STUDIES ON INFLUENCE OF ENVIRONMENTAL PARAMETERS AFFECTING THE BIOLOGY OF OYSTER *CRASSOSTREA MADRASENSIS* (PRESTON)

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(INDIAN COUNCIL OF AGRICULTURAL RESEARCH)

COCHIN 682 014

December 1994

Dedicated to My Parents

CERTIFICATE

*This is to certify that the thesis entitled "**STUDIES ON INFLUENCE OF ENVIRONMENTAL PARAMETERS AFFECTING THE BIOLOGY OF OYSTER CRASSOSTREA MADRASENSIS (PRESTON)**" is a bonafide record of the research work carried out by Mr. **VAHEED YAVARI** under my guidance and supervision under the Post-Graduate Education and Research Programme in Mariculture, at Central Marine Fisheries Research Institute, Cochin, and that no part thereof has been presented for the award of any other Degree.*

Cochin - 682 014
December 1994.

Dr. M.M. Thomas
(Supervising Guide),
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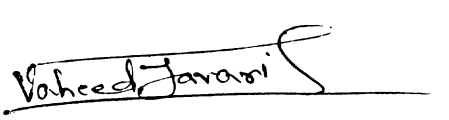
DECLARATION

*I hereby declare that this thesis entitled "**STUDIES ON INFLUENCE OF ENVIRONMENTAL PARAMETERS AFFECTING THE BIOLOGY OF OYSTER CRASSOSTREA MADRASENSIS (PRESTON)**" is a record of original and bonafide research carried out by me under the supervision and guidance of **Dr. M.M. Thomas, Principal Scientist, Central Marine Fisheries Research Institute, Cochin** and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.*



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VAHEED YAVARI

PREFACE

World demand for protein rich fishery products has grown at a steady pace. Capture fisheries can not meet this continually expanding demand due to the ever increasing human population coupled with stagnating coastal fish production and capital-intensive and technology-oriented nature of deep sea resource exploitation. On the other hand, aquaculture production has been recognised as a significant and rapidly growing segment of total world food production. Molluscs contribute substantially to world aquaculture production. Bivalve mollusc farming has been developing in many countries in recent years. This development, to a large extent is driven by market demand.

The Indian edible oyster Crassostrea madrasensis (Preston) is known to be a highly suitable candidate species for culture. Though C. madrasensis has been subjected to intensive research, there has been no significant attempt to culture this oyster commercially. One major reason for the lack of interest in oyster culture could be the disparity in growth, survival and production reported by earlier workers from different regions along the Indian coast. Greater predictability of production can create confidence and encourage entrepreneurs interested in oyster culture.

Among the important recent suggestions for development of oyster culture in India, is the need for a comprehensive picture of sites suitable for oyster farming for all maritime states (James et al., 1993). Thorough understanding of environment-species relationship leads to selection and identification of sites which have physical, chemical

and biological properties suitable for higher growth, survival and production of the candidate species (Brown and Hartwick, 1988a).

Growth and production are directly affected by ecological conditions of the farm site. Previous studies on growth and production of C. madrasensis lacked detailed monitoring of important environmental variables, mostly involved only one site at a time and did not attempt to explain the reason for such wide variations in growth at different regions. The present study, which is a detailed investigation on the influence of various environmental variables on growth and reproduction of C. madrasensis, is not confined to the impact of only hydrological parameters but is also extended to study the effect of different degrees of aerial exposure on growth and survival. The main objective of the study is to develop a background for subsequent development of a site suitability index for culture of C. madrasensis along the Indian coast.

Two sets of experiments were conducted during the present study. Details of the experiments are presented in the thesis under two major chapters comprising four sections each. Each chapter has a separate introduction, materials and methods, results and discussion.

INTRODUCTION to the first set of experiments is presented in the Section I of Chapter 1. This section surveys the literature pertaining to the status of research on bivalves in general and C. madrasensis in particular, with special reference to the influence of various environmental parameters on growth, condition index, survival and reproduction.

Section I of Chapter 2, INTRODUCTION, draws attention towards the importance of assessing the tidal preference of candidate species, before deciding to culture bivalves subtidally or intertidally.

The description of experimental sites, construction of experimental structures, materials and methods adopted for analysis of biological and hydrological parameters, and details of various statistical analysis applied are presented in Section II, MATERIALS AND METHODS, of Chapters 1 and 2.

RESULTS of the first experiment, constituting Section III of Chapter 1, deals with the variations observed in absolute growth of experimental oysters among stations, fluctuations in monthly instantaneous growth rates and fortnightly condition index values, and their correlation with environmental variables. The fortnightly mortality, monthly occurrence of oysters in different stages of maturity, sex ratio and fortnightly/seasonal variations in environmental variables are also described in this section.

Section III of Chapter 2, RESULTS, present the variations observed in growth and mortality of experimental oysters exposed to different degrees of aerial exposure.

The results of the two sets of experiments conducted in the present study are discussed in Section IV, the DISCUSSION of Chapters 1 and 2.

The SUMMARY of the major results of the present study is given in the final section of the thesis followed by the BIBLIOGRAPHY.

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CONTENTS

CHAPTER 1

SECTION I

INTRODUCTION

Man depended on hunting and gathering for subsistence until the neolithic period. Fishing developed as a part of this basic subsistence activity, but has witnessed considerable technological advances in modern times. Fish production from the sea increased at a rapid rate with the expansion of fishing fleets. Although new fishery resources were discovered, intensive fishing efforts began to show their effect on the resource base, and increase in production, particularly of the more valuable products, has steadily declined. Over fishing and depletion of stocks have become a living reality and the need to enhance or create new stocks by human intervention has begun to be recognised.

Although traditionally fish farming was part of rural life in certain areas, the present day aquaculture has a much greater significance in socio-economic development and natural resource management. The most optimistic estimates of total catch of conventional species from the wild are around 100 million tonnes, out of which about 70 million tonnes is available for human consumption at the rate of current utilization. It has been reported that even if this can be increased through harvesting of new unconventional species for food, which is considered unrealistic due to problems of consumer acceptance, harvesting technology and costs, total catch used for human consumption cannot be expected to surpass 80 million tonnes. On the other hand, it is estimated that about 100 to 140 million tonnes of edible fishery products will be required to meet the demand of the projected world population by the year 2000. There is thus a deficit of approximately 20

to 60 million tonnes to be made up, and the only means presently known to achieve this goal is an accelerated development of aquaculture (Pillay, 1990).

The estimates of world aquaculture production based on the data provided to Food and Agriculture Organisation of the United Nations, were over 13.2 million tonnes. The available figures of production over a period of several years clearly show the main trends in production and indicate that aquaculture is a rapidly growing industry. It is predicted that a production of over 26 million tonnes by the year 2000 can be achieved if the observed rate of increase is maintained. According to the composition of aquaculture products, molluscs are second to finfish in the list with an estimate of over 2.67 million tonnes (Pillay, 1990). Oysters account for about 12% of the total world production from aquaculture.

In India the picture is not different from what was explained on a global level. Though fish provides the largest single source of animal protein, its demand outstrips supply owing to the ever increasing human population. The annual per capita fish consumption in India is only 4kg against the recommended 31Kg by Nutrition Advisory Committee on human nutrition. This shows that our protein demand is so great that it is important to increase fish production, and the only alternative available is aquaculture (Santhanam et al., 1990).

India has a coastal line running to 7517 km and the total spread of continental shelf is about 40 million hectares. The east and west coasts of India are productive and are suitable for undertaking mariculture

practices. It has been suggested by many that while the coastal areas offer much scope for large scale culture of organisms such as oysters, mussels, seaweed etc. the open sea could be utilised for suspended cage, raft and long line culture of fish and shellfish. Mariculture is of recent origin in India, although Hornell visualised the vital importance of oyster farming in this country as early as 1917 and carried out the culture of Crassostrea madrasensis (Preston) in the Pulicat lake. India produces about 0.14 million tonnes of fish and shellfish through aquaculture and the contribution through coastal aquaculture is only 7% (Santhanam et al., 1990).

Aquaculture of molluscs, especially bivalves, is one of the earliest forms of mariculture. Being sessile and low trophic level filter feeders, bivalves can be raised at relatively low cost. Among several species of bivalves and a few gastropods which are cultivated, the important ones are the oysters (Family Ostreidae), mussels (Family Mytilidae and Aviculadae), clams (Family Veneridae), scallops (Family Pectenidae), the abalone (Family Haliotidae) and cockles (Family Arcidae). The group that accounts for the largest production through aquaculture is the oysters and several species are cultured in many parts of the world. Cultivated oysters belong to two genera, Crassostrea (cupped oysters) and Ostrea (flat oysters). The important species cultured are Crassostrea gigas (Pacific oyster), C. virginica (American oyster), C. angulata (Portugese oyster), C. commercialis (Sydney rock oyster), C. glomerata (Auckland rock oyster), C. plicata and C. rivularis (Chinese oysters), Ostrea edulis (European oyster) and

O. chilensis (Chilean oyster). The mangrove oyster, C. rhizophorae is cultivated on relatively smaller scale.

Despite favourable climatic conditions, availability of inexpensive labour and the need to produce protein food at low cost in tropical countries, most of the bivalve culture has developed in subtropical and temperate climatic countries (Quayle, 1980).

Considerations of habitat requirements of aquaculture in coastal management policies have gained great importance world wide. Long term viability of bivalve culture is particularly dependent upon selection of suitable sites, with conditions necessary to promote rapid growth, high survival and production of the candidate species.

Location specific variations in growth and survival of bivalves have been demonstrated for Mytilus edulis (Incze et al., 1980), Mya arnaria (Appeldoorn, 1983), Crassostrea virginica (Mallet and Haley, 1983), C. gigas (Brown and Hartwick, 1988a) and Ostrea edulis (Utting, 1988). Thorough understanding of environment-species relationship leads to selection of optimal sites which is an essential requirement for attaining higher production through culture.

Habitat variables potentially critical to culture of many bivalve species have been studied and identified. Bayne and Newell (1983) stated that growth in marine bivalves is principally affected by interaction of several environmental variables particularly water temperature and food availability. Sea water temperature is reported to have major seasonal influence on growth and survival of bivalve spat (Spencer and Gough,

1978). In the field experiments on C. virginica (Butler, 1953), Macoma balthica (Gilbert, 1973), Ostrea puelchana (Fernandez and Boddoy, 1987) and O. edulis (Wilson, 1987),water temperature has been reported to be the most important factor resulting in differences in growth among stations and growth rate in different periods. Loosanoff and Nomejko (1949), Quayle (1952), Askew (1972), Dame (1972) and Malouf and Breese (1977) reported that low temperatures arrested oyster growth and it increased with elevated water temperature.

Availability of sufficient food has been reported as essential to ensure fast growth, particularly at elevated temperatures (Walne, 1972; Malouf and Breese, 1977; Mann and Ryther, 1977; Malouf, 1981). The lower thermal limits for metabolic function in C. gigas were reported to be 8-10 °c and 6-8 °c (Quayle, 1969; Malouf and Breese, 1977). Loosanoff (1958) found that C. virginica from Long Island Sound ceased feeding at a temperature of 6-7 °c and that maximum ciliary activity occurred at 25-26 °c. He also found that oysters from other localities differ in their response to temperature (Loosanoff, 1969). The effect of low food levels at different tempratures on oysters has been reported by Malouf and Breese (1977), Bernard (1983) and on Mytilius edulis by Bayne and Widdows (1978) and lncze et al. (1980). Walne and Mann (1975) and Bayne et al. (1977) observed disproportionate increase in shell growth and physiological stress in bivalves at elevated temperatures. Hughes-Games (1977) reported high survival and growth rate in C. gigas at 34 °c and 41 ppt salinity. But Shipgel and Baylock (1991) suggested that 27 °c is the upper temperature limit for growth of C. gigas at a salinity of 41 ppt, and that above 27 °c growth rate decreased.

Temperature has been shown to have a profound influence on filtration rate of bivalves by Theed (1963), Galtsoff (1964), Winter (1969), Dame (1972), Widdows (1973), Wilson and Seed (1974), Schutle (1975), and Bayne et al. (1976). Filtration rate is observed to increase with temperature upto an optimum level and further increase in temperature results in a drastic decline in filtration rate. Winter (1978) in his experiments on M. edulis demonstrated the affect of temperature on assimilation rate.

Galtsoff (1964) stated that the quality of the meat of oyster, C. virginica grown in warm southern waters is poorer than that of animals from north, grown under lower temperatures. Soniat and Ray (1985) attributed the changes in condition indices, gonadal indices and spawning of C. virginica to temperature. Bargeton (1942), Loosanoff and Davis (1952) and Mann (1979) reported that in oysters maturation and spawning are temperature related. In British Columbian waters, spawning of introduced C. gigas was found to be rare in cold locations (Bernard, 1974). Extreme adverse effect of high temperature was reported by Lipvosky and Chew (1972) and Maguire et al. (1981) who attributed the oyster mortality to high water temperature.

Bayne and Newell (1983), Mac-Donald and Thompson (1985), Beukema and Desprez (1986), Wilson (1987), Brown and Hartwick (1988a), Thompson and Nichols (1988), Vincent et al. (1989) and Harvey and Vincent (1990) reported that food availability may have an equal if not greater influence on bivalve growth rate when compared with temperature. According to Elvin and Gonor (1979), food levels explained 96% of

variance of growth of M. californianus while water temperature accounted for only 3%. Food availability is found to be an important factor determining flesh growth rates of bivalves (Heral et al., 1984), and evidence of its action on shell growth rates has been given by Malouf and Breese (1977), Widdows et al. (1979), Malouf (1981), Brown (1988), Utting (1988) and Jones and Iwama (1991) for oysters, by Langton et al. (1977), Winter, (1978) and Kautsky (1982) for mussels and by Broom and Mason (1978), Vahl (1980) and Wallace and Reinsnes (1985) for clams.

Walne (1972) observed that water currents enhanced bivalve filtration rates, but the number of food particles per unit time coming in contact with the bivalve has been pointed out to be of greater importance by Frechette and Bourget (1985). Winter (1978) reported that the filtration rate decreases with increasing cell concentrations. Epifanio and Ewart (1977) stated that the filtration rate of C. virginica increases during low food concentration, in order to filter maximum quantities from water. Quayle (1969), Brown and Hartwick (1988b) and Jones and Iwama (1991) observed that condition index was positively correlated with food availability. Soniat and Ray (1985) correlated food index with gonad index in C. virginica and found that greatest amount of food was present during the time of greatest energy demand, namely the period of gametogenesis.

In bivalves, rapid fluctuations in salinity levels can reduce tolerance to changes in other variables (Medcof and Needler, 1941). The salinity values beyond a species' optimal zone can negatively affect growth and survival (Quayle, 1969). Critical salinity for C. gigas was

found to be between 8 ppt and 18 ppt while a decrease in ventillation function was observed to occur around 18 ppt (Bernard, 1983). Effects of salinity related stress on assimilation (Brown and Hartwick, 1988a) and growth (Chanley, 1958 and Brown, 1988) have been reported. There are also reports of successful cultivation of oysters in highly saline ponds of almost 40 ppt (King, 1977). Nell and Holiday (1988) have found that in Saccostrea commercialis the highest growth rates occurred at salinities of 23-39 ppt and survival rates at 27-39 ppt. They have also given the equivalent optimum salinity ranges for the larvae and spat of C. gigas. Butler (1949) observed that salinity below 6 ppt inhibited gametogenesis in oysters. Hughes - Games (1977) reported high survival, growth and condition index in cultured oysters at 41 ppt and there was no gametogenic or spawning activity.

Suspended micro-matter and turbidity are two important factors affecting the bilogy of bivalves. According to Loosanoff and Tommers (1948) and Loosanoff (1961), oysters are very sensitive to the presence of suspended silt and other substances and that there is a correlation between increase in concentration of such substances and decrease in pumping rate. Thomson and Bayne (1972) made similar observation in the mussel, M. edulis.

Utting (1988) attributed the low growth of spat at one of the experimental sites to high levels of particulate inorganic matter (PIM) and reported that high levels of PIM causes a reduction in assimilation efficiency. This phenomena was also found in other bivalves as reported by Vahl (1980) in Chlamys islandica, Kiørboe et al. (1981) in M. edulis,

Bernard (1983) in C. gigas and Bricelj and Malouf (1984) in Mercenaria mercenaria. There is some evidence that bivalves may be able to selectively reject PIM (Kiørboe and Møhlenberg, 1981; Newell and Jordan, 1983; Bricelj, 1984). Hughes-Games (1977) attributed the reduction in growth rate of C. gigas to excessive silt in water, whereas Kiørboe et al. (1981) and Winter (1976) reported that low levels of PIM do have a positive effect on bivalves. While Winter (1978) explained that as a consequence of low levels of PIM, more food is ingested and better growth is obtained per unit time, Bayne and Newell (1983) related it to possible absorption of organic compound by silt particles.

Univariate laboratory studies have indicated that pH and dissolved oxygen also can act as limiting factors to oyster growth and other biological activities (Galtsoff, 1964; Davis, 1975). In coastal waters, seasonal fluctuations in pH and dissolved oxygen levels tend to be within the tolerance zone of oysters (Westley, 1964; Kuwatani and Nishii 1969; Davis, 1975). Intolerable conditions of these variables are conceivable due to poor water circulation or pollution (Menzel, 1979). Bamber (1990) in his experiments using O. edulis, C. gigas and M. edulis stated that seawater with pH $\leqslant 7$ is intolerable to all bivalve molluscs and all these species showed suppressed growth, shell dissolution, tissue weight loss, feeding activity suppression and at pH 6.5 abnormal narcotic behaviour. Other abnormal responses to low pH reported are reduced pumping in adult C. virginica (Loosanoff and Tommers, 1947) increased mortality, inhibited development and reduced growth in larvae of C. viginica and M. mercenaria (Calabrese and Davis, 1966) and inhibition of feeding and shell growth, increased shell dissolution,

behavioural inhibition and increased mortality in Venerupis decussata (Bamber, 1987).

Oxygen consumption is a good measure of metabolic activities related to various biotic and abiotic parameters including the physiological condition of animals. Jørgensen (1976) and Winter (1978) reported that the rate of oxygen consumption increases with increasing body size and also with increase in temperature upto optimum levels. The adult oysters have been reported to be more tolerant than juvenile oysters to anoxic conditions (Galtsoff, 1964; Stickle et al., 1989; Widdows et al., 1989). Under hypoxic and anoxic conditions, oysters reduce energetically costly activities to minimise total metabolism (Widdows et al., 1989, Wang and Widdows, 1991 and Baker and Mann, 1992).

There are reports on the importance of calcium concentration in sea water to bivalve shell formation and growth. Bevelander (1952) concluded that all molluscs take up labelled calcium. Galtsoff (1964) found that C. virginica deposited 1.4mg of shell material/cm^2 of shell surface per day, during the peak growing season. Epifanio et al. (1975) stated that calcium carbonate is the major component of oyster and clam shells. Brown and Hartwick (1988a) reported that low salinity can lead to reduction in concentration of minerals such as calcium which is important to shell formation. Orton (1925) observed that the shells of English oyster continued to grow in the absence of food. Fox and Coe (1943) made similar observations in M. californianus and reported that food is not the only source of calcium.

Phytoplankters, which are known to form the major food of bivalves, must obtain a range of micro-nutrients from their environment in order to sustain growth and cell division (Raymont, 1980). Westley (1964) reported that areas with an adequate supply of nutrients and high sustained phytoplankton production tended to be areas of good oyster condition. Maguire et al. (1981) observed that the meat from Sydney rock oyster, S. commercialis grown in the ponds fertilized with urea and superphosphate, were significantly heavier than those from unfertilized ponds, and that oysters in fertilized ponds were in extremely good condition.

Although the above literature review outlines and identifies the environmental parameters important to bivalves, it also indicates that variations in the optimum ranges are to be expected for different species and from one region to another. In India, Hornell (1910, 1918, 1922, 1949a, b, c), Rai (1928), Rao (1941), Rao (1958, 1963, 1966), Jones (1968a, b), Jones and Alagarswami (1973), Narasimham (1973, 1985, 1987), Nayar and Mahadevan (1974), and Rao (1974) have drawn our attention to the immensely rich molluscan resources.

In Kerala, Karnataka and Maharashtra fisherfolk regularly exploit naturally available clams and mussels during certain seasons, whereas oysters are rarely harvested due to the difficulties involved in collecting them from their natural beds. Hours of work in the natural bed may yield but scanty oyster-flesh which has resulted in a total disregard for oyster exploitation (Nayar and Mahadevan, 1983; Mahadevan, 1987). Of the 8 species of Crassostrea reported by Awati and Rai (1931),

only C. madrasensis (Preston), C. gryphoides (Newton and South) and C. rivularis (Gould) are known to be economically and commercially important. Crassostrea spp. occurring in India are euryhaline and are found in estuaries, backwaters, and open sea coastal shallows. From resource point of view Tamilnadu and Kerala are rich in C. madrasensis, Maharashtra and Goa in C. gryphoides and Gujarat in C. rivularis.

