, their rapid growth and attainment of sexual maturity at a surprisingly early stage are all brought about as a result of the constant prevalence of high temperature throughout the year. Water temperature influences the metabolic activities, such as nutrition, growth, gametogenesis, spawning, and development (Nelson, 1921; 1921a; Galstoff, 1928; Hopkins, 1931; Elsey, 1936; Orton, 1937; Ranson, 1948; Loosanoff, 1950a; Loosanoff & Nomejko, 1949; Loosanoff & Davis, 1952; Galstoff, 1964; Walne, 1958; 1972; Pearse, 1965; Dame, 1972; Maurer & Aprill, 1973; Spencer & Gough, 1978).

Salinity of the water has been recognised as an important factor controlling the occurrence of animals. Salinity factor is relatively important especially along the south-west coast of India where the prevailing monsoons cause heavy rainfall. Accordingly the salinity shows considerable variations in the estuaries and coastal areas. While salinity and specific gravity ranges are insignificant in the open ocean, in the estuaries and harbour areas salinity fluctuations are very much marked owing to land drainage. Many of the marine organisms in these special habitats through years of acclimatization and physiological adjustments have shown remarkable tolerance for wide variations in salinity. Several studies pertaining to the metabolic activity of marine organisms in relation to salinity supports this view. (Panikkar & Aiyar, 1939; Loosanoff, 1950; Nagabhushanam, 1955; Pillay, 1958; Paul, 1942; Giese, 1959; Antony Raja, 1963; Nair, 1967; Sandison, 1966; Hill, 1967, Wilson, 1969).

Most of the fouling organisms are unable to withstand exposure to low salinity and such forms are usually absent on structures well inside the estuaries. However, there is considerable variation in the tolerance limits and there are forms capable of surviving even in very low salinities (Hutchins, 1945; Pilsbry, 1916). Many of the barnacles and other fouling organisms are killed and sloughed off during periods of low salinity and on the onset of normal conditions, the areas left bare are recolonised through the fresh settlement of planktonic larvae brought in by the tidal currents and other movements of the medium. Observations of Nair (1967) have shown that at Cochin Harbour the fouling has been the least in quantity and quality during the monsoon period which extends from the middle of May to the end of November (south-west and north-east inclusive) and the cause was reasonably attributed to the fall in the salinity of the water during the period.

The horizontal and vertical distribution of animals particularly the sedentary fouling organisms are also controlled to a considerable extent by the distribution of salinity in the area. A gradation can be seen in the incidence of some of the fouling organisms in estuaries or in the lower reaches of river mouths. They exhibit a characteristic zonation in distribution, correlated with the distribution of salinity. There are certain fouling animals which are characteristic of certain estuarine areas and are unable to survive under marine conditions. The extent of distribution by marine species in estuaries depends on the degree to which the salinity varies with tides. Several works on salinity responses of marine and brackish water animals are available of which Schleiper (1957) Pears & Gunter (1957), Kinne (1964, 1966, 1967, 1971), Moore (1958) deserve special mention. Some of the important works, on the effect of salinity with special reference to oysters are those of Ranson (1943), Butler (1949), Loosanoff (1950), Rao & Nayar (1956) and Durve & Bal (1962).

The availability of dissolved gases such as oxygen and carbon dioxide and the presence of hydrogen sulphide through organic decay in the aquatic environment where the fouling organisms occur have a profound influence on the whole community both directly and indirectly. Their abundance in the environment is of direct critical concern to the life of organisms in the respective habitats. Oxygen may act as a limiting factor in certain estuaries and harbour areas with sewage influence. The decay of organic matter may restrict or reduce the organisms present in an area. In certain harbours of India with heavy pollution, the oxygen content is always low and the production of hydrogen sulphide has been noted (Nagabhushanam, 1962). Under such condition oysters, mussels and such other fouling organisms remain cut off from the unfavourable ambient condition by closing their shells. This naturally could lead to a temporary cessation of normal activities, resulting in poor growth or if such conditions persist for long period they would ultimately perish. The influence of dissolved gases on marine invertebrates has been studied by Vernberg (1972). The ambient oxygen in the medium does not exert much influence on the metabolism of many molluscs untill very low oxygen tension is attained. Similar observation has been made in Crassostrea gigas, Ostrea edulis and Ostrea circumpicta by Nozawa (1929), Galtsoff & Whipple (1930) and Ishida (1935).

The enclosed waters of the harbour and other bodies of coastal waters contain silt, detritus and other particulate matter in fine suspension. These particles of suspended matter affect the organisms in many ways. It can smother sessile organisms by forming a thick mat-like cover over the substrata or prevent the very settlement of certain species. Large quantities of suspended matter can clog the respiratory organs and can disable the normal functioning of the ciliary feeders such as oysters, which in turn restrict the normal growth (Coker et al. 1919). Thick silt and resulting turbidity reduces the penetration of light, preventing the growth of green plants and restrict organic productivity. Those forms, which need plants as a substratum for settlement are, therefore, unable to settle in such situations.

The role of substances that cause turbidity in water and its consequent effects on the rate of pumping has been described by Loosanoff & Tommers (1948). According to them 0.1 g/l of the substance in sea water reduced the rate of pumping by 40% of the normal value. When the concentration was increased to 1.9 g/l and 3-4 g/l the experimental oysters pumped only 20% and 4% of the normal quantity of water through the gills. Even though oysters survived and reproduced in turbid waters a correlation between increase in concentration of turbidity producing substances and decrease in the rate of pumping of water by oysters was observed by them. Loosanoff & Engle (1947) also observed that the density of microorganisms influences the rate of pumping of water by oysters. However, Korringa (1952) concludes that "Certain inhibiting substances present in dense plankton cultures probably metabolic products of microorganisms" are responsible for the reduction in the pumping rate of water in oysters. According to Davis (1960) and Loosanoff (1961, 1965) higher turbidity can also influence survival and metamorphosis of eggs and larvae of oysters.

Changes in the hydrogen ion concentration of the water in an estuary may be due to freshwater infiltration owing to precipitation or ingress by sea water. pH is also influenced by influx of polluted water from industries. Loosanoff & Tommers (1947) observed the rate of pumping in oysters at various pH values. They noticed normal pumping at pH 7.75. From 6.75 to 7.0, oysters pumped more vigorously than the control ones for the initial few hours only. At pH 6.5, rate of pumping was slow and at 4.14, 10% decrease in pumping was noticed. Calabrese & Davis (1966, 1970) observed a critical pH of 6.75 for the successful recruitment of Crassostrea virginica.

Movements of water owing to waves, tides and currents affect the disperal, settlement and growth of sessile organisms. Water movement facilitates the existence of sessile animals, since food particles are brought to them and their waste products in turn are carried away. These movements of water are sometimes harmful when the larvae of the littoral forms are swept far away to the open sea where settlement is impossible or to places where conditions are unfavourable for settlement. The velocity of water currents on the surface of the substratum is important since larvae of foulers select suitable sites for settlement in relation to the velocity gradient of currents (Smith, 1946). The attachment and survival of barnacles are mostly influenced by water currents. Crisp & Stubbings (1957) have found that current has very little influence on the cyprids at the time of fixation. Regarding the effect of the stage of tide on the settlement of barnacle cyprids conflicting views are expressed. (Daniel, 1954; Weiss, 1947; Visscher & Luce, 1928; Pyefinch, 1948; Barnes, 1950).

Many of the larvae of foulers are negatively phototropic and they prefer darker surfaces, while a few are positively phototropic. There seems to be no agreement among various workers as regards to the probable effect of light on the settlement of barnacle cyprids. Visscher & Luce (1928) observed that the barnacle cyprids react negatively to light at the time of attachment, while Weiss (1946) and McDougall (1943) are of the view that they are positively phototropic at the time of attachment. Light has no apparent effect on the opening and closing of shell valves in oysters (Galstoff, 1964). Similar observations were made by Loosanoff & Nomejko (1946). However, these observations are not in agrement with those of Nelson (1921, 1923).

Thus it is clear that several factors of the aquatic environment are directly or indirectly responsible for the many life activities of sedentary organisms including oysters. A detailed study of the influence of hydrological and meteorological parameters such as salinity, temperature, turbidity, dissolved oxygen and rainfall on the various life activities of sedentary organisms with special reference to the backwater oysters was undertaken.

1.2. Materials and methods

Water samples were collected from the test-site daily for a period of eighteen months. Samples for dissolved oxygen were fixed immediately after collection. Dissolved oxygen was estimated by the method of Winkler and salinity by the Mohr-Knudson method, both as given in Strickland & Parsons (1968). Turbidity was measured with a turbidometer which can read turbidity from 0.1 to 50 p.p.m. (serial no.725, Applied Electronics Pvt. Ltd., Bombay). The air temperature and surface water temperature were recorded correct to 0.1°C using an ordinary thermometer.

1.3. Results

Daily data pertaining to air temperature, surface water temperature, salinity, dissolved oxygen and rainfall during the period of observation are given in Tables 1.2 to 1.10 and the weekly averages including turbidity in Table 1.1. Figures 1.3 - 1.7 present the hydrographic and meteorological data based on the weekly average values given in Table 1.1. The data on rainfall represent monthly averages (Table 1.10).

Table 1.10 shows that the maximum rainfall in Cochin was during June being 782.1 mm followed by July (574 mm). Based on rainfall at Cochin, the year can arbitrarily be divided into pre-monsoon (Feb-May), monsoon (June-September) and post-monsoon (October to January). The South-west monsoon started in May and extended to August-Sept. and contributed to the bulk of the rainfall in this region. After the South-west monsoon, the rainfall decreased gradually. This was followed by the North-East monsoon in October which lasted till November. From January onwards precipitation was negligible and the period was characterised by increasing drought.

The fluctuation of air temperature was not very significant. Maximum air temperature of 34.0°C was observed on May 13th (Table 1.3). The minimum was on July 8th being 27.2°C (Table 1.4). The difference observed between the maximum and minimum was only 6.8°C. The pattern in the fluctuation of air temperature and water temperature was more or less similar.

Water temperature also showed slight variations. The maximum water temperature recorded was 32.5°C on May 9th (Table 1.3) with minimum of 26.7°C during July, 8 (Table 1.4). The variation between maximum and minimum was only 5.8°C.

Dissolved oxygen recorded a maximum value of 8 ml/l on October 1st (Table 1.6) with a minimum of 1.4 ml/l during January 10 (Table 1.8). The difference in maximum and minimum was 6.6 ml/l.

Marked variation of salinity was observed. The maximum salinity observed was during the month of February 20th being 34.9 (Table 1.8) with a minimum of 0.6‰ during August

2 (Table 1.5). A wide fluctuation in salinity was thus noticed in the estuary ranging from almost fresh water conditions during the monsoon to typically marine conditions during the pre-monsoon. The abrupt drop of salinity from 34.9‰ to 0.6‰ was very significant. The pre-monsoon period February to May, registered uniformly high salinity. From October onwards the salinity gradually fluctuated and reached the maximum again during the post-monsoon period.

Turbidity recorded a maximum average value of 27.9 p.p.m during the **third** week of June and minimum of 10.2 p.p.m during the second week of February. The water was more turbid during the monsoon period than during the pre and post-monsoon periods.

1.4. Discussion

An understanding of the seasonal fluctuations in hydrographical characters of estuaries is an essential pre-requisite for interpreting the causative factors responsible for the incidence, relative abundance and distribution of animal populations. It is known that the hydrography of the Cochin Backwaters, is considerably influenced by the prevailing seasons (Wallershaus, 1972; Ramamirtham & Jayaraman, 1963; Shynamma & Balakrishnan, 1973; George & Kartha, 1963) which in turn are brought about by the monsoons in the locality. The river discharge consequent on the south-west monsoon results in

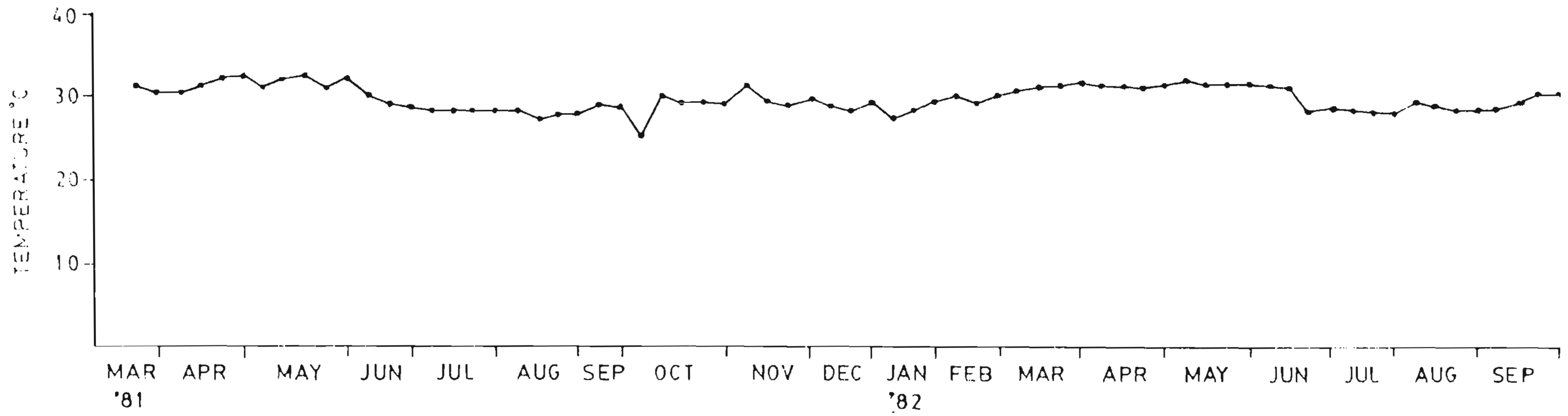


Fig.1.3. DISTRIBUTION OF AIR TEMPERATURE FROM MAR '81 TO SEP '82 AT THE TEST SITE IN MATTANCHERI CHANNEL OF THE COCHIN HARBOUR

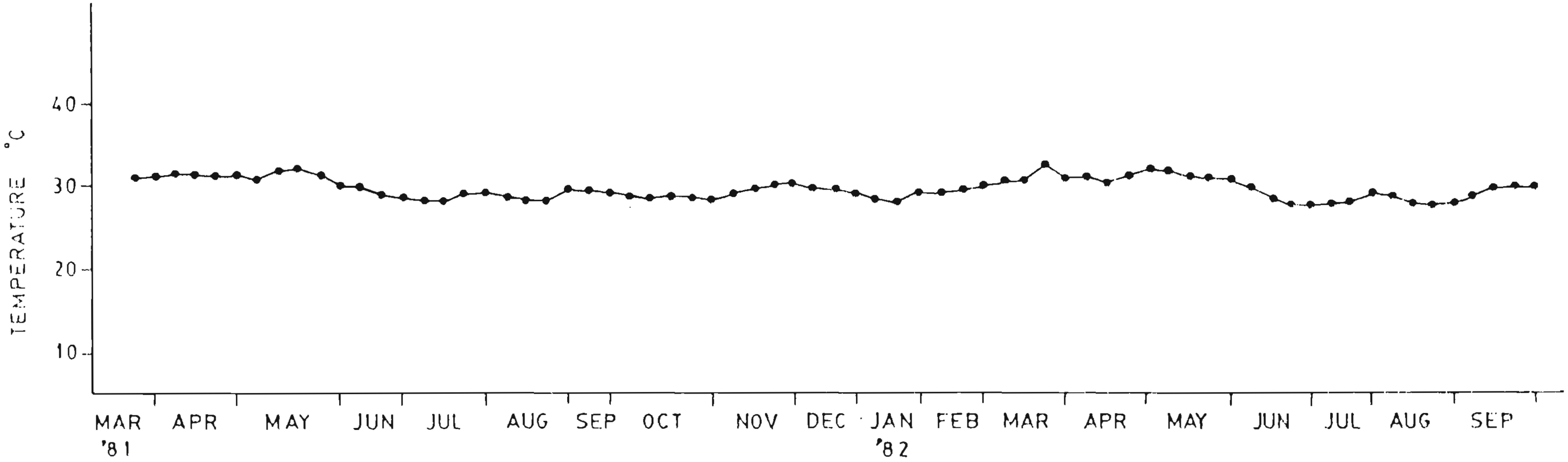


Fig. 1.4. DISTRIBUTION OF WATER TEMPERATURE FROM MAR'81 TO SEP'82 AT THE TEST SITE IN MATTANCHERI CHANNEL OF THE COCHIN HARBOUR

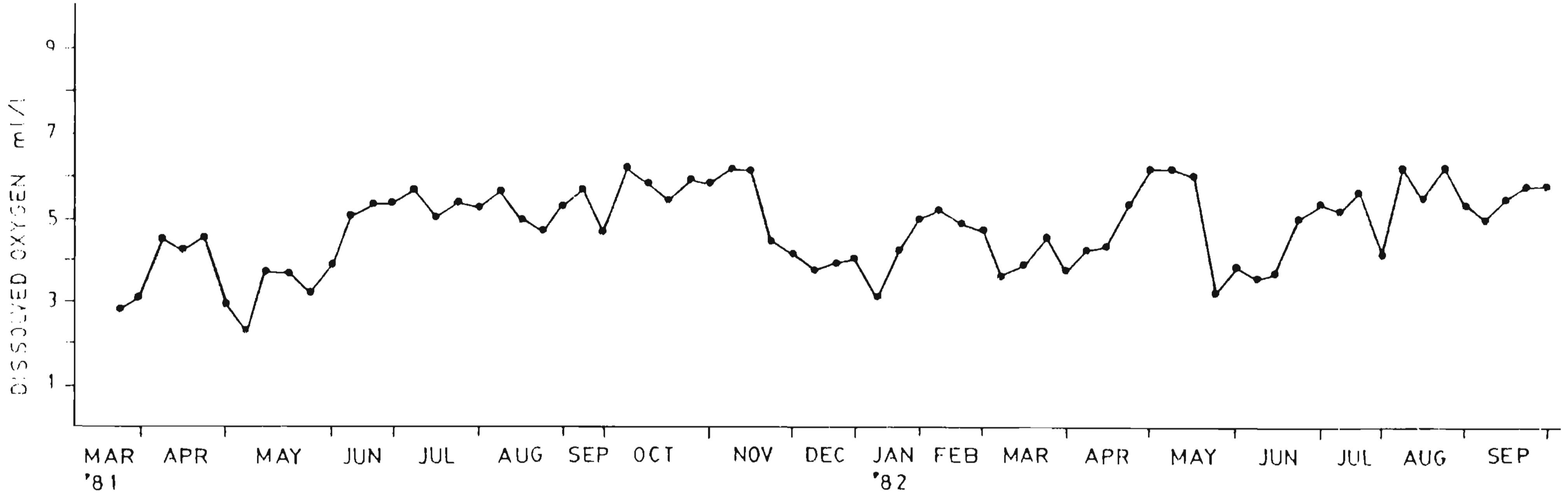


Fig.1.5.DISTRIBUTION OF DISSOLVED OXYGEN FROM MAR'81 TO SEP'82 AT THE TEST SITE IN MATTANCHERI CHANNEL OF THE COCHIN HARBOUR

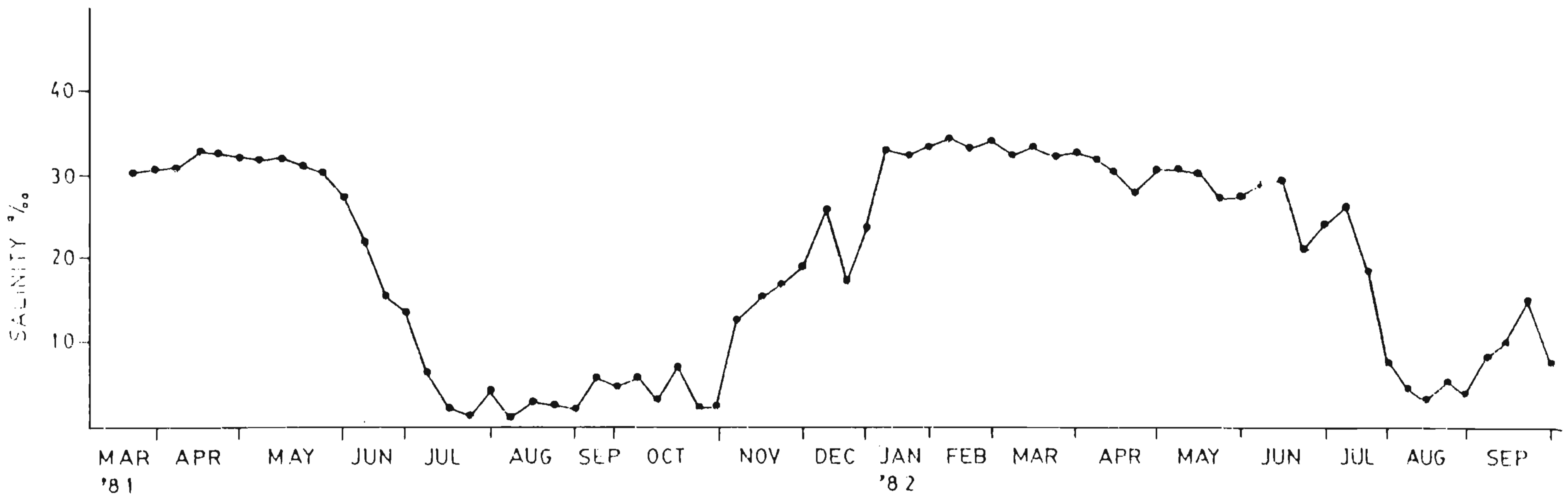


Fig. 1.6. DISTRIBUTION OF SALINITY FROM MAR '81 TO SEP '82 AT THE TEST SITE IN MATTANCHERI CHANNEL OF THE COCHIN HARBOUR

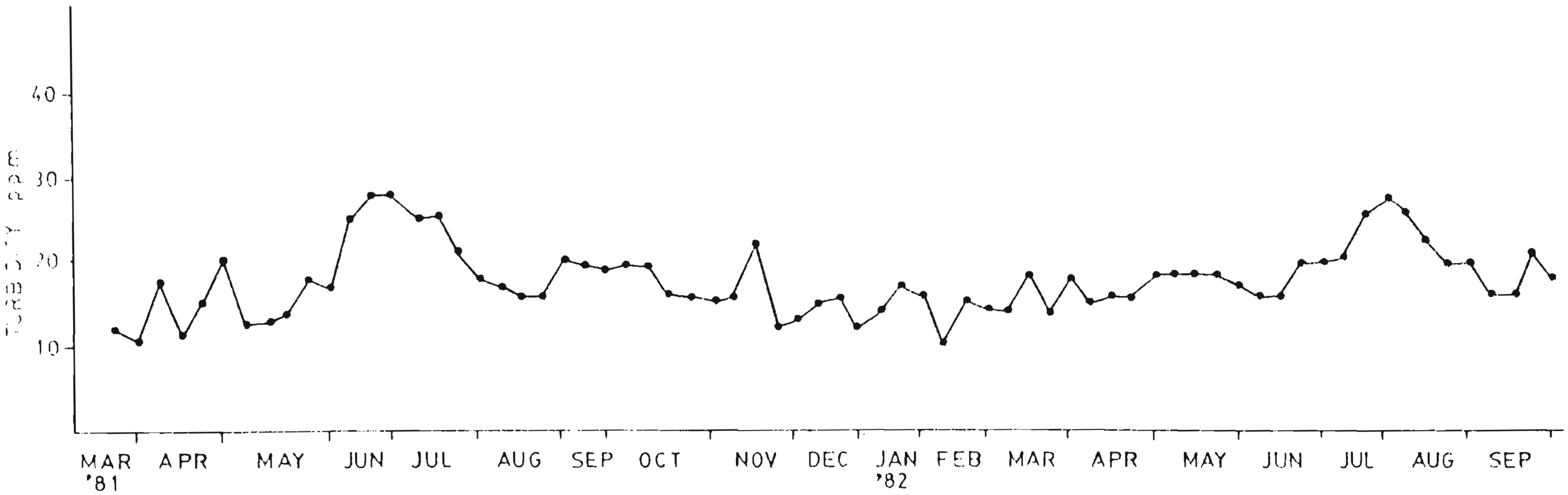


Fig. 1.7. DISTRIBUTION OF TURBIDITY FROM MAR'81 TO SEP'82 AT THE TEST SITE IN MATTANCHERI CHANNEL OF THE COCHIN HARBOUR

drastic changes in the physico-chemical variables such as temperatures, salinity, dissolved oxygen, turbidity, nutrients and pH which in turn affects the faunistic composition. The hydrographic conditions are also complicated by the nature of the basin, coastal piling and upwelling (Ramamirtham & Jayaraman, 1963).

No other environmental factor is as important as temperature in the ecology and distribution of organisms. The range in temperature of the open ocean is small when compared to that of estuaries. Temperature influences among others the geographical distribution, oxygen consumption, calcium precipitation, development, growth and reproduction of marine animals. Higher temperature can stimulate sexual activity, accelerate the development of the gonad, hasten maturity and shorten the free swimming larval period. Based on these factors the fouling community can be classified as those with continuous attachment throughout the year, those with continuous attachment but with increased intensity during definite periods, those with limited attachment during some definite periods of the year and a fourth type attaching at specific periods of the year (Paul, 1942). Since temperature cycle is a mere reflection of the annual fluctuation in solar radiation, it further influences the marine animals in other ways such as by affecting the rate of photosynthesis of microscopic plants, which form a part of the complicated food web of the sea. Temperature also influences precipitation thereby controlling the salinity of the medium through excessive run off.

In the present study air temperature was observed to fluctuate between 27.2°C to 34.0°C which is not appreciable enough to make any cyclical change as in temperate region. It remained uniformly high throughout the year except with slight reduction during the monsoon period. Similar observations were made earlier by Ramamirtham & Jayaraman (1963), Qasim & Gopinathan (1969); Qasim et al. (1969) in the Cochin Backwaters and Rao & George (1959) in the Korapuzha Estuary.

Ramamirtham & Jayaraman (1963) observed no marked reduction in surface and bottom temperature during June and July but as the season progressed (July to August), they observed lower values (23.8°C) in bottom temperature and resonably attributed it to the incursion of a tongue of cold water from the sea. They could also observe steep vertical thermal gradient only during the intrusion of cold oceanic waters and during other seasons of the year only isothermal conditions are noted by them. Sankaranarayanan & Qasim (1969) also observed reduction in temperature and stratification, consequent on the onset of the monsoon but Shynamma & Balakrishnan (1963) could not observe any such stratification as a regular feature in Cochin Backwaters.

The temperature of the estuary is mainly controlled by the warm incoming water of the rivers and also by the cold bottom water of the sea. Solar radiation also contributes its share, as the estuary is comparatively shallow except in the dredged shipping channels in the harbour area. Tidal exchanges are also important in this respect.

Salinity is the most important physical factor that controls the occurrence of organisms in the estuarine habitat. Salinity factor assumes considerable importance in a country like India, where the prevailing South-West and North-East monsoons cause considerable amount of precipitation over the region. Depending on the monsoons, the salinity shows marked variations in the estuaries and coasts of India. Salinity fluctuations are very much limited in the open ocean but owing to heavy land drainage consequent on the rains, salinity shows considerable variations in estuaries. Those animals which are acclimatized to changing salinities through several years of physiological adjustments survive wide fluctuations in salinity, while less tolerant forms are completely eliminated and the areas left bare by these organisms are subsequently recolonised by the larvae of these organisms brought in by tidal currents when optimum conditions are reestablished. The horizontal and vertical distribution of sedentary organisms are controlled to a considerable extent by the distribution of salinity. There is considerable difference in the salinity tolerance of different species and there are forms encountered which can even survive under fresh water conditions. Certain strains of barnacles and some species of bryozoans and shipworms belong to this category. There are certain sedentary forms which are characteristic of estuarine areas and are unable to survive in marine stituations. The extent of occurrence of marine species in estuaries depends on the degree to which salinity varies with the tides.

Many investigators have reported the adverse effect of salinity on oysters. Members of the genus Ostrea are more readily damaged and killed by low salinities compared with those of the genus Gryphaea (Korringa, 1952). Ranson (1943) noted damages in Gryphaea angulata below 13‰. Heavy mortalities were observed by Engle (1946) in Chesapeake Bay (USA), where salinities dropped down to below 10‰ by river discharge. Butler (1949) through his histological studies on oysters subjected to low salinity conditions, observed starvation and serious damage to the filtering capacity in oysters. Beaven (1946) also attributed early oyster mortality in Chesapeake Bay to excessive run off by fresh water. Experiments by Loosanoff & Smith (1949) showed that Gryphaea virginica can get accustomed to lower salinities than that prevailed in the medium where they are grown. Subsequent experiments by Loosanoff (1950) showed that Gryphaea virginica withstands changes from low to high salinity without serious physiological damage by prolonged sojourn in water of low salinity ultimately resulting in its death due to tissue damage. Ingle & Dawson (1951) noticed normal growth and survival of oysters from 0 - 42‰ salinity during different parts of the year. However, MedCof (1944) observed only starving of Gryphaea virginica in salinities below 20‰. Thus it is clear that oysters can tolerate a fairly wide range of salinity (Korringa, 1952).

The salinity of the Cochin Backwaters shows considerable variations which in turn are brought about by fresh water run off and tidal influences. During the period June to September (Monsoon), the salinity dropped considerably and there was indication of stratification with an upper layer of low salinity and a lower layer with high salinity. Salinity showed an increasing trend with depth (Wallershaus, 1972). This stratification was broken during the post-monsoon months when the river water discharge decreased and the backwater became homogeneously mixed again. Thus in Cochin Backwaters, there is homogeneous salinity during the pre-monsoon period which is followed by distinct stratification during the monsoon period. During this stratification period, most of the sedentary organisms (Stenohaline forms) in the upper few meters die out, while their counterparts survive in deeper layers of water. Thus salinity acts as a limiting factor in the occurrence and distribution of these sedentary animals during the monsoon period.

The concentration of dissolved oxygen varied from 1.4 ml/l to 8.0 ml/l (Table 1.1 and 1.8). During the monsoon period dissolved oxygen content was comparatively higher compared to the other parts of the year. Since the variation of dissolved oxygen was not appreciable, it seldom acted as a limiting factor in the distribution of the sedentary animals in Cochin Backwaters as the variation was within tolerable limits of these organisms.

Turbidity in Cochin Backwaters varied between 10.2 p.p.m and 27.9 p.p.m. Turbidity was higher during the monsoon period. The zonation of estuarine animals in relation to turbidity was observed by Doty (1957). Silt and resulting turbidity naturally reduces light penetration and this in turn restricts organic productivity, growth of green plants and restricts the distribution of animals which need plants as a substratum for settlement. Suspended matter in large quantities can also clog the gills of filter feeding organisms such as oysters. Heavy silting can also smother oysters living at the bottom, prevent the larval setting and survival. Turbid conditions in estuaries for longer duration also accounts for large scale mortalities of shell fishes like oysters and mussels (Korringa, 1952). Turbidity is greatly influenced by the salinity in estuaries and heavy load ofi silt is observed at lower salinities. Flocculation of large suspended particles which occur above 14‰ and cleaner waters are observed above 20‰ (Doty, 1957). Suspended organic matter is quite useful for filter feeding animals such as oysters and mussels since the detritus and other particulate materials in the water are used by these organisms as a source of food.

Table 1.1 Average weekly air temperature, water temperature, salinity, dissolved oxygen and turbidity from March 1981 to September, 1982

Period	Air temp. °C	Water temp. °C	Salinity ‰	Dissolved oxygen ml/l	Turbidity p.p.m.
Mar. 8, '81 to Mar,18	31.4	30.7	30.2	2.8	11.8
Mar.19 to Mar.26	30.6	31.1	31.1	3.1	11.3
Mar.27 to Apr. 4	30.5	31.2	31.2	4.5	17.5
Apr. 5 to Apr.11	31.4	31.1	32.5	4.2	11.4
Apr.11 to Apr.19	32.0	31.5	32.7	4.5	15.2
Apr.20 to Apr.27	31.5	31.4	32.3	2.9	20.2
Apr.28 to May 3	31.3	31.3	32.0	2.3	13.0
May 4 to May 10	32.1	32.1	32.2	3.7	13.5
May 11 to May 16	32.5	31.5	31.6	3.7	14.0
May 17 to May 23	30.9	31.2	30.5	3.2	18.0
May 24 to May 30	32.0	29.5	26.2	3.9	17.0
May 31 to Jun 7	30.0	30.0	21.9	5.0	25.5
Jun 4 to Jun 20	28.9	29.0	15.3	5.3	27.9
Jun 21 to Jun 27	28.8	28.7	12.9	5.3	28.0
Jun 28 to Jul 4	28.0	28.1	6.5	6.1	25.0
Jul 5 to Jul 12	28.0	27.9	2.3	5.0	25.2
Jul 15 to Jul 20	28.5	29.4	1.3	5.3	21.0
Jul 22 to Jul 26	28.1	28.8	4.1	5.2	18.0
Aug 1 to Aug 7	28.3	28.8	1.4	5.6	17.0
Aug 8 to Aug 14	27.2	28.4	2.9	4.9	15.5
Aug 16 to Aug 22	27.8	28.3	2.6	4.7	16.2
Aug 23 to Aug 30	27.6	28.3	1.7	5.3	20.0
Sep 4 to Sep 9	29.0	29.4	2.8	5.6	19.5
Sep 10 to Sep 19	28.8	29.1	5.4	4.6	19.0
Sep 27 to Oct 3	25.0	29.4	3.3	6.1	19.5
Oct 4 to Oct 10	30.0	29.2	10.9	5.8	19.0
Oct 11 to Oct 16	29.2	29.1	6.9	5.4	16.0
Oct 17 to Oct 23	29.3	28.6	1.9	5.9	15.7
Oct 24 to Oct 30	28.7	28.6	1.9	5.9	15.3
Oct 31 to Nov 6	30.7	29.4	13.4	6.1	16.1
Nov 7 to Nov 14	29.2	29.5	15.5	6.1	22.3
Nov 16 to Nov 22	29.3	29.9	17.8	4.5	12.0
Nov 23 to Nov 29	29.0	29.5	19.4	4.1	13.0
Nov 30 to Dec 6	28.0	28.6	26.2	3.7	15.0
Dec 7 to Dec 13	29.0	29.2	17.4	3.9	16.0
Dec 16 to Dec 24	28.1	28.4	23.5	4.0	12.0

Table contd.

Table 1.1 contd

Period	Air temp. °C	Water temp. °C	Salinity ‰	Dissolved oxygen ml/l	Turbidity p.p.m.
Jan. 6, '82 to Jan. 13	27.3	28.0	32.7	3.1	14.2
Jan. 15 to Jan. 21	27.9	28.3	32.2	4.2	16.6
Jan. 22 to Jan. 28	29.0	28.7	33.1	4.9	16.0
Jan. 30 to Feb. 6	29.4	29.0	33.8	5.1	10.2
Feb. 7 to Feb. 13	29.0	29.2	32.7	4.8	15.0
Feb. 17 to Feb. 22	30.2	29.7	33.9	4.7	13.8
Mar. 1 to Mar. 7	30.5	30.4	32.5	3.6	18.0
Mar. 8 to Mar. 15	31.0	30.5	33.0	3.8	14.0
Mar. 16 to Mar. 21	30.7	30.6	32.0	4.5	17.5
Mar. 22 to Mar. 31	31.5	31.4	32.7	3.7	15.0
Apr. 1 to Apr. 7	31.3	31.2	31.8	4.2	16.0
Apr. 8 to Apr. 15	31.4	31.3	30.5	4.3	15.9
Apr. 16 to Apr. 22	30.5	30.5	28.0	5.3	17.6
Apr. 23 to Apr. 30	31.3	31.0	30.5	6.1	18.0
May. 1 to May 7	32.1	32.0	30.5	6.1	18.5
May 8 to May 15	30.9	31.8	29.9	6.0	18.5
May 16 to May 22	31.0	30.9	26.7	3.2	17.4
May 23 to May 31	31.5	31.0	27.1	3.8	16.0
Jun 1 to Jun 7	31.0	31.2	29.0	3.5	16.3
Jun 8 to Jun 15	31.0	30.0	29.5	3.7	19.0
Jun 16 to Jun 22	28.0	28.5	21.3	5.0	20.0
Jun 23 to Jun 30	28.5	28.3	24.0	5.3	20.5
July 1 to July 7	28.1	28.4	25.6	5.2	25.6
July 8 to July 15	27.8	27.9	18.0	5.6	27.0
July 16 to July 22	28.0	28.3	7.5	4.0	25.5
Aug. 1 to Aug. 7	29.0	29.3	4.5	6.1	21.6
Aug. 8 to Aug. 15	28.5	28.7	2.8	5.5	19.0
Aug. 16 to Aug. 22	27.8	28.0	5.4	6.1	19.5
Aug. 23 to Aug. 31	28.3	28.2	3.9	5.3	20.0
Sep. 1 to Sep. 7	28.1	28.5	8.5	4.9	16.0
Sep. 8 to Sep. 15	29.0	29.1	10.0	5.4	16.5
Sep. 16 to Sep. 22	30.0	30.1	15.0	5.6	21.0
Sep. 23 to Sep. 30	30.1	30.0	7.5	5.6	18.0

Table 1.2 Fluctuations of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 8-3-81 to 19-4-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
8-3-81	31.7	30.5	30.0	2.5
12-3-81	31.5	30.8	29.0	3.0
13-3-81	31.8	30.8	31.4	3.5
14-3-81	31.5	31.0	30.5	3.0
15-3-81	31.0	30.5	31.0	2.5
16-3-81	31.0	30.5	30.0	2.7
18-3-81	31.0	30.5	29.4	2.5
19-3-81	31.0	31.5	29.5	2.2
20-3-81	31.5	30.5	30.5	2.2
21-3-81	30.5	31.5	32.3	2.5
22-3-81	31.0	31.0	31.8	4.0
23-3-81	30.5	31.0	32.0	2.4
25-3-81	30.0	31.0	30.5	4.4
26-3-81	30.0	31.5	31.0	4.3
27-3-81	30.0	31.5	29.0	4.2
28-3-81	30.0	31.5	29.0	3.7
29-3-81	31.5	30.0	30.1	4.2
30-3-81	31.5	31.3	30.4	5.6
1-4-81	29.9	31.1	33.6	4.4
3-4-81	30.4	31.5	33.4	4.6
4-4-81	30.0	31.3	33.1	4.5
5-4-81	29.8	30.0	33.9	4.4
6-4-81	31.2	31.1	32.4	3.8
8-4-81	32.9	31.7	32.4	4.2
9-4-81	31.8	31.6	32.2	4.1
10-4-81	32.4	31.2	32.2	4.4
11-4-81	30.2	31.1	31.5	4.4
15-4-81	32.4	31.2	32.4	4.1
16-4-81	31.2	31.3	32.0	4.8
17-4-81	31.8	31.8	33.3	5.1
18-4-81	31.8	31.8	33.3	4.7
19-4-81	33.8	32.1	32.9	3.9

Table 1.3 Fluctuations of air temperature water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 24-4-81 to 3-6-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
24-4-81	31.8	31.5	31.1	3.4
25-4-81	31.2	31.4	32.6	3.0
27-4-81	31.4	31.4	33.1	2.3
29-4-81	32.8	31.2	33.0	2.3
30-4-81	31.6	31.5	32.2	2.7
1-5-81	30.5	30.3	31.6	1.8
2-5-81	30.9	31.6	32.7	2.2
3-5-81	30.5	31.7	30.7	2.4
6-5-81	31.8	32.0	32.8	4.3
7-5-81	31.6	32.1	32.8	3.6
8-5-81	31.9	31.9	32.6	3.9
9-5-81	32.6	32.5	31.6	4.4
10-5-81	32.4	32.2	31.3	2.3
13-5-81	34.0	31.1	31.6	3.5
14-5-81	32.0	31.6	31.7	3.7
15-5-81	31.1	31.5	31.4	3.5
16-5-81	31.7	30.8	31.8	4.0
17-5-81	28.4	30.5	32.4	3.6
18-5-81	33.1	31.5	31.0	1.5
20-5-81	29.7	31.4	30.5	3.6
21-5-81	29.5	30.7	30.5	3.5
22-5-81	31.4	31.1	29.6	3.6
23-5-81	33.5	31.8	28.9	3.6
24-5-81	33.4	31.8	27.7	4.3
25-5-81	28.8	31.0	26.7	4.2
27-5-81	31.3	30.9	25.2	3.6
28-5-81	32.9	30.9	28.0	3.2
29-5-81	32.9	31.4	24.5	3.8
30-5-81	32.4	30.1	26.9	4.0
31-5-81	31.3	30.9	26.4	4.0
1-6-81	30.3	30.4	24.2	5.9
3-6-81	30.0	29.0	25.6	4.8

Table 1.4 Fluctuation of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 14-6-81 to 26-7-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
14-6-81	28.5	29.5	11.2	5.0
15-6-81	28.3	29.0	11.9	5.9
17-6-81	28.4	28.8	14.6	5.3
18-6-81	29.5	29.1	18.5	4.4
19-6-81	30.6	29.3	18.9	5.0
20-6-81	26.8	28.0	16.7	5.9
21-6-81	28.0	28.6	15.9	5.1
22-6-81	29.7	28.8	13.9	5.2
24-6-81	30.0	29.6	13.4	5.4
27-6-81	27.5	27.9	8.5	5.3
28-6-81	27.1	28.0	7.7	5.6
29-6-81	28.2	28.2	6.2	6.3
1-7-81	27.2	28.4	6.0	5.5
2-7-81	27.0	28.0	6.6	7.0
3-7-81	30.3	28.1	6.3	6.8
4-7-81	27.9	27.7	6.2	5.6
5-7-81	27.6	27.9	5.0	5.4
6-7-81	28.1	27.0	4.6	4.8
8-7-81	24.4	26.7	1.7	5.0
9-7-81	28.5	27.6	1.5	5.0
10-7-81	28.5	28.1	1.1	4.5
11-7-81	30.2	28.9	1.0	4.5
12-7-81	29.0	29.1	0.9	5.8
15-7-81	28.5	29.5	1.1	6.0
16-7-81	28.6	29.9	1.1	5.9
17-7-81	28.5	29.0	1.1	5.6
18-7-81	28.8	29.1	1.4	5.5
19-7-81	28.1	29.2	1.4	4.2
20-7-81	28.4	29.4	1.6	4.6
22-7-81	28.2	28.9	2.3	4.4
23-7-81	28.5	29.1	5.9	6.0
24-7-81	28.6	29.0	4.5	5.1
25-7-81	28.5	29.1	4.0	5.3
26-7-81	26.5	27.9	3.8	5.2

Table 1.5 Fluctuations of air temperature, water temperature and dissolved oxygen at the test site of Mattancherry Channel from 1-8-81 to 19-9-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
1-8-81	28.6	29.5	0.8	5.8
2-8-81	27.5	28.9	0.6	6.9
3-8-81	25.3	27.6	1.0	6.0
6-8-81	30.1	29.0	2.7	5.1
7-8-81	30.1	29.0	2.0	4.0
8-8-81	30.0	29.0	2.3	2.6
12-8-81	26.7	28.4	3.6	6.3
13-8-81	25.5	28.3	3.1	5.4
14-8-81	26.6	28.0	2.4	5.4
16-8-81	28.3	28.0	2.7	5.4
17-8-81	26.3	27.6	3.3	5.5
19-8-81	28.8	28.8	2.5	5.7
20-8-81	28.4	28.9	2.2	5.8
21-8-81	26.5	27.8	2.5	3.6
22-8-81	28.3	28.5	2.3	2.2
23-8-81	28.9	28.6	1.6	5.4
24-8-81	28.2	29.0	1.8	6.2
27-8-81	25.7	28.0	2.4	4.8
28-8-81	26.7	27.3	2.1	5.2
29-8-81	27.5	28.3	1.2	4.4
30-8-81	28.4	28.4	1.1	5.6
4-9-81	27.8	29.2	1.6	5.8
5-9-81	29.4	29.5	2.3	5.5
6-9-81	28.5	29.8	2.3	5.7
7-9-81	29.3	29.2	2.1	5.9
9-9-81	30.1	29.5	5.6	5.1
10-9-81	31.0	30.0	5.5	5.5
11-9-81	27.5	29.0	5.5	5.0
12-9-81	26.2	27.8	6.0	4.0
13-9-81	29.5	28.8	4.9	4.5
19-9-81	29.8	30.1	5.2	4.0

Table 1.6 Fluctuations of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 27-9-81 to 8-11-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
27- 9-81	28.2	29.5	2.1	5.6
28- 9-81	28.6	28.4	1.6	7.4
30- 9-81	30.3	30.1	2.2	8.0
1-10-81	32.5	29.5	3.9	3.8
3-10-81	30.4	29.6	6.7	5.6
4-10-81	26.9	29.1	6.7	6.2
5-10-81	28.5	28.9	9.1	5.0
7-10-81	31.2	28.6	15.6	5.8
8-10-81	30.2	29.3	11.1	6.0
10-10-81	31.0	30.0	12.0	6.2
11-10-81	29.5	29.5	9.6	5.2
14-10-81	29.5	30.0	7.3	7.4
15-10-81	28.5	29.4	8.2	6.6
16-10-81	29.4	29.9	10.3	5.4
17-10-81	28.6	29.4	7.5	6.0
18-10-81	29.0	30.0	5.7	5.0
19-10-81	29.4	30.0	5.7	6.0
21-10-81	28.4	29.1	8.9	5.0
22-10-81	29.0	28.2	7.9	5.2
23-10-81	27.3	28.1	5.6	5.1
24-10-81	25.5	27.5	3.6	5.7
26-10-81	30.1	28.1	2.6	6.6
28-10-81	28.8	29.0	0.7	4.8
29-10-81	30.0	29.0	0.8	6.4
30-10-81	29.0	29.5	1.8	6.2
31-10-81	30.0	29.2	3.3	6.0
1-11-81	30.3	29.5	7.6	6.0
2-11-81	30.0	28.0	7.8	6.4
4-11-81	30.9	29.8	13.9	5.4
5-11-81	31.0	29.9	17.5	6.2
6-11-81	31.8	30.0	30.0	6.5
7-11-81	28.6	29.2	14.7	6.1
8-11-81	29.0	29.2	16.7	6.2

Table 1.7 Fluctuations of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 14-11-81 to 28-12-81

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
14-11-81	29.9	30.0	15.1	6.0
16-11-81	29.0	31.0	14.8	5.8
18-11-81	29.0	29.4	16.6	4.8
19-11-81	29.0	29.4	15.6	3.6
20-11-81	29.7	29.9	24.8	4.2
21-11-81	29.3	29.9	16.3	4.2
22-11-81	29.5	30.0	18.8	4.2
23-11-81	31.4	30.5	17.0	4.2
27-11-81	28.1	30.0	20.6	4.0
28-11-81	27.9	28.5	14.1	4.2
29-11-81	28.4	28.8	26.0	4.1
30-11-81	28.6	28.9	25.1	3.9
2-12-81	28.0	28.9	25.7	3.8
3-12-81	28.7	29.2	26.0	3.9
4-12-81	27.7	28.0	27.7	2.8
5-12-81	27.2	28.3	27.7	3.8
6-12-81	27.9	28.5	24.9	3.8
7-12-81	28.3	28.5	26.3	3.3
9-12-81	30.4	29.5	21.9	3.6
10-12-81	27.0	28.5	13.2	4.2
11-12-81	30.0	29.3	13.2	4.2
12-12-81	29.2	29.8	14.1	3.8
13-12-81	29.1	29.5	15.9	4.2
16-12-81	28.3	28.6	17.4	4.0
17-12-81	27.8	28.2	21.3	4.0
18-12-81	28.4	28.4	24.0	4.0
19-12-81	27.4	28.0	26.4	4.2
24-12-81	28.6	28.8	28.5	4.0
26-12-81	26.2	28.6	31.8	3.6
28-12-81	28.0	29.0	29.8	3.4

Table 1.8 Fluctuations of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 6-1-82 to 24-2-82

Date of observation	Air temperature °C	Surface water temperature °C	Salinity ‰	Dissolved oxygen ml/l
6-1-82	28.4	28.4	32.5	4.0
7-1-82	27.4	27.7	33.1	4.2
8-1-82	27.0	28.0	33.1	3.8
9-1-82	26.5	28.0	33.1	1.8
10-1-82	26.4	27.2	32.7	1.4
13-1-82	28.0	28.5	31.6	3.[illegible]
15-1-82	26.8	28.0	31.6	4.0
16-1-82	28.0	28.1	31.8	3.8
17-1-82	28.4	28.0	32.3	4.2
18-1-82	28.5	28.5	32.3	4.2
20-1-82	27.5	28.4	32.2	4.6
22-2-82	27.7	28.0	32.7	5.6
23-1-82	27.6	28.1	32.2	4.4
24-1-82	29.5	28.1	32.9	4.4
25-1-82	30.0	28.3	33.1	4.5
28-1-82	30.2	31.0	34.5	5.6
30-1-82	28.1	29.1	33.4	5.4
31-1-82	31.0	29.0	33.1	2.4
1-2-82	28.5	29.1	33.1	6.2
3-2-82	28.1	28.6	34.3	5.0
4-2-82	30.0	29.0	34.3	5.8
6-2-82	30.5	29.5	34.3	5.8
7-2-82	29.4	29.5	30.7	5.4
10-2-82	30.5	30.0	33.5	4.0
12-2-82	28.0	28.5	33.4	3.8
13-2-82	28.7	28.8	33.0	6.0
17-2-82	29.7	29.1	34.0	4.5
18-2-82	29.6	29.1	33.9	5.0
19-2-82	29.7	29.5	33.6	4.4
20-2-82	31.0	30.0	34.9	4.8
21-2-82	31.0	30.0	34.0	3.8
22-2-82	30.0	30.4	32.9	5.8

Table 1.9 Fluctuations of air temperature, water temperature, salinity and dissolved oxygen at the test site of Mattancherry Channel from 2-3-82 to 23-5-82

Date of observation	Air temperature C°	Surface water temperature C°	Salinity ‰	Dissolved oxygen ml/1
2-3-82	30.4	30.4	32.0	5.0
4-3-82	30.2	30.7	32.0	5.0
13-3-82	32.0	31.2	33.6	2.6
16-3-82	31.3	31.0	32.2	2.0
17-3-82	31.3	30.6	32.9	3.8
1-4-82	31.2	30.0	32.9	6.4
18-4-82	31.0	30.5	32.0	6.4
24-4-82	31.8	31.0	34.0	4.8
25-4-82	32.0	31.6	33.8	6.1
4-5-82	30.0	30.5	33.1	6.0
6-5-82	32.0	31.5	33.1	3.6
7-5-82	31.0	30.5	31.4	3.0
11-5-82	31.0	30.5	31.4	3.0
18-5-82	31.6	31.0	32.9	4.2
20-5-82	31.0	30.7	32.9	4.2
23-5-82	30.5	30.8	32.9	4.2

Table 1.10 Average monthly rainfall at Cochin

Month	Rainfall mm
January	15.24
February	30.48
March	48.26
April	136.20
May	294.70
June	782.10
July	574.10
August	370.90
September	248.90
October	335.53
November	180.30
December	48.26

1.5 References

Antony Raja, B.T. (1963) Observation on the rate of growth, sexual maturity and breeding of four sedentary organisms from the Madras Harbour. *J. mar. biol. Ass. India* **5**, 113-132

Barnes, H. (1950) A note on the barnacle larval population of the Clyde Sea area as sampled by the Hardy continuous plankton recorder. *J. mar. biol. Ass. U.K.* **29**, 73-80

Beaven, G.F. (1946) Effect of Susquehanna River Stream flow on Chesapeake Bay salinities and history of past oyster mortalities on upper bay bars. *Conv. natn. Shell Fish. Ass. New York.* 38-41, *Contr. Chesapeake biol. La.* **68**, 1-11

Butler, P.A. (1949) Gametogenesis in the oyster under conditions of depressed salinity. *Biol. Bull.* **96**, 263-269

Calabrese, A. & Davis, H.C. (1966) The pH tolerance of embryos and larvae of *Mercenaria mercenaria* and *Crassostrea virginica*. *Biol. Bull. mar. biol. Lab. Woods Hole.* **131**, 427-436

Calabrese, A. & Davis, H.C. (1970) Tolerances and requirements of embryos and larvae of bivalve mulluscs. *Helgolander wiss Meeresunters.* **20**, 553-564

Cherian, T., Rao, L.V.G. & Varma, K.K. (1974) Hydrography and suspended sediment load of the oceanic and estuarine waters adjoining Marmagoa Harbour during early summer. Indian J. mar. Sci. 3 (2), 99-104

Cherian, T., Rao, L.V.G. & Varma, K.K. (1975) Variation in physical characteristics of the waters of Zuari Estuary. Indian J. mar. Sci. 4 (1), 5-10

*Coker, R.E., Shira, A.F., Clark, H.W. & Howard, A.D. (1919) Natural history and propagation of fresh water mussels. Bull. Bur. Fish. Wash. 37, 79

Crisp, D.J. & Stubbings, H.G. (1957) The orientation of barnacles to water currents. J. Anim. Ecol. 26, 179-196

Dame, R.F. (1972) The ecological energies of growth, respiration and assimilation in intertidal American oyster, Crassostrea virginica. Mar. Biol. 17(3) 243-250

Daniel, A. (1954) Influence of stage of tide on the attachment of barnacle cyprids, J. Bombay nat. Hist. Soc. 54(4) 866-868

Davis, H.C. (1960) Effects of turbidity producing materials in the sea water on eggs and larvae of clam Venus mercenaria mercenaria. Biol. Bull. mar. biol. Lab. Woods Hole. 118, 48-54

Dehadrai, P.V. (1970) Changes in the environmental features of the Zuari and Mandovi estuaries in relation to tides. Proc. Indian Acad. Sci. 72 (2B), 68-80

Dehadrai, P.V. & Bhargava, R.M.S. (1972) Seasonal organic production in relation to environmental features in Mandovi and Zuari estuaries, Goa. *Indian J. mar. Sci.* **1**(1), 52-56

Devassy, V.P. & Gopinathan, C.K. (1970) Hydrobiological features of the Kerala backwaters during the pre-monsoon and monsoon months. *Fish. Technol.* **7**(2), 190-194

Doty, M.S. (1957) Rocky intertidal surfaces. In '*Treatise on Marine Ecology and Paleoecology*' (Hedgpeth, J.W. Ed.,) Vol.1, *Mem. Geol. Soc. Am.* **67**, 535-538

Durve, V.S. & Bal. D.V. (1961) Hydrology of the Kelwa backwater and adjoining sea. *J. Univ. Bombay.* **29**, 39-48

Durve, V.S. & Bal. D.V. (1962) Preliminary observation on the growth of spat of oyster *Crassostrea gryphoides* (Schlotheim) *J. mar. biol. Ass. India.* **4** (2), 206-213

Dwivedi, S.N., Bhargava, R.M.S., Parulekar, A.H., Selvakumar, R.A., Singbal, S.Y.S. & Sankaranarayanan, V.N. (1975) Ecology and environmental monitoring of Mandovi, Zuari and Cumburjua Canal Complex. *J. Indian Fish. Ass.* **3**, 113-130

Engle, J.B. (1946) Commercial aspects of the upper Chesapeake Bay oyster bars in the light of the recent oyster mortalities. *Conv. Natn. Shell Fish. Ass. New York.* 42-46

Elsey, C.R. (1936) The feeding rate of Pacific Oysters. Progress Rep. Pacif. Biol. Stn. Nanaimo, B.C. No.29

Galtsoff, P.S. (1928) Experimental study of the function of oyster gill and its bearing on the problems of oyster culture and sanitary control of the oyster industry. Bull. U.S. Fish. 44, 1-39 (Document 1035)

Galtsoff, P.S. (1964) The American oyster *Crassostrea virginica* (Gmelin). Fish. Bull. Fish Wildl. Ser. 64, pp.80

Galtsoff, P.S. & Whipple, D.V. (1930) Oxygen consumption of normal and green oysters. Bull. Bur. Fish. Washington. 46, 489-508

Giese, A.C. (1959) Comparative Physiology. Annual reproductive cycles in marine invertebrates. A. Rev. Physiol. 21, 547-576

Giese A.C. & Pearse, J.S. (1974) Introduction: General Principles in Reproduction of Marine Invertebrates. (Giese, A.C. & Pearse, A.C. Eds) Vol.1, Acoelomate and Pseudocoelomate Metazoans. pp. 1-49, Academic Press, New York

George, M.J. & Krishna Kartha, K.N. (1963) Surface salinity of Cochin Backwater with reference to tide. J. mar. biol. Ass. India. 5, 178-184

Haridas, P., Madhupratap, M. & Rao, T.S.S. (1973) Salinity, temperature, oxygen and zooplankton biomass of the backwater from Cochin to Alleppey. Indian J. mar. Sci. 2, 94-102

Hill, M.B. (1967) The life cycles and salinity tolerance of the serpulids *Mercierella enigmatica Fauvel and Hydroides uncinata* Phillips at Lagos, Nigeria, *J. Anim. Ecol.* **36**, 303-321

Hopkins, A.E. (1931) Temperature and shell movements in oysters. *Bull. U.S. Bur. Fish.* **47**, 1-14

Hutchins, L.W. (1945) An annotated check list of salt water bryozoa of Long Island Sound. *Trans. Conn. Acad. Arts. Sci.* **36**, 533-551

Ingle, R.M. & Dawson, C.E. (1951) Variation in salinity and its relation to the Florida oyster. Salinity variations in Apalachicola Bay. *Proc. Gulf Caribb. Fish. Inst.* 1950, 35-42

Ishida, S. (1935) On the oxygen consumption in the oyster *Ostrea gigas* Thunberg under various conditions. *Sci. Rep. Tohoku Univ.* **4** (10), 619-638

Kinne, O. (1964) The effects of temperature and salinity on marine and brackish water animals. ii. Salinity and temperature-salinity combination. *Oceanography mar. biol. A. Rev.* **2**, 281-339

Kinne, O. (1966) *Physiological Aspects of Animal Life*. In '*Estuaries*' (Lauff, G.H. Ed.) *Am. Ass. Advt. Sci.* 83

Kinne, O. (1967) *Physiology of Estuarine Organisms with Special Reference to Salinity and Temperature*. In '*Estuaries*' (Lauff, G.H. Ed.) *Am. Ass. Advt. Sci.* 83

Kinne, O. (1970) Temperature. Animals Invertebrates. In Marine Ecology (Kinne, O. Ed.), Vol.1, Part 1. pp.407-514, Wiley Interscience, New York

Kinne, O. (1971) Salinity, Animals-Invertebrates. In 'Marine Ecology' (Kinne, O. Ed.) Vol.1, Part 2. pp.821-1083 Wiley Interscience, New York

Korringa, P. (1952) Recent advances in oyster biology. Q. Rev. Biol. 27(3), 266-308; 339-365

Loosanoff, V.L. (1950) On behaviour of oysters transferred from low to high salinities. Anat. Rec. 108, Abstract-147

Loosanoff, V.L. (1950a) Rate of water pumping and shell movements of oysters in relation to temperature. Anat. Rec. 108, Abstract-229

Loosanoff, V.L. (1961) Effects of turbidity on some larval and adult bivalves. Proc. Gulf Caribb. Fish. Inst. 14th Annual Session. 80-94

Loosanoff, V.L. (1965) The American or Eastern Oyster. U.S. Fish. Wildl. Ser. Bur. Comm. Fish. Circular 205, 1-36

Loosanoff, V.L. & Davis, H.C. (1952) Temperature requirements for maturation of gonads of northern oysters. Biol. Bull. 103 (1), 80-96

Loosanoff, V.L. & Engle, J.B. (1947) Feeding of Oysters in relation to density of microorganisms. Science. 105 (2723), 260-261

Loosanoff, V.L. & Nomejko, C.A. (1946) Feeding of oysters in relation to tidal stages and to period of light and darkness. Biol. Bull. 90 (3), 244-264

Loosanoff, V.L. & Nomejko, C.A. (1949) Growth of oysters O. virginica during different months. Biol. Bull 97 (1), 82-94

Loosanoff, V.L. & Smith, P.B. (1949) Some aspects of behaviour of oysters accustomed to different salinities. Anat. Rec. 105, 627 (Abstract-309)

Loosanoff, V.L. & Tommers, F.D. (1947) Effect of low pH upon the rate of water pumping of oysters. Ostrea virginica. Anat. Rec. 99, 668-669

Loosanoff, V.L. & Tommers, F.D. (1948) Effect of suspended silt and other substances on rate of feeding of oysters. Science, 107, 69-70

Manikoth, S. & Salih, K.Y.M. (1974) Distribution characteristics of nutrients in the estuarine complex of Cochin. Indian. J. mar. Sci. 3, 125-130

Maurer, D. & Aprill, G. (1973) Feasibility study of raft culture of oysters in the Delaware Bay area. Rep. Del. River Basin Comm. Univ. Delaware. 188 pp.

Mc Dougall, K.D. (1943) Sessile marine invertebrates at Beaufort, N.C. Ecol. Monogr. 13, 321-374

Medcof, J.C. (1944) How relaying and transferring at different seasons affect the fatness of oysters, Prog. Rep. Atl. Stn. 35, 11-14

Moore, H.B. (1958) Marine Ecology, John Wiley and Sons, New York, pp.493

Nagabhushanam, R. (1955) Tolerance of marine wood borer Martesia striata (Linn) to waters of low salinity. J. zool. Soc. India. 17(1), 83-86

Nagabhushanam, R. (1962) Bull. nat. Inst. Sci. India, 19, 138

Nair, N.Unnikrishnan (1967) The settlement and growth of major fouling organisms in Cochin Harbour. Hydrobiologia, 30(3.4) 503-512

*Nelson, T.C. (1921) Rep. Dep. Biol. New Jers. Agric. Coll. Exp. Stn. New Brunswick, N.J. for the year ending June 30, 1920. pp.317-349

Nelson, T.C. (1921a) Aids to successful oyster culture-1. Procuring the seed. Bull. New Jers. agric. Exp. Stn. 351, pp.59

Nelson, T.C. (1923) Rep. Dep. Biol. New Jers. Agric. Coll. Exp. Stn. New Brunswick, N.J. June 30, 1920, 317-349

Nozawa, A. (1929) The normal and abnormal respiration in the oyster Ostrea circumpicta (Pilsbry) Sci. Rep. Tohoku Univ. 4 (2), 133-138

Orton, J.H. (1920) Sea temperature, breeding and distribution of marine animals. J. mar. biol. Ass. U.K. 12, 339-366

Orton, J.H. (1937) Oyster Biology and Oyster Culture. The Buckland lecturers for 1935. Edward Arnold & Co. London, 211 pp

Panikkar, N.K. & Aiyar, R.G. (1939) Observations on breeding in brackish water animals of Madras. Proc. Indian Acad. Sci. 9B, 343-364

Parulekar, A.H. & Dwivedi, S.N. (1974) Benthic studies on Goa estuaries. Part 1. Standing crop and faunal composition in relation to bottom salinity distribution and substratum characteristics in the estuary of Mandovi River, Indian J. mar. Sci. 3, 41-45

Parulekar, A.H., Dwivedi, S.N. & Dhargalkar, V.K. (1973) Ecology of clam beds in Mandovi, Cumbarjua Canal and Zuari estuarine system of Goa. Indian J. mar. Sci. 2 (2) 122-126

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in the Madras Harbour. Proc. Indian Acad. Sci. 15(1) B, 1-42

Pearse, J.S. (1965) Reproduction periodicities in several contrasting populations of Odontaster validus Koehler, a common Antartic asteroid. Antarct. Res. Ser. 5, 39-85

Pears, A.S. & Gunter, G. (1957) Salinity. In 'Treatise on Marine Ecology and Paleoecology' (Hedgpeth, J.W. Ed.) Vol.1 pp.129-157

Pillai, N.K. (1958) Development of Balanus anphitrite, with a note on the early larvae of Chelonobia testudinari Bull. Res. Inst. Univ. Kerala Ser. C. 1, 117

*Pilsbry, H.A. (1916) The sessile barnacles (*Cirripedia*) contained in the collection of U.S. National Museum, including a monograph of the American species. *Bull. U.S. natn. Mus.* **93**, 1-366

Pyefinch, K.A. (1948) Notes on the biology of *Cirripedes*. *J. mar. biol. Ass. U.K.* **27**, 464-503

Qasim, S.Z., Bhattathiri, P.M.A. & Abidi, S.A.H. (1968) Solar radiation and its penetration in a tropical estuary. *J. exp. mar. biol. Ecol.* **2**, 87-103

Qasim, S.Z. & Gopinathan, C.K. (1969) Tidal cycle and the environmental features of Cochin Backwaters (a tropical estuary). *Proc. Indian Acad. Sci.* **69**B, 336-348

Qasim, S.Z. & Reddy, C.V.G. (1967) The estimation of plant pigments of Cochin Backwaters during the monsoon months. *Bull. mar. Sci.* **17**, 95-110

Qasim, S.Z., Wallershaus, S., Bhattathiri, P.M.S. & Abidi, S.A.H. (1969) Organic production in a tropical estuary. *Proc. Indian Acad. Sci.* **69**, 51-94

Ramamirtham, C.P. & Jayaraman, R. (1963) Some aspects of the hydrographical condition of the backwaters around Willingdon Island (Cochin) *J. mar. biol. Ass. India.* **5**, 170-177

*Ranson, G. (1943) La Vie des Huiters. *Historie Naturelles.* **1**, 260, Gullimard, Paris

*Ranson, G. (1948) Ecologie at repartition geographique des Osteides vivants. *Int. Congr. Zool.* (Paris) **13**, 455-456

Rao, S.V.S. & George, P.C. (1959) Hydrology of the Korapuzha Estuary, Malabar, Kerala State. *J. mar. biol. Ass. India*. **1**(2), 212-223

Rao, K.V. & Nayar, K.N. (1956) Rate of growth in spat and yearlings of the Indian backwater oyster *Ostrea madrasensis* (Preston) *Indian J. Fish.* **3**(2), 231-260

Reddy, M.P.H., Hariharan, V. & Kuriyan, N.P. (1979) Seasonal variations in hydrographic conditions of estuarine and oceanic waters adjoining the old Mangalore port. *Indian J. mar. Sci.* **8**, 73-77

Sandison, E.E. (1966) The effect of salinity fluctuations on the life cycle of *Balanus pallidus stutsburi* Darwin in Lagos Harbour, Nigeria, *J. Anim. Ecol.* **35**, 363-378

Sankaranarayanan, V.N. & Qasim, S.Z. (1969) Nutrients of Cochin Backwaters in relation to environmental characteristics. *Mar. biol.* **2** (3), 236-247

Schleiper, C. (1957) Comparative study of *Asteria rubens* and *Mytilus edulis* from the North Sea and the Western Baltic Sea. *Annee biol.* **33**, 117-127

Shynamma, C.S. & Balakrishnan, K.P. (1973) Diurnal variation of some physico-chemical factors in the Cochin Backwaters during south-west monsoon. *J. mar. biol. Ass. India* **15**, 391-398

Smith, F.G.W. (1946) Effect of water currents upon the attachment and growth of barnacles. *Biol. Bull.* **90**, 51-70

Spencer, B.E. & Gough, C.J. (1978) The growth and survival of experimental batches of hatchery reared spat of *Ostrea edulis* L and *Crassostrea gigas* Thunberg using different methods of tray cultivation. *Aquaculture*, **13**, 292-312

Strickland, J.D.H. & Parsons, T.R. (1968) *A Practical Hand Book of Sea Water Analysis*. *Bull. Fish. Res. Bd Can.* **167**, pp.309

Vernberg, F.T. (1972) *Dissolved gases - Animals*. In '*Marine Ecology*' (Kinne, O. Ed.) Vol.1, Part 3, pp.1491-1575, Wiley Interscience, New York

Visscher, J.P. & Luce, R.H. (1928) Reactions of the cyprid larvae of barnacles to light with special reference to spectral colours. *Biol. Bull.* **54**, 336-350

Walne, P.R. (1958) Growth of oysters (*Ostrea edulis* L.) *J. mar. biol. Ass. U.K.* **37**, 591-602

Walne, P.R. (1972) The influence of current speed, body size and water temperature on the filtration rate of five species of bivalves. J. mar. biol. Ass. U.K. 52, 345-347

Wallershaus, S. (1972) On the hydrography of the Cochin Backwater, A South Indian estuary. J. mar. biol. Ass. India. 14, 487-495

Weiss, C.M. (1946) The effect of illumination and the stage of tide on the attachment of barnacle cyprids. Biol. Bull. 93, 240-249

Wilson, B.R. (1969) Survival and reproduction of the mussel Xenostrobus securis (L) in a western Australian estuary. Part ii - Reproduction, growth and longevity. J. nat. Hist. 3, 93-120

---

*Original not consulted

CHAPTER 2

THE NATURE OF BIOFOULING IN THE COCHIN BACKWATERS, THE HABITAT OF CRASSOSTREA MADRASENSIS (PRESTON)

CHAPTER 2

THE NATURE OF BIOFOULING IN THE COCHIN BACKWATERS, THE HABITAT OF CRASSOSTREA MADRASENSIS (PRESTON)

2.1. Introduction

The settlement and growth of sedentary organisms and plants on submerged surfaces in a marine environment is commonly known as 'Marine fouling'. The growth of these biota on different surfaces such as hull of ships, navigational buoys, underwater acoustic devices, cables, conduits of cooling water systems, poses serious problems of considerable economic interest. Fouling growth adversely affects propulsion and thereby the economical operation of boats and ships (Woods Hole Oceanographic Institution, 1952). Fouling accumulation on ships' hull reduces the speed of the boat by several knots owing to increased frictional resistance. At the rate of an increase of ½% frictional resistance per day various types of ships consume 45-50% more of fuel to maintain a speed of 10 knots and 35-45% for a speed of 20 knots after six months (Woods Hole Oceanographic Institution, 1952). In addition to increased expenses required for driving fouled ships, the expenses incurred for dry docking these vessels periodically are also very high depending on the tonnage of the ship. As per an earlier estimate made by Visscher (1928), the United States shipping interest alone spends over $ 100,000,000 annually for fouling prevention. As per the estimate of Persoone (1977) U.S. commercial and military interests suffer an annual less of 500 million dollars owing to marine fouling and this does not include costs for increased fuel consumption and increased docking charges. Ships under idle condition in the port accumulate more of fouling when compared to those under active service condition. It is also estimated that approximately 200 tons of fouling is removed from a ship's bottom at a single docking (Adamson, 1937 quoted in Woods Hole Oceanographic Institution, 1952). The quantity and quality of fouling varies with the waters where the ship ply and is also related to the water temperature. Fouling is more severe in tropical waters than in temperate regions owing to uninterrupted temperature conditions existing in the tropics and also due to lack of clear cut or well marked seasons. Stationary structures are more prone to fouling, as foulers are not washed away as in ships' hull (Woods Hole Oceanographic Institution, 1952). Moored structures which are often exposed to tidal currents favour fouling accumulation and provide opportunity for fouling animals to settle in large numbers during periods of slack water even where the currents are strong. The fauna that attach on to moored structures are also different from that found on ships. Mussels and other soft bodied forms that are easily washed away from the ships' hull prefer such structures. The underwater acoustic devices of commercial and naval ships are also very seriously affected by fouling accumulation. These structures are not usually protected by any antifouling paint nor are they constructed out of metals which are toxic to marine fouling organisms. Heavy accumulation of fouling organisms seriously affect sound transmission by these equipments. Pipes and conduits of industrial plants, oil refineries and aquaria are very often clogged by these organisms which result in the interruption of water flow in these structures. Fouling reduces the carrying capacity of these conduits by reducing the pipe-line diameter. Occasionally the foulers are torn loose and swept into screens, tube-sheets or pumps resulting in the breakdown of the system. Pipes with constant flow of water accumulate no fouling but pipes with little flow of water or those with interrupted water supply are generally very badly fouled. Because of the complexity of the system, expenses incurred by the breakdown of such systems and consequent cleaning are enormous. Fouling results in the reduction of the carrying capacity of these conduits by increasing frictional resistance and also by reducing the pipe-line diameter. The fouling growth accumulated in these structures and occasionally the foulers that are torn loose and swept into screens, tube sheets or pumps resulting in the breakdown of these systems. The clogging and resultant stoppage of water flow may build up pressure in the pipes and may eventually result in the breakage of the pipes. The accumulation of deposits due to capsulated and slime forming bacteria adversely affect the heat transfer efficiency of condensers (Estes, 1938; Martin, 1938; Mathews, 1927). The torn off shells of certain foulers that hit the inner walls of pipes result in the wearing of the protective inner coating resulting in pitting corrosion and ultimate perforation of these pipes. Fouling may accelerate corrosion of metallic surfaces or may even injure paint coatings on the hull intended for prevention of rusting. In contrast to this, corrosion of steel surface may also proceed less rapidly under firmly adhering fouling than the base areas between the fouling organisms. Corrosion of fouled surface may be due to oxygen concentration cells enclosed under the base of the foulers particularly barnacles or protection from corrosion due to galvanic effects. The protective coatings are at times removed when firmly adhering foulers such as oysters and barnacles are torn loose or the cementing material secreted by certain foulers has deleterious effect on the paint films (Nelson & Kodet, 1944). The edge of the barnacle shell even ploughs into the paint coating (Woods Hole Oceanographic Institution, 1952). As observed by Weiss (1948b), a heavily fouled wooden surface may afford protection to the wood from the attack of marine wood borers.

Thus the problem of marine fouling has attracted the attention of biologists, chemists and engineers alike and a great volume of literature on fouling and its prevention has accumulated. However, inspite of many contributions and suggestions, boat owners and harbour authorities all over the world are still being plagued by this problem.

An impressive body of information has been compiled on the biology of fouling organisms of England (Pyefinch, 1950), the Continent (Caspers, 1960), the Pacific Islands (Edmondson & Ingram, 1939), West Indies (Bruce, 1976) Australia (Wood & Allen, 1958), Egypt (Ghobashy, 1976) and Canada (Weiss, 1948) but our information on this problem along the extensive Indian coasts with numerous ports is comparatively inadequate. Erlanson (1936) made a preliminary survey of the marine boring organisms at Cochin Harbour and she has made brief references to fouling organisms also. Paul (1937, 1942) studied the growth, sexual maturity and breeding of certain sedentary organisms in the Madras Harbour. At Krusadai Island, in the Gulf of Mannar, Kuriyan (1950) conducted studies on the fouling organisms of pearl oyster cages and also the attachment of marine sedentary organisms on different surfaces (Kuriyan, 1952). Later Kuriyan & Mahadevan (1953) studied the effect of light and colour of the substratum on the settlement of barnacles. Daniel (1954) observed the seasonal variations in the succession of fouling communities in Madras Harbour. He has also studied the gregarious attractions (Daniel, 1955) and the role of the primary film in the settlement of certain marine fouling organisms (Daniel, 1955a). Investigations of Daniel were also directed towards the systematics (Daniel, 1956), colour of the substratum (1956a), illumination (Daniel, 1957), stage of tide (Daniel, 1957a), development (Daniel, 1958) and settlement (Daniel, 1963) of the fouling animals in the Madras Harbour. Ganapathi et al. (1958) studied the biology of fouling in the Vishakhapatnam Harbour on the east coast. Antony Raja (1959, 1963) studied the distribution, succession and growth of sedentary organisms. Balasubramanyan & Menon (1963) studied the characteristics of certain fouling organisms in Cochin Harbour while investigating the causes of timber destruction. Nair (1965) published a review on marine fouling in Indian waters, and recorded (Nair, 1967) the settlement and growth of some major fouling organisms from Cochin Harbour. Alagarswami & Chellam (1976) studied the biology of fouling and boring organisms and the mortality of oysters in the farm at Veppalodai in the Gulf of Mannar. The role of the primary film in the settlement of barnacles was studied by Nair & Pillay (1977). Becker (1958) in his report on marine borers to the Government of India has offered useful suggestions for a study on marine fouling organisms in Indian waters. Karande (1978) observed marine fouling and timber deterioration in sub-oceanic islands of Andamans.

The organisms that constitute the fouling community comprise a large and heterogeneous assemblage of both animals and plants. The Woods Hole monograph on 'Marine Fouling and its Prevention' (Woods Hole Oceanographic Institution, 1952) lists 615 kinds of plants and 1,361 variety of animals, but many more species have been added to the fouling complex since them. Animals representing 13 out of 17 commonly accepted phyla are included in the list (Woods Hole Oceanographic Institution, 1952) together with all the major groups under marine thallophytes. The fauna and flora include microscopic forms such as bacteria, fungi, diatoms, protozoans and rotifers and macroscopic forms like sponges, coelenterates, flat worms, bryozoans, tube worms, amphipods, barnacles, molluscs etc. Different kinds of algae also contribute to the fouling community. The barnacles, the tube worms, the bryozoans and the mussels are by far the most important from the point of view of surface coverage, volume and weight. Many free living forms are also found amidst the sedentary organisms that form the fouling community and they must be considered as an inseparable part of this group. The chief among them are the planarians, nemertines, polychaetes, isopods, decapods, gastropods and also certain fishes.

Both qualitative and quantitative differences have been recorded of the fouling assemblages met with on moored structures and moving surfaces like the hull of ships. Moored structures in general support a denser and much greater variety of foulers than moving structures. Hentchel (1923) recorded an average number of 4.39 species and Visscher (1928) 4.18 species respectively from 43 and 83 ships examined by them. However, the average number of species is 22.4 with reference to 10 navigational buoys recorded by Milne (1940). Different groups of animals thus occur more frequently on buoys compared to ships, indicating the diversity of species on buoys.

During different seasons, these substrata may hold various types of fouling plants and animals depending on their location in different regions along the coast under different ecological conditions and also at different sites within the same harbour (Pyefinch, 1950). The fouling complex that occur on temporary substrata some what differ from that of natural population accumulated on permanent objects under immersion, the former containing a,large number of species. The dominant organism of the community determines the character of the community and the character of community in turn is governed by the nature of bottom and its depth. The fouling community depends also upon the characteristic nature of the structures on which they attach and the condition of exposure.

In India the different members of the fouling community have been identified and studied in some detail at Vishakhapatnam (Ganapathi et al. 1958) Krusadai Island (Kuriyan, 1950), Bombay (Iyengar et al. 1957; Karande, 1968), Cochin (Nair, 1967), Neendakarai (Dharmaraja & Nair, 1981) and Andaman Island (Karande, 1978). A total of nearly 54 different species of fouling organisms have so far been recorded from Vishakhapatnam Harbour (Ganapathi et al. 1958), 54 species from Madras Harbour (Daniel, 1954), 57 from Krusadai (Kuriyan, 1950) 50 from Bombay and neighbouring areas (Iyengar et al. 1957) 48 from Neendakara (Dharmaraja & Nair, 1981) 30 from the Andaman Islands (Karande, 1978).