Hornell (1910, 1916, 1918) had suggested the vast scope in the realm of oyster farming on the model of that in France. But except a few reports on small scale bottom culture of oysters with an insignificant production at Jaytapur and Utsali on the west coast, there has been no commercial attempt in this field (James, 1987).

Oyster meat could be a good source of animal protein to meet the nutritional requirements of the growing popualtion. It is in this context that oyster culture assumes special significance as oysters are easy to grow in farms.

The growth efficiency of C. madrasensis has been assessed by Paul (1942) in Madras Harbour, Rao and Nayar (1956) in Adayar estuary, Dhulkhed and Ramamurthy (1980) in Mulki estuary, Somasekar et al. (1982) in Vellar estuary, Joseph and Joseph (1983; 1985) in Mulki estuary, Nayar and Mahadeven (1983) in Karapad creek, Tuticorin, Purushan et al. (1983) in Cochin backwater, Reuben et al. (1983) in Bheemunipatnam backwaters, Narasimham (1987) in Kakinada canal and Rao et al. (1987) in Athankarai estuary. From these studies considerable disparity in growth is discernible at different areas. The most probable reason for the variability reported in the growth may be the different ecological

conditions prevailing at each site. However, these studies generally lacked detailed information on various ecological parameters and their effect on the growth of oysters.

Growth rate has been found to be slackened by very high or low salinity (Rao and Nayar, 1956; Reuben et al., 1983; Narasimham, 1987). Rao et al. (1983) and Purushan et al. (1983) observed that salinity also affects survival rate.

Unstable salinity regime characterises the tidal creeks and backwaters of the east and west coasts of India. Heavy mortalities among the oyster populations due to wide fluctuations in salinity have been reported by Rao (1956), Reuben et al. (1983), Mahadevan and Nayar (1987) and Rao et al. (1987) on the east coast and Purushan et al. (1981) and Joseph and Joseph (1983) on the west coast.

Thorough understanding of the breeding season and factors controlling breeding are prerequisite for planning large scale culture. Semi-annual, annual or biannual breeding seasons have been reported for C. madrasensis by Hornell (1922), Paul (1942), Rao (1951, 1956), Rao (1974), Menon et al. (1977), Stephen (1980), Joseph and Madhyastha (1982), Joseph and Joseph (1983), Rajapandian and Rajan (1983), Thangavelu and Sundaram (1983) and Narasimham (1987). Rao (1951 and 1956) and Stephen (1980) reported that major spawning in C. madrasensis coincides with period of sharp drop in salinity, whereas Rao (1974), Nayar and Mahadevan (1983), Rajapandian and Rajan (1983) and Narasimham (1987) attributed the induction of spawning to continuous rise in temperature and salinity.

Variability in gametogenic activity is the result of endogenous and exogenus factors. Many of the earlier studies have considered only a few ecological parameters. Mahadevan and Nayar (1987) in their review report on the ecology of oyster beds stated that compared to voluminous data available from abroad, the attention paid in India to the study of oyster in general and ecology in particular is limited. James et al. (1987, 1993) stated that while advances made in oyster culture technology have evoked wide spread interest amongst several entrepreneurs and agencies, precise information on the suitability of sites for developing oyster culture is lacking. In the present study, particular emphasis has been given to understand the interaction of the oyster C. madrasensis with different environmental parameters. The result as manifested in growth, reproduction, and survival, is hoped, would help develop criteria in the selection of suitable sites for developing oyster culture.

CHAPTER 1

SECTION II

MATERIALS AND METHODS

The research programme was carried out along the Tuticorin coast, latitude 8° 48' N and longitude 78° 14'E situated in the southeast coast of India (Fig. 1).

To assess the effect of various environmental parameters on the biology of the oysters, the animals had to be reared in different environments having wide variations in habitat conditions. Initially, on the basis of their physical and topographical characteristics, six sites were selected. Hydrological parameters of these sites were monitored at fortnightly intervals for a period of four months. On the basis of the data collected, available literature and discussions with scientists of the Tuticorin Research Centre of Central Marine Fisheries Research Institute, three sites which showed wide variations in the range of several ecological parameters were selected for carrying out the experiments. Another factor which was considered before finalization of sites, was poaching problem. Disappearance of materials used for construction of various experimental structure in this region is common. Therefore, selection of sites had to be restricted to secure areas, since providing watch and ward for each site was beset with practical difficulties.

SITES:

The three sites selected (Fig. 1) for the experiments are described below.

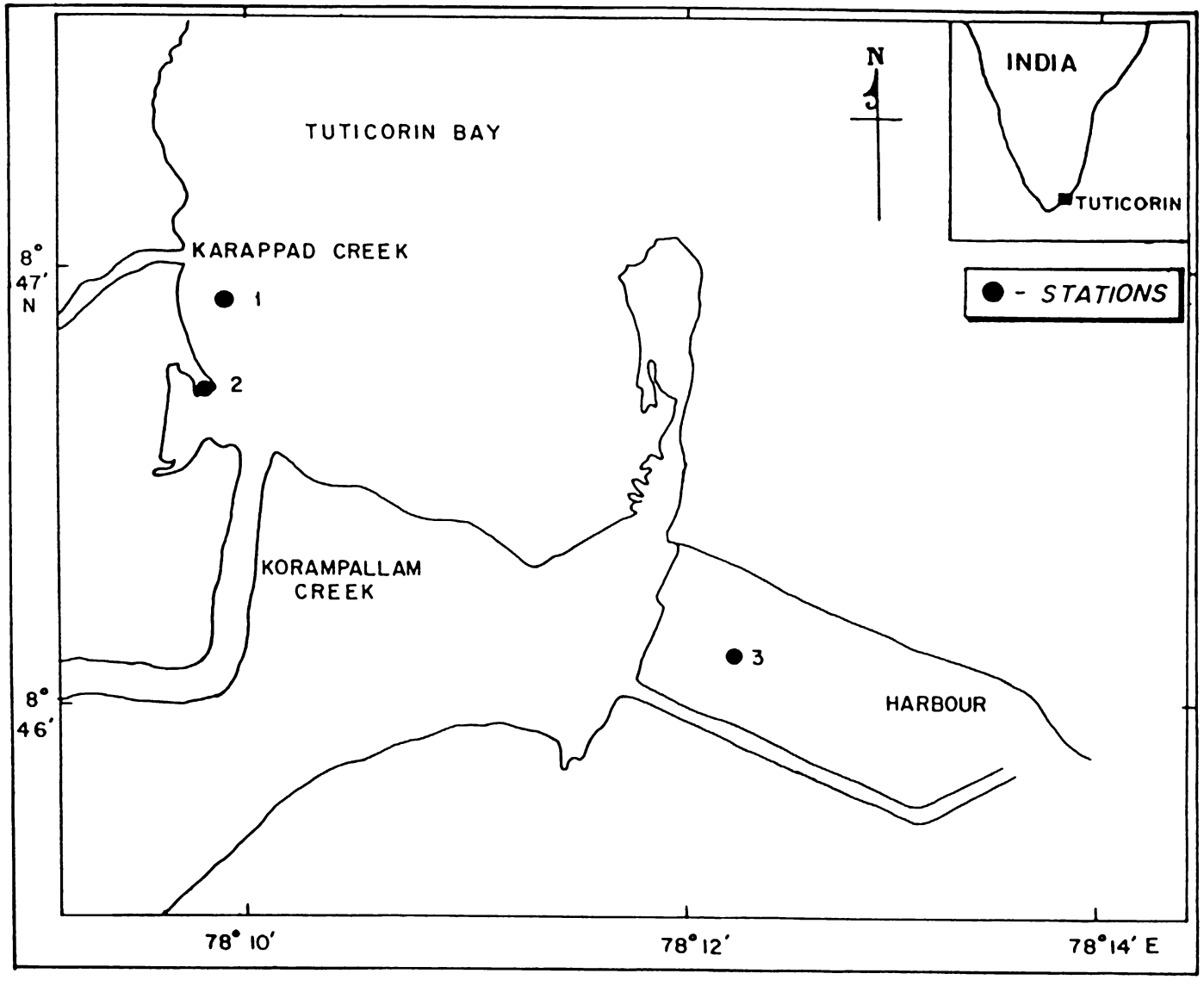


Fig. 1. Map of Tuticorin coast showing the experimental stations.

I. Tuticorin bay, (Station 1):

It is a semi-enclosed bay, having a shallow shore, with water depth ranging from 0.5 to 2.5m. The texture of bottom sediment is composed of sand (34.62%), silt (41.55%) and clay (23.83%). About 100 hectares of such shallow area is available, and it is not usually subjected to high waves or wind action. The experimental structures were erected in the tidal zone, where water depth varies from 0.7m to 1.5m (Plate I).

II. Coastal pond (Station 2):

One of the Research Centre's tidal fed earthen pond covering an area of 36x18m was selected as station 2. The pond is directly connected to the sea through a 2m wide opening without any sluice gate. The pond has not been maintained for a long time, thereby the walls are considerably eroded due to tidal and wave action. The bottom soil is slushy in nature and is composed of sand (13.13%), silt (36.72%) and clay (50.15%). Water levels of approximately 0.5m and 1.3m are maintained during low and high tides, respectively (Plate II).

III. Tuticorin harbour (Station 3):

It is located within the two arms of the breakwaters and hence is protected from winds and swells. The bottom sediment is comprised of sand (80.44%), silt (11.26%) and clay (9.31%). In this area there is a dense growth of sea grass (Cymodacea sp. and Halophila sp.) and also considerable populations of different species of corals. The depth ranges from 0.5 to 7.5m. The experimental structures were erected in the tidal zone where water depth varies from 0.8m to 1.7m (Plate III).

PLATE I. Experimental structures in Tuticorin Bay (Station 1).

A. Experimental racks.

B. Single rack with a box-type cage holding 0 age oysters shown.

C. Parallel racks raised above the low water level to expose the rectangular cages holding the 1+ age oysters.

PLATE I

CULTURE TECHNIQUE:

Suspended rack and tray/cage culture methods (Quayle, 1980) was adopted for rearing of oysters at each station. The method was earlier described and used by Nayar and Mahadevan (1983).

I. Racks: Two types of racks were constructed at each site, (A) Parallel racks (Plates Ic and IIIb) for rearing the older age group of oysters and (B) Single racks (Plates Ib and IIb) for the juvenile oysters.

A. Parallel racks:

Three numbers of 2.4 to 3m long wooden poles of 7 to 8cm diameter with conical ends were planted vertically in a straight line at intervals of 2m. Another set of three poles were driven parallel to the first row. The two rows of poles were connected horizontally by 2m long cross poles. Above these crosspoles, using 8 horizontally laid wooden poles, 4.5 to 5m in length and 5-6cm in diameter, a platform for keeping oyster rearing trays was constructed. Coir and 3mm synthetic ropes were used to fasten the poles. Each rack was constructed to accommodate 8 trays. The trays were rectangular in shape (90x60x15cm) and were fabricated with 6mm welded steel. The tray was covered with 2mm nylon twine netting of 20mm mesh on the sides and bottom and a lid was provided on the top. The height of the tray was so adjusted as to enable the oysters resting on the bottom of the tray to remain submerged in water during low tide periods also. The height of the trays ranged from 40 to 60cm from the bottom at the three stations.

PLATE II.

A. Single and parallel racks in the earthen pond (Station 2).

B. Single rack at station 2 with a box-type cage holding the 0 age oysters shown.

PLATE II

A

B

PLATE III.

A. Single and parallel racks at Tuticorin harbour (Station 3).

B. Parallel rack at station 3 with a rectangular cage holding the 1+ age oysters shown.

PLATE III

A

B

B. Single racks:

Single racks had three vertical wooden poles of similar dimensions as used in parallal racks, planted 2m apart in a row and a long horizontal pole tied across these poles at the top. Coir and 3mm synthetic ropes were used to fasten the poles. Cages holding the juvenile oysters were suspended from the horizontal pole, using 4mm thick and 1.5m long synthetic ropes.

The juvenile oysters were reared in box type cages of size 40x40x10cm, made of similar materials and constructed in the same manner as the trays. The box type cages were covered with 2mm synthetic twine netting of 5mm mesh at the time of stocking. In order to facilitate maximum water flow through the cage, the mesh size of the cage was increased periodically keeping it slightly smaller than the size of the smallest oysters.

The cages containing oysters were suspended from the racks in such a manner that they remained submerged in water during low tide periods also. The height of the cages from the bottom ranged from 40 to 60cm at the three stations.

EXPERIMENTAL OYSTERS:

Two age groups of cultchless oysters were experimented at each station: (A) juvenile oysters (0 age) and (B) adult oysters (1+ age).

A. Juvenile Oysters (0 age):

These oysters were produced in the edible oyster hatchery laboratory of the Tuticorin Research Centre of Central Marine Fisheries

Research Institute by inducing spawning by thermal stimulation in a group of conditioned oysters, collected from the Karapad natural bed. The larvae were reared and cultchless spat were produced. The settled spat were reared in the hatchery tanks for a period of three weeks. The hatchery techniques for spat production in C. madrasensis were described by Nayar et al. (1987) and the spat for this study were provided by the hatchery staff.

Three weeks old (from setting) spat were seperated from the polyethylene sheet which was laid inside the rearing tanks for cultchless spat production, transferred to cages lined by velon screen, and suspended in outdoor, artificially aerated cement tanks. Fresh seawater was pumped into the tanks every day for one week. During this week, the velon screen lining the cages was brushed everyday to permit maximum water flow. Finally the cages holding the spat were suspended from single racks in the Tuticorin Bay, and reared for a period of one month. The velon screen covering the cages was cleaned regularly with a brush to prevent clogging due to fouling. After one month, the juvenile oysters with retarded growth were rejected and the ones which apparently showed good growth and health, were selected for stocking at different stations. Care was taken to divide the oysters into three groups of the same length as far as possible. At each station, the juvenile oysters were stocked in six box-type cages and suspended from single racks. The stocking at all the stations was done in the beginning of October 1990, with 180 to 185 juvenile oysters per cage. The initial mean sizes of juveile oysters at the time of stocking were as follows.

At station 1, oysters had a mean shell height of 27.54mm (n=248; S.D.=± 6.74); mean whole weight of 4.802g (n=233; S.D.=± 1.98) and mean whole volume of 2.651ml (n=226; S.D.=± 1.25). At station 2 oysters had a mean shell height of 28.09mm (n=244; S.D.=± 5.36); mean whole weight of 5.11g (n=229; S.D.=± 2.10) and mean whole volume of 2.763ml (n=228; S.D.=± 1.36). At station 3 they had a mean shell height of 28.56mm (n=247; S.D.=± 6.21); mean whole weight of 5.3g (n=235; S.D.=± 1.96) and mean whole volume of 2.976ml, (n=236, S.D.=± 1.10). These juvenile oysters were designated as 0 age oysters.

B. Adult oysters (1 + age):

These oysters were procured from the oyster farm of the Tuticorin Research Centre of Central Marine Fisheries Research Institute. Hatchery produced oyster seed are reared in this farm on racks, following the shell strings suspended technique of culture. Adult oysters (19 months old and belonging to the same batch of settled spats) were separated from the cultch (oyster shells) carefully. The oysters with damaged shells and exposed flesh were rejected, and the ones with no apparent external injury were brushed and cleaned with jets of filtered sea water. In order to identify and select oysters which had not sustained internal and other undetectable injuries during the process of separation and removal from cultch, oysters were stocked in rectangular trays and reared on racks in the Tuticorin Bay for a period of one month. It was presumed that injured oysters not detected by naked eye, would not survive for one month. During this period the dead oysters were removed and the remaining ones were divided into three lots by

selecting the oysters of comparable length as far as possible. At each station the oysters were stocked in eight rectangular trays. The trays were tied and arranged in two rows, resting on the wooden platform of the parallel racks. The stocking at all stations was done in the beginning of October 1990 at the rate of 135-140 numbers per tray. The mean initial sizes of adult oysters, at the time of stocking at stations 1 to 3 are presented below.

At station 1, oysters had mean shell height of 103.60mm (n=241; S.D.=±12.31), mean whole weight of 163.028g (n=230; S.D.=± 27.21) and mean whole volume of 95.10ml (n=224; S.D.=± 16.43). At station 2, oysters had mean shell height of 107.09mm (n=245; S.D.=± 13.71); mean whole weight of 164.319g (n=237; S.D.=± 30.89) and mean whole volume of 98.94ml (n=228; S.D.=± 18.41). At station 3, oysters had mean shell height of 102.01mm (n=237; S.D.=±12.54); mean whole weight of 165.738g (n=228; S.D.=±29.62) and mean whole volume of 93.26ml (n=226; S.D.=± 16.46). These adult oysters were designated as 1+age oysters.

Maintenance of experimental racks, trays and cages:

Two sets of cages and trays were made for each age group of oysters at each station. The cages and trays were brushed and cleaned once in a week. Racks were carefully checked and in case of damage, the poles and ropes binding them were replaced.

Sampling frequency:

At stations 1 and 2, regular fortnightly collections of oyster and water samples were made for a period of 16 months (October 1990 to

January 1992). At station 3 due to heavy mortality of oysters, the experiments were terminated in May 1991 for 1+ age oysters and in mid July 1991 for 0 age group of oysters. As at other stations, regular fortnightly sampling was conducted at station 3, upto the date of termination of the experiments. Sampling was carried out between 0730 hrs to 0930 hrs during low or just rising tides. While sampling of station 1 and 2 was conducted on the same day, station 3 was sampled on the following day. The analysis of biological and hydrological parameters were carried out at the laboratories of Tuticorin Research Centre of Central Marine Fisheries Research Institute.

BIOLOGICAL PARAMETERS:

The biological parameters analysed and recorded for both age group of oysters from all the stations were, shell height, whole weight, whole volume, shell volume, shell cavity volume, wet meat weight, dry meat weight, condition index, sex ratio, maturity stage of gonad, and mortality.

During the fortnightly visit, 46 to 48 oysters from each age group were collected randomly from the cages and trays. Equal number of oysters were taken from each cage and tray. From the sample, 30 oysters were randomly collected for laboratory analysis. After measuring and recording the shell height of the remaining oysters at the site, they were returned to their respective cages and trays. The same method of sampling was followed for both the age groups of oysters at all the stations throughout the study period, except for 0 age oysters at

station 2 (from second fortnight of February 1991 onwards) and at station 3 (from second fortnight of December 1990 onwards). In these two cases, only 25 oysters were taken for laboratory analyses due to comparatively higher rate of mortality among these oysters. This reduction in the number of oysters for laboratory analyses was resorted to with a view to continue the experiments as long as possible.

In the laboratory the fouling organisms were carefully removed and the oysters were brushed and cleaned thoroughly using filtered seawater. Before carrying out any biological analysis, the cleaned oysters were kept in separate 1000 litre capacity fibre glass tanks provided with aerators and filled with filtered seawater for 18-24 hrs. Separate tanks were allotted to each age group from each station, and water in the tanks was changed twice during the above period. Half the number of oyster brought to the laboratory were utilized to study the reproductive cycle and the remaining for condition index, wet and dry meat weight analyses.

The methods used for biological analyses are presented below.

I. Shell height:

Shell height was measured as the distance from the end of the umbo to the ventral shell margin (Galtsoff, 1964). In addition to shell height of oysters measured at the sites, the shell height of all the oysters brought to the laboratory were also measured using Vernier calliper, upto the nearest 0.01mm.

II. Whole weight:

The oysters were air dried (for about 10 - minutes) using a table fan, and further blotted dry with blotting paper, before whole weight measurements. Taulaman balance was used for weighing the 1+ age oysters to the nearest 0.1g and electric Owalabor balance was used for 0 age oyster to record the weight to the nearest 0.01g. The individual whole weight of all the oysters brought to laboratory were recorded.

III. Whole volume:

The individual whole volume of all the oysters brought to the laboratory was recorded following the displacement technique of Quayle (1980). The air dried oysters were individually placed in 1 litre capacity container provided with an overflow pipe. The displaced water was collected in a measuring cylinder, and with the help of a thin pipette the water remaining on the inner walls of the overflow pipe and the measuring cylinder was carefully blown down. The final reading of the level of water collected in the measuring cylinder was determined to the nearest 0.1ml, using the same graduated pipette.

IV. Shell volume:

The meat of half the number of oysters brought to the laboratory was carefully shucked and after draining the water, the body tissues were separated from the shell using the sharp end of the shucking knife. The volume of the shell was measured in the same manner as the whole volume, to the nearest 0.1ml.

V. Shell cavity volume:

Shell cavity volume was determined for each individual oyster by subtracting its shell volume value from the value of whole volume.

VI. Wet meat weight:

The oyster tissue was air dried (for about 10-minutes) and the moisture removed using blotting paper. It was then placed in labelled and preweighed aluminium foil dish and weighed using an electric Sartorius balance (Type 1712) upto the nearest 0.001g.

VII. Dry meat weight:

The aluminium foil dishes holding the wet tissues, were placed in glass petridishes and dried in an oven at 95-98 ^{o}C to a constant weight. The dried tissues along with preweighed aluminium foil dishes were cooled in desicators, and weighed on the same electric Sartorius balance upto the nearest 0.001g.

VIII. Condition index:

The data on dry meat weight and shell cavity volume were used to determine the condition index of each individual oyster, using the formula recommended by Quayle (1980).

$$\text{Condition index} = \frac{\text{Dry meat weight (g)}}{\text{Shell cavity volume (ml)}} \times 1000$$

REPRODUCTIVE BIOLOGY:

The remaining half of the oyster samples of each age group from each station, were utilized for reproductive biology studies. The methodologies adopted for these analyses are described under the following headings.

IX. Sex ratio:

Total number of individuals belonging to each sex were counted and data was subjected to chi-square test to verify if the sex ratio differs significantly from the theoretical 1:1, male:female ratio.

X. Maturity stages of gonad:

The categorization of the maturity stages of gonad was made on the basis of morphological characteristics, fresh smear examination and histological sections of the gonad, following Joseph and Madhyastha (1982) for C. madrasensis (Tables 7A and B).

A. Morphology of gonad:

Macroscopic characteristics of fresh gonad like colour, size and shape were recorded and classified corresponding to different stages of maturity.

B. Fresh smear examination:

A representative piece from freshly collected gonad was teased on a glass slide. Oocyte diameter was measured along its broad axis, using an ocular micrometer, precalibrated with stage micrometer. One hundred oocytes were measured at random.

C. Light microscopic studies:

Sample pieces of gonad were taken from freshly shucked oysters and fixed in 10% neutral buffered formalin or Bouin's fixative for 20-24 hrs. The tissue was then thoroughly washed with running freshwater for 6-7 hrs and then stored in 70% ethyl alcohol until further processing. A code number was given for each tissue piece and its details recorded. The tissues were dehydrated in graded alcohol series by following the standard procedure. Dehydrated tissues were then cleared in pure chloroform for 3 hours, impregnated with and embedded in paraffin wax (Glaxo, melting point 58-60 ^{o}C). The prepared blocks were trimmed, catalogued and stored in labelled polyethene bags until sectioning. Serial sections of 6-8 μ thickness were cut manually using a rotary microtome. Mayor's egg albumen-glycerol (1:1 V/V) was used as the adhesive for fixing the paraffin ribbon with sections on clean, dry glass slides. The slides containing the spread ribbons were then incubated at 40 ^{o}C on a slide warmer. The dried sections were deparaffinised, hydrated and stained with Harris haematoxylin and eosin as counter stain. The stained sections were dehydrated, cleared and mounted using DPX as mounting medium.

The histological details were studied and photographed using compound microscope (Carlzeiss Jena), with automatic camera and light control attachment.

XII. Mortality:

Mortality for both age groups of oysters were determined from counts of left or cupped valves of dead oysters. Losses of empty shells

were assumed to be negligible, because the mesh size of the cages and trays were smaller than the size of the smallest individual oyster.

HYDROLOGICAL PARAMETERS:

From all the stations at each fortnightly visit, along with oyster samples, water samples also were collected from the sub-surface layers adjacent to the level of cages and trays. Before drawing the sample, water bottles were rinsed twice with the ambient water. At station 2, due to extreme slushiness and loose nature of the bottom, a small fibre glass dinghy was used for collection of water samples, in order not to disperse the bottom sediments. Stations 1 and 2 were sampled on the same day and station 3 on the following day. The time for sampling was from 0730 to 0930 hrs, during low or rising tides. Regular fortnightly sampling was conducted from stations 1 and 2 for a period of 16 months from October 1990 to January 1992. At station 3 also regular fortnightly sampling was conducted from October 1990 upto mid July 1991, the date of termination of experiments at this station. In order to sample the area around the experimental racks, triplicate water samples were taken and analysed for temperature, salinity, pH, dissolved oxygen, turbidity, total suspended micro-matter, calcium, and nutrients and duplicate water samples for chlorophyll-a and primary productivity.

The samples for estimation of dissolved oxygen were fixed at the sites immediately after collections, primary productivity sample bottles were suspended from the single racks, and the rest of the samples were brought to the laboratory within 1-1 1/2 hrs after collection. In the

laboratory nutrient samples were stored in deep freezer at -20°C; salinity, pH, turbidity and calcium were analysed and chlorophyll-a and total suspend micro-matter (TSM) samples were filtered using a suction pump. While membrane filters for estimation of TSM were kept in an oven for drying, the membrane filters for chlorophyll-a estimation were drawn dry, removed, folded in to half, backed with a piece of ordinary paper, placed in a desicator and stored under refrigeration.

The methodologies adopted for analyses of various hydrological parameters are described under the following headings.

I. Water temperature:

Immediately after collecting the water sample in a narrow mouthed polyethylene bottle, the temperature was recorded at the site itself by immersing a 0-50°C range thermometer upto 5cm deep in the water column.

II. Salinity:

The water samples were collected in narrow mouthed, polyethylene bottles of 300ml capacity. Salinity was determined by the classical Mohr titration method (Strickland and Parsons, 1968). For determining salinity, 10ml of water sample was titrated against the silver nitrate solution (14.5g silver nitrate dissolved in 1l of distilled water) with 10% potassium chromate as indicator. Care was taken to arrive at the exact end point colouration in all the samples, and for every set of titration. Silver nitrate solution was standardised using standard sea water supplied by the Oceanography Institute, Copenhagen. Each sample

was titrated 2 to 3 times and mean value was taken. Salinity of the sample was calculated using the formula,

$$\text{Salinity (ppt)} = \frac{V1 \times S}{V2}$$

where, V1 is the volume of silver nitrate for titrating 10ml of the sample, V2 is the volume of silver nitrate used for titrating 10ml of standard sea water and S is the salinity of standard sea water.

III. Dissolved oxygen:

The dissolved oxygen in the water samples was determined using Winkler method (Strickland and Parsons, 1968). The water samples were collected in standard 125ml capacity Corning reagent bottles with BOD stoppers. Care was taken to avoid entry and trapping of air bubbles during sampling. One ml of Winkler A (365g manganese sulphate dissolved in 1l of distilled water) and 1ml of Winkler B (mixture of sodium hydroxide and potassium iodide dissolved in distilled water) solutions were immediately added to the water samples. The stopper was carefully replaced without trapping any air bubbles. The solution was mixed by gently shaking the bottles several times and the precipitate was allowed to settle. To this 2ml of concentrated sulphuric acid was added and shaken gently until the precipitate was completely dissolved. From this 100ml of the sample was taken into a 250ml conical flask and titrated against sodium thiosulphate (0.01N) solution to a pale straw colour. About 5 drops of 1% starch indicator solution was added to this and titrated until the blue colour disappeared. The dissolved oxygen concentration was estimated using the formula,

$$\text{Oxygen (ml/l)} = \frac{V1 \times N \times 8 \times 1000 \times R}{V2 \times 1.429}$$

where, V1 = Volume in millilitre (ml) of sodium thiosulphate

N = Normality of sodium thiosulphate

V2 = Volume (ml) of sample

R = Correction factor equal to 1.01

1.429 = The weight of 1ml of oxygen in milligrams

IV. pH:

Hydrogen ion concentration of the water sample was determined using an ECIL digital pH meter (model 5651). The instrument was calibrated with pH buffers 4.0, 7.0, and 9.2. The samples collected for salinity were utilized for pH determination before salinity analysis.

V. Turbidity:

Turbidity was determined following the nephlometric turbidity estimation technique, described by APHA-AWWA-WPCF (1975). Samples were collected in 300ml cleaned glass bottles provided with glass stopper. Aqua analyser turbidity meter (METZ-391) manufactured by Metzer Optical Instrument Corporation, and provided with green filter disc, was used for determination of percentage transmission of sample and reference standard. Formazin polymer, which has gained acceptance as the turbidity standard reference suspension, was prepared and used as the reference turbidity standard. Turbidity standard reference suspension of 40-NTU (Nephlometric Turbidity Unit) concentration was prepared weekly by

diluting 10ml stock turbidity suspension to 100ml with turbidity free water (Distilled water filtered through 0.45 μ membrane filter using a suction pump). Stock turbidity suspension of 400 NTU concentration was prepared monthly in a 100ml volumetric flask by mixing 5ml of solution I (1g hydrazine sulphate dissolved in 100ml turbidity free water) with 5ml of solution II (10g hexamethylene tetramine, dissolved in 100ml turbidity free water) and allowing it to stand for 24 hrs at 25 ± 3^{o} C before diluting it to the mark and mixing.

Sample was thoroughly shaken, time was allotted until air bubbles disappeared and then it was poured into the turbidimeter tube. The tube was placed before the filter disc in the instrument and percentage transmission recorded. Similar procedure was followed for recording the percentage transmission in the standard reference suspension. Turbidity of the sample was estimated using the formula,

$$TS\ (NTU) = \frac{PTS \times TR}{PTR}$$

where, TS is the turbidity of sample in NTU, PTS is percentage transmission reading of sample, TR is the turbidity of standard reference suspension equal to 40 NTU, and PTR the percentage transmission reading of standard reference suspension.

VI. Total suspend micro-matter (TSM):

TSM was determined using Banse, Falls and Hobson method, described by Strickland and Parsons (1968). Water samples were collected in 3l capacity polyethylene bottles. The sample was thoroughly mixed by

shaking the bottle and 1l of it was passed through 200 μ seive. The water sample was filtered through washed and preweighed membrane filters (Sartorius 0.45 μ pore size) using suction pump. The filter and lower end of the funnel were rinsed twice with distilled water. After removing the funnel top, the edges of the filter paper free from precipitate was also washed. Filter was removed with great care using a flat bladed forceps. It was placed on aluminium foil and dried for 1 hr at 75°C. The filter and the foil were then transferred to a desicator for cooling, before weighing. For each set of filters, blank filter was used. All the weight measurements were taken using an electric Sartorius balance (Type 1712) to the nearest 0.001g. TSM was determined using the equation,

$$\text{TSM} = \text{Dry weight of microseston } (mg/m^3)$$

$$= \frac{W2 - W1 + X}{V}$$

where, V = Volume in litre of sample

X = Blank correction

W1 = Weight of the membrane filter before the filtration of water sample (mg)

W2 = Weight after filtration of water sample (mg)

VII. Calcium:

EDTA (ethylene diamine tetraacetic acid) titrimetric method, as described by APHA-AWWA-WPCF (1975) was used for the estimation of Calcium in the sample. The water samples were collected using 300ml capacity polyethylene bottles. Suitable aliquot of the water sample was taken and made up to 50ml in a conical flask. Few crystals of ascorbic

acid, 1ml of 2% potassium cyanide and 1ml of 2% potassium ferrocyanide were added to the sample, as a pretreatment measure (FAO, 1972). After a few minutes, 4ml of 1N potassium hydroxide solution (to raise pH to 12-13), and a spatula point of HHSNN or Pattom and Reader's indicator (1g HHSNN + 100g of anhydrous sodium sulphite) were added. Then the sample was titrated against 0.01 N disodium salt of EDTA (3.723g disodium EDTA in 1l of distilled water) to a pure turquoise blue. The amount of calcium was determined using the following equation,

$$\text{Calcium (mg/l)} = \frac{A \times B \times 400.8}{\text{ml sample}}$$

where, A = In ml titration for sample

B = mg $CaCo_3$ equivalent to 1ml EDTA titrant at the calcium indicator end point.

NUTRIENTS:

Water samples for nutrients were collected in 300ml capacity, narrow mouthed polyethylene bottles. The frozen stored water samples were brought to laboratory temperature using warm water baths. An ECIL spectrophotometer model GS 866C was used for measurement of intensities of colours developed in the water samples and their corresponding standard samples used for plotting of standard graphs.

VIII. Nitrite - Nitrogen:

Nitrite - Nitrogen was estimated by the method of Bendeschneider and Robinson, as described by Strickland and Parsons (1968). Fifty ml of

water sample was taken in a clean conical flask and 1ml of sulphanilamide solution (5g of sulphanilamide dissolved in 50ml of concentrated hydrochloric acid and made upto 500ml using distilled water) was added. The sample was mixed and after 2 to 8 minutes, 1ml of N - (1-Napthyl) - Ethylenediamine Dihydro chloride (NNED) solution (0.5g of NNED dissolved in 500ml of distilled water) was added and mixed thoroughly. Blank was prepared in the same manner using distilled water instead of sample water. Between 10 minutes to 2 hours later the extinction was measured against the blank at 543nM. Standard graph was prepared by using standard nitrite solutions of known concentrations, and nitrite concentration in the sample is expressed in µg at/1.

IX. Nitrate-Nitrogen:

Nitrate-nitrogen was estimated by the method of Morris and Riley as described by Strickland and Parsons (1968) with some modification. To 50ml of water sample, 2ml of buffer reagent (25ml of sodium hydroxide solution added to 25ml of phenol solution) was added. After rapid mixing, 1ml of reducing agent (a mixture of 25ml of copper sulphate solution and 25ml of hydrazine sulphate solution) was also added and the flasks were kept in the dark for about 20 hours in order to reduce nitrate to nitrite. After this period, 2ml of acetone was added. At two minutes intervals, 1ml each of sulphanilamide and NNED solution were added and mixed thoroughly. Blank was prepared in the same manner, using distilled water instead. After 10 minutes the absorbance was measured against blank at a wave length of 543nM in the spectrophotometer. Standard graph was prepared by using different concentrations of stock

standard nitrate solutions, and nitrate concentration in the sample is expressed in µg at/l.

X. Ammonia-Nitrogen:

Ammonia-nitrogen was determined following the phenol hypochlorite method adopted by Solorzano and described by Strickland and Parsons (1968). To 50ml of the water sample, 2ml of phenol solution (prepared by dissolving 10g of phenol in 100ml of ethanol) and 2ml of nitroprusside solution (1g of sodium nitroprusside dissolved in 200ml of de-ionized water) were added. After mixing well, 5ml of oxidizing solution (a mixture of 100ml alakaline reagent, prepared by dissolving 100g of sodium citrate and 5gm of sodium hydroxide, in 500ml of de-ionized water, and 25ml of 1.5N sodium hypochlorite solution) was added to the sample and mixed thoroughly. The colour was allowed to develop at room temperature for one hour, and the absorbance was measured against the de-ionized water blank at 640nM in the spectrophotometer. Ammonia concentration is expressed in µg at/l.

XI. Reactive phosphorus:

The method given by Murphy and Riley as described by Strickland and Parsons (1968) was used for determination of reactive phosphorus. To a 100ml of water sample taken in a clean conical flask, 10 $\pm$ 0.5ml of mixed reagent (prepared by mixing 50ml of ammonium molybdate solution, 125ml of sulphuric acid solution, 50ml of ascorbic acid solution and 25ml of potassium antimony tartrate solution) was added and mixed. The resulting complex heteropoly acid was reduced <u>in situ</u> to a blue

solution. After 15 minutes, the absorbance of the sample was measured against distilled water blank using a spectrophotometer at 885nM. For standard phosphorus, different concentrations of potassium dihydrogen phosphate were made and the standard graph was plotted. Phosphate concentration is expressed in µg at/l.

XII. Silicate:

Dissolved silicon of the sample was estimated by using the method of Mullin and Riley, as described by Strickland and Parsons (1968). In a 50ml measuring cylinder, 10ml of ammonium molybdate reagent (prepared by dissolving 4g of ammonium molybdate in 300ml of distilled water and 12ml of concentrated hydrochloric acid of 12 N) was taken and then 25ml of seawater sample was introduced and mixed thoroughly. After 10 minutes, 15ml of reducing agent (consisting of metol, oxalic acid and sulphuric acid) was added to the sample. The solution was allowed to stand for 2 hours to complete the reduction. The absorbance was measured against the blank at 810 nM. Standard graph was prepared by using the standard silicate solution and silicate concentration is expressed in µg at/l.

XIII. Primary production:

Oxygen technique of Gaarder and Gran (1927) was used for the estimation of primary production. Samples were collected in 125ml Corning bottles with glass stoppers. These bottles were catagorised into three groups, viz., initial bottle (IB), light bottle (LB) and dark bottle (DB). The dark bottles were painted black and wrapped in black rexin cloth.

Initial dissolved oxygen concentration was determined by fixing the initial bottle with Winkler-A and Winkler-B. The light and dark bottles were suspended at the sites from the single racks, for a period of six hours. The bottles were positioned in such a manner that bottom of each bottle was just above the top of the cages, with a view to avoid shading of bottles by the cages. After six hours of exposure the samples were fixed by adding Winkler-A and B solutions. In the dark bottles only respiration takes place, whereas in the light bottle both photosynthesis and respiration take place. The difference in the oxygen content between light and dark bottle was taken as gross production and the difference of oxygen content between light and initial bottle was taken as net production. Primary production was calculated as follows:

$$\text{Production (mgC)} = \frac{O_2 \text{ (mg)} \times 0.536}{PQ}$$

where, PQ (photosynthetic quotient) is taken as 1.25. Assuming that photosynthesis has taken place 12 hours a day, primary production per day was calculated as follows:

$$\text{Primary production (mgC/m}^3\text{/day)} = \frac{O_2 \times 0.536 \times 1000 \times 12}{1.25 \times A}$$

where, A is the number of hours of incubation.

XIV. Chlorophyll-a:

The method of Jeffrey and Humphrey as described by Parsons *et al.* (1984) was followed for chlorophyll-a estimation. The remaining portion of the water sample collected in 3l capacity polyethylene bottles for

TSM estimation, was utilized for chlorophyll-a estimation. After mixing thoroughly, 1l of the sample was poured into a millipore filtering equipment, containing a membrane filter (Sartorius, 0.45 μ pore size). Sample water was filtered under 1/2 atmospheric pressure vacuum. 3-5 drops of magnesium carbonate solution was added while filtering. Filter was drained thoroughly and was placed in a 15ml glass vial. To this 10ml of 90% acetone was added and was allowed to stand overnight in a dark container kept in a refrigerator. The contents of each tube was centrifuged for 5-10 minutes at 2000 rpm. The supernatant solution was decanted into the spectrophotometer cell and extinction was measured at different wave lengths (750, 664, 647, and 630nM).

Each extinction was corrected for turbidity blank by subtracting the 750nM from 664, 647 and 630nM absorptions. The amount of pigment in the original sample was determined using the equation:

$$(Ca) = \text{Chlorophyll-a} = 11.85\, E_{664} - 1.54\, E_{647} - 0.08\, E_{630}$$

where, E stands for absorbance at the corresponding wave length obtained and Ca the amount of chlorophyll-a (μg/ml), when a 1-cm light path cuvette is used, then

$$\text{mg chlorophyll-a/m}^3 = \frac{Ca \times V}{VI} = \text{Chlorophyll-a } \mu g/l$$

where, V is the volume of acetone in ml and V1 is the volume of seawater in litres.

METEOROLOGICAL PARAMETERS:

Monthly rainfall (in mm), wind velocity (km/hr) and atmospheric temperature (^{o}C) data were collected from the Meteorological station, Port Trust, Tuticorin.

SEDIMENT PARTICLE SIZE ANALYSIS:

The sand, silt and clay fraction of the bottom sediment at all the three stations was estimated at the beginning of the experiments. Particle size analysis was carried out following the sieving and pipette method of Krumbein and Pettijohn as described by Holme and Mc-Intyre (1971).

Fifty grams of dried sediment sample was transferred to a one litre beaker, 250ml of 6% hydrogen peroxide solution was added to it and was kept overnight. The following day, the beaker with sediment sample was heated gently on a water bath and small quantities of 6% hydrogen peroxide was added till there was no further reaction. The content of the beaker was washed thoroughly under gentle suction with distilled water on to a filter paper (Whatman No.50) spread inside a Buchner funnel. The sediment was then washed from the filter paper into a beaker using a jet of 200-300ml distilled water and a camel-hair brush. To this 10ml of sodium hexametaphospate solution (6.2g of sodium hexametaphosphate dissolved in 1l of distilled water) was added and stirred for 15 minutes. The sediment in the beaker was then left to soak overnight.

On the following day, the sediment was stirred again (15-minutes) and transferred into 62 μ sieve which was placed in a flat bottom white basin. Care was taken to see that the volume of distilled water used to sieve does not exceed 1l. The sediment was wet sieved by agitating and puddling. The sieve and its content were transferred to a drying oven. After drying at 100 °C, the sieve was taken out, thoroughly agitated over a large sheet of white glaced paper, and the material passed through was transferred into the suspension of silt and clay in the basin.