The fouling community that accumulates over the surface of any immersed object is controlled or influenced by a variety of factors. Slow growing, longer-living species may cover and spread over fast-growing, short-lived species. Temporal sequence and sometimes the presence of certain species may favour the settlement and growth of some species and this sequence is controlled by interdependent biological factors resulting in what is known as biotic succession. The sequence in which organisms appear on exposed structures is also influenced by different ecological factors both biotic and abiotic. The different fouling organisms reproduce and settle during periods that are favourable to them. This seasonal sequence in fouling is influenced, by the geographical location reflecting the effect of such factors as temperature, salinity and so on.

A newly exposed surface in the sea gets rapidly coated with microscopic organisms referred to as the primary film or slime film which is composed of bacteria, diatoms, algal spores mixed with organic and inorganic detritus, mud, sand and other particulate materials suspended in sea water. The bacteria multiply rapidly and attain dense populations in the span of several hours (Nair & Pillay, 1977). It has been found that the composition of the primary film is different in different areas. Zobell (1939) found that the primary film consists mainly of bacteria on the eastern coast of the United States. In the sub-tropical waters of Australia, Wood (1959) found that the film is composed of diatoms and algae and a smaller proportion of bacteria. Balasubramanyan & Menon (1963) have recorded bacteria, diatoms and protozoans as foremost of all settling organisms on the test panels in Cochin Harbour. American workers like Weiss (1948), Phelps Austin (as cited by Weiss, 1948) and Australian workers such as Wood (1950), Scheer (1945) support the view that bacterial slime forms the primary settlement. The observation of Nair & Pillay (1977) showed bacteria as the main constituent of the primary film at Cochin Harbour and they noted a progressive increase in the number of bacteria with increase in the duration of immersion. They also observed that diatoms and algal spores form only a small proportion of the slime film. Different stages in the development of slime have been noticed by various workers. Harris (1943) observed three stages in the development of the slime film, namely bacterial slime, diatom flora and the attachment of higher animals. However, Kuriyan (1953) could not observe separate stages in 10 day blocks. He stated that although a certain amount of primary film is formed consisting probably of bacteria and diatoms, the other organisms either settle simultaneously or follow immediately. Nair & Pillay (1977) observed three stages in the development of the primary film namely, bacterial slime, diatoms and finally the attachment of macrofoulers. According to them, primary film is not an essential prerequisite for fouling by barnacles, but they observed that the settlement of barnacle cyprids is facilitated to a great extent by the slime film. Phelps (1942) and Clarke (1943) as reported in Woods Hole Oceanographic Institution (1952) made similar observations, namely, attachment of larvae on freshly exposed panels, showing that the slime film is not essential for the settlement of barnacle cyprids. Miller (1946) studied the attachment of larvae of Bugula neritina and concluded, that the presence of slime film was not essential for the settlement of larvae of Bugula neritina even though slime facilitated the attachment. Scheer (1945) was able to demonstrate under natural conditions, the influence of slime on the settlement of bryozoans and ascidians and he attributed the diatoms of the slime film as the causative factor, which facilitated the settlement of bryozoan larvae on slimed panels when the larvae had a choice of slimed and non-slimed panels. He further observed that hydroids are favoured by the surface with bacterial slime. Wilson (1925) also noticed the influence of diatom populations of the slime in the subsequent macrofouling. Coe & Allen (1937) noticed heavy fouling on panels scrapped off fouling than clear surfaces and attributed "a more favourable physical surface, resulting from the retention of microscopic organisms and minute particles remaining from the previous growth for the increased fouling on such structures". The hypothesis of Wilson (1958) that different film forming microorganisms might vary in their ability to promote the settlement of macrofoulers has been substantiated by Meadows & Williams (1963). Their experiments showed that larvae of Spirorbis borealis, settled more readily on films developed in the presence of diatoms and their associated bacteria than on those developed in the presence of a green flagellate. Crisp & Ryland (1960) also observed primary film as capable of influencing settlement of larvae of Ophelia bicornis Thomson. Menon & Nair (1971) noticed that a conditioning of the panel, probably by means of the formation of primary film, as a pre-requisite for mass settlement of atleast some species of bryozoans and that the time required for the culmination of the phenomenon according to them at Cochin Harbour was more than three days. Daniel (1955a) observed that for the settlement of barnacles and serpulids, primary film as an essential pre-requisite. Corpe (1976) summarised the natural history of primary films, its role on the conditioning of the surface, the nature of the attachment of bacteria in the slime, the interaction of microbial film with soluble and particulate materials and the relationship of the primary film and initiation of macrofouling.

The primary film is followed by waves of the larvae of macrofoulers which settle, metamorphose and grow. The presence of certain species is essential for facilitating the subsequent attachment of other forms, leading to a sort of inter-specific dependence. This biological succession involves definite relations between organisms and is occasioned by factors of the environment. The earlier forms play a role for the establishment of forms that arrive later. In some cases the earlier forms are displaced or smothered as a result of successive settlement resulting ultimately in the establishment of a climax community consisting of forms which are slow growing and long living.

Seheer (1945) found at New Port Harbour, California four sequences in the biotic succession of fouling organisms and concluded that the succession is nearly, if not entirely, dependent on seasons. He also observed that mussels only colonise the surface harboured by bryozoa or *Stylea* community. From St. Andrews, New Brunswick, NewCombe (1935) reported rapid settlement of *Mytilus* on Mya arenaria killing the latter and changing the physical and chemical conditions of the surface layers which according to him is a true case of biotic succession. In many instances biotic succession is obscured by seasonal succession and in zones where seasons are prolonged and well marked, biotic succession may not be pronounced (McDougall, 1943; Moore, 1939; Pyefinch, 1943).

The only studies regarding this biotic succession in India are those of Daniel (1945) Antony Raja (1959) from Madras Harbour and Ganapathi et al. (1958) from Vishakhapatnam. According to Daniel (1954) the primary film is followed by barnacles, tube-dwelling polychaetes, polyzoans, molluscs, ascidians and once again the barnacles which finally occupy the whole area crowding out all other forms. Daniel observed the same sequence of events, taking place, irrespective of the season during which it is exposed (Daniel, 1954). In the observation on the succession of fouling communities at Vishakhapatnam Harbour (Ganapathi et al. 1958), the first arrivals have been reported to be bacteria, diatoms, protozoans and hydroids followed by serpulids, hydroids and polyzoans and later by simple ascidians, sea anemones, barnacles and oysters. However, Antony Raja (1959) during his studies has found no clear cut succession as has been reported from California (Coe & Allen, 1937), New Port (Scheer,

1945) and Australia (Allen & Wood, 1950), where a true ecological succession with a well defined community dominating at every stage, leading to a single climax community has been recorded. Antony Raja (1959) suggested that the ecological succession, if any, is not true, regular and definite, but is considerably modified under the prevailing ecological conditions. There was no clear cut seasonal succession in Madras Harbour as there was no sharp and well marked seasons as is usually seen in temperate countries.

Several factors of the environment are responsible for the seasonal succession of marine fouling organisms, of which, temperature, salinity, dissolved oxygen, turbidity, pollution, waves, tides, currents, light, colour, nature and texture of the substratum are important. American workers, like Bengough (1950), have divided the oceans of the world into a series of 10 zones, representing varying grades of fouling intensity. Zones 1 and 2 comprise a world-wide belt running roughly 30° North and 30° South of the equator, representing the zone of the greatest fouling intensity (India comes under this zone), whereas zones 9 and 10 (the Antarctic and Arctic seas) are with the lowest fouling intensity. Compared to tropical waters, settlement of marine fouling animals is more limited in temperate waters. Based on seasonal breeding behaviour, Paul (1942) distinguished four types of organisms, namely, those that attach without definite seasonal fluctuation throughout the year; those with increased frequency during definite portions of the year, those with limited attachments during a definite portion of the year and finally forms occurring at two definite periods of the year. Temperature influences reproduction and geographical distribution of marine animals. Extreme temperature conditions are not favourable for reproduction even though the adult organisms survive under such conditions. Paul (1942) observed no distinct periodicity in the breeding of marine sedentary organisms at Madras, where the differences between maximum and minimum temperatures are not appreciable. Continuous settling of sedentary organisms, their reproduction throughout the year, their rapid growth and attainment of sexual maturity at a surprisingly early age are all brought about by the constant prevalence of high temperature. Temperature influences the rate of photosynthesis of plants, thereby controlling primary productivity and the nutrition of animals. Temperature also influences precipitation, thereby controlling the salinity of the medium, through excessive run off. Annual variability in the quantity of fouling from year to year has been noticed by Coe & Allen (1937) and Weiss (1948) which they could not correlate with variation in physical aspects of the environment and the causes for these fluctuations in occurrence still remain unexplained.

Based on distinct temperature conditions, Ortman (1896) divided the shallow waters of the world into six regions and had further divided certain regions into sub-regions. The basic distinction is between the warm water tropics and the cold water zones towards the poles. Boundaries are usually with either summer or winter temperatures. The organisms are unable to breed or are otherwise killed by extreme cold towards the poles, thereby establishing a boundary. Similarly towards the equator, extreme summer temperature may either kill the organisms or prevent reproduction. Temperature factor restricting the distribution of the animals is also discussed by Hutchins (1947).

Salinity is recognised as the most important factor controlling the occurrence of fouling organisms. Salinity is relatively a very important factor in India, where the prevailing monsoons cause considerable amount of rainfall. Accordingly wide fluctuations in salinity are noticed along the coasts of India. Even though salinity fluctuations in the open ocean are insignificant, in estuaries and harbour areas salinity fluctuations are very much marked owing to land drainage. Very few species are able to tolerate these vide variations of salinity and animals exhibit differences in horizontal and vertical distribution correlated with the changes in salinity. Some fouling organisms through years of physiological adjustment and acclimatisation show considerable tolerance to variation in salinity. Experiments in this respect are few from India. Marine borers such as *Martesia striata* as observed by Nagabhushanam (1955) and *Sphaeroma* sp. as noticed by Pillay (1955) have been found to live in waters of very low salinity. American barnacles such as *Balanus tintinnabulum* and *Balanus amphitrite* are never observed in the upper reaches of the estuary, even though, they are common on coastal installations. Species such as *Balanus balanoides*, even though penetrate further, *Balanus eburneus* and *Balanus improvisus* common along the coast, are unable to withstand extreme variations of salinity (Pilsbry, 1916). The marine bryozoan *Bowerbankia gracilis* also shows tolerance to extreme variations in salinity (Hutchins, 1945; Osburn, 1944). Menon & Nair (1971) working on the ecology of bryozoans of the Cochin waters noticed *Victorella pavida* and *Electra crustulenta* settling only on panels during the monsoon period and *Electra bengalensis*, *Alderina arabianensis* and *Schizoporella cochinensis* occurring on panels during the pre-monsoon period. They have grouped bryozoans in the locality as typical brackish water forms not encountered under typical marine conditions (Eg. *Victorella pavida*), typical brackish water forms which may occur under marine conditions also (Eg. Electra crstulenta) and typical marine forms that never appear during low saline conditions (Eg. Nolella papuensis, Bowerbankia gracilis etc). Menon & Nair (1971) conclude that "a combination of higher range of salinity with higher range of temperature during the pre-monsson period seems to be associated with intense settlement and colonization of typical marine bryozoans in Cochin Backwaters during the pre-monsoon period and absence of species other than Victorella pavida and Electra crustulenta during the monsoon period is due to the absence of larvae of those bryozoans in low salinity prevailing at Cochin from June to December which imposes restrictions upon the effective recruitment of larvae of marine species from the open ocean to the estuary".

Salinity also controls the breeding of littoral animals (Panikkar & Aiyar, 1939) and their growth rates (Erlanson, 1936), thereby reducing the intensity of fouling in an area. Observation of Nair (1967) shows that the quality and quantity of fouling have been the least during the monsoon period at Cochin, which extends from the middle of May to the end of November (South-west and North-east inclusive).

Pollution is yet another factor of importance in the biology of fouling, particularly within the enclosed body of water in the harbours. Pollution is the outcome of sewage, industrial waste, petroleum by-products, oil etc. finding their exit into natural waters and changing both their physical and chemical nature. The substances that pollute may be harmful by possessing toxic effects or may lead to a serious depletion of oxygen of the medium resulting from oxidation of organic matter. Water polluted by harmful pollutants is normally devoid of fouling organisms. On the other hand, certain substances may act as nutrients thereby enriching the medium. In such situations detritus feeders, mud-tube dwelling polychaetes and amphipods (Nair, 1962) show luxurious growth and characteristic indicator species can be recognised (Barnard, 1958). It may also be mentioned that the two factors, salinity and pollution, can to a large extent be the limiting factors of the environment causing a natural check over the fouling community. According to Fox & Coe (1943) organic detritus, the chief source of food supply to the sedentary organisms has direct value for these organisms and certain shell fishes like oysters flourish under such conditions of pollution. However, it is rather difficult to draw conclusive evidence of the harmful effects of pollution. Galtsoff et al. (1938) have found that the oyster industry of the York River Estuary has declined owing to pulp - mill pollution.

Milne (1940) attributed differences in the fouling of buoys in the Tamar and Mersey Estuaries to differences in pollution. In the Tamar Estuary he observed more species than in the more polluted Mersey Estuary.

The enclosed coastal waters of the harbour and other bodies of coastal waters contain silt, detritus and other particulate materials in fine suspension. The settling of silt may smother sessile forms and form a mat-like cover over the substrata thereby preventing the settlement of certain species of organisms. Coe & Allen (1937) and Fuller (1946) observed that panels particularly exposed in a horizontal position accumulate more of silt rendering them unsuited for the attachment of sedentary animals. Large quantities of suspended silt can clog the respiratory organs and can disable normal functioning of the ciliary feeders. However, Milne (1940) could not observe any difference in the distribution of animals with ciliary feeding mechanism and other type of respiratory organs in silted and non-silted areas. Thick silt and resulting turbidity reduces the penetration of light preventing the growth of green plants. Those forms which need plant as a sustratum for settlement, are therefore, unable to settle in such a medium.

Movements of the water medium owing to waves, tides and currents also can affect the dispersl, settlement and growth of sessile organisms. Water movement facilitates the existence of sessile animals, since food particles are brought to them and the waste products are in turn carried away. These movements also help the distribution of the larvae and thus prevent over crowding in any particular substrata. These movements of the water mass are sometimes harmful when the larvae of the littoral forms are swept far away into the open sea where settlement is impossible or to places where conditions are unfavourable for settlement. The velocity of water currents on the substratum is important since larvae of foulers select suitable sites for settlement in relation to the velocity gradient of currents (Smith, 1946; McDougall, 1943). Smith (1946) found _Balanus_ _improvisus_ settling in currents up to about 0.5 knots and tube worms _Dasychone_ _conspersa_ up to about 1.0 knot. McDougall (1943) observed _Bugula_ and _Balanus_ grew best when the velocity of currents was minimum, _Tubularia_ and _Sabellaria_ preferring maximum velocities; sponges, oysters and tunicates preferring intermediate conditions. Hentchel (1923) recorded the maximum growth in barnacles settled on the stem, edge of bilge keel and rudder of ships and ascribed the pronounced growth of barnacles on these structures to abundant food supply in such places. Sumner _et_ _al_. (1911) observed good growth in tubularia, hydroids, mussels, bryozoa and ascidians in narrow passages carrying swift tidal currents up to 4 knots. Fox & Coe (1943) observed more rapid increase in weight of Mytilus californianus in wave washed sites than in calmer waters. The attachment and survival of barnacles are also mostly influenced by water currents. But Crisp & Stubbings (1957) have found that current has very little influence on the cyprids at the time of fixation. Regarding the effect of the stage of tide conflicting views are expressed by various workers. Weiss (1947) found maximum settlement of Balanus improvisus during the low tide period. However, Visscher & Luce (1928) observed increasing tide favouring the settlement of cyprids of Balanus improvisus and Balanus amphitrite. McDougall (1943) agrees with Visscher & Luce (1928), while working on the different distribution of barnacle Balanus eburneus. In the case of cyprids of Balanus crenatus, Pyefinch (1948) observed abundance later in the tide, that is, when the ebb flows away to slackwater. Barnes (1950) expressed doubt regarding the dominance of cyprids later in the tide at Millport Harbour. Daniel (1957, 1963) observed maximum attachment of Balanus amphitrite during low tide and virtually no influence of tide for Balanus tintinnabulum and Cthamalus stellatus which preferred to settle at high tide than at low tide. Daniel (1963) is of the view that "what little effect the stage of tide may have on the settlement, is masked by the influence of illumination due to sunlight during periods of low or high tide". He ascribed the difference in behaviour of these barnacles to the distinct habitats to which these species are confined.

Many of the larvae of foulers are negatively phototropic and they prefer darker surfaces, while few are positively phototropic. There seems to be no agreement among various workers as regards the probable effect of light on the settlement of barnacle cyprids. Visscher & Luce (1928) observed that the barnacle cyprids "react negatively to light at the time of attachment", while Weiss (1947) and McDougall (1943) are of the view that they are positively phototropic at the time of attachment. Pyefinch (1948) was not able to arrive at any definite conclusions regarding the effect of light on the settlement of barnacle cyprids. Investigations of Kuriyan & Mahadevan (1953) at Krusadai Island have revealed that barnacles attach mainly on surfaces deeply submerged and that those on a block near the surface are confined to its underside away from strong light. Sunlight according to them, has an effect on the settlement of barnacles. The influence of shaded surfaces rather than illuminated surfaces on the settlement of sedentary animals was observed by Gregg (1945), Smith

(1948), Cole ' Knight Jones (1939), Cole (1949), Wisely (1958), Ryland (1960), Dybern (1967), Bayne (1964) and De Silva (1968). It is debated whether foulers are truly phototropic or whether larval settlement is inhibited by illumination. Gregg (1945) is of the view that shading acts as a stimulus for favourable physiological conditions for the subsequent settlement of barnacle cyprids. Weiss (1947) studied the effect of artificial light at night and compared the settlement on panels that occurred during day time. However, artificial illumination increased the attachment of barnacle cyprids at night.

The colour of the substratum exposed also exerts a profound influence on the settlement of sedentary organisms. (Kuriyan & Mahadevan, 1953; Daniel, 1956; Nair, 1962; McDougall, 1943; Pomerat & Reiner, 1942; Ghobashy, 1976). It has been found that red, black and white attracted large numbers; blue, green and grey had fewer and grey panels attracted the poorest number. Visscher (1928) observed smaller number of foulers on lighter colours. Edmondson & Ingram (1939) found that white and green are more effective for discouraging fouler settlement than darker shades at Hawaii. Pomerat & Reiner (1942) while experimenting with black, clear and opal glass panels at Florida, found twice as many barnacles on black plates than on clear ones. Ghobashy (1976) working at the eastern harbour of Alexandria

(Egypt) noticed the colour preference of eleven species of fouling organisms to black and white panels. He observed preferential settlement of Hydroides norvegica, Spirorbis corrigatus, Balanus perforatus, Ciona intestinalis, Diplosoma listerianum on black backgrounds. However, Obelia geniculata, Tubularia larynx, Balanus amphitrite and Botryllus schlosseri were indifferent in their choice between the black and white panels. Balanus eburneus was the only animal that preferred white panels according to Ghobashy (1976). Visscher (1928), Edmondson & Ingram (1939) have showed that lighter colours are also densely fouled as that of darker ones, though initial fouling was more on darker ones. The influence of colour on settlement is of great practical importance, since this would help in the incorporation of the required colour pigments in the formulation of antifouling preparations intended for commercial purposes.

The nature and texture of the substratum have marked effect on the settlement of marine sedentary animals (Pyefinch, 1948; Pomerat & Reiner, 1942; Visscher, 1928; Pomerat & Weiss, 1946; Barnes & Powell, 1950; Ghobashy, (1976). This is particularly true in the case of barnacles, probably due to the walking movements of barnacles cyprids prior to final settlement as reported by

Visscher (1928). He states that the cyprid larvae make exploratory movements covering appreciable distances before attachment. Barnes & Powell (1950) found that the projecting bristles of staple clothes by their number and stiff character may prove a source of irritation or may mechanically restrict the movements of cyprids. Ghobashy (1976) noticed that rough panels promoted the settlement of *Tubularia larynx*, *Hydroides norvegica*, *Spirorbis corrigatus*, *Balanus perforatus*, *Bugula neritina*, *Ciona intestinalis* and *Diplosoma listerianum*. In the case of *Obelia geniculata* and *Botryllus schlosseri* the smooth panels were found more favourable by him. *Balanus eburneus* and *Balanus amphitrite* showed insignificant preference to rough and smooth panels. Among the animals that preferred rough panels, t - test analysis showed marked preference of *Tubularia*, *Hydroides*, *Balanus perforatus* and *Ciona* to rough panels compared to others. Sedentary animals prefer concave rather than plane surfaces were observed by Moore (1935), Gregg (1948), Barnes *et al.* (1951), Crisp & Barnes (1954), Moyse (1971), Wisley (1960) and Williams (1965). Thus the quantity and quality of fouling organisms seem to show variations with reference to nature and texture of the substratum on which they settle such as rock, concrete, asbestos, earthern tiles, glass, metallic surfaces and fibrous structures.

The existence of a mutual relationship between marine fouling animals and boring organisms has been noted by various workers (Nair, 1962; Weiss, 1948b). Many of the fouling organisms, particularly those with special calcareous protective structures, offer a physical barrier to the subsequent borer settlement in the same substratum or perhaps may be the fouling organisms prey upon the larvae of borers. It is also often questioned whether there is any evidence of a casual relationship between the onset of fouling and initiation of corrosion or vice versa. Authentic information on this subject of fundamental studies on the mechanism by which marine organisms directly or indirectly affect corrosion and the role of fouling organisms in preventing corrosion in tropical waters is still wanting.

Thus the problem of marine fouling and its prevention appears to be an evasive subject. A thorough study on the different marine fouling organisms, their mode of attachment, complete life cycle, their reaction to environmental conditions are all very important. The physico-chemical variables of sea water, the effects on the time of exposure, the nature of the substratum and its location in relation to depth, the mechanical effect of currents and condition of illumination are some of the important factors that affect any natural population.

Intra-specific and inter-specific competitions and the presence or absence of predators and parasites also have an abiding influence. The intensity of fouling in an area is, therefore, dependent upon many factors which are directly or indirectly concerned.

Fouling considerably varies with the locality and results obtained from investigations of one area have only local importance. Therefore, in the present study a detailed investigation has been undertaken on the biology of fouling from Cochin Harbour as part of a general study of the ecology of the oysters of this harbour. Hitherto work done on biofouling in the Cochin Backwaters has been chiefly qualitative. In this work an effort has been made to give emphasis on quantification of the data so that comparisons could be made in future on the nature of biofouling and variation in its comparison through man made changes in the environment.

2.2. Materials and methods

The fouling organisms of the test site were collected by exposing smooth glass panels of 150 x 100 x 3 mm fitted into a grooved wooden rack in two rows of seventeen each. The wooden rack together with the panels was exposed subtidally 30 cm below low water line from the quay of the Central Institute of Fisheries Technology, in the Mattancherry Channel of Cochin Harbour. 34 panels exposed together formed one series, each removed for examination at the end of every day. These panels gave an idea of the settlement and growth of animals that had taken place from 1-34 days. However, this strict schedule could not be followed in all instances as may be evident from the Tables 2.4 to 2.32. Ten animals that showed the maximum growth in each panel were taken for measurements and only the average values of these are presented as representative growth for that corresponding day. The intensity of settlement was recorded by counting the total number of organisms settled on the panels. The intensity of hydroid settlement was noticed by counting the number of vertical stolons present in 6.3 cm^2 area and expressed in 100 cm^2 as, R = Rare (1 to 100/100 cm^2), C = Common (101 to 300/100 cm^2), VC = Very common (301 to 800/100 cm^2) and A = Abundant (801 and above/100 cm^2). While recording the growth of the various organisms, the following measurements were made. Hydroids - the height of the vertical hydrocauli; tube worms-length of the calcareous tube; encrusting bryozoans - two measurements at right angles to each other and their average, barnacles - restro-carinal diameter and the height from the base to the apex of shell; modiolus - height (Distance from Umbo to the free edge) and length (maximum distance of shell at right angles to height. Only the above mentioned five major fouling organisms that are commonly met with on experimental panels and various other substrata at the test site and contributing substantially to the quality and quantity of fouling alone are included in the biofouling studies. Altogether 7 series of panels were exposed during the period from March 6, 1979 to February 24, 1980. The limited surface area of the experimental glass panels offer only restricted lodging place for the foulers and the chances of obtaining representative marine sedentary organisms present in the locality are naturally small. However, the data obtained after careful scrutiny from these day to day panels numbering approximately 500 spread over a period of nearly 28 months are deemed sufficient to draw reliable conclusions on the various aspects of biofouling in Cochin Harbour. These conclusions have also been checked from data obtained by the examination of various substrata such as the hull of fishing boats, concrete piles, navigational buoys and piles or piers of quays and jetties in the neighbourhood. For studies on the primary film, smooth glass panels of 150 x 100 x 3 mm were immersed in sea water kept in aquarium tanks in the laboratory and were allowed to accumulate slime for about 24 hours. Slimed panels together with sterilized controls were exposed in the backwaters by arranging them on grooved wooden racks and suspended from the quay 30 cm below low water line. After 48 hours of immersion, all the panels were removed from the water and examined under a stereomicroscope. The micro-foulers together with settled macro-foulers were counted and recorded (Tables 2.1 and 2.2). During the monsoon period (mid May to September), there was very little fouling both qualitatively and quantitatively and data pertaining to certain animals during this period were practically negligible and hence not included. For determining the quantitative formation of bacterial film, sterilized glass panels (microscope slides) were exposed in the backwaters on a grooved rack and examined after 2, 4, 6, 18, 24 and 72 hours. Scrappings from these panels were cultured for determining bacterial counts (Table 2.3).

Day to day hydrographic data of the test site such as air temperature, surface water temperature, salinity, dissolved oxygen, and turbidity were collected and recorded in Tables 1.2 to 1.10 and their weekly averages in Table 1.1 and Figs. 1.3 to 1.7 of chapter 1.

To study the relationship of age on height, length and diameter in the various animals, the experimental data were analysed statistically by fitting growth models. The mathematical model employed was $Y = AB^x$, where Y represents either length, height or diameter as the case may be and x represents age in days. This mathematical model was converted to a straight line for fitting. On taking log,

$$\log Y = \log A + x \log B$$

Let $\log Y = y$, $\log A = a$ and $\log B = b$, then the above equation becomes,

$y = a+bx$, which is the logarithmic line of the mathematical model. Fitting this line to the data by the method of least squares, the following normal equations were arrived at

$$b \sum x^2 + a \sum x = \sum xy \quad (1)$$

$$b \sum x + na = \sum y \quad (2)$$

From these two equations, a and b were solved. Also the co-efficient of correlation between the logarithm of age and the logarithm of each of the variables, namely, height, length and diameter were worked out by Pearson's formula

$$r = \frac{\sum (x - \bar{x})\ (y - \bar{y})}{n\, \sigma x\, \sigma y}$$

where $\bar{x} = \frac{\sum x}{n}$, $\bar{y} = \frac{\sum y}{n}$

and n represents number of pairs of values. The significance of the co-efficient of correlation was tested by 't' test.

$$t = r \frac{\sqrt{n-2}}{\sqrt{1-r^2}}$$

The degrees of freedom of 't' is n-2. The value of r, a, b, n and the significant level of correlation co-efficients are presented in Tables 2.33, 2.34 and 2.35. A and B in the models are obtained by taking the antilogarithm of a and b. The goodness of fit of the model for the experimental data pertaining to bryozoans, barnacles, oysters and modiolus are shown in Figs. 2.1 to 2.27. The figs. are in the three dimensional scale, age on x axis, length or height or diameter along the y axis and the number settled along the Z axis. In all the figures the fitted model is very close to the experimental data indicating that the model fitted represents the data closely.

2.3. Results

2.3.1. The primary film

A perusal of Tables 2.1 and 2.2 shows that settlement of balanids was influenced by the primary film as may be seen from the nature of settlement on slimed panels and unslimed controls. Of the nine slimed panels examined, the total balanids settled was 67 while the number settled on non-slimed controls was only 23. The settlement of micro foulers was uniform both on slimed and non-slimed panels. Species of Vorticellids and Zoothaminium were predominent among the micro foulers. Altogether twelve genera of diatoms namely, Nitzchia, Navicula, Bacillaria, Melosira, Pleurosigma, Coscinodiscus, Cyclostella, Rhizosolenia, Thallasiosira and Closterium, were recorded. Qualitative variations of bacteria during the different periods of exposure are presented in Table 2.3. 85% of the bacterial isolates were nitrate reducers and 5% sulphate reducers. Majority were found to be non-sporing gram negative, motile rods with flagella. A few genera of *Vibrio*, *Acromobacter* and *Aeromonas* were also identified. Bacteria were the first settlers and their number increased progressively after 2, 4, 6, 18, 24 and 72 hours (Table 2.3). The presence of diatoms in the slime film was noticed only after 48 hours.

2.3.2. Principal fouling organisms

The diatoms collected from the primary film were also found occurring on panels under the different series.

Protozoa

The colonical ciliate protozoan *Zoothaminium* sp. was invariably present on all the panels examined. This suggests that these protozoans are able to survive both in brackish water and typical marine conditions. In most of the panels *Zoothaminium* sp. and *Vorticellaids* sp. were the first to arrive. *Folliculina* sp. were also recorded from the panels occasionally.

Coelenterata

Within 48 hours, hydroids made their appearance on the panels. *Obelia bicuspidata* and *Obelia gracilis* occurred on the panels during the pre-monsoon and post-monsoon periods. They were totally absent during the monsoon period when salinity was low. The hydrorhiza ramified the surface of the panels from which erect branches (hydrocauli) appeared. The height of these erect branches was measured to record the growth rate of hydroids. A maximum growth of 53.6 mm was recorded in the sixth series of panels during December 1979. The occurrence and rate of growth of hydroids are presented in Tables 2.4 to 2.8. The maximum growth attained by the hydroids was 14.1, 15.8, 14.2, 53.6, 17.1 mm in the 1st, 2nd, 3rd, 6th & 7th series respectively after 42, 44, 27 and 43 and 50 days respectively (Tables 2.4, 2.5, 2.6, 2.7 and 2.8). These hydroids attained sexual maturity in 10 - 14 days and ripe gonophores were seen in individuals 10 days old and above and medusae were also liberated during this period.

Caprellid sp. was often found browsing on hydroid colonies. Nudibranchs were also seen amidst the hydroids. A few sea anemones were also recorded from the panels during the pre-monsoon and post-monsoon months.

Bryozoa

The bryozoans found fouling the panels were *Electra bengalensis* (Stoliczka), *Alderina arabianensis* Menon & Nair, *Schizoporella cochinensis* Menon & Nair, *Victorella pavida* Kent, *Electra crustulenta* Pallas, *Conopeum reticulum* (Linnaeus), *Membranipora savartii*

(Hentschel). Of the seven species of bryozoans recorded Victorella pavida and Electra crustulenta settled abundantly during the monsoon period (June to September). During the post-monsoon period (October to January) Electra crustulenta and Victorella pavida settled in fewer numbers till December. However, large numbers of Electra bengalensis and Alderina arabianensis settled during this period. During the pre-monsoon period (February to May), particularly towards the latter part, Alderina arabianensis and Electra bengalensis continued to settle. Schizoporella cochinensis started settling from February onwards. A maximum growth of 52.9 mm after 45 days in the 1st series (Table 2.9), 28.5 mm after 44 days in the 2nd series (Table 2.10), 17.3 mm after 42 days in series 3 (Table 2.11), 25 mm after 50 days in the 4th series (Table 2.12), 16.7 mm after 44 days in the 5th series (Table 2.13), 29 mm after 43 days in series 6 (Table 2.14), 20 mm after 53 days in the 7th series (Table 2.15) was recorded.

Annelida

Hydroides norvegica Gunnerus and Mercierella enigmatica were the serpulid worms found settling on the panels. They were found totally absent during the low saline period existed during August, September (4th series) and October (5th series). Their peak settlement was in June-July as is evident from Table 2.18. A maximum tube length of 49.3 mm was observed after 43 days in the 1st short term series (Table 2.16) during April. However, they attained 16.8, 13.2, 14.0, 15.0, 29.5, 32.0 and 19 mm after 42, 43, 44, 33 and 51 days in series 1, 2, 3, 5, 6 and 7 respectively.

Polychaete worms like *Eunice* sp. *Polydora* sp. accumulated significant quantities of mud over the panels. The settlement of mud-tube dwelling polychaetes was numerous during the post-monsoon and pre-monsoon periods.

Crustacea

The most dominant fouling crustaceans encountered in the Cochin Harbour was the cirripede, *Balanus amphitrite communis* Darwin with their presence throughout the year. *Balanus amphitrite* was found settling in large numbers particularly during the post-monsoon period, in fair numbers during the pre-monsoon period and settlement was very much reduced during the monsoon period. The months during which a distinct peak in settlement occurred were September, October, November and December (Tables 2.26, 2.27) thereby contributing the major share in surface coverage, volume and weight of fouling. Rostro-carinal diameter of 14.8 mm and height of 6.9 mm were recorded after 42 days during April 1979 in the 1st series (Table 2.22). *Balanus amphitrite communis* appears to be a continuous breeder in this locality based on its settlement on glass panels, even though the intensity of settlement was different during different months.

Mollusca

Bivalves were next in abundance to balanids in so far as surface coverage, volume and weight are concerned. The predominant bivalve molluscs recorded were the edible backwater oyster *Crassostrea madrasensis*, the rock oyster *Crassostrea cucullata* Born and *Modiolus carvalhoi*. The green mussel *Perna viridis* (Linnaeus) appeared only very rarely on the panels. *Modiolus carvalhoi* contributed substantially to the bulk of fouling particularly during November to December (Table 2.30). They grew to a maximum height of 11.5 mm and length of 6.0 mm after 51 days in the 7th series (Table 2.31).

Simple and compound ascidians were also recorded from several panels. They were found settling on panels during March, April and May (Pre-monsoon) and were completely absent during other periods. Both the simple and the compound ascidians appeared to be typically marine forms as their settlement was confined to high saline condition of the pre-monsoon period.

As the settlement and growth rate of the backwater oyster *Crassostrea madrasensis* are dealt with separately in chapers 3 and 7, respectively, these aspects are not considered in this chapter along with the other fouling organisms.

2.4. Discussion

2.4.1. Fouling in relation to environmental factors

The sedentary fouling communities are very much influenced by the fluctuation in environmental factors. In regions where seasons are well marked, as in temperate regions the reproduction and growth of these organisms are inhibited by low temperature conditions prevailing during the winter period. However, in the tropics, clear cut seasons are absent and because of the uniformly high temperature conditions, the sedentary fouling organisms breed and settle almost continuously throughout the year, producing several generations. The cycle of breeding and settlement may be interrupted during unfavourable conditions but will be restored when conditions become normal.

Lowering of salinity considerably affects the settlement of sedentary organisms (Edmondson & Ingram, 1939; McDougall, 1943; Weiss, 1948a; Erlanson, 1936; Ganapathi, et al. 1958; Antony Raja, 1959, 1963, Panikkar & Aiyar, 1939; Nair, 1967). In the Cochin Harbour, owing to heavy precipitation during the monsoon and the consequent land drainage, pronounced fluctuations are noticed in the distribution of salinity. It varied from 33.9‰ in Feb. to 1.3‰ in July (Table 1.1 Ch.1). Owing to drastic reduction in the salinity, notably of the surface waters, fouling is considerably reduced both in quantity and in quality. Antony Raja (1963) during his observations on sedentary organisms has noticed that the lowering of salinity retards the growth of individuals at different locations within the Madras Harbour. He has further observed an uninterrupted growth of sedentary organisms at the Quay, where the salinity values are not affected during October. Erlanson (1936) observed a comparatively lower rate of growth of certain boring organisms at Cochin Harbour. Salinity also plays a decisive role in the breeding and subsequent settlement of the larvae of foulers. Panikkar & Aiyar (1939) have observed that the lowering of salinity affects the breeding of brackishwater animals of Madras. The present study also showed that fouling organisms such as hydroids, Hydroides norwegica, and Crassostrea madrasensis were eliminated during the major part of the monsoon and the early post-monsoon period (They were absent in series 3, 4 and 5 exposed from June-September). As observed by Crisp (1959), Hutchins (1947) and Barnes (1957) the liberation of larvae of barnacles depends on one or more factors like temperature, salinity, oxygen tension and availability of nutrients. However, variations in hydrological factors other than salinity in the Cochin Harbour were not appreciable enough to bring out pronounced changes in the faunistic composition (Table 1.1 ch.1). Air temperature varied from 27.2 to 32.1°C, water temperature from 27.4 to 32.2°C, dissolved oxygen from

1.4 to 8.0 ml/l while salinity fluctuated between 0.6 to 33.9‰. Thus, an alternation of marine and freshwater conditions occurs in the Cochin Harbour and thus the salinity factor plays a significant role in the ecology of the fouling organisms occurring there.

Pillay (1955) observed continous breeding of Balanus amphitrite communis (Darwin) from Kerala backwaters with reduced intensity during the monsoons. Balasubramanyan & Menon (1963), Nair (1966) and Nair (1967) have all noticed the influence of hydrographic conditions on the settlement of marine fouling and wood boring organisms in the Cochin Harbour. Karande & Palekar (1963) found that the incidence of Chthamalus malayensis (Pilsbry) with larvae, as almost negligible during the monsoon period between July, August and September and had resonably attributed the causative factor to specific variations of environmental conditions. Dharmaraja & Nair (1981) also attributed the fluctuation in marine and estuarine forms of the fouling community to fluctuations in salinity consequent on the monsoons at the Neendakara Port.

The existence of certain strains of barnacles and encrusting bryozoans at the Cochin Harbour during the monsoon period may be due to many years of physiological adjustment and gradual acclimatisation. Erlanson (1936) also noticed the occurrence of certain strains of barnacles and oysters adapted to low salinity. The forms which cannot tolerate the low salinity are eliminated during the monsoon period and the areas left bare by these organisms are found later recolonised by the planktonic larvae brought to the site by tidal currents and other movements of the water mass.

2.4.2. Succession of fouling communities: The primary film

The results of the present study indicate that bacteria were the first settlers and their number increased progressively after 2, 4, 8, 16, 24 and 72h(Table 2.3). The presence of diatoms in the slime film was noticed only after 18 h. At Bombay Harbour, Almeida (1964) observed diatoms only after 48 h in the slime film. The formation of slime film appears to be a favourable factor for the settlement of atleast barnacle cyprids. However, their settlement on non-slimed controls, though fewer in number, indicate that slime film is not an essential pre-requisite for their settlement. Phelp's (1942) experiment indicates that the presence of the slime film may favour the attachment of the cyprid larvae of barnacles. Clarke's (1952) observation of large number of cyprid larvae attaching to glass panels within an hour also supports this view.

Daniel (1955, 1963) observed that fouling commences only after 48 h in Madras Harbour, that is, only after the formation of the primary film and filmed panels facilitated the settlement of larvae without delay. According to him (Daniel, 1963) larvae of foulers avoid non-slimed surfaces and perish rather than settling on non-slimed surfaces. However, this could not be observed during the present study.

Miller (1946) studied the settlement of larvae of *Bugula neritina* on non-toxic surfaces in the laboratory. He concluded that the presence of slime film facilitated but was not essential for the attachment of *Bugula* larvae. As noted in the present study, Miller *et al*. (1948) observed greater number of attachment on slimed surface when the larvae had a choice of both slimed and non-slimed panels. In some cases, fifteen fold preference for slimed panels was also noticed by them. Whedon (1937) observed that the number of erect bryozoans mostly *Bugula neritina* increased on slimed panels under natural conditions, but he could not observe any settlement during the first two or three weeks of exposure, although many bryozoans settled on older panels. Scheer (1945a) attributed the favourable factor for bryozoan settlement to an algal population consisting mainly of diatoms in the primary film. He also observed that hydroid settlement was increased due to bacterial slimes but not that of bryozoans.

The hypothesis of Wilson (1958) that different film forming microorganisms might vary in their ability to promote settlement has been substantiated by the studies of Meadows & Williams (1963). Their experiments showed that larvae of Spirorbis borealis, settled more readily on films developed in the presence of diatoms and their associated bacteria than on those developed in the presence of a green flagellate. Crisp & Ryland (1960) also observed that primary film is capable of influencing the settlement of the larvae of Ophelia bicornis Savingny, Spirorbis borealis Daudin and Bugula flabellata Thomson. Menon & Nair (1971) noticed that a conditioning of the panel, probably by means of the formation of primary film, as a pre-requisite for the mass settlement of atleast some species of bryozoans and that the time required for the culmination of this phenomenon at the Cochin Harbour was more than three days.

At the Madras Harbour, Daniel (1955, 1963) observed that the primary film is constituted chiefly of diatoms and algal spores with a relatively smaller proportion of bacteria. The present study showed bacteria as the main constituent of the primary film at the Cochin Harbour and a progressive increase has been noticed in their number corresponding to the increase in the duration of immersion. Diatoms and algal spores formed only a smaller proportion of the slime film at the Cochin Harbour. In this respect the present observation agrees with that of Zobell (1939) who found that the primary film constituted mainly of bacteria on the estern coasts of the United States. Weiss (1948), Phelps Austin (as cited by Weiss, 1948), Wood (1950) and Scheer (1945) also support the view that bacterial slime forms the primary settlement. As observed by Harris (1943) the present observation also showed three stages in the development of the primary film, namely, bacterial slime, diatom flora and finally the attachment of the higher fouling animals. From the present study, it can be assumed that the primary film does not seem to be an essential pre-requisite for fouling by barnacles but it can facilitate the settlement of barnacle cyprids to a greater extent.

Soon after the formation of the slime film, the panels were found fouled by several macro foulers. During the pre and post-monsoon periods, the primary film was closely followed by the hydroids. The hydrorhiza spreads very rapidly all over the panels from which rose the vertical stolons (hydrocauli). This gave rise to the vegetative polyps and sexual gonophores. Hydroids were followed by the tube worm Hydroides norvegica, encrusting bryozoans and barnacles. Hydroids were totally absent during monsoon periods. Of the seven species of bryozoans, Victorella pavida and Electra crustulenta settled during the low saline period existed during the monsoon (June-September). However, during the post-monsoon period

(October-January) Electra crustulenta and Victorella pavida colonised the panels and large numbers of Electra bengalensis. Alderina arabinaensis settled during the pre-monsoon months. Barnacle population was represented by Balanus amphitrite communis and they settled in large numbers during the post-monsoon period when salinity registered a steady increase. Bivalves were represented by the edible oyster Crassostrea madrasensis and Modiolus carvalhoi. Oysters settled in large numbers from January to February. Peak settlement of Modiolus carvalhoi was during November-December. Mud-tude dwelling polychaetes such as Eunice and Polydora were abundant during the post-monsoon months. Simple ascidians and compound ascidians were confined to March, April and May and were totally absent during other periods. By the onset of monsoon, the community that settled in large numbers during the hot, highly saline pre-monsoon ceased to settle and hydroids, calcareous tube worms, Modiolus and oysters were absent on the panels. Soon after the monsoon, when favourable conditions were restored, the community described above appeared again and the cycle was repeated.

Table 2.1 Settlement of foulers on slimed panels

Panel no.	Microfoulers	Settled cyprids
S_1	Rotifers, vorticellids and *Zoothaminium*	4
S_2	Rotifers, *Zoothaminium*, vorticellids and algal spores	5
S_3	*Zoothaminium*, vorticellids, rotifers, *Nitzchia* sp. *Navicula* sp., *Melosira* sp. and *Storoneis* sp.	15
S_4	*Zoothaminium*, vorticellids, rotifers, *Rhizosolenia* sp. *Pleurosigma* sp. *Thallasiosira* sp. *Storoneis* sp. *Navicula* sp. and *Closterium* sp.	2
S_5	Soil nematodes, *Zoothaminium*, rotifera, vorticellids, *Closterium* sp. *Cyclostella* sp. *Coscinodiscus* sp. and *Cymbella* sp.	9
S_6	Copepods, *Zoothaminium*, vorticellids, nauplii, erect polyzoans, *Navicula* sp. *Pleurosigma* sp. *Storoneis* sp. *Cymbella* sp. and *Closterium* sp.	10
S_7	Vorticellids, *Zoothaminium*, rotifers, *Thallasiosira* sp. *Closterium* sp. *Pleurosigma* sp. and *Navicula* sp.	5
S_8	*Zoothaminium*, vorticellids, *Storoneis* sp. *Navicula* sp. *Pleurosigma* sp.	9
S_9	Rotifers, *Zoothaminium*, vorticellids, *Cyclostella* sp. *Pleurosigma* and *Storoneis* sp.	8

Table 2.2 Settlement of foulers on control panels (non-slimed)

Panel no.	Microfoulers	Settled cyprids
C_1	Rotifers, Zoothaminium, vorticellids, algal filaments, Pleurosigma sp. and Melosira sp.	1
C_2	Rotifers, Zoothaminium, vorticellids, copepods, Nitzchia sp. and Thallasiosira sp.	Nil, Oyster 1
C_3	Vorticellids, Zoothaminium, rotifers, copepods, Nauplii Pleurosigmal sp. and Coscinodiscus sp.	3
C_4	Vorticellids, rotifers, Zoothaminium, copepods, Closterium sp. and Cymbella sp.	2
C_5	Zoothaminium, vorticellids, and rotifers	1
C_6	Zoothaminium, vorticellids, soil nematodes, rotifers and Pleurosigma sp.	2
C_7	Zoothaminium, vorticellids, rotifers, algal filaments and storoneis sp.	1
C_8	Vorticellids, Zoothaminium, rotifers and copepods	2
C_9	Vorticellids, algal filaments, copepods, Coscinodiscus sp. Thallasiosira sp. Storoneis sp. Pleurosigma sp.	Nil
C_{10}	Zoothaminium, algal filaments, vorticellids, rotifers, copepods and Pleurosigma sp.	10

Table 2.3 Number of bacteria settled during different intervals

Period of immersion h	Number of bacteria settled per cm^2 area
2	75
4	102
6	220
18	26,000
24	28,000
72	60,000

Table 2.4 <u>Settlement and growth of *Obelia gracilis* in the first series</u> (6-3-81 to 19-4-'81)

Age in days	Mean height of vertical stolon mm	Settlement
1-5	-	-
6	4.7	R
7	4.8	C
8	5.1	A
9	7.1	C
10	7.5	C
12	7.8	C
13	7.8	R
14	7.8	R
15	7.9	VC
16	8.0	VC
17	8.1	A
19	8.1	C
20	8.2	C
21	8.6	R
22	8.8	C
23	9.0	VC
24	9.3	R
25	9.5	VC
27	9.6	C
28	9.8	C
29	10.0	C
30	10.0	VC
32	10.1	C
33	10.2	C
34	11.6	C
35	11.7	C
39	12.8	C
40	13.0	C
41	14.0	C
42	14.1	C

Key:- - = absent; R = rare (1-100/100 cm^2); C = common (101-300/100 cm^2); VC = very common (301-800/100 cm^2) A = abundant (801 and above/100 cm^2)

Table 2.5 Settlement and growth of *Obelia gracilis* in the second series (23-4-81 to 6-6-81)

Age in days	Mean height of vertical stolon mm	Settlement
1-3	-	-
4	2.8	R
6	4.5	C
7	6.0	C
8	6.2	C
9	6.2	R
13	6.8	R
14	7.6	VC
15	8.2	R
16	8.7	VC
17	9.5	R
20	9.6	R
21	10.4	C
22	10.5	R
23	10.6	C
24	10.8	R
25	11.5	C
27	11.5	VC
28	11.7	C
29	11.8	C
30	12.1	R
31	12.2	VC
32	12.3	VC
34	12.3	VC
35	12.9	A
36	13.0	VC
37	13.5	C
38	14.3	C
39	14.6	C
41	14.8	C
42	15.7	VC
44	15.8	VC

Key: - = absent; R = rare (1-100/100 cm^2); C = common (101-300/100 cm^2); VC = very common (301-800/100 cm^2); A = abundant (801 and above/100 cm^2)

Table 2.6 Settlement and growth of *Obelia gracilis* in the third series (13-6-81 to 26-7-81)

Age in days	Mean height of vertical stolon mm	Settlement
1-8	-	-
9	6.3	R
10	6.9	R
12	6.9	R
15	7.2	R
16	7.3	R
17	7.8	R
19	8.0	R
20	8.4	R
21	8.5	R
22	8.8	R
23	9.1	R
24	10.3	R
25	10.4	R
26	11.3	R
27	14.2	R
28-44	-	-

Key: - = absent; R = rare (1 to 100/100 cm^2)

Table 2.7 Settlement and growth of *Obelia gracilis* in the sixth series (13-11-81 to 28-12-81)

Age in days	Mean height of vertical stolon mm	Settlement
1-5	-	-
6	5.0	R
7	5.3	R
8	5.4	R
9	6.0	R
10	6.1	R
14	9.2	R
15	10.4	R
16	11.4	R
17	11.8	R
19	11.8	R
20	11.9	R
21	15.8	R
22	16.0	R
23	19.9	R
24	22.1	C
25	23.5	C
27	24.5	R
28	24.9	C
29	28.3	C
32	31.2	C
33	31.9	C
34	40.8	C
35	40.8	C
40	46.8	C
42	49.2	C
43	53.6	VC

Key: - = absent; R = rare (1-100/100 cm^2); C = common (101-300/100 cm^2); VC=very common (301-800/100 cm^2)

Table 2.8 Settlement and growth of *Obelia gracilis* in the seventh series (4-1-82 to 24-2-82)

Age in days	Mean height of vertical stolon mm	Settlement
2-5	-	-
6	4.5	R
7	5.2	R
10	6.1	R
12	6.3	C
13	6.6	R
14	8.1	C
15	8.6	C
17	8.8	R
18	9.0	R
19	9.0	R
20	9.7	R
21	10.0	R
22	10.0	R
26	10.1	R
28	10.3	R
29	10.5	R
30	10.6	R
32	10.7	R
33	11.3	R
35	11.4	R
36	11.6	R
39	12.0	R
41	13.7	R
46	13.9	R
47	14.2	R
48	16.5	R
49	17.0	R
50	17.1	R

Key: - = absent; R = rare (1-100/100 cm^2); C = common (101-800/100 cm^2)

Table 2.9 Settlement and growth of *Electra bengalensis* in first series (6-3-81 to 19-4-81)

Age in days	No. settled	Mean diameter mm
1-5	-	-
6	36	2.4
7	39	3.2
8	43	4.4
9	27	4.4
10	44	5.5
12	41	6.5
13	42	7.6
14	39	8.2
15	42	12.6
16	32	14.9
17	32	18.1
19	31	18.7
20	40	22.3
21	27	22.7
22	24	25.5
23	22	27.7
24	25	33.0
26	15	34.0
28	33	36.2
29	46	36.2
30	26	37.7
31	30	38.5
33	30	39.6
34	30	39.8
35	28	40.0
36	5	40.5
41	23	43.5
42	28	44.6
43	23	46.6
44	31	48.9
45	33	52.9

Key: - = absent

Table 2.10 <u>Settlement and growth of Alderina arabianensis in second series</u> (23-4-81 to 6-6-81)

Age in days	No. settled	Mean diameter mm
1-5	-	-
6	1	1
7	2	1.3
13	9	1.5
14	2	1.5
15	3	3.0
16	2	2.5
17	7	3.6
20	8	5.4
21	11	5.4
22	5	10.2
23	5	11.0
24	4	11.2
28	3	11.2
29	10	12.4
30	6	13.0
31	8	13.0
32	7	13.3
34	7	13.5
35	9	13.6
36	5	14.5
37	4	16.0
39	4	18.0
44	3	28.5

Key: - = absent

Table 2.11 Settlement and growth of Electra crustulenta in 3rd series (13-6-81 to 26-7-81)

Age in days	No. settled	Mean diamter mm
1-4	-	-
5	5	1.2
6	12	1.2
7	18	2.0
8	56	2.1
9	36	2.6
11	51	2.6
14	43	2.6
15	46	3.0
16	23	3.2
18	61	4.5
19	53	4.5
20	60	4.6
21	80	4.8
22	120	5.0
23	85	5.1
25	87	5.5
26	92	6.0
27	178	7.2
28	61	7.5
29	88	7.7
32	101	7.8
33	135	9.0
34	201	9.0
35	108	9.5
36	131	9.5
37	110	10.0
39	105	10.0
40	121	11.6
41	95	13.5
42	65	17.3

Key: - = absent

Table 2.12 Settlement and growth of *Electra crustulenta* in 4th series (31-7-81 to 19-9-81)

Age in days	No. settled	Mean diameter mm
1-16	-	-
17	22	2.7
19	24	3.6
20	31	4.0
21	31	5.0
22	36	7.1
23	47	9.5
24	26	9.6
27	47	10.1
28	49	11.0
29	33	12.2
30	56	14.3
35	31	15.0
36	38	15.2
37	34	16.0
38	38	19.0
40	50	19.5
41	50	20.0
42	31	22.5
50	46	25.0

Key: - = absent

Table 2.13 Settlement and growth of *Electra crustulenta* in 5th series (26-9-81 to 8-11-81)

Age in days	No. settled	Mean diameter mm
1-11	-	-
12	4	1.5
14	5	1.8
18	6	2.1
19	12	2.2
20	6	2.6
21	6	3.1
22	23	5.3
23	5	5.3
25	3	5.7
26	19	5.8
27	29	6.8
28	24	7.0
30	19	7.2
32	15	8.0
33	27	8.9
34	34	9.2
35	36	10.7
36	40	11.0
37	35	11.4
39	35	12.4
40	29	13.0
41	40	13.5
43	39	14.0
44	29	16.7

Key: - = absent

Table 2.14 Settlement and growth of *Electra bengalensis* in the 6th series (13-11-81 to 28-12-81)

Age in days	No. settled	Mean diameter mm
1-6	-	-
7	1	1.0
8	3	1.5
9	5	1.9
10	3	4.0
14	6	6.3
15	7	6.3
16	8	7.0
17	3	8.0
19	4	8.0
20	9	8.0
21	11	8.7
22	4	9.5
23	6	10.0
24	5	10.5
25	6	12.0
27	2	12.5
28	9	12.5
29	2	13.0
32	9	13.5
33	9	13.5
34	8	14.2
40	3	14.2
42	2	15.0
43	5	29.0

Key: - = absent

Table 2.15 Settlement and growth of *Alderina arabianensis* in the 7th series (4-1-82 to 24-2-82)

Age in days	No. settled	Mean diameter mm
1-9	-	-
10	6	1.3
14	1	1.5
29	1	1.7
30	1	2.0
36	1	3.0
41	3	3.5
42	2	6.2
46	19	6.4
47	10	9.5
48	7	10.5
49	9	11.0
50	3	13.0
51	3	15.5
53	3	20.0

Key: - = absent

Table 2.16 Settlement and growth of Hydroides norvegica in first series (6-3-81 to 19-4-81)

Age in days	No. settled	Mean length mm
1-11	-	-
12	1	7.0
13	14	8.0
14	11	7.6
15	10	8.6
16	10	8.4
17	15	9.6
18	15	10.5
19	7	11.3
20	20	12.5
21	7	12.5
22	18	12.8
23	14	12.9
25	6	13.0
27	15	13.5
28	3	14.0
29	22	14.3
30	9	14.6
32	15	15.0
33	9	16.6
34	1	17.0
35	11	20.3
39	6	20.3
40	14	21.8
41	7	26.5
42	13	28.2
43	15	49.3

Key: - = absent

Table 2.17 Settlement and growth of *Hydroides norvegica* in second series (23-4-81 to 6-6-81)

Age in days	No. settled	Mean length mm
1-6	-	-
7	7	4.5
8	5	6.0
9	3	6.8
10	29	7.8
13	27	7.8
14	17	8.3
15	55	8.5
16	11	9.0
17	8	9.6
20	6	10.1
21	39	10.4
22	31	10.7
23	22	10.9
24	70	11.8
25	6	12.3
27	33	12.6
28	45	12.6
29	16	13.0
30	38	13.1
31	26	13.4
32	62	14.0
34	28	14.5
35	28	14.8
36	31	14.9
37	66	15.3
38	37	15.6
39	33	16.1
41	49	16.7
42	24	16.8

Key: - = absent

Table 2.18 Settlement and growth of Hydroides norvegica in 3rd series (13-6-81 to 26-7-81)

Age in days	No. settled	Mean length mm
1-4	-	-
5	2	1.5
6	18	4.1
7	76	5.2
8	110	5.9
9	163	6.3
11	130	6.4
14	113	7.1
15	155	7.1
16	200	7.3
18	121	7.7
19	156	7.7
20	84	7.7
21	90	8.1
22	84	8.6
23	73	8.8
25	33	8.9
26	55	8.9
27	20	8.9
28	25	8.9
29	9	9.0
32	15	9.0
33	44	9.4
34	20	9.8
35	15	9.9
36	32	10.3
37	62	10.4
39	23	11.0
40	40	11.2
41	3	12.2
42	4	12.5
43	1	13.2

Key: - = absent

Table 2.19 Settlement and growth of *Hydroides norvegica* in 5th series (26-9-81 to 8-11-81)

Age in days	No. settled	Mean length mm
1-25	-	-
26	1	5.0
28	1	5.5
30	1	6.5
32	2	6.5
33	2	6.8
34	1	7.5
35	1	7.5
36	3	7.8
37	4	8.8
39	1	9.0
40	2	11.0
41	4	13.5
43	4	13.6
44	1	14.0

Key: - = absent

Table 2.20 Settlement and growth of *Hydroides norvegica* in 6th series (13-11-'81 to 28-12-81)

Age in days	No. settled	Mean length mm
1-7	-	-
7	1	2.0
8	2	2.0
10	1	4.0
14	2	6.0
15	2	7.8
16	1	9.0
17	1	11.0
19	1	12.0
24	1	13.0
28	1	13.6
29	1	14.0
33	1	15.0

Key: - = absent

Table 2.21 Settlement and growth of Hydroides norvegica in 7th series (4-1-82 to 24-2-82)

Age in days	No. settled	Mean length mm
1-9	-	-
10	1	2.0
17	3	2.5
18	2	3.5
19	8	4.0
21	5	4.0
22	5	4.5
26	9	4.5
29	1	6.0
30	6	7.0
32	6	7.3
33	4	7.3
35	4	7.8
36	7	8.5
39	10	11.0
41	2	11.0
42	5	15.3
46	10	16.0
47	21	17.6
48	11	19.3
49	10	21.2
50	7	21.5
51	15	29.5

Key: - = absent

Table 2.22 <u>Settlement and growth of *Balanus amphitrite communis* in first series</u> (6-3-81 to 19-4-81)

Age in days	No. settled	Mean diameter mm	Mean height mm
1-8	-	-	-
9	1	1.0	0.5
10	4	1.1	0.5
12	7	1.2	0.5
13	13	1.3	0.5
14	7	1.8	0.8
15	3	1.8	1.0
16	6	1.9	1.0
18	5	2.0	1.0
19	13	2.0	1.0
20	12	2.3	1.0
21	9	2.3	1.0
22	2	2.5	1.5
23	3	2.5	1.5
24	2	3.3	2.0
25	10	4.3	2.3
27	40	4.3	2.5
28	4	4.8	2.6
29	5	4.8	2.7
30	15	5.0	2.8
32	22	5.2	3.3
33	6	5.3	4.3
34	20	6.2	4.5
35	7	7.0	5.0
39	3	7.3	5.2
40	19	9.3	5.5
41	7	11.0	6.8
42	12	14.8	6.9

Key: - = absent

Table 2.23 Settlement and growth of *Balanus amphitrite communis* in second series (23-4-'81 to 6-6-81)

Age in days	No. settled	Mean diameter mm	Mean height mm
1-5	-	-	-
6	50	0.5	0.5
7	57	0.5	0.5
8	50	1.0	1.0
9	69	1.0	1.0
10	75	1.6	1.0
13	239	3.3	1.6
14	135	3.4	1.8
15	100	3.4	1.8
16	400	3.5	1.8
17	373	3.5	2.2
20	73	4.4	2.4
21	300	4.7	2.8
22	400	5.2	2.8
23	358	5.6	2.8
24	249	5.8	2.8
25	250	6.1	2.8
27	408	6.1	3.0
28	200	6.2	3.1
29	428	6.6	3.2
30	408	6.7	3.2
31	314	7.1	3.3
32	320	7.1	3.5
34	220	7.3	3.5
35	200	7.4	3.7
36	700	7.4	3.8
37	300	7.8	4.1
38	400	8.0	4.3
39	400	8.2	4.5
41	189	8.3	4.6

Key: - = absent

Table 2.24 Settlement and growth of *Balanus amphitrite communis* in 3rd series (13-6-81 to 26-7-81)

Age in days	No. settled	Mean diameter mm	Mean height mm
1-3	-	-	-
4	11	0.5	0.5
5	32	0.5	0.5
6	70	1.0	0.5
7	166	1.0	0.5
8	200	1.0	0.5
9	365	1.0	0.5
11	57	1.0	0.8
14	146	1.0	0.9
15	150	1.3	1.0
16	113	1.5	1.0
18	69	1.5	1.0
19	46	1.5	1.0
20	90	1.5	1.0
21	53	1.5	1.0
22	56	1.7	1.0
23	17	1.9	1.0
25	37	2.0	1.0
26	42	2.0	1.0
27	38	2.0	1.0
28	5	2.2	1.0
29	23	2.3	1.3
32	6	2.3	1.3
34	6	2.3	1.3
35	5	2.3	1.5
36	5	2.5	1.5
39	5	2.7	1.5
40	5	4.4	2.2
41	5	8.5	4.0

Key: - = absent

Table 2.25 Settlement and growth of Balanus amphitrite communis in 4th series (31-7-81 to 19-9-81)

Age in days	No. settled	Mean diameter mm	Mean height mm
1-16	-	-	-
17	5	0.5	0.5
19	7	0.5	0.5
20	303	0.5	0.5
21	257	0.5	0.5
22	460	0.5	0.5
23	66	1.0	0.5
24	15	1.2	1.0
28	200	1.3	1.0
29	231	1.3	1.0
30	306	2.0	1.0
35	185	2.0	1.2
36	127	2.0	1.2
37	41	2.1	1.2
38	44	2.6	1.3
40	22	2.7	1.5
41	17	2.9	1.5
42	18	3.0	1.7

Key: - = absent

Table 2.27 Settlement and growth of Balanus amphitrite communis in 5th series (26-9-81 to 8-11-81)

Age in days	No. settled	Mean diamter mm	Mean height mm
1-13	-	-	-
14	17	0.5	0.5
18	164	2.0	1.0
19	265	2.1	1.0
20	240	2.9	1.3
21	486	2.9	1.3
22	456	3.0	1.5
23	706	3.2	1.8
25	1120	4.1	2.1
26	1460	4.1	2.1
27	1208	4.4	2.2
28	760	4.5	2.2
30	938	4.8	2.3
32	1040	4.9	2.3
33	682	4.9	2.3
34	342	5.1	2.3
35	740	5.2	2.3
36	702	5.3	2.6
37	720	5.5	2.6
39	328	5.5	2.7
40	336	5.6	2.0
41	508	6.3	3.2
43	500	6.8	3.5
44	450	6.8	3.6

Key: - = absent

Table 2.27 <u>Settlement and growth of Balanus amphitrite communis in 6th series</u> (13-11-81 to 28-12-81)

Age in days	No. settled	Mean diameter mm	Mean height mm
3	16	0.5	0.5
5	334	0.5	0.5
6	400	1.8	1.0
7	400	2.8	1.2
8	404	2.4	1.3
9	548	3.0	1.5
10	560	3.0	1.8
14	420	4.4	2.2
15	1040	5.3	2.5
16	688	5.9	2.9
17	704	5.9	3.1
19	400	6.5	3.3
20	500	6.7	3.5
21	840	6.9	3.7
22	730	6.9	3.8
23	520	7.0	3.9
24	800	7.1	3.9
25	600	7.3	4.0
27	400	7.4	4.0
28	800	7.5	4.1
29	400	7.6	4.2
32	320	7.7	4.3
33	800	8.0	4.5
34	480	8.4	4.6
35	550	8.9	5.0
40	500	9.3	5.1
42	300	11.3	5.1
43	234	12.8	5.6

Table 2.28 <u>Settlement and growth of Balanus amphitrite communis in 7th series</u> (4-1-82 to 24-2-82)

Age in days	No. settled	Mean diameter mm	Mean height mm
4	8	0.5	0.5
5	14	0.5	0.5
6	15	0.7	0.5
7	18	0.8	0.5
10	58	1.0	0.5
13	19	1.0	0.5
14	1	1.0	0.5
15	22	1.0	1.0
17	35	1.0	1.0
18	44	1.0	1.0
19	80	1.0	1.0
20	50	1.5	1.3
21	33	2.0	1.5
22	60	2.5	1.5
26	160	2.5	2.0
30	50	2.5	2.0
32	52	4.0	2.0
33	27	4.3	2.3
35	44	4.5	2.8
36	800	4.7	3.0
39	60	7.0	3.5
40	8	7.0	4.0
42	400	7.8	4.0
46	250	8.0	4.0
47	120	8.0	4.5
48	200	8.0	4.5
49	100	9.0	4.8
50	200	10.3	5.0

Table 2.29 Settlement and growth of Modiolus carvalhoi in first series (6-3-81 to 19-4-81)

Age in days	No. settled	Mean length mm	Mean breadth mm
1-14	-	-	-
15	9	1.7	0.75
16	7	1.7	1.0
17	23	1.8	1.0
19	7	2.0	1.2
20	25	2.2	1.3
21	18	2.8	1.7
22	80	2.8	1.8
23	52	3.0	2.2
25	61	3.5	2.5
27	78	4.1	2.6
28	71	4.5	2.9
29	86	4.6	2.9
30	18	4.7	3.0
32	32	5.0	3.1
33	10	6.2	3.2
34	10	6.2	3.8
35	33	6.3	3.8
39	35	6.3	3.8
40	23	6.5	3.8
41	27	6.5	4.4
42	33	6.9	4.5
43	30	7.9	4.8

Key: - = absent

Table 2.30 Settlement and growth of Modiolus carvalhoi in 6th series (13-11-'81 to 28-12-'81)

Age in days	No. settled	Mean height mm	Mean length mm
1-7	-	-	-
8	2	0.5	0.5
9	11	0.5	0.5
10	4	0.7	0.5
14	39	2.5	1.5
15	15	3.0	1.7
16	17	3.0	2.0
17	62	3.5	2.1
19	41	3.8	2.3
20	95	4.0	2.4
21	26	4.0	2.4
22	35	4.6	2.5
23	77	4.8	2.8
24	47	4.9	3.0
25	91	5.0	3.1
27	35	5.1	3.8
28	35	6.0	3.9
29	17	6.3	4.3
32	5	7.0	4.4
33	40	7.1	4.4
34	23	7.4	4.5
35	31	7.5	5.2
40	14	8.4	5.5
42	5	9.8	5.6
43	6	10.5	7.0

Key: - = absent

Table 2.32 Settlement and growth of Modiolus carvalhoi in 7th series (4-1-82 to 24-2-82)

Age in days	No. settled	Mean height mm	Mean length mm
1-13	-	-	-
14	1	1.5	1.0
17	3	2.5	1.5
22	2	3.0	2.0
26	1	3.0	2.0
29	3	3.5	2.0
35	2	4.3	2.5
39	2	4.5	3.5
41	2	6.5	4.0
42	2	6.8	4.3
46	2	7.0	4.3
48	2	8.0	4.8
49	5	8.3	5.0
51	1	11.5	6.0

Key: - = absent

Table 2.33 The coefficient correlation (r) regression coefficient (b), y - intercepts (a) and number of observation (n) for Balanus amphitrite communis

Series	Age on log diameter				Age on log height			
	r	b	a	n	r	b	a	n
1	0.9870	0.03158	-.26178	27	0.9865	0.03662	-.64789	27
2	0.8780	0.02933	-.08013	29	0.91968	0.02265	-.17120	29
3	0.9216	0.0206	-.2338	28	0.9117	0.01670	-.36855	28
4	0.9220	0.07438	-1.81954	17	0.94428	0.02228	-.70914	17
5	0.83805	0.02350	-.10836	23	0.91038	0.02097	-.32966	23
6	0.8177	0.02433	0.18412	28	0.8790	0.02207	-.03687	28
7	0.9830	0.02865	-.38000	28	0.9770	0.02403	-.43833	28

Table 2.34 The coefficient of correlations (r), regression coefficient (b), y intercepts (a) and number of observations for bryozoans

Series	Species	Age on log diameter			
		r	b	a	n
1	*Electra bengalensis*	0.9179	0.03118	0.53905	31
2	*Alderina arabianensis*	0.9189	0.03889	-.11241	23
3	*Electra crustulenta*	0.9686	0.02693	0.06006	30
4	*Electra crustulenta*	0.9258	0.02805	0.17305	19
5	*Electra crustulenta*	0.7826	0.02455	0.25403	24
6	*Electra bengalensis*	0.8685	0.02455	0.11315	24
7	*Alderina arabianensis*	0.4770	0.0131	0.00538	14

Table 2.35 The coefficient correlation (r), regression coefficients (b), y - intercepts (b) and number of observation (n) for *Modiolus carvalhoi*

Series	Age on log height				Age on log length			
	r	b	a	n	r	b	a	n
1	0.9666	0.02390	-.08903	22	0.9481	0.02536	-.34615	22
6	0.8777	0.03161	-.17510	24	0.91819	0.91819	-.30611	22
7	0.9749	0.01949	-.01632	13	0.98065	0.01840	-.18436	13

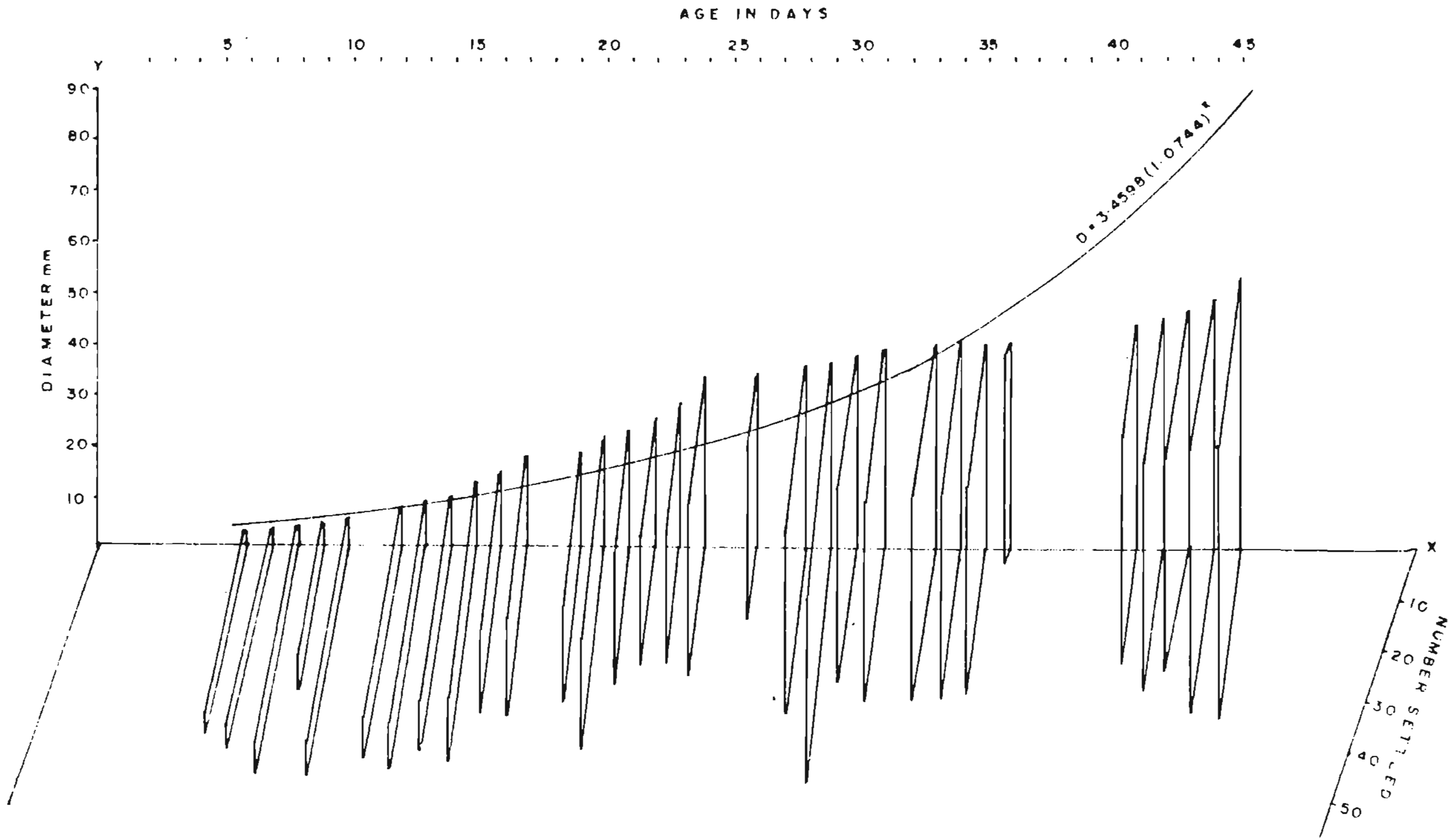


Fig. 2.1. ELECTRA BENGALENSIS (STOLICZKA). THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 1st SERIES OF PANELS DURING 6-3-1980 TO 19-4-1980

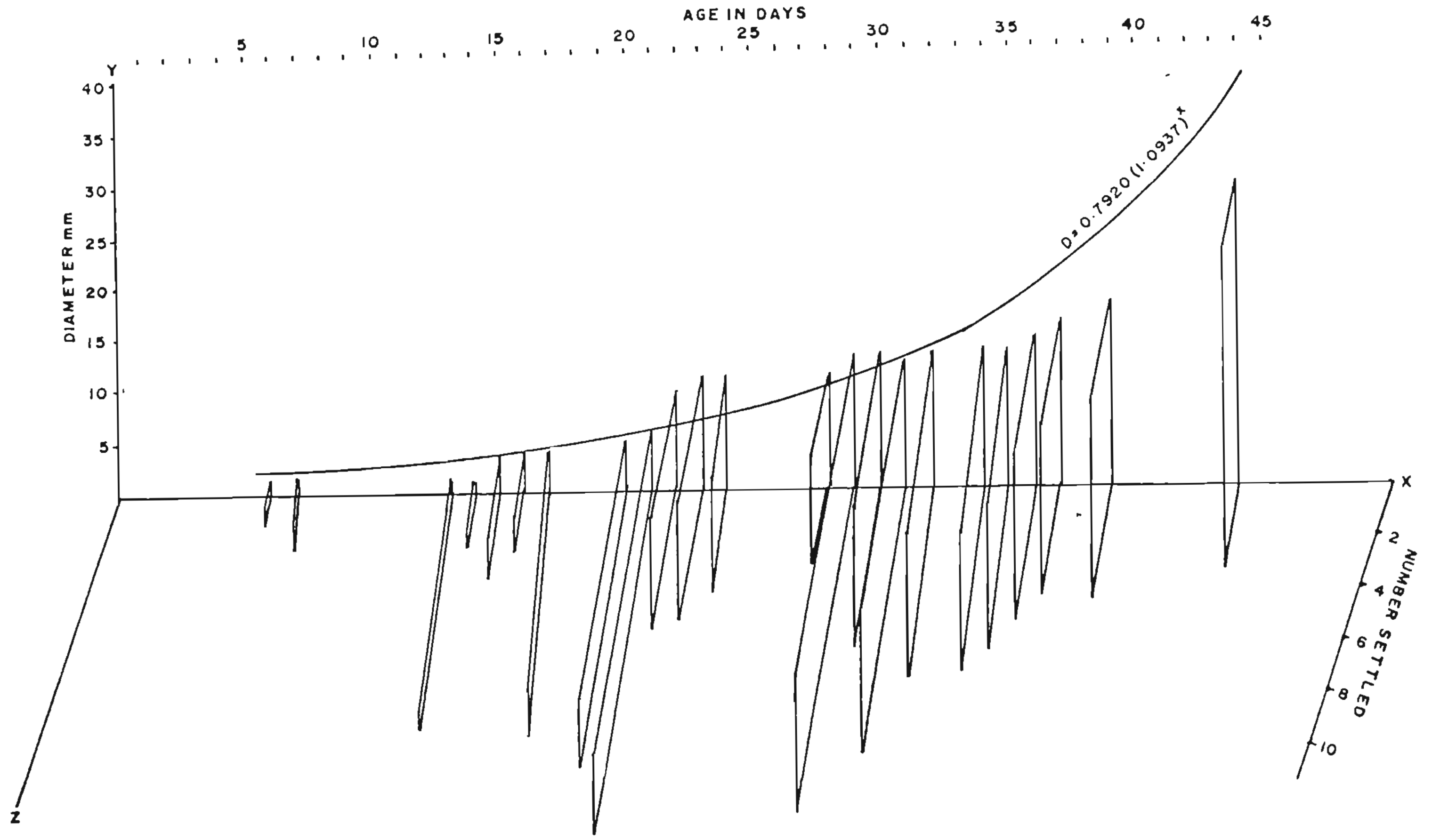


Fig. 2.2. ALDERINA ARABIANENSIS MENON & NAIR. THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 2nd SERIES OF PANELS DURING 23-4-1980 TO 6-6-1980.

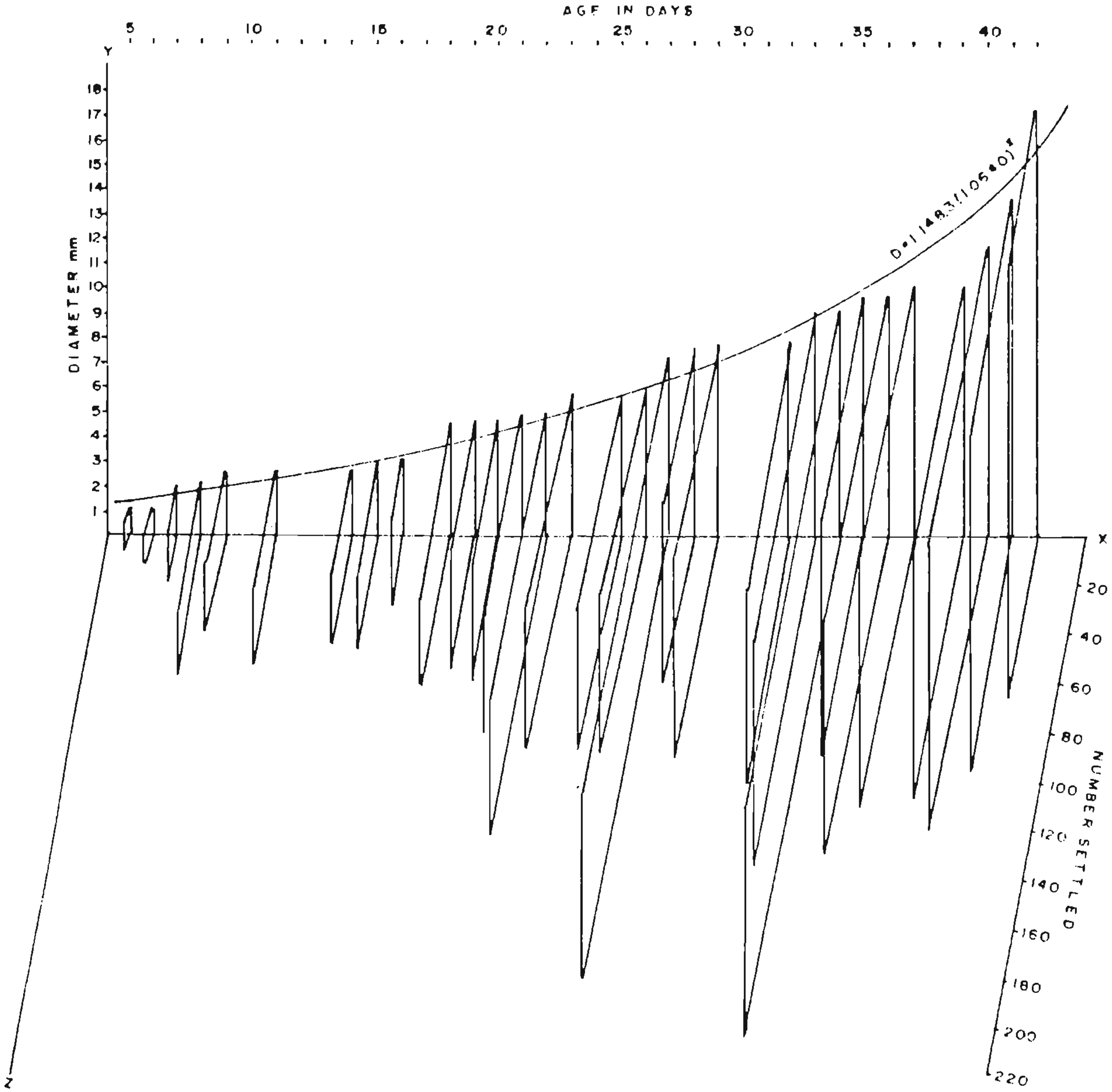


Fig. 2.3 ELECTRA CRUSTULENTA (PALLAS):THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 3rd SERIES OF PANELS DURING 13-6-1981 TO 26-7-1981

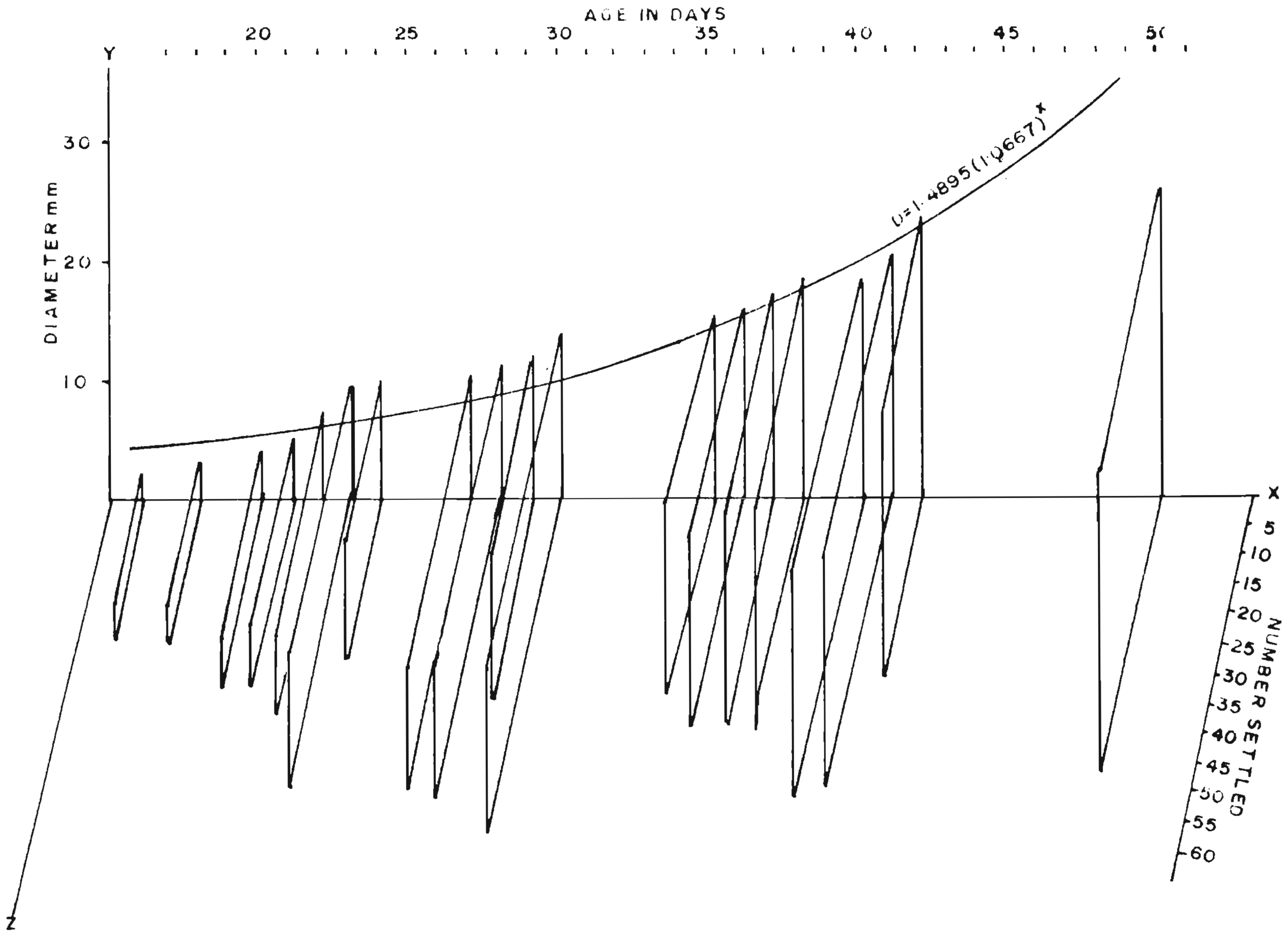


Fig. 2.4. ELECTRA CRUSTULENTA (PALLAS). THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 4th SERIES OF PANELS DURING 31-7-'81 TO 19-9-1981

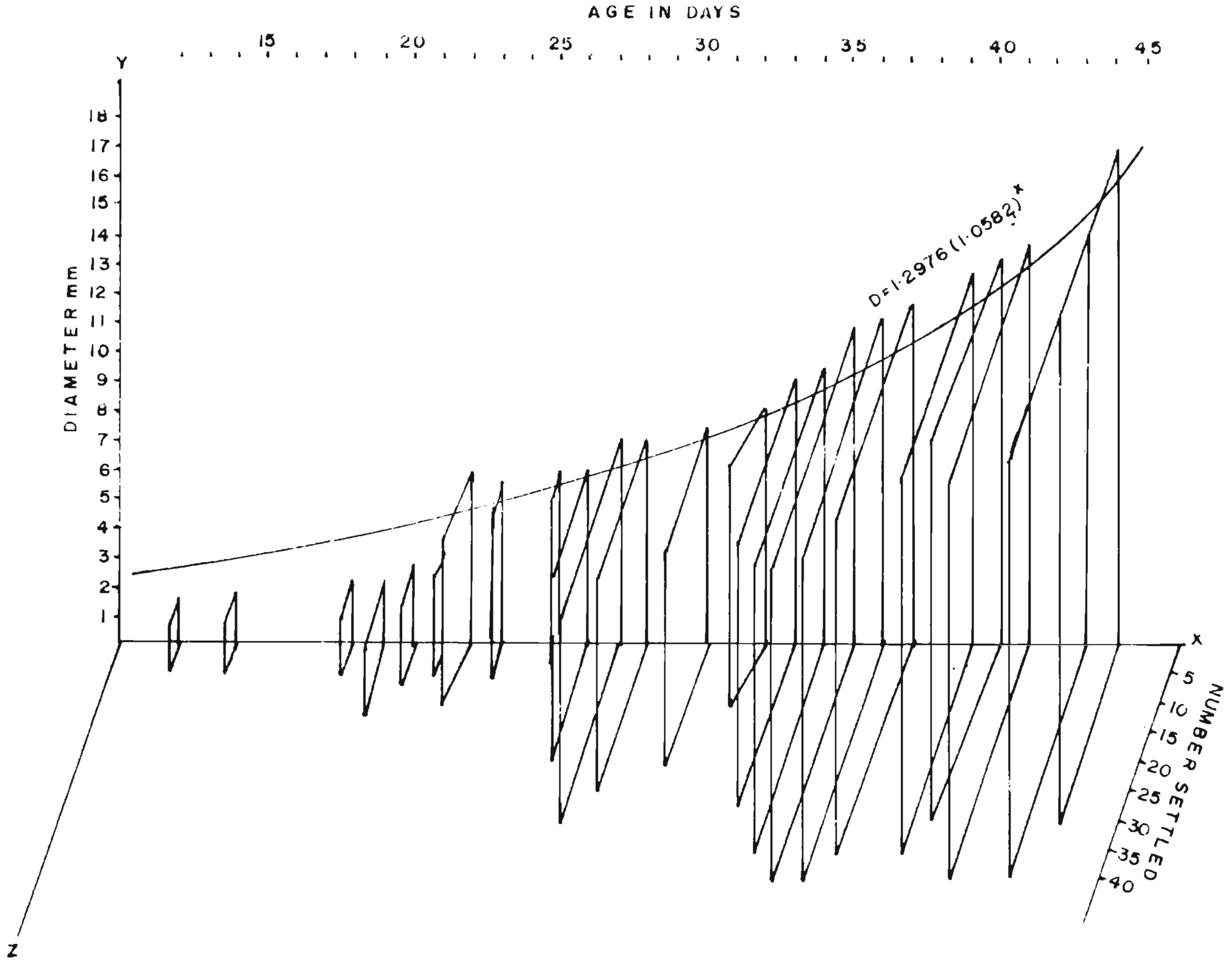


Fig. 2.5. ELECTRA CRUSTULENTA (PALLAS). THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 5th SERIES OF PANELS DURING 26-9-'81 TO 8-11-1981

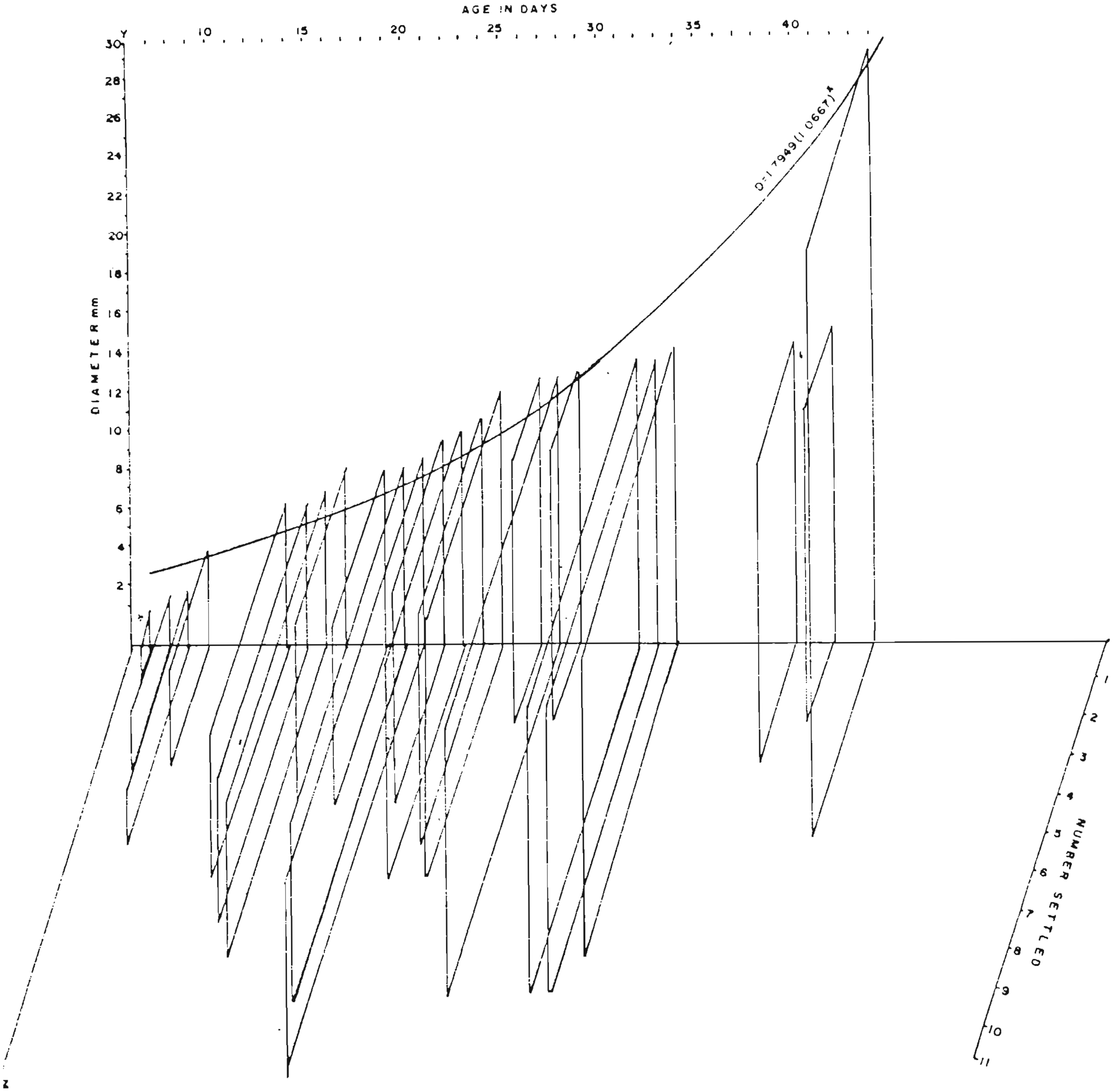


Fig. 2.6. ELECTRA BENGALENSIS (STOLICZKA). THEORETICAL GROWTH, OBSERVED GROWTH, AGE AND SETTLEMENT IN THE 6th SERIES OF PANELS DURING 13-11-'81 TO 28-12-1981

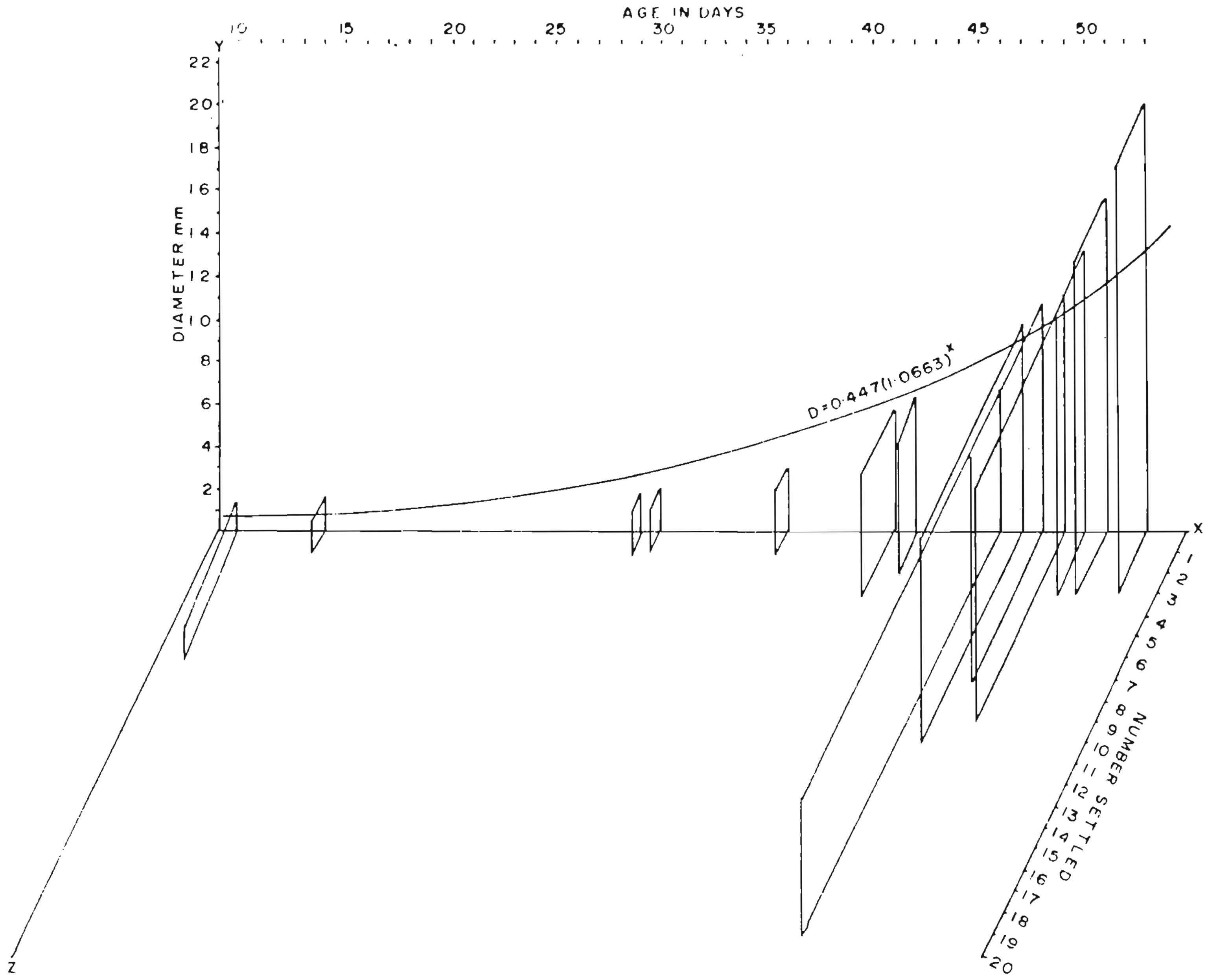


Fig. 2.7. ALDERINA ARABIANENSIS MENON & NAIR. THEORETICAL GROWTH, OBSERVED GROWTH AGE AND SETTLEMENT IN THE 7th SERIES OF PANELS DURING 4-1-'82 TO 24-2-1982

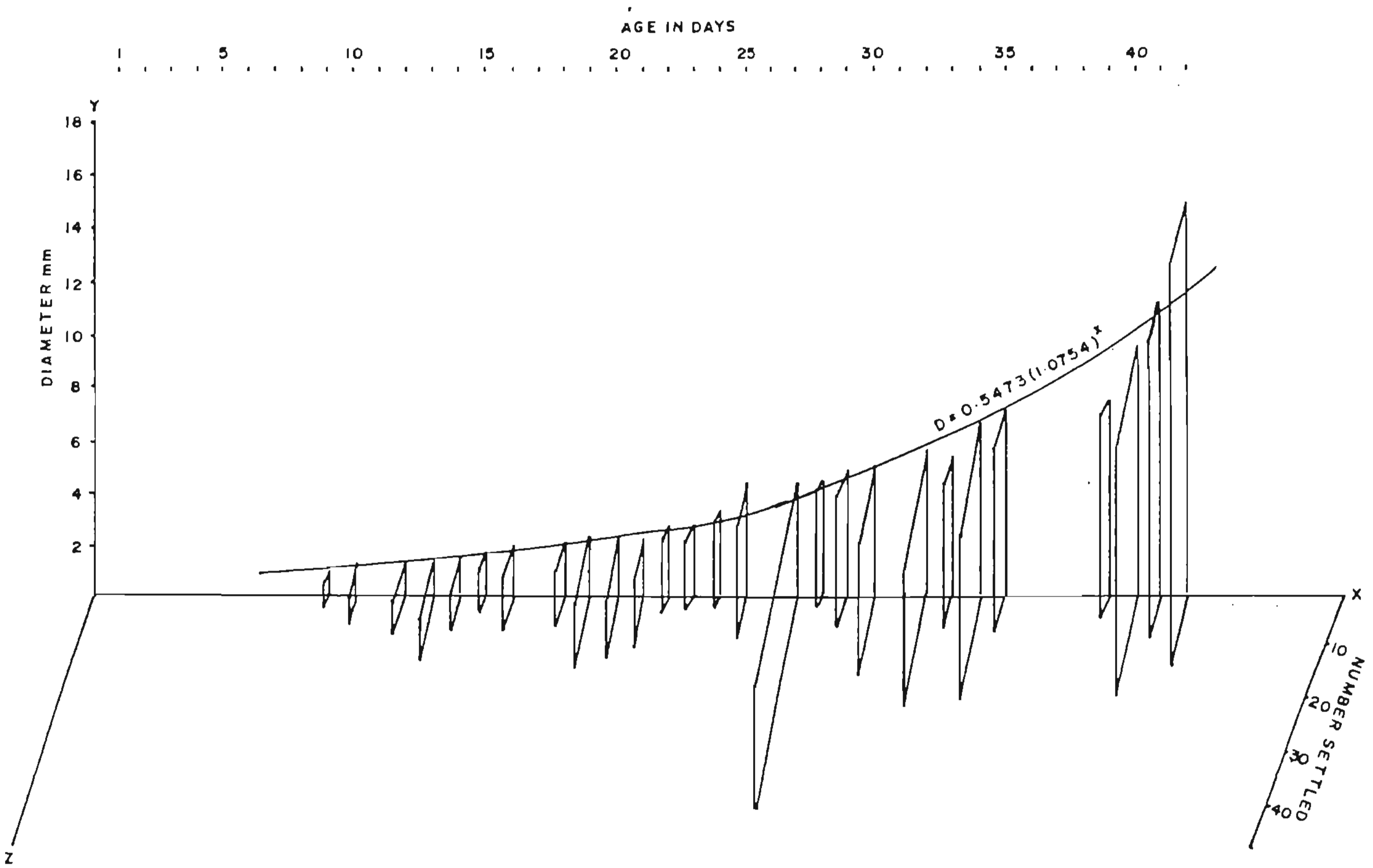


Fig. 2. 8. <u>BALANUS AMPHITRITE COMMUNIS</u>. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AGE AND SETTLEMENT IN THE 1st SERIES OF PANELS DURING 6-3-81 TO 19-4-1981

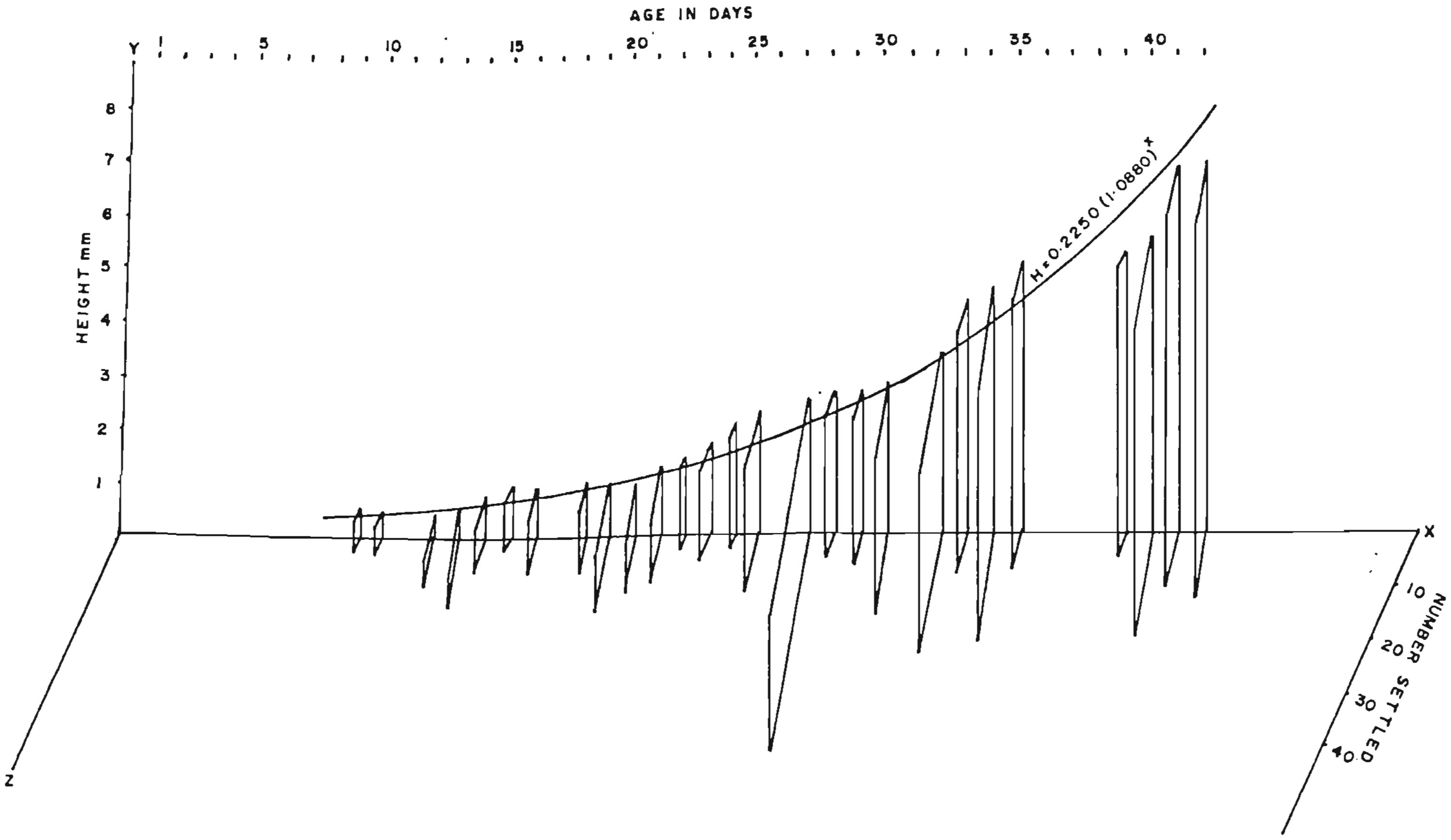


Fig. 2.9. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 1st SERIES OF PANELS DURING 6-3-81 TO 19-4-1981

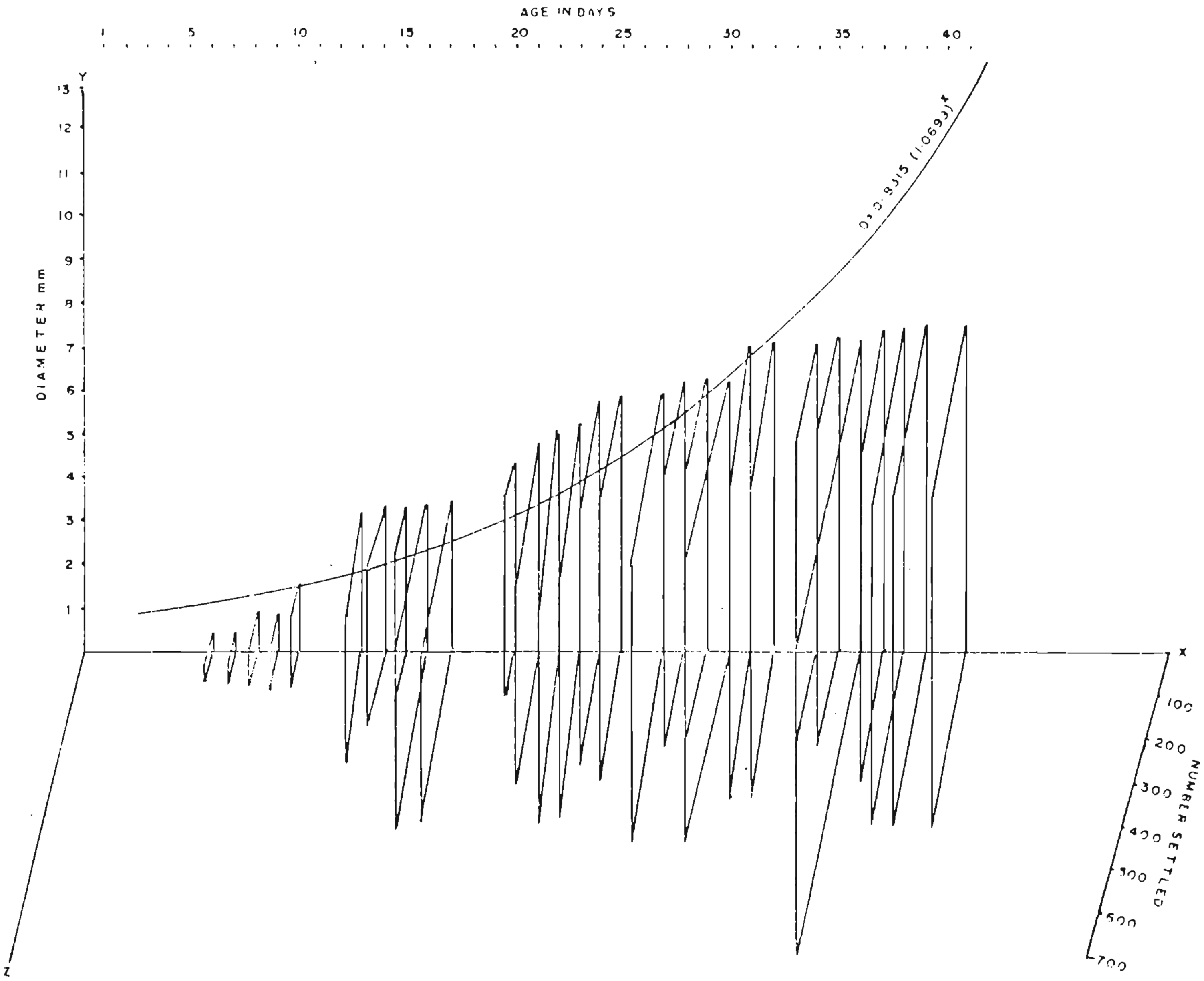


Fig. 2 10 BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AND SETTLEMENT IN THE 2nd SERIES OF PANELS DURING 23-4-81 TO 6-6-1981

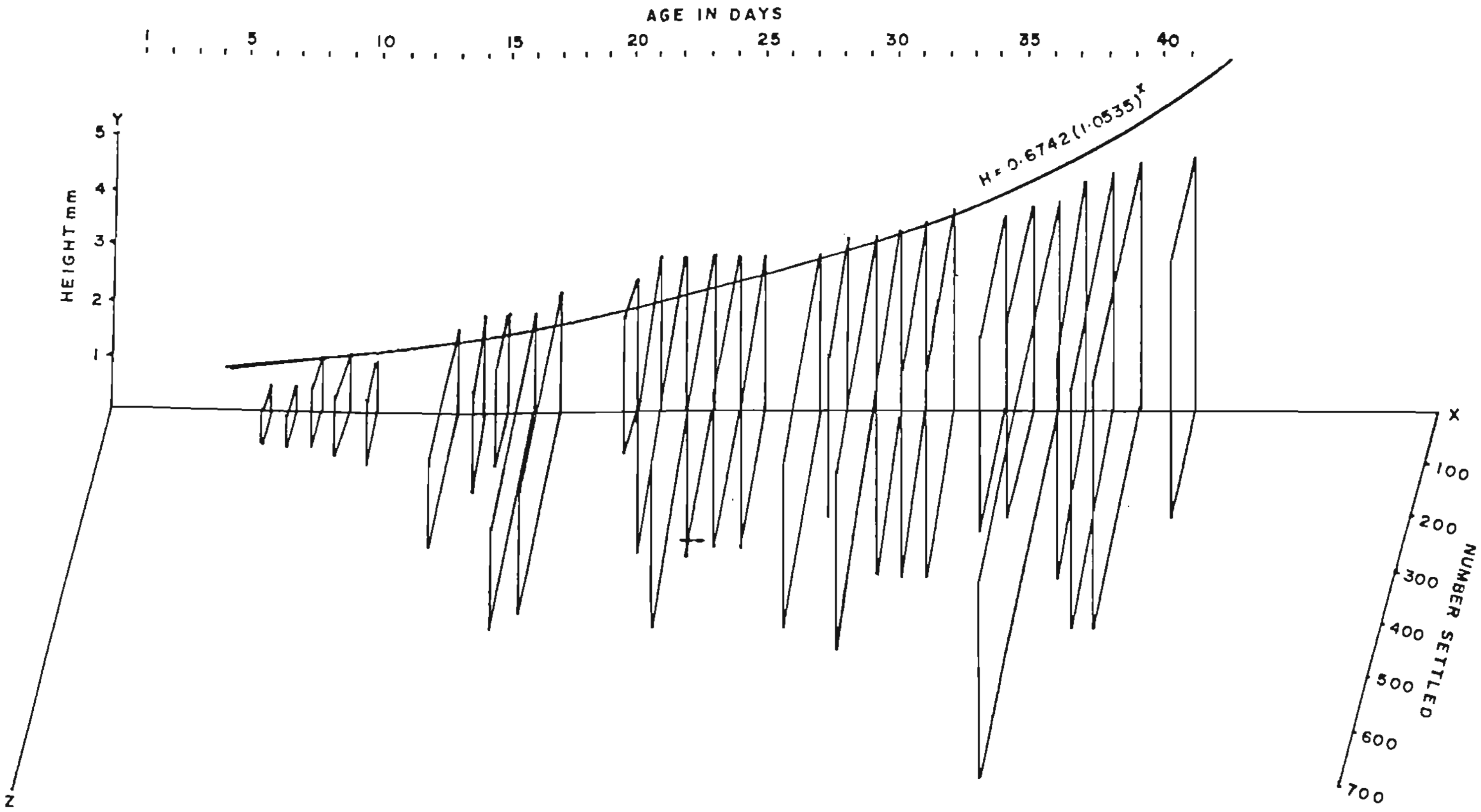


Fig. 2.11. BALANUS AMPHITRITE COMMUNIS, THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 2^{nd} SERIES OF PANELS DURING 23-4-'81 TO 6-6-1981

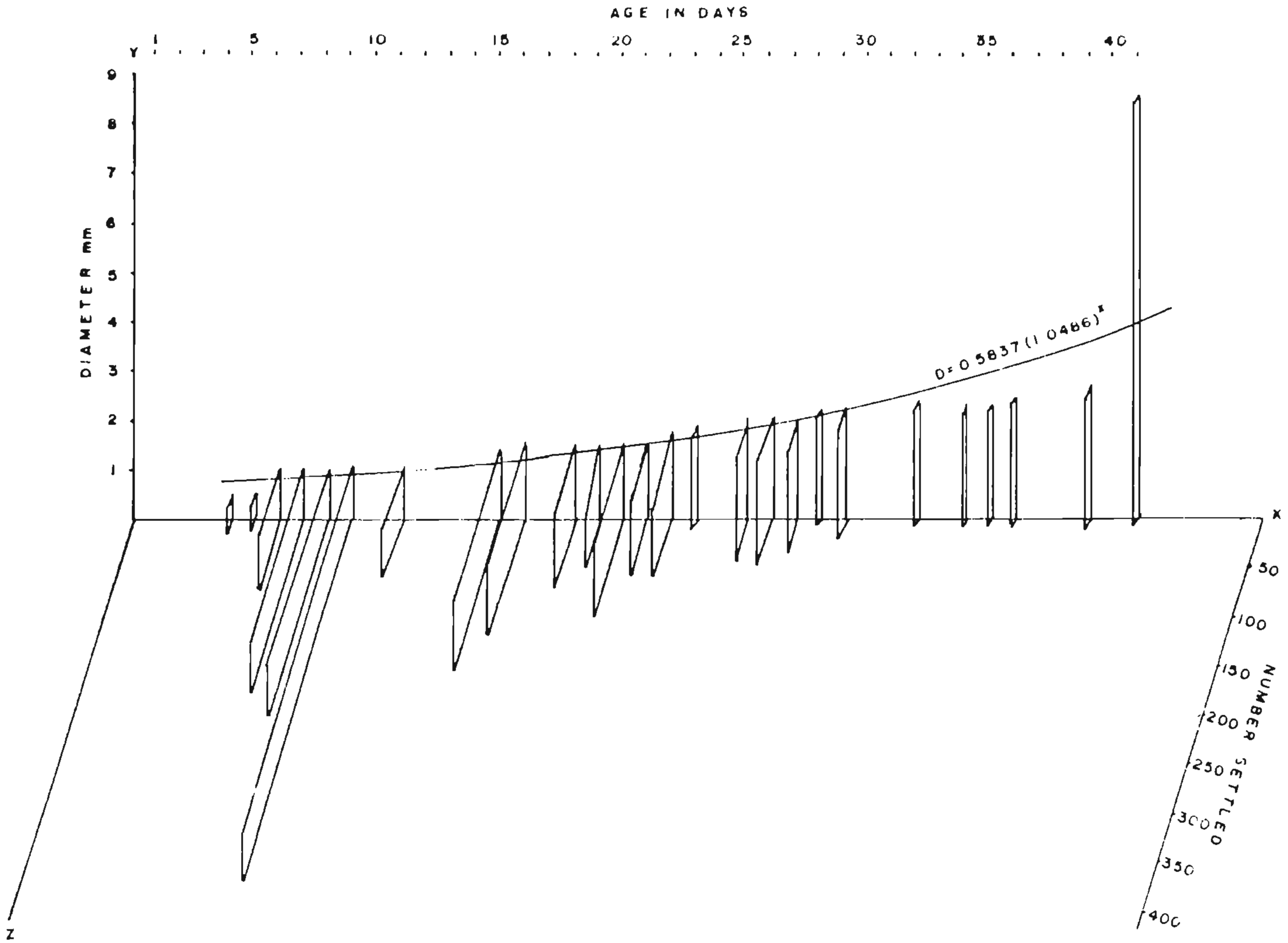


Fig. 2.12. <u>BALANUS AMPHITRITE COMMUNIS</u>. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AGE AND SETTLEMENT IN THE 3rd SERIES DURING 13-6-1981 TO 26-7-1981

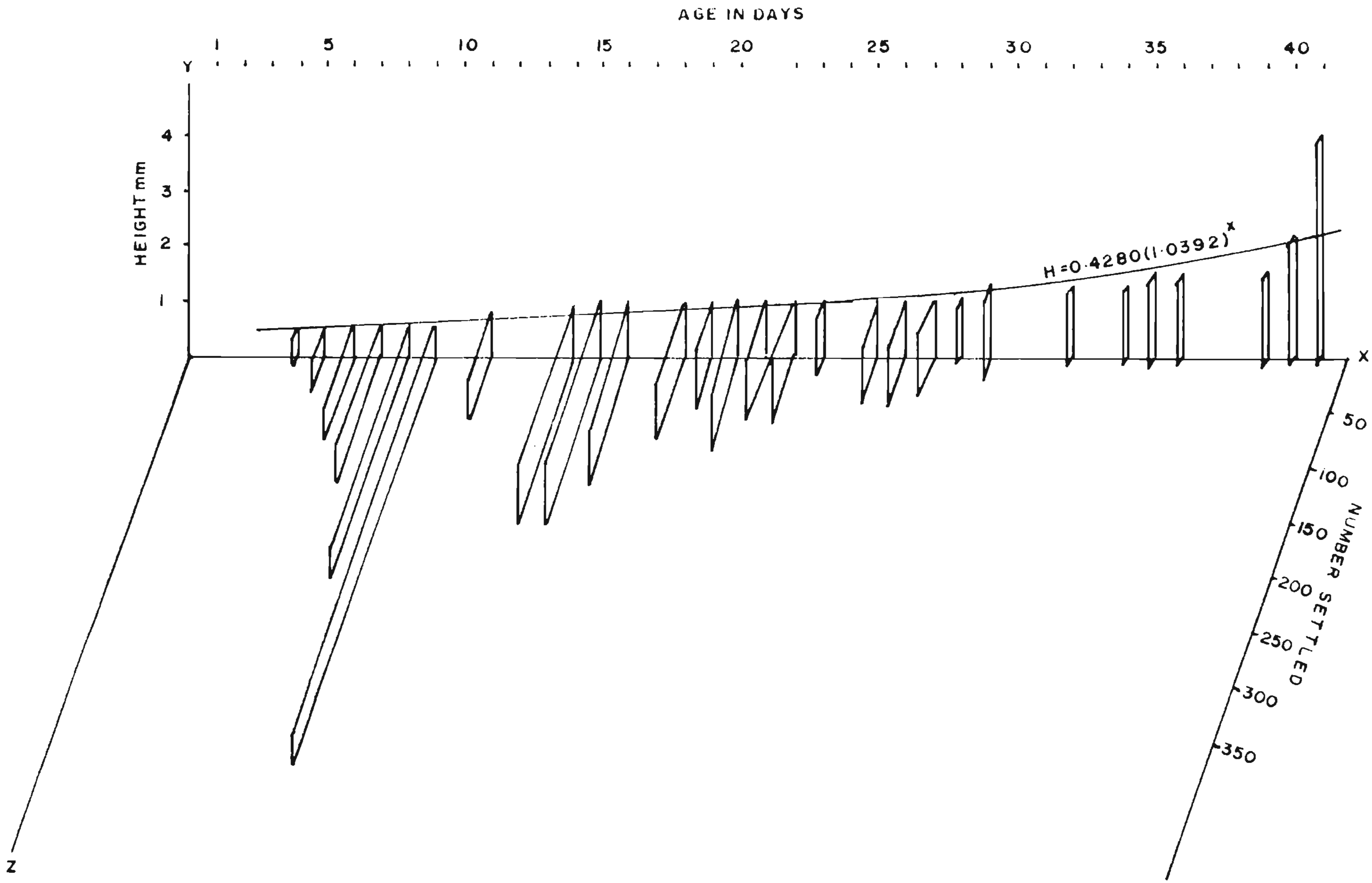
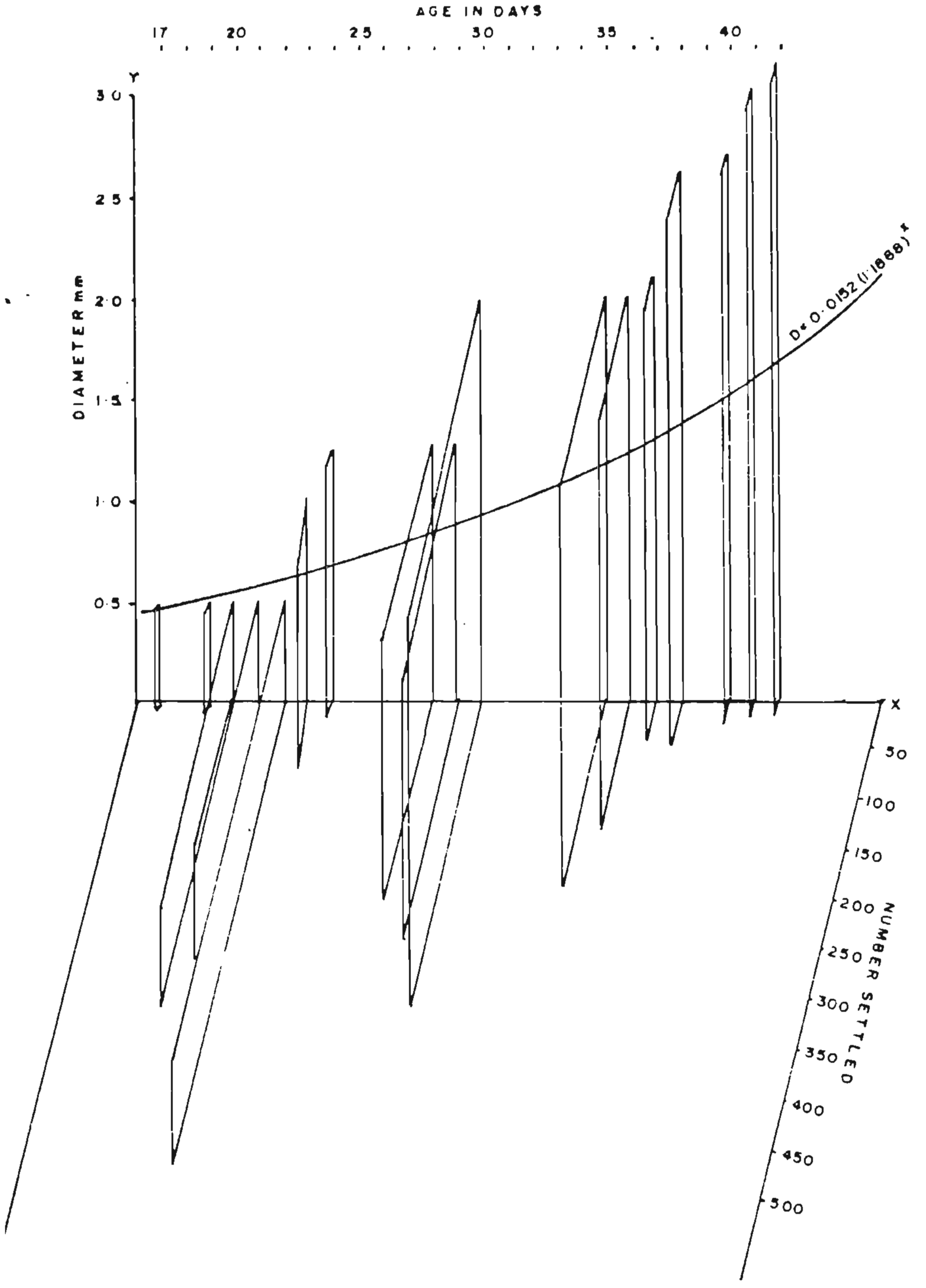


Fig. 2.13. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 3rd SERIES OF PANELS DURING 13-6-1981 TO 26-7-1981



ig.2.14. BALANUS AMPHITRITE COMMUNIS-THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER).AGE AND SETTLEMENT IN THE 4th SERIES OF PANELS DURING 31-7-81 TO 19-9-1981

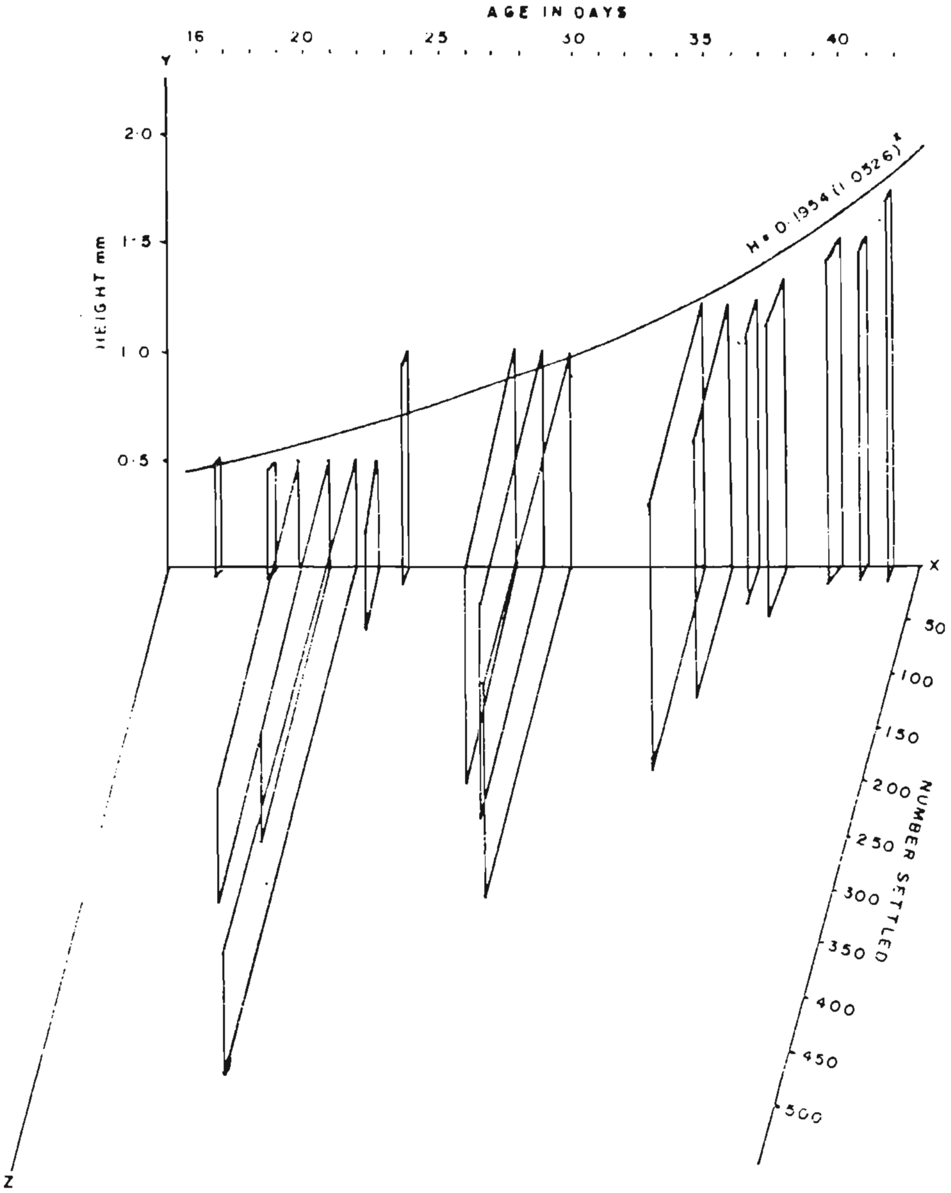


Fig. 2.15. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 4th SERIES OF PANELS DURING 31-7-1981 TO 19-9-1981

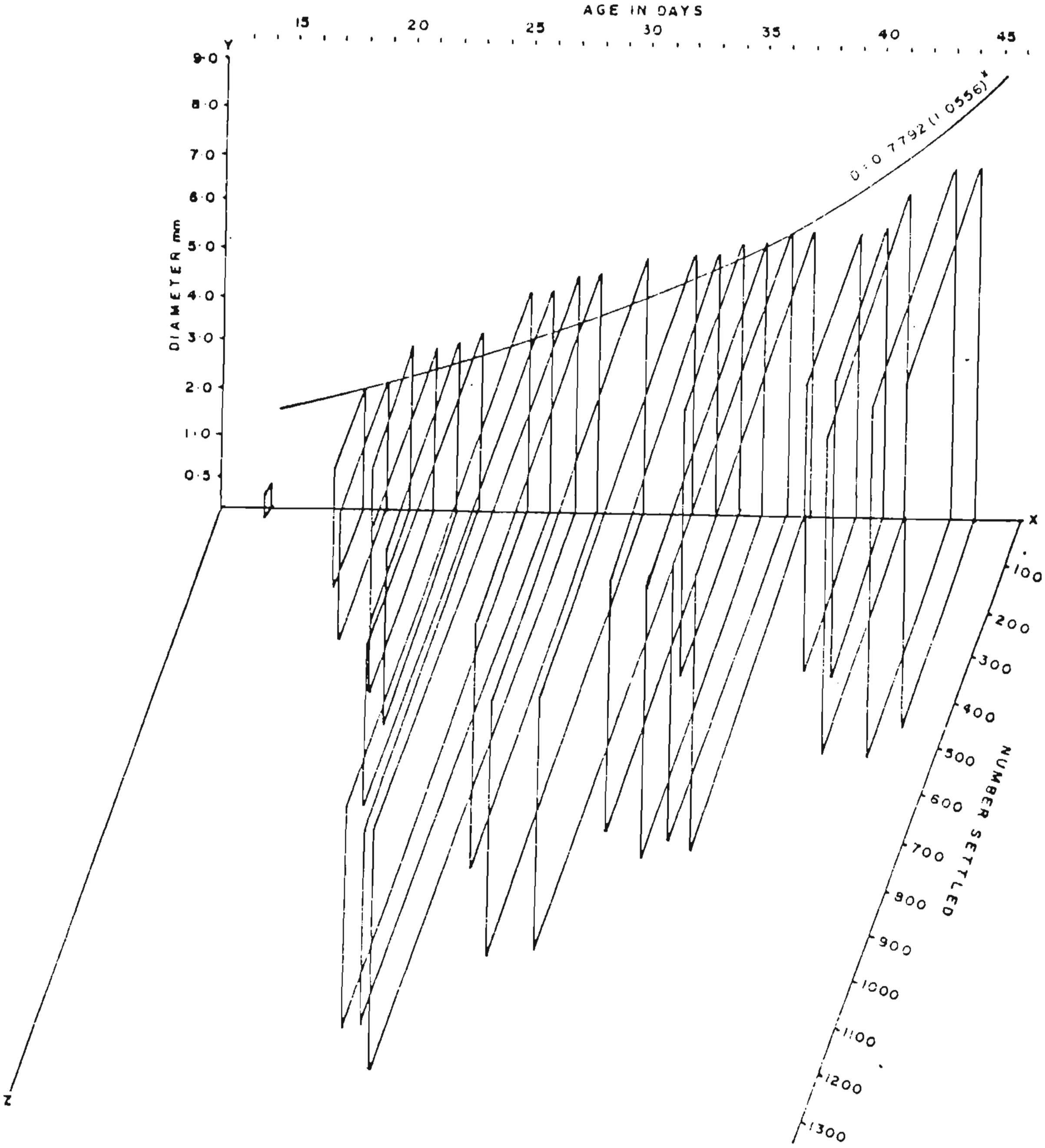


Fig. 2.16. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AGE AND SETTLEMENT IN THE 5th SERIES OF PANELS DURING 26-9-'81 TO 8-11-1981

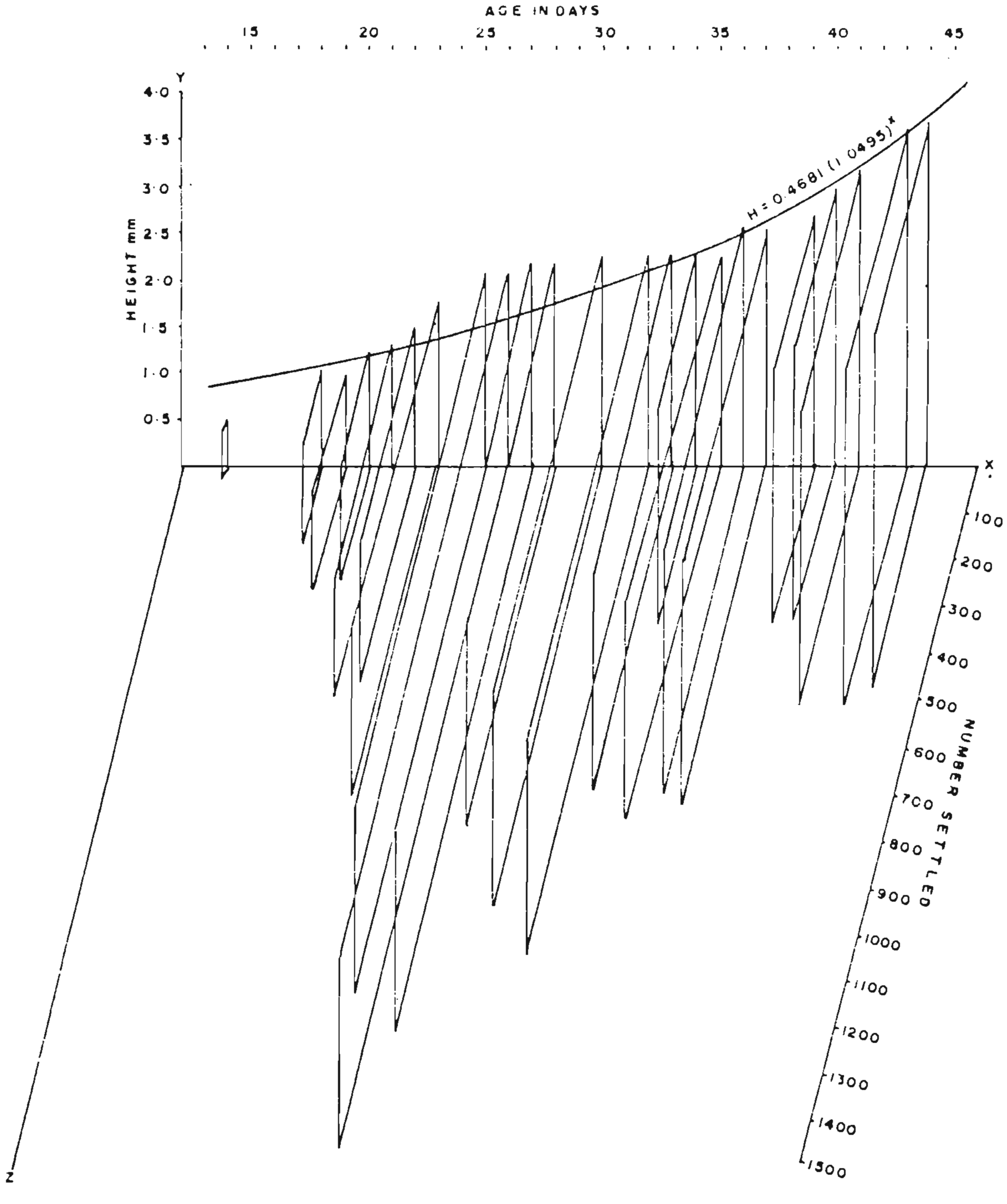


Fig. 2.17. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 5th SERIES OF PANELS DURING 26-9-1981 TO 8-11-1981

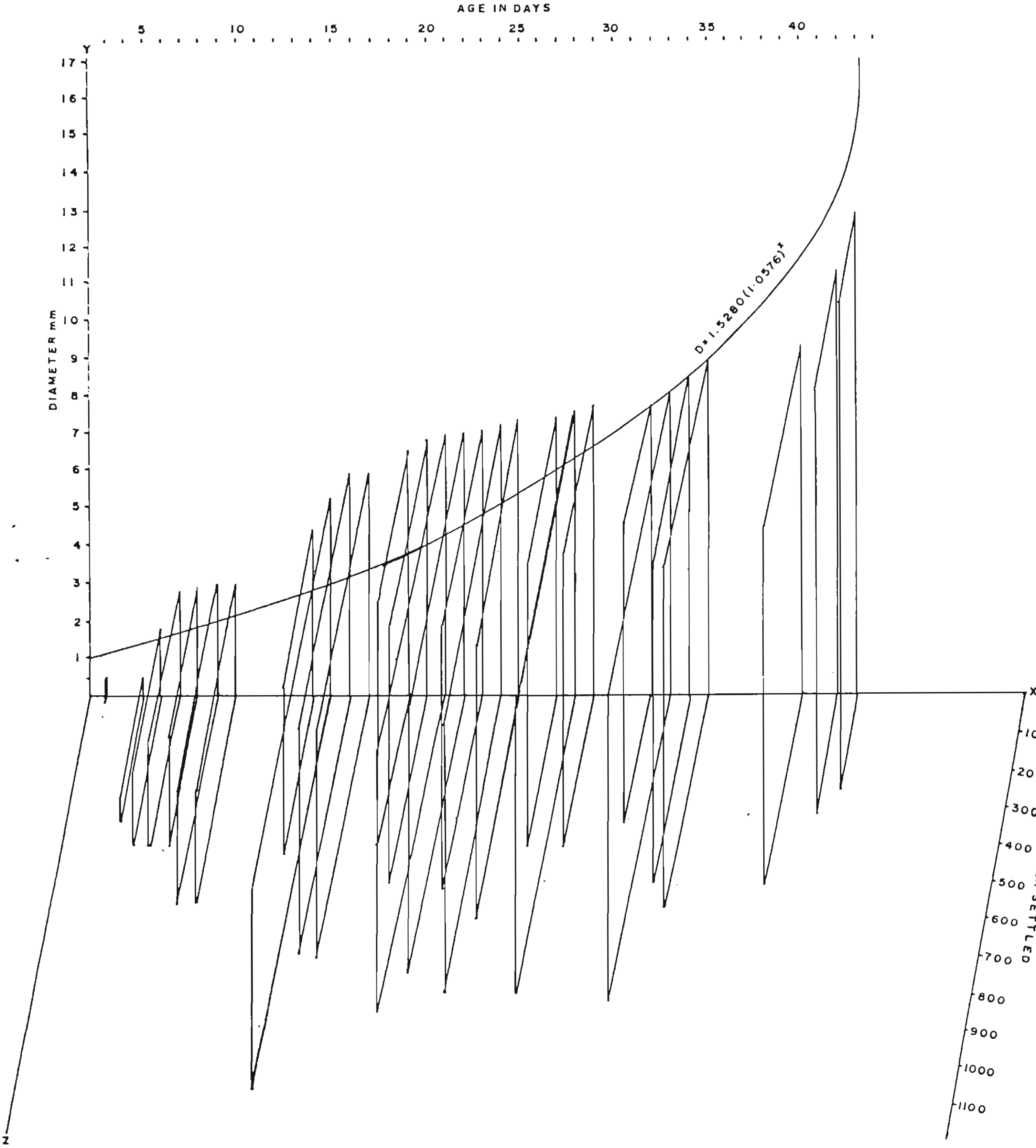


Fig. 2.18. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AGE AND SETTLEMENT IN THE 6th SERIES OF PANELS DURING 13-11-1981 TO 28-12-1981.

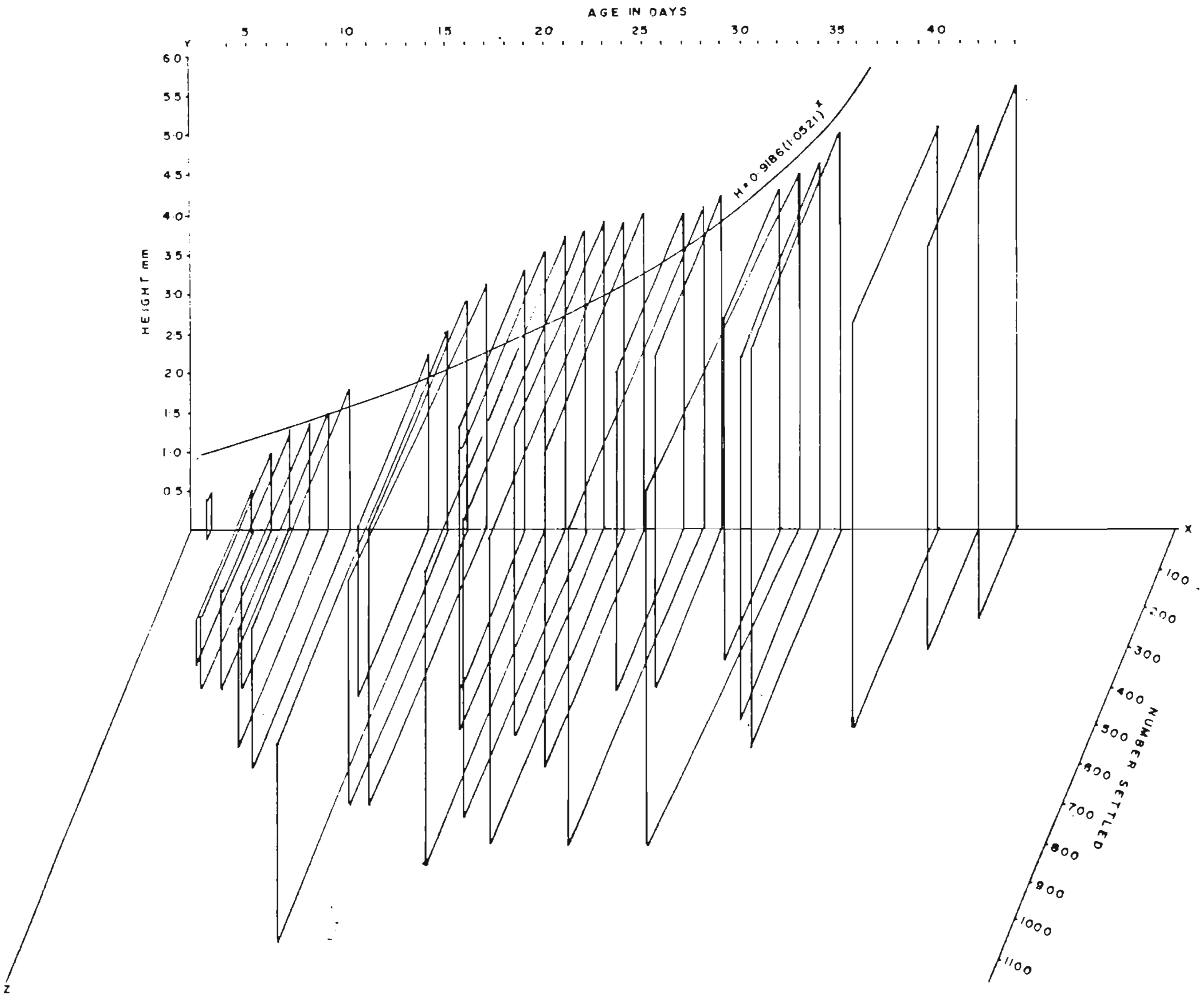


Fig. 2.19. BALANUS AMPHITRITE COMMUNIS. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 6th SERIES OF PANELS DURING 13-11-1981 TO 28-12-1981

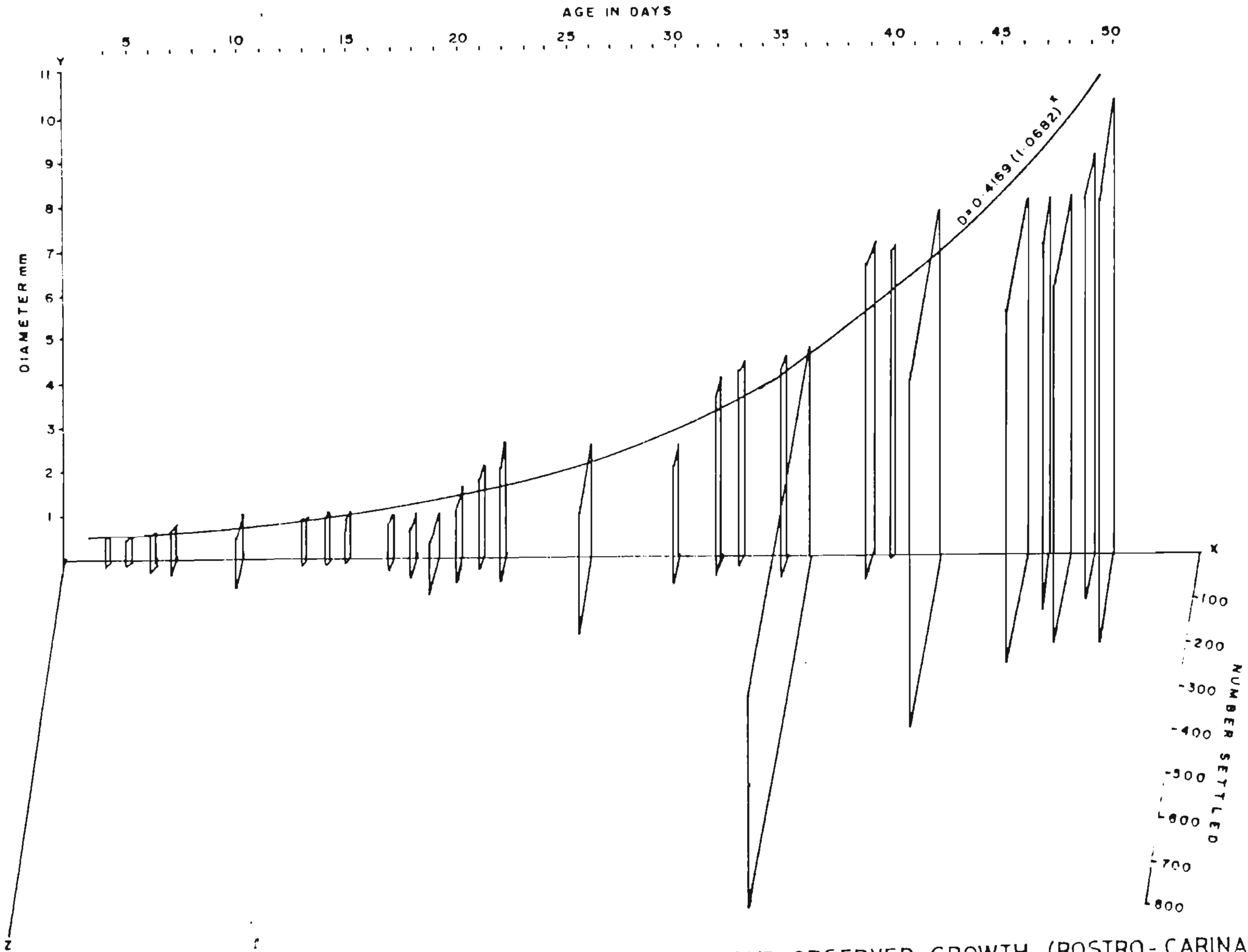


Fig. 2.20. *BALANUS AMPHITRITE COMMUNIS*. THEORETICAL AND OBSERVED GROWTH (ROSTRO-CARINAL DIAMETER), AGE AND SETTLEMENT IN THE 7th SERIES OF PANELS DURING 4-1-82 TO 24-2-1982.

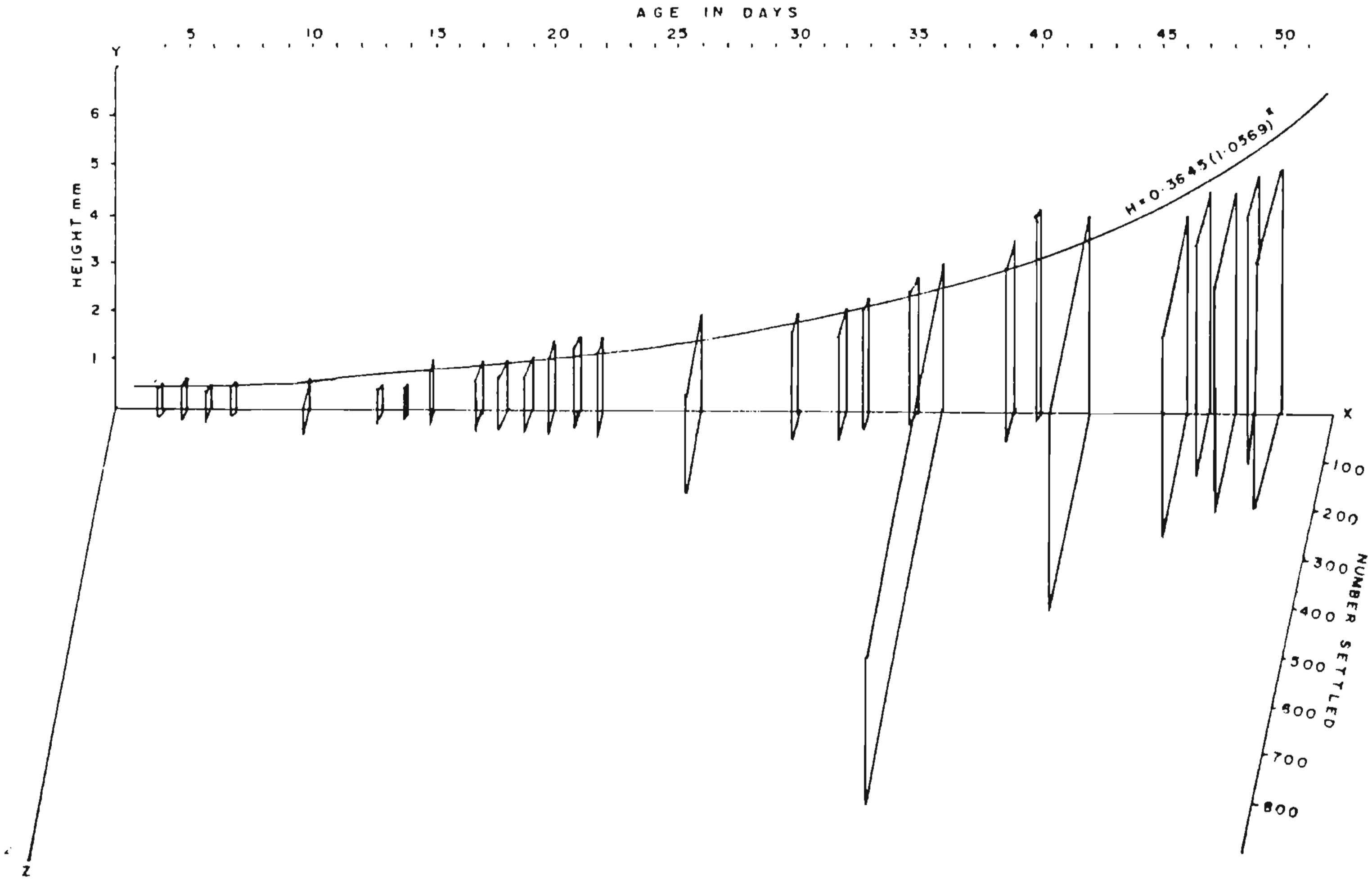


Fig. 2.21. *BALANUS AMPHITRITE COMMUNIS*. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 7th SERIES OF PANELS DURING 4-1-1982 TO 24-2-1982.

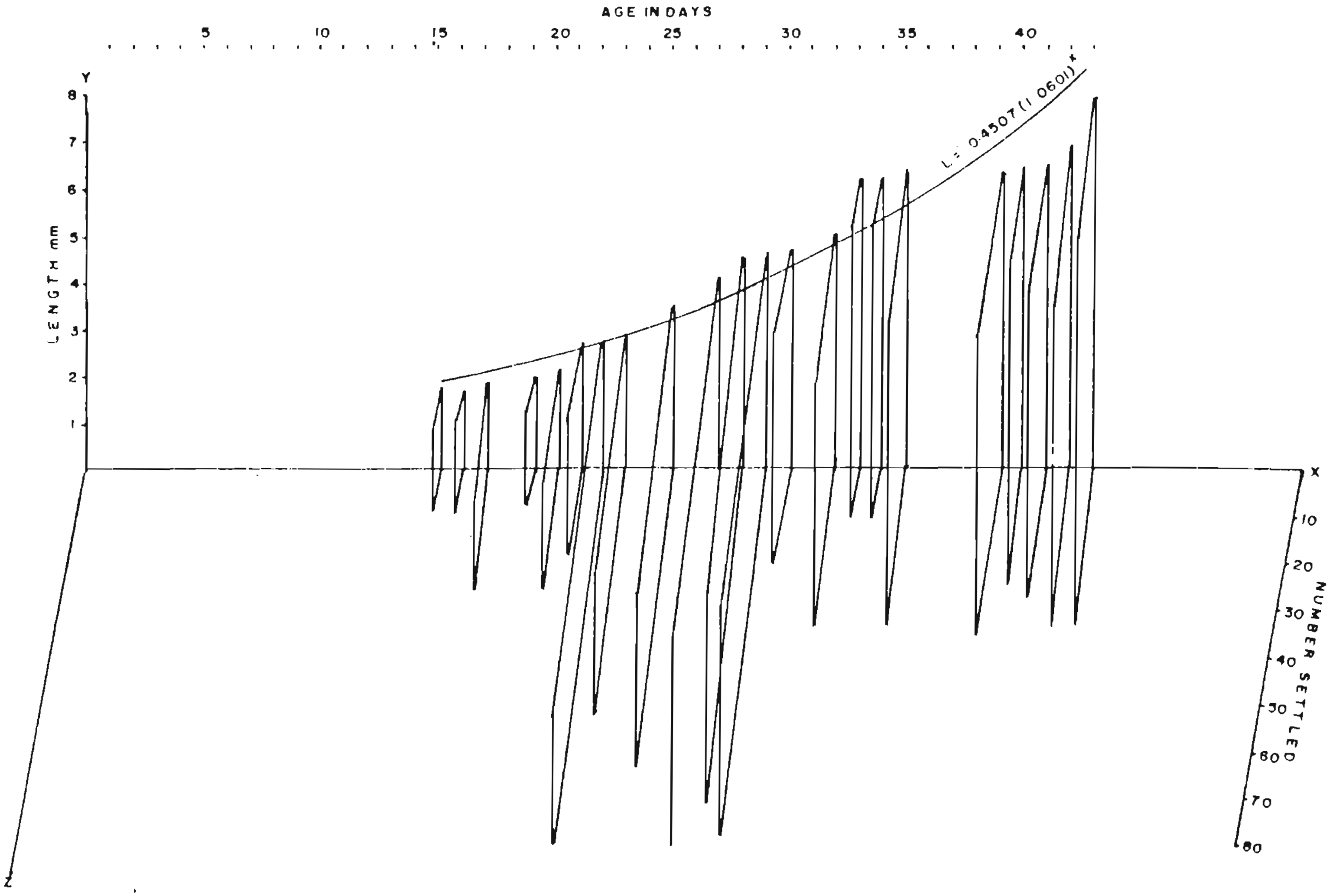


Fig. 2.22. *MODIOLUS CARVALHOI*. THEORETICAL AND OBSERVED GROWTH (LENGTH), AGE AND SETTLEMENT IN THE 1st SERIES OF PANELS DURING 6-3-1981 TO 19-4-1981.