The silt and clay content in the basin along with the water was then transferred to a 1l stoppered cylinder and the suspension was made exactly upto 1l by adding distilled water. The sediment was suspended by shaking the cylinder vigorously in order to disperse the contents uniformly. The cylinder was then placed upright and using a clean pipette, 20ml of sample was drawn immediately from a depth of 20cm. The pipette sample was transfered into pre-weighed petridish and dried in an oven at 100 °C and the content was weighed. The weight of this material was considered as the total amount of sediment less than 62 μ in the sample.

After reshaking the suspension, the cylinder was kept upright and few seconds before the expiry of 7 minutes and 44 seconds, the pipette tip was lowered to a depth of exactly 10cm below the surface of the suspension and 20ml of the sample was drawn at the exact time. The pipette content was transferred to a preweighed petridish and dried at 100 °C before weighing. The weight of this dried material was considered as the total amount of sediment less than 15.6μ in the suspension.

After resuspending the sediment, the cylinder was placed up right. After 2 hours and 3 minutes, 20ml of sample was taken from a depth of 10cm and transferred into a preweighed petridish. The material was dried at 100 ^{o}C and was weighed. The weight of the material was considered as the total amount of sediment less than 3.9μ present in the suspension.

The material that remained on the 62 μ sieve was regarded as the sand fraction. The weight of the pipette material was multiplied by 50 to find out the weight of the silt and clay fraction in 1$\frac{1}{1}$ of the sample. The percentage weight of silt was calculated from the percentage of sand and clay fractions.

STATISTICAL ANALYSES:

In order to determine the variation in growth between stations, polynominal regressions were fitted to mean fortnightly data of all body variables (shell height, whole weight, whole volume, wet and dry meat weight) of both age groups of oysters at all the three stations (Brown and Hartwick, 1988a). The mean fortnightly instantaneous growth rate was calculated for all the body variables of 0 age group of oysters at all the three stations using the formula,

$$G = \frac{\log_e (Dt + t) - \log_e (Dt)}{t} \times 15 \quad \text{(Gillmor, 1982)}$$

where, G is the instantaneous growth rate, (Dt + t) is the current mean measurement value of one of the body variables, (Dt) is the previous mean value of the same body variable, and t is the number of

days between observations. The values of two fortnightly instantaneous growth rates during each month was combined to obtain the monthly instantaneous growth rate for the month.

To understand the relationship between the monthly instantaneous growth rates of each body variable and mean monthly environmental parameters, their values were subjected to computer analysis for the estimation of correlation coefficient 'r'. The mean monthly value for each environmental parameter was calculated by pooling the values of the fotnightly data recorded during each month and dividing the same by the number of observations.

Similarly, the correlation between mean fortnightly condition index values of each age group of oyster with their respective mean environmental parameters at each station was obtained by subjecting their values to computer analysis for estimation of correlation coefficient 'r'. Principal component analysis (PCA) test was applied to the mean fortnightly data of hydrological parameters like salinity, water temperature, dissolved oxygen, pH, turbidity, total suspended micro-matter, nitrate-N, nitrite-N, ammonia-N, calcium, silicate, and reactive phosphorus.

The mean fortnightly data of food availability indices (chlorophyll-a, net and gross primary productivity) were subjected to analysis of variance (ANOVA) test.

CHAPTER 1

SECTION III

RESULTS

The results of various biological and environmental parameters studied during the period from October 1990 to January 1992 at stations 1 and 2, and October 1990 to July 1991 at station 3 are presented in this section.

ABSOLUTE GROWTH:

The results of polynomial regressions fitted to fortnightly data of body variables (shell height, whole weight, whole volume, wet and dry meat weights) of both age groups of oysters at all the three stations are presented below. Except in the case of 1+age group of oysters at station 3, growth curves could be fitted to the observed fortnightly data of above body variables of all other experimental group of oysters.

I. Shell height growth:

The fitted and observed fortnightly shell height values of 0 age and 1+ age oysters at all the three stations are presented in Figs. 2 (A to C) and 3 (A to C), respectively.

Cubic polynomials described shell height growth of 0 age (Table 1) and 1+age (Table 2) oysters at all the stations, though poor performance of 1+age group of oysters at station 3 resulted in poor fit of the model. Cubic polynomials were fitted to these data for comparison. Stations with significantly ($P \leq 0.05$) different shell height growth were placed in separate groups designated as high, medium and low growth

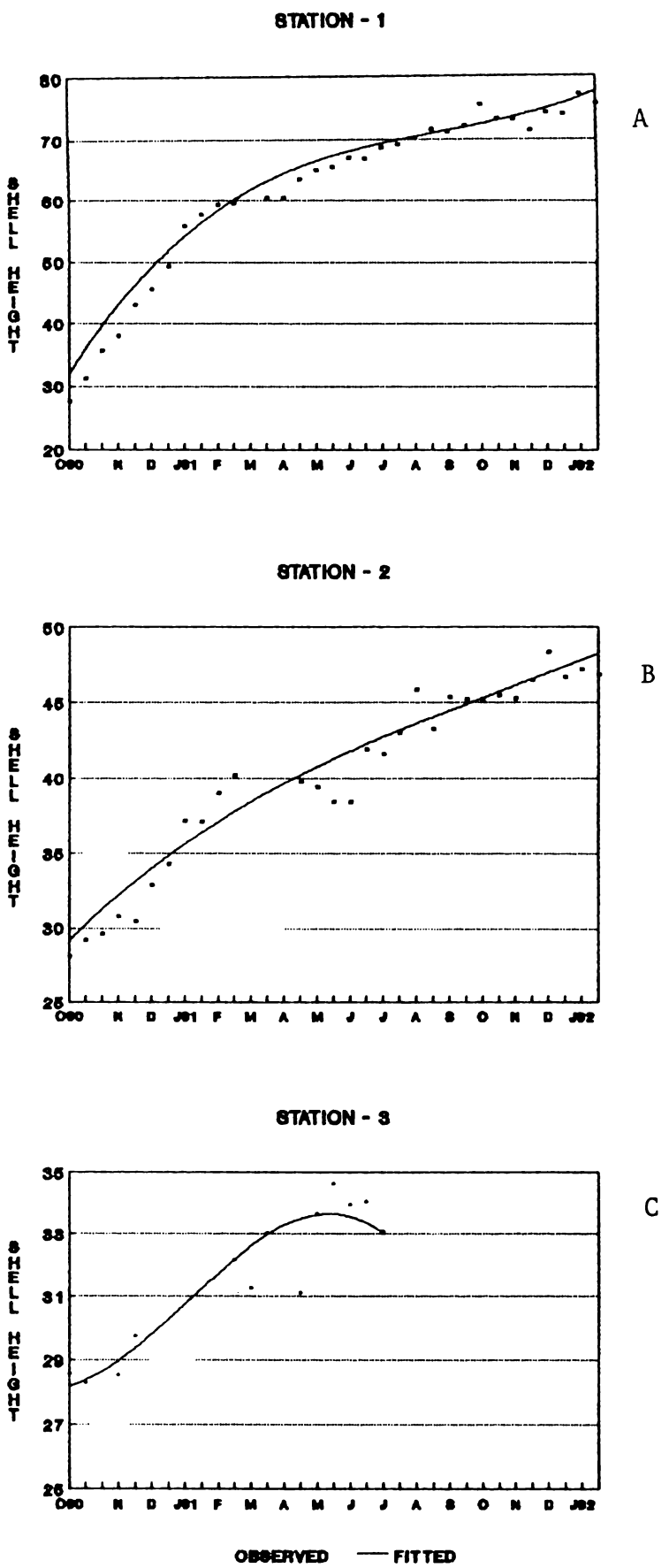


Fig. 2. Fortnightly mean shell height (mm) growth of 0 age oysters.

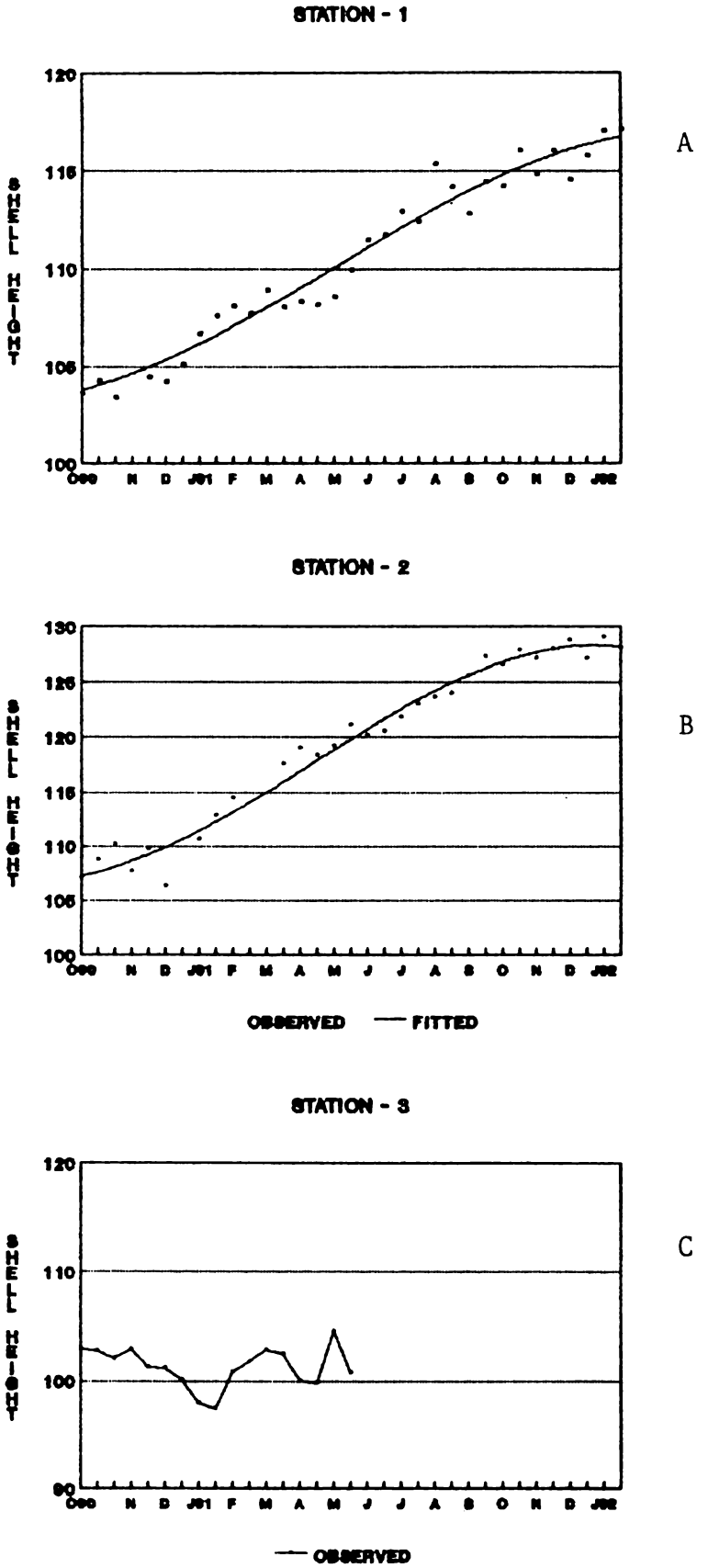


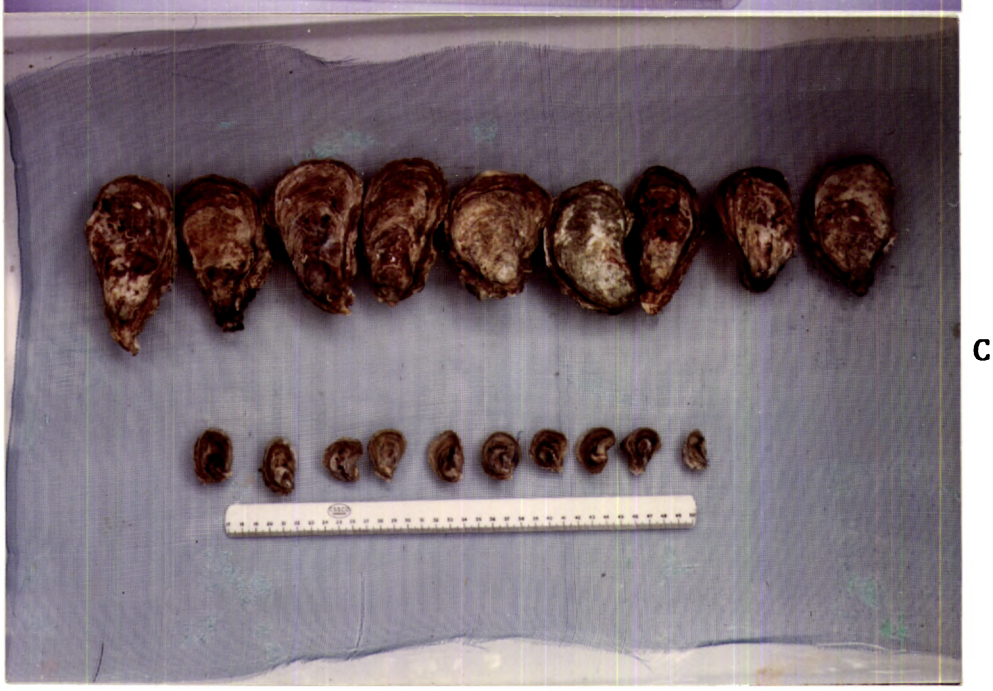
Fig. 3. Fortnightly mean shell height (mm) growth of 1+ age oysters.

PLATE IV. Samples of 1+ age group (upper row) and 0 age group (lower row) oysters at the end of the experiments at: A Station 1, B Station 2, and C. Station 3.

PLATE IV

A

B



C

stations (Table 3). While among 0 age group, the oysters at station 1 had the highest shell height growth, in the case of 1+ ge group, the oysters at station 2 had better shell height growth than at other stations.

Growth in shell height was highly variable for both the age groups of oysters. Final mean shell height in the second fortnight of January 1992 was 46.82mm (n=48; S.D.=±8.77) at station 2 (Plate IV B) and 75.67mm (n=49; S.D.=±7.63) at station 1 (Plate IV A) for 0 age oysters (Figs. 2A and B), and 117.16mm (n=50; S.D.=±15.59) at station 1 (Plate IV A) and 128.07mm (n=48; S.D.=±16.28) at station 2 (Plate IV B) for 1+ age oysters (Figs. 3A and B). At station 3, the final mean shell height in the first fortnight of July 1991 was 33.05mm (n=48; S.D.=±5.90) for 0 age oysters (Fig. 2C); (Plate IV C) and in the second fortnight of May 1991 it was 100.74mm (n=48; S.D.=± 13.36) for 1+ age oysters (Fig. 3C); (Plate IV C).

II. Whole weight growth:

Figures 4 (A to C) and 5 (A to C) present the fitted and observed fortnightly whole weight values of 0 age and 1+age oysters at all the experimental stations, respectively.

The whole weight growth of 0 age (Table 1) and 1+age (Table 2) oysters was described by cubic polynomials for all the stations, though the fit of the model was poor for 1+age oysters at station 3. A cubic polynomial was fitted to these data and inter-station comparisons were conducted. Comparisons of whole weight growth curves for both age group

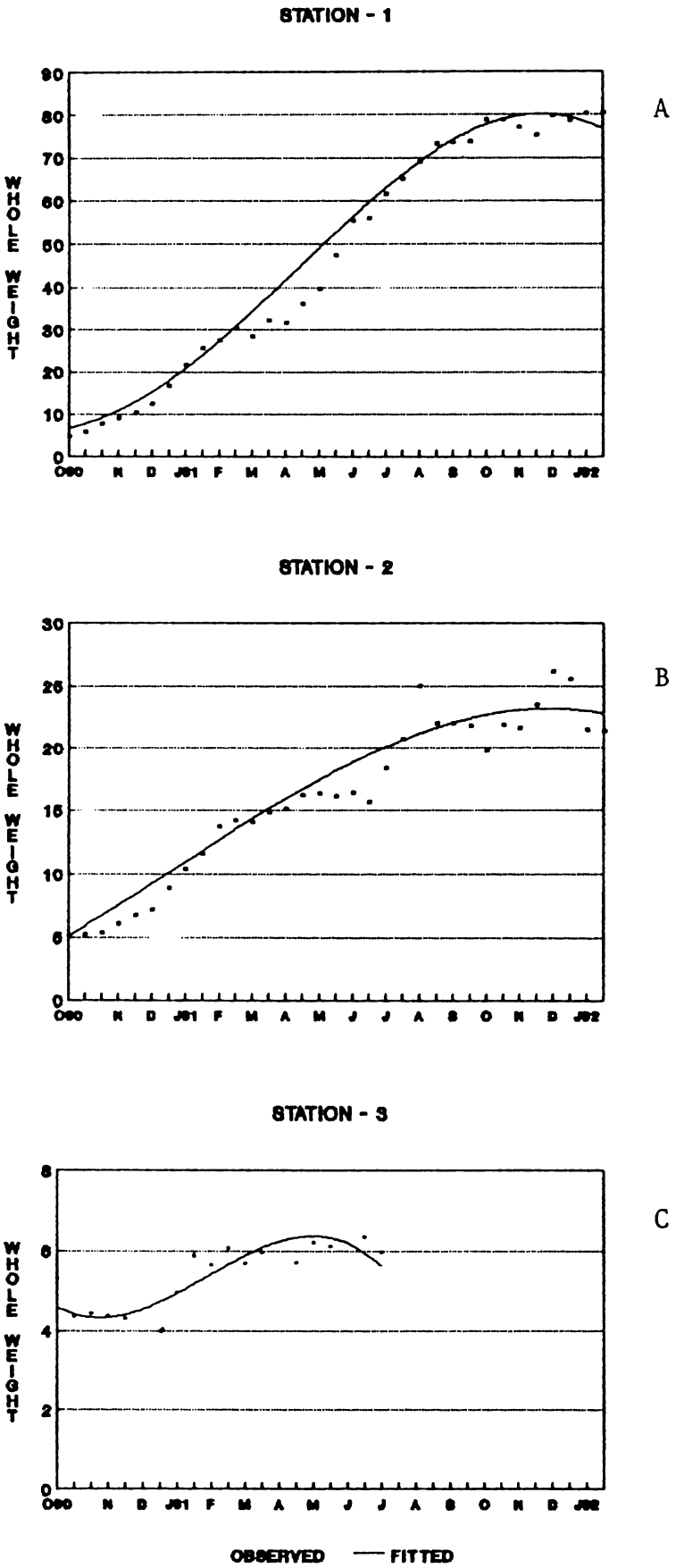


Fig. 4. Fortnightly mean whole weight (g) growth of 0 age oysters.

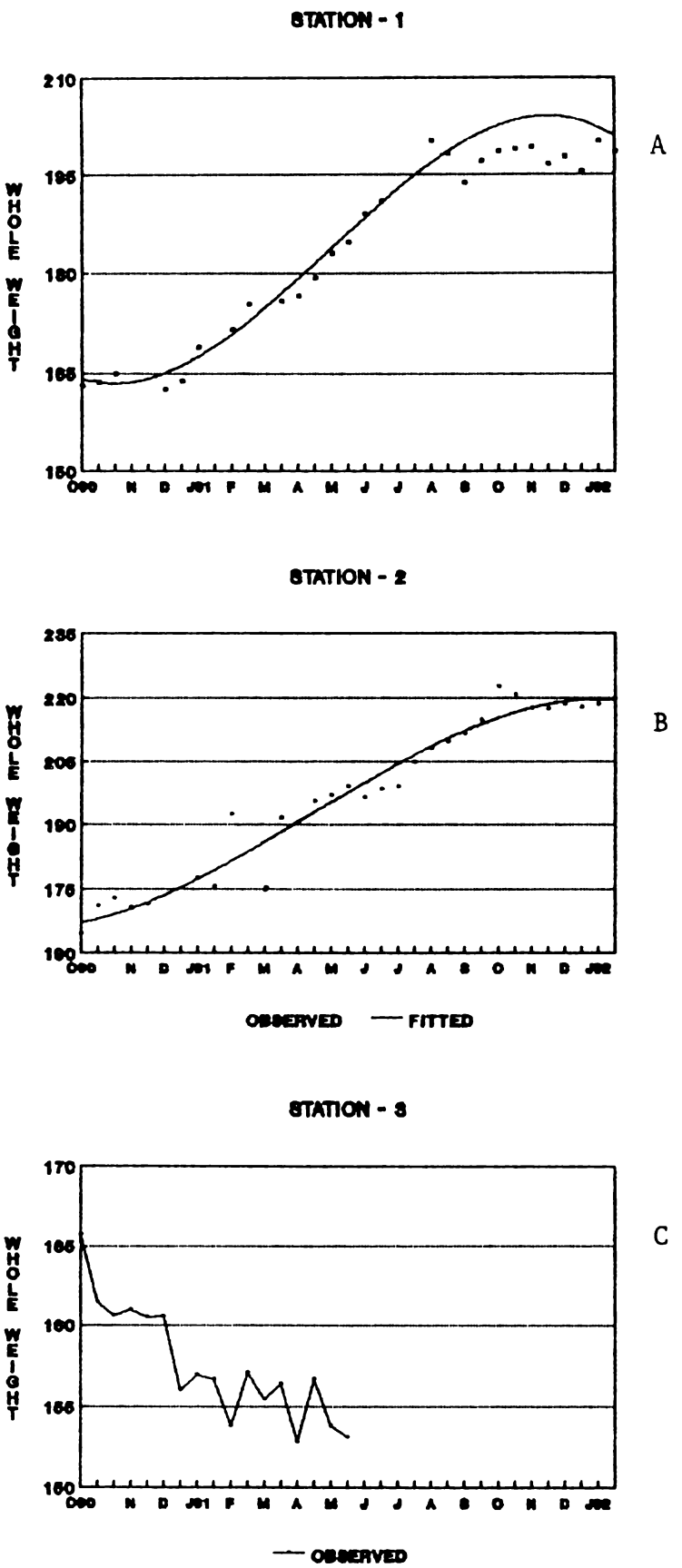


Fig. 5. Fortnightly mean whole weight (g) growth of 1+ age oysters.

of oysters resulted in similar groupings of stations as for shell height growth (Table 3).

Final mean whole weight in the second fortnight of January 1992 ranged from 21.31g (n=26; S.D.=±7.95) at station 2 to 80.46g (n=31; S.D.=±14.85) at station 1 for 0 age oysters (Figs. 4A and B), and from 198.54g (n=30; S.D.=±33.86) at station 1 to 219.81g (n=30; S.D.=±39.49) at station 2 for 1+age oysters (Figs. 5A and B). At station 3, the final mean whole weight in the first fortnight of July 1991 was 5.96g (n=25; S.D.=±2.02) for 0 age oysters (Fig. 4C) and in the second fortnight of May 1991 it was 153.12g (n=30; S.D=±31.68) for 1+age oysters (Fig. 5C).

III. Whole volume growth:

The fitted and observed fortnightly whole volume values of 0 age and 1+age oysters at all the stations are presented in Figs. 6 (A to C) and 7 (A to C), respectively.

Cubic polynomials described whole volume growth of 0 age (Table 1) and 1+ age (Table 2) oysters at all the stations, though in the case of 1+ age oysters of staion 3 the model fitted poorly. Comparisons of whole volume growth curves for both the age groups of oysters resulted in similar groupings of stations as for shell height and whole weight growth (Table. 3).

Final mean whole volume in the second fortnight of January 1992 was 13.78ml (n=25; S.D.=±4.33) at station 2 and 48.67ml (n=30; S.D.=±9.25) at station 1 for 0 age oysters (Figs. 6A and B), and 117.55ml (n=30; S.D.=±24.15) at station 1 and 133.57ml (n=30; S.D.=±24.15) at station 2

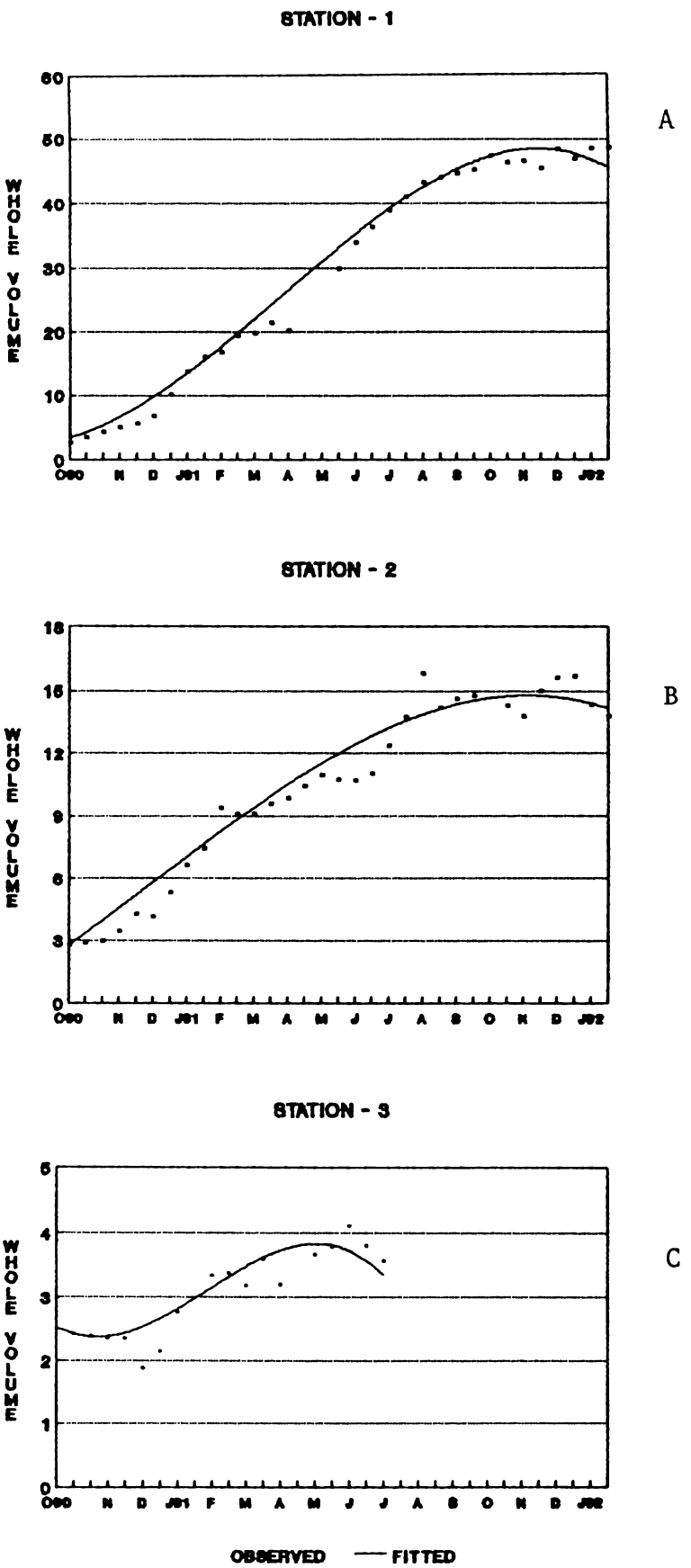


Fig. 6. Fortnightly mean whole volume(ml) growth of 0 age oysters.

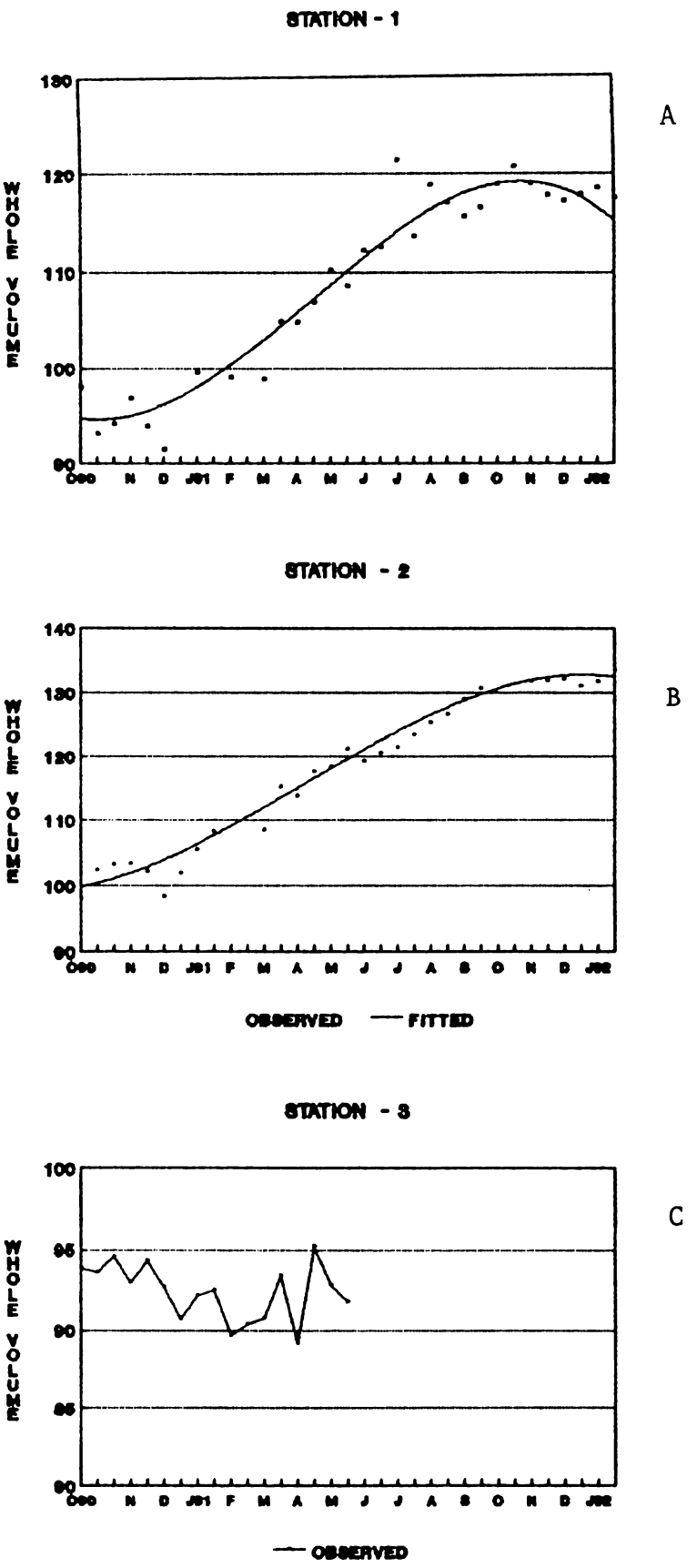


Fig. 7. Fortnighly mean whole volume (ml) growth of 1+ age oysters.

Table 1. Parameters of polynomial regressions fitted to various body variables of 0 age oysters ($Y = A+B_1x+B_2x^2+B_3x^3$).

Body variables	Coefficients	Station 1	Station 2	Station 3
Shell height	A	27.4581	28.0438	28.1225
	B1	4.56801	1.1495	0.02435
	B2	-0.1721	-0.0277	0.05633
	B3	0.00242	0.00035	-0.00226
	r^2	0.964802	0.94410	0.70604
Whole weight	A	6.2631	4.2687	4.8807
	B1	0.24838	0.7801	-0.3436
	B2	0.24089	0.0114	0.06027
	B3	-0.00556	-0.0005	-0.00206
	r^2	0.95865	0.94258	0.73323
Whole volume	A	2.6607	2.1294	2.7170
	B1	0.53311	0.59402	-0.2276
	B2	0.12838	0.00565	0.04119
	B3	-0.00318	-0.000382	-0.00141
	r^2	0.96197	0.95222	0.76991
Wet meat weight	A	1.3983	0.4840	0.2849
	B1	-0.0094	0.09852	0.00720
	B2	0.03078	-0.002475	0.001601
	B3	-0.000877	0.000012	-0.000108
	r^2	0.86476	0.82697	0.58580
Dry meat weight	A	0.2149	0.0787	0.0534
	B1	0.03478	0.02588	-0.00027
	B2	0.00438	-0.00046	0.000422
	B3	-0.000153	0.000001	-0.000022
	r^2	0.831237	0.85765	0.436032

($P \leqslant 0.05$ for all regressions).

for 1+age oysters (Figs. 7A and B). At station 3 the final mean whole volume in the first fortnight of July 1991 was 3.55ml (n=25; S.D.=±1.64) for 0 age oysters (Fig. 6C) and in the second fortnight of May 1991 it was 91.84ml (n=30; S.D.=±16.68) for 1+age oysters (Fig. 7C).

IV. Wet meat weight growth:

The observed and fitted fortnightly wet meat weight values of 0 age oysters are presented in Figs. 8A to C, and observed fortnightly wet meat weight values of 1+ age oysters in Figs. 9A to C.

While the wet meat weight growth of 0 age oysters was described by cubic polynomials for all the stations (Table 1), very low growth rates and wide fluctuations most probably due to metabolic reduction and/or reproductive status of 1+ age oysters, resulted in poor fit of the model at all the three stations. Comparison of wet meat growth curves of 0 age oysters resulted in similar groupings of stations as for all other body variables (Table 3), and since no growth curves could be fitted for 1+ age oysters, such comparisons could not be carried out.

Final observed mean wet meat weight in the second fortnight of January 1992 was 1.45g (n=10; S.D.=±0.57) at station 2 and 6.35g (n=15; S.D.=± 1.17) at station 1 for 0 age oysters (Figs. 8A and B), and 11.58g (n=15; S.D.=±2.40) at station 2 and 11.74g (n=15, S.D.=±2.75) at station 1 for 1+ age oysters (Figs. 9A and B). At station 3 the final observed mean wet meat weight in the first fortnight of July 1991 was 0.36g (n=10; S.D.=±0.11) for 0 age oysters (Fig. 8C) and in the second fortnight of May 1991 it was 2.85g (n=15; S.D.=±0.56) for 1+age oysters (Fig. 9C).

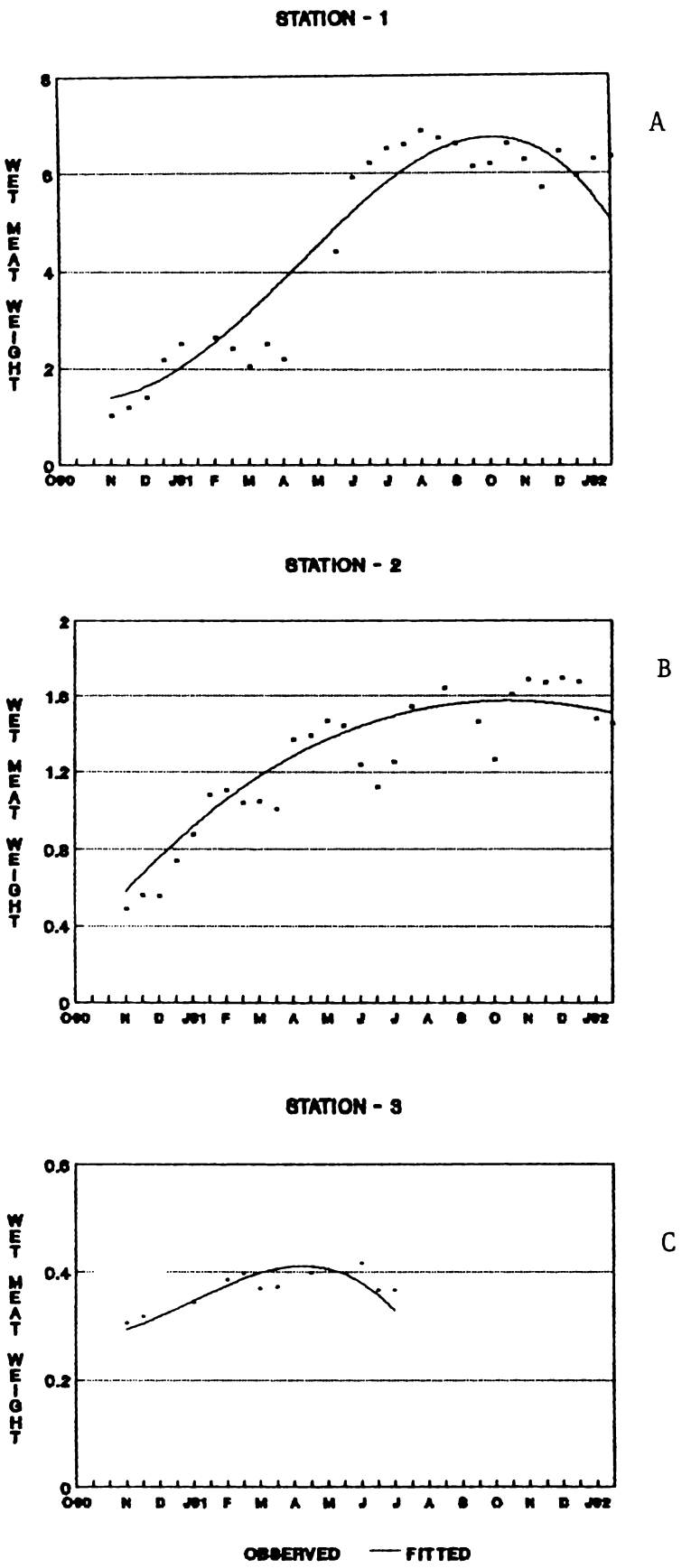


Fig. 8. Fortnightly mean wet meat weight (g) growth of 0 age oysters.

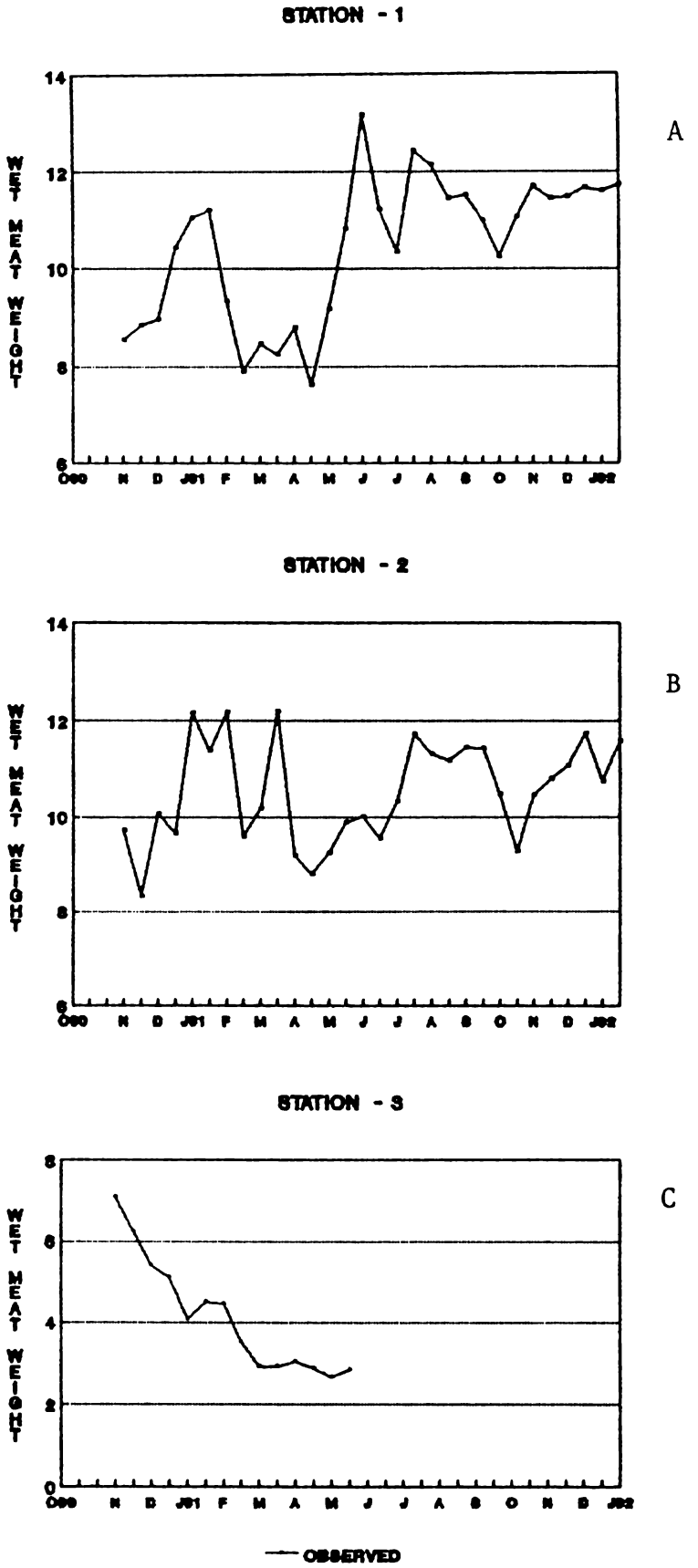


Fig. 9. Fortnightly mean wet meat weight (g) growth of 1+ age oysters.

Table 2. Parameters of polynomial regressions fitted to body variables of 1+ age oysters ($Y = A+B_1x+B_2x^2+B_3x^3$).