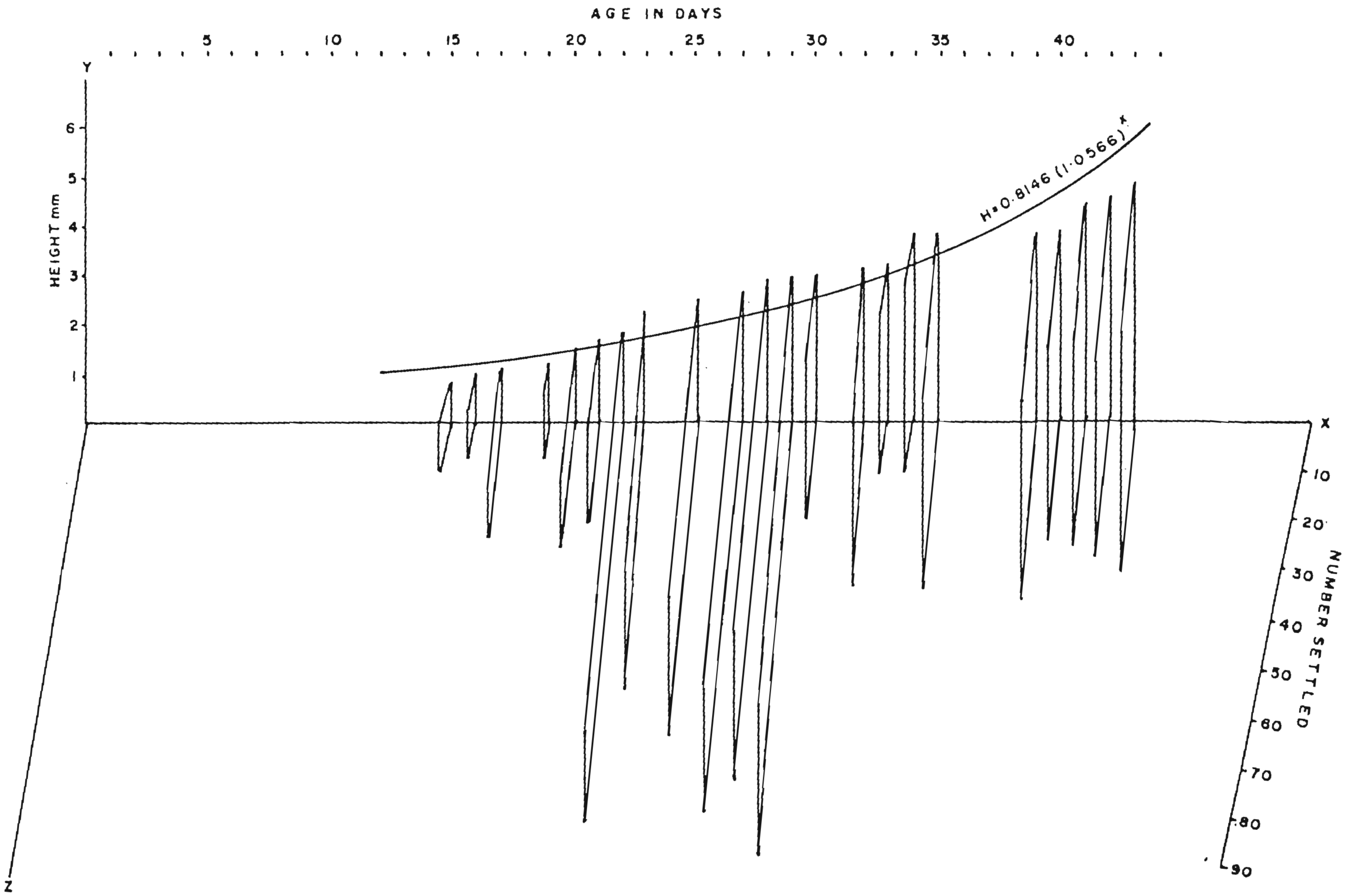


Fig.2.23. <u>MODIOLUS CARVALHOI</u>. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 1st SERIES OF PANELS DURING 6-3-1981 TO 19-4-1981.

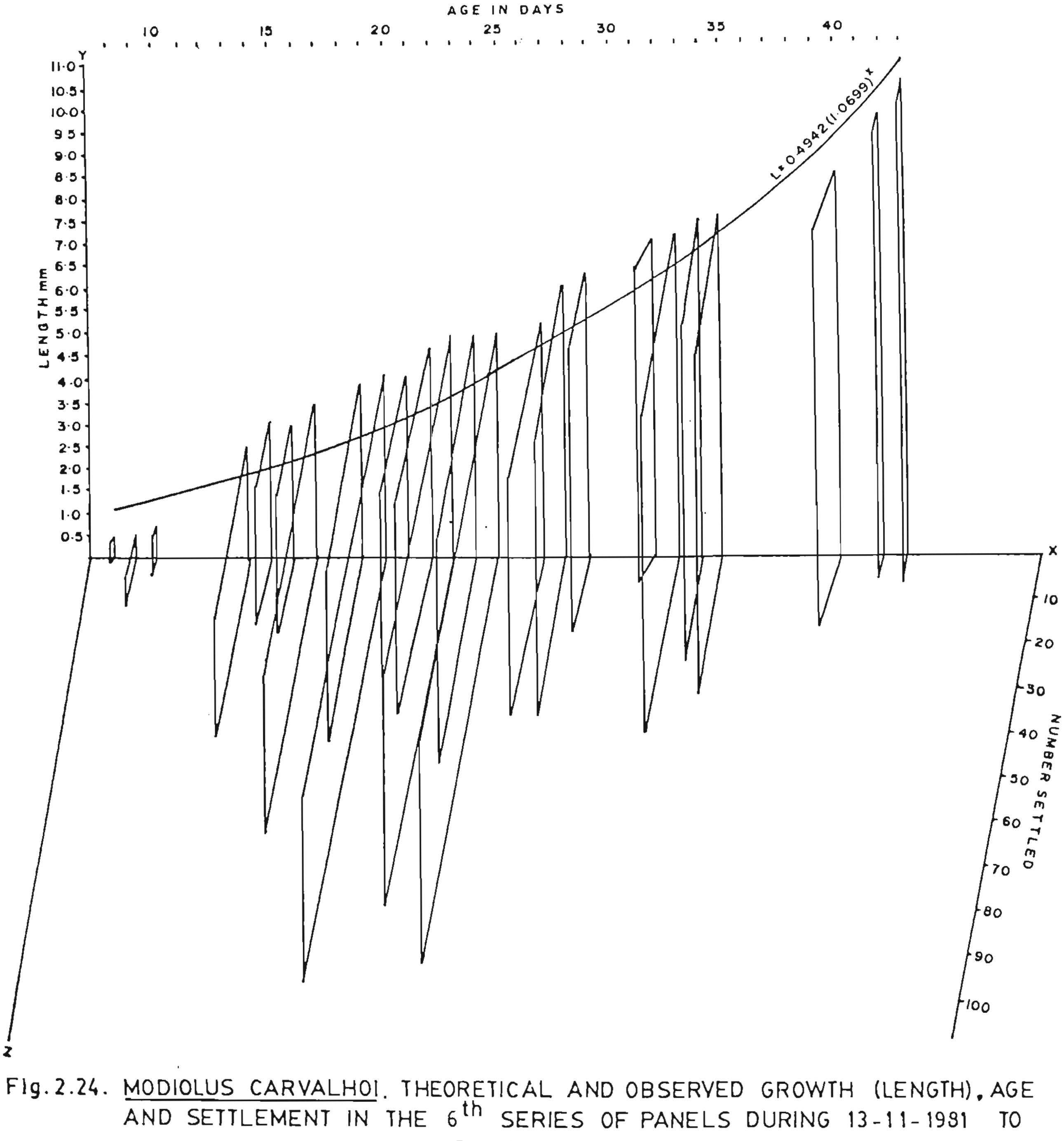


Fig.2.24. MODIOLUS CARVALHOI. THEORETICAL AND OBSERVED GROWTH (LENGTH), AGE AND SETTLEMENT IN THE 6th SERIES OF PANELS DURING 13-11-1981 TO 28-12-1981.

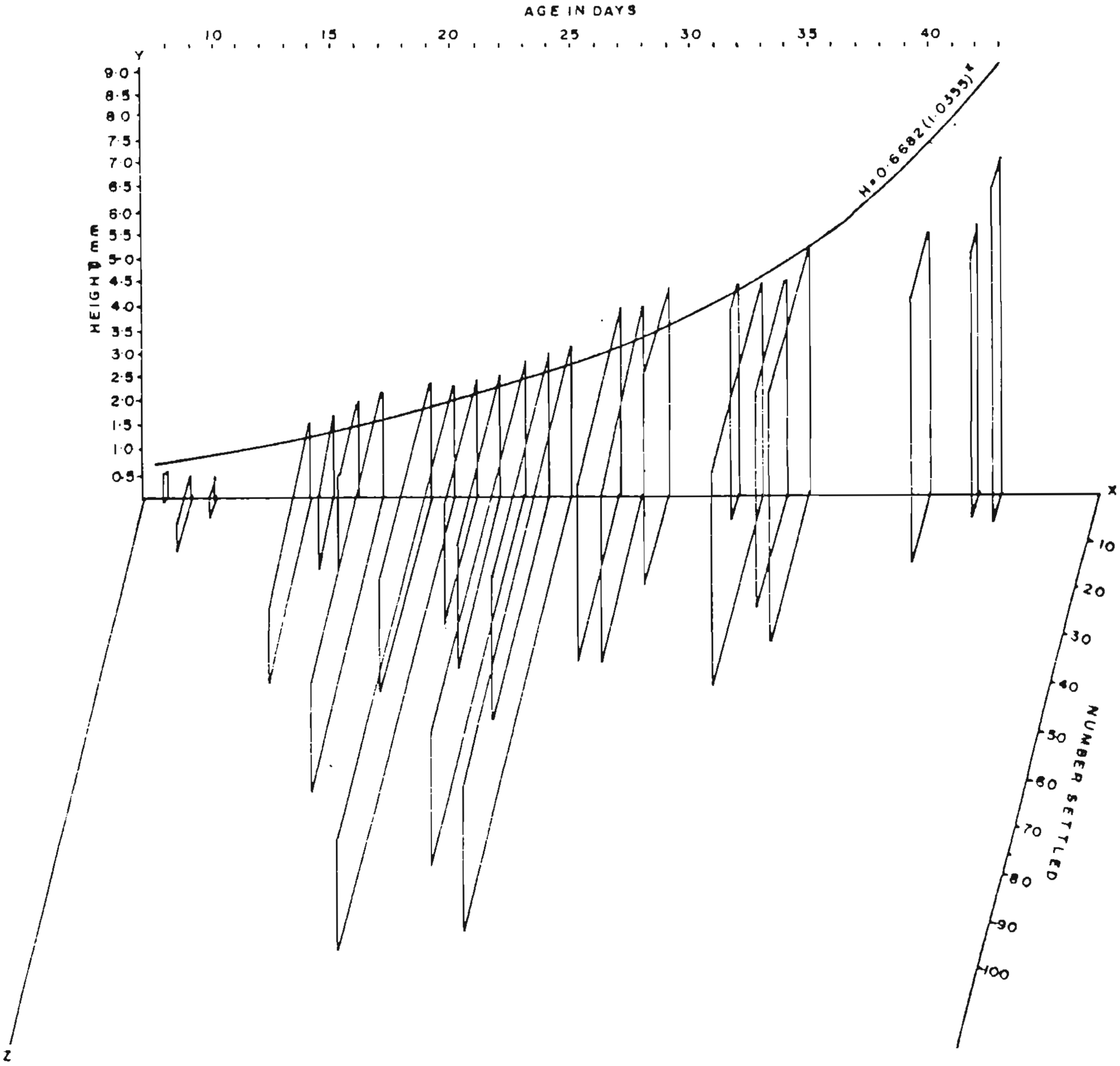


Fig. 2.25. MODIOLUS CARVALHOI. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 6th SERIES OF PANELS IMMERSED DURING 13-11-1981 TO 28-12-1981

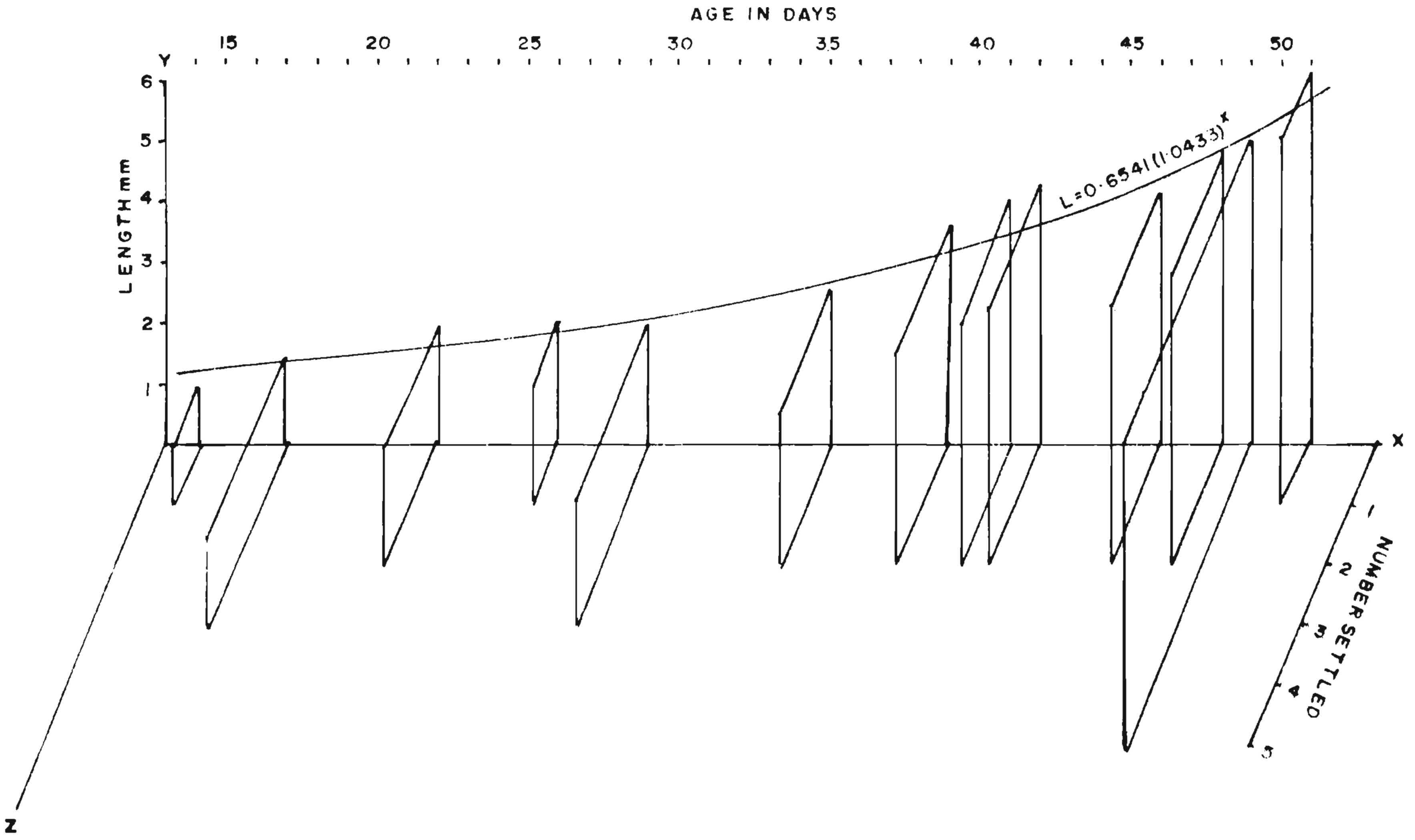


Fig. 2.26. MODIOLUS CARVALHOI. THEORETICAL AND OBSERVED GROWTH (LENGTH), AGE AND SETTLEMENT IN THE 7th SERIES OF PANEL DURING 26-4-1982 TO 23-5-1982

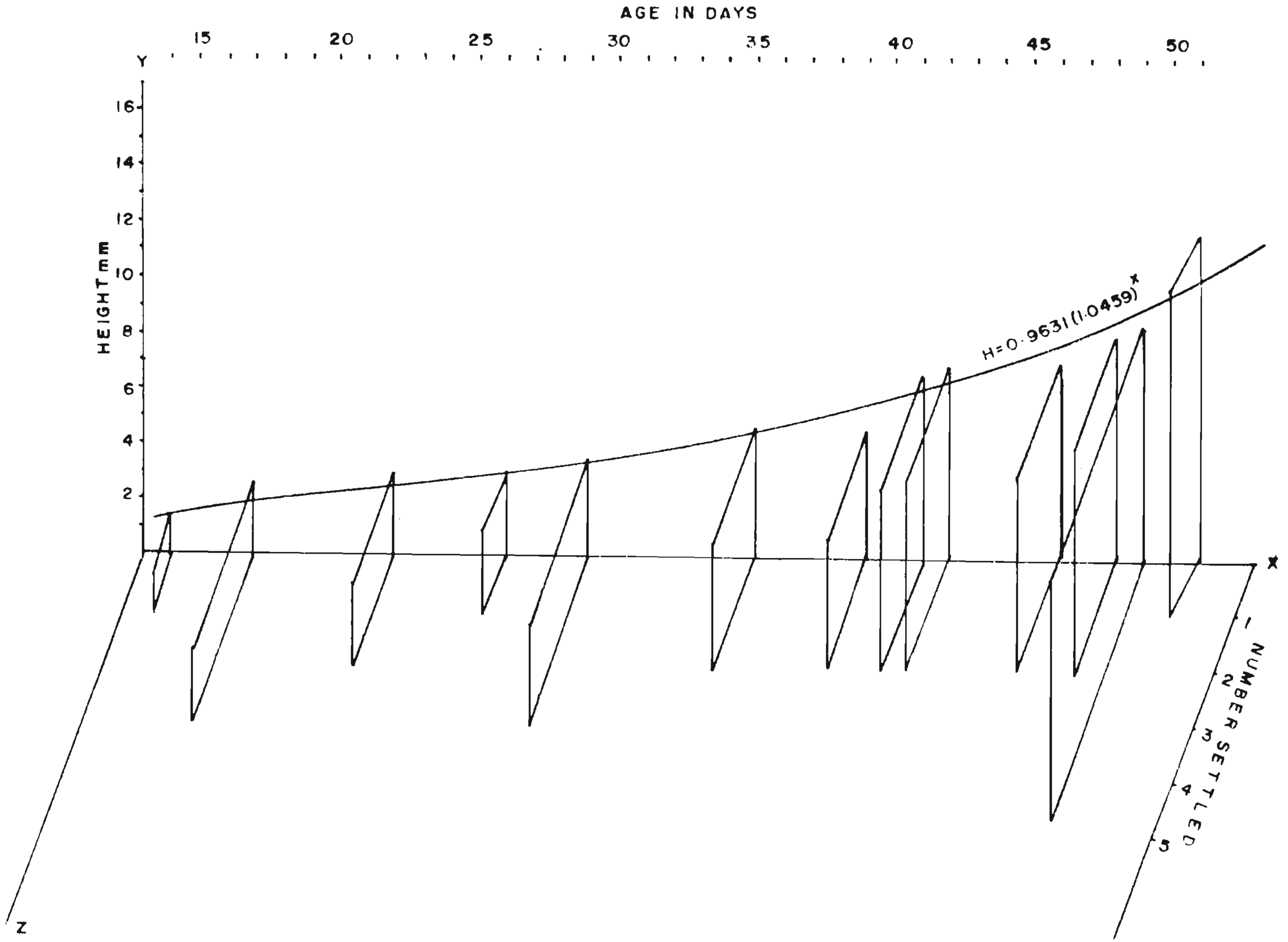


Fig. 2.27. MODIOLUS CARVALHOI. THEORETICAL AND OBSERVED GROWTH (HEIGHT), AGE AND SETTLEMENT IN THE 7th SERIES OF PANELS DURING 4-1-1982 TO 24-2-1982

2.5. References

*Adamson, N.E. (1937) Technology of ship bottom paints and its importance to commercial and naval activities. C. & R. Bull. No.10, 1-36, Bur. Construction and Repair, Navy Department, Washington

Alagarswami, K. & Cellam, A. (1976) The fouling and boring organisms and mortality of pearl oysters in the farm at Veppalodai, Gulf of Mannar. Indian J. Fish. **23** (1-2), 10-22

Allen, F.E. & Wood, F. (1950) Investigations on underwater fouling. Aust. J. mar. Freshwat. Res. **1**, 92-105

Almeida, L.J. (1964) Study of micro-organisms incident on timber submerged in the sea at Bombay. Proc. Symp. mar. Paints. Organised by Def. Res. Dev. Orgn. at Bombay, pp.108-109

Antony Raja, B.T. (1959) Studies on the distribution and succession of sedentary organisms of the Madras Harbour. J. mar. biol. Ass. India. **1**, 180-197

Antony Raja, B.T. (1963) Observation on the rate of growth, sexual maturity and breeding of four sedentary organisms of the Madras Harbour. J. mar. biol. Ass. India. **5**, 113-132

Balasubramanyan, R. & Menon, T.R. (1963) Destruction of boat building timbers by marine organisms in the Port of Cochin, Part 1. Raft tests. J. mar. biol. Ass. India. **5** (2), 294-310

Barnard, J.L. (1958) Amphipod crustaceans as fouling organisms in Los Angels - Long Beach Harbours, with reference to the influence of sea water turbidity. Calif. Fish Game. 44 (2), 161-170

Barnes, H. (1950) A note on the barnacle larvae population of the Clyde Sea area as sampled by the Hardy continuous plankton recorder. J. mar. biol. Ass. U.K. 29, 73-80

Barnes, H., Crisp, D.J. & Powell, H.T. (1951) Observations on the orientation of some species of barnacles. J. Anim. Ecol. 20, 227-241

Barnes, H. (1957) Process of restoration and synchronization in marine ecology. The spring diatom increase and spawning of the common barnacles, *Balanus balanoides*. Annls Biol. 33, 67-85

Barnes. H. & Powell, H.T. (1950) Some observations on the effect of fibrous glass surfaces upon the settlement of certain sedentary marine organisms. J. mar. biol. Ass. U.K. 29 (2), 299-302

Barnes, H. & Powell, H.T. (1951) Observation on the orientation of some species of barnacles. J. Anim. Ecol. 20, 227-241

Bayne, B.L. (1964) The response of the larvae of *Mytilus edulis* (L) to light and gravity. Oikos. 15, 162-174

Becker, G. (1958) *Report to the Government of India on the Protection of Wood Against Marine Borers*. FAO Proj. IND/FO, No.795, pp.112

Bengough, G.D. (1950) Cited by Pyefinch, K.A. (1950) Notes on the ecology of ship fouling organisms. *J. Anim. Ecol*. **19**(10), 29-35

Bruce, J.A. (1976) Marine biofouling studies in Montego and oyster bays, Jamaica. *Proc. 4th Int. Congr*. *mar.corro* *Fouling.* Centre de Recherches et'd Etudes Oceanographique, Boulogne (France), 79-83

Caspers, H. (1960) *Zool. Rec*. **97**(8):4

Coe, W.R. & Allen, W.E. (1937) Growth of marine sedentary organisms on experimental blocks and plates for nine successive years at the pier of the Scripps Institution of Oceanography, La Jolla, California. *Bull. Scripps Instn. Oceanogr. Tech. Ser*. **4**, 101-136

Cole, H.A. (1949) The setting behaviour of larvae of the European flat oyster. *Fish. Invest. Ser*. **11**, 17(3), 1-39

Cole, H.A. & Knight Jones, E.W. (1939) Some observations and experiments on the settling behaviour of larvae of *Ostrea edulis* L. *J. Cons. Ins. Explor. Mer*. **14**, 86-105

Corpe, W.A. (1976) Primary bacterial films and marine microfouling. *Proc. 4th Int. Conq. mar. Corr. Fouling*. Centre de Recherches et.d' Etudes Oceanographique, Boulogne (France), pp.105-108

Crisp, D.J. (1959) Factors influencing the time of breeding of Balanus balanoides. Oikos. 10, 275-289

Crisp, D.J. & Barnes, H. (1954) The orientation and distribution of barnacles at settlement, with particular reference to surface contour. J. Anim. Ecol. 23, 142-162

Crisp, D.J. & Ryland, J.S. (1960) Influence of filming and of surface texture on the settlement of marine organisms. Nature. 185, 119-121

Crisp, D.J. & Stubbings, H.G. (1957) The orientation of barnacles to water currents. J. Anim. Ecol. 26, 179-196

Daniel, A. (1954) The seasonal variations and succession of the fouling communities in the Madras Harbour waters. J. Madras Univ. 24B, 189-212

Daniel, A. (1955) Gregarious attraction as a factor influencing the settlement of barnacle cyprids. J. Madras Univ. 25B(1), 97-107

Daniel, A. (1955a) The primary film as a factor in the settlement of marine foulers. J. Madras Univ. 25B, 189-200

Daniel, A. (1956) The cirripedia of the Madras Coast. Bull. Madras Govt. Mus. 6(2), 1-40

Daniel, A. (1956a) Colour as a factor influencing the settlement of barnacles. Curr. Sci. 25, 21-22

Daniel, A. (1957) Illumination and its effect on the settlement of barnacle cyprids. Proc. zool. Soc. London, 129(3), 305-313

Daniel, A. (1957a) Influence of the stage of tide on the attachment of barnacle cyprids. J. Bombay nat. Hist. Soc. 54(4), 866-868

Daniel, A. (1958) Development and metamorphosis of three species of sessile barnacles. J. Madras Univ. 28B, 23-47

Daniel, A. (1963) Factors influencing the settlement of marine foulers and borers in tropical seas. Proc. First Summer School Zool. Simla. pp.363-382 Manager of Publications, Govt. of India, Delhi

Dharmaraja, R. & Nair, N.B. (1981) Biology of fouling in Neendakara Port, a tropical estuary in the south-west coast of India. Fish. Technol. 18, 79-94

DeSilva, P.H.D. (1968) Experiment on choice of substrate by Spirorbis larvae. J. exp. Biol. 39, 483-490

Dybern, B.J. (1967) Settlement of sessile animals on eternite slabs in two polls near Bergen. Sarsia. 29, 137-150

Edmondson, C.H. & Ingram, W.M. (1939) Fouling organisms in Hawaii, Occ. Pap. Bernice P. Bishop Mus. 14, 251-300

Erlanson, E.W. (1936) A preliminary survey of marine boring organisms in Cochin Harbour. Curr. Sci. 4, 726-732

Estes, N.C. (1938) Chlorination of cooling water. Refiner nat. Gasol. Mfr. **17**

Fox, D.L. & Coe, W.R. (1943) Biology of the California sea mussel (*Mytilus californianus*) ii - Nutrition, metabolism, growth and calcium deposition, J. exp. Zool. **93**, 205-249

Fuller, J. (1946) Season of attachment and growth of sedentary organisms at Limoine, Maine. Ecology. **27**, 150-158

Galtsoff, P.S., Chipman, W.A., Hasler, A.D. & Engle, J.B. (1938) Preliminary report on the cause of decline of the oyster industry of the York River, Va and the effects of pulp mill pollution on oysters. U.S. Bur. Fish. Invest. Rep. **37**, 1-42

Ganapathi, P.N., Lakshmana Rao, M.V. & Nagabhushanam, R. (1958) Biology of fouling in Vishakhapatnam Harbour. Andhra Univ. Mem. Oceanogr. **62**, 193-209

Ghobashy, A.F.A. (1976) Seasonal variation and settlement behaviour of the principal fouling organisms in the eastern harbour of Alexandria. Proc. 4th Int. Congr. Mar. Corros. Fouling. Centre de Recherches et d' Etudes Oceanographique, Boulogne (France) 213-220

Gregg, J.H. (1945) Background illumination as a factor in the attachment of barnacle cyprids. Biol. Bull. **88**, 44-49

Gregg, J.M. (1948) Replication of substrate detail by barnacle and some other marine organisms. Biol. Bull. 94(3), 161-168

Harris, J.E. (1943) First Rep. Mar. Corros. Sub Comm. Iron and Steel Institute, U.K. 67-82

*Hentchel, E. (1923) Der Bewuchs an Seeschiffen. Inst. Rev. ges. Hydrog. Hydrob. 11(3,4) 238-264

*Hutchins, L.W. (1945) An annotated check list of the salt water bryozoa of Long Island Sound. Trans. Conn. Acad. Arts Sci. 36, 533-551

Hutchins, L.W. (1947) The bases for temperature zonation in geographical distribution. Ecol. Monogr. 17(3) 325-335

Iyengar, S.R., Gopalakrishnan, V. & Kelkar, V.V. (1957) Studies on marine fouling organisms in Bombay Harbour. Def. Sci. J. 7, 1-17

Karande, A.A. (1978) Marine Fouling and timber deterioration in the sub oceanic islands of Andamans. Indian J. Mar. Sci. 7, 39-43

Karande, A.A. & Palekar, V.C. (1963) Observation on the breeding activities of the shore barnacle, Chthamalus malayensis (Pilsbry) in Bombay Harbour Def. Sci. J. 13, 130-137

Karande, A.A. (1968) Studies on marine fouling and boring organisms in Bombay Harbour. Proc. 2nd Int. Congr. mar. Corros. Fouling. 563, Athens, Greece

Kuriyan, G.K. (1950) The fouling organisms of pearl oyster cages. J. Bombay nat. Hist. Soc. 49(1), 90-92

Kuriyan, G.K. (1952) Notes on the attachment of marine sedentary organisms on different surface. J. Zool. Soc. India. 4(2), 157-171

Kuriyan, G.K. (1953) Biology of fouling in the Gulf of Mannar, a preliminary report. Ecology, 34, 689-692

Kuriyan, G.K. & Mahadevan, S. (1953) A note on the effect of light and colour of the substrata on the settlement of barnacles. J. Bombay nat. Hist. Soc. 50, 522-524

*Martin, R.B. (1938) Chlorination of condenser cooling water. Trans. Am. Soc. mech. Engrs. 60, 475-483

*Mathews, F.J. (1927) Chlorination of industrial waters. Pwr Wks. Engng. 32(370), 19-21

McDougall, K.D. (1943) Sessile marine invertebrates at Beaufort, North Carolina: a study of settlement, growth and seasonal fluctuations among pile dwelling organisms. Ecol. Monogr. 13, 321-374

Meadows, P.S. & Williams, G.B. (1963) Settlement of Spirorbis borealis Daudin larvae on surfaces bearing films of microorganisms. Nature. 198(4880), 610-611

Menon, N.R. & Nair, N.B. (1971) Ecology of fouling bryozoans in Cochin waters. Mar. Biol. 8(4), 280-307

Miller, M.A. (1946) Toxic effects of copper on attachment and growth of Bugula neritina. Biol Bull. 90, 102-140

Miller, M.A., Rapean, J.C. & Whedon, W.F. (1948) The role of slime film in the attachment of fouling organisms. Biol. Bull. 94, 143-157

Milne, A. (1940) The ecology of Tamar Estuary, iv-The distribution of the fauna and flora on buoys. J. mar. biol. Ass. U.K. (n.s) 24, 69-87

Moore, H.B. (1935) The biology of Balanus balanoides. iv-Relation to environmental factors. J. mar. biol. Ass. U.K. 20, 279-307

Moore, H.B. (1939) The colonization of a new rocky shore at Plymouth. J. Anim. Ecol. 8, 29-38

Moyse, J. (1971) Settlement and growth pattern of the parasitic barnacle Pyrgoma anglicum. 4th Europ. mar. biol. Symp. (Crisp D.J. Ed.), 125-141 Cambridge University Press

Nagabhushanam, R. (1955) Tolerance of the marine wood borer Martesia striata to water of low salinity J. zool. Soc. India 7, 83-86

Nair, N.B. (1962) Ecology of marine fouling and wood boring organisms of Western Norway. Sarsia 8, 1-88

Nair, N.B. (1966) Vertical distribution of marine wood borers in Cochin Harbour, south-west coast of India. Hydrobiologia. 27(1-2) 248-259

Nair, N.Unnikrishnan (1965) Marine fouling in Indian waters. J. Scient. ind. Res. 24(9), 483-488

Nair, N.Unnikrishnan (1967) The settlement and growth of major marine fouling organisms in Cochin Harbour. Hydrobiologia. 30(3-4), 503-512

Nair, N.Unnikrishnan & Pillai, A.G.G.K. (1977) Observation on the composition of slime film and its influence in the settlement of certain marine fouling organisms in Cochin Harbour. Proc. Symp. 'Protection of Materials in the Sea' pp.283-286 Naval Chemical and Metallurgical Laboratory, Bombay

*Nelson, T.C. & Kodet, E.R. (1944) Paint destruction and metal corrosion - zoological aspects. O.S.R.D. Rep. 4512

NewCombe, C.L. (1935) Certain environmental factors of a sand beach in the St. Andrews region, New Brunswick, with a preliminary designation of the inter-tidal communities. J. Ecol. 22, 334-355

*Ortman, A.E. (1896) Grundzuge der marinen Tiergeographic. 96 pp, Jena

*Osburn, R.C. (1944) A survey of bryozoa of Chesapeake Bay. Dept. Res. and Edn. State of Maryland, Bd. Nat. Resources. Publ. 63, 1-59

Paul, M.D. (1937) Sexual maturity of some sedentary organisms in Madras Harbour. Curr. Sci. 5, 478-479

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in the Madras Harbour. Proc. Indian Acad. Sci. 15(1)B:1-42

Panikkar, N.K. & Aiyar, R.G. (1939) Observations on breeding in brackish water animals of Madras. Proc. Indian Acad. Sci. 9B, 343-364

Persoone, G. (1977) Applications for copper in mariculture industry, a review. INCRA Res. Rep. 41pp.

Phelps, E. (1942) Observation on reaction of barnacle larvae and growth of metamorphosed forms at Beaufort, N.C. Fourth Rep. Woods Hole Oceanogr. Inst. (Beareau of ships)

Pillay, N.K. (1955) Wood boring crustacea of Travancore 1. Sphaeromidae Bull. Cent. Res. Inst. Univ. Travancore 4C, 125-138

*Pilsbry, H.A. (1916) The sessile barnacles (Cirripedia) contained in the collection of the U.S. National Mus. including a monograph of the American species. Bull. U.S. Nat. Mus. 93, 1-366

Pomerat, C.M. & Reiner, E.R. (1942) The influence of the surface angle and of light on the attachment of barnacles and other sedentary organisms. Biol. Bull. 82, 14-25

Pomerat, C.M. & Weiss, C.M. (1946) The influence of texture and composition of surface on the attachment of sedentary marine organisms. Biol. Bull. 91, 57-65

Pyefinch, K.A. (1943) The inter-tidal ecology of Bardsey Island, North Wales, with special reference to the recolonization of rock surfaces and the rock pool environment. J. Anim. Ecol. 12, 82-108

Pyefinch, K.A. (1947) The biology of ship fouling. New Biol. 3, 128-148

Pyefinch, K.A. (1948) Notes on the biology of cirripedes. J. mar. biol. Ass. U.K. 27, 464-503

Pyefinch, K.A. (1950) Notes on the ecology of ship fouling organisms. J. Anim. Ecol. 19(1), 29-35

Ryland, J.S. (1960) The British species of Bugula (Polyzoa) Proc. zool. Soc. London. 134(1), 65-105

Scheer, B.T. (1945) The development of marine fouling communities. Biol. Bull. 89, 103-121

Scheer, B.T. (1945a) The development of marine fouling communities. Biol. Bull. 89, 236

Smith, F.G.W. (1946) Effect of water currents upon the attachment and growth of barnacles. Biol. Bull. 90, 51-70

Smith, F.G. (1948) Surface illumination and barnacle attachment. Biol. Bull. 94, 33-39

Sumner, F.G., Osburn, R.C. & Cole, L.J. (1911) A biological survey of the waters of Woods Hole and viscinity. Bull. U.S. Bur. Fish. 31 (i & ii), 860

Visscher, J.P. (1928) Nature and extent of fouling of ships' bottoms. Bull. Bur. Fish. 43 (Pt2), 193-258

Visscher, J.P. & Luce, R.H. (1928) Reactions of the cyprid larvae of barnacles to light with special reference to spectral colours. Biol. Bull. 54, 336-350

Weiss, C.M. (1947) The effect of illumination and stage of tide on the attachment of barnacle cyprids. Biol. Bull. 93, 240-249

Weiss, C.M. (1948) The seasonal occurrence of sedentary marine organisms in Biscayne Bay, Florida Ecology, 29(2), 153-172

Weiss, C.M. (1948a) Seasonal and annual variations in the attachment and survival of barnacle cyprids. Biol. Bull. 94(3), 236-243

Weiss, C.M. (1948b) An observation on the inhibition of marine wood destroyers by heavy fouling accumulation. Ecology. 29(1), 120

Whedon, L.F. (1937) Investigations pertaining to the fouling of ships' bottoms. Rep. Scripps Oceanogr. Inst. LaJolla, California (Beareau of Ships)

Wilson, D.P. (1958) In 'Perspectives in Marine Biology' University of California Press

Wilson, O.T. (1925) Some experimental observations of marine algal succession. Ecology, 6, 303-311

Williams, G.B. (1965) Observation on the behaviour of the planula larvae of Clava squamata. J. mar. biol. Ass. U.K. 95, 257-273

Wisely, D. (1958) The setting and some experimental reactions of a bryozoan larvae of Watersipora cucullata (Busk). Aust. J. mar. Freshwat. Res. **9**(3), 351-361

Wisely, D. (1960) Observations on the settling behaviour of larvae of the tube worm Spirorbis borealis Daudin (Polychaeta) Aust. J. mar. Freshwat. Res. **11**(1), 55-73

Wood, E.J.F. (1950) Investigations on underwater fouling: The role of bacteria in the early stages of fouling. Aust. J. mar. Freshwat. Res. **1**, 85-91

Wood, E.J.F. & Allen, F.E. (1958) Common marine fouling organisms of Australian waters. Department of the Navy, Melbourne, 1-23

Woods Hole Oceanographic Institution (1952) Marine Fouling and its Prevention. Contribution 580 of Woods Hole Oceanographic Institution, prepared for Bureau of Ships, Navy Department, United States Naval Institute, Annapolis, Maryland, pp.388

Zobell, C.E. (1939) The role of bacteria in the fouling of submerged surfaces. Biol. Bull. **77**, 302-308

---

*Not consulted the original

CHAPTER 3

SETTLEMENT CHARACTERISTICS OF CRASSOSTREA MADRASENSIS (PRESTON) IN THE COCHIN BACKWATERS

CHAPTER 3

SETTLEMENT CHARACTERISTICS OF *CRASSOSTREA MADRASENSIS* IN THE COCHIN BACKWATERS

3.1 Introduction

For the successful cultivation of oysters a knowledge of the factors influencing spawning, larval development and settling is an essential prerequisite. Studies pertaining to the settlement of oysters from the Indian waters are those of Hornell (1910), Awati & Rai (1931), Paul (1942), Kuriyan (1952), Ganapathi *et al*. (1958), Rao (1951), Rao & Nayar (1956), Nair (1967), Balasubramanyan & Nair (1968), Rao & Menon (1978), Menon *et al*. (1977) and Dharmaraja & Nair (1981). Detailed studies on the settlement of oysters from the Cochin Backwaters are few and it was thought worthwhile to undertake a detailed study on this aspect.

3.2 Stations investigated

Settlement of oysters was studied at 5 different locations in the Cochin Backwaters (The test stations 1, 2, 3, 4 and 5 are shown in Fig.1.1, Chapter 1).

Station 1: Pier of the Department of Marine Sciences, University of Cochin, in the Ernakulam Channel on the estern side of Willingdon Island, about 4 km away from the barmouth. The depth here is about 2.5 m.

Station 2: Drydock of the Cochin Harbour, in the Mattancheri Channel, about 2 km away from barmouth. The water here is usually turbid, owing to the churning action of propellers of fishing boats and ships. The depth at this station is around 4 m.

Station 3: Pier of the Exploratory Fisheries Project. This station is situated just opposite to station 2 on the western side of the Dry Dock (Station 2) in the Mattancheri Channel about 2 km from barmouth. As in station 2, here also the water is turbid owing to the frequent plying of fishing boats. The Cochin Fishing Harbour is situated adjacent to this station on the southern side. The depth at this station is about 2 m.

Station 4. Thevara: This station is also located on the eastern side of Willingdon Island about 1 km south of station 1. It is separated from the Ernakulam Channel by a low belt of sand. The depth is approximately 2.5 m. Here the water is comparatively less polluted and less turbid.

Station 5. Aroor: This station is situated about 20 km from the barmouth towards the south, silting and turbidity are negligible and the depth here is about 2.5 m.

3.3 Materials and methods

3 Glass panels 10x10 cm size were suspended and kept at the intertidal, the subtidal and the bottom positions at stations 1, 4 and 5 by passing a rope through holes drilled at the centre of the glass panels. The glass panels were kept in position by providing a knot above and below each panel. At station 2, (Dry Dock) owing to greater depth, than at other stations, six glass panels were suspended from the intertidal region to the mudline at intervals of 50 cm. To avoid the effects of silting, the bottom panel was kept 50 cm above the mudline. At station 3, glass panels were arranged on a grooved wooden rack and exposed subtidally 30 cm below low water line. With the aid of this system of panels, it was possible to observe the pattern of settlement of oysters at the stations mentioned above and at different depths in station 2 (Dry Dock).

Short-term (A series)

Short-term series were put out and changed at the end of 15 days at station 1 and 5 (Tables 3.2 and 3.6) and at intervals of 30 days at stations 2 and 4 (Tables 3.3 and 3.5). At station 3, thirty panels were exposed together for each month. The panels were mounted on a grooved wooden rack, one panel removed for examination every day.

The settlement of oysters on the 30 panels was averaged and represented for each month (Table 3.4).

Long-term series (B series)

Eight sets were exposed at the beginning of each period and recovered one by one at intervals of 15 days at stations 1 and 5 (Tables 3.2 and 3.6). Four sets were exposed at the beginning of each period and recovered one by one at intervals of 30 days at stations 2 and 4 (Tables 3.3 and 3.5).

3.4 Pattern of settlement of *C. madrasensis*

The settlement characteristics of *C. madrasensis* at stations 1, 2, 3, 4 and 5 are presented in Tables 3.2 to 3.6. As is evident from the tables, during the major part of the monsoon period and early post-monsoon period there was no settlement of oysters on panels at any locality investigated. The general trend in the settlement of oysters was a well defined one, though the post and pre-monsoon months in general recorded the incidence of oyster spat. During the monsoon period and early post-monsoon periods, no settlement was noticed on panels at the various stations except on the subtidal and bottom panels at station 4 (Table 3.5) in the month of June. The station-wise settlement is outlined below.

3.4.1 Marine science Pier (Ernakulam Channel)

The panels exposed at three depths at this station during the monsoon period did not register the presence of oyster spat at any time (Table 3.2) during the period beginning from June and ending in September. This trend was continued till the middle of December. The settlement of oysters was confined to the period beginning with the end of December to the end of May. Although oyster spat appeared on the panels throughout this period, two peaks in settlement were noticed, the first one being the major one occurring during January and a second minor peak during early March. The average number of oysters settled was 5/200 cm^2 in December and 57/200 cm^2 during January and 15/200 cm^2 during March and 10/200 cm^2 in April and 5/200 cm^2 in May (Table 3.2) on short-term panels. Another feature of the pattern of settlement was that, fresh attachment was not continuous in short-term although the long-term panels continued to harbour oysters throughout the post and pre-monsoon period from January to May.

3.4.2 Dry dock (Mattancheri Channel)

Fresh settlement as evidenced by the incidence of oysters on short-term panels, occurred in this area during November to May (Table 3.3) which include both the post and pre-monsoon months. In the locality no settlement of oysters was recorded during the monsoon period. The peak settlement was in January when the average number of oyster settled was 19/200 cm^2 in short-term panels. More number settled, on panels maintained in the midwater and bottom.

3.4.3 Exploratory Fisheries Project Pier

The maximum settlement of oysters at this station was during December being 60/200 cm^2. Oysters settled from November to July but were totally absent during August, September and October (Table 3.4).

3.4.4 Thevara (Mid-estuarine region)

The settlement of oysters in this station was very poor. Although fresh settlement was noticed from March to June, the number of oysters settled here was small. A spurt in oyster settlement was noticed during June (37/200 cm^2). Apart from this settlement was insignificant during the other months (Table 3.5).

3.4.5 Aroor

The settlement of oysters occurred at this station for a short duration of four months commencing from January in the short-term panels. Maximum settlement was noticed during March being 60/200 cm^2 in the short-term panels. In long term panels (Table 3.6) peak settlement was recorded in February being 42/200 cm^2.

3.6.0 Discussion

Crassostrea madrasensis enjoys a wide distribution in the backwater environment of South India. It is a very common representative of the sedentary community of brackish water benthos. The settlement of oysters on submerged

Table 3.1 Salinity and temperature data of the stations investigated

Month	Station 1		Station 2		Station 3		Station 4		Station 5	
	Water temp. °C	S‰	Water temp. °C	S‰	Water temp. °C	S‰	Water temp. °C	S‰	Water temp. °C	S‰
June, 1981	29.6	2.4	29.5	21.5	29.7	22.0	31.0	18.8	29.0	3.6
July	29.5	3.2	29.0	1.7	28.5	4.5	28.5	2.0	28.3	0.3
August	27.6	1.9	27.5	6.4	28.3	2.1	29.5	3.8	28.0	1.8
September	29.5	10.1	31.0	10.6	29.4	2.8	30.5	1.7	30.0	1.3
October	28.5	16.3	31.0	19.3	28.0	7.2	31.0	4.2	31.2	3.8
November	29.9	18.1	29.0	29.6	29.8	12.5	29.5	7.0	32.0	15.0
December	28.8	20.4	31.5	28.7	28.8	22.4	31.0	19.3	29.0	18.6
January, 1981	30.7	28.3	32.0	30.2	27.9	32.4	32.5	29.1	32.0	26.5
February	30.5	33.0	31.3	31.5	29.4	33.4	30.2	31.7	33.0	28.9
March	30.0	33.4	32.1	33.9	30.5	32.0	34.0	33.6	31.9	31.9
April	32.0	32.0	32.9	31.0	31.0	33.0	32.4	28.6	33.5	31.7
May	30.0	34.0	29.5	34.0	31.0	32.5	29.5	20.6	31.5	31.0

Table 3.2 Station 1. (Marine Science Pier) - Settlement of C. madrasensis on short-term and long-term panels (200 cm^2 area)

	Monsoon								Postmonsoon								Pre-monsoon							
	Jun 1981		July		Aug		Sept		Oct		Nov		Dec		Jan 1982		Feb		Mar		Apr		May	
Short-term panels	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8
Inter-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	1	43	-	-	-	16	-	7	-	-	-
Sub-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	2	34	27	-	-	15	-	-	9	-	-
Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	12	114	68	-	-	13	-	4	18	--	5
Monthly average														5	57				15			10		5
Long-term panels	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Inter-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	14	19	-	8	2	-	2
Sub-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	43	5	-	1	2	1	3
Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	50	13	-	13	8	-	6
Monthly average																		36	12			6		3

- = absent

Table 3.3 Station 2. Dry Dock-settlement of C. madrasensis and short and long-term panels (200 cm^2 area)

	Monsoon					Post-monsoon			Pre-monsoon			
Period	Jun 1981	July	Aug	Sep	Oct	Nov	Dec	Jan 1982	Feb	Mar	Apr	May
Short-term panels	A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4
30 cm	-	-	-	-	-	-	-	-	-	-	-	-
60 cm	-	-	-	-	-	-	2	8	13	-	-	-
90 cm	-	-	-	-	-	-	4	-	19	8	16	-
120 cm	-	-	-	-	-	-	7	28	27	6	7	-
130 cm	-	-	-	-	-	4	5	170	28	13	26	-
160 cm	-	-	-	-	-	5	-	-	27	8	5	-
Average	-	-	-	-	-	5	5	69	23	9	14	-
Long-term panels	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
30 cm	-	-	-	-	-	-	-	-	-	7	-	-
60 cm	-	-	-	-	-	-	-	-	-	7	9	10
90 cm	-	-	-	-	-	-	4	2	-	8	18	7
120 cm	-	-	-	-	-	-	2	-	-	13	13	4
130 cm	-	-	-	-	-	-	8	5	-	10	10	7
160 cm	-	-	-	-	-	-	4	30	-	10	2	5
Average	-	-	-	-	-	-	5	12	-	9	10	7

- = absent

Table 3.4 Station 3. Exploratory Fisheries Project Pier - Settlement of C. madrasensis on test panels (200 cm^2 area)

	Monsoon				Post-monsoon				Pre-monsoon		
June 1981	July	Aug	Sept	Oct	Nov	Dec	Jan 1982	Feb	Mar	Apr	May
10	7	-	-	-	14	60	5	5	9	8	5

Table 3.5 Station 4. Theyara. Settlement of C. madrasensis on short-term and long-term panels (200 cm^2 area)

	Monsoon				Post-monsoon				Pre-monsoon			
Period	Jun 1981	Jul	Aug	Sep	Oct	Nov	Dec	Jan 1982	Feb	Mar	Apr	May
Short term	A1	A2	A3	A4	A1	A2	A3	A4	A1	A2	A3	A4
Intertidal	-	-	-	-	-	-	-	-	-	-	-	-
Subtidal	23	-	-	-	-	-	-	-	-	-	-	2
Bottom	50	-	-	-	-	-	-	-	-	5	13	2
Average	37	-	-	-	-	-	-	-	-	5	13	2
Long term	B1	B2	B3	B4	B1	B2	B3	B4	B1	B2	B3	B4
Intertidal	-	-	-	-	-	-	-	-	-	-	-	-
Subtidal	-	-	-	-	-	-	-	-	2	-	-	-
Bottom	-	-	-	-	-	-	-	-	2	-	5	-
Average									2		5	

- = absent

Table 3.6 Station 5. Aroor - Settlement of C. madrasensis on short and long-term panels (200 cm^2 area)

			Monsoon								Post-monsoon								Pre-monsoon					
	Jun 1981		Jul		Aug		Sep		Oct		Nov		Dec		Jan 1982		Feb		Mar		Apr		May	
Short term Panels	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8	A1	A2	A3	A4	A5	A6	A7	A8
Inter-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	35	-	-	-	-	-	-	-	-
sub-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	30	-	2	-	-	-	-	-	-
Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	49	-	-	50	-	60	-	16	-	-
Average															33			26		60		16		
Long term panels	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
Inter-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Sub-tidal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	2	2	2	2	3	-
Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	-	-	-	-	-	2
Average																		42	3		2	2	3	

substrata is a direct indication that spawning had taken place. Usually oysters may settle on any hard substrata. Therefore the settlement data obtained from a series of panels exposed at the different localities should give a general picture of the pattern of settlement of these bivalves. Five stations studied here represent five localities with varying salinity conditions (Table 3.1).

It is clear from the settlement data presented in Tables 3.2 to 3.6, that in general, the larvae of C. madrasensis settle in the estuary during the period November to May/June. However, there could be regional difference in their settlement and abundance. At station 3, nearer to barmouth with a perennial oyster bed nearby, the locality from which oysters were collected for various studies in the present case, oyster settlement was noticed for nine months from November to July (Table 3.4). During this period, major settlement was confined to the panels kept at relatively greater depths ($<$ 90 cm) at station 2 (Table 3.3). The duration of settlement was reduced to six months at station 1 beginning from December and ending in May, nearly seven months at station 2 from November to May, five months at station 4 (Thevara) from February to June and about four months (February to May) at Stations 5 (Aroor). At station 4, settlement was confined to February-June period, in intertidal, subtidal and bottom panels. In the short-term series settlement was chiefly on bottom panels from March to June. Very sparce settlement was noticed in the subtidal panels during February and April in the long-term series. The most important hydrographical parameter which inhibited wide fluctuation was salinity. The settlement of oysters occurred when the salinity of the water was above 20.4, 29.6 and 12.5‰ at stations 1, 2 and 3 respectively. However, at Thevara (Station 4) and Aroor (Station 5) settlement of oysters occurred only when the salinity exceeded 29‰. The total absence of settlement of oysters during the monsoon period and early post-monsoon period (June to October), when very low salinity conditions existed clearly indicates the inability of the larvae to settle at these salinities. Further, observations showed a declining trend in the condition index from November to May (Chapter 6). This lowered condition index is evidently due to spawning in oysters. During this period comparatively high salinities exist and larvae settle in large numbers in the Cochin Backwaters.

In the Madras Harbour peak settlement of oyster takes place during April and May but settlement continues till the end of October (Paul, 1942). In the Publicat Backwaters, near Madras, Hornell (1910) observed two peaks in spawning of oysters, the first during August and September and a second one in March and April. According to Awati & Rai (1931) Ostrea cucullata spawns in the Bombay coast during October and continues upto the end of June. Awati & Rai

(1931) distinguished a regular breeding season from March to June with intense breeding and an irregular season from October to February. Malpas (1933) observed in the Ceylon pearl oyster Margaritifera vulgaris two spawning maxima the first during July to August coinciding with the S.W. Monsoon and the second in December to January, coinciding with the N.E. Monsoon with an irregular spawning in between the two peak spawning periods. In the Adayar Backwaters, Rao (1951) observed spatfall throughout January and during the first week of February when the salinity ranged between 27.3‰.and 29.01‰. In the Ennur Backwaters, Rao observed spatfall at salinities 31.09‰ and 30.21‰ during December in shallow water and deep water respectively when the estuaries maintained connection with the sea. Spatfall in both the backwaters was maximum when the salinity was 29‰ to 31.09‰. Rao (1951) has also observed the breeding of oysters in the Madras Harbour for most part of the year with two peaks, one in November-December and the other in May-August as against a single peak observed by Paul (1942). In the Mangalore Harbour area, Menon et al. (1977) observed continuous settlement of oysters throughout the year. However, in the estuarine locality, Menon et al. (1977) observed settlement of oysters only during the period November to June. The settlement pattern observed in this study also follows a comparable trend to that observed by Awati & Rai (1931) and Menon et al. (1977) from Bombay coast and the estuarine waters of Mangalore respectively. Peak settlement of oyster noticed in this study at stations 1 and 2 was during January and February, during December at station 3 and in April at stations 4 and 5. The salinity of the backwaters during this period ranged from 22.4‰ to 33‰ (Table 3.1). It is clear that stations 1, 2 and 3 which are nearer to the barmouth recorded peak settlement during December to February while stations 4 and 5 located comparatively at longer distances from the barmouth showed peaks in settlement during April as these stations take longer time to attain the optimum salinity conditions condusive for oyster settlement.

It is well known that temperature fluctuations are chiefly responsible for spawning and setting in European and American oysters (Stafford, 1913; Nelson, 1921, 1928; Churchill, 1920; Prytherch, 1929, 1932). However, in the Cochin Backwaters temperature fluctuations are limited (Table 1.1, ch.1 and Table 3.1, ch.3) throughout the year. As Rao (1951) points out "under tropical conditions of our coasts the water temperature of the sea or the backwaters are maintained high throughout the year and does not even fall at any time below the optimum requirement of the oysters". Thus factors other than temperature seems to govern spawning and setting of oysters in the Cochin Backwaters. Although temperature has been proved to influence the development and settlement pattern of oysters, in the present study salinity seem to exert more influence by virtue of its wide fluctuations (Tables 1 and 3.1 in chapters 1 and 3 respectively) Rao (1931) observed fluctuations between 20.3 and 28‰ at the Adayar Estuary when oysters spawned and the optimum salinity of 22 to 26‰ is attained either by evaporation of water or by the influx of freshwater. Hopkins (1931) noticed a correlation between salinity and setting in the oyster Ostrea virginica at Galveston Bay, Texas and observed that larval setting is stimulated by a salinity of 20‰. According to Rao (1951) "in the small estuaries and backwaters of our coasts, however, periodical inflow and outflow of tidal and flood waters respectively with the tidal amplitude as small as three feet influence the fluctuation in salinity and consequently of the spawning and setting of the oysters". Panikkar & Aiyar (1939) also attributed fluctuation in salinity to the periodicity of breeding in brackish water animals. The influence of salinity in the spawning and setting of oysters has been observed by several other workers. Within the normal temperature range Clarke (1935) observed normal activity of spermatozoa in salinities 5‰ to 40‰ with longest sperm life at 23‰. Ontogenetic development proceeded normally to the first swimming state in salinities 14.5‰ to 39‰. Even though development of eggs took place in 14.5 to 39‰ salinities, no swimming larvae were obtained (Clarke, 1935). In the oyster O. gigas spawning was inhibited below 27‰ salinity. Salinities between

23‰ and 28‰ provided optimum conditions for fertilization and development of embryos (Fujiya, 1970). C. virginica inhabiting Long Island Sound, USA, attains maturity and spawns at 27.5±1‰ salinity. However, it is uncertain how much these limiting salinities may be affected by the salinity at which the parent oysters develop gonads and spawn. Very few eggs yield straight hinge larvae at 12.5‰ salinity, but larvae rared to setting size at 27.5‰ salinity can successfully complete metamorphosis in salinities as low as 9‰ or 10‰ (Calabrese & Davis, 1970). Prytherch (1934) observed larvae of O. virginica undergoing complete fixation in 12 to 19 minutes in salinities of the range 16 and 18.5‰. However, in salinities above or below 16‰ - 18.5‰ the process of fixation was prolonged. The evidence obtained during the present study mainly shows that the conditions that prevailed in the estuary during the post-monsoon and pre-monsoon periods are favourable for successful settlement and colonisation by C. madrasensis. Further two important ecological aspects could control colonisation, the total distributional area of a population can have a reproductive centre and a peripheral area subsisting on regular recruitment of larvae from reproductive areas. Salinity may be a master factor controlling settlement (Colonisation) within a specific intensity range only and outside that critical range, the importance of salinity decreases to that of a secondary or even teritiary environmental entity, other factors (Substrata; larval life and longevity) take over primary distributional control. It is likely that these generalisations hold good for the native population and the settlement pattern of C. madrasensis in the Cochin Backwaters. The discontinuity in the setting of oysters during the monsoon period at the Cochin Backwaters and continuous setting during other periods may be attributed to fluctuations in salinity. Panikkar & Aiyar (1939) also noticed discontinuity in the breeding of brackish water animals and attributed this to rains. Rao (1951) observed C. madrasensis breeding throughout the year in the Madras Harbour with two peaks, one in November - December and another in May-August as against a single peak observed by Paul (1942) and noticed that the two peaks correspond to those of salinity and high temperature of the coastal waters and the two peaks corresponding with the restricted breeding in November-December and March-April in the backwaters.

3.7.0 References

Awati, P.R. & Rai, H.S. (1931) Ostrea cucullata (The Bombay Oyster). Indian Zool. Mem. 3, 107 pp

Balasubramanyan, R. & Nair, N.Unnikrishnan (1968) Fouling of oysters and its prevention. Proc. Symp. Mollusca. Pt. iii, Mar. biol. Ass. India. 730-735

Calabrese, A. & Davis, H.C. (1970) Tolerances and requirements of embryos and larvae of bivalve molluscs. Helgolander Wiss Meeresunters. 20, 553-564

*Clarke, A.E. (1935) Effects of temperature and salinity on the early development of the oyster. Progr. Rep. Atl. Biol. Stat. St. Andrews 16, 10

*Churchill, E.P. (1920) The oyster and oyster industry of the Atlantic and Gulf coasts. Appendix vii, Rept. U.S. Comm. Fish. U.S. Bur. Fish. Document No.890, 5

Dharmaraja, R. & Nair, N.B. (1981) Biology of fouling in Neendakara Port, a tropical estuary in the South-west coast of India. Fish. Technol. 18, 79-94

Fujiya, M. (1970) Oyster farming in Japan. Helgolander Wiss. Meeresunters. 20, 464-479

Galtsoff, P.S. (1930) The role of chemical stimulation in the spawning reaction of Ostrea virginica. Proc. Nat. Acad. Sci. Washington. 555-559

Galtsoff, P.S. (1932) Spawning reactions of three species of oysters. J. Wash. Acad. Sci. 22, 65-69

Ganapathi, P.N., Lakshmana Rao, M.V. & Nagabhushanam, R. (1958) Biology of fouling in Vishakhapatnam Harbour Andhra Univ. Memo. Oceanogr. 62, 193-209

Hopkins, A.E. (1931) Factors influencing the spawning and setting of oysters in Galveston Bay, Texas. U.S. Bull. Bur. Fish. 47, 57-83

Hornell, J. (1910) Note on an attempt to ascertain the principal determing factor in oyster spawning in Madras backwaters (Madras Fish. Investigations, 1908) Madras Fish. Bur. Bull. 4, 25-31

Kuriyan, G.K. (1952) Notes on the attachment of marine sedentary organisms on different surfaces. J. Zool. Soc. India, 4(2), 157-171

Malpas, A.H. (1933) Further observations on the age and growth rate of the Ceylon pearl oyster *Margaritifera vulgaris*, with special reference to oysters of Donnan's Muthuvarathu Paar. Cey. J. Sci. (c) 5

Menon., N.R., Katti, R.J. & Shetty, H.P.C. (1977) Biology of marine fouling in Mangalore waters. Mar. Biol. 41, 127-410

Nair, N.Unnikrishnan (1967) The settlement and growth of major marine fouling organisms in Cochin Harbour. Hydrobiologia. 30(3-4) 503-512

Nelson, T.C. (1921) Aids to successful oyster culture 1. Procuring the seed. New Jersey Agric. Exp. Stat. Bull. 351

Nelson, T.C. (1928) Relation of spawning of the oyster to temperature. Ecology. 9, 145-154

Panikkar, N.K. & Aiyar, R.G. (1939) Observations on breeding in brackish water animals of Madras. Proc. Indian Acad. Sci. 9B, 343-364

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in the Madras Harbour. Proc. Indian Acad. Sci. 15(1)B, 1-42

Prytherch, H.F. (1929) Investigations of the physical conditions controlling spawning of oysters and the occurrence, distribution and setting of the oyster larvae in Milford Harbour, Connecticut Bull. U.S. Bur. Fish. 44, 429-503

Prytherch, H.F. (1934) The role of copper in the setting, metamorphosis of the oyster. Ostrea virginica. Ecol. monogr. 4, 49-107

Rao, K.V. (1951) Observations on the probable effects of salinity on the spawning,development and setting of the Indian backwater oyster Ostrea madrasensis (Preston) Proc. Indian Acad. Sci. 33B, 231-256

Rao, D.S.K. & Menon, N.R. (1978) Settlement characteristics on different substrata by three commercially important bivalves in Mangalore waters, Arabian Sea. Int. Rev. Ges. Hydrobiol. 64

Rao, K.V. & Nayar, K.N. (1956) Rate of growth in spat and yearlings of the Indian backwater oyster Ostrea madrasensis (Preston). Indian J. Fish. 3(2), 231-260

Stafford, J. (1913) The Canadian oyster, its development, environment and culture. Comm. of Conservation, Canada, Ottawa. 159

---

* Not consulted the original

CHAPTER 4

SHELL DIMENSIONS AND THEIR INTER-RELATIONS IN *C. MADRASENSIS*

CHAPTER 4

SHELL DIMENSIONS AND THEIR INTER-RELATIONS IN C. MADRASENSIS

4.1. Introduction

Shell dimensions and their inter-relation in bivalve molluscs have been reported by several workers (Weymouth, 1923; Wilton & Wilton, 1929; NewCombe, 1935, 1936, 1950; Kellog, 1903; Mossop, 1922; Orton, 1926b; Stephen, 1928, 1929, 1932; Quayle, 1952; Ford, 1925; Winckworth, 1931; Paul, 1942; Rao, 1951; Abraham, 1953; Gokhale et al. 1954; Herdman, 1903; Malpas, 1933; Galtsoff, 1931 and Hamai, 1934, 1934a, 1935, 1935a). Shell growth is undoubtedly correlated with the growth of the soft tissues in bivalve molluscs. Studies on shell dimensions of oysters are very important in the sense that it is essential to determine the optimum marketable size of oysters.

Growth in bivalve molluscs is influenced by several factors of the environment such as food (Needler, 1941; Nelson, 1941, 1947; Ranson, 1949b; Loosanoff & Engle, 1947), density of population (Korringa, 1947; Hopkins, 1946; Imai et al. (1951). nutrients (Lambert, 1950; Rochford, 1951), spawning (Gunter, 1942; Needler, 1941; Ranson, 1949b), salinity (Halewyck & Leloup, 1951; Hamai, 1935), temperature (Medcoff & Needler, 1941; Hamai, 1935), nature of the substratum (Durve & Dharmaraja, 1965; Orton, 1926b), depth (Bae & Bae, 1972; Holme, 1961), tides (Fox & Coe, 1943; Dame, 1972a) and crowding (Tanita & Kikuchi, 1957).

Differences in the growth of widely separated population of the clam _Venus mercenaria_ of the Atlantic coast of the United States were noticed by NewCome _et al_. (1938) which they ascribed to differences in the environment. The relation between the weight, volume and linear dimensions in _Meretrix meretrix_, the local variations in the shells of the same species with reference to growth, and growth in relation to seasonal variations of the environment were studied by Hamai (1934, 1934a, 1935 and 1935a). He showed that the growth of shell in _Meretrix meretrix_ from different localities is influenced by the nature of the substrata, temperature, salinity and other parameters of water. Durve & Dharmaraja (1965) studied the dimensional relationship in the clam _Meretrix casta_ (Chemnitz) collected from two different localities and the relation of depth, height and weight on width were worked out by employing the technique of analysis of covariance. The differences in the morphometry noticed were due to different environmental conditions prevailing in the locality. Nayar (1955) made a detailed study of the length-weight, length-breadth and length-thickness relationships in the clam *Donax* (*Latona*) *cuneatus* Linnaeus and observed proportional variation of length in all size groups indicating that the general form is more or less the same throughout its life. Changes in the ratio of dimensional relationship at definite stages of life in *Tapes japonica* were noticed by Ohba (1959). Mason (1957) observed single allometric relationship in length-breadth and length-thickness relationship in *Pecten maximus*. Noteworthy publications on the morphometry of clams are those of Pohlo (1964), Hanoka & Shimadzu (1949) and Kristensen (1957). Shafee (1976) studied the various allometric relationship in the intertidal green mussel *Perna viridis* Linnaeus from the Ennur Backwaters, Madras. Changes in shell dimensions in *Mya arenaria* at different stages of growth have been demonstrated by Swan (1952). The structure and energy flow of a mussel population in Georgia salt marsh were examined by Kuenzler (1961). Galtsoff (1931) attributed differences in growth ratios of the pearl oyster *Pinctada* sp. to differences in its origin.

Studies pertaining to the morphometry of shells in oysters are also not few. As in the case of clams, several authors observed variations in shell dimensions owing to differences in habitats, environment, tides, depth, overcrowding etc. NewCombe (1950) ascribed differences in habitats of *Crassostrea virginica* for the considerable variations noticed in shell dimensions. Dame (1972) working on the various allometric relationships in oysters of the same species inhabiting inter-tidal and sub-tidal regions of North America, noticed variations in shell dimensions. Thomson (1969) working on three species of oysters, namely, Crassostrea commercialis, C. gigas and Ostrea angasi set out in adjacent compartments on wire trays in Pittwater, Tasmania noticed much less variations in shell dimensions and opined that even though shell dimensions in oysters are highly variable, it becomes much less when grown in uniform conditions with ample space. Recently Lee & Yoo (1975) analysed morphometric variations in shell dimensions in Crassostrea gigas at Gajado oyster farm. From Bombay waters, Durve & Shrikhande (1976) reported the relation between the area of the oyster shell and its dimensions and pointed out that from the height and length of shell, its area can be determined in Crassostrea gryphoides. They employed multiple linear regression technique in their study and arrived at mathematical relations between shell length, shell height and shell area.

The environment plays a major role in the growth of bivalves. Wave action, current velocity, nature of the substrata etc affects the pattern of shell growth as demonstrated by Wilton & Wilton (1929), Hamai (1934a, 1935, 1935a), Moore (1936), NewCombe (1935), NewCombe et al. (1938), Swan (1953), Korringa (1952), Hanso (1958) and Durve & Dharmaraja (1965). Mode of habits are also known to influence the morphometry of shells (Kristensen, 1957; Pohlo, 1964; Durve & Dharmaraja, 1965; Kuenzler, 1961; Shafee, 1976; Lee & Yoo, 1975). Orton (1936) observed considerable variation in length-width ratio in the oyster Ostrea angulata growing on soft and hard bottoms and the same phenomena was observed by Gunter (1938) also. The shell height-length ratio was observed to decrease with depth in Venurupis rhomboides (Holme, 1961). Tanita & Kikuchi (1957) noticed in Pinctada martensii a decrease in length-width ratio of shell owing to over-crowding. In Mytilus californianus, Fox & Coe (1943) observed narrow and thin shells in those forms occurring below low water level than in those found at the inter-tidal zones. Joseph (1979) observed only less gain in shell depth in spats.

Animals exhibit isometric and allometric growth. In the case of isometric growth the functional regression value, b would be 3 and this would characterise an unchanging body form and unchanging specific gravity, even though many species show changes in weight consequent to spawning, stomach contents etc, However, in the case of certain species, the b values appear to be greater or less than 3, a condition described as allometric growth (Ricker, 1975). The growth particularly in molluscs is usually reflected in shell characteristics. The allometric growth recognised by Huxley & Teissier (1936) has been demonstrated by several workers in many animals (Needham, 1942; Teissier, 1960). In some bivalve molluscs, allometry characterised by variations in the ratio of shell dimensions have been demonstrated more particularly during definite stages in cases such as Mya arenaria (Swan, 1952), Tapes japonica (Ohba, 1959), Meretrix meretrix (Hamai, 1936), Meretrix casta (Durve & Dharmaraja, 1965) and Cardium edule (Kristensen, 1957).

Thus a review of literature on the dimensional relationship of shells in bivalves more particularly in oysters shows that only very little work has been carried out on this important aspect of bivalve morphometry from Indian waters. Works pertaining to this aspect from Indian waters are those of Paul (1942), Rao & Nayar (1956), Durve & Shrikande (1976) and Durve & Dharmaraja (1965). No published data on oysters from Cochin Backwaters are available and hence a detailed study on this aspect to establish the relations between shell dimensions have been carried out.

4.2. Materials and Methods

For determining height-length and height-depth relationships, morphometric data of oysters ranging from 0.2 to 16.9 cm in height were employed. 'Height' is the maximum distance recorded from hinge to the opposite side of the shell, 'length' the greatest dimension of the anterio-posterior axis and 'depth' is the maximum distance between the outer sides of the two shells at a point where the axes of the other two dimensions crossed (Galtsoff, 1964). Random samples of wild oysters were collected from the shipping channel, near bar-mouth of Cochin Backwaters during different months and a total of 1195 oysters of different sizes were used in the morphometric studies.

4.3. Results

Height and length were plotted on a graph with length on abscissa and height on ordinate in the form of a scatter graph (Fig.4.1). The plot of height against length showed an exponential trend and a relationship of the form $H = AL^B$ was found to be appropriate. On taking logarithm, this gave a linear relationship of the form $Y = a+bX$, where Y is $\log H$, $X = \log L$, $a = \log A$ and $b = B$.

The plot (Fig.4.1) showed larger deviations in height for longer oysters. For oysters with height below 3.5 cm, the height and length tends to approximate. However, the ratio change and larger deviations were observed for oysters above 8 cm in height. Therefore, possibilities for three different relationships between height and length were examined. It was found possible and three different equations were fitted, one for oysters of height 3.5 cm and below, the second for those between 3.5 to 8 cm in height and the third for those above 8.0 cm in height. The three equations in the logarthmic scale with standard error (SE) of regression coefficients and correlation coefficients are presented in Table 4.1. The corrected

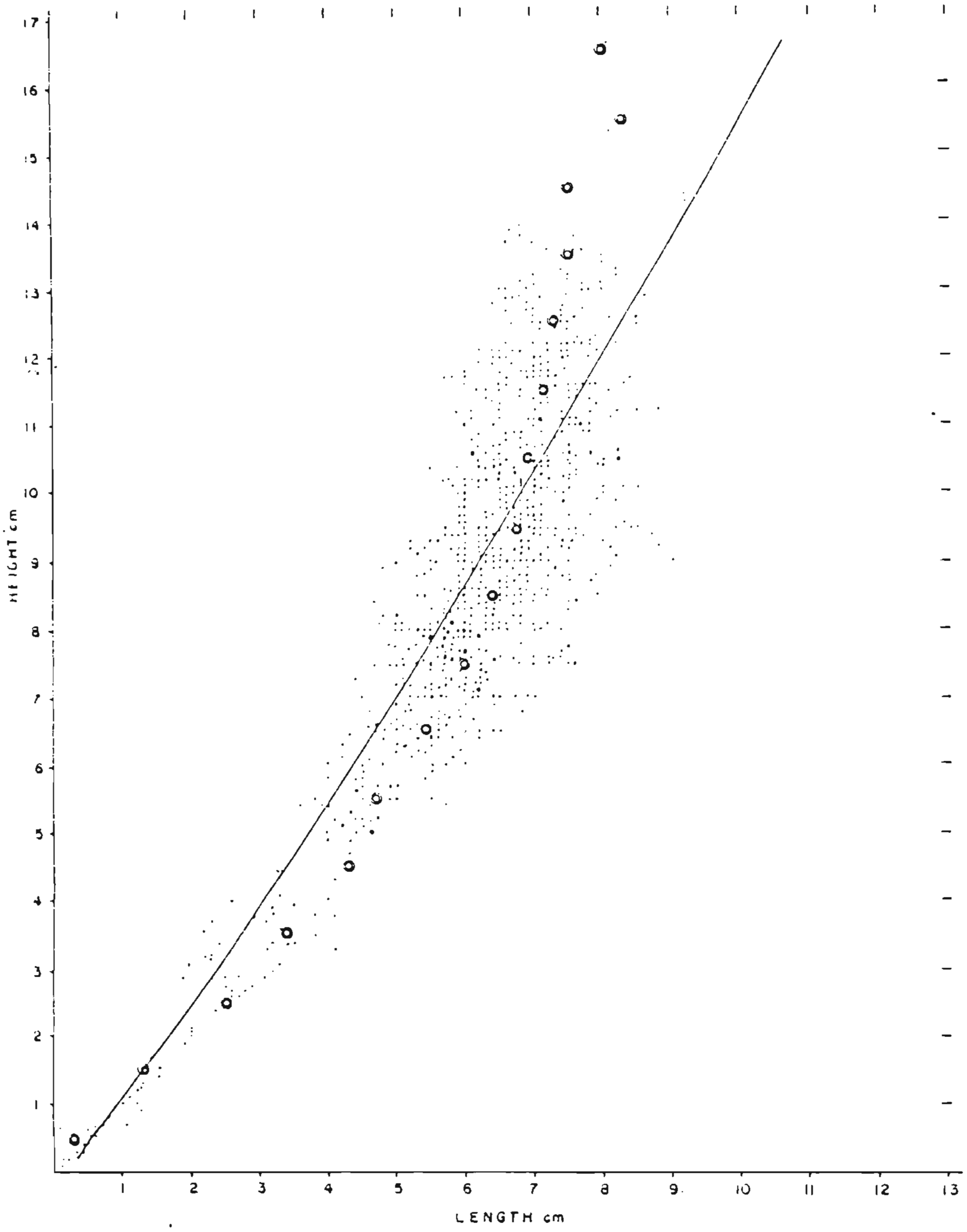


Fig. 4.1 HEIGHT - LENGTH RELATIONSHIP OF C.MADRASENSIS. CIRCLES INDICATE THE MEAN VALUES OF LENGTH FOR THE DIFFERENT SIZE GROUPS IN HEIGHT

sum of squares, cross products and deviation from regression for the three groups are given in Table 4.2.

Table 4.1 Regression lines of log height on log length

Group	Regression equation	SE of b	r
Oysters with shell height below 3.5 cm (Group 1)	$Y=0.01378+0.9866X$	0.03320	0.9318
Oysters with shell height 3.5 to 8 cm (Group 2)	$Y=0.4028+0.5712X$	0.02313	0.6938
Oysters with shell height above 8 cm (Group 3)	$Y=0.8675+0.1669X$	0.06220	0.0965

The residual variance were observed to be heterogeneous. This was further tested by Bartlett's test of homogeneity of variance following Snedecor & Cochran (1968). The computations for the test are furnished in Table 4.3.

To determine the height-depth relation, height and depth were plotted on a graph with depth on abscissa and height on ordinates. The plot of height against depth (Fig.4.2) showed an exponential trend and a relationship of the form $H = AD^B$ was found to be appropriate. On taking logarithm, this gave a linear relationship of the form $Y = a+b_z$, where $Y = \log H$, $z = \log D$, $a = \log A$ and $b = B$. The plot (Fig.4.2) showed larger deviations in height for oyster with greater depth. As done in the case of the relationship of height and length in oysters, the

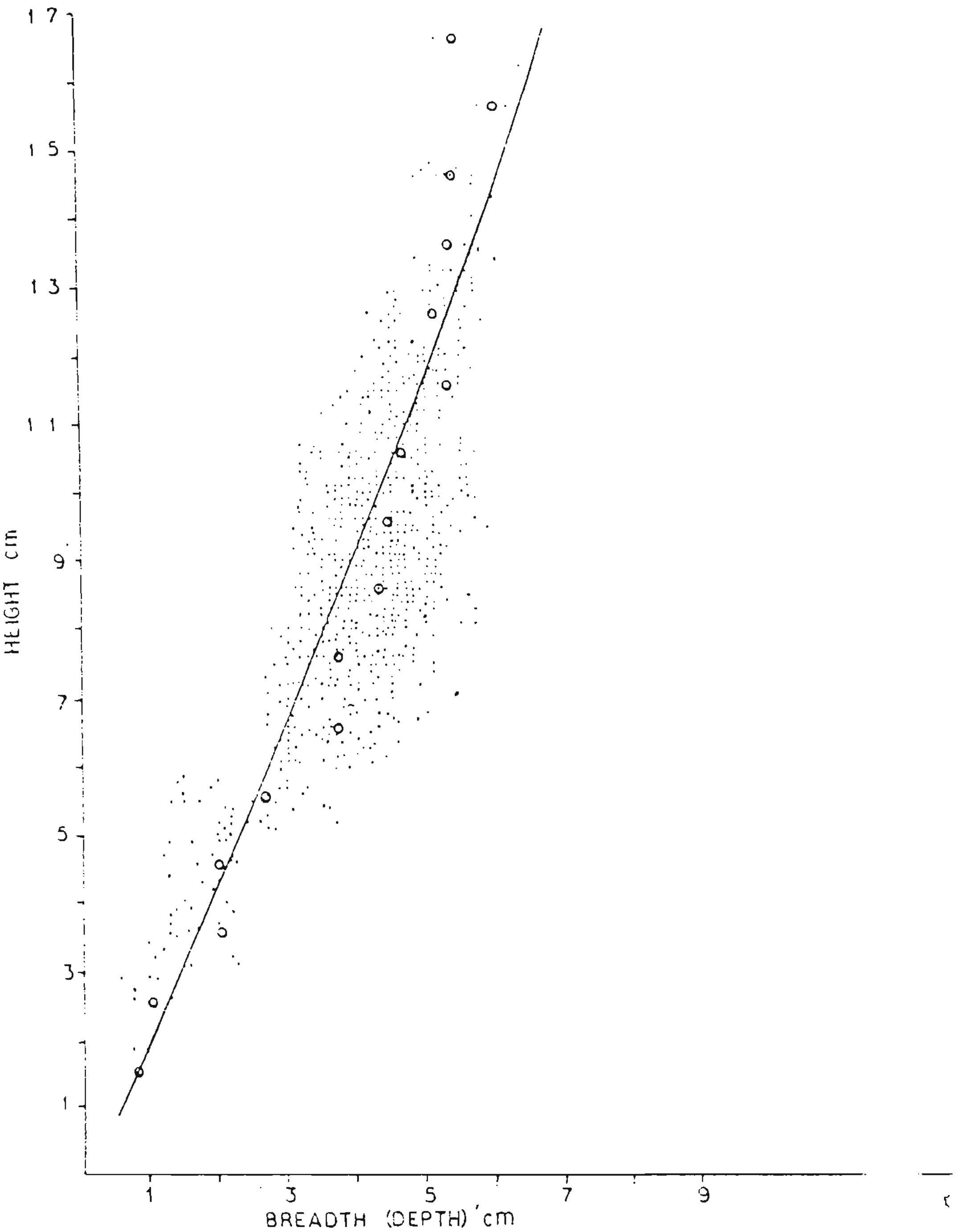


Fig. 4.2. HEIGHT-DEPTH (BREADTH) RELATIONSHIP IN C. MADRASENSIS. CIRCLES INDICATE THE MEAN VALUES OF DEPTH FOR THE DIFFERENT SIZE GROUPS IN HEIGHT

Table 4.2 Analysis of covriance of log height on log length

	dt	$\sum x^2$	$\sum xy$	$\sum y^2$	Regression coefficient	Deviation from regression df	ss	ms
Group 1	135	22.1273	21.8303	24.8054	0.9318	134	3.2681	0.024389
Group 2	291	7.8964	4.5103	3.8009	0.5712	290	1.2250	0.004224
Group 3	766	2.1136	0.3527	6.3153	0.1669	765	6.2564	0.008178

Table 4.3 Bartlett's test of homogeneity of variance

Group	Sum of squares $d^2. x$ or $(f_i s_i^2)$	Degree of freedom	Mean squares $s^2 y. x$ or (s_i^2)	log s_i^2	f_i logsi^2	Reciprocals $(1/f_i)$
1	3.2681	134	0.024389	-1.6128	-216.1152	0.007463
2	1.2250	290	0.004224	-2.3743	-668.5470	0.003448
3	6.2564	765	0.008178	-2.0873	-1586.8250	0.001307
a=3	10.7495	1189			-2451.4872	-0.004482

$$\bar{s}^2 = \Sigma f_i s_i^2 / \Sigma f_i = \frac{10.74951}{1189} = 0.009041$$

$$(\Sigma f_i) \log \bar{s}^2 = (1198)\ (-2.04378) = 2430.0544$$

$$M = 2.3026 \left[(\Sigma f_i) \log \bar{s}^2 - \Sigma f_i \log s_i^2 \right]$$

$$= 118.4292$$

$$C = 1 + \frac{1}{3 \times 2} \times 0.01158$$

$$\chi^2 = M/C = \frac{118.4292}{1.0019} = 118.2046$$

(Highly significant)

$$df = (a-1) = 2$$

$$P < 0.001$$

relationship of height and depth was worked out for the groups with height above 8 cm and below 8 cm. The corrected sum of squares, sums of cross products and deviation from regression for the two groups are given in Table 4.4.

Table 4.4 Analysis of covariance of log height on log length

	df	Σx^2	Σxy	Σy^2	Regression coefficient	Deviation from regression df	ss	ms
Group 1 (Height 8 cm and below)	291	9.8646	5.3064	3.8009	0.5379	290	0.9464	0.003263
Group 2 (Height 8 cm and above)	766	3.6912	1.4529	6.3153	0.3936	765	5.7435	0.007508

Residual variances were observed to be heterogeneous. The F-test for equality of variances showed that the variances were significantly different (F = 2.30, df = 766, 291).

4.4. Discussion

4.4.1. Height-length relationship

Several workers have noticed pronounced fluctuation in the shape of oyster shells (Yonge, 1960). The nature of the substrata, density of population (over-crowding), waves, currents, depth, salinity and availability of food are all known to influence the growth pattern of bivalve molluscs including oysters. (Korringa, 1952; Wilton & Wilton, 1929; Hamai, 1934, 1934a, 1935 and 1935a). Shell growth is correlated with the growth of tissues of the oyster. NewCombe (1950) analysed certain dimensional relationships of the Virginia oyster, Crassostrea virginica. Difference in the ratios, namely, length to breadth were observed by him. Rao & Nayar (1956) while studying the rate of growth in the Indian backwater oyster Crassostrea madrasensis from Adayar Estuary at Madras, observed the relationship of heightwidth (=height-length) in spat and yearlings. They observed deviations of the actual values from the mean values consequent on the increase in the size of the oysters. Upto 25 mm size groups, height was the same as that of width, resulting in spats of orbicular shape. However, in size groups of 35-55 mm, width was less than height resulting in oysters of oval shape. In the size range 65 mm and above, the animals were distinctly elongate, the width approximating to about three fourth of the height. A similar observation was noticed in this study also, even though the size group in which the deviation of actual values from the mean, resulting in the change of shape was different from that observed by Rao & Nayar (1956). In the present study, for oysters with less than 3.5 cm height approximately, length was found to be more or less the same as that of height. Deviation in length was more pronounced in larger oysters of 8 cm and above in height. It was possible to fit three regression equations for the three groups of oysters as shown in Table 4.1. It is obvious from a glance of Table 4.1, that the regression coefficients where significantly different from zero for all the three groups. The small value of the correlation coefficient 'r' for group 3 (0.0965) can be reasonably attributed to larger variations in length for a given height.

The residual variations were observed to be heterogeneous. This was further tested by Bartlett's test of homogeneity of variance (Table 4.3). The test showed that the residual variances are highly heterogeneous, χ^2 (Chi-square) being significant with $P < 0.001$. So there was no need to analyse further; the three groups were represented by three different equations. The equations to the three curves are,

1. $H = 1.0322\ L^{0.9866}$
2. $H = 2.5283\ L^{0.5712}$
3. $H = 7.3704\ L^{0.1669}$

As the standard error of b was found to be larger for group 3, equation 3 could not be used for prediction of average height against a given length. Rao & Nayar (1956) also observed deviation in height for larger oysters. Following them, mean values were calculated for members within size group of 1 cm class interval as given in Table 4.5.

As is evident from Table 4.5, upto 3.5 cm height, height and breadth were found to be almost equal, showing orbicular shape and this is in agreement to what has been observed by Rao & Nayar (1956). As the increase in height is faster compared to the increase in length (Fig.4.1), the oysters are more or less oval in shape in the height range 3.5 to 8 cm. Above 8 cm, they become further elongated in shape.

As the mean values provide a smooth curve to read the approximate height or length an oyster may attain when either of the measurements is known (Rao & Nayar, 1956), a curve was fitted to the mean values given in Table 4.5. The equation in terms of the logarithm worked out to, $Y = 0.07229+1.1156\ X$. The regression coefficient was found to be highly significant. The correlation

Table 4.5 Mean values of length for the various height groups

Class interval cm	Midpoint	Number	Average length cm
0- 1	0.5	108	0.34
1.1- 2	1.5	17	1.32
2.1- 3	2.5	11	2.59
3.1- 4	3.5	18	3.41
4.1- 5	4.5	17	4.25
5.1- 6	5.5	40	4.67
6.1- 7	6.5	80	5.44
7.1- 8	7.5	140	5.95
8.1- 9	8.5	189	6.37
9.1-10	9.5	171	6.69
10.1-11	10.5	124	6.89
11.1-12	11.5	100	7.06
12.1-13	12.5	63	7.34
13.1-14	13.5	33	7.51
14.1-15	14.5	28	7.58
15.1-16	15.5	8	8.26
16.1-17	16.5	9	8.03

coefficient was 0.9734. The standard error of b was 0.0677 and the 95% confidence interval for b was 0.9710 to 1.2600. The equation to the curve in the original scale worked out to $H = 1.1811\ L^{1.1156}$. This curve with the observed mean lengths (circled points in Fig.4.1) is shown in Fig.4.1. The analysis of height-length relationship shows that the variations in height are not fully explained by variations in length, especially for large sized oysters. This evidently suggests the probable influence of other factors operating or influencing the shell growth in oysters.

The height-length relation in Crassostrea madrasensis from Cochin Backwaters shows a non-linear relationship with an index (B value) of 1.1156 for the grouped data. As the B value is not very much different from unity, a linear relationship also holds good ($H = -2.5424+ 2.0036\ L$). Several other workers also observed linear relationship between height and length in oysters of different species inhabiting other parts of the world. Thomson (1969) observed the relation $Y = 0.96X-1.01$, where Y is length and X is height in Crassostrea gigas of Tasmania. For Crassostrea commercialis, Thomson (1969) found the relation $Y = 0.65X-0.11$ and for Ostrea angasi $y = x$. In Crassostrea gigas, Bae & Bae (1972) found different height-length relations depending on the depth at which they are grown. Pronounced variation in height-length relationship in C. gigas even for small variations in depth was noticed by them. Apart from depth, the substrata on which oysters grow are also known to influence the height-width (= height-length) relation in O. angulata and C. virginica (Orton, 1936; Newcombe, 1950; Gunter, 1938). The ratio was found greater in oysters grown in soft bottoms rather than on hard substrata.

4.4.2. Height-depth relationship

To study the height-depth relation, measurements were plotted on a graph with depth on abscissa and height on ordinate (Fig.4.2). Height-depth relationship showed an exponential relation in the form of $H = AD^B$. As done in height-length relation, a curve ($H = AD^B$) was fitted to the mean values presented in Table 4.6. The equation in terms of log values worked out to $Y = 0.3059+1.0936Z$. The regression coefficient was found to be highly significant, with a correlation coefficient of 0.9775. The standard error of the regression coefficient (b) was 0.0631 and 95% confidence interval of b was 0.9583 to 1.2289. The equation in the original scale worked out to $H = 2.0225\ D^{1.0936}$. As the B values of 1.0936 for the grouped data is not very much different from unity, a linear relationship between height and depth also holds good ($H = -1.4618+2.7450\ D$). The above analysis of height-depth relationship shows that variations in height does not result in corresponding variation in depth, particularly in oysters with increased height.

Variation in shell depth consequent to increase in shell height was noticed in Tapes japonica by Ohba (1959). The relation of height to depth was not the same for the entire growth range as observed in the present study. Wilber & Owen (1964) also pointed out the same phenomena and opined that a single allometric relation is inappropriate for the entire growth range. Allometric relation of height-depth was observed in Mya arenaria by NewCombe & Kessler (1936), Donax cuneatus by Nayar (1955), Pecten maximus (Mason, 1957) and Donax faba (Alagarswami, 1966). Thomson (1969) observed a height-depth ratio of $y = 0.10+ 0.25 X$ in Crassostrea gigas, $y = 0.44+-0.11 x$ in Crassostrea commercialis and $y = 0.45+0.18x$ in Ostrea gigas, where y = depth and x = height. As observed by Rao & Nayar (1956), oysters vary a great deal in shape even among the members of the same species. Oysters are sedentary throughout their life and the substratum on which they settle after the free swimming larval life is of great importance (Galtsoff, 1964). Corresponding with the contour of the substrata, oysters assume flat or uneven shape. Over-crowding, results in a variety of shapes. As pointed out by Korringa (1952), salinity, velocity of water currents, wave action, depth and exposure all have an abiding influence in determining the shape of oyster shells.

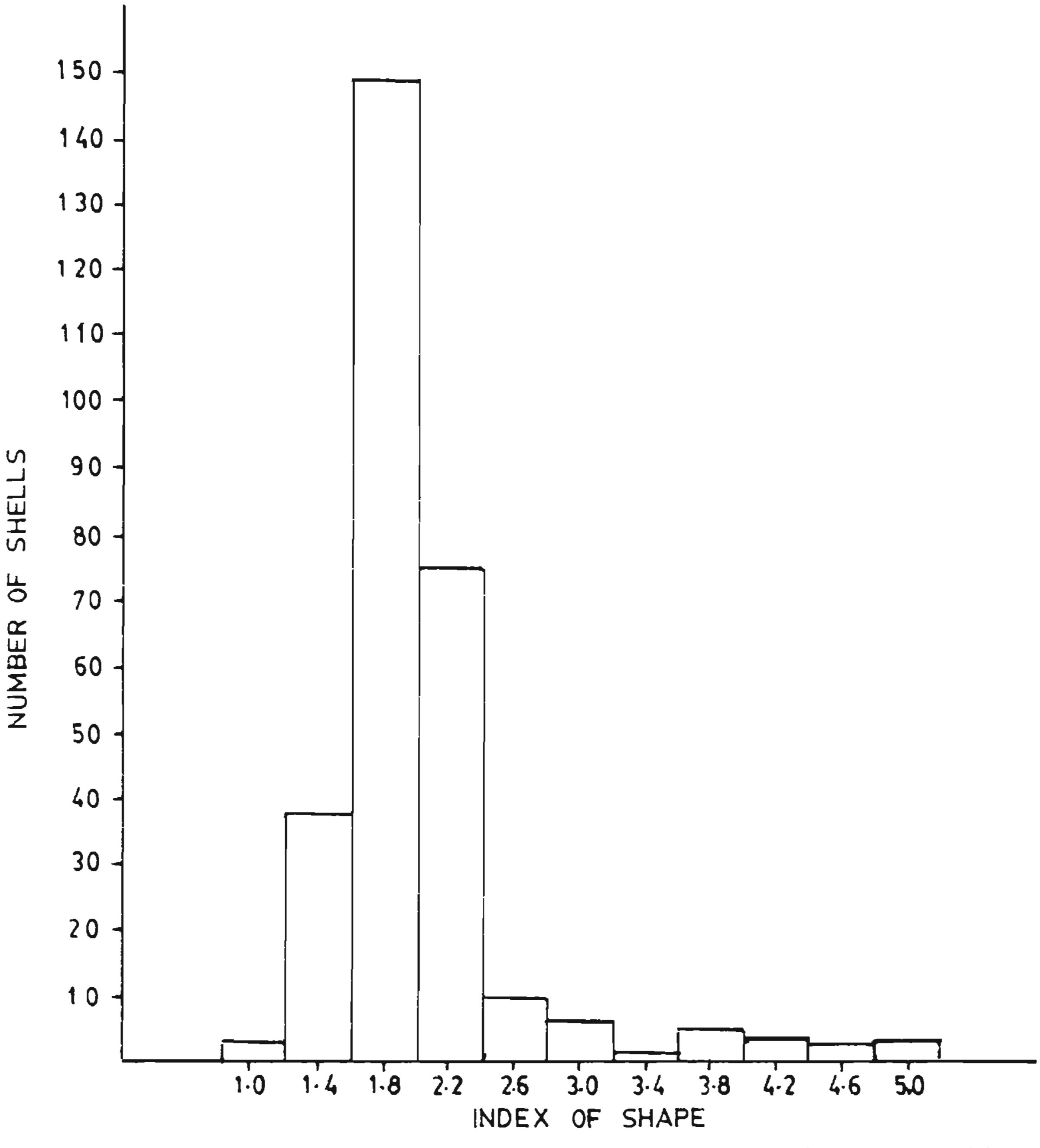


Fig.4·3. FREQUENCY DISTRIBUTION OF THE INDEX OF SHAPE IN SHELLS OF C.MADRASENSIS

Table 4.6 Mean values of depth for the various size (Height) group of oysters

Class interval cm	Mid point	Number	Average depth cm
1.1- 2	1.5	1	0.80
2.1- 3	2.5	6	0.95
3.1- 4	3.5	24	1.97
4.1- 5	4.5	20	1.95
5.1- 6	5.5	44	2.63
6.1- 7	6.5	88	3.67
7.1- 8	7.5	151	3.70
8.1- 9	8.5	194	4.26
9.1-10	9.5	172	4.42
10.1-11	10.5	123	4.59
11.1-12	11.5	101	4.83
12.1-13	12.5	64	5.06
13.1-14	13.5	32	5.30
14.1-15	14.5	28	5.38
15.1-16	15.5	7	6.11
16.1-17	16.5	10	5.36

As pointed by Lison (quoted by Galtsoff, 1964) oyster shell cannot be expressed in precise geometrical terms because of its variability. The index of shape determined as a ratio of the sum of height and width to its length $\left(\frac{\text{height+width}}{\text{length}}\right)$ by Crozier (as quoted by Galtsoff, 1964) was also employed in this study. The frequency distribution of the index of shape is presented in Fig.4.3. The index varied from 1.05-5.23 indicating that increase in height and width are not directly proportional to the increase in length in *Crassostrea madrasensis* collected from wild population in the Cochin Harbour. Galtsoff (1964) also noticed that the index of shape in American oyster *Crassostrea virginica* as highly variable. For the entire range of distribution of *Crassostrea virginica* from Atlantic and Gulf States the index of shape varied between 0.5 to 1.3 (Galtsoff, 1964). The difference in index of shape was not very significant between the northern and southern oyster population in United States according to him.

4.5. References

Abraham, K.C. (1953) Observations on the biology of *Meretrix casta* (Chemnitz) *J. zool. Soc. India*, **5**, 163-190

Alagarswami, K. (1966) Studies on some aspects of biology of the wedge-clam *Donax fabra* (Gmelin) from Mandapam coast in the Gulf of Mannar. *J. mar. biol. Ass. (India)* **8**(1), 56-75

Bae, G.M. & Bae, P.A. (1972) Studies on suspended culture of oyster Crassostrea gigas in the Korean coastal waters. 1. On the growth of oyster in the growing area. Bull. Fish. Res. Dev. Agency, Pusan, 9:71-84

Dame, R.F. (1972) Comparison of various allometric relationship in inter-tidal and sub-tidal American oysters. Fish. Bull. 70, 1121-1126

Durve, V.S. & Dharmaraja, S.K. (1965) A study of the dimensional relationship in the clam Meretrix casta (Chemnitz) collected from two localities. J. mar. biol. Ass. India. 7(1), 69-71

Durve, V.S. & Shrikande, V.J. (1976) Shell area in relation to linear dimensions of the oyster Crassostrea gryphoides. Indian J. Fish. 23 (1&2), 261-262

Ford, E. (1925) On the growth of some lamellibranchs in relation to the food supply of fishes. J. mar. biol. Ass. U.K. 13, 531-559

Fox, D.L. & Coe, W.R. (1943) Biology of the California sea mussel (Mytilus californianus) ii. J. exp. Zool. 93, 205-250

Galtsoff, P.S. (1931) The weight-length relationship of the Hawaiian pearl oyster Pinctada sp. Am. Nat. 65, 423-433

Galtsoff, P.S. (1964) The American oyster *Crassostrea virginica* (Gmelin) *Fish. Bull. Fish & Wildlife Ser.* **64**, 1-480

Gokhale, S.V., Eswaran, C.R. & Narasimhan, R. (1954) Growth rate of the pearl oyster *Pinctada pinctada* in the Gulf of Kutch with a note on the pearl fishery of 1953. *J. Bombay nat. Hist. Soc.* **52**, 124-136

Gunter, G. (1938) Comments on the shape, growth and quality of the American oyster. *Science* (N.S), **88**, 546-547

Gunter, G. (1942) Seasonal condition of Texas oysters. *Proc. Tex. Acad. Sci.* **25**, 89-93

Halewyck, R. & Leloup, E. (1951) La situation de I'ostreiculture dans le Bassin de chasse d'ostende de 1939 & 1948 *Rapp. Cons. Explor Mer.* **128** (ii) 19

Hamai, I. (1934) Relation between the weight, volume and linear dimensions in *Meretrix meretrix* (L). *Sci. Rep. Tohoku Univ.* **4**(9), 205-212

Hamai, I. (1934a) On the local variations in the shells of *Meretrix meretrix* (L) with special reference to growth of organism. *Sci. Rep. Tohoku Univ.* **9**, 131

Hamai, I. (1935) On the growth of shell of *Meretrix meretrix*, especially with regard to periodicity of growth relatively to the seasonal variations in the environment. *Sci. Rep. Tohoku Univ. Fourth Ser.* **9**, 339-371

Hamai, I. (1935a) A study of one case in which different environmental conditions produce different types of *Meretrix meretrix*. *Sci. Rep. Tohoku Univ. Fourth Ser*. **10**, 485-498

Hamai, I. (1936) Relative growth in some bivalves. *Sci. Rep. Tohoku Univ. Fourth Ser*. **10**, 753-765

Hanoka, T. & Shimadzu, T. (1949) Studies on the morphometry and rate of growth in the clam *Mactra sulcataria* Reeve in Tokyo Bay. *Bull. Jap. Soc. Sci. Fish*. **15**, 311-317

Hanso, M. (1958) The shell variations during growth in the Mie pearl oysters and those transplanted from Nagasaki, Prefecture. *Bull. natn. Pearl Res. Lab*. **4**, 318-324

Herdman, W.A. (1903) Observations and experiments on the life history and habits of the pearl oyster. *Rep. Pearl oyster Fish*. *Gulf of Mannar. R. Soc. London*. **1**, 125-146

Holme, N.A. (1961) Shell form in *Venerupsis rhomboides*, *J. mar. biol. Ass. U.K*. **41**, 705-722

Hopkins, A.E. (1946) Observations of Japanese oyster culture in the State of Washington. *Conv. natn. shellfish. Ass. New York*. June 5-7, pp.8-11

Huxley, J.S. & Teissier, G. (1936) Terminology of relative growth. *Nature*, **137**, 780-781

Imai, T., Hatanaka, M., Sato, T. & Saki, S. (1951) Ecology of Mangoku - Ura inlet with special reference to the seed - oyster production. *Scient. Rep. Res. Inst. Tohoku Univ.* 1-2, 137-156

Joseph, M.M. (1979) Shell characteristics of the spat of the two species of oysters *Crassostrea madrasensis* (Preston) and *Crassostrea cucullata* (Born). *J. Bombay nat. Hist. Soc.* **75** (2), 519-523

*Kellog, J.L. (1903) Feeding habits and growth of *Venus mercenaria*. *Bull. N.Y. St. Mus.* No.71

*Korringa, P. (1947) Les Vicissitudes del Ostreiculture Hollandaise elucidees par la science Ostreicole moderne. *Ostreiculture cult Mar. Paris* **16**, 3-9

Korringa, P. (1952) Recent advances in oyster biology *Q. Rev. Biol.* **27** (3), 266-308

Kristensen, J. (1957) Differences in density and growth in a cockle population in the Dutch Wadden Sea. *Archs. neerl. Zool.* **12**, 351-453

Kuenzler, E.J. (1961) Structure and energy flow of a mussel population in a Georgia salt marsh. *Limnol. Oceanogr.* **6**, 191-204

*Lambert, L. (1950) L' application des engrais a l' Ostrei culture. *Peehe Marit.* **29**, 394-396

Lee, C.K. & Yoo, S.K. (1975) Growth of *Crassostrea gigas* (Thunberg) at oyster farm of Gajodo. *Bull. natn. Fish. Univ. Basan* (Nat. Sci.) **14** (2), 41-50

Loosanoff, V.L. & Engle, J.B. (1947) Effect of different concentrations of micro organisms on the feeding of oysters. (*O. virginica*). *U.S. Dept. of the Interior Fish and Wildlife Service, Fishery Bulletin*. **42**, 31-57

Malpas, A.H. (1933) Further observations on the age and growth rate of Ceylon pearl oyster *Margaritifera vulgaris* with special reference to oysters of Dornan's Muthuvarathu paar. *Ceylon J. Sci*. **5**(c), 21-48

Mason, J. (1957) Age and growth of scallop *Pecten maximus* (L) in Manx waters. *J. mar. biol. Ass. U.K*. **36**, 473-492

MedCof, J.C. & Needler, A.W.H. (1941) The influence of temperature and salinity on the condition of oysters (*Ostrea virginica*). *J. Fish. Res. Bd Can*. **5**, 253-257

Moore, H.B. (1936) The biology of *Purpurea lapillus*. 1. shell variation in relation to environment. *J. mar. biol. Ass. U.K*. **21**, 61-89

Mossop, B.K. (1922) The rate of growth of sea mussel *Mytilus edulis* L. at St. Andrews, N.B. Digby, N.S. and in Hudson Bay. *Trans. R. Can. Inst*. **14**, 13

Nayar, K.N. (1955) Studies on the growth of the Wedge clam *Donax* (*Latona*) *cuneatus* Linnaeus. *Indian J. Fish*. **2**(2), 325-348

Needham, J. (1942) *Biochemistry* and *Morphogenesis*. Cambridge University Press, London and New York

Needler, A.W.H. (1941) Oyster farming in Eastern Canada. *Bull. Fish. Res. Bd Can*. **60**, 1-83

Nelson, T.C. (1941) Oysters. "Science and land". *A. Rep. New Jers. agric. Exp. Stn. Rutgers Univ*. 1940-41, 108-110

Nelson, T.C. (1947) Some contributions from the land in determining conditions of life in the sea. *Ecol. Monogr*. **17**, 337-346

Newcombe, C.L. (1935) Growth of *Mya arenaria* L. in the Bay of Fundy region. *Can. J. Res*. **13** (Sec.D), 97-137

Newcombe, C.L. (1936) Validity of concentric rings of *Mya arenaria* L. for determining age. *Nature*. **137**,

Newcombe, C.L. (1950) An analysis of certain dimensional relationships of the virginia oyster *Crassostrea virginica* (Gmelin) *Amer. Nat*. **84**, 203-204

Newcombe, C.L. & Kessler, H. (1936) Variations in the growth indices of *Mya arenaria* L. on the Atlantic Coast of America. *Ecology*, **17**:429-443

Newcombe, C.L., Thompson, S.J. & Kessler, H. (1938) Variations in the growth indices of *Venus mercenaria* L from widely separated environment of the Atlantic coast. *Am. Nat*. **16**(1), 1-5

Ohba, S. (1959) Ecological studies in the natural population of a clam *Tapes japonica*, with special reference to seasonal variations in the size and structure of the population and to individual growth. *Biol. J. Okayama Univ.* **5**, 13-42

Orton, J.H. (1926b) On the rate of growth of Canadian edule P.1. Experimental observations. *J. mar. biol. Ass. U.K.* **14**, 239-279

Orton, J.H. (1936) Habit and shell shape in the Portuguese oyster, *Ostrea angulata*. *Nature*. **138**, 466-467

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in Madras Harbour. *Proc. Indian Acad. Sci.* **15**(1) B, 1-42

Pohlo, R.H. (1964) Ontogenetic changes of form and mode of life in *Tresus nuttalli* (*Bivalvia*: *Mactridae*). *Malacologia*. **1**(3), 321-330

Quayle, D.B. (1952) The rate of growth of *Venerupis pullastra* (Montagu) at Millport, Scotland, *Proc. R. Soc. Edinb.* **6413**, 384-406

Ranson, G. (1949b) Note sur trois especes Lamarckiennes d' ostreides. *Bull. Mus. Hist. nat. Paris*. **21**, 248-254

Rao, K.V. (1951) Studies on the growth of *Katelysia opima* (Gmelin) *Proc. Indo-Pacif. Fish. Coun. Sec*. ii, 94-102

Rao, K.V. & Nayar, K.V. (1956) Rate of growth in spat and yearlings of the Indian backwater oyster *Ostrea madrasensis* (Preston), *Indian J. Fish*. **3**, 231-260

Ricker, W.E. (1975) Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd Can*. **191**, p.209

Rochford, D.J. (1951) Studies in Australian estuarine hydrology. 1. Introductory and comparative features. *Aust. J. mar. Freswat. Res*. **2**, 1-116

Snedecor, G.W. & Cochran, W.G. (1968) *Statistical Methods* 6th edn, The Iowa State University Press, Iowa, U.S.A, 593 pp

Shafee, M.S. (1976) Studies on the various allometric relationship in the inter-tidal green mussel *Perna viridis* Linnaeus of Ennur Estuary, Madras. *Indian J. Fish*. **23** (1&2) 1-9

Stephen, A.C. (1928) Notes on the biology of *Tellina tenuis* de costa. *J. mar. biol. Ass. U.K*. **15**, 683-702

Stephen, A.C. (1929) Notes on the rate of growth of *Tellina tenuis* de costa. *J. mar. biol. Ass. U.K*. **16**, 117-129

Stephen, A.C. (1932) Notes on the biology of some lamellibranchs in the Clyde area. *J. mar. biol. Ass..U.K*. **18**, 51-68

Swan, E.F. (1952) Growth indices of the clam Mya arenaria. Ecology. 33, 365-374

Swan, E.F. (1953) The effect of substratum on the growth rate, shell weight and shape of Mya arenaria. 4th A. Conf. on clam Res. U.S. Fish Wildlife Serv. Boothbay Harbour, Maine, 43-46

Tanita, S. & Kikuchi, S. (1957) On the density effect of the raft cultured oysters. 1. The density effect within one plate. Bull. Tohoku Reg. Fish. Res. Lab. 9, 133-142

Teissier, G. (1960) Relative growth. In 'The Physiology of Crustacea' (Waterman, T.H. Ed.,) Vol.1, pp.537-560, Academic Press, New York

Thomson, J.M. (1969) A note on oyster dimension. Proc. Symp. Mollusca. mar. biol. Ass. India. p.ii, 436-438

Weymouth, F.W. (1923) The life history and growth of pismo clam (Tivela stultorum Mawne) Bull. Calif. Fish. Game, Fish. Bull. 7, 1-20

Wilber, K.M. & Oven, G. (1964) Growth. In "Physiology of Mollusca" vol.1. Wilber, K.M. & Yonge, C.M. (Eds.) Academic Press, New York, pp.211-242

Wilton, M.H. & Wilton, H.I. (1929) Conditions affecting the growth of the soft shell clam Mya arenaria L. Contr. Can. Biol. Fish. 4(6), 83-93

Winckworth, R. (1931) On the growth of _Paphia_ _undulata_ (_Veneridae_) _Proc. malac. Soc. Lond_. _19_, 171-174

Yonge, C.M. (1960) _Oysters_. Collins, London, 209 pp

---

*Not consulted the original

CHAPTER 5

RELATION BETWEEN WEIGHT AND LINEAR MEASUREMENTS OF SHELL IN C. MADRASENSIS

Page

CHAPTER 5

RELATION BETWEEN WEIGHT AND LINEAR MEASUREMENTS OF SHELL IN C. MADRASENSIS

5.1. Introduction

Several publications on the length-weight relationship in lamellibranchs are available. Newcombe & Kessler (1936) while studying the variations in the growth indices of the clam *Mya arenaria* (L), studied the length-weight relationship. The growth indices of the same clam was studied by Swan (1952). Notable works pertaining to this aspect in other species of clams are those of Hamai (1934) on the relationship of weight, volume and linear dimensions in *Meretrix meretrix*, studies on the morphometry and rate of growth in the clam *Mactra sulcataria* Reev in Tokyo Bay by Hanoka & Shimadzu (1949), and ecological studies in the natural population of the clam *Tapes japonica* with special reference to seasonal variations in the size and structure of the population and to individual growth by Ohba (1959).

From the Indian sub-continent, Nayar (1955) studied the growth of wedge clam *Donax* (*Latona*) *cuneatus* (L) which includes studies pertaining to length-weight relation also. He has computed the calculated weights from observed weights by applying the formula $W = AL^{\alpha}$ and found that $W = 0.00045\ L^{2.8079}$ or $\text{Log } W = -.05165+ 2.8079 \text{ Log } L$, where W and L were weight and length respectively. Other studies on length-weight relations in clams are those of Alagarswami (1966), Talikkedkar *et al.* (1976) in *Donax cuneatus* and Narasimham (1968) in *Anadara granosa*. On plotting observed and calculated weights against the respective lengths, Talikkhedkar *et al.* (1976) found clear agreement between observed and calculated weights. They employed the formula $W = aL^{b}$ to determine the calculated weights from observed weights for establishing the relationships. By using logarithms, the exponential relation was found to be $\text{Log } W = \text{Log } a+b \text{ Log } L$, where W and L are weight and length respectively and a and b are constants. They established the relation $W = 0.1352\ L^{3.1079}$ or $\text{Log } W = -0.8690+3.1079 \text{ Log } L$ for length and weight. However, Narasimham (1968) observed, two separate regression equations for expressing the length-weight relationship in 3-19 mm and 20-63 mm groups. He obtained the relation $Y = -3.7130+3.20.96\ X$ for the 3 to 19 mm group and $Y = -2.8732+2.6459\ X$ for the 20 to 63 mm group, where Y = log weight and X = log length.

Richards (1928) studied the growth in the green mussel *Mytilus californianus*. Comparative growth in two mussels, namely, *M. californianus* and *M. edulis* at

La Jolla, California and Woods Hole, Massachusetts respectively were also carried out by him subsequently (Richards, 1946). Other works pertaining to mussels are those of Fox & Coe (1943), Kuenzler (1961), Seed (1976) and Andreu (1968). Kuenzler (1961) observed in *Modiolus demissus* variation in length-weight slope consequent to sexual maturity. Andreu (1968) observed the relationship between length and gross weight in the Mediterranean mussel *Mytilus galloprovincialis* and expressed it by the equation, $W = 185.10^{-6} L^{2.6764}$.

In the Hawaiian pearl oyster *Pinctada* sp. the weight-length relationship was worked out by Galtsoff (1931). Alagaraja (1962) established a linear relation $W = a+bL$ between length and weight in pearl oysters of Krusadai Island, Gulf of Mannar. The linear relationship was statistically tested by him and found to be significantly different for each year age group. The equality of slopes was tested for the same oysters of particular year spats at different ages and found to be not different. The use of length-weight relationship in predicting pearl fishery has also been pointed out by Alagaraja (1962).

Studies on length-weight relationship in edible oysters are also not few. In the British oyster *Ostrea edulis*, Orton (1935) observed a length-weight relation, $W = 0.0404xL^{3.531}$. In Spain, Andreu (1968) noticed a length-weight relation $W = 487.10^{-6} L^{2.7365}$. The growth of oysters in the Galician waters of Spain is very high according to him. At the end of the second year, oysters were observed to reach a weight of 78 g (Andreu, 1969). Lee & Yoo (1975) reported a length-weight relation of $W = 0.0689\ H^{2.1963}$ for hardened oysters and $W = 0.1379\ H^{2.0603}$ for seed oysters in Korea. Hughes Games (1977) obtained a length-weight relation of $W = 2.75\ L^{2.34}$ for Crassostrea gigas and $W = 4.34\ L^{2.08}$ for the British oysters.

The foregoing review of literature shows that no study pertaining to the length-weight relation in edible oysters (Crassostrea madrasensis), more particularly from those inhabiting the Cochin Backwaters has been carried out. As weight is a power function of length and since length and other morphometric measurements are inter-related it is thought worthwhile to investigate the relation of weight not only to length but also to height and breadth.

5.2 Material and methods

930 wild oysters collected from the shipping channel near bar-mouth in the Cochin Harbour during the different months spread over a period of one year formed the material for the study. The oysters were thoroughly washed with the help of a brush to remove mud and other particulate material found attached to the shell. The fouling animals on the shells were also scrapped off. The height, length and depth were recorded as mentioned in Chapter 4. The whole weight of the oyster was taken and after this the

oysters were shucked open, the meat taken out from shell, and excess water from meat removed by keeping the meat in between the folds of filter paper and then weighed. The shells were also weighed separately. All the weighings were made in an Owa Labor, German, single pan electrical balance with an accurancy of 0.1 g.

5.3. Results

As the weight of the oyster depends on its volume, the appropriate procedure appeared to represent the weight as a function of length, height and breadth. To bring down to linear scale, logarithm of weight, length, height and breadth was taken. Representing logarithms of weight, length, height and breadth by V, X, Y and Z respectively, a multiple regression of V on X, Y, Z, namely,

$$\hat{V} = a+b_1X+b_2Y+b_3Z$$

was fitted. (Table 5.1)

When the variables were measured from their respective means, the above relation became,

$$\hat{V} = \bar{V}+b_1x+b_2y+b_3z$$

where $x = X-\bar{X}$, $y = Y-\bar{Y}$ and $z = Z-\bar{Z}$

Table 5.1 The sums, corrected sums of squares and cross products of height, length, breadth and weight

n	ΣV	ΣX	ΣY	ΣZ
931	803.9502	750.5771	904.3807	589.6504

Σv^2	Σx^2	Σy^2	Σz^2
29.75232	5.56049	10.19369	7.84403

Σxy	Σxz	Σxv	Σyz	Σyv	Σzv
5.04121	3.58044	7.24851	5.80447	11.55687	7.52180

By minimising $(v-\hat{v})^2$, the values of a, b_1, b_2 and b_3 were obtained (Snedecor & Cochran, 1968) as,

$a = \bar{V}-b_1\bar{X}-b_2\bar{Y}-b_3\bar{Z} = -0.4017$

$b_1= 0.4674$

$b_2= 0.8278$ and

$b_3= 0.1330$

Thus the fitted multiple regression became,

$V = 0.8635+0.4674x+0.8278y+0.1330y$ ---- (1)

or $V = -0.4017+0.46743X+0.8278Y+0.1330Z$ ---- (2)

Looking at the standard partial regression coefficient (Snedecor & Cochran, 1968), $B_1 = 0.2021$, $B_2 = 0.4845$ and $B_3 = 0.06825$, the relative importance of the variables on weight were found in the order: height, length and breadth.

The response lines of V on X when Y and Z were held fixed at their mean values; of V on Y, when X and Z were held fixed at their mean values; and of V on Z, when X and Y were held fixed at their mean values are shown in Fig.5.1. The t-tests for the significance of regression coefficients showed all the three coefficients to be significantly different from zero (Table 5.2). Thus all the three morphometric parameters, namely, height, length and breadth contributed to the weight of oysters. The relative importance of these three measurements as suggested by the standard partial regression coefficients is also evident from the t - values, the regression coefficients, corresponding to height and length being highly significant.

Table 5.2 t-test for the significance of regression coefficients

$b_1 = 0.4674$ $s(b_1) = 0.0759$ $t_1 = \frac{b_1}{s(b_1)} = 6.16^{***}$ $(P < 0.001)$

$b_2 = 0.8278$ $s(b_2) = 0.06193$ $t_2 = \frac{b_2}{s(b_2)} = 13.36^{***}$ $(P < 0.001)$

$b_3 = 0.1330$ $s(b_3) = 0.06240$ $t_3 = \frac{b_3}{s(b_3)} = 2.13^{*}$

The multiple correlation coefficient (R^2) is 0.4693 which is highly significant from the F-test,

$$F = \frac{R^2}{1-R^2} \times \frac{n-K-1}{K} \text{ with } K \text{ and } n-K-1$$

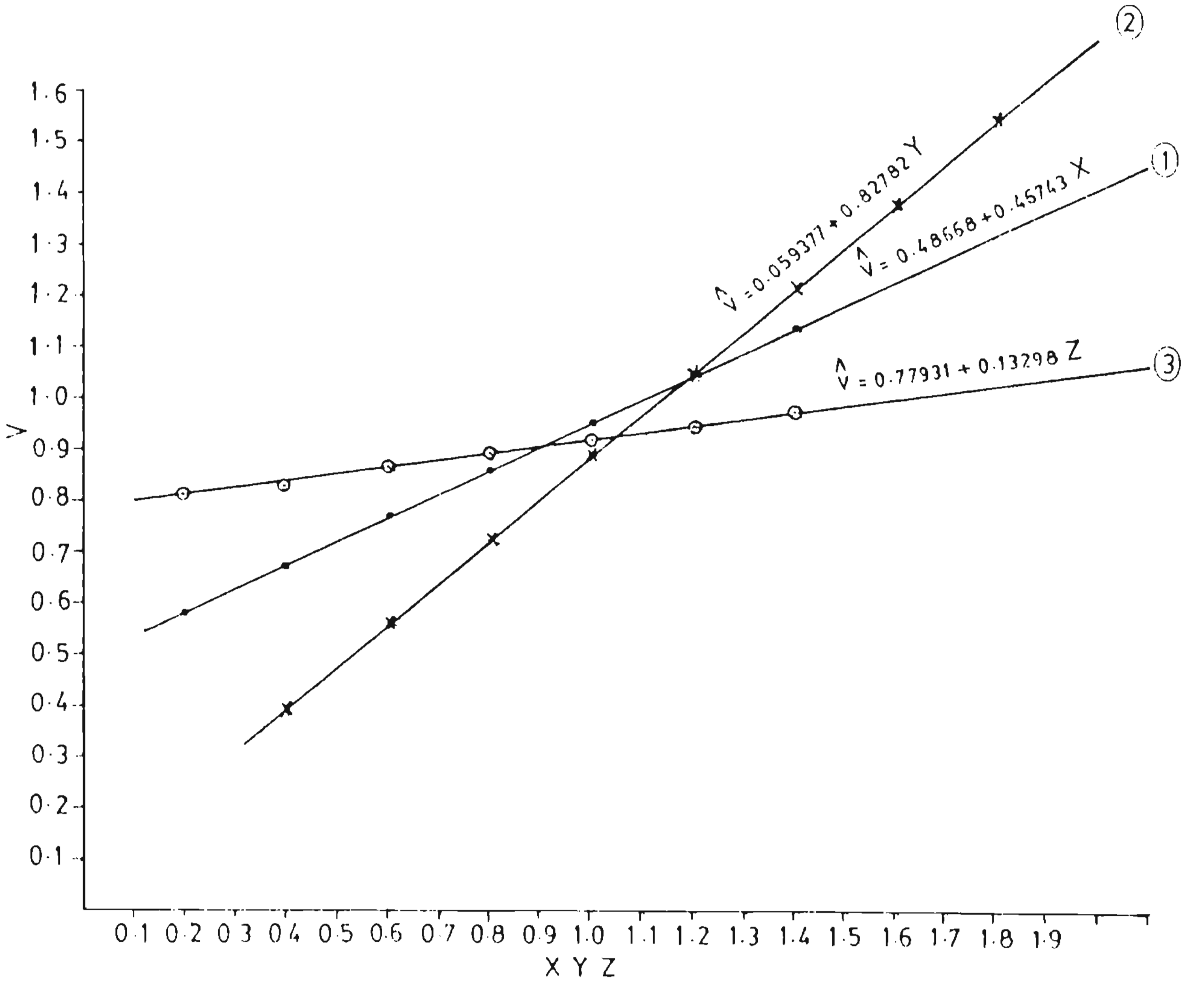


Fig. 5.1. THE RESPONSE LINES OF 'V' ON 'X' WHEN 'Y' AND 'Z' ARE FIXED AT THEIR MEAN VALUES ① OF 'V' ON 'Y' WHEN 'X' AND 'Z' ARE FIXED AT THEIR MEAN VALUES ② AND 'V' ON 'Z' WHEN 'X' AND 'Y' ARE FIXED AT THEIR MEAN VALUES ③

d.f. Here, n being 931 and K being 3, F = 273.28 with 3 and 927 d.f. which is highly significant. The prediction equation (2) can be used to estimate the meat weight (logarithm) for given dimensions of length, height and breadth (all in logarithms).

To represent weight W, in terms of height H, an exponential relation of the form,

$$W = AH^{B}$$

was considered, On taking logarithm, this transformed to,

$$\log W = a + b \log H,$$

where $a = \log A$ and $b = B$. By the method of least squares, a and b were estimated at $a = -0.1874$ and $b = 1.3033$. The correlation coefficient between log H and log W worked out to 0.5635, which was highly significant, Thus the linear relationship between log W and log H and therefore the exponential relationship between W and H is justified. The relationship in terms of logarithms worked out to,

$$\log w = -0.1874 + 1.3036 \log H$$

and in terms of original measurements to,

$$W = 0.6495\ H^{1.3036}$$

5.4. Discussion

Several workers on clams (Kristensen, 1957; Nayar, 1955; Alagarswami, 1966; Talikedkar et al. 1976; Narasimham, 1968), mussels (Richards, 1928, 1946; Seed, 1973; Fox & Coe, 1943), Pearl oysters (Alagaraja, 1962; Galtsoff, 1931), edible oysters (Orton, 1935; Andreu, 1968; Lee & Yoo, 1975; Hughes Games, 1977) have established length-weight relations. However, as pointed out by Lison (Quoted by Galtsoff, 1964) oyster shell cannot be expressed in precise geometrical terms owing to its variability. The index of shape of oyster shells computed in this study also showed a variation of 1.05 to 5.23 indicating that increase in height and width are not directly proportional to the increase in length (Chapter 4). Unlike in clams, oysters vary a great deal in shape even among members of the same species, the substratum, overcrowding, salinity, velocity of water currents, wave action, depth and exposure all contributing to this phenomenon. The standard partial regression coefficients obtained from the regression analysis of weight on length, height and breadth shows that weight is more influenced by height ($B_2 = 0.4845$), followed by length ($B_1 = 0.2021$) and breadth ($B_3 = 0.06825$) in their order of magnitude. This is also evidenced by the shape of the line 2 in Fig.5.1, obtained when the length and breadth were held constant in the multiple regression equation (2). The t-test for the significance of regression coefficients substantiated this and also showed that the contribution of length, height and breadth was significant on meat weight. The multiple regression coefficient (R^2) is 0.4693, which is also found to be highly significant by F-test. This indicated that the weight of the oyster meat is related not only to height but to length and breadth also. Krakatitsa & Patlaj (1975) found that in Ostrea edulis var. taurica, the total weight, shell weight and meat weight are related to height, length and thickness.

The regression equation worked out to study the relation of height (= Length, L in other studies) and weight of oysters in this study showed an exponential relation, $W = 0.6495\ H^{1.3036}$. However, Orton (1935) observed $W = 0.0404\ L^{3.531}$ and Andreu (1968) noticed $W = 187.10^{-6}\ L^{2.7365}$ in English Oyster Ostrea edulis at Britain and Spain respectively. But Hughes Games (1977) observed a relation $W = 2.75\ L^{2.34}$ in Crassostrea gigas at a sub-tropical pond in Israel and $W = 4.34\ L^{2.08}$ in Great Britain. King (1977) observed the relation $W = 0.005\ L^{2.152}$ in Crassostrea gigas grown in Australia. Compared to these studies the index B of the height-weight relation in Crassostrea madrasensis inhabiting Cochin Backwaters was found to be less being 1.3036. The smaller index B value obtained in this study shows that changes in length do not introduce appreciably larger changes in meat weight, contrary to what was observed in the studies cited above. The different B values obtained by several workers for the length-weight relationship show that these variations can be reasonably ascribed to changes in ecological conditions.

5.5. References

Alagaraja, K. (1962) Observations on the length-weight relationship of pearl oysters. J. mar. biol. Ass. India. 4, 198-205

Alagarswami, K. (1966) Studies on some aspects of biology of the wedge clam, Donax faba Gmelin from Mandapam coast in the Gulf of Mannar. J. mar. biol. Ass. India. 8(1), 56-75

Andreu, B. (1968) Fishery and culture of mussels and oysters in Spain. Proc. Symp. Mullusca. mar. biol. Ass. India. Part iii, 835-846

Fox, D.L. & Coe, W.R. (1943) Biology of the California sea mussel Mytilus californianus. J. exp. Zool. 93, 205-250

Galtsoff, P.S. (1931) The weight-length relationship of the Hawaiian pearl oyster Pinctada sp. Am. Nat. 65, 423-433

Hamai, I. (1934) Relation between the weight, volume and linear dimensions in Meretrix meretrix (L) Sci. Rep. Tohoku Univ. Ser. 4, 9:205-212

Hanoka, T. & Shimadzu, T. (1949) Studies on the morphometry and rate of growth in the clam Macta sulcataria Reeve in Tokyo Bay. Bull. Jap. Soc. Scient. Fish. 15, 311-317

Hughes-Games, W.L. (1977) Growing the Japanese oyster (*Crassostrea gigas*) in sub-tropical sea water fish ponds. 1. Growth rate, survival and quality index. *Aquaculture*, **11**, 217-229

King, M.G. (1977) Cultivation of the Pacific oyster (*Crassostrea gigas*) in a non-tidal hyper saline pond. *Aquaculture*, **11**, 123-136

Krakatitsa, T.F. & Patlaj, A.C. (1975) Svyaz' merzhdy vesom i linejnymi razmerami u Chernomorskikh Ustrits'. *Ivz. A.N.S.S.S.R*. (Biol) No.**3**, 428-438

Kristensen, I. (1957) Differences in density and growth in a cockle population in the Dutch Wadden Sea. *Arch. neerl. Zool*. **12**, 351-453

Kuenzler, E.J. (1961) Structure and energy flow of a mussel population in a Georgea salt marsh. *Limnol, Oceanogr*. **6**:191-204

Lee, C.K. & Yoo, S.K. (1975) Growth of *Crassostrea gigas* (Thunberg) at the oyster farm of Gajodo. *Bull. natn. Fish. Univ. Busan* (Nat Sci) **14**, 41-50

Narasimham, K.A. (1968) Studies on some aspects of biology and fishery of the cockle *Anadara granosa* (L) from Kakinada Bay. *Proc. Symp. Mullusca. mar. biol. Ass. India*. Part ii, 407-417

Nayar, K.N. (1955) Studies on the growth of the wedge clam *Donax* (Latona) *cuneatus* (L). *Indian J. Fish*. **2**(2), 325-348

Newcombe, C.L. & Kessler, H. (1936) Variation in the growth indices of *Mya arenaria* (L) on the Atlantic coast of North America. *Ecology*. **17**, 429-443

Ohba, S. (1959) Ecological studies in the natural population of a clam *Tapes japonica* with special reference to seasonal variations in the size and structure of the population and to individual growth. *Biol. J. Okayama Univ.* **5**, 13-42

Orton, J.H. (1935) Laws of shell-growth in English native oysters (*O. edulis*). *Nature*, **135**, 1-340

Richards, O.W. (1928) The growth of the mussel *Mytilus californianus*. *Nautilus*, **41**, 99-101

Richards, O.W. (1946) Comparative growth of *Mytilus californianus* at La Jolla, California and *Mytilus edulis* at Woods Hole, Massachusetts. *Ecology*, **27**, 370-372

Seed, R. (1973) Absolute and allometric growth in the mussel *Mytilus edulis* L. (Mollusca, bivalvia) *Proc. malac. Soc. Lond.* **40**, 343-357

Seed, R. (1976) Ecology. In "*Marine Mussels, Their Ecology and Physiology*" (Bayne, B.L. Ed.), Cambridge Univ. Press, pp.506

Snedecor, G.W. & Cochran, W.G. (1968) Statistical Methods. (6th Edn) Oxford and IBH Publishing Co., New Delhi, pp.593

Swan, E.F. (1952) Growth indices of the clam *Mya arenaria*. Ecology. 33, 365-374

Thalikhedkar, P.M., Mane, U.H. & Nagabhushanam, R. (1976) Growth rate of wedge clam *Donax cuneatus* at Miriya Bay, Ratnagiri. Indian J. Fish. 23:183-193

CHAPTER 6

CONDITION INDEX AND PERCENTAGE EDIBILITY OF *C. MADRASENSIS*

CHAPTER 6

CONDITION INDEX AND PERCENTAGE EDIBILITY OF *C. MADRASENSIS*

6.1. Introduction

Depending on physiological conditions, fluctuations in environmental factors and seasons, oysters show considerable variation in the quality of their meat. The quality of fatness or the physiological condition of oysters is determined by several methods. Oysters of good quality have been observed to contain large amounts of meat in relation to their total volume (Galtsoff, 1964). Dry weights, glycogen contents and total chemical analysis were employed by Coulson (1933), Humphrey (1941), Galtsoff *et al.* (1947), Jacobs (1951) and Frieger *et al.*(1958). These methods are time consuming and are not suitable when large number of oysters are to be examined. Condition index and percentage edibility determinations are objective methods employed by various workers for determining the quality when they had to deal with large number of oysters.

Some of the notable works on the nutritive value and quality of meat of oysters are those of Coulson (1933) from the North American coast, the biochemistry of the proximate constituents of oysters inhabiting Australian waters by Humphrey (1941) the influence of temperature and salinity on the condition of oysters by MedCof & Needler (1941), the ecological and physiological studies on the effect of sulphate pulp mill wastes on oysters in York river, Virginia by Galtsoff _et_ _al_. (1947), chemical analysis of oysters by Jacobs (1951), estimation of quality in mussels and oysters (Korringa, 1955), the seasonal variation of meat and glycogen content of seven populations of oysters by Walne (1970) and changes in the condition index and biochemical content of oysters under hatchery conditions by Gabbot & Walker (1971). These workers have employed either dry meat weight or shell cavity volume or the general biochemical composition to study the condition in bivalves.

Assessment of quality by objective methods such as estimation of condition index and percentage edibility have been employed by Odlaug (1946), Ingle (1949), Venkataraman & Chari (1951), Korringa (1955), Rao (1956), Baird (1958, 1966), Durve (1964), Durve & George (1973), Shafee (1976) and others.

The condition index in _C_. _virginica_ has been studied by Medcof & Needler (1941) employing the relation between dry meat weight and shell cavity volume. However, Odlaug (1946) used meat volume shell cavity volume relationships in _O_. _lurida_. The glycogen content in _C_. _virginica_ could be used to determine the index of condition according to

Galtsoff *et al*. (1947). However, Ingle (1949) attempted to correlate the values obtained from dry meat weights and glycogen contents in *C. virginica* and found that estimation of glycogen content as the most suitable method in determining condition index in oysters. Korringa (1955) employed the ratio of dry meat weight to shell contents as the index of condition. Baird (1958) has used a simple and quick method to evaluate the condition index. He suggested that the index of condition is the percentage of shell cavity occupied by the wet meat and is given by the ratio,

$$\frac{\text{Meat volume} \times 100}{\text{Shell cavity volume}}$$

Rao (1956) employed a relationship between meat weight and whole weight (Total weight) to determine the condition of *Crassostrea madrasensis* from Ennur, near Madras. He attributed the changes in the condition of oysters to gonadal and spawning activities. Durve (1964) used condition index and percentage edibility in *C. gryphoides* from the Kelwa Backwaters to determine their quality. He employed Bairds index of condition mentioned earlier (Baird, 1958). The percentage edibility was obtained by the ratio,

$$\frac{\text{Meat weight} \times 100}{\text{whole weight}}$$

He also ascribed fluctuation in condition index and percentage edibility to seasonal gonadal cycle of the oyster.

Studies on condition index in bivalve molluscs are also aimed to determine the physiological and ecological requirements in these animals. Dame (1971) studied the ecological energies of growth, respiration and assimilation in the American inter-tidal oyster C. virginica. The present study is aimed at collecting information on the condition index and percentage edibility with a view to assessing the quality of meat in C. madrasensis inhabiting the Cochin Backwaters.

6.2. Material and methods

For determining the index of condition and percentage edibility, monthly samples of oysters were collected from the feral population inhabiting the Cochin Backwaters. The oysters were washed in water with the help of a brush to remove the silt adhering to the shell. The fouling organisms found on the shell were scrapped off. Individual oysters were weighed separately in an Owa Labor, German single pan electrical balance correct to 0.1 g, determined the total volume and then shucked. The meat weight, shell weight, meat volume, and shell volume were also determined. Bairds' (1958) method was followed to determine the index of condition $\frac{\text{Meat volume (ml) x 100}}{\text{shell cavity volume (ml)}}$. An apparatus with a graduated side tube was used to determine the total volume, shell volume and meat volume (Displacement method). The sex of individual oysters was determined by examining a gonadal smear under the microscope. Percentage edibility was computed using the equation,

$$\frac{\text{Meat weight (g)}}{\text{whole weight (g)}} \times 100$$

A total of 1046 oysters were examined for determining the condition index and percentage edibility.

6.3. Results

Monthly variations in the index of condition values for the total population and sexwise for males, females and indeterminates from October 1981 to September 1982 are presented in Table 6.1. Fig.6.1 depicts the monthly variation in the average index of condition and Fig.6.2 represents the average monthly index of condition for males, females and indeterminates separately. As seen from Fig.6.1 and Table 6.1, the condition index attained peak values in October 1981 (49.31) for the total population. Considerable fall in the index was noticed in the subsequent months reaching the lowest in February and March 1982. From February onwards there was steady increase in the index of condition reaching the maximum again in August and September 1982. The same trend was exhibited by males, females and indeterminates when examined sexwise separately (Fig.6.2). After reaching the peak in September-October months, the average values of the index of condition declined and reached the minimum in February-March. Comparatively the values were found to be higher

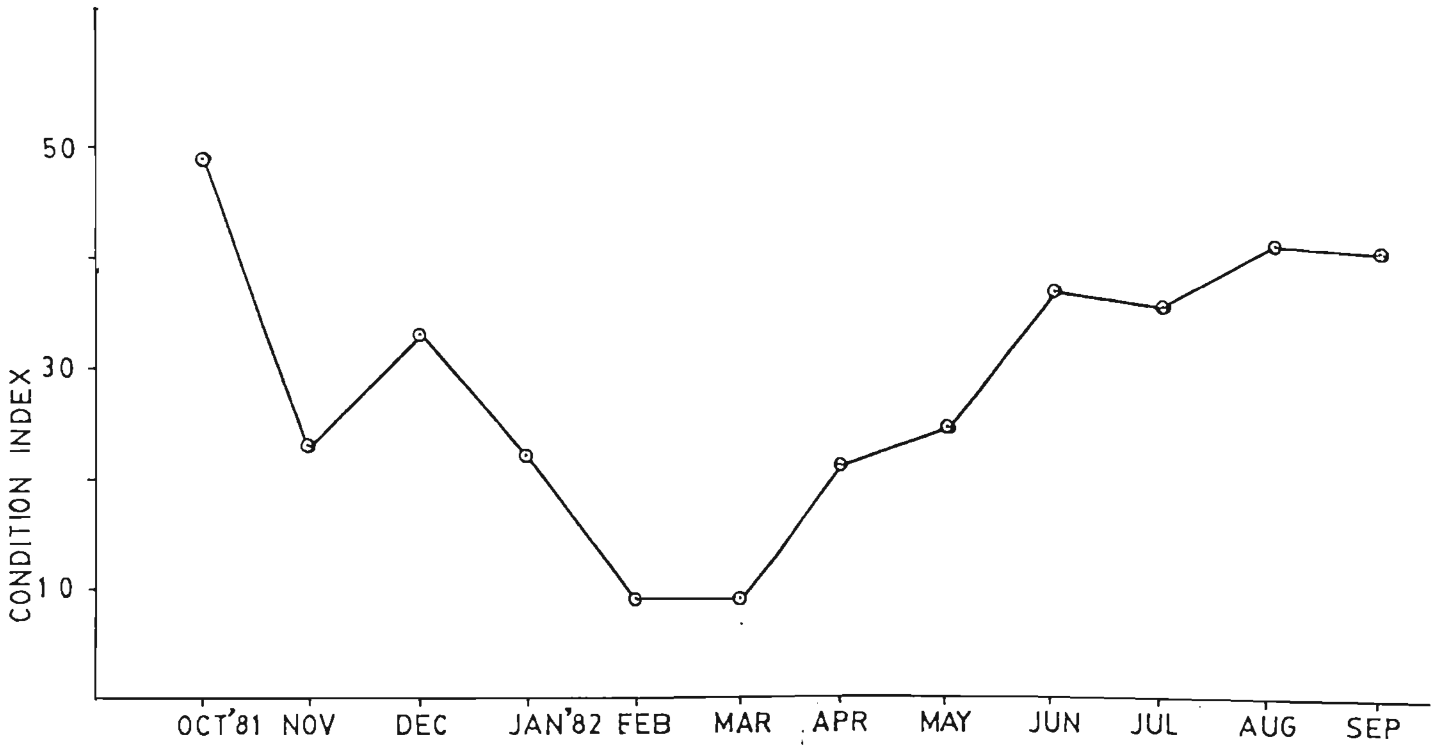


Fig. 6.1. MONTHLY VARIATIONS IN THE AVERAGE CONDITION INDEX OF *C. MADRASENSIS* DURING OCT. 1981 – SEP. 1982

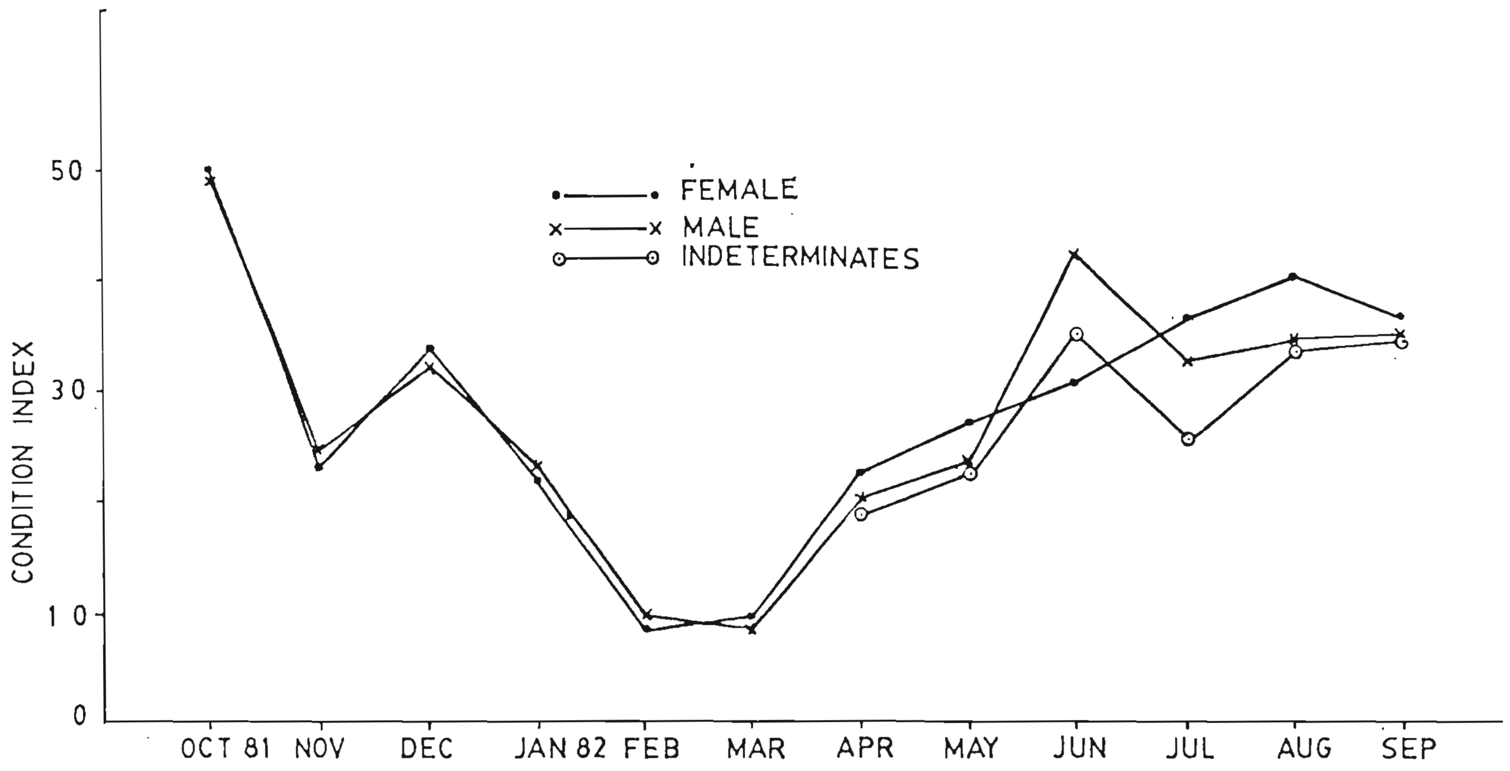


Fig. 6.2. THE MONTHLY VARIATIONS IN THE AVERAGE CONDITION INDEX OF C.MADRASENSIS MALE, FEMALE AND INDETERMINATE SEX DURING OCT. 1981 SEP. 1982

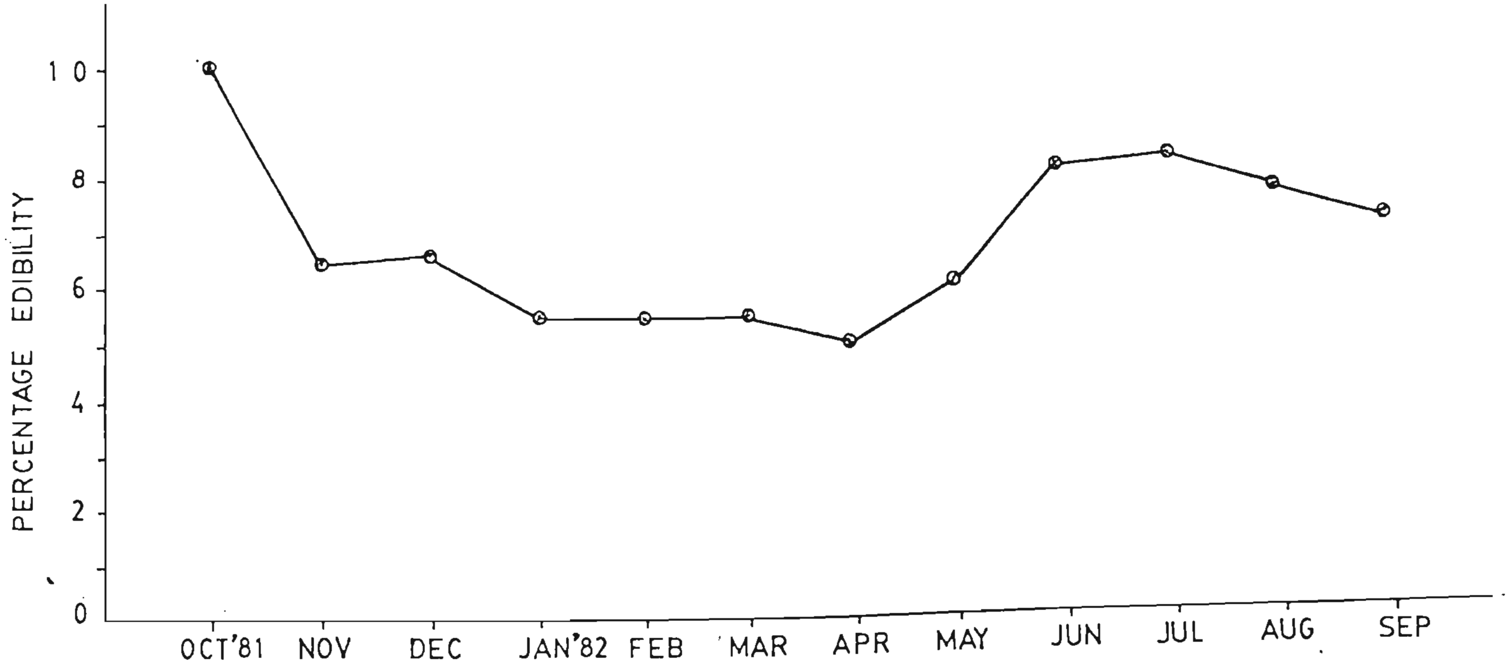


Fig. 6.3. MONTHLY VARIATIONS IN THE AVERAGE PERCENTAGE EDIBILITY OF *C. MADRASENSIS* DURING OCT. 1981 TO SEP. 1982

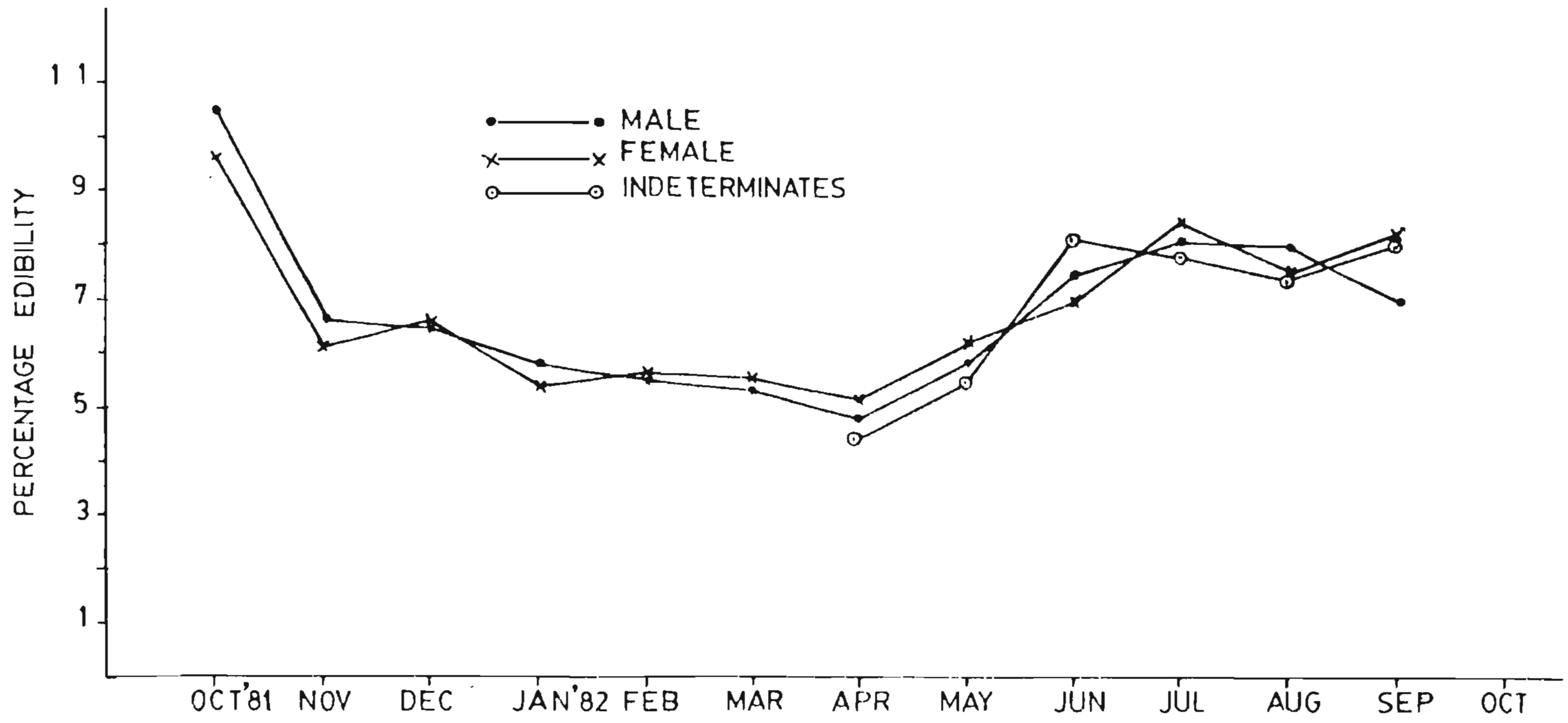


Fig.6.4. MONTHLY VARIATIONS IN THE AVERAGE PERCENTAGE EDIBILITY FOR MALES, FEMALES AND INDETERMINATES OF <u>C. MADRASENSIS</u> DURING OCTOBER 1981 - SEPTEMBER 1982

Table 6.1 Index of condition: Monthly variation from October 1981 to September 1982

Month	Number of oysters examined	Male	Female	Indeterminate	Sexes pooled
Oct. 81	56	48.95	49.68	0	49.31
Nov.	113	24.70	22.51	0	23.50
Dec.	204	32.56	33.82	0	33.39
Jan. 82	140	23.24	22.80	0	22.98
Feb.	61	9.50	9.43	0	9.46
Mar.	126	9.20	9.93	0	9.61
Apr.	86	20.22	22.51	18.68	21.07
May	80	23.72	27.07	22.67	24.06
June	35	47.63	30.63	34.67	37.90
July	50	32.74	37.20	25.29	36.40
Aug.	45	39.58	44.80	39.52	41.15
Sept.	50	40.20	40.30	40.00	40.16

for males in May and June, 1982. The indeterminates appeared in the population in April and persited till September (Fig.6.2, Tables 6.1 and 6.2). The highest values for indeterminates were also noticed in September, 1982 (40.3).

Table 6.3 and Fig.6.5 represents the percentage distribution of oysters in various class intervals of condition indices. Fig.6.6 shows the trend in the shifting

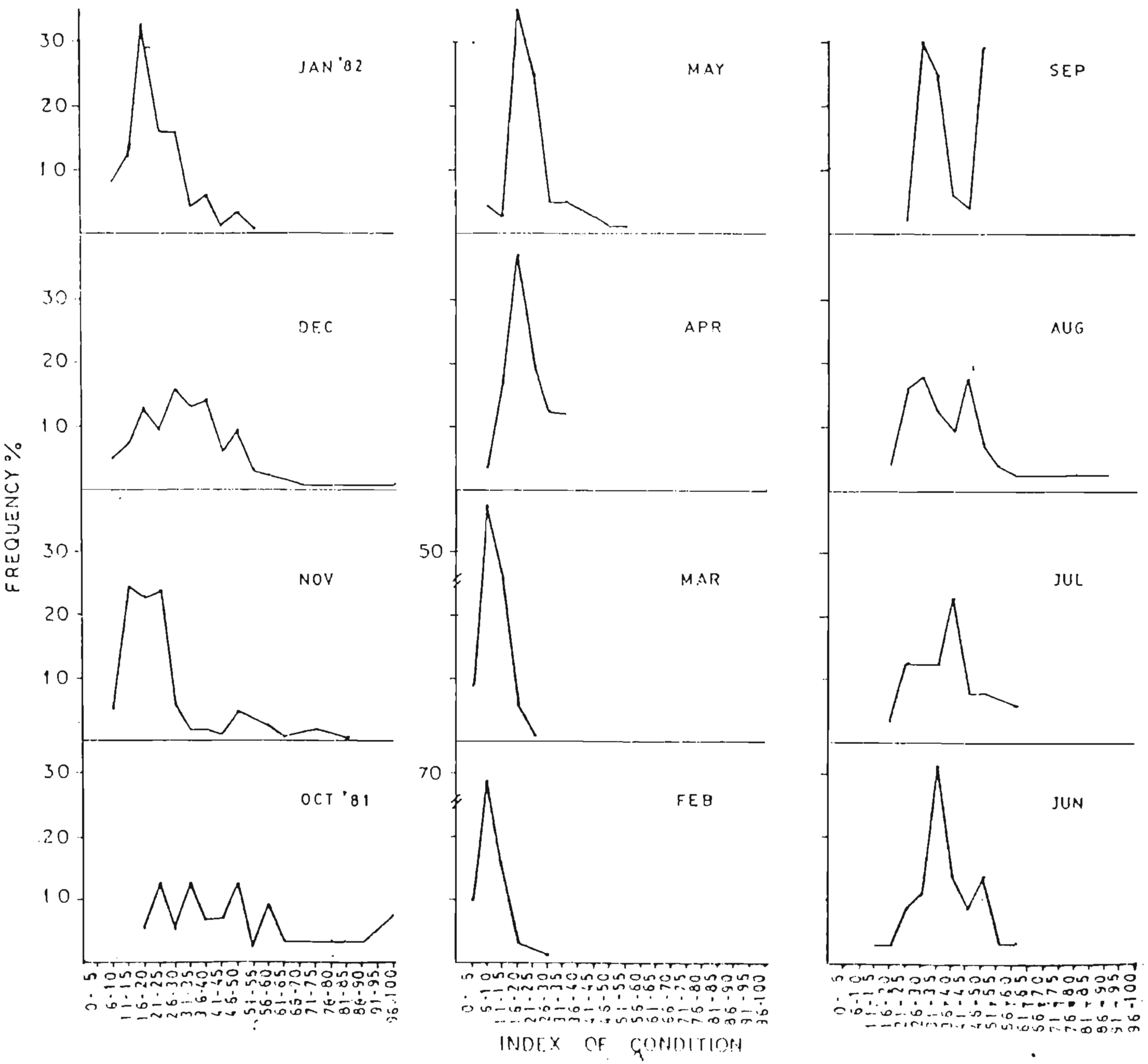


Fig. 6.5. THE MONTHLY VARIATIONS IN THE FREQUENCY DISTRIBUTION OF C.MADRASENSIS IN DIFFERENT CLASSES OF INDEX OF CONDITION VALUES DURING OCT. '81 SEP. '82

Table 6.2 Percentage edibility: Monthly variation from October 1981 to September 1982

Month	Number of oysters examined	Male	Female	Indeterminate	Sexes pooled
Oct. 81	56	10.41	9.66	0	10.03
Nov.	113	6.62	6.21	0	6.42
Dec.	204	6.50	6.51	0	6.55
Jan. 82	140	5.67	5.42	0	5.52
Feb.	61	5.54	5.52	0	5.52
March	126	5.34	5.64	0	5.51
Apr.	86	4.83	5.32	4.55	5.02
May	80	5.91	6.23	5.45	5.85
June	35	7.44	6.94	8.19	8.00
July	50	8.22	8.37	7.86	8.29
Aug.	45	7.98	7.32	7.31	7.51
Sept.	50	6.96	7.81	6.68	7.05

of monthly modes of condition indices. The modes of class group 46-50 (modal index 47.5) in October '81 declined to lower values (Fig.6) in November (class group 21-25 with modal index 22.5). December witnessed a slight increase and the modal index was observed to be 27.5. Excepting this increase in December, the deline of the modal values started in October '81 continued till it reached the lowest value of 7.5 in February and March,1982. During

Table 6.3 Index of condition: Percentage frequency distribution of the average values (K) noticed during October 1981 to September 1982

Frequency	Oct. 81	Nov.	Dec.	Jan. 82	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
0- 5	-	-	-	-	9.84	8.73	-	-	-	-	-	-
6-10	-	5.31	4.9	7.86	68.85	57.14	3.49	3.75	-	-	-	-
11-15	-	24.80	7.35	12.14	16.39	27.78	17.44	2.50	2.86	-	-	-
16-20	5.36	23.00	13.24	32.85	3.28	5.56	38.37	35.00	2.86	4.0	4.4	-
21-25	12.30	23.89	9.31	16.42	-	0.79	19.76	25.00	8.57	14.0	15.56	2.0
26-30	5.36	6.19	16.18	15.71	1.64	-	12.79	17.50	11.43	16.0	17.78	30.0
31-35	12.20	1.77	13.24	3.57	-	-	4.65	5.00	31.43	16.0	13.33	24.0
36-40	7.14	1.77	14.22	5.71	-	-	3.48	5.00	14.29	28.0	8.79	6.0
41-45	7.14	0.88	6.37	0.71	-	-	-	-	8.57	8.0	17.78	4.0
46-50	12.50	5.31	8.82	3.57	-	-	-	2.50	14.29	8.0	6.67	34.0
51-55	3.57	-	2.94	1.43	-	-	-	1.25	2.86	-	4.44	-
56-60	8.93	2.65	1.96	-	-	-	-	1.25	2.86	6.0	2.22	-
61-65	3.57	0.88	-	-	-	-	-	-	-	-	-	-
66-70	3.57	0.88	0.98	-	-	-	-	-	-	-	-	-
71-75	3.57	-	0.49	-	-	-	-	-	-	-	-	-
76-80	3.57	1.77	-	-	-	-	-	-	-	-	2.22	-
81-85	-	-	-	-	-	-	-	-	-	-	-	-
86-90	3.57	0.88	-	-	-	-	-	-	-	-	2.22	-
91-95	-	-	-	-	-	-	-	-	-	-	2.20	-
96-100	7.14	-	1.96	-	-	-	-	1.25	-	-	2.20	-

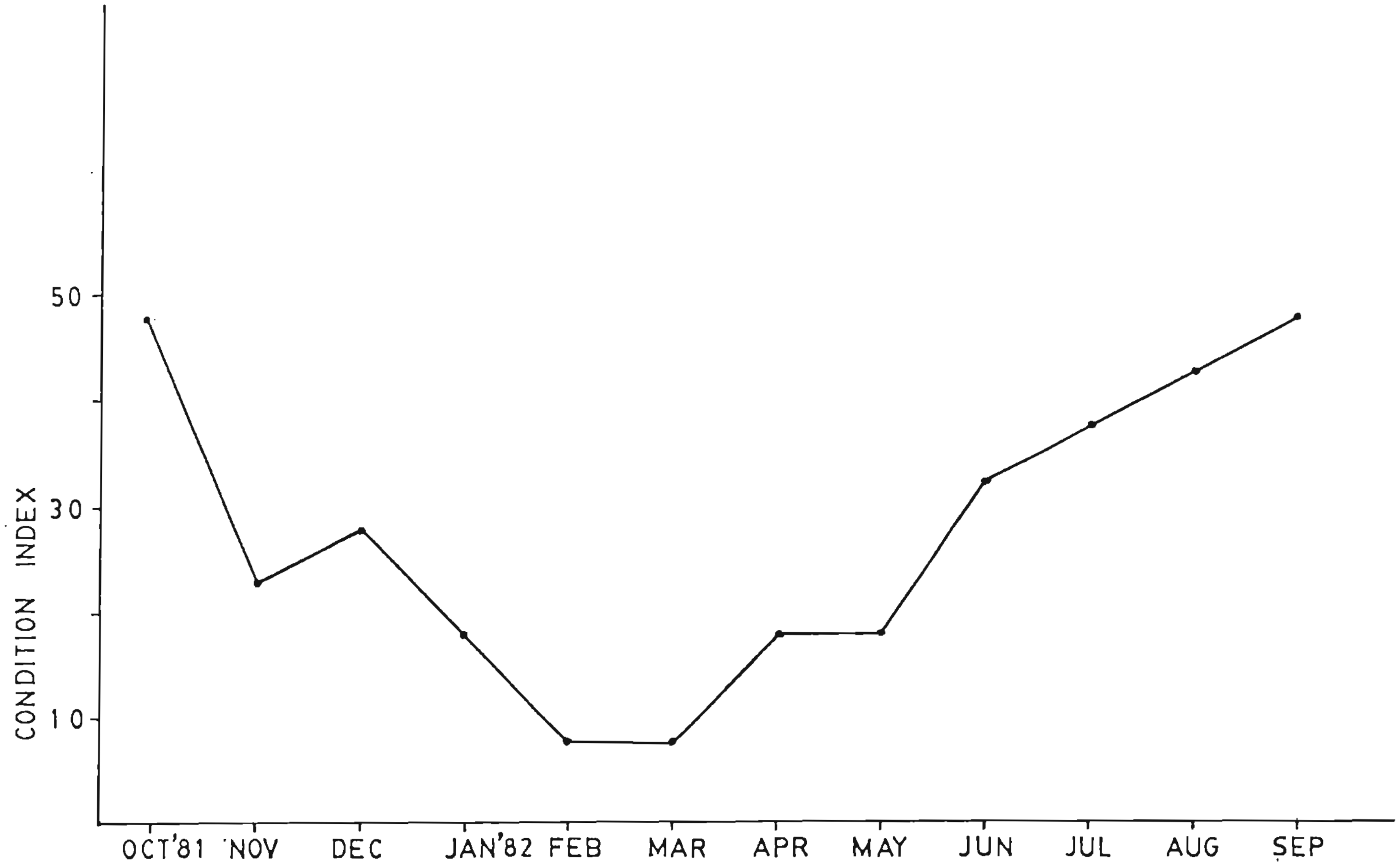


Fig. 6.6. TRENDS IN THE SHIFTING OF MONTHLY MODES OF CONDITION INDEX IN <u>C.MADRASENSIS</u> FROM OCT. 1981 TO SEP. 1982

April and May it rose and remained at 17.5. The modes of class groups 16-20 (32.5) in June shifted to higher values steadily, reaching 37.5 in July (class group 36-40), 42.5 in August (class group 41.55) and 47.5 in September, (Class group 46-50) 1982 (Fig.6.6).