Body variables	Coefficients	Station 1	Station 2	Station 3
Shell height	A	103.7822	107.238	103.934
	B1	0.2286	0.3247	-1.2103
	B2	0.0190	0.0471	0.1033
	B3	-0.00042	-0.00115	-0.00135
	r^2	0.9360	0.9456	0.2986
Whole weight	A	164.155	167.205	164.715
	B1	-0.758	0.7822	-1.726
	B2	0.2037	0.1137	0.0962
	B3	-0.0046	-0.00272	-0.00125
	r^2	0.9037	0.9251	0.34521
Whole volume	A	94.760	98.838	94.520
	B1	-0.2516	0.4914	-0.4663
	B2	0.1239	0.0765	0.00913
	B3	-0.003	-0.00187	0.000057
	r^2	0.9162	0.9362	0.3162

($P \leq 0.05$ for all regressions).

V. Dry meat weight growth:

Cubic polynomials were fitted to observed fortnightly mean dry meat weight data of 0 age oysters (Table 1) at all the three stations (Figs. 10A to C), and as in the case of wet meat weights, no growth curves could be fitted to the observed fortnightly mean dry meat weight data of 1+ age oysters and therefore only the observed values are plotted (Figs. 11A to C). The grouping of stations based on comparisons of dry meat weight growth curves of 0 age oysters were similar to the other body variables described above (Table 3).

Final observed mean dry meat weight in the second fortnight of January 1992 was 0.42g (n=10; S.D.=±0.16) at station 2 and 1.39g (n=15; S.D.=±0.24) at station 1 for 0 age oysters (Figs. 10A and B), and 2.68g (n=15; S.D.=±0.55) at station 2 and 3.03g (n=15; S.D.=±0.73) at station 1 for 1+ age oysters (Figs. 11A and B). At station 3 the final observed mean dry meat weight in the first fortnight of July 1991 was 0.064g (n=10; S.D.=±0.022) for 0 age oysters (Fig. 10C) and in the second fortnight of May 1991 it was 0.41g (n=15; S.D.=±0.26) for 1+ age oysters (Fig. 11C).

INSTANTANEOUS GROWTH RATES:

The monthly instantaneous growth rate was calculated for all the body variables (shell height, whole weight, whole volume, wet and dry meat weights) of 0 age oysters at all the stations. Among the stations, oysters of station 1 had higher growth rates than those at the other two stations. The periodic fluctuations in monthly instantaneous growth

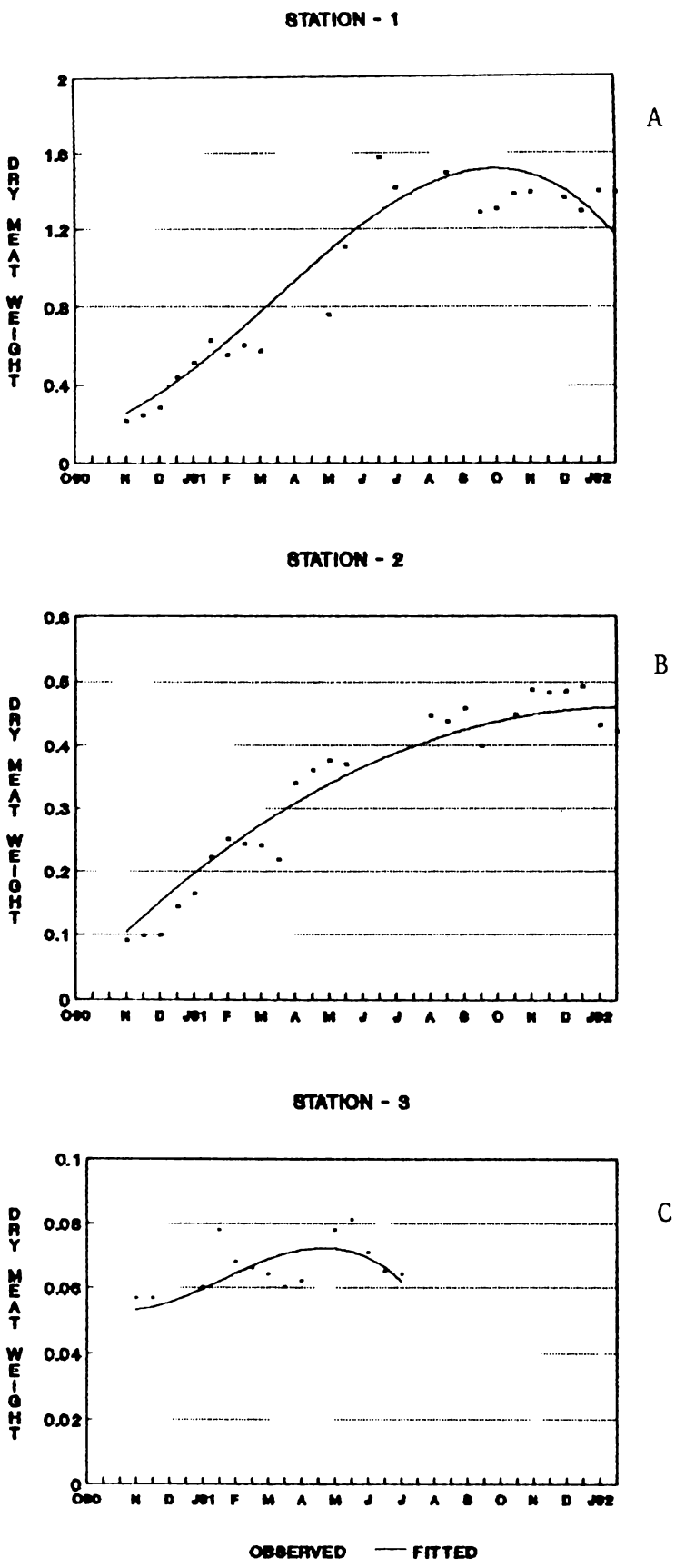


Fig. 10. Fortnightly mean dry meat weight (g) growth of 0 age oysters.

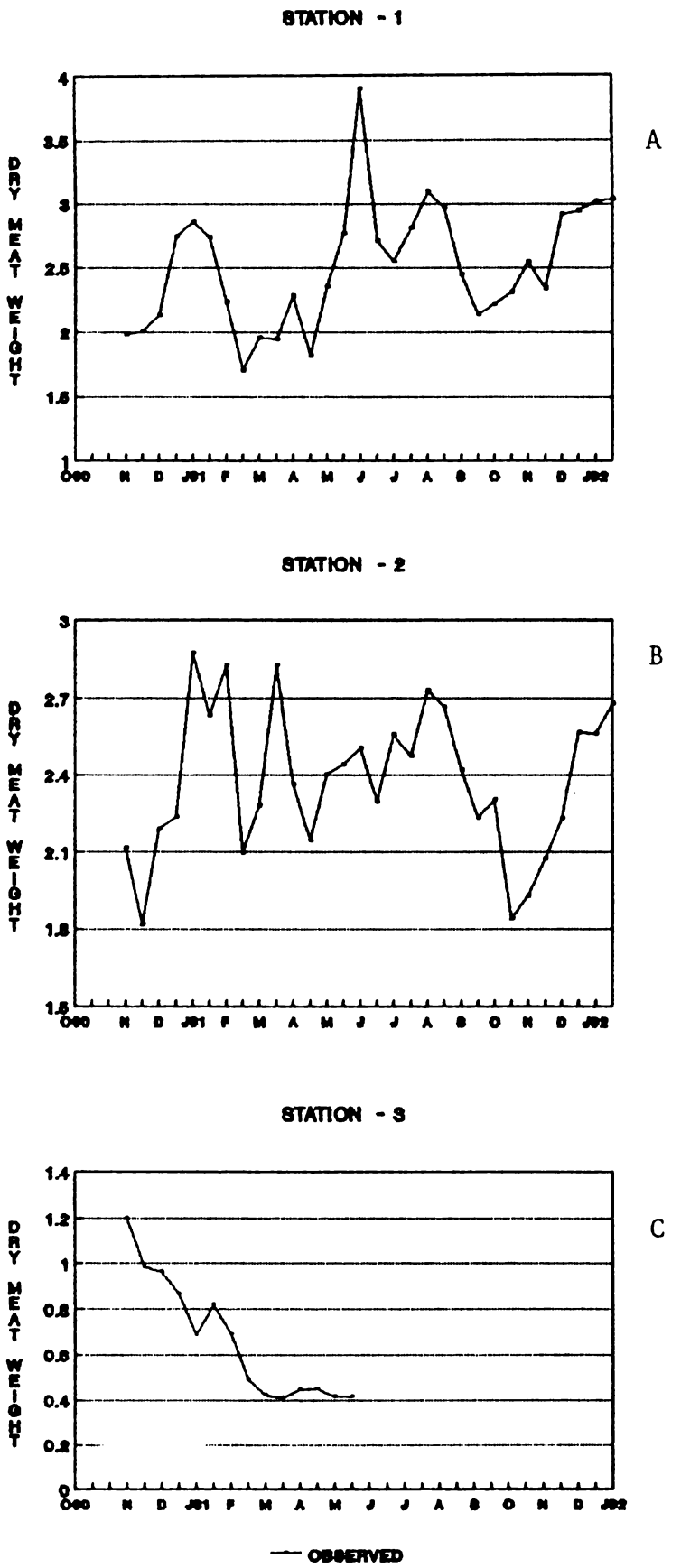


Fig. 11. Fortnightly mean dry meat weight (g) growth of 1+ age oysters.

Table 3. Summary of comparisons of regressions fitted to station specific growth data of 0 age and 1+ age oysters.

Body variables	Station 1	Station 2	Station 3
Shell height (0 age)	H	M	L
Shell height (1+ age)	M	H	L
Whole weight (0 age)	H	M	L
Whole weight (1+ age)	M	H	L
Whole volume (0 age)	H	M	L
Whole volume (1+ age)	M	H	L
Wet meat weight (0 age)	H	M	L
Dry meat weight (o age)	H	M	L

High (H), Medium (M), and Low (L) growth groups indicate stations with significantly ($P \leq 0.05$) different growth.

rates and their correlation with monthly mean values of various environmental parameters are presented under the following headings.

I. Shell height:

It should be noted that different growth rates which exist among the individuals of a population, could give an impression of negative growth rate in shell height of the population (which is not acceptable theoretically) during the periods of no growth and where the mortality rate of larger size groups is very high. While Brown (1988) in his studies on monthly instantaneous growth rate in shell height of Crassostrea gigas has presented such negative growth rate values as periods of nil growth, Fernandez and Bodoy (1987) in their work on instantaneous shell height growth rate of Ostrea puelchana, have presented the negative growth rates as such. In the present study, while the negative growth rates in shell height have been presented in the graphs as was observed, in the text they are described as periods of nil growth.

At station 1, maximum monthly shell height instantaneous growth rates for 0 age oysters occurred during the initial months of the experiment (October 1990 to January 1991). There was a sharp decline in the growth rates by February 1991, followed by a more or less uniform low growth rates with minor variations in the remaining period of study (Fig.12A).

In contrast to oysters at station 1, the oysters at station 2 had moderate shell height growth rates during the initial months (October

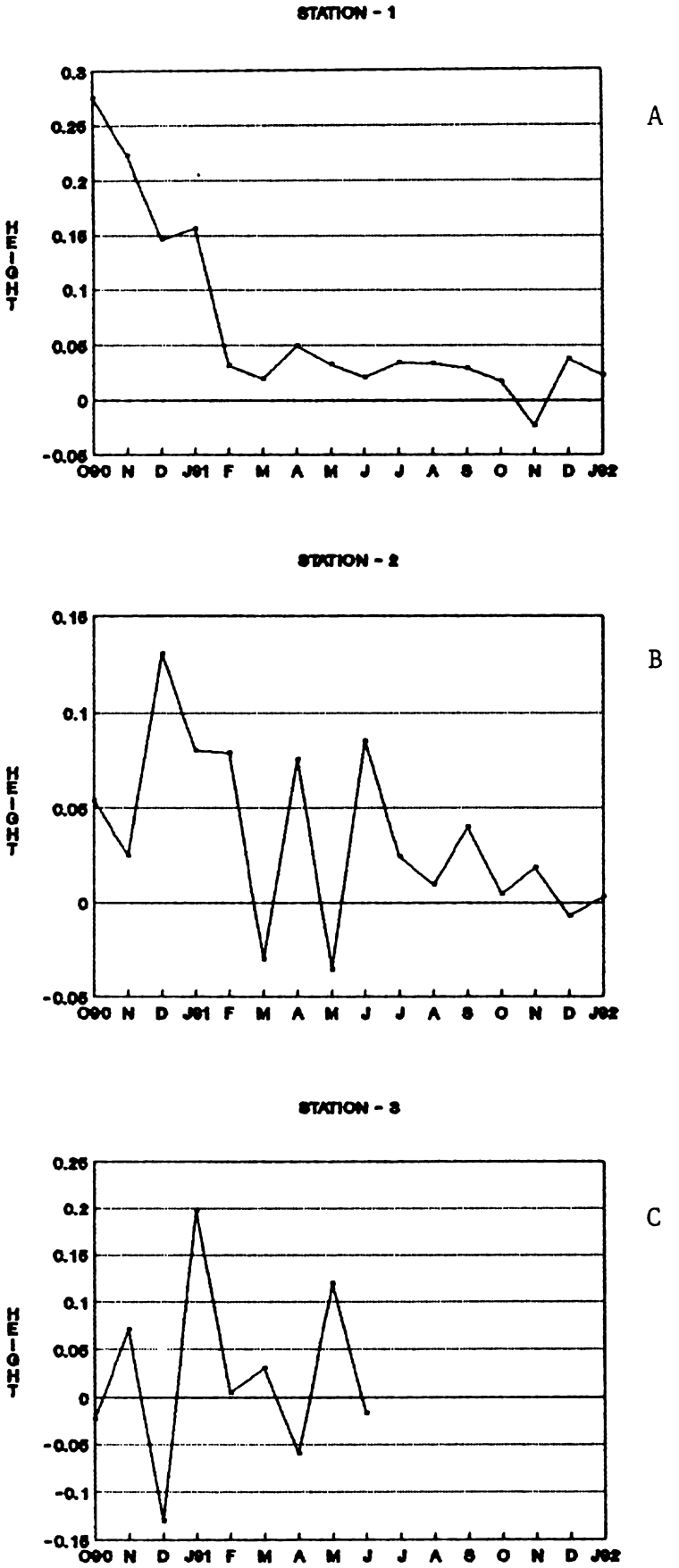


Fig. 12. Monthly shell height instantaneous growth rate of 0 age oysters.

and November 1990), and there after higher growth rates were observed from December 1990 to February 1992, and also during the months of April and June 1991. No growth was observed during the months of March, May and December 1991, and from July to November 1991 a fluctuation from moderate to low growth rates was recorded (Fig.12B).

At station 3, oysters had high shell height growth rates during January and May 1991 and comparatively moderate growth rates during the month of November 1990 and March 1991. No growth was observed in the remaining months of the experiment at this station (Fig. 12C).

The highest monthly shell height instantaneous growth rates recorded for 0 age oysters were, 0.2749 (October 1990) at Station 1 (Fig. 12A), 0.1301 (December 1990) at station 2 (Fig. 12B), and 0.1977 (January 1991) at station 3 (Fig. 12C).

The correlations between the monthly instantaneous growth rate in shell height and monthly mean values of environmental parameters were non-significant at all the experimental stations (Tables 4A and B).

II. Whole Weight:

At station 1, high whole weight instantaneous growth rates were recorded during the initial months of the experiment (October 1990 to January 1991). In February 1991 the growth rate sharply decreased and remained at low levels upto April 1991. An increase in growth rate to moderate level in May 1991 was followed by a gradual decrease to low and nil growth rates during the remaining period of study. A slight reduction in whole weight or negative growth rate was observed during November 1991 (Fig. 13A).

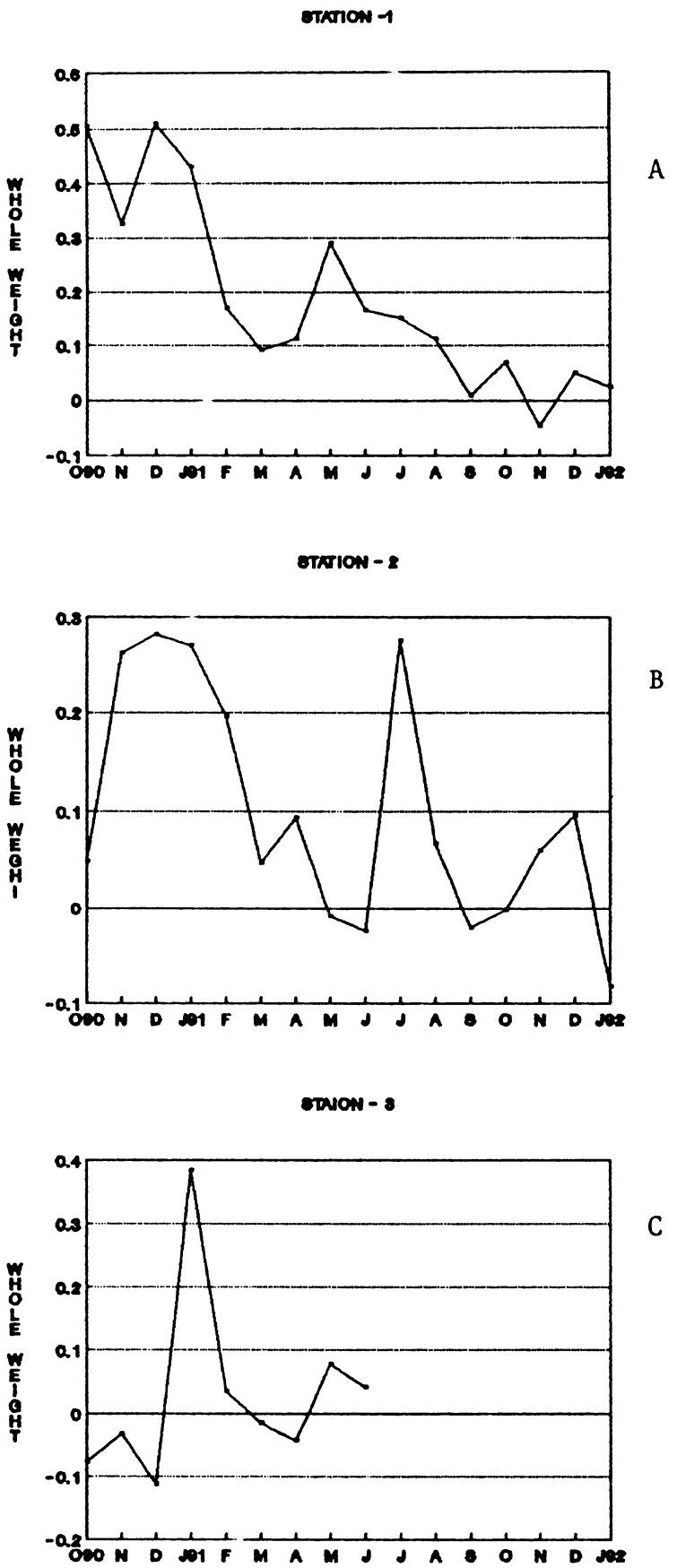


Fig. 13. Monthly whole weight instantaneous growth rate of 0 age oysters.

At station 2, oysters had low growth rate in the initial month of the experiment (October 1990) and thereafter high growth rate was maintained during November 1990 to February 1991. In the subsequent months from March to June 1991, a declining trend from low to nil and minor negative growth rates were recorded. A sharp increase to high growth rate level observed in July 1991 was followed by a sudden decrease to low and nil growth rate from August to October 1991. A gradual increase in growth rates was discernible during November 1990 and December 1991, which was followed by a sudden decrease during the last month of the experiment (Fig. 13B).

At station 3, negative growth rates observed during the beginning of the experiment (October to December 1990) were followed by a sharp increase in the growth rate during January 1991. Thereafter, low growth rates were observed during February, May and June 1991, and minor negative growth rates in the months of March and April 1991 (Fig. 13C).

The maximum monthly whole weight instantaneous growth rate recorded were, 0.5094 (December 1990) at station 1 (Fig.13A), 0.2826 (December 1990) at station 2 (Fig.13B) and 0.3889 (January 1991) at station 3 (Fig. 13C).

The monthly whole weight instantaneous growth rates of 0 age oysters exhibited significant ($P \leqslant 0.01$) positive correlation with net and gross primary productivity, significant ($P \leqslant 0.05$) positive correlation with chlorophyll-a, silicate, nitrite and dissolved oxygen at station 1. At stations 2 and 3 the whole weight growth rates of

experimental oysters showed no significant correlation with any of the environmental parameters (Table 4A and B).

III. Whole Volume:

At all the three stations the periodic variations in monthly whole volume instantaneous growth rate of 0 age oysters followed a comparable trend as was described for the monthly whole weight instantaneous growth rate of these groups of oysters (Figs. 14A, B and C).

The highest monthly whole volume instantaneous growth rate of 0 age oysters recorded were, 0.6164 (December 1990) at station 1 (Fig. 14A), 0.4192 (November 1990) at station 2 (Fig. 14B), and 0.4527 (January 1991) at station 3 (Fig.14C).