The monthly variations in the average values of percentage edibility for the total population as well as for males, females and indeterminates are presented in Table 6.2. Fig.6.3 shows the distribution of average monthly percentage edibility for the total population and Fig.6.4 the sexwise split up for males, females and indeterminates. Table 6.4 gives the percentage frequency distribution of average values of percentage edibility. As in the case of condition index, the percentage edibility also followed the same trend. The mean value for the whole population was the highest being 10.03 in October, '81 which declined gradually reaching 5.02 in April '82. From April onwards it started increasing and reached 8.29 in July. However, there was a slight fall in the values during August and September 1982. Sexwise also, percentage edibility followed the same trend (Fig.6.4 and Table 6.2). Fig.6.7 shows the monthly variations in the frequency distribution of C. madrasensis in different class groups of percentage edibility during October, 1981 to September, 1982 and Fig.6.8 the trends in the shifting of monthly modes of percentage edibility for

Table 6.4 Percentage edibility: Percentage frequency distribution of the average values during October 1981 to September 1982

Frequency	Oct. 81	Nov.	Dec.	Jan. 82	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
0- 1	-	-	-	-	-	-	-	-	-	-	-	-
1.1- 2	-	-	-	-	-	0.79	2.33	-	-	-	-	-
2.1- 3	-	1.77	1.96	7.86	-	5.56	11.62	1.25	-	-	-	-
3.1- 4	-	6.19	6.86	20.00	16.40	11.90	16.28	8.75	2.86	2.0	6.12	8.0
4.1- 5	8.93	11.50	11.27	19.29	18.03	23.02	26.74	22.50	5.71	4.0	10.2	6.0
5.1- 6	1.79	23.00	25.00	17.85	37.70	26.19	16.27	22.05	11.43	14.0	10.2	20.0
6.1- 7	7.14	24.78	19.11	17.14	16.40	12.69	11.63	23.75	22.86	14.0	14.29	24.0
7.1- 8	14.20	15.04	18.63	6.43	6.56	10.32	10.47	11.25	17.14	10.0	16.33	6.0
8.1- 9	16.07	7.96	9.80	8.57	1.64	4.76	3.49	5.0	8.57	20.0	14.29	18.1
9.1-10	19.64	7.08	3.43	2.14	-	2.38	1.16	3.75	11.42	16.0	12.25	10.0
10.1-11	10.64	1.77	2.94	0.71	-	2.38	-	1.25	11.42	10.0	16.67	4.0
11.1-12	7.14	0.88	0.98	-	1.64	-	-	-	2.86	4.0	-	4.0
12.1-13	-	-	-	-	1.64	-	-	-	2.86	4.0	-	-
13.1-14	-	-	-	-	-	-	-	-	-	2.0	-	-
14.1-15	-	-	-	-	-	-	-	-	-	-	-	-
15.1-16	-	-	-	-	-	-	-	-	2.86	-	-	-

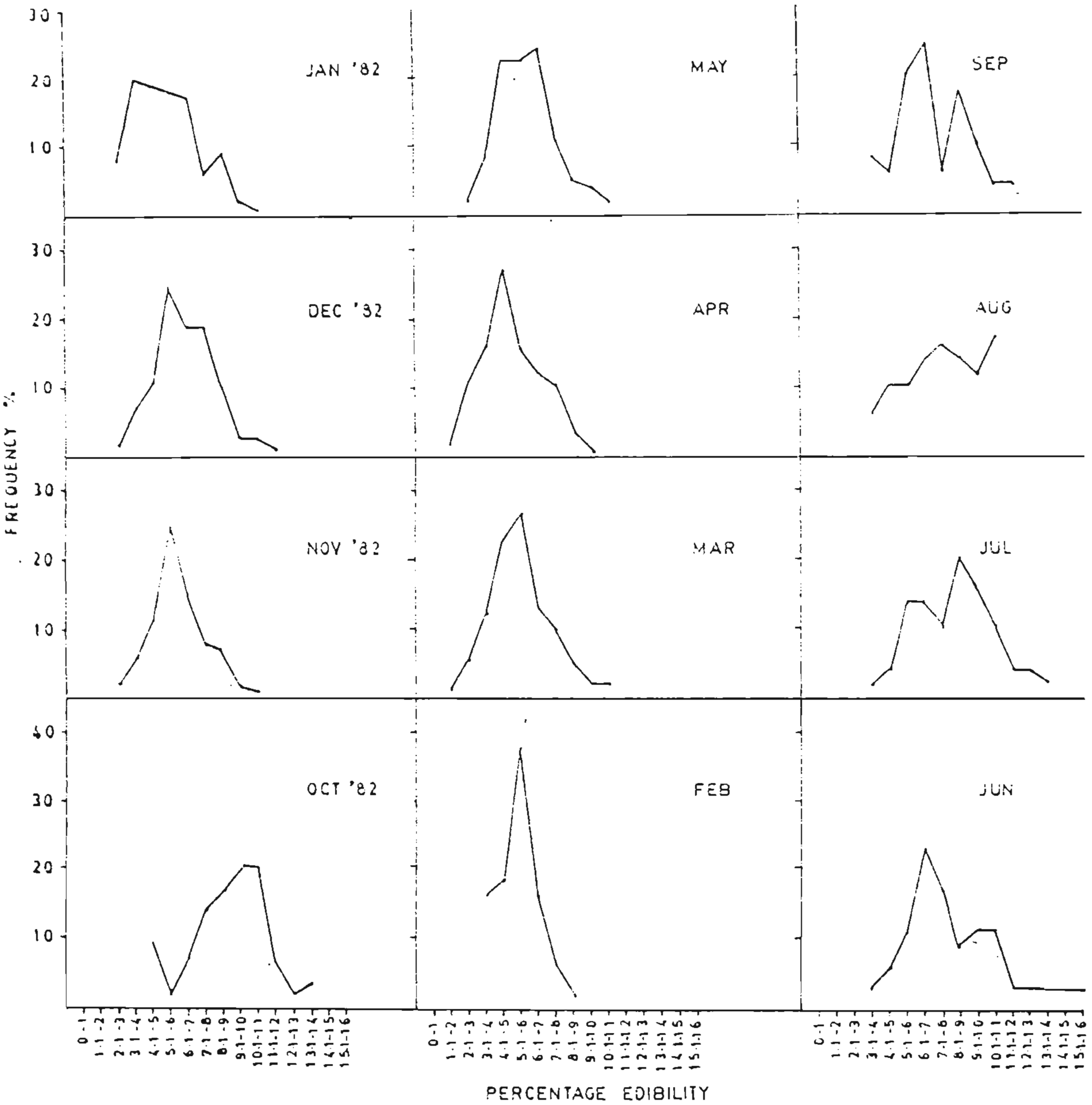


Fig. 6.7. THE MONTHLY VARIATIONS IN THE FREQUENCY DISTRIBUTION OF C.MADRASENSIS IN DIFFERENT CLASSES OF PERCENTAGE EDIBILITY VALUES DURING THE PERIOD OCT. 81-SEP. 82

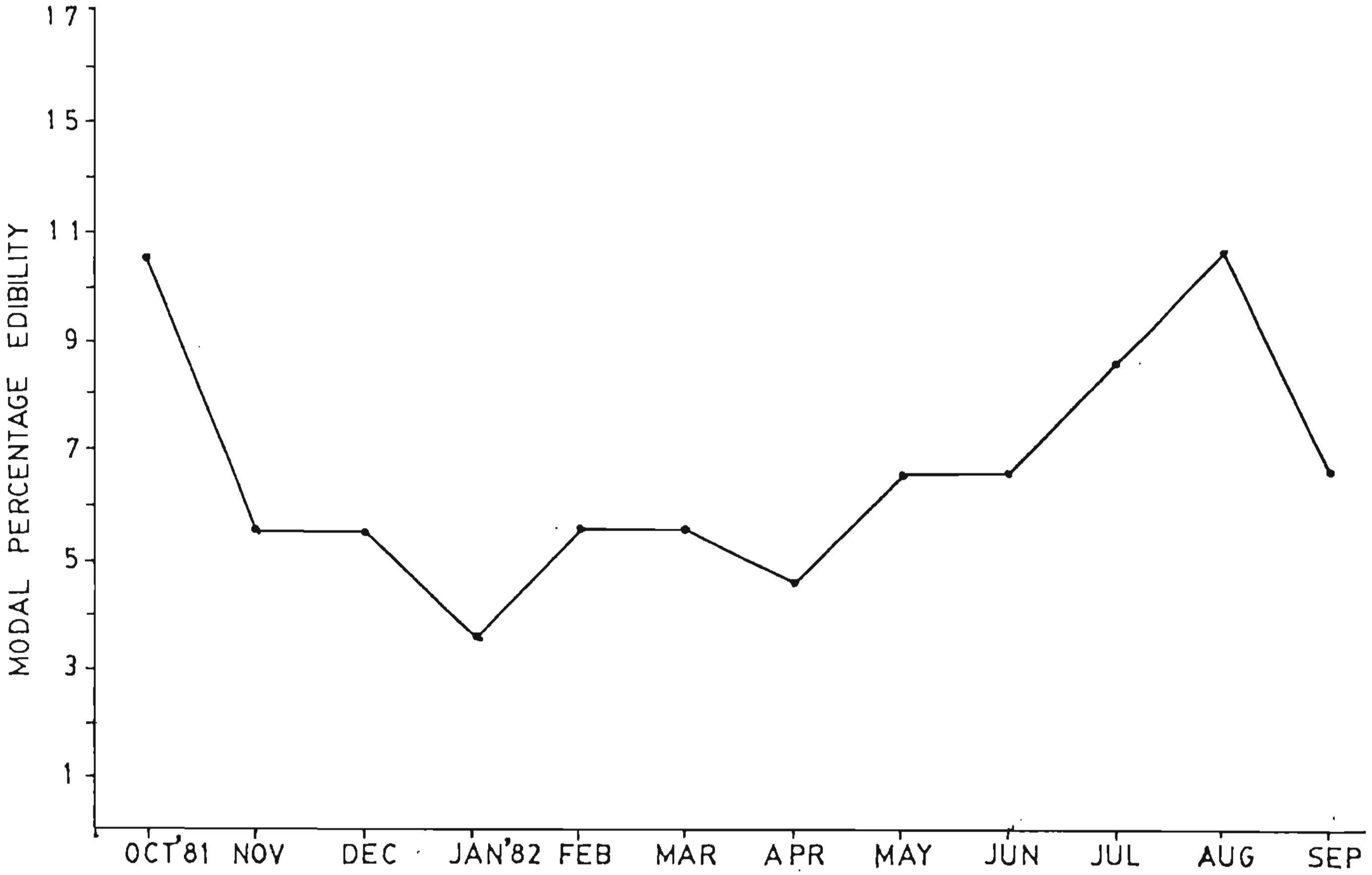


Fig. 6.8. TRENDS IN THE SHIFTING OF MONTHLY MODES OF PERCENTAGE EDIBILITY FROM OCT. 1981 TO SEP.1982

the same period. During October 1981, the modal value of percentage edibility (Fig.8.8) was 10.5 (10.1-11 class group). This declined to 5.5 (5.1-6 class group) in November and December, 1981. In January 1982, it further declined to 3.5 (3.1-4 class group) and shifted to 5.5 (5.1-6 class group) during February and March, 1982. In April the mode was at 4.5 (4.1-5 class group). During May and June, the modal values shifted to 6.5 (6.1-7 class group). In July there was further shifting and reached 8,5 (8.1-9 class group) and in August 10.5 (10.1-11 class group). There was again a decline to 6.5 in September. The highest values of percentage edibility were observed in October, 1981 (10.5) and August, 1982 and the minimum in January and April 1982.

6.4. Discussion

The results clearly indicate that the quality of the meat of C. madrasensis shows a definite seasonal variation. The index of condition showed a delining trend from November, 1981 to March, 1982 (excepting December). The following months, namely, April to September witnessed a rapid increase in the values of condition index (Table 1) for the total population and the same trend was observed for males and females when considered separately. After reaching the maximum value in October, it further declined, and thus presented a definite seasonal cycle. This seasonal cycle in condition index closely followed the sexual cycle in oysters. Soon after the monsoons, oysters started spawning from October onwards and fully spent forms were observed during March-April. They built up the gonads from April onwards and during this period sexually indeterminate forms appeared in the population (Table 6.1 and 6.2). Oysters accumulated large quantities of carbohydrates during this period and became bulky and this condition extended from April to October. This accounted for the progressive increase in condition index values from April onwards attaining the maximum during October. Thus the oysters were in the best condition from April to October in the Cochin Backwaters.

Durve (1964) observed close correlation between the gonadal cycle and condition index in C. gryphoides. The oysters were fatty and cream coloured from late October or November to June when they were not spawning and were in the best condition for human consumption according to him. Coulson (1933) observed fluctuation in condition indices correlated with the sexual cycle in the American oyster (C. virginica). The quality of the meat of oysters and mussels show variation according to Korringa (1955). In the English oyster, Ostrea edulis, Gabbot & Walker (1971) also observed variation in the condition indices. In the Pacific oyster C. gigas, Askew (1972) reported a fall in condition index values as a result of spawning.

Fluctuation in percentage edibility was also found to be similar to the variation in condition indices and thus followed a distinct seasonal cycle correlated to the sexual cycle in oysters. Similar to condition index values, the maximum percentage edibility (10.03) was observed in October, 1981 and the minimum from January to April, 1982. From April, 1982 onwards it showed a steady increase. Venkataraman & Chary (1951) recorded the highest value of 17.36 for percentage edibility in October and the lowest in July (5.03). In *Crassostrea madrasensis*, Rao (1956) observed higher values during August-November and lower values in February, July and August. Compared to the Ennur oysters reported by Rao (1956) the Cochin oysters had similar percentage edibility, as the mean values ranged from 5.02 to 10.03 in the present study. (Table 6.2). Very high values for percentage edibility (17.36) are reported by Venkataraman&Chari (1951), 16.6 in *C. gigas* by Fujiya (1970), 22 and 20.9 in the United Kingdom and Israel respectively by HughesGames (1977). The highest values of percentage edibility coincided with the inactive phase of the oyster in this study similar to that observed by Durve (1964) in *C. gryphoides*.

6.5. References

Askew, C.G. (1972) The growth of oysters *Ostrea edulis* and *Crassostrea gigas* in Emsworth Harbour, *Aquaculture*, **1**, 237-260

Baird, R.H. (1958) Measurement of condition in mussels and oysters. *J. Cons. perm. int. Explor. Mer.* **23**(2), 249-257

Baird, R.H. (1966) Factors affecting the growth and condition in mussels (*Mylilus edulis*) *Fish. Invest. London Ser.* 2, 25(2), 3300

Coulson, E.J. (1933) Studies on the nutritive value of oysters. *U.S. Bur. Fish. Invest. Rep.* No.17

Dame, R.F. (1971) *The Ecological Energies of Growth, Respiration and Assimilation in the American Inter-tidal oyster C. virginica*. Ph.D. Dissertation, University of South Carolina, 81 pp

Durve, V.S. (1964) On the percentage edibility and the index of condition of the oyster *C. gryphoides* (Schlotheim) *J. mar. biol. Ass. India*. **6**(1), 128-135

Durve, V.S. & George, K.V. (1973) Some observations on the index of condition of the clam *Meretrix casta* (Chemnitz) in relation to mud and water qualities. *Indian J. Fish*. 20(2), 326-332

Frieger, E.A., Novak, A.F., Bailey, M.F., Friedrich, A.V. & Lyle, S.A. (1958) Observation on the composition of oysters. *Sea Fd Merch. A. Rev.* **18**, 26-27

Fujiya, M. (1970) Oyster farming in Japan. *Helgolander Wiss. Meeresunters*, **20**, 464-479

Gabbot, P.A. & Walker, A.J.M. (1971) Changes in the condition index and biochemical content of adult oysters (Ostrea edulis L) maintained under hatchery conditions. J. Cons. int. Explor. Mer. 34:99-106

Galtsoff, P.S. (1964) The American Oyster, Crassostrea virginica (Gmelin), Fish. Bull. Fish Wildlife Serv. 64, U.S. Dept. of the Interior, Washington

Galtsoff, P.S., Chipman, W.A., Engle, J.B. & Calderwood, H.N. (1947) Ecological and physiological studies on the effect of sulphate pulp mill wastes on oysters in York River, Virginia. Fish. Bull. Fish. Wild Life Serv. U.S. 51:59-186

Hughes Games, W.L.(1977) Growing the Japanese Oyster, Crassostrea gigas in sub-tropical sea water fish ponds. 1. Growth rate, survival and quality index. Aquaculture, 11:217-229

Humphrey, G.F. (1941) The biology and cultivation of oysters in Australia. iii. Biochemistry of the proximate constituents. Pamph. Coun. Scient. ind. Res. Aust. 3, 21-40

Ingle, R.M. (1949) A comparative study of oyster condition. Science, 109 (2841):593

Jacobs, M.B. (1951) The chemical Analysis of Food and Food Products. In "Chemical composition of oysters", Van Nostrant Co. N.Y. 677-682

Korringa, P. (1955) Quality estimation in mussels and oysters. *Arch. F. Fichereiwiss*. 6(¾) Braunsch weigh

Medcof, J.C. & Needler, A.W.H. (1941) The influence of temperature and salinity on the condition of oysters (*Ostrea virginica*) *J. Fish. Res. Bd Can*. 5:253-257

Odlaug, T.O. (1946) The effect of the copepod *Mytilicola Orientalis* upon the Olympia Oyster, *Ostrea lurida*. *Trans. Am. microsc. Soc*. 65(4), 311-317

Rao, K.V. (1956) Seasonal gonadal changes in the adult back water oyster, *Ostrea* (*Crassostrea madrasensis* Preston) from Ennur, near Madras. *Proc. Indian Acad. Sci*. Vol. XLIV, 332-356

Shafee, M.S. (1976) Effect of salinity and time of exposure to air on the metabolism of green mussel, *Mytilus viridis* L. *Indian J. mar. Sci*. 5(1), 130

Walne, P.R. (1970) The seasonal variation of meat and glycogen content of seven populations of oysters, *Ostrea edulis* (L) and review of literature. *Fish. Invest. Ser*. ii. vol.24, No.3

Venkataraman, R. & Chari, S.T. (1951) Studies on oysters and clams: biochemical variations. *Indian J. med. Res*. 39, 533-541

CHAPTER 7

AGE AND GROWTH IN *C. MADRASENSIS*

CHAPTER 7

AGE AND GROWTH IN *C. MADRASENSIS*

7.1. Introduction

Culture of edible oysters has acquired considerable significance in recent years owing to the high productivity of these bivalves. The Indian coastal and estuarine areas sustain vast resources of edible oysters. The growth rates of oysters form an important aspect of the study of oyster biology owing to their high potential for culture. Culture of edible oysters has been resorted to by many maritime nations of the world with good dividents. Oysters, namely, *Crassostrea gigas* are successfully cultured in large scale in Japan, *Crassostrea virginica* and *Crassostrea gigas* on the Atlantic and Pacific coasts of the United States respectively, *Ostrea edulis* and *Crassostrea angulata* in France. Several other countries such as Korea, Australia, Philippines, Cuba, Venezuela have also resorted to oyster culture, the species employed being *Crassostrea gigas*, *Crassostrea commercialis*, *C. iredalei* and *Crassostrea rhizophorae* respectively. In India, culture of edible oysters is taken up on a major scale at Tuticorin on the east coast. Oyster farmers all over the world, prefer fast growing species for shortening the time required for attaining marketable size and in this connexion studies on the growth rate of oysters are of paramount importance. As observed by Loosanoff & Nomejko (1949) "an understanding of the growth of oysters is of undeniable importance not only from a purely biological but also from a practical point of view". Growth of oysters has been examined from various parts of the world and the phenomenon exhibits considerable variations in the different regions.

Systematic study of the various growth phases of oysters dates back to Nelson (1922). He noticed increase in size and weight of oysters measured during 1919 and 1920. Working at Milford Harbour, Connecticut, Loosanoff (1947) observed increase in size of oysters grown during a three year period. The relative increase in size and volume of oysters during all the months of an year has been recorded by Loosanoff & Nomejko (1949). They observed no increment in growth during the hybernation period. The oysters at Milford Harbour grow only for about 8 months in an year according to them, namely, from April to November. Rapid growth was observed during May, June and July (19 to 22.5%). Changes in length and width showed only partial relation to changes in temperature but definite relationship was observed between rate of increase in volume and changes in water temperature.

Orton (1928, 1937) studied the growth in European oyster *Ostrea edulis* and ascribed the fluctuation in temperature as responsible for variation in growth rate in this oyster. Walne (1958) observed lesser growth in larger specimens and pronounced growth in smaller individuals of *O. edulis*. He further observed an average of 18 g weight increase for a 20 g oyster and 3% increase in dry meat weight per day (Walne, 1975).

Other important studies pertaining to the growth of American and Japanese oysters are those of Ingle (1950), Menzel (1950), Ingle & Dawson (1952), Hanley *et al.* (1976), Ferreira (1975), Newkirk *et al.* (1977), Fujiya (1970), Quayle (1952, 1971), Losee (1979), Walne & Spencer (1974), Gunter (1938), Galtsoff (1964), McHugh & Andrews (1955), Bae & Bae (1972), Meixner (1974), Glaser (1903), Lee & Yoo (1975), Hughes (1977), Havinga (1928) and Anjell (1975). A survey of the literature shows that the growth of oysters from different localities and regions of the world are different and are influenced by various factors of the environment. A pronounced growth of 104 mm in 31 weeks has been reported by Ingle (1950) for *C. virginica* from Florida waters and 100 mm in 36 weeks for oysters in Lousiana waters (Menzel, 1950). Ingle & Dawson (1952) observed reduced growth in older individuals of *C. virginica*. Habitat plays a major role in the growth rates and variation in growth rate of oysters inhabiting different habitats was reported by Menzel *et al*. (1977). The duration of larval life may also exert some influence, as metamorphosed spats after three days of larval life grew to larger oysters compared to spats metamorphosed after a larval period of more than 3 days. (Losee, 1979). The yearly increase in weight of *Crassostrea gigas* was observed by Fujiya (1970), Quayle (1971), Walne & Spencer (1974). They respectively observed a weight increase of 60 g, 68.5 g (for oysters with initial weight of 50.1 g) and 3 to 10 g (initial weight 5 to 50 g) after one year. The growth rate was much more faster in Korea in oysters grown at the surface waters compared to those grown at middle and bottom (Bae & Bae, 1972). In Emsworth Harbour the growth rates were 3.9 to 64.7 g for a period of 12 months (Askew, 1972). The pacific oyster *C. gigas* exhibited a slower growth rate of 6.7 cm after two years in the coastal waters of Germany as observed by Meixner (1974). Lee & Yoo (1975) reported variation in growth rate for hardened and ordinary seed oysters of *C. gigas*. An average size of 9.6 cm and 7.4 cm was attained by oyster spats of weight 15.6 and 6.7 g respectively after one year. The monthly increase in weight of *C. gigas* grown at Israel were 2 to 9.5 g. *Crassostrea rhizhophorae* as reported by Angell (1975) grows to a maximum of 7 cm after 10 months.

Ingle (1950) reported a diameter of 4.5 mm after one week, 8 mm after two weeks and 104 mm after 31 weeks in Apalachicola Bay, Florida. According to Menzel (1951) in Lousiana waters, oysters grow throughout the year and attain a diameter of 50 mm in 2 months and 100 mm within nine months after setting.

The notable works from Indian waters are those of Hornell (1910b), Paul (1942), Rao (1951) Rao & Nayar (1956), Durve & Bal (1962), Balasubramanyan & Nair (1968) and Nair (1967). Hornell (1910a) observed 2½ times faster growth in Madras oysters compared to that of French oysters. The French oysters grew to 18 mm in 90 days while it was 27 mm in 52 days for the Madras oyster. Orton (1937), Havinga (1928) and Korringa (1952) observed wide range in the growth of oysters from the same brood in the same locality owing to the variation in the nature of substratum, salinity and temperature. This lead Rao & Nayar (1956) to study the maximum and mean rates of growth of spat and yearlings of <u>C. madrasensis</u> from the natural habitat as they felt maximum growth alone was of little significance. Rao & Nayar (1956) observed a maximum growth of 8.5, 35, 45, 61, 84, 96, 102, 107 and 109 mm after 3 weeks, 7 weeks, 5, 6, 13, 15, 16 & 17 months respectively. Paul (1942) noticed only 0.8, 4.4, 6.3, 12.0, 21.5 and 66 mm after 3, 10, 13, 16, 19, 44 and 243 days respectively in oysters of the Madras Harbour. Growth was more pronounced in brackish waters in this species (Rao & Nayar, 1956) compared to that of the oysters inhabiting typical marine habitat of the harbour (Paul, 1942). Subsequently Durve & Bal (1962) studied the growth of C. gryphoides from Kelwa backwaters and reported a maximum growth of 37.2 mm and 47.9 mm after 6 months and one year respectively. The average heights of spats during July, August and September were 2.5, 4.2 and 7.8 mm respectively. The monthly increase in growth rates were 2.5, 1.7 and 3.6 mm for July, August and September. The growth rate in C. madrasensis is much faster than in O. edulis which grew to 5 and 35 mm after one year (Orton, 1926; 1937). However, the growth of C. madrasensis is about the same as that of C. virginica observed by Ingle (1950) and Menzel (1950). This growth rate was slow compared to 84 mm after one year reported from Madras (Rao & Nayar, 1956). They found that the growth of the oyster varied widely with tidal height, food availability and salinity of the area in which they are grown.

The growth of oysters is influenced by several factors of the environment such as water temperature, availability of food, pH of the medium, salinity, nature of the substratum and water flow. The temperature of water has an abiding influence in the growth of oysters. This is because of the oyster's rapid feeding at high temperatures. Higher temperature limits the growth to warmer months at least in temperate regions (Korringa, 1952). Orton (1937) observed growth in O. edulis confined to summer and autumn seasons. A similar observation was made by Loosanoff & Nomejko (1949) in C. virginica of Chesapeake Bay. However, uninterrupted growth of O. edulis during summer was noticed by Korringa (1951). Over population also resulted in poor growth owing to scarcity for food (Korringa, 1947). The influence of higher temperature of water on oyster growth has been observed by Nelson (1921), Galtsoff (1928), Hopkins (1931a), Elsey (1936) and Loosanoff (1950a). During lower temperature, oysters remain closed resulting in reduced water propulsion and thereby reduced food availability. Korringa (1952) opined that deposition of shell material goes uninterruptedly when temperature remained above 10°C. Quayle (1952) also observed 9°C as the minimum temperature for growth in C. gigas. 10 to 25°C was found suitable for rapid shell growth in C. angulata in the east coast of the Isle of Oleron (Ranson, 1948). The seasonal growth in inter-tidal oysters was studied by Dame (1972). He observed reduction in instantaneous growth corresponding to decrease in size and lowering of temperature. The Q 10 values obtained from instantaneous growth rate were lower during warm growing seasons than in lower temperature conditions.

Growth influenced by temperature during different seasons was also observed by Maurer & Aprill (1973), Walne (1958, 1972), Walne & Mann (1975) and Spencer & Gough (1978). In Kelwa Backwaters temperature varies between 25.7 to 33.4°C, with no influence in the growth of Crassostrea gryphoides (Durve & Bal, 1960).

The availability of food is a major factor controlling the growth in oysters. The influence of food on growth has been observed by several workers (Nelson, 1921; Ranson, 1948; Galtsoff, 1928; Hopkins, 1931a; Elsey, 1936; Loosanoff, 1950). Depending on the availability of food during different seasons a corresponding fluctuation in growth was noticed (Dame, 1972; Maurer & Aprill, 1973). The concentration of food in the water is also important as the filter feeding efficiency of oysters depends on the concentration of food available and accordingly there is an optimum concentration of food for these bivalves (Winter, 1969). The quality of food available also influences growth rates. However, Baughman & Baker (1951) could not observe a correlation between abundunce of diatoms and growth rate in Gryphaea virginica in Texas. Gaarder & Alvsaker (1941) as quoted by Korringa (1952) found good growth in water poor in diatoms but abundant in nannoplankton. Tenore & Dunstan (1973) observed that the food removed from water is directly proportional to the particle concentration, while an inverse relation between the assimilation efficiencies and concentration of food in water has been noticed by Widdows & Bayne (1970) and Foster-Smith (1976).

The influence of pH values on the rate of winter pumping has been noticed by Loosanoff & Tommers (1948). They noticed that a lowering of pH below seven, reduced the rate of pumping of water in Gryphaea virginica. Calabrese & Davis (1970) also observed that reduction of pH below 6.75 adversely affecting the recruitment of larvae of C. virginica.

Salinity is yet another factor influencing the growth of oysters. Prolonged immersion in very low and very high salinities has adverse effects on the growth of oysters in the Adayar Estuary (Rao & Nayar, 1956). According to them short spells of low salinity occurring during tidal cycles have no effect on the growth rates. Tissue degeneration below 7‰ salinity has been observed by Ranson (1943) in Gryphaea angulata. However experiments of Loosanoff (1950) show that Ostrea virginica as capable of tolerating abrupt changes from low to high salinities without pronounced physiological injuries, but prolonged exposition to low salinity lead to starvation and death. Chanley (1958) observed cessation of growth in juveniles of C. virginica below 5‰ salinity, even though they survived in such salinities. Cole & Hepper (1954) noticed that low salinity has a depressing effect on mussels. Hopkins (1931a) found that increased salinity accelerated the larval development in Ostrea edulis. Fluctuations in salinity according to him had adverse effect on the feeding mechanism which in turn resulted in the poor growth on the oyster. Cahn (1950) and Hopkins (1936) observed maximum growth in C. gigas at salinities 27 and 35‰ respectively. Rapid growth, slow growth and no growth were observed by Durve & Bal (1962) in moderate, high and very low salinities respectively. They found correlation between salinity values and intensity of growth. High salinity retarded growth and constant low salinity resulted in almost no growth in C. gryphoides under tropical conditions.

Needler (1941) and Ranson (1948) observed continuous growth in spat and yearlings in summer, but interrupted shell growth during the spawning period. But according to Korringa (1952) in waters with rich food, spawning activities seldom leads to any interruption in growth. The cessation of growth according to him in Older oysters accounted to poor food in the medium during the period of reproduction. Overpopulation also lead to interruption in growth in older oysters (Korringa, 1947).

Apart from the study of Rao & Nayar (1956) and Durve & Bal (1962) no systematic attempt appears to have been made on this important aspect of oyster biology. Even though the edible oyster, Crassostrea madrasensis is widely distributed along the east and west coasts of India and offer immense potentialities for culture, no concerted effort has been made to study the growth rate of this commercially important mollusc from various habitats. This study was undertaken with a view to filling up this important gap in our knowledge of oyster biology particularly from the Cochin Harbour and its environs.

7.2. Material and methods

The growth rate in height was studied from the wild population of C. madrasensis collected from the Cochin Backwaters for the period from August 1981 to June 1982. The height of the oysters was measured correct to 0.1 cm.

The frequency distribution of height was assessed by taking the class interval as 0.1 cm for each month. The percentage frequencies of height were then worked out (Table 7.1). The height frequencies (in percentages) were used to prepare height frequency polygons (Figs.7.1 to 7.5). The modal heights were noted from these figures and presented in Table 7.2a and were plotted against the respective month (Fig.7.5). The progression of modes during different months were represented by lines connecting the modal values as shown in Fig.7.5. From the data on oyster height against known age collected from

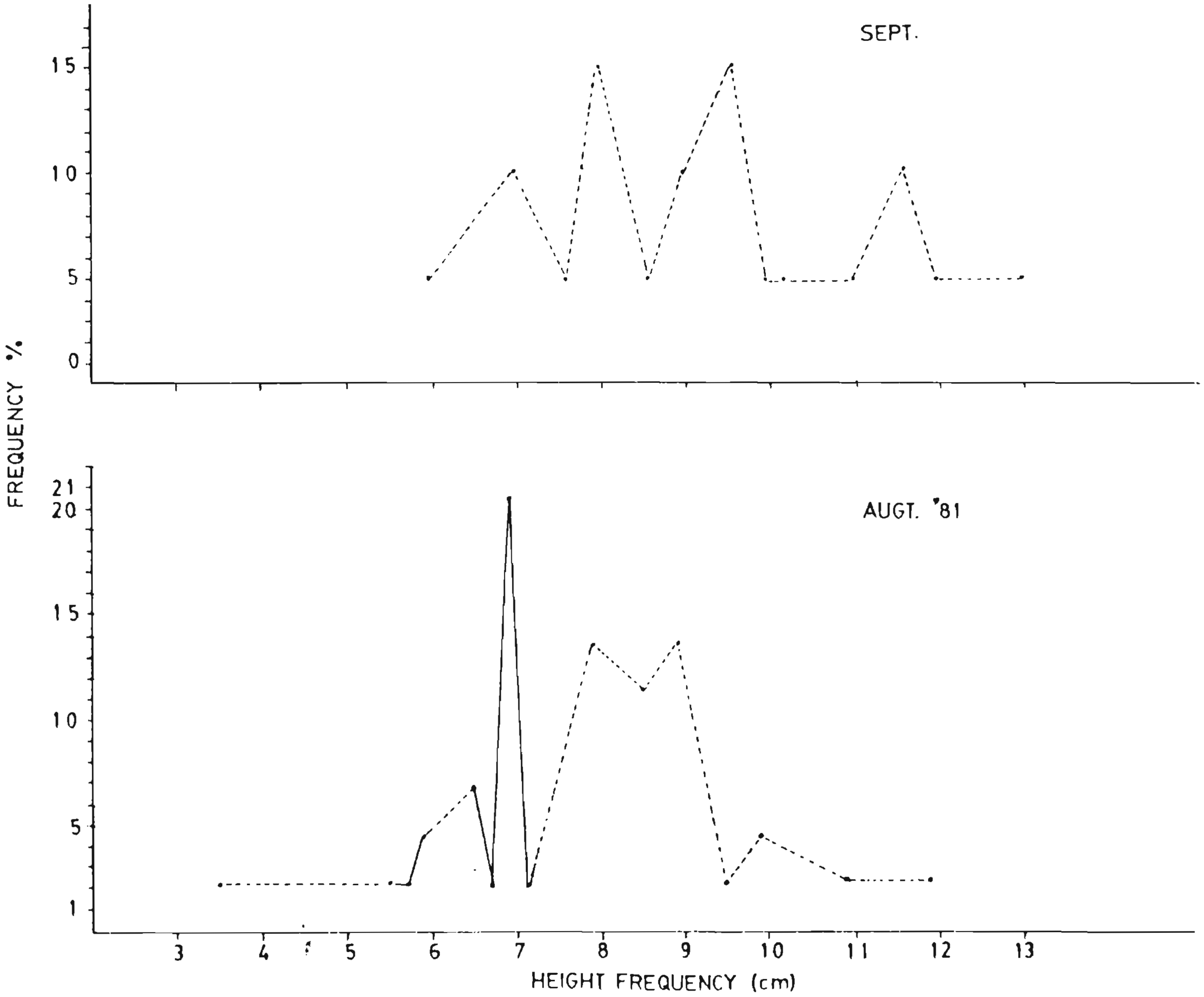


Fig. 7.1. AGE AND GROWTH IN C.MADRASENSIS. PERCENTAGE FREQUENY DISTRIBUTION OF SHELL HEIGHTS DURING AUGUST AND SEPTEMBER 1981

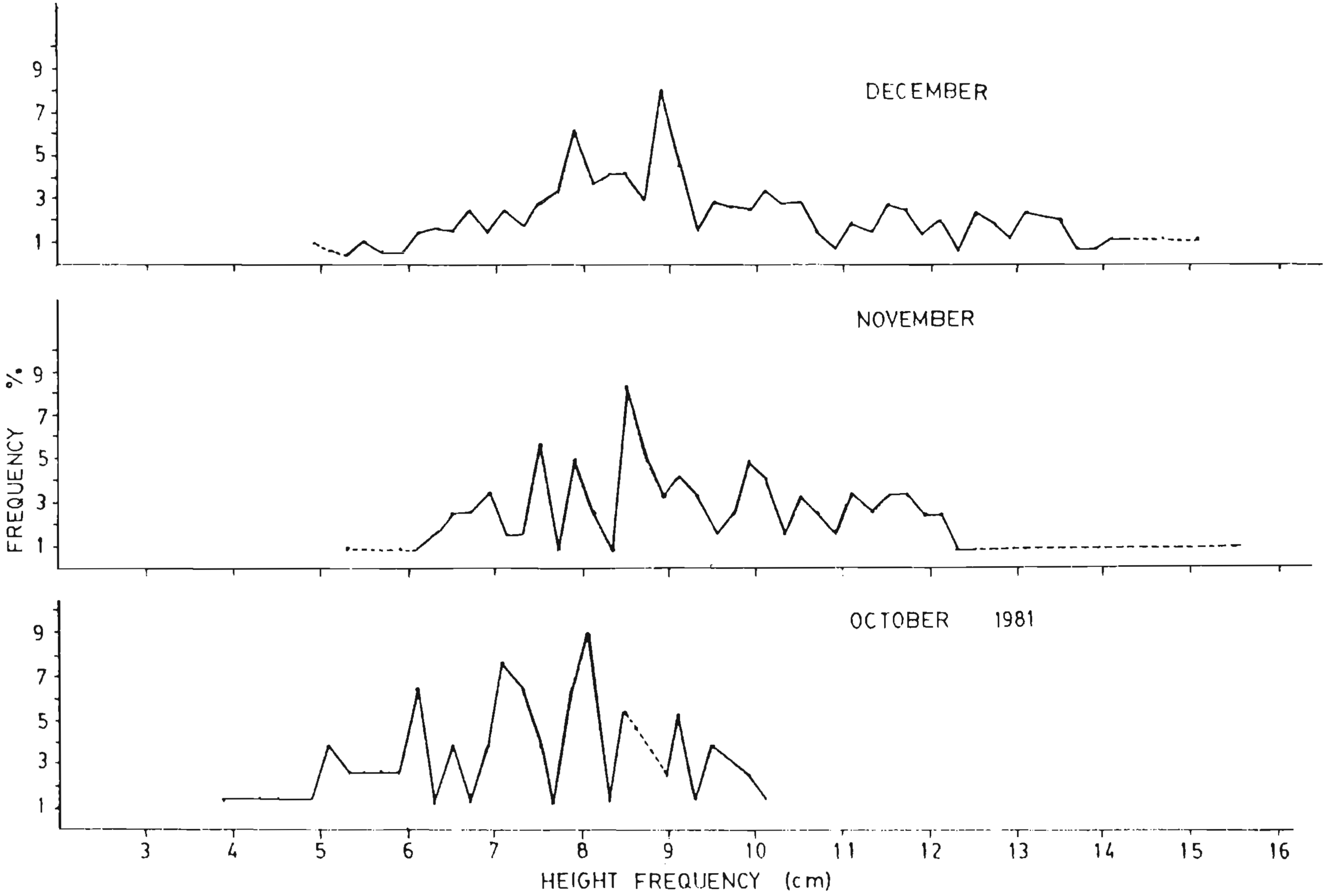


Fig. 7. 2. AGE AND GROWTH IN C. MADRASENSIS. PERCENTAGE FREQUENCY DISTRIBUTION OF SHELL HEIGHTS DURING OCTOBER, NOVEMBER AND DECEMBER, 1981

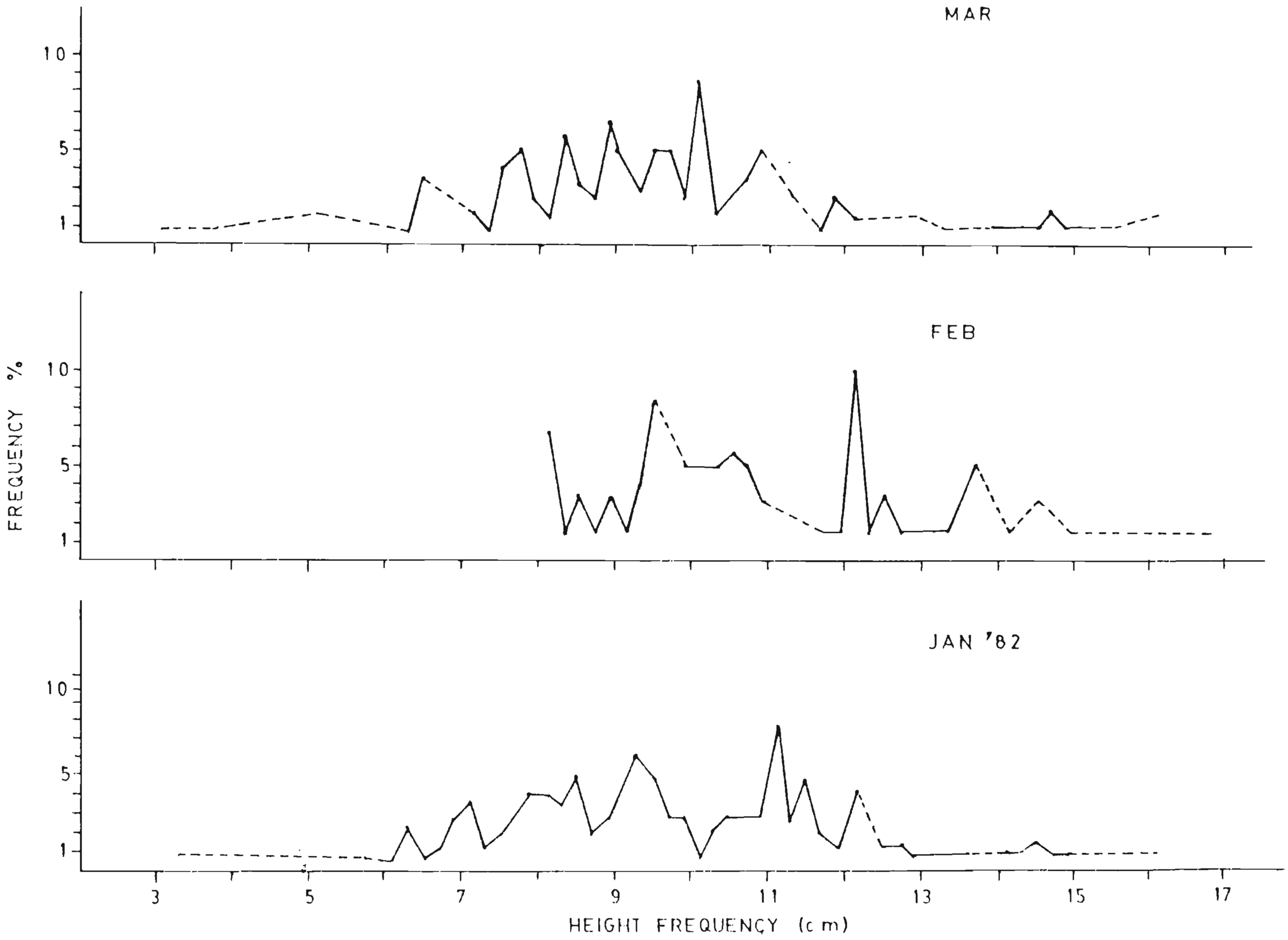


Fig. 7.3. AGE AND GROWTH IN C. MADRASENSIS. PERCENTAGE FREQUENCY DISTRIBUTION OF SHELL HEIGHT DURING JAN, FEB AND MAR '82

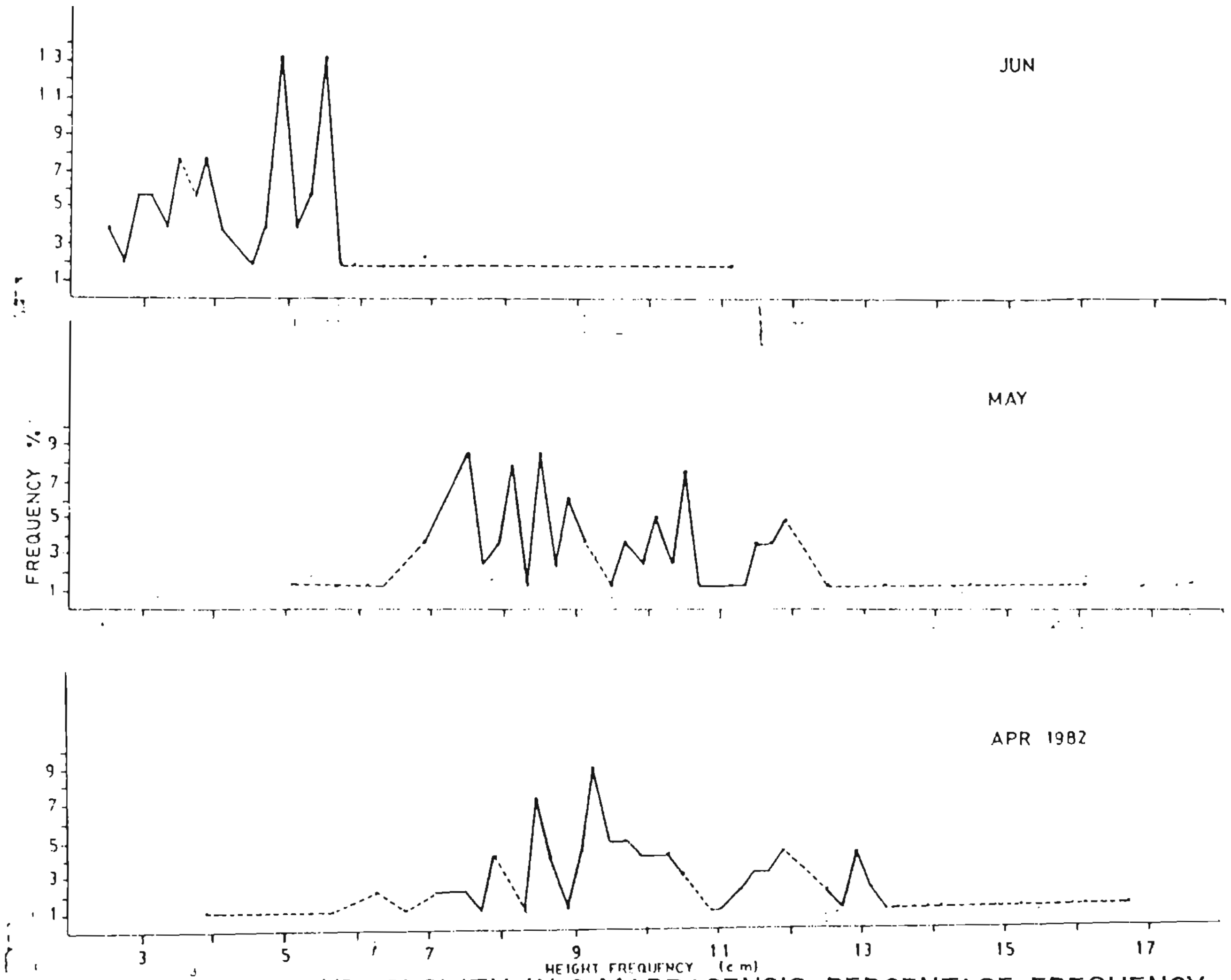


Fig.7. 4. AGE AND GROWTH IN C.MADRASENSIS. PERCENTAGE FREQUENCY DISTRIBUTION OF SHELL HEIGHTS DURING APRIL,MAY AND JUNE, 1982

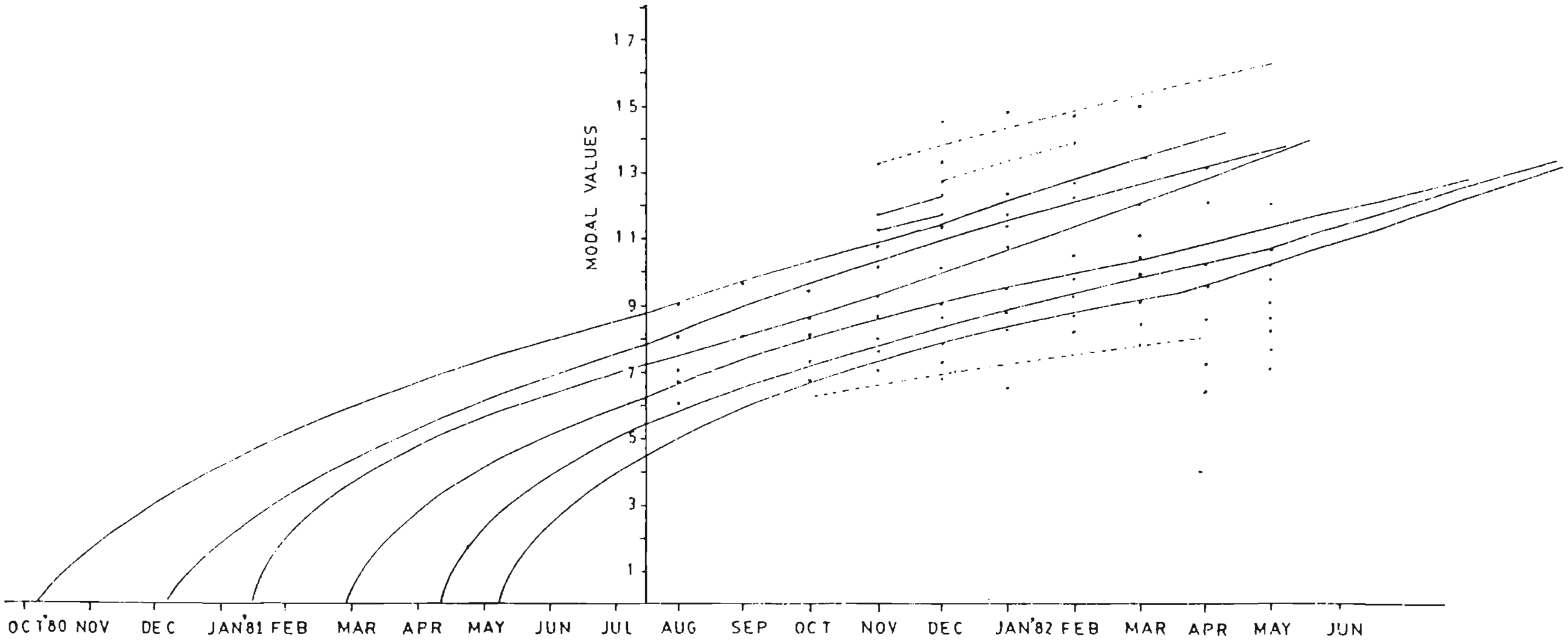


Fig. 7.5. AGE AND GROWTH IN C. MADRASENSIS. DISTRIBUTION OF MODAL VALUES ARRIVED AT BY PETERSEN'S METHOD

immersed panels and other suitable cultch materials, it was found that the oyster spat grew approximately 0.6 to 0.7 cm per month, particularly during the initial stages and 2 cm was fixed as the growth of the oyster when they attain 3 months of age. Six curves, namely, A,B,C,D,E and F were obtained (Fig.7.5) and these curves were extrapolated to the time axis to obtain the length at earlier periods. Average height attained after quarter years was noted from Fig.7.5 and presented in Table 7.3. The height at age (quarter years) was calculated by taking the average of the six length measurements corresponding to respective ages given in Table 7.3. Von Bertalanffy growth curve (Von Bertlanffy, 1938; 1957)

$$l_t = L\alpha \left[1-e^{-K(t-t_o)}\right]$$

was fitted to the length at age data (Table 7.4).

The maximum age to which the oyster can grow ($L\alpha$) and the coefficient of catabolism K ($\log_e \tan\theta$) were estimated by Ford-Walford (Ford, 1933; Walford, 1946) plot (Fig.7.6). The theoretical time at which the height of oysters is zero (t_o) was determined by plotting $\log_e (L\alpha - l_t)$ on t (Fig.7.7). From this plot t_o was read as the time relating to $\log_e L\alpha$ (corresponding to $l_t = o$).

7.3. Results

Examination of Table 7.1 on frequency distribution of height and the frequency polygons presented in Figs. 7.1 to 7.5 shows the presence of distinct modes in most of the months during the period of observation from August 1981 to June 1982. However, modes of the previous month could not be traced to subsequent months in certain cases and this may be attributed to sampling errors. As the oysters used in this study were mainly collected from the feral population of oysters from the Cochin Backwaters by diving and handpicking, oysters with height less than 4 cm were seldom represented in the samples and majority of them belonged to the height group 4 cm and above.

The shifting of modes is presented in Fig.7.5 and Table 7.2b. The primary mode in August is 8.9 with lesser modes at 5.9, 6.5, 6.9 and 7.9. In September the primary mode of 8.9 observed during August shifted to 9.5. No change in the shifting of modes such as 5.9, 6.5, 6.9 and 7.9 from August to September was discernible. In October, 7 modes, namely, 5.1, 6.1, 6.5, 7.1, 8.1, 8.5 and 9.1 were discernible, but only 6.5, 7.1, 8.1 and 9.1 alone could be traced from the previous month. The modes of 5.9, 6.5 and 7.9 in August might have shifted to 7.1, 8.1 and 9.1 resprectively in October. The mode of 9.5 observed to have shifted from August to September could not be traced in October. In November even though 11 modes were present, only six were traceable, namely, 6.9, 7.9, 8.5, 9.1, 9.9 and 10.5. The mode 6.9 ought to have shifted from 6.5 in October, 7.9 from 7.1 in October, 8.5 from 8.1 in

October 9.1 from 7.9 in September, 9.9 from 9.1 in October and 10.5 from 9.5 in September. The maximum number of modes, namely, 14 were observed in December, out of which only 4, that is 7.9, 8.9, 10.1 and 11.1 were traceable, 7.9 from 6.9 in November, 8.9 from 8.5 in November, 10.1 from 9.1 in November and 11.1 from 10.5 in November. January presented 10 modes, of which 4 were traceable, such as 8.1 from 7.9 in December, 8.5 from 7.9 in November, 9.3 from 8.9 in December, 11.5 from 9.9 in November and 12.1 from 11.1 in December. During February 10 modes were discernible of which 4 modes, namely, 8.5 from 8.1 in January, 8.9 from 8.5 in January, 12.1 from 11.5 in January and 12.5 from 12.1 in January. Of the 10 broods in March, only three shifted from previous months. They were 8.9 from 8.5 in February, 9.7 from 8.9 in February and 10.1 from 9.3 in January. During April, inspite of the occurrence of 8 modes, only 9.3 shifted from 8.9 in March, 10.1 from 9.7 in March and 12.9 from 12.1 in February. May had altogether 10 modes of which 10.1 was from 9.3 in April, 11.9 from 10.1 in March and 13.3 from 12 in March alone were traceable from the previous months.

The progression of modes could not be traced clearly in certain months. As already pointed out this can be accounted only due to errors in sampling. The presence of larger number of modes particularly in November and

December indicates the breeding season of the oyster. This is further strengthened by the presence of large number of oyster spats settling during November-January period on suspended experimental panels (Tables 3.2, 3.3 and 3.7 in Chapter 3). The shifting of the modes shows, that the oysters grow at an average rate of 0.9 cm per month. The absence of larger modes during August and September (Table 7.2a) may be ascribed to large scale mortality of bigger oysters consequent on the monsoon and the excessive run off experienced during May to July when salinity of the medium showed a drastic reduction.

Growth

The shifting of modes indicated by graphs A,B,C,D, E and F in Fig.7.5 gives the nature of the growth of the oyster. All the curves were extrapolated to the time axis at the same rate of growth attained during various months to locate the origin of broods. The origin of broods represented by graphs A to F was found to be October (1980), December (1980), January (1981), February (1981), April (1981) and May (1981) respectively. On fitting the Von Bertalanffy curve to the length at age data, $L \alpha$ was obtained as 21 cm. The fitted curve is shown in Fig.7.8. The value of K, that is $(-\log_e \tan\theta)$ was found to be 0.179 and the age at zero length (t_o) was found to be 0.3 (Fig.7.7).

Table 7.1 Frequency distribution of height of oysters (Values in parenthesis denote percentages)

Class interval of height (cm)	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1.5 - 2.6	-	-	-	-	-	-	-	-	-	-	2(3.77)
2.7 - 2.8	-	-	-	-	-	-	-	-	-	-	1(1.88)
2.9 - 3.0	-	-	-	-	-	-	-	-	-	-	3(5.66)
3.1 - 3.2	-	-	-	-	-	-	-	1(0.79)	-	-	3(5.66)
3.3 - 3.4	-	-	-	-	-	1(0.67)	-	-	-	-	2(3.77)
3.5 - 3.6	1(2.27)	-	-	-	-	-	-	-	-	-	4(7.54)
3.7 - 3.8	-	-		-	-	-	-	1(0.79)	-	-	3(5.66)
3.9 - 4.0	-	-	1(1.28)	-	-	-	-	-	1(0.98)	-	4(7.54)
4.1 - 4.2	-	-	-	-	-	-	-	-	-	-	2(3.77)
4.3 - 4.4	-	-	1(1.28)	-	-	-	-	-	-	-	2(3.77)
4.5 - 4.6	-	-	1(1.29)	-	-	-	-	-	-	-	1(1.88)
4.7 - 4.8	-	-	1(1.28)	-	-	-	-	-	-	-	2(3.77)
4.9 - 5.0	-	-	1(1.28)	-	2(0.91)	2(0.91)	-	-	-	-	7(13.20)
5.1 - 5.2	-	-	3(3.84)	-	-	-	-	-	-	1(1.23)	2(3.77)
5.3 - 5.4	-	-	2(2.56)	1(0.81)	1(0.45)	-	-	-	-	-	3(5.66)
5.5 - 5.6	1(2.27)	-	2(2.56)	-	2(0.91)	-	-	-	-	-	7(13.20)
5.7 - 5.8	1(2.27)	-	2(2.56)	-	1(0.45)	1(0.67)	-	-	1(0.98)	1(1.23)	1(1.88)
5.9 - 6.0	2(4.54)	1(5)	2(2.56)	1(0.81)	1(0.45)	-	-	-	-	1(1.23)	1(1.88)
6.1 - 6.2	-	-	5(6.41)	1(0.81)	3(1.36)	1(0.67)	-	-	-	1(1.23)	-
6.3 - 6.4	-	-	2(2.56)	2(1.62)	4(1.82)	2(2.01)	-	1(0.79)	2(1.96)	1(1.23)	1(1.88)
6.5 - 6.6	3(6.81)	-	3(3.84)	3(2.43)	4(1.82)	1(0.67)	-	4(3.17)	-	-	-
6.7 - 6.8	1(1.27)	-	2(2.56)	3(2.43)	5(2.28)	2(1.34)	-	-	1(0.98)	-	-
6.9 - 7.0	9(20.45)	2(10)	3(2.84)	4(3.24)	3(1.36)	4(2.68	-	-	-	3(2.70)	-
7.1 - 7.2	1(2.27)	-	6(7.68)	2(1.62)	5(2.28)	5(3.35)	-	2(1.58)	2(1.96)	-	-
7.3 - 7.4	-	-	5(6.41)	2(1.62)	4(1.82)	2(1.34)	-	1(0.079)	-	-	-
7.5 - 7.6	3(6.81)	1(5)	3(3.84)	7(5.69)	6(2.73)	3(1.01)	-	5(2.96)	2(1.96)	7(8.64)	-
7.7 - 7.8	6(13.63)	-	2(2.56)	1(0.81)	7(3.19)	2(1.34)	-	6(4.76)	1(0.98)	2(2.46)	-

Table contd.

Table 7.1 contd.

7.9 - 8.0	-	3(15)	5(6.41)	6(4.87)	13(5.93)	6(4.02)	-	3(2.38)	4(3.92)	3(3.70)
8.1 - 8.2	-	-	7(8.97)	3(2.43)	8(3.65)	6(4.02)	4(6.55)	2(1.58)	-	6(7.40)
8.3 - 8.4	-	-	2(2.56)	1(0.81)	9(4.10)	5(3.35)	1(1.63)	7(5.55)	1(0.98)	1(1.23)
8.5 - 8.6	5(11.36)	1(5)	4(5.12)	10(8.13)	9(4.10)	7(4.69)	2(3.27)	4(3.17)	7(6.86)	7(8.64)
8.7 - 8.8	-	-	-	6(4.8)	5(2.28)	3(2.01)	1(1.63)	3(2.38)	4(3.92)	2(2.46)
8.9 - 9.0	6(13.63)	2(10)	2(2.56)	4(3.24)	17(7.76)	4(2.68)	2(3.27)	8(6.34)	1(0.98)	5(6.17)
9.1 - 9.2	-	-	4(5.12)	5(4.06)	10(4.56)	6(4.02)	1(1.63)	6(4.76)	5(4.90)	3(3.70)
9.3 - 9.4	-	-	1(1.28)	4(3.24)	3(1.36)	9)6.04)	3(4.91)	3(2.38)	9(8.82)	-
9.5 - 9.6	1(2.27)	3(15)	3(3.84)	2(2.62)	6(2.73)	7(4.69)	5(8.19)	6(4.70)	5(4.90)	1(1.23)
9.7 - 9.8	-	-	-	3(2.43)	6(2.73)	4(2.68)	-	6(4.76)	5(4.90)	3(3.70)
9.9 - 10.0	2(4.54)	1(5)	2(2.56)	6(4.87)	6(2.73)	4(2.68)	3(4.91)	3(2.38)	4(3.92)	2(2.46)
10.1 - 10.2	-	1(5)	1(1.28)	5(4.06)	7(3.19)	1(0.67)	3(4.91)	11(8.73)	4(3.92)	4(4.93)
10.3 - 10.4)	-	-	-	2(1.62)	6(2.73)	3(2.01)	3(4.91)	2(1.58)	4(3.92)	2(2.46)
10.5 - 10.6	-	-	-	4(3.24)	6(2.73)	4(2.68)	4(6.55)	3(2.38)	3(2.94)	6(7.40)
10.7 - 10.8	-	-	-	3(2.43)	3(1.36)	4(2.68)	3(4.91)	4(3.17)	-	1(1.23)
10.9 - 11.0	1(2.27)	1(5)	-	2(1.62)	1(0.45)	4(2.68)	2(3.27)	6(4.76)	1(0.98)	1(1.23)
11.1 - 11.2	-	-	-	4(3.24)	4(1.82)	11(7.38)	-	-	1(0.98)	1(1.23)
11.3 - 11.4	-	-	-	3(2.43)	3(1.36)	4(2.68)	-	3(2.38)	2(1.96)	1(1.23)
11.5 - 11.6	-	2(10)	-	4(3.24)	6(2.73)	7(4.69)	-	-	3(2.94)	3(3.70)
11.7 - 11.8	-	-	-	4(3.24)	5(2.28)	3(2.01)	1(1.63)	1(0.79)	3(2.94)	3(3.70)
11.9 - 12.0	1(2.27)	1(5)	-	3(2.43)	3(1.36)	2(1.34)	1(1.63)	3(2.38)	4(3.92)	4(4.92)
12.1 - 12.2	-	-	-	3(2.43)	4(1.82)	6(4.02)	6(9.83)	2(1.58)	-	-
12.3 - 12.4	-	-	-	1(0.81)	1(0.45)	-	1(1.63)	-	-	-
12.5 - 12.6	-	-	-	1(0.81)	7(3.10)	2(1.34)	2(3.27)	2(1.58)	2(1.96)	1(1.23)
12.7 - 12.8	-	-	-	-	4(1.82)	2(1.34)	1(1.63)	2(1.58)	4(3.92)	-
13.5 - 13.6	-	-	-	-	4(1.82)	1(0.67)	-	1(0.79)	1(0.96)	-
13.7 - 13.8	-	-	-	-	1(0.45)	-	3(4.91)	-	1(0.98)	-
13.9 - 14.0	-	-	-	-	1(0.45)	-	-	1(0.79)	1(0.98)	-
14.1 - 14.2	-	-	-	-	2(0.91)	1(0.67)	1(1.63)	1(0.79)	1(0.98)	-
14.3 - 14.4	-	-	-	-	2(0.91)	1(0.67)	-	1(0.79)	1(0.98)	1(1.23)
14.5 - 14.6	-	-	-	-	-	2(1.34)	2(3.27)	1(0.79)	-	1(1.23)
14.7 - 14.8	-	-	-	-	1(0.91)	1(0.67)	-	2(1.58)	1(0.98)	-
14.9 - 15.0	-	-	-	-	-	1(0.67)	1(0.79)	1(0.79)	-	1(1.23)

Table contd.

Table 7.1 contd.

15.1 - 15.2	-	-	-	-	(1(0.91)	-	-	1(0.79)	-	-
15.3 - 15.4	-	-	-	-	-	-	-	-	-	-
15.5 - 15.6	-	-	-	1(0.81)	-	-	-	1(0.79)	1(0.98)	-
15.7 - 15.8	-	-	-	-	-	-	-	-	1(0.98)	-
15.9 - 16.0	-	-	-	-	-	-	-	-	1(0.98)	-
16.1 - 16.2	-	-	-	-	-	1(0.67)	-	2(1.58)	2(1.58)	1(0.98)
16.3 - 16.4	-	-	-	-	-	-	-	-	-	-
16.5 - 16.6	-	-	-	-	-	-	-	-	1(0.98)	-
16.7 - 16.8	-	-	-	-	-	-	1(1.63)	-	1(0.98)	-
16.9 - 17.0	-	-	-	-	-	-	-	-	-	-

Table 7.2a Distribution of modal values

Month	Modal height (cm)												
August, 81	5.9	6.5	6.9	7.9	8.9	9.9							
September	7.9	9.5	11.5	-	-	-							
October	5.1	6.1	6.5	7.1	8.1	9.5	9.1						
November	6.9	7.5	7.9	8.5	9.1	9.9	10.5	11.1	11.5	15.5			
December	5.5	6.7	7.1	8.5	8.9	8.9	9.5	10.1	11.1	11.5	12.1	13.1	15.1
January, 82	6.3	7.1	8.1	8.5	9.3	10.3	11.1	11.5	12.1	14.5	16.1	-	-
February	8.1	8.5	8.9	9.5	10.5	12.1	12.5	13.7	14.5	16.8	-	-	-
March	6.5	7.7	8.3	8.9	9.7	10.1	10.9	11.9	14.9	16.1	-	-	-
April	6.3	7.1	7.9	8.5	9.3	10.1	11.9	12.9	-	-	-	-	-
May	6.9	7.5	8.1	8.5	8.9	9.7	10.1	10.5	11.9	16.1	-	-	-
June	2.5	2.9	3.5	3.9	4.9	5.5	-	-	-	-	-	-	-

Table 7.2b Shifting of the modes during various months

Curve A*	Curve B*	Curve C*	Curve D*	Curve E*	Curve F*
8.9 (Aug)	7.9 (Aug)	7.9(Sep)	6.5 (Aug)	5.9 (Aug)	6.5 (Oct)
↓	↓	↓	↓	↓	↓
9.5 (Sep)	9.1 (Oct)	9.1 (Nov)	8,1 (Oct)	7.1 (Oct)	6.9 (Nov)
↓	↓	↓	↓	↓	↓
10.5 (Nov)	9.9 (Nov)	10.1 (Dec)	9.5 (Nov)	7.9 (Nov)	7.9 (Dec)
↓	↓	↓	↓	↓	↓
11.1 (Dec)	11.5 (Jan)	12.0 (Mar)	8.9 (Dec)	8.5 (Jan)	8.1 (Jan)
↓	↓	↓	↓	↓	↓
12.1 (Jan)	12.1 (Feb)	13.3 (May)	9.3 (Jan)	8.9 (Feb)	8.5 (Feb)
↓	↓		↓	↓	↓
12.5 (Feb)	12.9 (Apr)		10.1 (Mar)	9.7 (Mar)	8.9 (Mar)
			↓	↓	↓
			11.9 (Mar)	10.1 (Apr)	9.3 (Apr)
				↓	↓
				10.5 (May)	10.1 (May)

*Refer to curves in Fig.7.5

Table 7.3 Average height obtained by Petersen's method

Age quarter years (t)	Height (cm)					
	A*	B*	C*	D*	E*	F*
1	2.0	2.0	2.0	2.0	2.0	2.0
2	5.0	5.5	5.2	5.5	5.3	5.4
3	7.1	8.0	7.5	7.4	7.1	7.7
4	8.8	10.2	9.2	8.8	8.3	9.3
5	10.5	11.8	10.6	10.0	9.4	10.6
6	12.5	13.0	12.0	11.0	10.0	11.7

*Refer to curves in Fig.7.5

Table 7.4 Length at age data used for fitting Von Bertalanffy curve

Age quarter years (t)	l_t
1	2.0
2	5.4
3	7.5
4	9.0
5	10.9
6	12.5

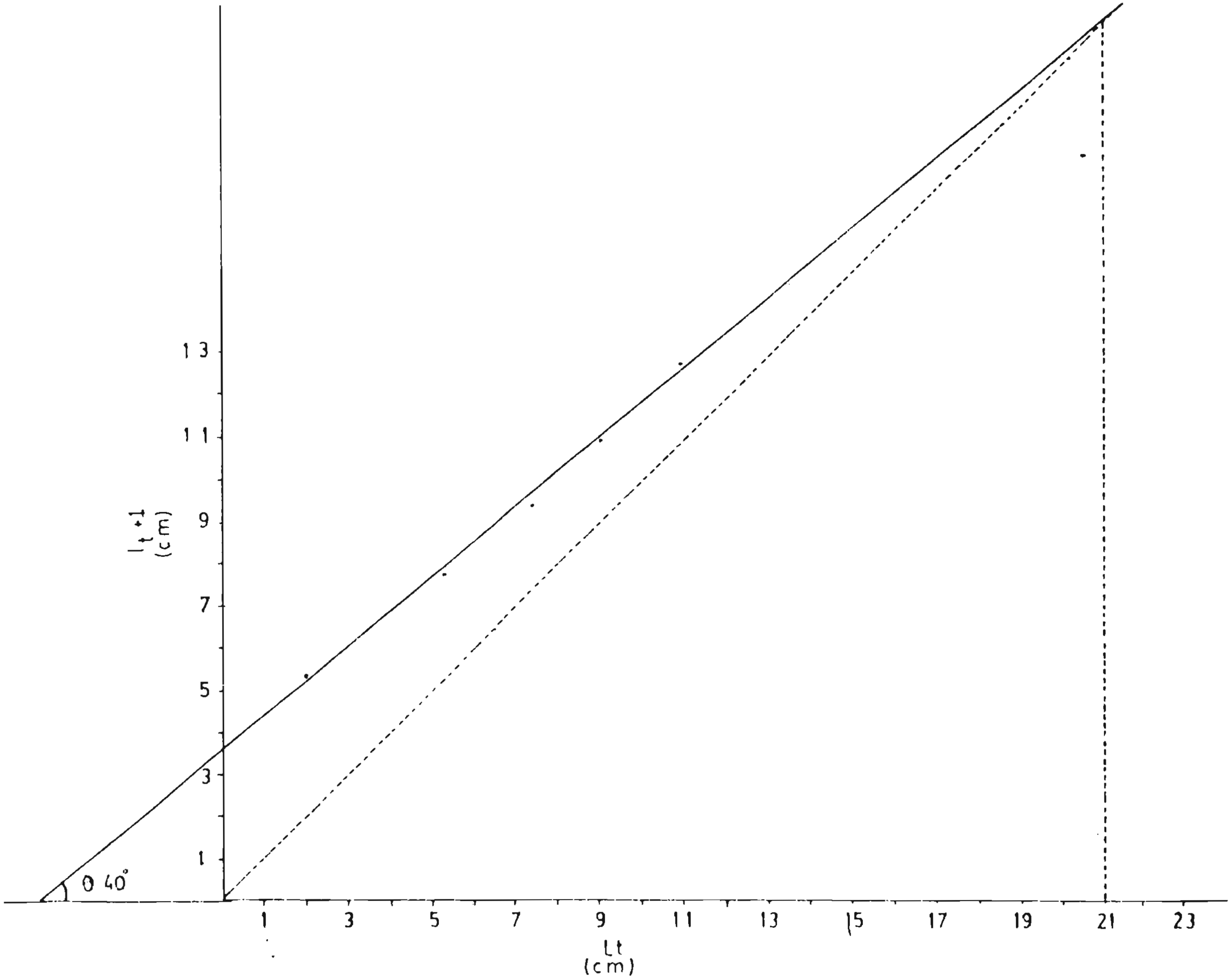


Fig 7.6. AGE AND GROWTH IN C.MADRASENSIS. FORD-WALFORD PLOT TO OBTAIN L∞ AND K FROM THE DATA DERIVED BY PETERSEN'S METHOD

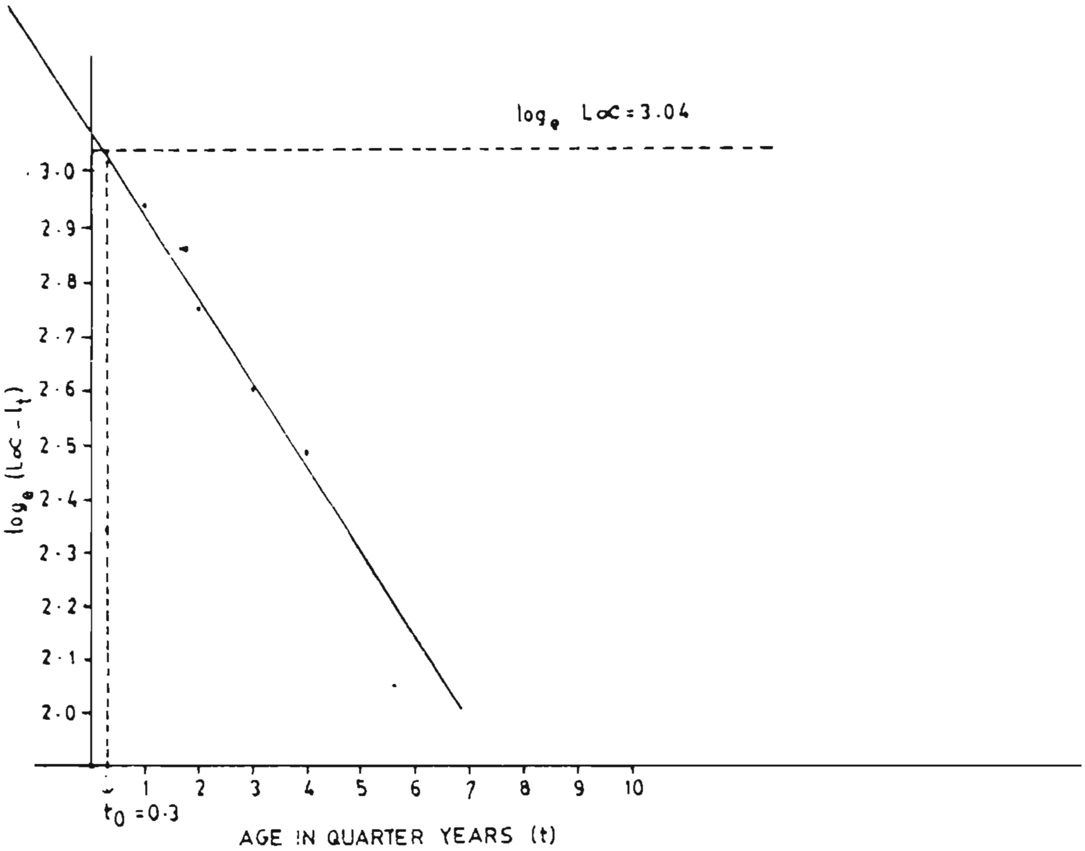


Fig.7.7. AGE AND GROWTH IN C.MADRASENSIS. CALCULATION OF t_0 FROM $\log_e (L\infty l_t)$ AGAINST AGE (l_t AND $L\infty$ FROM PETERSEN'S METHOD)

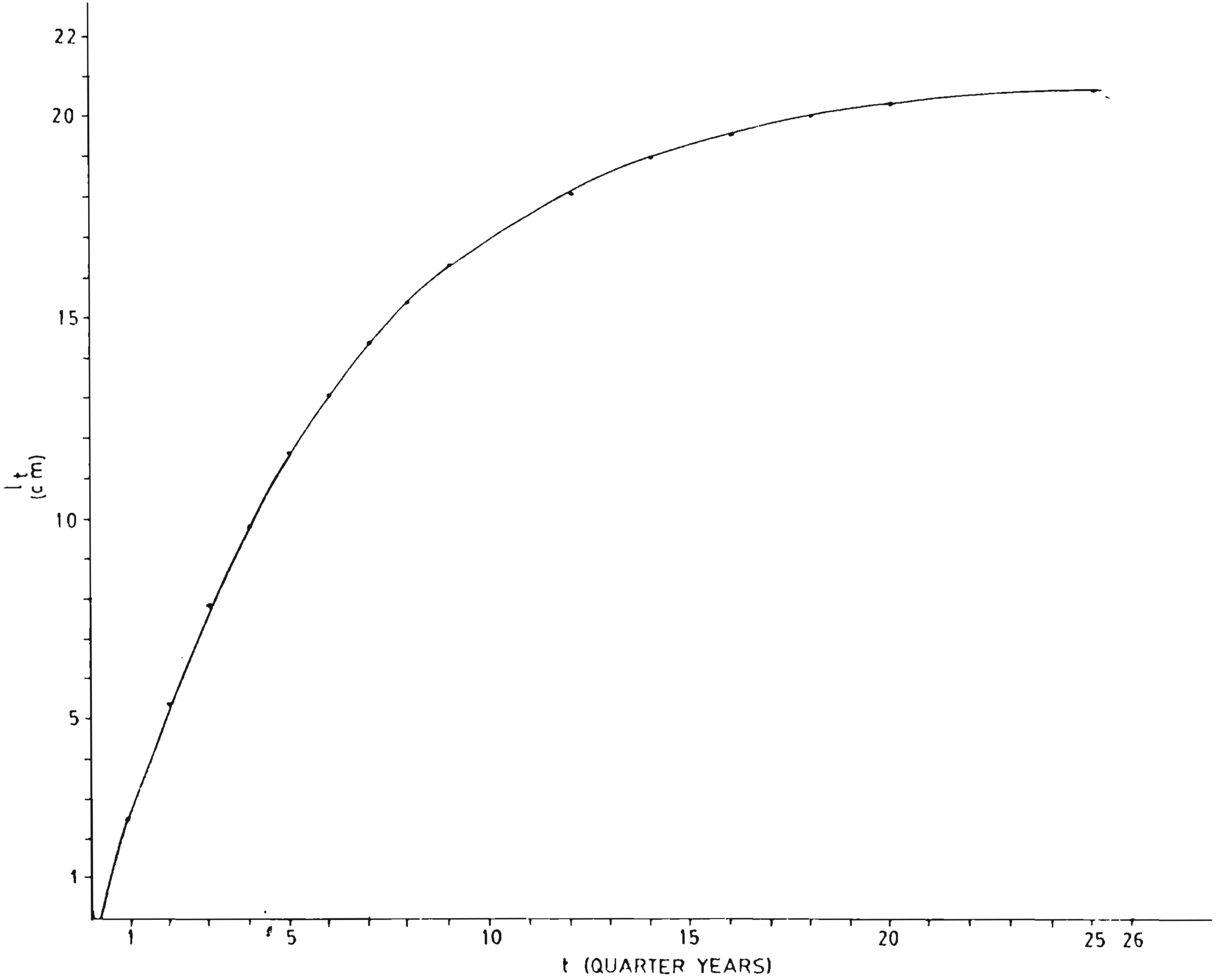


Fig. 7. 8. AGE AND GROWTH. VON BERTALANFFY'S GROWTH CURVE (BASED ON DATA OBTAINED BY PETERSEN'S METHOD)

7.4. Discussion

Growth of oysters was studied by several workers and several papers are available from different parts of the world. At the Thames Estuary oyster beds, Orton (1926, 1937) observed in oysters of the size range 5-35 mm, an average height of 19.6 mm towards the end of twelve months. He also noticed variation in mean sizes from year to year in the same oyster bed for spats of the same age. In 1922, owing to higher temperature, he observed an average height of 27.4 mm after 13 months. In the American oyster C. virginica, very fluctuating growth rates were reported by different workers from different places. From Apalachicola Bay in Florida, Ingle (1950) reported a growth of 4.5 mm after one week, 8.0 mm after 2 weeks, 62.4 mm after 15 weeks and 104 mm after 31 weeks. However, in Lousiana waters, the same species grows to 50 mm in 2 months, 75 mm in 4-5 months and 100 mm after 9 months according to Menzel (1951). Manzi et al. (1977) reported variation in growth depending on the different habitats and that C. virginica at Wando River grew 1 mm per month. However, it was 2.25 mm in oysters inhabiting the tidal creeks and 3.11 mm for those from the Blue Heron Pond in North Carolina salt marsh impoundments. Loosanoff & Nomejko (1949) observed a maximum increase of 37.2 mm during seven months in C. virginica at Milford Harbour, Connecticut. The larger monthly increase in length recorded by them is 15.2 mm with a minimum of 3.4. In the Pacific oyster C. gigas Bae & Bae (1972) reported progressive decrease in growth of oysters grown at different levels. In surface waters annual growth rate was 74.1 mm, at the middle depth it was 69.1 mm and at the bottom 68.3 mm. Meixner (1974) reported that at German waters oysters grow to 6-7 cm in two years. Lee & Yoo (1975) observed annual growth of 9.64 cm or less in hardened oysters and 7.4 cm in ordinary oysters. Angell (1975) found that at Venezuela, the mangroove oyster C. rhizophorae growing 7 cm in 10 months. In C. gryphoides, Durve & Bal (1962) observed slower growth rate, namely, 2.5, 1.7 and 3.6 respectively for July, August and September. However, during October to February the monthly growth values were 4.7, 6.5, 4.0, 5.0 and 3.0 mm respectively which were higher than what has been observed for July to September period. Growth was extremely slow from March to May, with a monthly rate of increase 1.0, 1.0 and 0.5 mm respectively. Thereafter, they observed complete cessation of growth. According to Durve & Bal (1962) C. gryphoides attains a maximum size of 37.2 mm in six months and 47.9 mm in about one year and takes about 2 years to reach the marketable size of 60-70 mm. The incidental observations of Hornell (1910a) on growth rate of oysters at the Ennur Backwaters near Madras confined to the first two months after setting, show that after 7 weeks the spats attain 2.7 cm. Paul's (1942) observation on spats from the Madras Harbour indicates that Ostrea madrasensis grow to 0.8, 4.4, 6.3, 6.5, 12.0, 12.5, 15.0, 21.5, 37 and 66 mm in length (height) after 3, 10, 13, 16, 19, 31, 44, 84 and 243 days respectively. Rao & Nayar (1956) working on the same species in the Adayar Estuary, Madras reported a maximum height of 8.5 mm in 3 weeks, 61 mm in 6 months, 84 mm in 13 months, 96 mm in 14 months, 102 mm in 15 months and 109 mm in 17 months. This suggests that the growth of oysters in the Adayar Estuary is faster than that of the same species in the Madras Harbour. An average growth rate of 51 mm after one year was recorded by Rao & Nayar (1956).

Growth rate data obtained in the present study show (Table 7.4) that the oysters grow to 2, 5.4, 7.5, 9.0, 10.9 and 12.5 cm after 3, 6, 9, 12, 15 and 18 months respectively and suggests that oysters in the Cochin Backwaters grow much faster than those inhabiting the Adayar Estuary reported by Rao & Nayar (1956). The average values obtained by Rao & Nayar (1956) is 2.6 cm after 3 months (Maximum 4 cm), 3.7 cm after 6 months (Maximum 5.3), 4.9 cm after 9 months (Maximum 6.5 cm), 5.5 cm after 12 months (Maximum 9.6 cm). The average values of the present study corresponds to the maximum values of Rao &

Nayar (1956) for the same period. Durve & Bal (1962) observed much slower growth rate in C. gryphoides at Kelwa, 50 miles north of Bombay. They observed an average height of 0.89 cm after 3 months, (Maximum 1.26 cm), 2.13 cm after 6 months (Maximum 3.72 cm), 3.24 after 9 months (Maximum 4.83 cm) and 3.38 cm after 12 months (Maximum 4.79 cm). The oysters in Cochin need about 9 months to reach the marketable size of 7-8 cm shell height.

The growth of shell in oysters is influenced by a variety of environmental factors prevailing in the habitat and the physiological condition of the oyster. Among these factors temperature, salinity, feeding (nutrition) and spawning are of importance. The paramount importance of temperature in growth of bivalves is highlighted by several workers. Korringa (1952) pointed out that faster growth takes place during summer owing to the active feeding of oysters during warmer months. Orton (1937) observed summer and autumn growth in English oyster beds. At Chesapeake Bay, Loosanoff & Nomejko (1949) observed cessation of growth in winter. Elsey (1936), Loosanoff (1950a), Nelson (1921) Galtsoff (1928) and Hopkins (1931b) demonstrated in C. virginica, C. gigas and O. lurida that shell openings are adversely affected by low temperature which in turn results in poor circulation of water and consequent scarcity of food leading to poor growth. Dame

(1972) while working on the seasonal variation in growth of inter-tidal C. virginica of various sizes observed that the instantaneous growth decreases as a result of low temperature and increased size. The Q10 values obtained from instantaneous growth rates were approximately 2 during the warmer season and were found to be higher during colder months. However, temperature fluctuations are not very much pronounced in tropical waters owing to the absence of well marked seasons contrary to what is occurring in temperate waters. Rao & Nayar (1956) could not observe any appreciable difference in temperature distribution during periods of rapid growth during October-March, moderate growth during April to June and poor growth in July-September period and concluded that such fluctuation in temperature are not sufficient enough to be the determining factor in the growth of Madras oysters. Observations in this study at Cochin also showed narrower fluctuations (4.8°C) in temperature (Table 1.1, Chapter, 1) which is not appreciable enough to bring out pronounced changes in growth.

Hornell (1910a), Paul (1942), Rao & Nayar (1956), Durve & Bal (1962) Nair (1967) have all found that the salinity of the medium influencing the growth rate rather than temperature. The fluctuation of salinity in the Cochin Backwaters is very much pronounced owing to the prevalence of the monsoons and consequent land drainage of freshwater into the estuary. Table 1.1 (Chapter 1) shows that salinity fluctuations between 1.1‰ in July to 33.9‰ in February. The minimal shifting of the modal values during May-June period (Fig.7.5) indicates poor growth and the absence of larger modal values during June can be due to decimation of adult oysters owing to very low salinity existing during this period. Rao & Nayar (1956) observed that growth is rapid during October to March, moderate from April to June and poor during July to September, coinciding with high, medium and low salinities. They also found that growth rate is not affected by short spells of low salinity, but regarded that growth is considerably retarded by prolonged sojourn under low salinity conditions in the Adayar Estuary consequent to flooding by freshwater. The deleterious effects of a drop in salinity on oysters are also demonstrated by Ranson (1943) on <u>Gryphaea angulata</u> and Chestnut (1946) on <u>C</u>. <u>virginica</u>. Loosanoff (1950b) observed <u>C</u>. <u>virginica</u> as capable of withstanding sudden changes in salinity. However, prolonged exposition to waters of low salinity is detrimental according to him. Even though juveniles survived under low salinities such as 5‰, <u>C</u>. <u>virginica</u> failed to grow in these salinities according to Chanley (1958). Galtsoff (1964) observed that oysters exposed to salinities beyond 30‰ and below 5‰ existing under marginal conditions, growth and gonad formation are considerably inhibited.

The fluctuation of salinity in Cochin Backwaters presents an alternation of mesohaline and polyhaline conditions. The mesohaline conditions existing during the monsoon period, June to September is marked by the absence of settlement or reduced intensity of oyster larvae particularly in the inter-tidal regions. This is so with regard to most of the fouling organisms and the quantity and quality of fouling is the lowest during this period (Nair, 1965, 1967). Reduction in salinity below 5‰ acts as a limiting factor which in turn increases the physiological stress of the species. Declension of salinity below 6‰ was observed to bring about starvation and cessation of physiological activities (Bütler, 1949) which results in restricted growth. According to Galtsoff (1964) at a salinity of 13‰ water filtration is very little even if the oysters were allowed to adapt for several days under such conditions. Failure of gonad development under low salinity was observed by Loosanoff (1950) and Butler (1949).

Reduced salinity observed during the monsoon period is often accompanied by the increase in the turbidity of the medium. Table 1.1 (Chapter 1) shows that maximum turbidity of the water existed during June to August (monsoon). Even though no experimental work has been carried out during this study on the effect of turbidity on oysters, it is reasonable to assume that high turbidity leads to the clogging of the gills in oysters thereby interfering with their normal feeding activity (Korringa, 1952) and oxygen consumption. These might have contributed to the lower growth observed during the monsoon period.

7.4. References

Angell, C.L. (1975) Crecimento Y mortalidad de la ostra de mangle cultivada (Crassostrea rhizophorae) Publ. Estac. Invest. Mar. Margarita. 49, 11

Askew, C.G. (1972) The growth of oysters Ostrea edulis and Crassostrea gigas in Emsworth Harbour. Aquaculture. 1, 237-260

Bae, G.M. & Bae, P.A. (1972) Studies on suspended culture of oyster Crassostrea gigas in the Korean coastal waters. 1. on the growth of oyster in the growing area. Bull. Fish. Res. Dev. Ag. Fusan, 9, 71-84

Balasubramanyan, R. & Nair, N.U.K. (1968) Fouling by oysters and its prevention. Proc. Symp. Mollusca. Pt. iii. Mar. biol. Ass. India. 730-735

*Baughman, J.L. & Baker, B.B. (1951) Oysters in Texas. Tex. Game Fish Oyster Comm. Bull. 29, 37 pp

Butler, P.A. (1949) Gametogenesis in oyster under conditions of depressed salinity. Biol. Bull. 96(3), 263-269

Cahn, A.C. (1950) Oyster culture in Japan. U.S.Fish wild Life Ser. Fish. Leaft. 383, 1-80

Calabrese, A. & Davis, H.C. (1970) Tolerances and requirements of embryos and larvae of bivalve molluscs. Helgolander Wiss. Meeresunters. 20, 553-564

Chanley, D.E. (1958) Survival of some juvenile bivalves in water of low salinity. Proc. natn. Shellfish. Ass. 48

Chestnut, A.F. (1946) Some observations on the feeding of oyster with special reference to the tide, Conv. natn.. shell fish Ass. New York, 5-7; 22-27

Cole, H.A. & Hepper, B.T. (1954) The use of neutral red solution for the comparative study of filtration rates in lamellibranchs. J. Cons. int. Explor. mar. 20, 197-203

Dame, R.F. (1972) The ecological energies of growth, respiration and assimilation in the inter-tidal American oyster, Crassostrea virginica. Mar. Biol. 17 (3), 243-250

Durve, V.S. & Bal, D.V. (1960) Hydrology of the Kelwa backwater and adjoining sea. J. Univ. Bombay. 29, 39-48

Durve, V.S. & Bal, D.V. (1962) Preliminary observations on the growth of spat of oyster Crassostrea gryphoides (Scholtheim). J. mar. biol. Ass. India. 4(2), 206-213

Elsey, C.R. (1936) The feeding rate of Pacific oysters. Prog. Rep. Pacif. Biol. Stn. Nanaimo, B.C. No.27

*Ferreira, L. (1975) Estudio comparativo de tecnicas de cultivo experimental de ostras (Ostrea chilensis) Inf. Pseq. Inst. Form. Pseq. Santiago. 58, 1-18

Ford, E. (1933) An account of herring investigations conducted at Plymonth during the years 1924-1933. J. mar. biol. Ass. U.K. 19, 305-384

Foster-Smith, R.L. (1976) Some mechanisms for the control of pumping activity in bivalves. Mar. Behav. Physiol. 4(1), 41-59

Fujiya, M. (1970) Oyster farming in Japan. Helgolander Wiss. Meeresunters. 20, 464-479

Galtsoff, P.S. (1928) Experimental study of the function of the oyster gill and its bearing on the problems of oyster culture and sanitary control of the oyster industry. Bull. U.S. Fish. 44, 1-39

Galtsoff, P.S. (1964) The American oyster Crassostrea virginica (Ghelin). Fish Bull. Fish. Wildlife Ser. 64, 1-480

Glaser, O.C. (1903) Some experiments on the growth of oysters. Science New. Ser. 17, 529-530

Gunter, G. (1938) Comments on the shape, growth and quality of the American oyster. Science New. Ser. 88, 546-547

Hanley, L.E., Newkirk, G.F., Wauga, D.W. & Dayle, R.W. (1976) A report on the quantitative genetics of growth and survivourship of the American oyster Crassostrea virginica under laboratory condition. Proc. 10th Eur. mar. biol. Symp. 1976

Havinga, B. (1928) The daily rate of growth of oysters during summer. J. Cons. int. Explor. mar. 3, 231-245

Hopkins, A.E. (1931a) Factors influencing the spawning and setting of oysters in Galreston Bay, Texas. U.S. Bur. Fish. 47, 57-83

Hopkins, A.E. (1931b) Temperature and shell movements of oysters. Bull. U.S. Bur. Fish. 47, 1-14

Hopkins, A.E. (1936) Adaptation of the feeding mechanism of the oyster (Ostrea gigas) to changes in salinity. Bull. U.S. Bur. Fish. 48, 345-364

Hornell, J. (1910a) Note on an attempt to ascertain the principal determining factor in oyster spawning in Madras Backwaters. Madras Fish. Bull. 4, 25-31

Hughes, G.W.L. (1977) Growing the Japanese oyster (Crassostrea gigas) in sub-tropical sea water fish ponds. 1. Growth rate, survival and quality index. Aquaculture. 11, 217-229

Ingle, R.M. (1950) Summer growth of the American oyster in Florida waters. Science, 112, 338-339

Ingle, R.M. & Dawson, C.E. (1952) Growth of American Oyster Crassostrea virginica in Florida waters. Bull. mar. Sci. Gulf Carribb. 2, 393-404

*Korringa, P. (1947) "Les Vicissitudes de l' Ostreiculture Hollandaise elucidees par la science ostreicole moderne. Ostreiculture cult. Mar. Paris. 16, 3-9

*Korringa, P. (1951) Structure et Croisance de la Coquille de l' huitre. C.R. Soc. Neerl. Zool. Seance. Archs. neerl. Zool. 8, 442-443

Korringa, P. (1952) Recent advances in oyster biology Q. Rev. Biol. 27(3) 266-308; 339-365

Lee, C.K. & Yoo, S.K. (1975) Growth of Crassostrea gigas (Thunburg) at the oyster farm of Gajodo, Bull. natn. Fish. Univ. Busan. (Nat. Sci) 14 (2), 41-50

Loosanoff, V.L. (1947) Growth of oysters of different ages in Milford Harbour, Connecticut. Southern Fisherman, 7, 22-225

Loosanoff, V.L. (1950) The behaviour of oysters transferred from low to high salinties. Anat. Rec. 108, Abstract 147

Loosanoff, V.L. (1950a) Rate of water pumping and shell movements of oysters in relation to temperature. Anat. Rec. 108, Abstract 229

Loosanoff, V.L. (1950b) Variations in intensity of setting of oysters in Long Island Sound. Atlant. Fisherman. 30, 14, 16, 47

Loosanoff, V.L. & Nomejko, C.A. (1949) Growth of oysters O. virginica during different months. Biol. Bull. 97(1) 82-94

Loosanoff, V.L. & Tommers, F.D. (1948) Effect of suspended silt and other substances on rate of pumping activity in bivalves. Mar. Behav. Physiol. 41(1), 41-49

Losee, E. (1979) Relationship between larval and spat growth rates in the oyster Crassostrea virginica. Aquaculture. 16(2), 123-126

Manzi, J.J., Burrel, V.G. & Carson, W.Z. (1977) A comparison of growth and survival of sub-tidal Crassostrea virginica (Gmelin) in South Carolina Salt Marsh Impoundments. Aquaculture. 12, 293-310

Maurer, D. & Aprill, G. (1973) Feasibility study of raft culture of oysters in the Delaware Bay area. Rep. Del. River Basin Comm. Univ. Del. Lewes, Del. 180 pp

McHugh, J.L. & Andrews, J.D. (1955) Computation of oyster yields in Virginia. Proc. natn. Shell Fish. Ass. 45, 217-239

*Meixner, R. (1974) Erfahrungen bei der vertikalen Aufzucht Von Pfahlumuschelu und Austern in den deutschen Kuestengewaessern. Arab. Dtsch. Fischereiverb. 16, 175-179

Menzel, R.W. (1950) Early sexual development and growth of the American oyster in Lousiana waters. Science. 113, 719-721

Nair, N.U.K. (1965) Marine fouling in Indian Waters. J. scient. ind. Res. 24(9), 483-488

Nair, N.U.K. (1967) The settlement and growth of major fouling organisms in Cochin Harbour. Hydrobiologia. 30 (3-4), 503-512

Needler, A.W.H. (1941) Oyster farming in Eastern Canada. Bull. Fish. Res. Bd Can. 60, 1-83

Nelson, T.C. (1921) Aids to successfull oyster culture. 1. Procuring the seed. Bull. New Jers. agric. Exp. Stn. 351, 59 pp

Nelson, T.C. (1922) Rept. New Jers. agric. Exp. Stn. for the year ending June, 30, 1921. 287-299

Newkirk, G.F., Galey, L.E., Waugh, D.L. & Doyle, R. (1977) Genetics of larvae and spat growth rate in oyster Crassostrea virginica. Mar. Biol. 41(1) 49-52

*Orton, J.H. (1926) Report on a Survey of the Fal Estuary Oyster Beds with Notes on the Biology of the Oyster (O. edulis). J.H. Lake & Co. Falmouth

Orton, J.H. (1928) On rhythmic periods in shell growth in Ostrea edulis with a note on fattening. J. mar. biol. Ass. U.K. 15, 365-427

Orton, J.H. (1937) Oyster Biology and Oyster Culture. The Buckland lectures for 1935. Edward Arnold & Co. London, 211 pp

Paul, M.D. (1942) Studies on the growth and breeding of certain sedentary organisms in the Madras Harbour. Proc. Indian Acad. Sci. 15, 1-42

Quayle, D.B. (1952) The seasonal growth of the Pacific oyster (Ostrea gigas) in Ladysmith Harbour. Rep. prov. Dep. Fish. Br. Columb. 85-90

Quayle, D.B. (1971) Pacific oyster culture in British Columbia. Bull. Fish. Res. Bd Can. 169, 34

*Ranson, G. (1943) La Vie des Huitres. Historie Naturelles. 1. 1,260, Gallimard, Paris

*Ranson, G. (1948) Ecologie et repartition geographique des Osteides vivants. Int. Congr. Zool. 13 (Paris) 455-456

Rao, K.V. (1951) Observations on the probable effects of salinity on the spawning, development and setting of the Indian backwater oyster, Ostrea madrasensis Preston. Proc. Indian Acad. Sci. 33 B, 231-256

Rao, K.V. & Nayar, K.N. (1956) Rate of growth in spat and yearlings of the Indian backwater oyster Ostrea madrasensis Preston. Indian J. Fish. 3(2) 231-260

Spencer, B.E. & Gough, C.J. (1978) The growth and survival of experimental batches of hatchery reared spat of Ostrea edulis L. and Crassostrea gigas Thunburg using different methods of tray cultivation. Aquaculture. 13, 293-312

Tenore, K.R. & Dunstan, W.M. (1973) Comparison of feeding and biodeposition of three bivalves at different food levels. Mar. Biol. 21, 190-195

Von Bertalanffy, L. (1938) A quantitative theory of organic growth. Hum. Biol. 10(2), 181-213

Von Vertalanffy, L. (1957) Quantitative laws in metabolism and growth. Q. Rev. Biol. 32, 217-231

Walford, L.A. (1946) A new graphic method of describing the growth of animals. Biol. Bull. Woods Hole. 90, 141-147

Walne, P.R. (1958) Growth of oysters (*Ostrea edulis* L) J. mar. biol. Ass. U.K. 37, 591-602

Walne, P.R. (1972) The influence of current speed, body size and water temperature on the filtration rate of five species of bivalves. J. mar. biol. Ass. U.K. 52, 345-347

Walne, P.R. (1975) On growth of *Ostrea edulis* in Menai Straits. Proc. Challenger Soc. 4(6) 273

Walne, P.R. & Mann, R. (1975) Growth and biochemical composition of *Ostrea edulis* and *Crassostrea gigas*. Proc. 9th Eur. mar. biol. Symp. (Barnes, H. Ed.) Aberdeen Univ. Press pp.587-607

Walne, P.R. & Spencer, B.E. (1974) Experiments on the growth and food conversion efficiency of the spat of *Ostrea edulis* L. in a recirculating system. J. Cons. Int. Explor. Mer. 35, 303-318

Widdows, J. & Bayne, B.L. (1971) Temperature acclimation of Mytilus edulis with reference to its energy budget. J. mar. biol. Ass. U.K. 51, 827-843

*Winter, J.E. (1969) Uber den Einfluss der Nahrungs Konzentration und anderer Faktoren auf. Filtrienleistung und Nahrung sausnutzing der Muschelr Arctica islandica und Modiolus modiolus. Mar. Biol. 4, 87-135

---

*Not consulted in original

CHAPTER 8

BIOCHEMICAL CHANGES AND SEASONALITY OF TRACE METAL CONTENTS OF SOFT TISSUE IN *C. MADRASENSIS*

CHAPTER 8

BIOCHEMICAL CHANGES AND SEASONALITY OF TRACE METAL CONTENTS OF SOFT TISSUE IN *C. MADRASENSIS*

8.1. Introduction

The chemical composition of several marine organisms has been studied in detail and a considerable body of information has been accumulated on this subject (Vinagradov, 1953). Basically such information is useful to understand the role of major biochemical constituents such as carbohydrate, lipid and protein in the metabolic activities of the animal. Outstanding contributions in the metabolic transformation of fuel reserves in bivalves are those of Mitchell (1915), Russel (1923), Milroy (1909), Okazaki & Kobayashi (1929), Tully (1934), Giese (1966) Hammen (1969), Cambell & Bishop (1970), Gabbot & Walker (1971), Gilles (1972), Dame (1972b), Gabbot & Holland (1973), Holland & Spencer (1973), Holland & Hannant (1974, 1976) and Bernard (1974).

Several species of oysters have been studied for their biochemical composition from different parts of the world. Species such as *Crassostrea virginica* has been studied by Galtsoff et al. (1947), Menzel & Hopkins (1952), Lee et al. (1960). and Dame (1972b); C. gigas by Sekine et al. (1929); Masumoto et al. (1934); Establier (1966); Gastaud et al. (1972); C. madrasensis (Venkataraman & Chari, 1951); C. gryphoides by Durve & Bal (1961b); Sarvaiya (1977); C. cucullata by Rajagopal et al. (1975); Sarvaiya (1977b); Ostrea edulis by Russel (1923), Garrder & Alvsaker (1941); Kravarie (1953); Walne (1970) Gabbot & Walker (1971); Gabbot & Holland (1973), Holland & Spencer (1973); Helm et al. (1973); Holland & Hannant (1974, 1976); O. lurida by Tully (1936); O. lutaria by Malcom (1929) and O. circumpicta by Okasaki & Kobayashi (1929).

Giese et al. (1959a) and Giese (1959) have remarked that "the gonad is the locus of intensive biochemical synthesis, at the time gametes are being formed. In the male large amounts of nucleic acid are needed for the sperm heads and in the female much lipids and protein mobilized to be stored in the eggs. When reserves are stored in other organs preceding gametogenesis, transfer of these reserves to gonadal synthetic centres occurs at gametogenesis". Fluctuation in biochemical constituents with respect to reproductive cycles in mussels was observed by Lubet (1959); Lubet & Le Feron de Long Camp (1969); Widdows & Bayne (1971) De Zwann & Zandee (1977), Bayne

(1973), Gabbot & Bayne (1973), George & Nair (1975). In the sea urchins considerable work on this aspect of reproductive biology has been carried out by Giese & Araki (1962), Giese *et al*. (1964); Greenfield *et al*. (1958) and Giese *et al*. (1959, 1959a, 1959b).

The present study was carried out with a view to collecting information on the biochemical variations accompanying breeding cycle in *C. madrasensis* inhabiting the Cochin Backwaters and to determine whether systematic variations of any of the biochemical constituents might be correlated with the annual breeding cycle. If any such variations exist, it might help in a clearer understanding of the reproductive cycle and other important physiological status of this commercially important bivalve. Further, it would also facilitate comparison to some extent with other species of oysters studied from other habitats. A few studies on the accumulation of biochemical constituents and their transformation during the reproductive period in bivalve mulluscs have been carried out from the Indian sub-continent and they are chiefly those of Nagabhushanam (1961), Saraswathy & Nair (1969), Suryanarayanan & Alexander (1972), Nagabhushanam & Deshmuk (1974), George & Nair (1975), Nagabhushanam & Talikedkar (1977), Nagabhushanam & Dhamne (1977), Mane & Nagabhushanam (1977). In the present study an effort has been made to examine the nature of fluctuations in water content, carbohydrate, protein, lipids, ash, cadmium, copper, iron, manganese, zinc and mercury in C. madrasensis of the Cochin Backwaters.

Detailed comparisons and broad generalisations are difficult in these biochemical studies. This is mainly due to variations in the habitat, seasonality and breeding periodicity of the species concerned. Moreover aspects like age and physiological status of such experimental animals are seldom taken into consideration. In the present study, estimation were made on the whole tissue to serve as a basis for more detailed studies of specific organs and tissues later.

8.2. Material and methods

Live specimens of C. madrasensis were collected monthly from August 1981 to September 1982 from the shipping channel near barmouth in the Cochin Backwaters and were brought to the laboratory for biochemical estimations. Individual oysters were shucked and the sex of the oyster was determined by examining a gonadal smear under the microscope. As the weight of a single oyster meat was insufficient for the estimations, pooled samples of male and female oysters separately were employed in the biochemical estimations.

Indeterminate oysters were not employed in biochemical estimations as sufficient number was not available each time. After pulverising the samples in a blender, glycogen was estimated by the method of Umbriet & Burris (1959) and measurement of optical density was carried out in a spectronic 20 (Bosch & Lomb) calorimeter at 620 nm.

For the determination of water content the method outlined in AOAC (1975) was followed. For the determination of protein, fat and ash, the oven dried samples were employed. For protein estimation, a known quantity of the dry material was digested with concentrated sulphuric acid and a pinch of digestion mixture containing copper sulphate and potassium sulphate in the ratio 1:5. This was heated till it cleared and made upto a known volume and analysed for nitrogen in a Technicon Auto Analyser (Technicon Industrial Systems, Tarry Town, N.Y. 10591) using ammonium sulphate as standard. The determination of nitrogen by this method is based on a colorimetric method in which an emerald green colour is formed by the reaction of ammonia, sodium salicylate, sodium nitroprusside and sodium hypochlorite in a buffered alkaline media at a pH of 12.8 to 13.0. The ammonia salicylate complex is read at 660 nm. The method followed is as per Industrial Method no.334-74 W/B$^+$. All the reagents used were of analar quality. The quantity of protein was derived by multiplying the total nitrogen value by 6.25. Fat and ash were estimated as per the method outlined in AOAC (1975).

8.3. Results

8.3.1. Water content: The changes in the tissue levels are summarised in Table 8.1 and Figs.8.1 and 8.2. A survey of the table and figure shows that the moisture varied in males from 79% to 89.55% with an average of 84.75%. In females a minimum of 80.7% and a maximum of 85.48% were observed with a mean value of 83.96%. The water level recorded here is that maintained by the whole tissue.

8.3.2. Protein content: The total protein content varied from 2.34% to 6.04% with an average value of 4.36% in males. The corresponding values for female were 2.67% and 6.01% with a mean value of 4.4%. The fluctuation of protein was more or less similar in male and female (Fig.8.1 and 8.3). From October 1981 onwards, there was a build up in the protein content (except in October 1981) reaching the maximum in February 1982 (6.04%) in males. This gradually delined and reached 2.34% during August 1982. The maximum value recorded for female was 6.01% in April 1982 and minimum of 2.67% in October, 1981. From October to February-March during which period the oysters were spawning, the protein content of the whole tissue increased and from April onwards, the post-spawning period, the oysters registered a decline in the protein content.

8.3.3. Glycogen content: Glycogen showed distinct fluctuation with the breeding condition and development of the gonad. In female, the glycogen content was low in February (0.04%), which is the late phase of the spawning season. During July when the oysters were not spawning this rose to 9.3%. In male oysters also, glycogen followed a similar trend in distribution with a minimum of 0.02% in May, 1982 and maximum of 10.43% in September. The major spawning of oysters takes place during October to March in Cochin Backwaters and during this period the glycogen values were at the lowest. From March-April onwards oysters pass on to a resting stage and glycogen started accumulating during this period till the next spawning season. Glycogen showed an inverse relationship with protein content in oysters.

8.3.4. Fat content: Fat content showed a similar trend as that of glycogen. As is evident from Fig.8.1 it registered a peak value of 2.81% in September, and a minimum of 0.47% during April with an average value of 0.9% in males. Females showed (Fig.8.2) a slightly higher value, a maximum of 3.37% in September and a minimum of 0.95% during March, with an average of 1.49%. Fat content was low during the period from December to May, with peak values in September in both the sexes.

8.3.5. Ash content: (Mineral matter). A maximum ash content of 2.71% was noticed in January, and a minimum of 0.72% in July with a mean value of 1.65% in males. In females maximum of 2.86% in February and minimum of 0.53% in

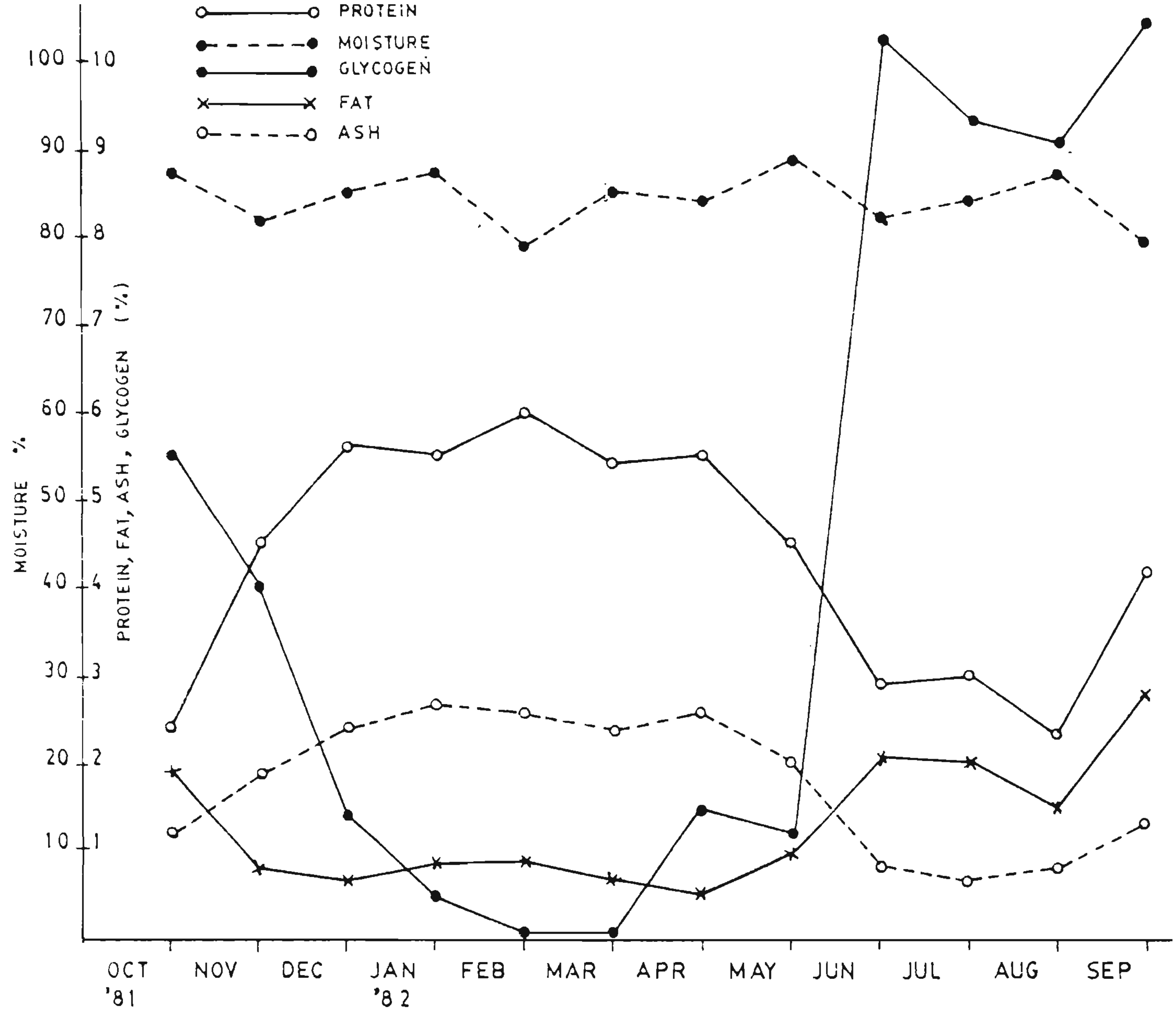


Fig. 8.1. THE BIOCHEMICAL COMPOSITION OF C. MADRASENSIS (MALE). DURING OCT.'81 TO SEP. '82

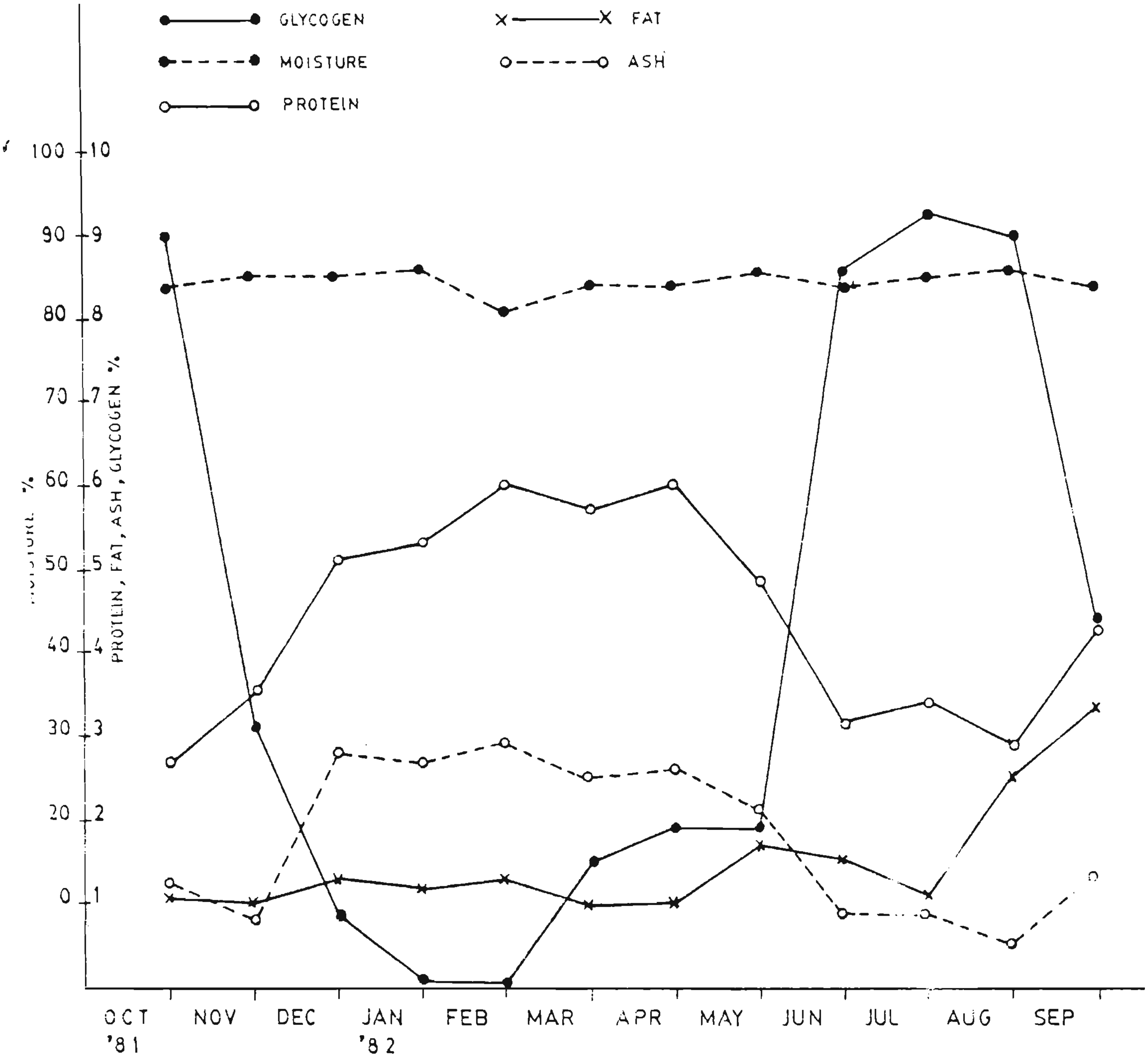


Fig. 8.2. THE BIOCHEMICAL COMPOSITION OF C.MADRASENSIS (FEMALE) DURING OCT. '81 TO SEP. '82

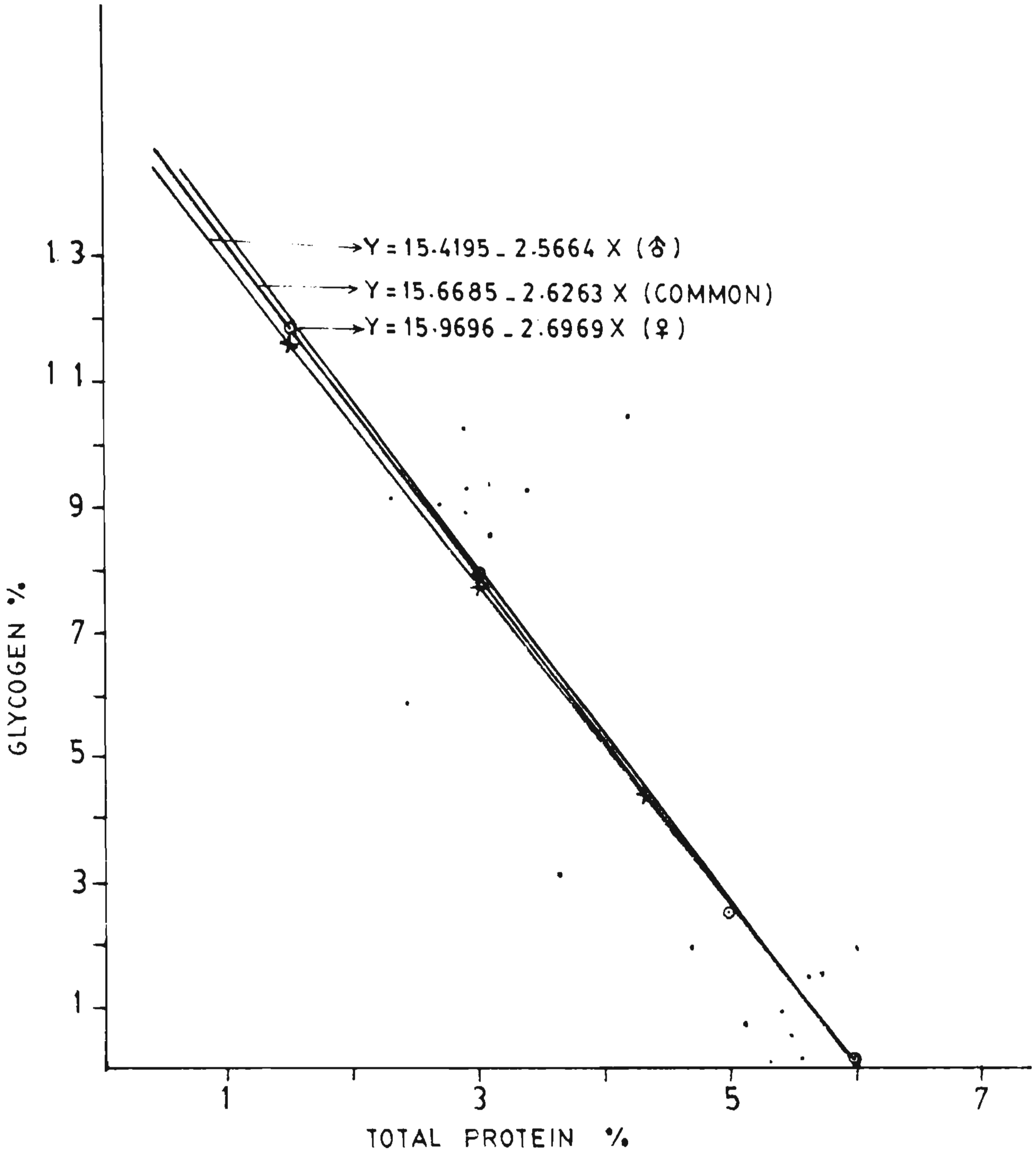


Fig. 8. 3. RELATION BETWEEN GLYCOGEN AND TOTAL PROTEIN

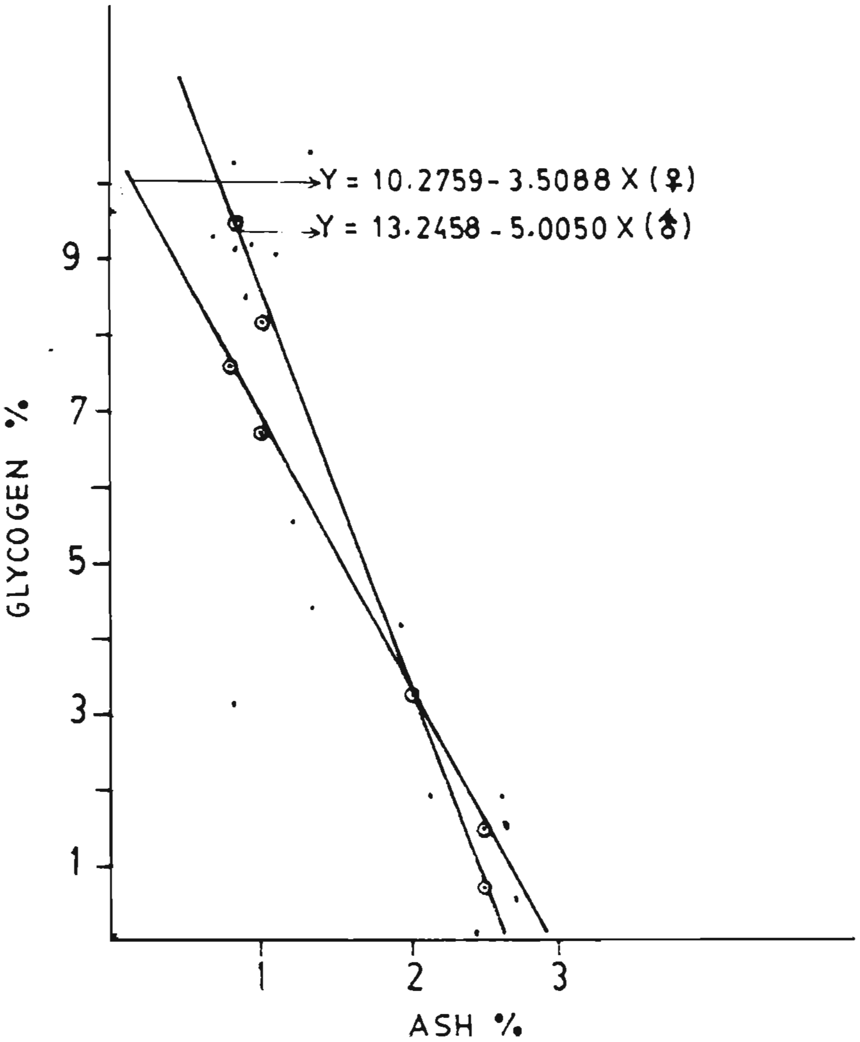


Fig. 8.4. RELATION BETWEEN GLYCOGEN AND ASH CONTENT

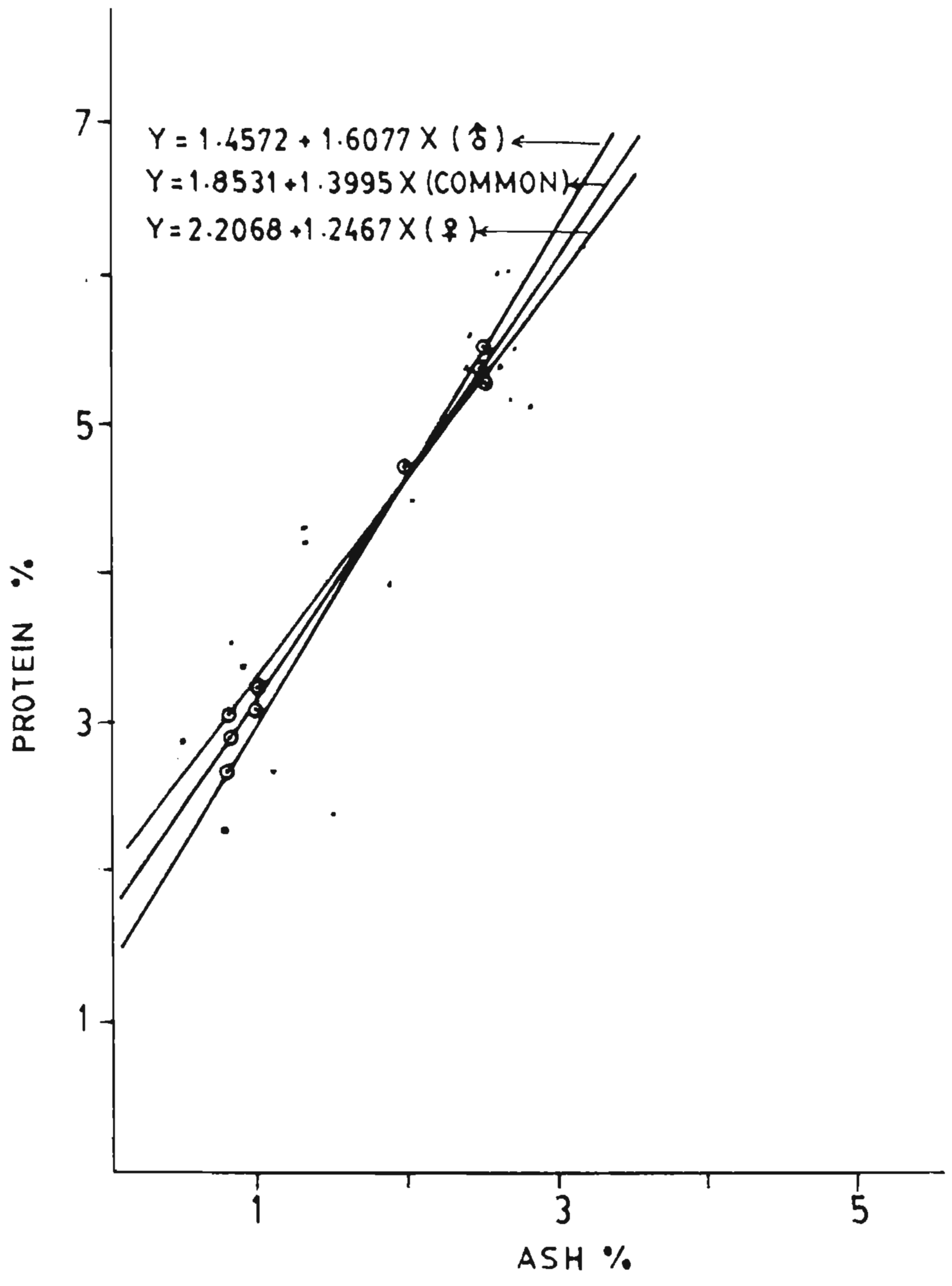


Fig. 8.5. RELATION BETWEEN PROTEIN AND ASH CONTENT

August were recorded with an average of 1.76%. The fluctuation of ash content also followed a pattern similar to that of protein.

Biochemical constituents such as glycogen, ash and total protein which showed inter-relationship among themselves were statistically analysed to determine the significance of their inter-relationships and also to check whether there is any difference in the form of relationship between the sexes.

Variability in the distribution of glycogen in males appeared to be relatively larger than in females (Table 8.2). However, F test (two tailed) for homogeneity for differences between variances showed no significance. The relationship between glycogen and total protein for male and female was,

♂ $Y = 15.4195-2.5664\ X$

♀ $X = 15.9696-1.9696\ X$

where X is the total protein % and Y is glycogen %.
The linear relationship between glycogen and total protein was highly significant ($r = -0.80007$** for males and $r = -0.8939$** for females) showing an inverse relationship between glycogen and protein. Whether the rate of change in glycogen in relation to protein was the same in males and females was tested by analysis of co-variance (Table 8.2). The regression lines did not differ in their slopes

Table 8.1 The distribution of glycogen, total protein, fat, ash and moisture in male and female *C. madrasensis* during October 1981 to September 1982 (WWB)

Date of sampling	Glycogen % ♂	Glycogen % ♀	Total protein % ♂	Total protein % ♀	Fat % ♂	Fat % ♀	Ash % ♂	Ash % ♀	Moisture % ♂	Moisture % ♀
15-10-81	5.50	9.00	2.40	2.67	1.88	1.11	1.15	1.11	87.06	84.84
16-11-81	4.03	3.07	4.53	3.56	0.79	1.00	1.90	0.76	82.20	84.90
14-12-81	1.38	0.76	5.61	5.12	0.67	1.32	2.43	2.83	84.50	85.20
13-1-82	0.47	0.14	5.54	5.26	0.88	1.23	2.71	2.72	86.46	85.48
8-2-82	0.11	0.04	6.04	5.99	0.92	1.33	2.56	2.86	79.00	80.70
15-3-82	0.04	1.49	5.38	5.72	0.73	0.95	2.42	2.50	84.56	83.94
19-4-82	1.46	1.91	5.46	6.01	0.47	0.98	2.64	2.62	83.88	84.04
12-5-82	1.20	1.91	4.47	4.76	0.96	1.66	2.04	2.13	88.02	85.13
14-6-82	10.17	8.48	2.90	3.12	2.08	1.52	0.76	0.85	82.33	83.19
12-7-82	9.31	9.20	2.96	3.42	2.08	1.14	0.72	0.88	83.77	83.82
12-8-82	9.05	8.88	2.34	2.80	1.47	2.50	0.75	0.53	86.46	85.42
13-9-83	10.43	4.32	4.23	4.31	2.81	3.27	1.30	1.33	79.14	82.94
Maximum	10.43	9.20	6.03	5.99	2.81	3.27	2.71	2.86	89.57	85.48
Minimum	0.04	0.04	2.34	2.67	0.47	0.95	0.72	0.53	79.00	80.70
Average	4.20	4.10	4.36	4.40	0.9	1.49	1.65	1.76	84.75	83.96

Table 8.2 Analysis of Covariance of glycogen and total protein

	df	ΣX^2	ΣXY	ΣY^2	Reg. Coeff	df	Deviation SS	from mean M
1 Within males	11	20.0763	-51.5240	206.5764	-2.5664	10	74.3447	7.4345
2 Within females	11	16.8822	-45.5293	152.8119	-2.6969	10	30.0246	2.0025
3						20	104.3692	5.2185
4 Pooled within	22	36.9585	-97.0533	359.3883	-2.6260	21	104.5253	4.9774
5	Difference between slopes					1	0.156117	0.1561
6 Between B	1	0.0380	-0.1090	0.3128				
7 W + B	23	36.9965	-97.1624	359.7011	-2.6263	22	104.5276	
8	Between adjusted means					1	0.0022	0.0023

Comparison of slopes $F = \frac{0.1561}{2.2160} < 1$ NS (df = 1,20)

Comparision of elevation $F = \frac{0.0022}{4.9776} < 1$ NS (df = 1,21)

Table 8.3 Analysis of covariance of glycogen and ash

	df	ΣX^2	ΣXY	ΣY^2	Reg. coeff	Deviation from regression		
						df	SS	M.S
With in								
1 Males	11	6.9813	-34.9415	206.5764	-5.0050	10	31.6933	3.1693
2 Females	11	9.4228	-33.0626	152.8119	-3.5088	10	36.8025	3.6903
3						20	68.4958	3.4348
4 Pooled within	22	16.4041	-67.0041	359.3883	-4.0846	21	85.7037	4.0811
5	Difference between slopes					1	17.2079	17.2079

Comparison of slopes $F = \frac{17.2079}{3.4248} = 5.02^*$ (df = 1,20)

Table 8.4 Analysis of covariance of total protein on ash

	df	ΣX^2	ΣXY	ΣY^2	Reg. coeff	Deviation from regression df	SS	MS.
1 Within males	11	6.9813	11.2235	20.0763	1.6076	10	2.0327	0.2033
2 Females	11	9.4228	11.7478	16.8822	1.2467	10	2.2359	0.2236
3						20	4.2686	0.2134
4 Pooled within	22	16.4041	22.9713	36.9585	1.4003	21	4.7909	0.2281
5	Difference between slopes					1	0.5224	0.5224
6 Between B		0.0028	-0.0103	0.0380				
7 W + B	23	16.4069	22.9609	36.9965	1.3995	22	4.8634	
8	Between adjusted means					1	0.0743	0.0624

Comparison of slopes $F = \frac{0.5224}{0.2134} = 2.45$ (df = 1,20) N.S

Comparison of elevations $F = \frac{0.0724}{0.2281} < 1$ (df = 1,21) N.S

Table 8.5 <u>Trace metals load in C. madrasensis</u>

Month	Cd p.p.m.	Cu p.p.m.	Fe p.p.m.	Mn p.p.m.	Zn mg/g	Hg p.p.b.
September, 81	1.15	13.40	44.0	1.00	0.288	26.50
October	2.93	15.00	59.3	1.00	0.960	57.90
November	1.54	13.25	70.0	2.05	0.800	52.50
December	1.57	14.00	117.0	7.60	0.640	45.56
January, 82	2.25	33.50	100.0	5.20	0.992	72.52
February	2.67	38.50	113.5	3.90	1.408	44.24
March	2.51	32.50	98.0	3.10	0.648	22.32
April	1.57	27.50	29.0	1.00	0.640	20.92
May	1.52	30.50	25.0	0.70	0.664	18.10
June	1.88	35.50	31.0	0.80	0.920	19.71
July	1.68	28.30	40.3	0.90	0.816	23.86

as revealed by F test (Table 8.2). The two regression lines are shown in Fig.8.3. The difference between the elevation of the two lines were also tested (Table 8.2) and was found to be insignificant. This shows that the difference in glycogen between sexes was not significant. The relationship could be fiffted by a common regression line;

$$Y = 15.6685 - 2.6263\ X$$

The plot of glycogen on ash is shown in Fig.8.3. As the plot showed an inverse linear relationship between the two, a regression line of glycogen (y) on ash (x) was fitted separately for males and females. The fitted lines are,

$$♂\ Y = 13.2458 - 5.0050\ X$$

$$♀\ Y = 10.2759 - 3.5088\ X$$

The linear relationships were found to be highly significant as evidenced by the high correlation coefficient ($r = -0.9201^{**}$ and -0.8713^{**} for females). Some apparent differences is noted in the slopes of the two lines. This was further tested by analysis of covariance (Table 8.3). Table 8.3 shows that the difference between the slopes is significant at 5% level. Thus the rate of change in glycogen for a unit change in ash content differs for males and females. Therefore, two separate regression lines are required for males and females. These are shown in Fig. 8.3. Fig.8.4 shows a plot of total protein (y) on ash (x) separately for males and females. As a linear trend is observed, a straight line was fitted by the method of least squares. The equations are,

♂ $Y = 1.4572+1.6077\ X$

♀ $Y = 1.2068+1.2467\ X$

Straight lines are found adequate fits as evidenced by the highly significant correlation coefficient ($r = 0.9480^{**}$ for males and 0.9314^{**} for females). Whether a single straight line will hold good for both the sexes was tested by analysis of covariance (Table 8.4). The difference between the slopes was found to be insignificant indicating that the change in total protein for a unit change in ash content was the same in both the sexes. The F test for difference in the elevations of the two lines showed insignificance (Table 8.4). Thus a common regression line could be fitted to both the sexes and the common equation worked out to:

$Y = 1.8831+1.3995\ X$

The common regression line together with the separate ones is shown in Fig.8.4

8.4. Discussion

Estimation of the fluctuation in biochemical constituents is aimed at gathering information pertaining to the biochemical make up of the animal and to correlate it with its various life activities. The energy required for various metabolic activities of the animal during different phases of life particularly reproductive phase, is used from the stored energy. Even though animals directly depend on utilisation of energy trapped from food, several animals resort to utilising stored energy, particularly during the breeding period, cease. feeding and draining out the reserve food supply (Bailey, 1952).

The water content in the body of males and females followed the same trend. Cyclic variation in water content corresponding with breeding cycle have been noticed in oysters (Durve & Bal, 1961b; Greenfied *et al.* 1958), prawns and lobsters (George & Patel, 1956). In *C. virginica*, Galtsoff (1964) observed unfavourable conditions as responsible for fluctuation of water content. However, no definite pattern can be delineated in the present instance. Increase in water content after spawning has been noticed by Saraswathy & Nair (1969).

A definite pattern in the distribution of protein content was discernible. It showed an inverse relation to glycogen. Protein content was maximum in February and during this period glycogen content in male and female was at the lowest. A definite shift in the values of protein, corresponding with the reproductive phase of the animal was noticed. An inverse relationship between water level and organic constituents (lipids, carbohydrate and protein) is discernible in the case of *C. madrasensis* occurring in

Cochin Backwaters. The protein decreased and maintained as such with minor fluctuations till the next breeding cycle in Musculista arcuatula (George & Nair, 1975). The highest nitrogen values were observed by them during the maturing stage and lowest during spawning. An inverse relation of nitrogen (protein) and glycogen values was also noticed by them as in the present study. Lakshmanan & Nambisan (1980) also observed an inverse relationship between protein and carbohydrate in Villorita cyprinoides and Meretrix casta inhabiting the Cochin Backwaters. Many workers observed high protein content during the maturing of gametes (Giese & Araki, 1962; Giese et al. 1959a; Tucker & Giese, 1962; Barnes et al. 1963; Pillay & Nair, 1973). It is probable that the comparatively high protein content observed in the whole tissue is the total protein content of the vegetative and reproductive (gametes) components of the pooled samples. A clear cut reduction in the glycogen content further supports the assumption that glycogen isconverted into lipids and proteins during the peak breeding season. The energy reserve of gametes in general has a high lipid consistency (Giese, 1966).

Of all the three energy reserves, namely, glycogen, lipid and protein, glycogen is the most readily utilised. The glycogen content (carbohydrate) showed distinct fluctuation correlated with the spawning in oysters.

Carbohydrate level remained high prior to spawning and suddenly dropped to very low values from November to April. According to Walne (1970) glycogen varies from 30-35% in oysters and forms the chief storage reserve. Wide fluctuations in glycogen values with a peak, prior to spawning in *O. edulis* were noticed by Miller & Scot (1967), Holland & Spencer (1973), Holland & Hannant (1974, 1976). Very high values for carbohydrate were noticed by Lee & Pepper (1956) and Galtsoff (1964) in the American oyster *C. virginica* and in the Japanese oyster *C. gigas* by Masumoto *et al*. (1934) particularly prior to maturation. This corresponded well with the present study. The drastic drop in glycogen values during the spawning period from October to April may be due to the utilization of glycogen for the extra energy needed for maturation and spawning. Similar observations by Walne (1970), Gabbot & Walker (1971), Holland & Hannant (1976) supports this view. Dependence on carbohydrate reserves, during different phases of development varies in fishes as noticed by several workers. (Greene, 1926; Chang & Idler, 1960; Yanni, 1961). Saraswathy & Nair (1969) observed high glycogen values during the non-breeding months especially during February-May in *Nausitora hedlei*. From June to January the values were comparatively low and on the onset of the breeding season, there was a perceivable fall in glycogen, probably owing to the initial mass spawning during June. After January the values were comparatively high in Nausitora hedlei and reached the highest during March (Saraswathy & Nair, 1969). Nagabhushanam & Talikedkar (1977) observed peak values in glycogen during gametogenetic phase. Matsumoto et al. (1934), Giese (1966), Goddard & Martin (1966), Bayne (1975), Gabbot (1975, 1976) all opined that glycogen is mobilised and converted to lipid during gemetogenesis. The increase in the glycogen content soon after the breeding season, until the next breeding season shows storage of this component which would be utilised for the energy demand for the subsequent breeding.

Lamellibranchs in general, have a prominent glycogen economy with a corresponding lesser storage of lipids (Giese, 1966). The lipid and glycogen content are generally higher in females, which may be attributed to a higher biochemical budget required for egg production. Since the larvae of oysters are lecithotrophic, the egg should contain a greater amount of stored energy and this is easily made possible by the storage of lipid in the yolk of the eggs.

Venkataraman & Chari (1951) noticed a range of 0.99% to 2.06% ash content in C. madrasensis inhabiting Ennore, Madras. However, wide fluctuation in ash is noticed in Cochin oysters, such as 0.72% to 2.71% in male and 0.5% to 2.86% in females (Table 8.1).

From the above account it is clear that ash and protein increased and remained at high level during October to April coinciding with the breeding period of oysters. The glycogen showed an inverse relation to the fluctuation in ash and protein.

SEASONALITY OF TRACE METALS IN CRASSOSTREA MADRASENSIS

8.5. Introduction

Seasonal fluctuation in the distribution of trace metals in a sedentary organism in an estuary is controlled by an array of extrinisic and intrinsic factors, such as: (i) the extent of pollutant delivery into the estuary and the associated dilution *in situ* (ii) changes in the weight of the organism, (soft tissue in the case of bivalves) and (iii) the direct effects of temperature, salinity and other water quality parameters which show seasonal variations. The seasonal profiles of trace metal availability may vary according to estuarine position and also the locality of occurrence of the animal. It is proved that the biota of the lower reaches of an estuary and the estuarine mouth contain more trace metals in a season of high run-off (Luoma, 1977). It is also known that the concentrations of trace metals in estuaries fluctuate widely, over both the short and long-term and factors other than run off may be responsible for these alterations.

The trace metal content in an estuarine organism could either increase or decrease in quantity at any particular time. This change would mainly depend on the availability of the concerned trace metals in the ambient water and the sediment. An increase in the trace metal in the tissue of a benthic bivalve is usually controlled by the increased availability in the bottom sediments, although a decrease in the trace metal levels in the tissue depends on the biological half life of the metal in the organism. The half lives of metals in an organism varies enormously between species and within a species (Phillips, 1979). The kinetics of mercury in the shrimp *Palemon dibilis* and the polychaete *Nereis succinea* indicated that mercury can persist in the tissue even after episodic increase in their uptake rates to obviate the possibility of their being excreted in toto prior to the next influx (Luoma, 1977).

8.6. Material and methods

For the estimation of trace metals, 50 g of the sample was digested with nitric acid sulphuric acid mixture, following the method of Agemian *et al.* (1980). The trace metals such as iron, copper, cadmium, manganese and zinc in the digested sample were determined by flame atomic absorption spectrophotometry using a Varian Techtron, Model 1100 atomic absorption spectrophotometer.

Sample digestion for the determination of mercury was done according to the AOAC (1975) method 25.112 and estimation of mercury was carried out by cold vapour atomic absorption spectrophotometric technique (Hatch & Ott, 1968), on a mercury analyser (Model MA 5800 of ECIL).

8.7. Results

The load of Cd, Cu, Fe, Mn, Zn and Hg in the whole tissue of *C. madrasensis* is presented in the Table 8.5 and Fig.8.2. It is evident from Table 8.5 that Cu, Fe and Zn showed clear cut seasonality.

8.7.1. Cadmium

This trace metal, which is a non-essential one recorded uniformly low values. A slight change in this pattern was noticeable in the samples analysed during October, January, February and March. The maximum quantity registered during the period was in October, interestingly at the commencement of the breeding season.

8.7.2. Copper

This is an essential trace metal for bivalves and is an important component of the haemocyanin and a constituent of the oxygen carrying pigments. Based on availability, this metal showed a distinct fluctuation, recording higher values during the period January to July and lower values during October to December. Cu was third in the order of abundance.

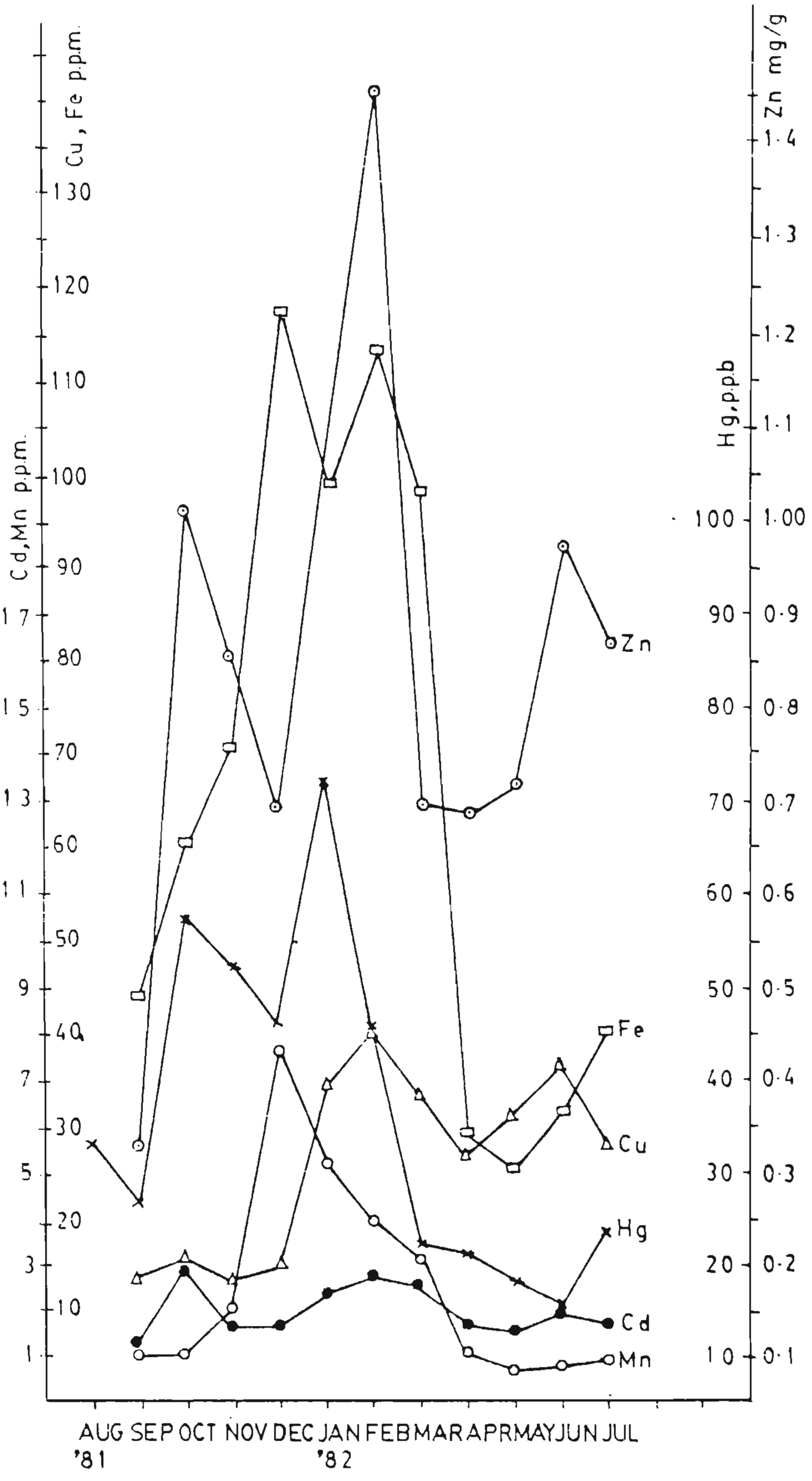


Fig. 8.6. TRACE METAL DISTRIBUTION IN C.MADRASENSIS
AUG. '81 TO JUL. '82

8.7.3. Iron

This is an essential trace metal for the bivalves. Specimen samples from December to March had high load of Fe. Ranking second in the degree of abundance, ferric content of the tissue was comparatively less during April and May.

8.7.4. Manganese

Behaving very similar to Fe with regard to abundance, Mn recorded higher values during December to March. The soft tissue of *C. madrasensis* had low Mn content during May and June.

8.7.5. Zinc

This is also an essential trace metal for bivalves. Compared to all the other trace metals studied Zn recorded the highest values all through the year. With reference to comparative abundance the month of February recorded maximum and March, April and December minimum.

8.7.6. Mercury

This is a non-essential metal. Among the trace metals analysed during the present study Hg registered the lowest profile. However, compared with the natural sea-water load (0.01 to 0.03 p.p.b.), the quantities present in the tissues of *C. madrasensis* were quite high. During the breeding season the animals harboured high concentration of mercury.

8.8. Discussion

It has been proved that different marine species respond to different portion of the total trace metal load in an ecosystem. Therefore, the profiles for trace metal concentrations in one organism do not always match those seen in another species from the same locality (Bryan & Hummerstone, 1971; Phillips, 1979). This phenomenon is important in determining the seasonal changes in the availability of trace metal in a coastal animal. Since a filter feeder like *C. madrasensis* can take metal from the ambient water and from inorganic particulates, the seasonal fluctuation in the trace metal availability in such organisms is a composite function of these two factors. The present results indicate that the heavy metal load in the tissue of *C. madrasensis* exhibits seasonality which could possibly be due to variations in these in the ambient water rather than in the sediments. The increase or decrease in the availability of trace metals in the sediment is less temporary in nature as against that of the ambient water. Filter feeding bivalve molluscs such as *Mytilus*, *Crassostrea* will take up metals rapidly from solution or from food, although the latter route is more predominant. The uptake of metals from particulates is probably more important for those metals which exhibit a preference to particulate association rather than remaining in solution. These metals would include iron, lead and manganese. Therefore, the variations in the quantity of Zn, Cu, Mg and Cd recorded in the soft tissue of C. madrasensis suggest that the availability of these metals to the animal was more during certain periods of the year. Further at least three among these metals showed a clear cut increase during the late post-monsoon and early pre-monsoon period which coincided with the breeding period of C. madrasensis. According to Ayling (1974), the uptake of a trace metal from sediments by oyster has a close relation between the metal availability in the sediment and the animal's intake abilities. He has suggested that this route is so important that concentration factor for metals in oyster should be based on the element levels in the ambient sediments, rather than water. However, Boyden & Romeril (1974) feel that although bivalves undoubtedly respond to metals in sediments, the role of this response in determining total body loads of metals in the organism probably varies with, both species and metals and that a generalisation cannot be completely defended because of this variation. Sankaranarayanan et al. (1978) assumed that low load of Zn, Fe, Cu and Mn in C. madrasensis from the Cochin Backwaters during December to May was due to freshwater influx during this period on the ground that reduction in salinity reduced the availability of these metal ions.