The monthly whole volume instantaneous growth rates of 0 age oysters at station 1 exhibited significant positive correlation with gross primary productivity values ($P \leqslant 0.01$), net primary productivity and nitrite concentration ($P \leqslant 0.05$), and significant ($P \leqslant 0.05$) negative correlation with ammonia. Whole volume growth rates of 0 age oysters at station 2 showed significant ($P \leqslant 0.05$) positive correlation with silicate. The whole volume growth rates at station 3 had no significant correlation with any of the envirnomental variables (Tables 4A and B).

IV. Wet meat:

At station 1, a continuous decrease from high growth rate to moderate and finally negative level was recorded in the initial months of the experiment (December 1990 to February 1991). In the following

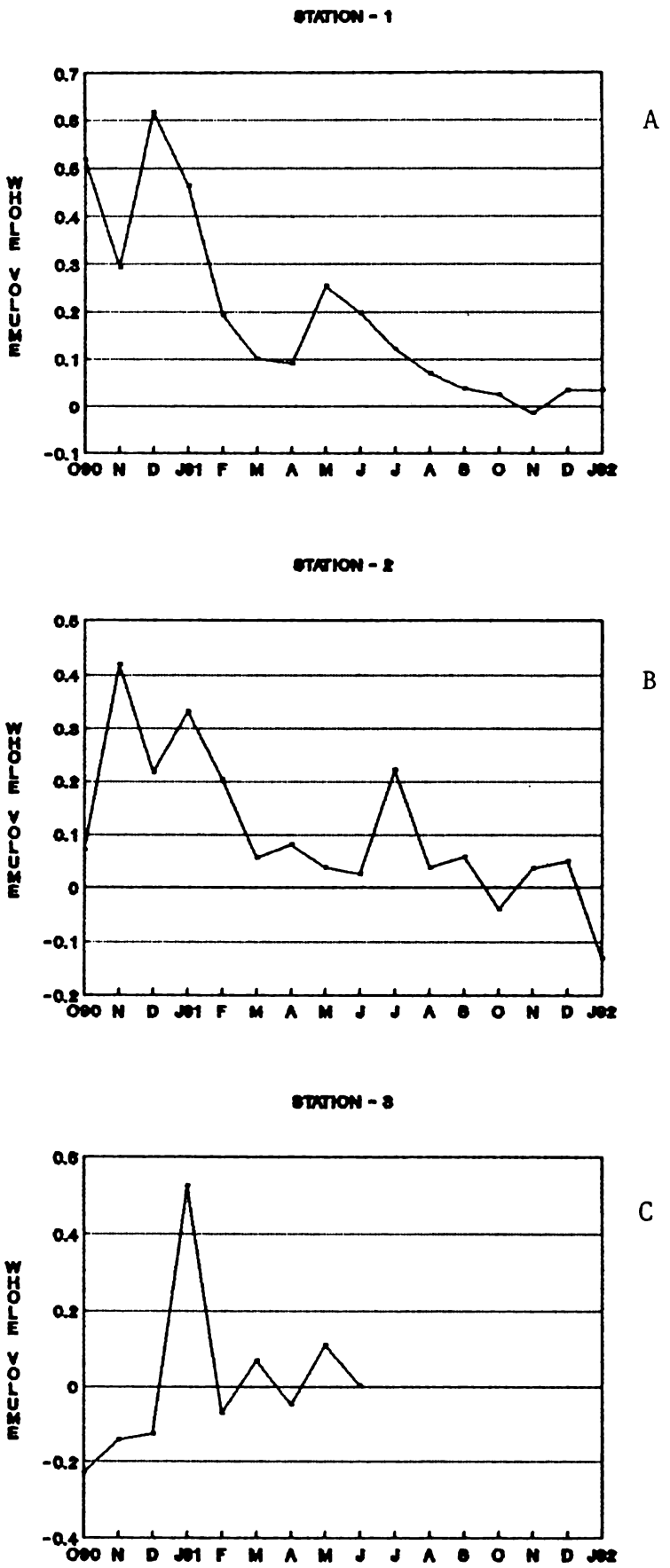


Fig. 14. Monthly whole volume instantaneous growth rate of 0 age oysters.

months an increase from low to high growth rate levels (March to May 1991), was followed by a gradual decrease to moderate and negative levels from June to September 1991. In the remaining period of study, except a minor negative growth rate recorded in the month of November 1991, the oysters maintained low growth rates (Fig. 15A).

At station 2, the monthly wet meat instantaneous growth rate of 0 age oysters dropped from high growth rate levels observed during December 1990 and January 1991 to minor negative levels during February and March 1991. In the subsequent months, a similar declining trend from high to low and negative growth rate values were recorded during the periods April to June 1991 and July to September 1991. Thereafter, the growth rates remained low from October to November 1991 and in the last two months of December 1991 and January 1992 nil and minor negative growth rates were recorded, respectively (Fig. 15B).

At station 3 the monthly wet meat instantaneous growth rate increased from negative level in December 1990 to a peak position in January 1991. In subsequent months, a sharp drop to minor negative growth rate levels was observed in February and March 1991, followed by an increase to low growth rate levels during April and May 1991. In June 1991 once again negative growth rate was observed (Fig. 15C).

The maximum monthly wet meat instantaneous growth rates recorded for 0 age oysters were, 0.6183 (December 1990) at station 1 (Fig. 15A), 0.3812 (January 1991) at station 2 (Fig. 15B), and 0.5255 (January 1991) at station 3 (Fig. 15C).

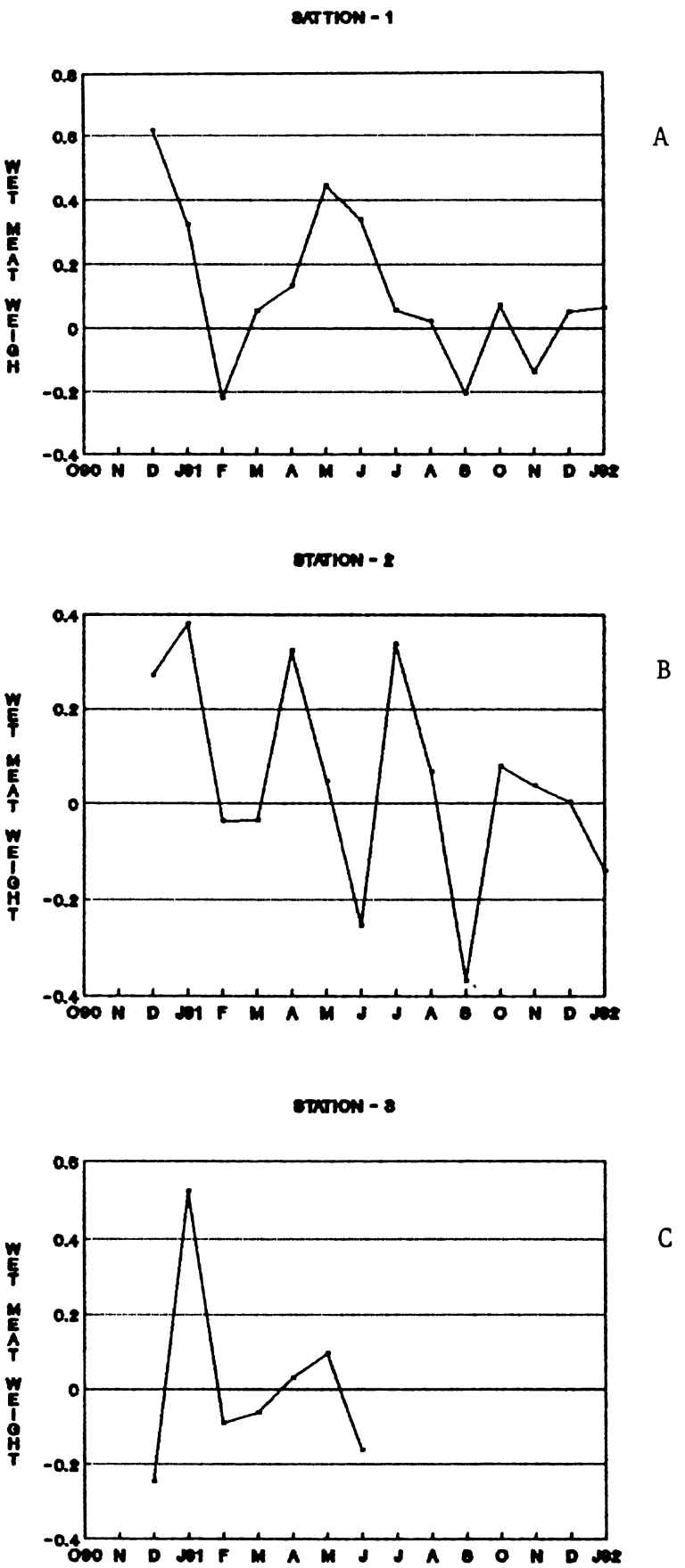


Fig. 15. Monthly wet meat weight instantaneous growth rate of 0 age oysters.

As seen in the Tables 4A and B, the monthly wet meat instantaneous growth rates of 0 age oysters showed significant ($P \leqslant 0.05$) positive correlation with dissolved oxygen, net and gross primary productivity values and significant ($P \leqslant 0.05$) negative correlation with ammonia values at station 1. The statistical analysis revealed no significant correlation between wet meat growth rates and any of the environmental variables at stations 2 and 3.

V. Dry meat:

The monthly dry meat instantaneous growth rate of 0 age oysters at all the three stations followed a comparable trend as was described for wet meat monthly instantaneous growth rates of these oysters (Figs. 16A, B, and C).

The maximum monthly dry meat instantaneous growth rates of 0 age oysters were 0.6103 (December 1990) at station 1 (Fig. 16A), 0.4970 (April 1991) at station 2 (Fig. 16B), and 0.5955 (January 1991) at station 3 (Fig.16C).

The monthly dry meat instantaneous growth rates of 0 age oysters showed significant ($P \leqslant 0.05$) positive correlation with dissolved oxygen, net and gross primary productivity values at Station 1. The dry meat growth rates of oysters at stations 2 and 3 showed no significant correlation with any of the environemtnal parameters (Tables 4A and B).

CONDITION INDEX:

The periodical variations in the fortnightly mean condition index (C.I.) values of both the age groups of oysters at all the three stations are presented below.

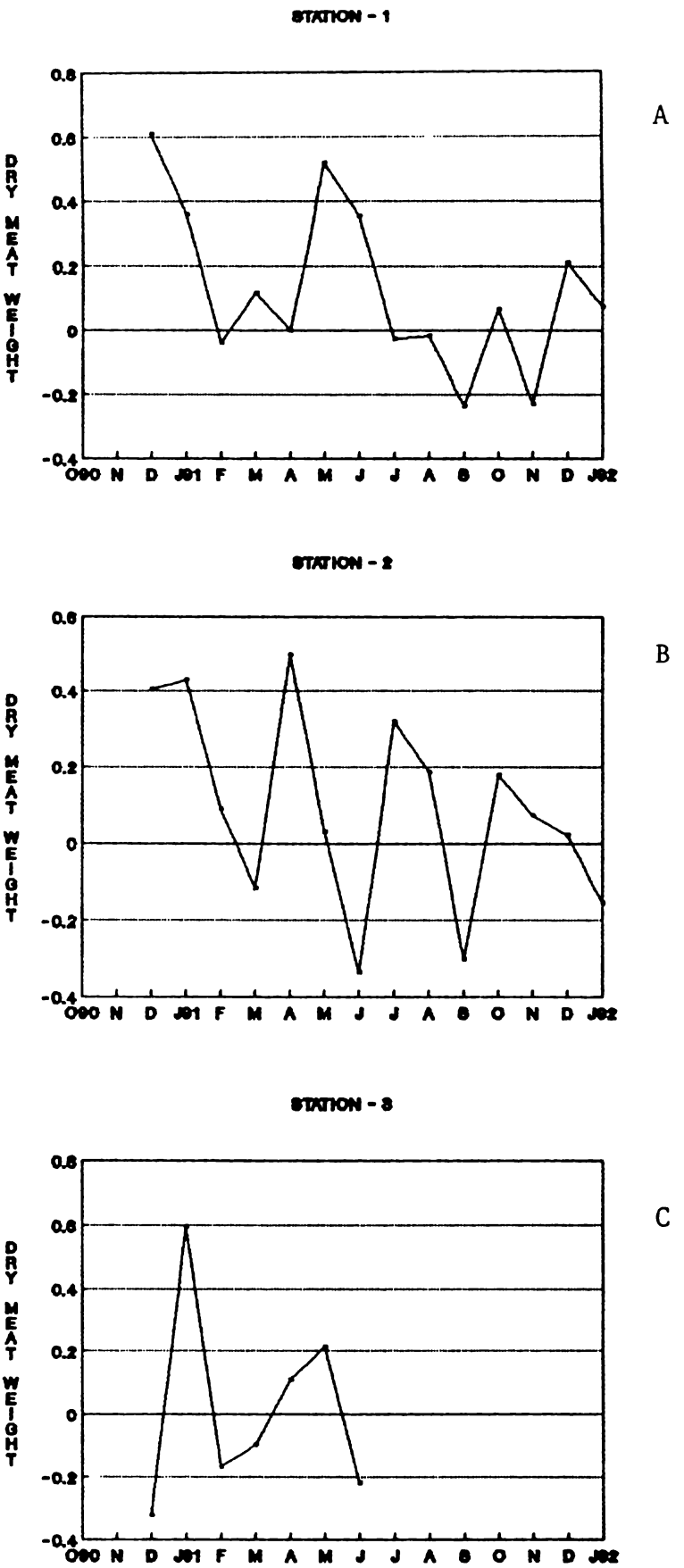


Fig. 16. Monthly dry meat weight instantaneous growth rate of 0 age oysters.

Table 4A. The correlation between instantaneous growth rate of 0 age oysters and environmental parameters.

	Body variables	Salinity	Water temperature	Dissolved oxygen	Turbidity	Total suspended micro-matter	pH
Station (1)	Shell height	-0.069	-0.409	0.218	0.414	0.399	-0.144
	Whole weight	0.013	-0.338	0.504*	0.463	0.425	-0.041
	Whole volume	-0.073	-0.433	0.487	0.486	0.471	-0.067
	Wet meat weight	-0.024	-0.058	0.584*	0.429	0.283	0.069
	Dry meat weight	-0.099	-0.208	0.616*	0.404	0.324	-0.008
Station (2)	Shell height	-0.130	-0.416	0.206	0.204	-0.030	-0.124
	Whole weight	-0.162	-0.437	0.290	0.154	-0.197	-0.327
	Whole volume	-0.050	-0.424	0.201	0.196	-0.189	-0.161
	Wet meat weight	-0.169	-0.203	0.110	0.031	-0.238	-0.405
	Dry meat weight	-0.157	-0.176	0.034	-0.045	-0.345	-0.399
Station (3)	Shell height	0.017	0.048	-0.284	0.151	0.088	-0.052
	Whole weight	-0.102	-0.193	-0.166	0.091	0.107	-0.302
	Whole volume	-0.117	-0.128	-0.224	0.046	0.128	-0.278
	Wet meat weight	-0.092	0.073	-0.305	-0.080	-0.016	-0.301
	Dry meat weight	0.034	0.204	-0.412	-0.006	-0.007	-0.151

* Significant at 5% level.

Table 4B. The correlation between instantaneous growth rate of 0 age oysters and environmental parameters.

Body variables		Calcium	Nitrate-N	Nitrite-N	Ammonia-N	Silicate	Phosphorous	Chloro-phyll-a	Net Productivity	Gross productivity
S t a t i o n (1)	Shell height	-0.314	0.024	0.482	-0.471	0.483	-0.300	0.298	0.401	0.482
	Whole weight	-0.289	0.125	0.619*	-0.654**	0.572*	-0.310	0.560*	0.693**	0.747**
	Whole volume	-0.313	0.050	0.596*	-0.602*	0.488	-0.250	0.481	0.620*	0.694**
	Wet meat weight	-0.191	0.215	0.491	-0.610*	0.394	-0.480	0.490	0.608*	0.613*
	Dry meat weight	-0.212	0.120	0.482	-0.464	0.421	-0.350	0.462	0.612*	0.620*
S t a t i o n (2)	Shell height	-0.164	0.160	0.207	-0.337	0.392	-0.121	0.194	0.372	0.402
	Whole weight	-0.154	-0.022	0.156	-0.398	0.460	0.112	0.140	0.274	0.358
	Whole volume	-0.119	0.043	0.205	-0.421	0.614*	-0.089	0.210	0.336	0.426
	Wet meat weight	-0.196	-0.070	0.182	-0.328	0.268	0.030	0.044	0.112	0.212
	Dry meat weight	-0.140	-0.050	0.102	-0.302	0.201	0.047	-0.013	0.076	0.173
S t a t i o n (3)	Shell height	0.051	0.320	0.562	-0.222	0.732*	-0.045	0.572	0.496	0.562
	Whole weight	-0.140	0.372	0.318	-0.154	0.612	-0.150	0.432	0.501	0.580
	Whole volume	-0.151	0.342	0.332	-0.212	0.582	-0.102	0.396	0.462	0.501
	Wet meat weight	0.084	0.238	0.307	-0.251	0.571	-0.055	0.305	0.356	0.471
	Dry meat weight	0.212	0.315	0.398	-0.245	0.726*	-0.128	0.406	0.392	0.512

* Significant at 5% level ($P \leq 0.05$).
** Significant at 1% level ($P \leq 0.01$).

A. 0 age oysters:

The fortnightly mean C.I. values of 0 age oysters at station 1 were considerably higher than the C.I. values of the same age group of oysters at the other two stations.

At station 1 oysters maintained high C.I. values during the initial months of the experiment (November 1990 to January 1991). A gradual decline from moderate to low condition index level from February to April 1991, was followed by a rapid rise to a high level from May to June 1991. Thereafter, a continuous declining trend to low values was recorded from July to October 1991. In the remaining period (November 1991 to January 1992) the values fluctuated between low and moderate levels (Fig.17A).

At station 2, the 0 age oysters were in poor condition during most of the study period. The mean C.I. values of this group of oyster was very low initially (November December 1990). Subsequently (January to May 1991), the values gradually rose to moderate and then to high levels. Low and moderate C.I. values were recorded during June July and August 1991, respectively. In the following months of September 1991 to January 1992, C.I. values increased rapidly from low to the highest level recorded for this group of oyster at this station (Fig. 17B).

At station 3, the C.I. values of the 0 age oysters were very poor when compared to those obtained at the other two stations. The low C.I.values recorded during November 1990 - January 1991, dropped to

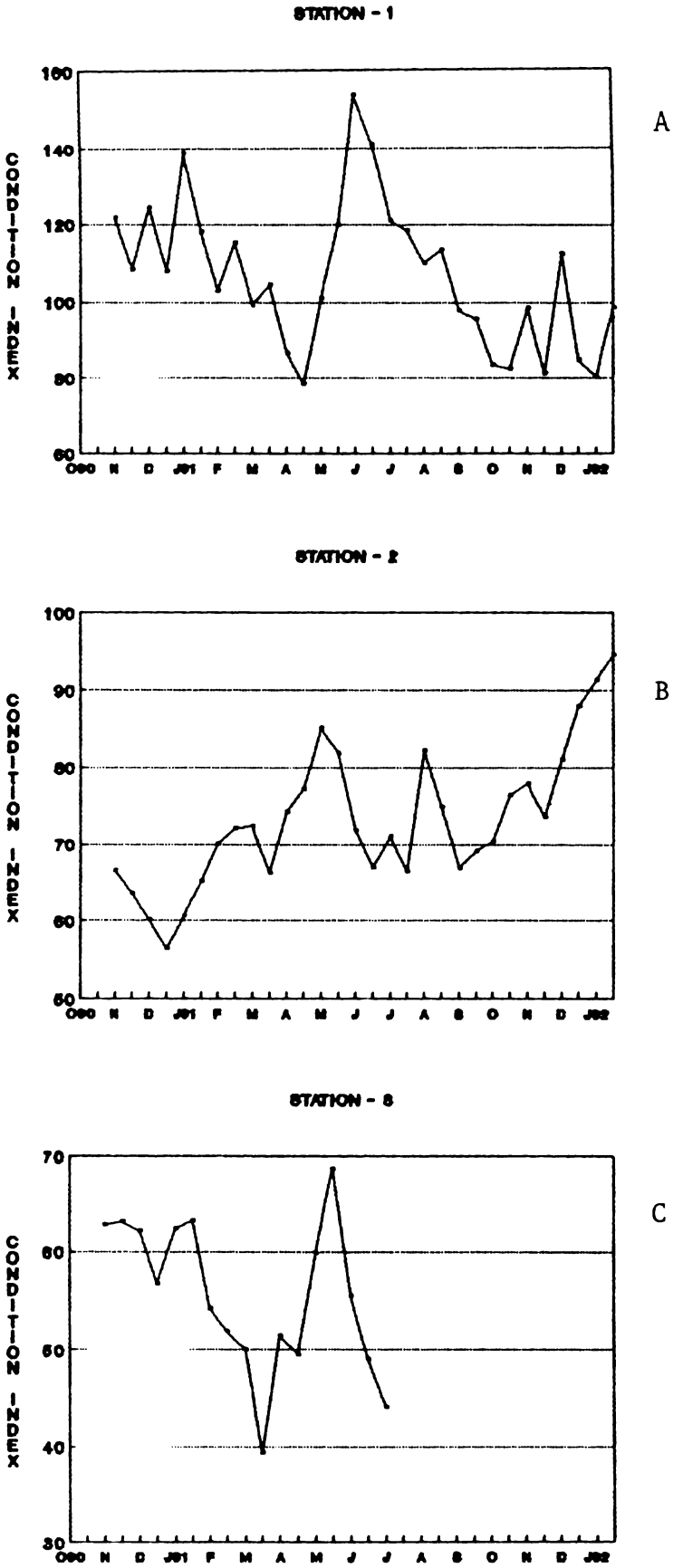


Fig. 17. Fortnightly mean condition index of 0 age oysters.

lower levels in February and March 1991. Thereafter, a sharp increase in the values from April to second fortnight of May 1991, was followed by a sharp decrease in the remaining period of study (Fig. 17C).