The changes in the physiological status of an organism, when controlled by the season will super-impose itself on the trace metal availability in the whole tissue, or the defined tissues of a coastal species. One of the major physiological changes which exerts a significant effect on temporal trend in the trace metal levels of higher invertebrates is the reproductive cycle. These changes are directly connected with seasons which in turn influences maturation of gametes and spawning. These physiological changes involve fluctuations in all biochemical components as well as animal weight, water content and conditions. The loss of gametes and the concomitant loss of body weight in oyster at spawning has consequences for trace metal seasonality. The quantity of trace metals in the gonads of oyster and mytilids is very low when compared with that in the other soft tissues (Pentreath, 1973; Cunningham & Tripp, 1975). Since most of the trace metals are concentrated in the digestive glands, kidney and gills of bivalves during the breeding season, a gradual reduction in weight of the tissues owing to massive transport of stored energy from the storage organs for reproductive purposes would lead to a high trace metal content per unit weight. This might be one of the contributing causes for the present observation of comparatively high metal load in the tissues. Depuration of trace metal during breeding season is remote because, the major quantity of trace metals taken into the organic system is tucked away in selected sites. Therefore, when the metal load of oyster is worked out on a wet weight basis, there is a possibility of recording increased trace metal content soon after breeding when the total weight will be less. The quantity of trace metals found in the digestive glands, kidney and gills account for about 75% of the total body load of the elements (Holcombe *et al.* 1976). However, exception to this generally accepted hypothesis is the presence of more zinc in the gonads of *Pecten maximus* (Topping, 1973) and *Modiolus modiolus* (Segar *et al.* 1971). The presence of 0.992 mg/ g and 1.408 mg/ g (wet weight basis) of zinc in *C. madrasensis* during January and February is significant in the above context.

The influence of sex on the trace metal load of soft tissue has also been recognised. In general, the female bivalves of some species have been found to harbour more quantity of trace metals compared to their male counterparts (Alexander & Young, 1976; Gorden, 1978). However, the degree of gonad maturity would greatly influence the trace metal levels in a species. Since a detailed analysis of trace metal content in the soft tissues of two sexes and indeterminate stages of *C. madrasensis* was not within the perview of the present studies, a reasonable explanation could not be offered with regard to this aspect. Crassostrea virginica in Long Island Sound spawns during the period July-August. At this time the seasonal profiles of copper, iron and zinc exhibited considerable increase in concentration (Galtsoff, 1964). Since the breeding season of C. madrasensis in the Cochin Harbour is a protracted one, it is difficult to make a comparison with the above observation, although it is apparent that in general the quantity of all the trace metals was high during the breeding season in C. madrasensis. The apparent increase in the trace metal level during the breeding season, according to Galtsoff (1964) is owing to the drop in the soft tissue weight as a result of loss of gametes, which have relatively low metal content. The fact that there is a reciprocal relationship between bivalve weight and their trace metal concentrations was indicated in Mylitus edulis by Phillips (1979). It was shown by Phillips (1979) that the total body burdens of cadmium, copper, lead and zinc varied in Mytilus edulis throughout the year, although the metal concentration varied quite appreciably, because of the fluctuation in the tissue weight immediately subsequent to spawning and metals were at minimum concentrations prior to spawning, when the gonads were full of gametes of low metal content. The trace metal load of Mytilus galloprovincialis from the North-west Mediterranean showed distinct seasonality, although some metals fluctuated in concentration much more than the others (Fowler & Oregioni, 1976). Simpson (1979) felt that the metal concentrations in bivalves depend greatly on the body weight and hence the reproductive stage of the individual studied.

Environmental factors such as temperature and salinity are known to influence the trace metal availability in bivalves. The influence of these factors on the organism could be direct or indirect. In the case of an estuary, freshwater run off usually brings about an increase in the trace metal content of the estuary. The quantities of trace metals maintained in the water column in estuary, are commonly found to be a simple function of salinity. Therefore, sedentary bivalves of an estuary will be exposed to altered concentrations of trace metals incidental to lower salinities during periods of greater run off. Fluctuating salinity affect the basic physiological functions like filtration and feeding of bivalves. The present results show that during the period when the estuary maintained high salinities, C. madrasensis harboured more quantities of trace metals. The oyster sampled during the present investigation occupied the bed of the estuary, very near to the bar mouth. Therefore, the ratio of sediment-organism contact was high throughout the life time of the animal. Hence the trace metal load showed by this species indicates a combined effect of sediment and ambient water load. Such seldom comes into direct contact with the bottom sediment habitually, but would be more in contact with the sediment in the water column. Rucker & Valentine (1961) showed that changes in salinity affect the quantity of boron, copper, mangnesium, manganese, sodium and strontium in the shells of Crassostrea virginica. It was proved that the uptake of zinc was unaffected by salinity changes, whereas that of cadmium was greater at low salinities, and that of lead was great at greater salinity regimes and the uptake of copper was erratic in Mytilus edulis (Phillips, 1979). According to Jackim et al. (1977) the uptake of cadmium by M. edulis, Mulina lateralis and Nucula proxima from solution could be salinity dependent. Fowler & Oregioni (1976) also provided a similar relationship in the case of Mytilus gallopovincialis. However, it is essential here to delineate the true effects of salinity on the uptake of trace metals by bivalves which are not under stress and the effects of salinity stress on metal uptake. These lines of study would be a meaningful continuation of the present finding in C. madrasensis.

8.9. References

Agemian, H., Sturtevant, D.P. & Austen, K.D. (1980) Analyst. 105, 125

Alexander, G.V. & Young, D.R. (1976) Trace metals in Southern California mussels. Mar. Poll. Bull. 7(1), 7-9

A.O.A.C. (1975) *Official Methods of Analysis*. 12th edn., Association of Official Analytical Chemists, Washington

Ayling, G.M. (1974) Uptake of cadmium, zinc, copper, lead and chromium in the Pacific oyster *Crassostrea gigas* grown in the Tamar river, Tasmania. *Wat*. *Res*. **8**, 729-738

Bailey, B.E. (1952) Marine oils with particular reference to those of Canada. *Bull. Fish. Res. Bd Can*. **89**, 39

Barnes, H., Barnes, M. & Finlayson, D.M. (1963) The seasonal changes in body weight, biochemical composition and oxygen uptake of two common boreo-artie Cirripedes *Balanus balanoides* and *B*. *balanus*. *J. mar. biol. Ass. U.K*. **43**, 185-211

Bayne, B.L. (1973) Physiological changes in *Mytilus edulis* L. induced by temperature and nutritive stress. *J. mar. biol. Ass. U.K*. **53**, 39-58

Bayne, B.L. (1975) Reproduction in bivalve molluscs under environmental stress. In "*Physiological Ecology of Estuarine Organisms*. (Vernberg, F.V. Ed.) pp.259-277, University of South Carolina Press, Columbia, South Carolina

Bernad, F.R. (1974) Annual biodeposition and gross energy budget of mature Pacific oysters, *Crassostrea gigas*. *J. Fish. Res. Bd Can*. **31**, 185-190

Boolootian, R. & Laskar, R. (1959a) Organic productivity in the reproductive cycle of the purple sea urchin. *Biol. Bull.* **116**(1), 49-59

Boyden, C.R. & Romeril, M.G. (1974) A trace metal problem in pond oyster culture. *Mar. Poll. Bull.* **5**(5), 74-78

Bryan, G.W. & Hummerstone, L.G. (1971) Adaptation of the polychaete *Nereis divercicolor* to estuarine sediments containing high concentration of heavy metals. *J. mar. biol. Ass. U.K.* **51**, 845-863

Campbell, J.W. & Bishop, S.H. (1970) Nitrogen metabolism in mulluses: In "*Comparative Biochemistry of Nitrogen Metabolism*". (Campbell, J.W., Ed.) vol.1, 103-206, Academic Press, New York and London

Chang, V.M. & Idler, D.R. (1960) Biochemical studies on sockeye salmon during spawning migration. xii, Liver glycogen. *Can. J. Biochem. Physiol.* **38**, 553-558

Cunningham, P.A. & Tripp, M.R. (1975) Accumulation tissue distribution and elimination of 203 Hgcl$_2$ and CH$_3$ 203 Hgcl in the tissue of the American Oyster *Crassostrea virginica*. *Mar. Biol.* **31**, 321-334

Dame, R.F. (1972b) The ecological energies of growth, respiration and assimilation in the inter-tidal American oyster *Crassostrea virginica*. *Mar. Biol.* **17**(3) 243-250

De Zwann, A. & Zandee, D.I. (1977) Body distribution and seasonal changes in the glycogen content of common sea mussel *Mytilus edulis*. *Comp. Biochem. Physiol.* **43**, 53-58

Durve, V.S. & Bal, D.V. (1961b) Studies on the chemical composition of the oyster, *Crassostrea gryphoides* (Schlotheim). *J. zool. Soc. India* **13**, 70-77

Establier, R. (1966) Variacion estacional de le composicion gumica del ostion (*Crassostrea angulata Lmk*) Ysu relacion con las variaciona hidrologicas Y de fito plancton. *Investigacion Pesq*, **30**, 501-528

Fowler, S.W. & Oregioni, B. (1976) Trace metals in mussels from the North-west Mediterranean. *Mar. Poll. Bull.* **7** (2), 26-29

Garder, T. & Alvsakar, E. (1941) Biologie, und chemie de Auster in den norwegischen Pollen. *Bergens Mus. Ab. Naturv. rekke*. **6**, 1-236

Gabbot, P.A. (1975) Storage cycle in marine bivalve molluscs: a hypothesis concerning the relationship between glycogen metabolism and gemetogenesis. In "*Proceedings of the ninth European Marine Biology* Symposium", (Barnes, H.Ed.) pp.191-211, Aberdeen University Press.

Gabbot, P.A. (1976) Energy metabolism. In *Marine Mussels: Their Ecology and Physiology*. (Bayne, B.L. Ed.,) pp.239 Cambridge University Press

Gabbot, P.A. & Bayne, B.L. (1973) Biochemical effects of temperature and nutritive stress on Mytilus edulis L. J. mar. biol, Ass. U.K. 53, 269-286

Gabbot, P.A. & Holland, D.L. (1973) Growth and metabolism of Ostrea edulis larvae. Nature. 241, 475-476

Gabbot, P.A. & Walker, A.J.M. (1971) Changes in condition index and biochemical content of adult oysters . (Ostrea edulis L.) maintained under hatchery condition J. Cons. int. Explor. Mer. 34, 99-106

Galtsoff, P.S. (1964) The American Oyster Crassostrea virginica (Gmelin). Fish Bull. Fish. Wildlife Ser. U.S. Department of the Interior, 64

Galtsoff, P.S., Chipman, W.A., Engle, J.B. & Calderwood, H.N. (1947) Ecological and physiological studies on the effect of sulphate pulp mill wastes on oysters in the York River, Virginia. Fish. Bull. Fish. Wildl. Ser. U.S. 51, 59-186

Galtsoff, J.M., Huguet, R. & Solere, M. (1972) Variations des fractions lipidiques de Mytilus galloprovincialis Lmk. et de Crassostrea angulata Lmk, de letang de Than. Comm. Int. Explor. Sci. Mer. Mediterr. Monacv 21 (5):243-244

Gastaud, J.M., Huguet, R. & Solere, M. (1972) Variations des fractions lipiques de Mytilus galloprovincialis LMK et de Crassostrea angulata LMK, de letang de Than. Comm. Int. Explor. Sci. Mer: Mediterr. Monacv. 21(5) 243-244

George, J.C. & Patel, B.S. (1956) The seasonal variation in the fat content of the liver and gonads in marine and freshwater decapod. J. Anim. Morph. Physiol. 3, 49-55

George, E.L. & Nair, N.B. (1975) Biochemical changes in relation to the breeding of *Musculista arcuatula* Yamoto and Hibino (Bivalvia: Mytildae) Sci. Cult. 41 (4), 167-169

Giese, A.C. (1966) Lipids in the economy of marine invertebrates. Physiol. Rev. 46, 244-248

Giese, A.C. (1959) Comparative physiology - Annual reproductive cycles in marine invertebrates. A Rev. Physiol. 21, 547-576

Giese, A.C. & Araki, G. (1962) Chemical changes with reproductive activity of the Chitons *Katherina tunicata* and *Mopalina hindsii*. J. exp. Zool. 151 (3), 259-267

Giese, A.C., Greenfield, L., Huang, H., Farmanfarmaian, A., Boolootian, R.A. & Lasker, R. (1959a) Organic productivity in the reproductive cycle of the purple seaurchin. Biol. Bull. mar. biol. Lab. Woods Hole, 116, 49-58

Giese, A.C., Tucker, J.S. & Boolootian, P.A. (1959) Annual reproductive cycles of the chitons *Katherina tunicata* and *Mopalina hindsii*. Biol. Bull. 117(1), 81-88

Giese, A.C., Krishnaswamy, S., Vasu, B.S. & Lawrence, J. (1964) Reproductive and biochemical studies on a sea urchin Stomopneustes variolaria from Madras Harbour. Comp. Biochem. Physiol. 13, 367-380

Giese, A.C. Tucker, J.S. & Boolootian, R.A. (1959b) Annual reproductive cycles of the chitons Katherina tunicata and Mopalina hindsii. Biol. Bull. mar. biol. Lab. Woods Hole. 117(1), 81-88

Gilles, R. (1972) Biochemical ecology of molluses. In "Chemical Zoology" (Florkin, M. & Scheer, B.T. eds.) vol. VII, 467-499, Academic Press, New York and London

Goddard, C.K. & Martin, A.W. (1966) Carbohydrate Metabolism In "Physiology of Mollusca", Vol.2 (Wilber, K.M. & Yong, C.M. Eds.,) pp.275-308, Academic Press, New York

Gorden, M. (1978) Inter-tidal study of the Southern California Bight. Report of the Moss Landing Marine Laboratory, California (Sept. 1978) 39 pp. (Mimiograph)

Greene, C.W. (1926) The physiology of the spawning salmon. Physiol. Rev. 6, 201-241

Greenfield, L.J., Giese, A.C., Farmanfarmaian, A. & Boolootian, R.A. (1958) Cyclic biochemical changes in several echinoderms. J. exp. Zool. 139 (3) 507-524

Hammen, C.S. (1969) Metabolism of the oyster Crassostrea virginica. Am. Zool. 9, 309-318

Hatch, W.R. & Ott, W.L. (1968) Determination of sub-microgram quantities of mercury by atomic absorption spectrophotometry. Anal. Chem. 40, 2085

Helm, M.M., Holland, D.L. & Stephensen, R.R. (1973) The effect of supplementary algal feeding of a hatchery breeding stock of Ostrea edulis L. on larval vigour. J. mar. biol. Ass. U.K. 53, 673-684

HolCombe, G.W., Benoit, D.A., Leonard, M. & Makin, J.M. (1976) Long term effects of lead exposure on three generation of brook trout (Salvelinus frontanalis) J. Fish. Res. Bd Can. 33, 1731-1741

Holland, D.L. & Hannant, P.J. (1974) Biochemical changes during growth of the spat of the oyster Ostrea edulis L. J. mar. biol. Ass. U.K. 53, 1004-1016

Holland, D.L. & Hannant, P.J. (1976) The glycogen content in winter and summer of oysters Ostrea edulis L. of different ages. J. Cons. int. Explor. Mer. 36 (3) 240-242

Holland, D.L. & Spencer, B.E. (1973) Biochemical changes in fed and starved oysters, Ostrea edulis L. during larval development, metamorphosis and early spat growth. J. mar. biol. Ass. U.K. 53, 287-298

Jackim, E., Morrison, G. & Steele, R. (1977) Effects of environmental factors on radio cadmium uptake by four species of marine bivalves. *Mar. Biol*. **40**, 303-308

Kravarie, M. (1953) Investigations into the nutritive value of Adriatic oyster (*Ostrea edulis*) *Acta adriat*. **5**(4), 1-20

Lakshmanan, P.T. & Krishnan Nambisan, P.N. (1980) Biochemical composition of the bivalve molluscs *Villorita cyprinoides* Var. *Cochinensis* (Hanley) and *Meretrix casta* (Chemnitz) *Indian J. mar. Sci*. **9**(1), 65-67

Lee, C.F., Kurtzman, C.M. & Pepper, L. (1960) Proximate composition of southern oysters-Factors affecting variability. *Comml. Fish. Rev*. **22** (7), 1-8

Lee, C.P. & Pepper, L. (1956) Composition of southern oysters. *Comml. Fish. Rev*. **18** (7), 1-6

Lubet, P. (1959) Recherches sur le cycle sexual et lemission des gametes chezles Mytilidae et les Pectinidas (Mollusca, Bivalves). *Rev. trav. Peches marit*. **23** 387-548

Lubet, P. & Le Feron De Longcamp, D. (1969) Etude des variations annuelles des constituants lipidiques chez *Mytilus edulis* L. de la Baie de Seine (Calvados) *Comp. Rend. Sean. Soc. Biol*. 163, 1110-1112

Luoma, S.N. (1977) The dynamics of biologically available mercury in a small estuary. Est. Cstl. mar. sci. 5, 643-652

Malcom, J. (1929) Food values of New Zealand fish. Part 10, Seasonal variation in Steward Island oysters. Trans. Proc. N. Z. Inst. 59(4), 668-677

Mane, U.H. & Nagabhushanam, R. (1977) Body distribution and seasonal changes in the biochemical composition of the estuarine mussel Mytilus viridis at Ratnagiri. Hydrobiologia. 14(3), 163-175

Masumoto, B., Masumoto, M. & Hilino, M. (1934) Biochemical studies of magaki (Ostrea gigas Thumberg) 2. The seasonal variation in the composition of Ostrea gigas Thumberg. Hiroshima Univ. J. Sci. 44, 47-56

Menzel, R.W. & Hopkins, S.H. (1952) Report on Commercial Scale Oyster Planting Experiments in Bayon Bas Blue and in Bay Sainto Elaine Oil Field. Tex. A & M Res. Foundation. Texas

Milroy, J.A. (1909) Seasonal variation in glycogen made by oysters. Scient. Invest. Fish. Brch. Ire. 190 (2) 1-5

Mitchell, P.H. (1915) Nutrition of oysters, glycogen formation and storage. Bull. Bur. Fish. Washington 35, 157-162

Miller, R.H. & Scot, J.M. (1967) The larvae of the oyster *Ostrea edulis* during starvation. *J. mar. biol. Ass. U.K.* **47**:475-484

Nagabhushanam, R. (1961) Biochemical studies on the marine wood-boring mollusc *Martesia striata*. *J. scient. ind. Res.* **20C**(6), 171-173

Nagabhushanam, R. & Deshmuk, R.S. (1974) Seasonal changes in body component indices and chemical composition in the estuarine clam *Meretrix meretrix*. *Indian J. Fish.* **21**(2), 531-542

Nagabhushanam, R. & Dhamne, K.P. (1977) Seasonal variation in biochemical constituents of the clam, *Paphia laterisulca*. *Hydrobiologia*, **14**(3), 209-214

Nagabhushanam, R. & Talikhedkar, P.M. (1977) Seasonal variations in proteins, fat and glycogen of the wedge clam *Donax cuneatus*. *Indian J. mar. Sci.* **6**(1), 86-87

Okazaki, K. & Kobayashi, S. (1929) The seasonal variation in the glycogen content in the oyster, *Ostrea circumspecta*. *Scient. Rep. Tohoku Univ.* 183-191

Pentreath, R.J. (1973) The accumulation from water of 652n, 54Mn, 58Co and 59 Fe by the mussel *Mytilus edulis*. *J. mar. biol. Ass. U.K.* **53**, 127-143

Phillips, D.T.H. (1979) Trace metals in the common mussel *Mytilus edulis* (L) and in the alga *Fucus vesiculosus* (L) from the region of the Sund (Oresund) *Environ. Pollut.* **18**, 31-43

Pillay, K.K. & Nair, N.B. (1973) Observations on the biochemical changes in gonads and other organs of *Uca annulipes*, *Portunus pelagicus* and *Metapenaeus affinis* (Decapoda: Crustacea) during the reproductive cycle. *Mar. Biol*. **18**, 167-198

Rajagopal, M.D., Vijayaraghavan, S. & Kumari, L.K. (1975) Nutritive value of the rock oyster *Crassostrea elliptica*. *Mahasagar*, **8**, 203-205

Rucker, J.B. & Valentine, J.W. (1961) Salinity response of trace element concentration in *Crassostrea virginica*. *Nature, Lond*. **190**, 1099-1100

Russel, E.S. (1923) Report on seasonal variation in the chemical composition of oysters. *Fish. Invest. London. Ser*. **6**(1), 1-24

Sankaranarayanan, V.N., Purushan, K.S. & Rao, T.S.S. (1978) Concentrations of some of the heavy metals in the oyster *Crassostrea madrasensis* (Preston) from Cochin region. *Indian J. mar. Sci*. **7**, 130-131

Saraswathy, M. & Nair, N.B. (1969) Biochemical changes in relation to breeding cycles of *Nausitora hedlei* Schepman. *Curr. Sci*. **38**, 158-160

Sarvaiya, R.T. (1977) Studies on mollusca of Saurastra Coast-2. (Pelecypoda) *Fish. Technol*. **14**(1), 33-38

Sarvaiya, R.T. (1977b) Mollusca of Saurastra Coast. *Fish. Technol*. **14**(2), 170-175

Segar, D.A., Collins, J.D. & Riley, J.P. (1971) The distribution of the major and some minor elements in marine animals - ii. Molluscs. *J. mar. biol. Ass. U.K.* **51**, 131-136

Sekine, S., Tatsuno, S. & Mamura, F.A. (1929) On the seasonal variation in chemical composition of oysters. *Proc. 4th Pacific. Sci. Congr.* **3**:349-351

Simpson, R.D. (1979) Uptake and loss of zinc and lead in mussels (*Mytilus edulis*) and relationships with body weight and reproductive cycle. *Mar. Poll. Bull.* **10**(3), 74-78

Suryanarayanan, H. & Alexander, K.M. (1972) Biochemical investigations on edible molluscs of Kerala. 1. A study of the nutritional value of some bivalves. *Fish. Technol.* **9**(1), 42-47

Topping, G. (1973) Heavy metals in shell fish from Scottish waters. *Aquaculture.* **1**, 379-384

Tueker, J.S. & Giese, A.C. (1962) Reproductive cycle of *Chryptochiton stelleri* (Middendorff) *J. exp. Zool.* **150**, 33-43

Tully, J.P. (1934) Chemical analysis of oysters - small scale canning of Pacific oysters. *Rep. biol. Bd Can.* 1-103

Tully, J.P. (1936) The nutritive value of marine products. XIV. Proximate analysis of fresh British Columbia, oysters. *J. Fish. Res. Bd Can.* **2**, 477-484

Umbreit, W.W., Burris, R.H. & Stauffer, J.F. (1959) *Manometric Techniques*. p.238, Burgess Publishing Co. 426 South Sixth Street, Minneapolis.

Venkataraman, R. & Chari, S.T. (1951) Studies on oysters and clams: Biochemical variations. *Ind. J. Med. Res*. **39**, 533-541

Vinagradov, A.P. (1953) The elementary chemical composition of marine organisms. *Mem. Sears Fdn. mar. Res*. **2**, 1-647

Walne, P.R. (1970) The seasonal variation of meat and glycogen content of seven populations of oysters. *Ostrea edulis* (L) and review of the literature. *Fish. Invest. Ser*. II, vol.24, No.3, 1-35

Widdows, J. & Bayne, B.L. (1971) Temperature acclimation of *Mytilus edulis* with reference to its energy budget. *J. mar. biol. Ass. U.K*. **51**, 827-843

Yanni, M. (1961) Studies on carbohydrate content of the tissue of *Clarias lazera*. *Z. vergl. Physiol*. **45**, 56-60

CHAPTER 9

PREDATORS, COMMENSALS AND PARASITES OF *C. MADRASENSIS*

CHAPTER 9

PREDATORS, COMMENSALS AND PARASITES OF *C. MADRASENSIS*

9.1 Introduction

Being a sedentary organism the oyster is subjected to several perils during its life. Several parasites were identified as causing diseases in oysters particularly from USA, Canada, Germany, Denmark and Holland. Several natural oyster beds were reported to have completely devastated by fungal and bacterial pathogens in Europe. Besides these microbes, oysters are also attacked by several other animal parasites affecting their growth, reproduction and other life activities. Parasitism leads to mortality, affects reproduction and makes oysters susce~~s~~ptible to predation by several other organisms. The more common symptoms according to Galtsoff (1964) are "slow growth, failure to fatten and develop gonad, recession of the mantle and valves that remain slightly agape. There is often a corresponding abnormal deposition of shell material, that in a chronic condition causes the formation of short and thick shells. The valves do not close tightly because the adductor muscle is weakened. The body of a sick oyster is watery, often discoloured (dirty green and brown) and bloody with blood cells accumulating on the mantle and on the surface of the gills".

Several workers have studied the fauna harbouring the shell of oysters. Many marine fouling organisms use oyster shells for attachment either permanently or temporarily. They do not cause any damage to the shell of the oyster but compete with the oyster for food and space and sometimes smother the oyster when they settle in large numbers. In United States, Verrill (1873) studied the epifauna of oyster beds. The account of Mobius (1883) pertains to oysters inhabiting German waters and those of Zernov (1913) to oyster beds from Black Sea. Korringa (1951a) has given a detailed account of the shell of *Ostrea edulis* as a habitat.

Edible oysters have attracted the attention of several workers and several compilations pertaining to prasites and diseases have been published (Dollfus, 1921; Pelseneer, 1928; Ranson, 1936; Sindermann & Rosenfield, 1967; Cheng, 1967; Sindermann, 1968, 1977). Several bacterial and fungal parasites are known to infect the edible oysters. Guillard (1959), Tubiash *et al.* (1965) identified several bacteria belonging to *Aeromonas* and *Vibrio*. A gram positive bacillus was recorded by Numachi *et al.* (1965) from the Japanese oyster *C. gigas*. From the same species a Gram negative bacillus Acromobacter was recorded by Takeuchi et al. (1960), which has been found responsible for mass mortalities in C. gigas.

Very little is known about the fungal pathogens in oysters. Cladothrix dichotoma an actinomycete cause mortalities in O. edulis (Eyre, 1924). Mackin (1962), Sindermann & Rosenfield (1967) have also reported diseases caused by actinomycetes in C. virginica and C. angulata respectively. Other fungal pathogens reported are Sirolpidium zoophthorum (Vishniac, 1955), Monilia causing shell disease in O. edulis and C. angulata (Voisin, 1931; Cole, 1950; Korringa, 1947, 1951a, 1951b; Cole & Waugh, 1956; Korringa, 1976). Another fungal parasite Myotomus ostrearum causing "foot disease" (maladie du pied) in O. edulis and C. angulata has been reported by Giard (1907) and Dollfus (1921). The area of attachment of adductor muscle is affected, causing difficulty in closing the shell in oysters causing the oysters an easy prey to the enemies. Hornell (1910b) and Orton (1937) also reported mass mortalities in cultured oysters in Europe due to "maladie du peid". Rarely "maladie du peid" is found in American oysters. (Galtsoff, 1964). Durve & Bal (1960) recorded a shell disease in C. gryphoides akin to the foot disease of European oysters. Ostracoblabe implexa, a fungal parasite causing shell disease in O. edulis in Netherlands and France (Korringa, 1976).

The most dreaded fungal pathogen Dermocystidium marinum causes periodic mortalities in oysters (Galtsoff 1964). This was first recorded by Mackin et al. (1950) from C. virginica. Dermocystidium marinum infects tissues producing single, spherical, vacuolate cells (Galtsoff, 1964). This pathogen is known as Labrinthomyxia marina after Quick & Mackin (1971) and the mass mortalities caused by Labrinthomyxia marina has been reported by Mackin et al. (1950), Mackin (1953), Andrews & Hewatt (1954), Hewatt & Andrews (1954), Ray (1954a,b). Reduction in growth rate (Menzel & Hopkins, 1955b) and other results such as formation of abscesses, inhibition of gametogenesis (Ray et al. 1953 and Ray, 1954b) were also reported.

The protozoan parasite Hexamita inflata causing breakdown of connective tissue cells and other symptoms in O. edulis and C. virginica (Mackin et al. 1952; Stein et al. 1961; Scheltema, 1962; Schlicht & Mackin, 1968). Stein et al. (1961) could not observe any significant difference in the mortality between experimental and control ones. Scheltema (1962) has opined that Hexamita may be pathogenic, particularly during adverse environmental conditions.

The teleosporean Nematopsis ostrearum has been described by Prytherch (1940) from C. virginica. However, Landau & Galtsoff (1951), Sprague & Orr (1955) could not find any correlation between distribution and mortality at Virginia and Lousiana, USA, even though Prytherch (1940) believed mortality in oysters in Virginia and Lousiana was caused by this gregarine (Galtsoff, 1964). Two haplosporidian parasites *Minchinia costalis* and *M. nelsoni* are also thought to cause mortality in the American oyster *C. virginica*. *M. costalis* earlier known by the name 'SSO' was first recorded by Wood & Andrews (1962) from the connective tissue of *C. virginica* from USA. Andrews *et al.* (1962), Haskin *et al.* (1966), Couch (1967), Couch & Rosenfield (1968) also reported the pathogenic nature of *M. costalis*. Another Haplosporidian microorganism regularly recorded from oyster tissues was designated by the code name 'MSX'. 'MSX' invades the connective tissue around the intestine and digestive gland and are known to be the most destructive oyster parasite. This was later identified as *M. nelsoni*. Mortalities caused by *M. nelsoni* have been recorded by Mackin (1960), Haskin *et al.* (1965, 1966), Engle & Rosenfield (1963), Andrews (1964). A bibliography on *M. nelsoni* has been published by Kren (1976). Several aspects of the life cycles of *M. costalis* and *M. nelsoni* are yet to be known. Another haplosporidian parasite causing large scale mortalities in *O. edulis* is *Marteilia refringens* (Grizel *et al.* 1974). Aldermann (1979), Balonet (1979), Grizel (1979) reported it occurring in estuaries of France and Spain. *Marteilia sydnei* is reported from *C. commercialis* by Wolf (1972) and Perkins & Wolf (1976). From oyster farms of Brittany, France, Cahour (1979) reported another species of *Marteilia refringens* causing havocin *O. edulis*. *Chytridiopsis ovicola* is a microsporidian parasitising eggs of *O. edulis* (Leger & Hollande, 1917).

Certain ciliates are also reported as parasites on oysters. *Ancistrocoma pelseneeri* is a ciliate reported by Mackin (1962) as occurring in *C. virginica*. Burton (1961) and Cheng (1967) also reported another *Ancistrocoma* sp. from *C. virginica*. According to Sindermann & Rosenfield (1967) *Sphenophyra* and *Orchitophyra* genera also cause infections in *C. virginica*.

Boring sponges of the genus *Cliona* are serious competitors of oysters and are found very commonly on oyster shells drilling tunnels in the calcareous shells to provide itself suitable shelter. Heavy infestation often leads to mortality, as the oysters are physically exhausted with reduced natural resistance against pathogenenic organisms. According to Korringa (1951a, 1952) the threatening of the conchyolin layers of shells with perforations exhaust the oyster.

Many epizoic cnidarians are also associated with edible oysters. *Eugymnanthea* is reported as commensals from the mantle cavity of *C. rhizophorae* (Mattox & Crowell, 1951). Yamada (1950) recorded E. japonica in the mantle cavity of C. gigas from Japan.

Stylochus and Pseudostylochus belonging to turbellaria and thought to be predators are reported by Cheng (1967). Loosanoff (1956) observed Stylochopsis elipticus causing widespread destruction in C. virginica at Milford. Pearse & Wharton (1938) recorded Stylochus frontalis from young ones of C. virginica. Another species Pseudostylochus ostreophagus is reported by Woelke (1957) from O. lurida, C. virginica and C. gigas.

The trematode parasite Bucephalus haimeanus is reported from O. edulis and C. virginica. Increased salinity is not conducive to them and they thrive well under brackish water conditions (Tennent, 1906). McCardy (1874) reported an allied species B. cuculus from C. virginica. Records are also there of an unidentified Bucephalus from C. virginica (Cheng & Burton, 1965; Cheng, 1950b). Sindermann's (1968) compilation contains several other references pertaining to Bucephalus. Other reports pertaining to Bucephalus occurrence in other oysters are those of Miller (1963) in O. lutaria, Howell (1967) in oyster beds in New Zealand, Sindermann & Rosefield (1967) in C. gigas from Taiwan, Samuel (1976) in C. madrasensis from the east coast of India, Stephen & Joseph (1977) from the west coast of India. Joseph (1978a) reported the morphology and pathology of the Indian west coast species. Other trematode parasites are Acanthoparyphium spinulosum from C. virginica (Little et al. 1966), Himasthla quissetensis (Cheng et al. 1966), Proteces ostrae (Fujita, 1925) and Metacercaria gymnophalloides tokiensis (Fujita, 1925; 1943) all from C. gigas.

Cestodes recorded are Tylocephalum (Sparks, 1963; Cheng, 1965) from Crassostrea virginica and larval cestodes of Tylocephalum from Crassostrea virginica (Sindermann, 1970) and from C. madrasensis (Stephen, 1978a)

Several species of polychaetes live in close association with oysters of which Polydora is very important. The worms collect mud and make U shaped tubes in oyster shells covered by semitransparent shell materials and the formation of this is known as blisters. Common Polydora sp. are P. ciliata (Roughley, 1925), P. websteri (Hartman, 1945; Cheng, 1967), P. ligni (Hopkins, 1958), P. hoplura (Nickolic & Alfonso, 1970), Whether Polydora is destructive to oysters is controversial. In very large numbers Polydora may be able to smother an entire oyster population with their tubes (Galtsoff, 1964). Roughley (1925) also observed extensive mortalities of oysters in Australia. In Dutch waters Korringa (1951c) found no serious damage to O. edulis by P. cilita. Rao (1974) recorded P. ciliata and P. armata from C. madrasensis inhabiting Athankarai estuary. He observed that the oysters attacked by *Polydora* are weak and the meat of such oysters are poor in quality.

The copepod *Mytilicola intestinalis* is a parasite on Mediterranean clams and *M. orientalis* infests *C. gigas* (Mori, 1935). *M. orientalis* infests the gut, destroys the ciliated epithelium and penetrates the underlying connective tissue (Sparks, 1962a).

Wilson (1944) reported *Ostrincola gracilis* from the mantle cavity of *C. virginica* from North Carolina. *O. simplex* and *O. clavator* were reported by Humes (1958) from *Ostrea* sp. off the coast of Medagascar. From Japan Yamaguti (1936) reported another *Ostrincola* namely, *Pseudomyicola ostrae* from the mantle cavity of *O. densalamellosa*. From *C. virginica*, *P. glabra* has been described by Pearse (1947) and *P. mirabiles* is reported from *O. tulipra*.

Several species of crabs belonging to family Pinnotheridae and commonly referred to as pea crabs are associated with many bivalves including oysters. The American species *Pinnotherus ostreum* is recorded from the mantle cavity of *C. virginica* (Say, 1818; Christensen & McDermott, 1958). The life history of *P. ostreum* has been studied by Sandoz & Hopkins (1947) and pathology by Haven (1959), Christensen & McDermott (1958). Awati & Rai (1931) recorded it from *O. cucullata*. Other species reported are *P. pisum* from *O. edulis* (Orton, 1920b), *P. pholadis* from *C. gigas* (Sakai, 1934; 1936 & 1965). The female pea crabs are found on the surface of the gill of oysters, while males are not permanently attached. Even though they are thought to be commensalic, the female crab was found to erode the gills of oyster and impair their function. *Pinnotherus* sp. is observed by Durve (1965) to infest *C. gryphoides* but its incidence was low. Only 5 out of several hundreds of oysters revealed its presence. As observed by Awati & Rai (1931); Durve (1965) could not observe the influence of sex change by *Pinnotherus* as he could not collect the crab in hermaphrodites.

The mud crab *Panopeus herbsti* is an active predator on *C. virginica* (McDermott & Flower, 1952; McDermott, 1962). The crabs *Scylla serrata* and *Thalamita crenata* feed on oysters and are predators (Rao, 1974).

The foregoing review shows that very little is known about the parasites, predators and commensals of oysters particularly *C. madrasensis* occurring in Indian waters. Hence, the present work was undertaken on this aspect with a view to enriching the knowledge on this aspect.

9.2 Material and methods

Monthly samples of *C. madrasensis* were collected from the Cochin Backwaters from August 1981 to September 1982. Altogether 1261 oysters were examined to study the associates, parasites and predators. The animals found on the exterior of the shell were carefully examined, removed and kept for identification. The oysters were then shucked, the inner side of the shell, mantle, gills, blood, gonad and digestive system were carefully examined for the occurrence of associates and parasites. Bacteria and fungi were not identified. *Bucephalus* sp. was identified by examining only fresh smears.

9.3. Results

The shells were found commonly drilled by boring sponges of the genus *Cliona* (Fig.9.1). The shells were not penetrated completely by *Cliona*, thereby establishing connection with the soft tissue inside.

Many bryozoans were recorded from the exterior of the shells. During the pre-monsoon period (February-May), *Electra bengalensis* (Stoliczka), *Alderina arabianensis* (Menon & Nair) and *Schizoporella cochinensis* (Menon & Nair) were found settling on the shells. During the pre-monsoon period, *Nolella paupensis* (Busk), *Bowerbankia impricata* (Adams) were also common. During the monsoon period (June-September) characteristic species such as *Electra crustulenta* (Pallas) and *Victorella pavida* (Kent) were very common. During the post-monsoon period *Alderina arabianensis* Menon & Nair, *Electra bengalensis* (Stolicaka) were the common forms.

Fig. 9.1 : Oyster Shells Showing borer holes drilled by <u>Cliona</u> Sp.

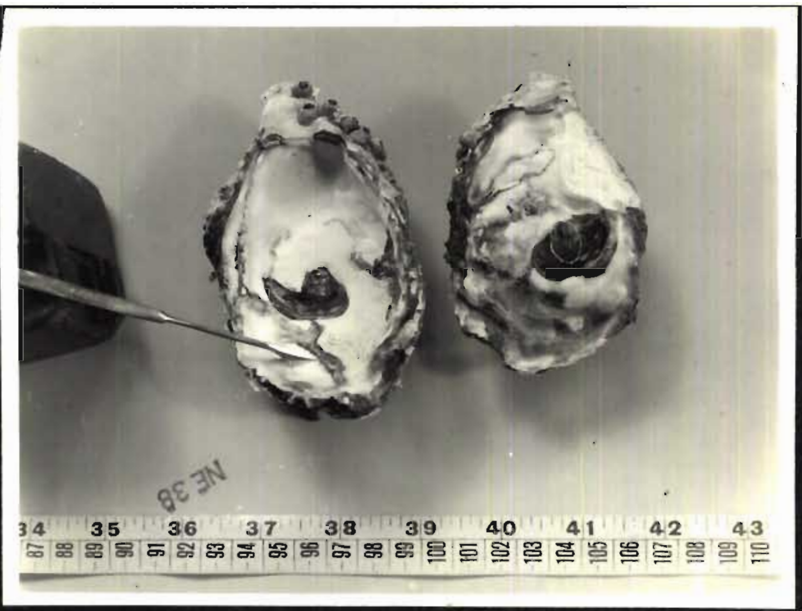


Fig. 9.2 : The Oyster shells with mud-blisters made by <u>Polydora</u> <u>ciliata</u>

Polychaetes with calcareous tube fixed to the oyster shell, polychaetes living in mud-tubes attached to the shells and several free living polychaetes were recorded from oysters. These animals were found throughout the year, but those living in mud-tubes were found predominant during the post-monsoon months. The common polychaetes with calcareous tubes were *Hydroides norvegica* (Gunnerus), *Pomatoceros triquetor* (Linnaeus) and *Spirorbis* sp. The mud tube dwelling polychaetes included *Polydora ciliata* (Johnston), *Eunice* sp. and *Perinereis* sp.

Among the parasites, *Bucephalus* sp. (Digenea: Trematoda) and *Polydora ciliata* Johston (Spionidae: polychaeta) were recorded. Only one instance of *Bucephalus* infection could be noticed during this study. Large number of sporocysts could be identified. Sporocysts were tubular and packed in large numbers in the mantle and underlying gonad and an examination of a fresh smear could reveal several of them. The infected oyster did not show any sign of gonad development. *Polydora ciliata* causing "mud-blisters" was common. The "mud-blisters" were clearly visible on the inner side of the valves as tubular projections (Fig.9.2). By opening the blisters with the help of a needle, the worm could be easily removed. The blisters extended to several mm in length (50 to 60 mm) and 3 to 5 mm in width. The mud inside the blisters was clearly visible through the thin transparent shell material. Blisters were found both in the right and left valves.

Several crustaceans were also recorded. The common cirripede found attached to the shell was *Balanus amphitrite var. communis* (Darwin). The maximum *Balanus amphitrite* settlement on oyster shells was recorded during the post-monsoon period, October-November, during which time hundreds of small barnacles were found on each oyster shell. Mud-tube forming amphipods and tanaids such as *Corophium triaenonyx* and *Tanais estuaris* were also recorded. These were quite prevalent when siliting was common during the post-monsoon period. The isopod *Sphaeroma walkeri* was also present thoughout the year.

Among the bivalve molluscs, *Anomia* sp. *Perna viridis*, *Modiolus carvalhoi*, *Musculista senhausia*, *Musculista arcuatula* were recorded. Spats of *Crassostrea cucullata* and *C. madrasensis* were also recorded from the oyster shells.

Several instances of yellow and green warts often accompanied by blisters were noticed inside the shells. It is not clear which organism is responsible for this discolouration in the otherwise white glistening surface of the inner side of the shell valves.

Out of the 1,262 *C. madrasensis* examined only one instance of pearl formation was detected (Fig.9.3). The pearl was white in colour, 3 mm in diameter and non-lustrous.

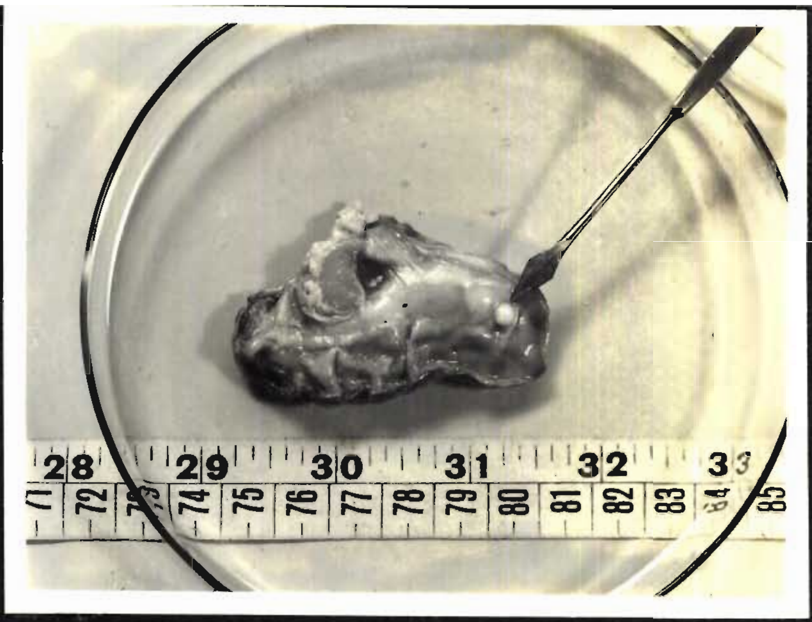


Fig. 9.3 : Crassostrea madrasensis with the insitu pearl

9.4. Discussion

Table 1 presents the commensals, predators and parasites recorded from C. madrasensis in this study from time to time. Excepting the trematode Bucephalus, almost all the other animals recorded from shells were leading a sort of commensalic life. The polychaete Polydora ciliata is parasitic forming "mud-blisters" in the oyster shells. The role of the various commensals recorded from C. madrasensis, in the life of the host is chiefly as competitions for space and food. Rao & Menon (1978) observed that the breeding of these commensals coiciding with breeding of the oysters. As several of them inhabit the shell of oyster, severe competition for food is experienced as many of them feed on the plankton available in the water on which oysters also depend. Heavy fouling can also lead to difficulty in the opening of shells owing to the extra weight added to the shell by the fouling organisms.

There is only a single instance of Bucephalus infestation noticed and the site of infection was the mantle and the immediate gonadal tissue below the mantle. Tennet (1906) and Hopkins (1954) recorded Bucephalus cuculus from the gonad of C. virginica. Cheng & Burton (1965) recorded Bucephalus cuculus from the digestive tissue of the same species inhabiting Rhode Island. George & Nair (1974) observed Buchephalus infecting the mantle of Musculista arcuatula. Parasitic castration of the host by Bucephalus was observed by Cheng & Burton (1965). In the present study also, the oyster infected by Bucephalus was an indeterminate one, may be due to the infilteration by the sporocysts of Bucephalus, thereby inhibiting gametogenesis. Gigantism in molluscs consequent on trematode infection was noticed by Wesenberg Lund (1934), Rothchild (1938, 1941a, b), Rothschild & Rothchild (1939), Abnormal growth may be due to the utilization of the nutrients for somatic growth, as gonads are incapable of utilizing the nutrients for gametogenesis, being degenerated by parasitic castration (Wright, 1971). The oyster from which Bucephalus sp. was recorded in this study did not exhibit any gigantism.

Polydora infection was chiefly during the pre-monsoon and post-monsoon periods. They were virtually absent during the monsoon spells as they may be less tolerant to the very low salinity conditions experienced during the monsoon period (Chapter 1). Lunz (1940, 1941), Korringa (1952) and Clark (1956) and several others have studied the effect of Polydora infestation on oysters. According to Korringa (1952), the shell volume is considerably reduced owing to the formation of 'mud-blisters'. The oyster expends considerable energy to secrete new shell material, which ultimately exhausts the oysters thereby exposing them to the attack of predators (Sindermann, 1970)

Table 9.1 Associates (Commensals) recorded from C. madrasensis

Animals recorded	Group	Occurrence	Type of association
Cliona sp.	Porifera	Throughout the year	Parasitic commensal
Electra bengalensis (Stoliczka)	Bryozoa	Pre & post monsoon	Commensal
Alderina arabianensis Menon and Nair	"	"	"
Schizoporella cochinensis Menon and Nair.	"	"	"
Nolella paupensis (Busk)	"	"	"
Bowerbankia impricata (Adams)	"	"	"
Electra crustulenta (Pallas)	"	Monsoon	"
Victorella pavida (Kent)	"	"	"
Hydroides norwegica (Gunnerus)	Annelida (Polyehaeta)	Throughout the year	"
Mercierella enigmatica	"	"	"
Spirorbis sp.	"	"	"
Polydora ciliata (Johnston)	"	Pre-monsoon	Parasitic commensal
Eunice sp.	"	"	Commensal
Perinereis sp.	Platyhelminthes (Trematoda)	"	"
Bucephalus sp.	"	"	Parasite

Table contd.

Table contd.

Balanus amphitrite communis (Darwin)	Crustacea (Cirripedia)	Pre & Post monsoon	Commensal
Corophium triaeonyx	Crustacea (Amphipoda)	Post-monsoon	"
Tanais estuaris	Crustacea	Throughout the year	"
Sphaeroma walkeri	Crustacea (Isopoda)	"	"
Perna viridis (Linnaeus)	Mollusca (Bivalvia)	"	"
Anomia sp.	"	"	"
Crassostrea cucullata	"	"	"
Modiolus carvalhoi	"	"	"
Musculista sp.	"	"	"

Pearl formation is a very rare phenomenon observed in edible oysters. Nacrezation around a foreign material leads to the formation of pearls, which is an internal defence mechanism (Cheng, 1967). Nacrezation is influenced by a variety of trematodes and cestodes (Southwell, 1924; Palombi, 1940; Stunkard & Uzmann, 1958). The causative agent for the formation of pearl noticed in this study is not known. Of the 1261 oysters examined, pearl formation was noticed only in one instance, which indicates that pearl formation is a very rare phenomena in *C. madrasensis*.

9.5. References

Aldermann, D. (1979) Epizootiology of *Marteilia refringens*. In "*Haplosporidian and Haplosporidian Like Diseases of Shell Fish*" (Perkins, F.O. Ed.) *Mar. Fish. Rev.* **41**, 67-69

Andrews, J.D. (1964) Oyster mortality studies in Virginia IV. MSX in James River Public Seed Beds. *Proc. natn. Shell Fish. Ass.* **53**, 65-84

Andrews, J.D. & Hewatt, W.G. (1954) Incidence of *Dermocystidium marinum* Mackin, Collier and Owen, a fungus disease of oysters in Virginia. *Convn. Address. natn. Shell Fish. Ass.* **79**

Andrews, J.D., Wood, J.L. & Hoese, H.D. (1962) Oyster mortality in Virginia iii - Epizootiogy of a disease caused by *Haplosporidium costale* Wood and Andrews. *J. Insect. Path.* **4**, 327-343

Awati, P.R. & Rai, H.S. (1931) Ostrea cucullata (The Bombay Oyster) Indian zool. Mem. 3, 1-107

Balonet, G. (1979) Marteilia refringens. Considerations of the life cycle and development of Abers disease in Ostrea edulis. In "Haplosporidian and Haplosporidian Like Diseases of Shell Fish" (F.O.Perkins, Ed.) Mar. Fish. Rev. 41, 64-66

Burton, R.W. (1961) Distribution of oyster microparasites in Chesapeake Bay, Maryland, 1959-1960. Proc. natn. Shell Fish. Ass. 52, 65-74

Cahour, A. (1979) Marteilia refringens and Crassostrea gigas In "Haplosporidian and Haplosporidian Like Diseases of Shell Fish. (Perkins, F.O. Ed.,) Mar. Fish. Rev. 41, 19-20

Cheng, T.C. (1950b) On the structure and alteration of cellular polarity of the sporocysts of Bucephalus sp. as a function of age.Proc. Pacif. Acad. Sci. 39, 180-186

Cheng, T.C. (1966) The coracidium of the cestode Tylocephalum and the migration and fat of this parasite in the American oyster Crassostrea virginica. Trans. Am. microsc. Soc. 85, 246-255

Cheng, T.C. (1967) Marine mulluscs as hosts for symbiosis with a review of known parasites of commercially important species. Advances in Marine Biology, vol.5, (Russel, F.S. Ed.,) Academic Press, London & New York

Cheng, T.C. & Burton, R.W. (1965) Relationships between *Bucephalus* sp. and *Crassostrea virginica*, histopathology and sites of infection. *Chesapeake Sci.* **6**, 3-16

Cheng, T.C., Shuster, C.N. & Anderson, A.H. (1966) A comparative study of the suceptibility and response of eight species of marine pelecypods to the trematode *Himasthla quissetensis*. *Trans. Am. microsc. Soc.* **85**, 284-295

Christensen, A.M. & McDermott, J.J. (1958) Life history and biology of the oyster crab, *Pinnotherus ostreum* Say. *Biol. Bull. mar. biol. Lab. Woods Hole.* **114**:146-179

Clark, R.B. (1956) *Capitella capitata* as a commensal, with a bibliography of parasitism and commensalism in the polychaetes. *Annls. Mag. nat. Hist.* **125**(9) 433-448

Cole, H.A. (1950) Shell disease in re-laid French oysters. *Nature*, Lond. **166**, 19-20

Cole, H.A. & Waugh, G.D. (1956) Shell disease in Portuguese oysters. *Nature*, Lond. **178**, 422

Couch, J.A. (1967) Concurrent haplosporidian infections of the oyster, *Crassostrea virginica* (Gmelin). *J. Parasitol.* **53**, 248-253

Couch, J.A. & Rosefield, A. (1968) Epizootiology of *Minchinia costalis* and *Minchinia nelsoni* in oysters introduced to Chincoteague Bay, Virginia. *Proc. natn. shellfish Ass.* **58**, 51-59

*Dollfus, R.Ph. (1921) Resume de nos principales cannaissances pratiques sur les maladies et les ennemis de I'huitre. *Notes Mem. Off. Scient. tech. Pech. marit*. **7**, 1-46

Durve, V.S. (1965) On the seasonal gonadal changes and spawning in the adult oyster *Crassostrea gryphoides* (Schlotheim) *J. mar. biol. Ass. India* **7**, 328-344

Durve, V.S. & Bal, D.V. (1960) Shell disease in *Crassostrea gryphoides* (Schlotheim). *Curr. Sci*. **29**, 489-490

Engle, J.B. & Rosenfield, A. (1963) Progress in oyster mortality studies. *Proc. Gulf Caribb. Fish. Inst*. 15th Ann. Ser. 116-124

Eyre, J.H. (1924) An account of investigations into the cause or causes of the unusual mortality among oysters in English oyster beds during 1920 and 1921. Part ii. Apendix D, Final bacteriological report. *Min. Agric. Fish. Fishery Invest. Lond*. 2, 6(4)

*Fujita, T. (1925) Etudes sur les parasites de lhuitre comestible du Japan, *Ostrea gigas* Thunberg. *Annls. Parasit. hum. comp*. **3**, 37-59

*Fujita, T. (1943) "*Gyokai No Shippei* (Diseases of fish and shell fish) Koa Nippon C., Japan (JP)

Galtsoff, P.S. (1964) The American oyster *Crassostrea virginica* (Gmelin) *Fish. Bull. Fish. Wildl. Ser*. **64**, 1-480

George, E.L. & Nair, N.B. (1974) Observations on *Bucephalus* sp. parasitic in *Musculista arcuatula*. *J. Invert. Pathol*. **24**, 63-69

*Giard, A. (1907) Sur les trematodes *Margaritigens* du Pas-decalais (*Gymnophallus somateriae* Levinsen et *G. bursicola odhner*) *C.r. Seane. Soc. Biol*. **63**, 416-420

*Grizel, H. (1979) *Marteilia refringens* and oyster disease-recent observations. In "Haplosporidian and Haplosporidian Like Diseases of Shell Fish". (Perkins, F.O. Ed.) *Mar. Fish. Rev*. **41**, 38-39

*Grizel, H., Comps, M., Bonami, J.R., Cousserans, F., Duchoit, J.L. & Le Pennec, M.A. (1974) Richerche Sur lajent de la maladie de la glande digestive de *Ostrea edulis* Linne. *Sci. Peche*, **240**:7-30

Guillard, R.R.L. (1959) Further evidence of the destruction of bivalve larvae by bacteria. *Biol. Bull. mar. biol. lab. Woods Hole*. **117**, 258-266

Hartman, O. (1945) The marine annelids of North Carolina. *Bull. Duke University Marine Station*, **2**, 1-151

Haskin, H.H., Canzonier, W.J. & Myhre, J.L. (1965) The history of "MSX" on Delaware Bay oyster grounds. *A. Rep. Am. Malacological Union*. pp.20-21

Haskin, H.H., Stamber, L.A. & Mackin, J.C. (1966) *Michinia nelsoni* n. sp (Haplosporidia, Haplosporidiidae) Causative agent of the Delaware Bay oyster eizoolic. *Science*. N.Y. **153**, 1414-1416

Haven, D. (1959) Effects of pea crabs Pinnotherus Ostreum on oysters Crassostrea virginica. Proc. natn. shell Fish. Ass. 49, 77-86

Hewatt, W.G. & Andrews, J.D. (1954) Oyster mortality studies in virginia 1. Mortalities of oysters in trays at Gloucester Print, York River. Tex. J. Sci. 6, 121-133

Hopkins, S.H. (1954) The American species of trematode confused with Bucephalus (Bucephalopsis) haineanus. Parasitology. 44, 353-370

Hopkins, S.H. (1958) The planktonic larvae of Polydora websteri Hartman (Annelida, Polychaeta) and their settling on oysters. Bull. mar. Sci. Gulf Caribb. 8(3), 268-277

Hornell, J. (1910b) The practice of oyster culture at Arcachon (France) and its lessons for India. Madras Fish. Bull. 5, 1-90

Howell, M. (1967) The trematode, Bucephalus longicornutus (Manter, 1954) in the New Zealand mud-oyster Ostrea lurida. Trans. R. Soc. New Zealand, 8, 221-355

Humes, A.G. (1958) Copepodes parasites de Mollusques a Madagascar. Mem. Inst. Sci. Madagascar (F) 2, 285-342

Joseph, M.M. (1978a) Observations on the larval trematode Bucephalus sp. parasitic in the oyster Crassostrea madrasensis. M. Invert. Pathol. 32, 381-383

Korringa, P. (1947) Les Vicissitudes del Ostreiculture Hollandaise elucidees par la science Ostreicole Moderne. Ostreiculture cult. mar. 16, 3-9

Korringa, P. (1951a) The shell of Ostrea edulis as a Habitat. Archs. neerl. Zool. 10, 32-152

Korringa, P. (1951b) Investigation on shell disease in oyster, Ostrea edulis L. Rapp. Cons. Explor. Mer. 128, 50-54

Korringa, P. (1951c) Investigation on shell-disease in the oyster Ostrea edulis L. Conseil Permanent International pour l' Exploration de la Mer, Rapports et Proces Verbaux des Reunions, Vol.128, Contributions to special Scientific Meetings 1949, Part-2, Shellfish Investigations, 50-54

Korringa, P. (1952) Recent advances in oyster biology, Q. Rev. Biol. 27(3), 266-308; 339-365

Korringa, P. (1976) Farming the cupped oysters of the Genus Crassostrea. Dev. Aquaculture Fish. Sci. 2, 224

Kren, F.G. (1976) Minchinia nelsoni (MSX) disease of the American oyster. Mar. Fish. Rev. 38, 22-24

Landau, H. & Galtsoff, P.S. (1951) Distribution of Nematopsis infection on the oyster grounds of the Chesapeake Bay and in other waters of the Atlantic and Gulf States. Tex. J. Sci. 3, 115-130

*Leger, L. & Hollande, A.C. (1917) Surun mouvean protist a facies de Chystridiopsis parasite des Ovules de 1 huitre. *C.r. Seane. Soc. Biol.* **80**, 61-64

Little, J.W., Hopkins, S.H. & Schlicht, F.G. (1966) *Acanthoparyphium spinulosum* (Tematoda: Echinos - stomatidae) in oysters at Port Isabel, Texas. *J. Parasit.* **52**, 663

Loosanoff, V.L. (1956) Two obscure oyster enemies in New England Waters. *Science*, **123** (3208) 1119-1120

Lunz, G.R. Jr. (1940) The annelid worm Polydora as an oyster pest. *Science*. N.Y. **92**, 310

Lunz, G.R. Jr. (1941) Polydora, a pest in South Carolia oysters. *J. Elisha Mitchell scient. Soc.* **57**, 273-

Mackin, J.G. (1953) Incidence of infection of oysters by *Dermocystidium* in the Barataria Bay area of Lousia *Convention Address. natn. Shellfish Ass.* 22-35

Mackin, J.G. (1962) Oyster disease caused by *Dermocystid marinum* and other microorganisms in Lousiana. *Publs. Inst. mar. sci. Univ. Tex.* **7**:132-229

Mackin, J.G. (1960) Status of researches on oyster diseases in North America. *Proc. Gulf. Caribb. Fi Inst. A. Ser.* **13**, 98-113

Mackin, J.G., Korringa, P. & Hopkins, S.H. (1952) Hexami tiasis of *Ostrea edulis* L. and *Crassostrea virgini* (Gmelin) *Bull. mar. Sci. Gulf. Caribb.* **1**, 266-277

Mackin, J.G., Owen, H.M. & Collier, A. (1950) Preliminary note on the occurrence of a new protistan parasite _Dermocystidium marinum_ n.sp. in _C. virginica_ (Gmeli _Science_, N.Y. iii, 328-329

Mattox, N.T. & Crowell, S. (1951) A new commensal hydroid of the mantle cavity of an oyster. _Biol. Bull. mar biol. Lab. 191_, 162-170

*McCardy, J. (1874) Observations on the food and reproduct organs of _Ostrea virginica_ with some account of _Bucephalus cuculus_ nov. spec. _Proc. Boston Soc. nat. Hist._ _16_, 170-192

McDermott, J.J. (1960) The predation of oysters and barnacles by crabs of the family Xanthidae. _Proc. Pacif. Acad. Sci._ _34_, 199-211

Menzel, R.W. & Hopkins, S.H. (1955b) The growth of oyster parasitized by the fungus _Dermocystidium marinum_ and by the trematode _Bucephalus cuculus_. _J. Parasi_ _41_, 33-342

McDermott, J.J. & Flower, F.B. (1952) Preliminary studies of the common mud crab on the oyster beds of Delaware Bay. _Convention Address, natn. Shell Fish Ass._ 47-50

Miller, R.H. (1963) Oysters killed by trematode parasites _Nature_. _197_ (4807), 616

Mobius, K. (1883) XXVII. The oyster and oyster culture. U.S. Comm. Fish Pt. 8, pp.683-751

Mori, T. (1935) Mytilicola orientalis, a new species of parasitic copepod. Zool. Mag. Tokyo. 47, 687-693

Nikolic, M. & Alfonso, S.J. (1970) Initial experiments of farming the mangrove oyster (Crassostrea rhizophorae Guilding, 1828) Proc. Sym. Mollusca. Part iii. Mar. Biol. Assn. (India) pp.967-971

Numachi, K., Oizumi, J., Sato, S. & Imai, T. (1965) Studies on the mass mortality of the oyster in Matsushima Bay iii - The pathological changes of the oyster caused by Gram positive bacteria and the frequency of their infection. Bull. Tohoku Reg. Fish. Res. Lab. 25, 39-47

Orton, J.H. (1920b) Mode of feeding and the sex phenomena in the pea-crab (Pinnotherus pisum). Nature, Lond 106, 533-534

Orton, J.H. (1937) Oyster Biology and Oyster Culture. The Bukland Lectures for 1935. Edward Arnold & Co. London 211 pp

Palombi, A. (1940) Gli stadi larvali dei trematodi del Galfo di Napoli. 3. Contributo allo studio della morfologia, biologia e systematica della cercarie marine. Riv. Parassit; 4, 7-30

Pearse, A.S. (1947) Parasitic copepods from Beaufort, North Carolina J. Elisha Mitchell scient, Soc. 63, 1-16

Pearse, A.S. & Wharton, G.W. (1938) The oyster "leech" Stylochus inimicus Palombi, associated with oysters on the coasts of Florida. Ecol. Monogr. 8, 4, 605-655

*Pelseneer, P. (1928) Les parasites des mollusques et les mollusquee parasites. Bull. Soc. Zool. Fr. 53, 158-189

Perkins, F.O. & Wolf, P.H. (1976) Fine structure of Marteilia sydnei sp. n. Halosporidian pathogen of Australian oysters. J. Parasit. 62, 528-538

Prytherch, H.F. (1940) The life cycle and morphology of Nematopsis ostrearum sp. nov; a gregarine parasite of the mud crabs and oysters. J. Morph. 66, 39-65

Quick, J.A. Jr. & Mackin, J.G. (1971) Oyster parasitism by Labrynthomyxa marina in Florida. Fla. Dept. nat. Resources Prof. Pap. Ser. No.13, pp.55

Ranson, G. (1936) Sur quelques maladies des Huitres. Rev. Pathol. Comp. Hyg. Gen. 475, 506-526

Rao, K.S. (1974) Edible bivalves: mussels and oysters, Comml. mollucs India, 24, 4-39

Rao, D.S.K. & Menon, N.R. (1978) Settlement characteristics on different substrata by three commercially important bivalves in Mangalore waters, Arabian sea. Int. Rev. ges. Hydrobiol.

Ray, S.M. (1954a) Experimental studies on the transmission of pathogenecity of *Dermocystidium marinum*, a fungus parasite of oysters. *J. Parasit*. **40**:235

Ray, S.M. (1954b) Biological studies of *Dermocystidium* marinum, a fungus parasite of oysters. *Rice Inst*. *Pampt*., Spec. Issue. Nov. 1954 Monograph in Biology, pp.114

Ray, S.M., Mackin, J.G. & Boswell, J.L. (1953) Quantitative measurement of the effect on oysters of disease caused by *Dermocystidium marinum*. *Bull. mar. Sci*. *Gulf. Caribb*. **3**, 6-33

Rothchild, M. (1936) Further observations on the effect of trematode parasites on *Peringia ulvae* (Pennant) *Novit. zool*. **41**, 84-102

Rothchild,M. (1941a) Observation on the growth and trematode infections of *Peringia ulvae* (Pennant) 1977 in a pool in the Tamar saltings, Plymouth. *Parasitology*. **33**, 406-415

Rothchild, M. (1941b) The effect of trematode parasites on the growth of *Littorina neritoides* (L) *J. mar. biol*. *Ass. U.K*. **25**, 69-80

Rothchild, A. & Rothchild, M. (1939) Some observations on the growth of *Peringia ulvae* (Pennant) 1977 in the laboratory. *Novit. zool*. **41**, 240-247

Roughly, T.C. (1925) The story of the oyster. iv. The perils of an oyster. *Austr. Mus. Mag*. **2**, 25-32

Sakai, T. (1934) Brachyura from the coast of Kyusyn, Japan. *Sci. Rep. Tokyo Bunrika Daig, Sect. B*. **1**, 281-330

Sakai, T. (1936) *Crabs of Japan*, Tokyo

Sakai, T. (1965) *The Crabs of Sagami Bay*, East-west Center Press. Honolulu

Samuel, D. (1976) A digenic trematode infection in the edible oyster *Crassostrea madrassensis* (Preston) *Indian J. Fish.* **23**, 153-159

Sandoz, M. & Hopkins, S.H. (1947) Early life history of the oyster crab, *Pinnotherus ostreum* (Say) *Biol. Bull.* **93**, (3), 250-258

Say, T. (1818) An account of the crustacea of the United States. *J. Acad. natn. Scient. Soc*. **63**, 1-16

Scheltema, R.S. (1962) The relationship between the flogellate protozoan *Hexamita* and the oyster *Crassostrea virginica*. *J. Parasit*. **48**, 137-141

Schlicht, F.G. & Mackin, J.G. (1968) *Hexamita nelsoni* sp. n (Polymastigina: Hexamitidae) parasitic in oysters. *J. Invertebr. Pathol*. **11**, 35-39

Sindermann, C.J. (1968) Bibliography of oyster parasites and diseases. *U.S. Fish Wildl. Serv. Spl. Sci. Rep*. 563, 1-13

Sindermann, C.J. (1970) Disease Diagnosis and Control in North American Marine Aquaculture. Development in Aquaculture and Fisheries Science No.6, Elsivier Scientific Publishing Company, Amsterdam, 1-329

Sindermann, C.J. (1977) Disease diagnosis and control in North American marine aquaculture. Development in Aquaculture and Fisheries Science. No.6, Elsivier Scientific Publishing Company, Amsterdam, pp.1-329

Sindermann, C.J. & Rosenfield, A. (1967) Principal diseases of commercially important marine bivalve mollusca and crustacea. U.S. Fish Wldl. Ser. Fish. Bull. 66(2): 335-385

Southwell, T. (1924) The pearl inducing worm in the Ceylon peal oyster. Ann. trop. Med. Parasit. 18, 37-53

Sparks, A.K. (1962a) Metaplasia of the gut of the oyster C. gigas (Thumberg) caused by infection with the copepod Mytilicola orientalis Mori. J. Insect Path. 4(1), 57-62

Sparks, A.K. (1962b) Infection of Crassostrea virginica (Gmelin) from Hawaii with a larval tapeworm, Tylocephalum, J. Insect. Path. 5, 284-288

Sprague, V. & Orr, P.E. Jr. (1955) Nematopsis ostrearum and N. Prytherchi (Eugregarinida: Porosporidae) with special reference to the host parasite relations. J. Parasit. 41, 89-104

Stein, J.E., Denison, J.G. & Mackin, J.G. (1961) Hexamita sp. as an infectious disease in the oyster, Ostrea lurida, Proc. natn. shell. fish Ass. 50, 67-81

Stephen, D. (1978a) First record of the larval cestode Tylocephalum from Indian backwater oyster Crassostrea madrasensis. J. Invertebr. Path. 32, 110-111

Stephen, D. & Joseph, M.M. (1977) Parasitic castration of the Indian backwater oyster Crassostrea madrasensis (Preston) by the larval trematode Bucephalus sp. Sci. Cult. 43, 387-388

Stunkard, H.W. & Uzmann, J.R. (1958) Studies on digenetic trematodes of the genera Gymnophallus and Parvatrema. Biol. Bull. mar. biol. Lab. Woods. 115, 276-302

Takeuchi, T.,Takemoto, Y.& Matsubara, T. (1960) Hematological study of bacteria infected oysters. Rep. Hiroshima Prefect. Fish. exp. Stn. 22, 1-7

Tennent, D.H. (1906) A study of the life history of Bucephalus haimeanus a parasite of the oyster. Q. J. microsc. Sci. 49, (196), 635-690

Tubiash, H.S., Chanky, P.E. & Leifson, E. (1965) Bacillary necrosis, a disease of larval and juvenile bivalve molluscs. Etiology and epizootiology. J. Bact. 90, 1036-1044

Verrill, A.E. (1873) Report upon invertebrate animals of Vineyard Sound and adjacent waters, with an account of the physical character of the region. U.S. Commission of Fisheries. Miscellaneous Documents to the Senate of the US. 42nd Congress, 2nd Session vol.1, 295-778

Vishniac, H.S. (1955) The morphology and nutrition of a new species of Sirolpidium. Mycologia. 47, 633-645

*Voisin, P.C. (1931) Biologie Ostreicole La maladie des Huitres de Zelande. Rev. Trauv off Sci. Tech. Peaches Marit. 4, 221-222

Wesenberg-Lund, C.J. (1934) Contribution to the development of the trematoda Digena. Pt ii - The Biology of the freshwater cercariae in Danish freshwaters. K. danske vidensk. Selsk. Skr. 9, 5, 1-22

Wilson, C.B. (1944) Parasitic copepods in the United States National Museum. Proc. U.S. natn. Mus. 94, 529-582

Woelke, C.E. (1957) The flat worms Pseudostylochus Ostreophagus Hyman, a predator of oysters. Proc. natn. shell fish. Ass. 47, 62-66

Wolf, P.H. (1972) Occurrence of a haplosporidian in Sydney rock oysters (Crassostrea commercialis) from Morton Bay, Queensland, Australia, J. Invertebr. Path. 19, 416-417

Wood, J.L. & Andrews, J.D. (1962) Haplosporidium costale (Sporozoa) associated with a disease of Virginia oysters. Science, N.Y. 136, 710-711

Wright, C.A. (1971) Flukes and snails. In 'The Science of Biology, Ser. 4, 168

Yamada, M. (1950) A epizoic athecate hydroid attached to the oyster body. Annotnes Zool. jap. 23, 17

Yamaguti, S. (1936) Parasitic copepods from Beaufort, North Carolina. J. Elisha Mitchell scient. Soc. 63, 1-16

*Zernov, S.A. (1913) Contribution to the knowledge of the life of the Black Sea. Zap. imp. Akad. Nauk. 32, 1-229 (Ru)

---

*Not consulted the original

SUMMARY

SUMMARY

1. A detailed study of the hydrography of the Cochin Backwaters, the habitat of *Crassostrea madrasensis* has been carried out. Data pertaining to air temperature, water temperature, salinity, dissolved oxygen, turbidity and rainfall have been collected and presented. The temperature fluctuation was in the range of 5°C only and that of salinity between 1.1‰ and 32.9‰. Fairly steady salinity has been recorded during the pre-monsoon period (February to May) and drastic declension during the monsoon period (June-September). Dissolved oxygen varied between 2.5 ml/l and 6.5 ml/l. Turbidity was highest in June (27.9 p.p.m.) and minimum (10.2 p.p.m.) in February.
2. A detailed study on marine biofouling in the Cochin Backwaters has been made with special reference to primary film, settlement and growth of the fouling organisms such as hydroids, bryozoans, tube-dwelling polychaetes, barnacles and modiolus.
3. An account of the settlement of *C. madrasensis* in the Cochin Backwaters is presented. *C. madrasensis* enjoys

a wide distribution in the backwaters. In the five stations investigated, no settlement of *C. madrasensis* was observed during the monsoon period owing to reduced salinity. Settlement in general was confined to the late post-monsoon period and throughout the pre-monsoon period.

4. Height-length studies in *C. madrasensis* revealed an exponential trend in the form $H = AL^B$. Larger deviations in height for longer oysters were observed. For oysters below 3.5 cm in height, height and length approximated. The ratio changed for oysters of 8 cm and above in height. Height-depth relation also showed an exponential relation in the form $H = AD^B$. The variations in height did not bring about corresponding variations in depth. The frequency distribution of the index of shape also showed that height and width are not directly proportional to increase in length.

5. The relation of weight to height, length and depth was examined by a multiple regression. t-tests showed that the regression co-efficients were significantly different from zero, suggesting that increase in height, length and breadth contributed to the weight in *C. madrasensis*. Partial regression co-efficients showed that weight is influenced by height, length and depth in their order of preference.

6. Condition index and percentage edibility for the total oyster populations were worked out. Condition index and percentage edibility showed a similar trend for the total population and also for males, females and indeterminates. Maximum condition index and percentage edibility were noticed during October which declined and reached the lowest in February-March. From April, it showed steady increase reaching the maximum again in October.

7. Studies on age and growth showed faster growth rate in *C. madrasensis* inhabiting the Cochin Backwaters compared to those reported from Madras. Salinity fluctuations and alteration of mesohaline and polyhaline condition at the Cochin Harbour influenced the growth in *C. madrasensis*. Growth was determined by the progression of modal height during different months. The maximum size which oysters can attain ($L\infty$) and catabolism co-efficient K, ($\log_e \tan \theta$) were determined by Ford-Walford technique. The theoretical time at which oyster height is zero (t_0) was determined by plotting $\log_e (L\infty - l_t)$ on t. From this, it was read as the time relating to logL. $L\infty$ was found to be 21 cm.

8. Biochemical studies have been shown similar trend in the fluctuation of water content in male and female oysters. A definite pattern in the distribution of

protein was noticed. It showed an inverse relation to glycogen. A definite shift in the value of protein corresponding to the reproductive phase of oysters was noticed. Fat content was low during December to May with peaks in September in both the sexes. Ash also showed a trend similar to protein.

9. Trace metal load of cadmium, copper, iron, manganese, zinc and mercury was estimated. The study has shown that heavy metal load in *C. madrasensis* exhibits seasonality, correlated with reproductive cycle.

10. A brief account is furnished of the associates and their ecology. The parasites include, the boring sponge *cliona*, the polychaete *Polidora ciliata* and the trematode *Bucephalus* sp. Several species of bryozoans such as *Electra bengalensis*, *Alderina arabianensis*, *Schizoporella cochinensis*, *Nolella paupensis*, *Bowerbankia impricata*, *Electra crustulenta*, *Victorella pavida* and tubicolous polychaetes such as *Hydroides norvegica*, *Mercierella enigmatica* and crustaceans such as *Balanus amphitrate*, *Corophium triaenonyx*, *Sphaeroma walkeri* were recorded as associates. The formation of pearl in one instance has also been recorded in this edible oyster. The results of the present studies are discussed in detail with earlier work on oysters from India and abroad.

APPENDIX

Research Publications of N.Unnikrishnan Nair

A. As single author

1. Marine fouling in Indian Waters. J. Sci. Ind. Res. 24(9) 483-488, 1965
2. The settlement and growth of major fouling organisms in Cochin harbour. Hydrobiologia, 30: FASC 3-4, 503-512, 1967
3. Studies on the occurrence and growth rate of two intertidal fouling bryozoans in the Mattancherry Channel of Cochin harbour South-west coast of India. Fishery Technology. 8(2), 174-184, 1971
4. Observation on the fouling characteristics of four bryozoans in Cochin harbour. Fishery Technology, 10(1), 61-65, 1973

B. As first author

1. Studies on arsenical creosote as a wood preservative for marine structures. Part 1. Incorporation of arsenic in creosote at various temperatures. Fishery Technology, 9(1), 76-80, 1972 (with M/S A.G.Gopalakrishna Pillay & R.Balasubramanyan)
2. Studies on arsenical creosote as a wood preservative for marine structures - Part ii - Observations on leaching corrosion and resistance to borer attack. Fishery Technology, 9(2), 126-132 (with M/S A.G. Gopalakrishna Pillay & R.Balasubramanyan)

--2

3. Observations on the composition of slime film and its influence in the settlement of certain marine fouling organisms in Cochin harbour. *Proc. Symp. "Protection of Materials in the Sea"*, 283-286, Conducted by the Naval Chemical and Mettalurgical Laboratory under the aegis of Defence Research and Development Organisation, Ministry of Defence, Government of India, 1977 (with Shri A.G.Gopalakrishna Pillay)
4. Studies on the influence of moisture and specific gravity on the strength properties of mango wood (*Mangifera indica*). *Fishery Technology*, 16, 7-9, 1979 (with M/S K.Ravindran & A.G.Gopalakrishna Pillay)
5. Wood preservation - An appropriate technology for the use of small scale fishermen - Paper presented at the symposium on Harvest and Post-harvest Technology of Fish held under the aegis of the Society of Fisheries Technologists (India) Cochin, Nov. 24-27, 1982 (with M/S A.G.Gopalakrishna Pillay, K.Ravindran and R.Balasubramanyan)
6. Studies on marine biofouling and its prevention with special reference to fishing craft. Paper accepted for presentation and publication in the proceedings of the 6th International Congress on Marine Corrosion and Fouling scheduled to be held in Sept. 1984, at Athens, Greece.

Other combined publications

1. Protection against borers, foulers and corrosion through the use of aluminium alloy sheathing in a marine environment. Paper presented at the Second International Congress on Marine Corrosion and Fouling, Athens (Greece) in 1963 (with M/S R.Balasubramanyan, K.Ravindran & A.G.Gopalakrishna Pillay)
2. Fouling by oysters and its prevention. Paper presented at the 'Symposium on Mullusca' held under the auspices of the Marine Biological Association (India), 1970 (with Shri R.Balasubramanyan)
3. Experimental formulation of an antifouling coating with tributyltin oxide as the toxic pigment. Fishery Technology, 9(2), 153-158, 1972 (with Shri A.G.Gopalakrishna Pillay)
4. The problem of marine fouling in coastal waters of India and its economic implications, with special reference to fishing fleet management. 'Paper presented at the III International Congress on Marine Corrosion and Fouling, October 2-6, 1972 held under the aegis of National Bureau of Standards, Gaithersburg, Maryland, U.S.A. (with M/s R.Balasubramanyan & A.G.Gopalakrishna Pillay)
5. On the importance of ship-bottom fouling by marine organisms - A techno-economic survey. Fishery Technology, 10(2) 120-123, 1973

--4

6. 'Copper creosote'. A new preservative for marine wooden structures. Paper presented at the symposium on Harvest and Post-harvest Technology of Fish held under the aegis of the Society of Fisheries Technologists (India) at Cochin, November 24-27, 1982 (with M/S K.Ravindran & A.G.Gopalakrishna Pillay)
7. Elastomeric antifouling Coating - A novel approach. Paper presented at the Symposium on Harvest and Post-harvest Technology of Fish organised by Society of Fisheries Technologists (India) November 24-27, Cochin, 1982 (with Shri K.Ravindran and Smt. Rany Mary Jacob)