The minimum and maximum mean condition index values of 0 age oysters ranged from 78.25 (n=15; S.D.=10.82); (second fortnight of April 1991) to 153.67 (n=15; S.D.=24.46); (first fortnight of June 1991) at station 1 (Fig. 17A), from 56.43 (n=15; S.D.=9.16); (second fortnight of December 1990) to 94.71 (n=10; S.D.=12.73); (second fortnight of January 1992) at station 2 (Fig. 17B) and from 39.36 (n=10; S.D.=7.86); (second fortnight of March 1991) to 68.66 (n=10; S.D.=11.25); (second fortnight of May 1991) at station 3 (Fig. 17C).

The mean C.I. values of 0 age oysters showed significant ($P \leqslant 0.01$) positive correlation with dissolved oxygen, silicate, chlorophyll-a, net and gross primary productivity values, significant ($P \leqslant 0.05$) positive correlation with turbidity, total suspended micro-matter, nitrate and nitrite values at station 1, significant ($P \leqslant 0.05$) negative correlation with turbidity and silicate values at station 2, and at station 3 the correlations were significant ($P \leqslant 0.01$) and positive with nitrite and also significant ($P \leqslant 0.05$) and positive with turbidity, total suspended micro-matter, silicate, and net primary productivity values (Tables 5A and B).

B. 1+ age oyster:

The 1+ age oysters at station 1 had higher fortnightly mean condition index values than 1+ age oysters at station 2 throughout most

of the study period, and the 1+ age oysters at station 3 maintained the lowest mean condition index values among the three stations.

At station 1, the variations in mean fortnightly C.I. values of 1+ age oysters, followed more or less comparable trend as that of 0 age oysters of this station. High C.I. values were observed for this group of oysters during November 1990 to the first fortnight of February 1991. Thereafter, the values decreased and remained at low levels during the second fortnight of February to April 1991. A rapid increase to peak condition index levels in May and June 1991, was followed by a gradual decrease to moderate and then low levels in the subsequent months of July to October 1991. In the last three months of the experiment an increasing trend from low to moderate condition index values was recorded (Fig. 18A).

At station 2, the C.I. rose from moderate to high levels in the initial months of November 1990 to first fortnight of February 1991. In the following period, till April 1991, sharp fluctuations from moderate to high and then low condition index levels were recorded. During May August 1991, the C.I values remained at moderate levels, with minor fluctuations. Thereafter, a sharp drop from moderate to very low levels in the September and October 1991 was followed by a gradual increase from low to moderate levels from November 1991 to January 1992 (Fig. 18B). At station 3, a continuous decline from low to very low C.I. values was observed from the beginning to the date of termination (May 1991) of the experiment (Fig. 18C).

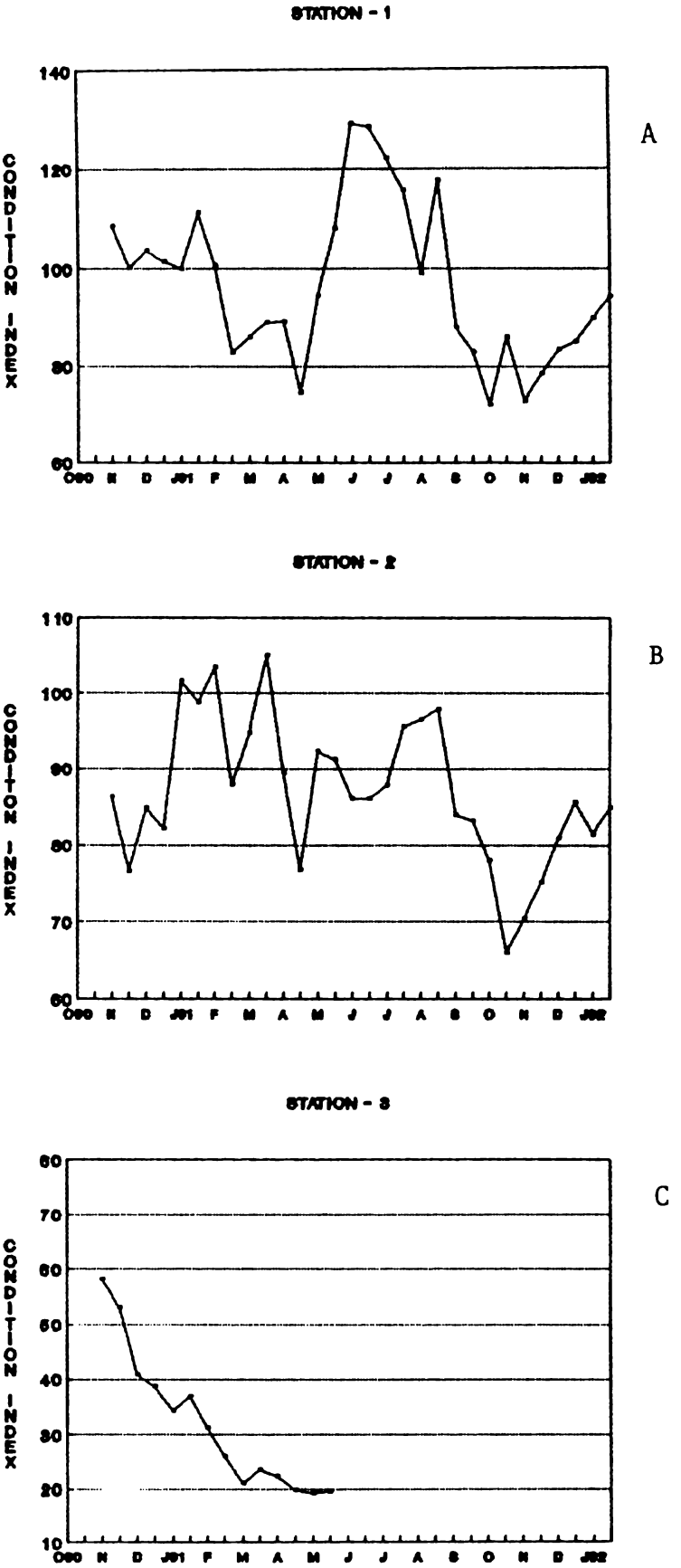


Fig. 18. Fortnightly mean condition index of 1+ age oysters.

Table 5A. The correlation between condition index values of 0 age oysters and environmental parameters.

Stations	Salinity	Water temperature	Dissolved oxygen	Turbidity	Total suspended micro-matter	pH
1	0.198	-0.209	0.599**	0.454*	0.445*	0.245
2	0.095	0.303	-0.206	-0.433*	-0.161	0.186
3	-0.194	-0.264	0.305	0.579*	0.577*	-0.068

Table 6A. The correlation between condition index values of 1+ age oysters and environmental parameters.

Stations	Salinity	Water temperature	Dissolved oxygen	Turbidity	Total suspended micro-matter	pH
1	0.236	-0.030	0.427*	0.271	0.177	0.212
2	0.352	-0.068	-0.133	-0.007	-0.322	0.293
3	-0.802**	-0.620*	0.523	0.323	0.504	-0.738**

* Significant at 5% level ($P \leq 0.05$).
** Significant at 1% level ($P \leq 0.01$).

Table 5B. The correlation between condition index values of 0 age oysters and environmental parameters.

Stations	Calcium	Nitrate-N	Nitrite-N	Ammonia-N	Silicate	Phosphorus	Chloro-phyll-a	Net Productivity	Gross productivity
1	0.100	0.443*	0.411*	-0.353	0.493**	-0.202	0.642**	0.636**	0.612**
2	0.135	-0.076	-0.349	0.299	-0.405*	-0.085	-0.295	-0.273	-0.301
3	-0.343	0.424	0.737**	0.053	0.597*	-0.352	0.286	0.522*	0.475

Table 6B. The correlations between condition index values of 1+ age oysters and environmental parameters.

Stations	Calcium	Nitrate-N	Nitrite-N	Ammonia-N	Silicate	Phosphorus	Chloro-phyll-a	Net Productivity	Gross productivity
1	0.017	0.627**	0.427*	-0.483**	0.434*	-0.495**	0.636**	0.612**	0.625**
2	0.215	0.130	0.171	-0.304	0.282	-0.100	0.051	0.158	0.245
3	-0.868**	-0.142	0.307	0.417	0.315	-0.185	-0.235	0.316	-0.007

* Significant at 5% level ($P \leq 0.05$).
** Significant at 1% level ($P \leq 0.01$).

The lowest and highest fortnightly mean condition index values recorded for 1+ age oysters were, 72.16 (n=15; S.D.=±12.22); (first fortnight of October 1991) and 129.16 (n=15; S.D.=±23.78); first fortnight of June 1991) at station 1 (Fig. 18A), 65.95 (n=15; S.D.=±18.56); (second fortnight of October 1991) and 109.09 (n=15; S.D.=±23.08); (second fortnight of March 1991) at station 2 (Fig. 18B) and 19.18 (n=19; S.D.=±3.58); (first fortnight of May 1991) and 58.12 (n=15; S.D.=±16.89); (first fortnight of November 1990) at station 3 (Fig. 18C).

The fortnightly mean condition index values of 1+age oysters exhibited significant ($P \leqslant 0.01$) positive correlation with nitrate, chlorophyll - a, net and gross primary productivity values, significant ($P \leqslant 0.01$) negative correlation with ammonia and phosphorus values, and also significant ($P \leqslant 0.05$) positive correlations with dissolved oxygen, nitrite and silicate values at station 1. At station 2 no significant correlations were observed. At station 3, though the mean fortnightly condition index values of 1+ age oysters showed significant correlations with some of the environmental parameters (Table 6A and B), keeping in view the periodical trend of condition index values at this station, one can say that these are chance correlations and coincidental.

MATURITY STAGES OF GONAD:

The categorisation of the stage of gonad maturity for both age groups of oysters was made following the classification scheme of Joseph and Madhyastha (1982) with slight modifications. Characteristics of various maturity stages of gonad are given in Tables 7A and B.

Table 7A. Characteristics of female gonad in various stages of maturity.

Maturity stage	Macroscopic appearance of gonad	Microscopic characteristics of fresh smear	Histological characteristics
Stage-I (Maturing)	Gonad thickening and white in colour. Genital ductules visible through body wall.	Large number of primary oocytes with distinct nuclei present.	Follicles expanded but not uniformly developed. Follicular walls lined with primary and secondary oocytes. Interfollicular tissue present.
Stage-II (Advance maturing)	Gonad bulky. Genital tubes highly branched.	Large number of secondary oocytes 34-36 um diameter present. Most oocytes elongated with narrow stalks.	Follicles enlarged and more or less uniformly developed. While the pedunculate secondary oocytes line the follicular wall, the suboval ones fill the lumen. Primary and free oocytes few.
Stage-III (Ripe)	Gonad thick and highly enlarged. Colour creamish. Spreads over the whole of visceral mass. Gonad oozes freely when incised.	Numerous free oocytes (45-67µm) with spherical nuclei present. Shape conical or spherical. Number of seondary oocytes highly reduced.	Follicles fill the gonad. free oocytes with unclei fill lumen of follicles. Pedunculate secondary oocytes few.
Stage-IV (Partially spawned)	Gonad and mantle brown in colour. Gonad does not ooze freely when punctured. Underlying digestive gland partly visible.	Number of free oocytes appear but they are not densely packed.	Follicles appear shrunken and partly or fully empty. Interfollicular tissue starts developing.
Stage-V (Spent)	Gonad brown in colour and greatly shrunken. Tissue overlying gonad very thin. Digestive gland clearly visible. Residual germ cells visible as white patches in the gonad.	Few residual oocytes present. Large quantity of fluid in the gonad.	Follicles appear collapsed. Very few residual ova seen in the lumen. Connective tissue developed. Active reabsorption of residual gametes observable in advanced stage of spent gonad.

Table 7B. Characteristics of male gonad in various stages of maturity. Also indeterminate gonad described.

Maturity stage	Macroscopic appearance of gonad	Microscopic characteristics of fresh smear	Histological characteristics
Stage-I (Maturing)	Gonad thin and whitish in colour.	Spermatocytes as spherical bodies. Rest of the tissue mostly connective tissue.	Follicles are few, small in size, mostly contracted and scattered in the connective tissue.
Stage-II (Advance maturing)	Gonad thick. Genital ductules visible through body wall.	Secondary spermatocytes and spermatids appear as spherical bodies. Few motile spermatozoa seen.	Follicles appear as large irregular patches with spread out branches. Secondary spermatocytes and spermatids form a wide band along follicular wall. A few spermatozoa appear in lumen.
Stage-III (Ripe)	Gonad cream coloured and bulky. Gonad oozes freely when punctured.	Abundant free motile spermatozoa present and densely packed.	Follicles fill entire area of gonad. Large number of darkly stained free spermatozoa occupy the entire lumen of follices. Narrow band of spermatocytes along the follicular wall.
Stage-IV (Partially spawned)	Gonad pale brown in colour and digestive gland partly visible. Gonad does not ooze freely when punctured.	The number of motile spermatozoa reduced and less densely packed.	Follicles appear partly empty with central portion devoid of spermatozoa. Connective tissue startes developing in between the follices.
Stage-V (Spent)	Gonad brown in colour and greatly shrunken. Fluid accumulates near the labial palps. Residual germ cells visible as white patches. Digestive gland clearly visible.	Very few motile spermatozoa present.	Follicles collapsed and empty except for few residual spermatozoa. Gonad connective tissue well developed.
Stage-VI (Indeterminate)	Normal sight of gonad white, well developed and healthy in appearance. Tissues thickly packed and break with slight pressure. Gonad does not ooze when punctured. Labial palps thick and whitish. In the case of oysters at station 3, gonad size greatly reduced and wall brownish in colour. Body filled with large quantity of fluid. Digestive gland clearly visible.	No gonadal matter discernible.	Gonad filled with connective tissue and the follicles are not discernible.

The fortnightly data of maturity stages were pooled and are presented and described under the following headings as monthly percentage occurrence of males, females and the sexes pooled (males, females and indeterminate oysters) belonging to various stages of maturity. However, since in most of the cases the variations in gonad maturity stages of males and females follow a similar periodical trend, the description of monthly periodical variation in percentage occurrence of oysters belonging to various stages of maturity are based on the sexes pooled. And in the case of any distinct variations in monthly periodical occurrence of male and female maturity stages, the variations are discussed under their respective headings.

A. 0 age oysters:

The monthly variations in the occurrence of 0 age oysters belonging to various stages of gonad maturity at stations 1 to 3 are described under the following sub-headings.

I. Station 1:

The monthly percentage composition of male, female and the sexes pooled of oysters in various stages of gonad maturity are presented in Figs. 19A ,B, and C, respectively.

Oysters in maturing stage or stage I (Tables 7A and B; Plate V A and B) were recorded during November 1990 - February 1991, May - August 1991, and October 1991 - January 1992 (Fig. 19C).

High percentage of this stage occurred in November 1990 (63.33%), December 1990 (53.33%), June 1991 (40%), December 1991 (43.33%) and

PLATE V.

A. Male gonad in early maturing stage (stage I). x 125

B. Female gonad in maturing stage (stage I). x 125

C. Male gonad in advance stage of maturation (stage II). x 125

D. Female gonad in advance stage of maturation (stage II). x 125

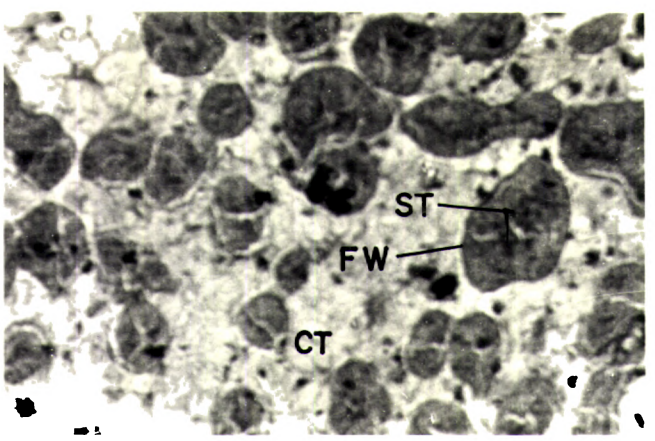
E. Male gonad in ripe stage (stage III). x 125

F. Female gonad in ripe stage (stage III). x 125

FW - follicular wall; ST - spermatid;
SZ - spermatozoa; SO - secondary oocyte;
FO - free oocyte; IF interfollicular tissue;
CT - connective tissue

PLATE V

A



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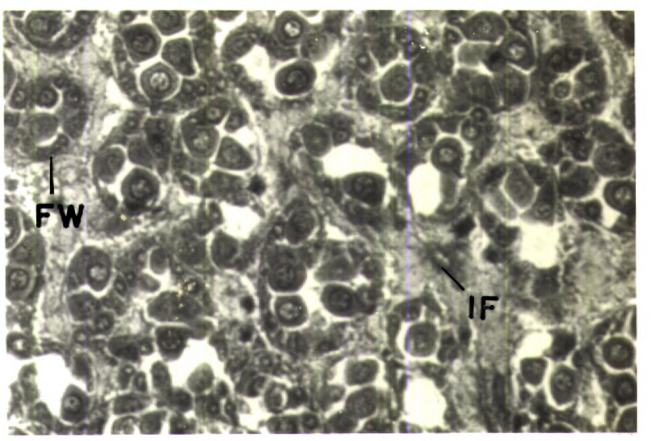

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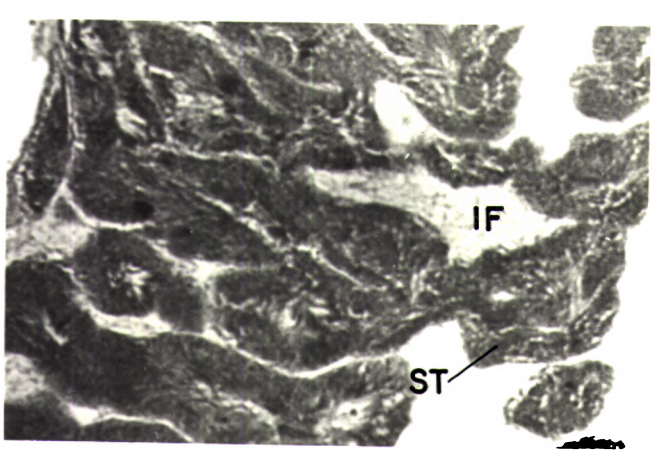

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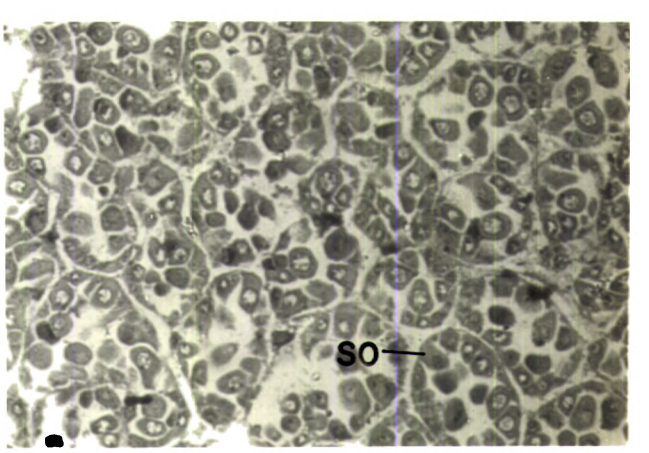

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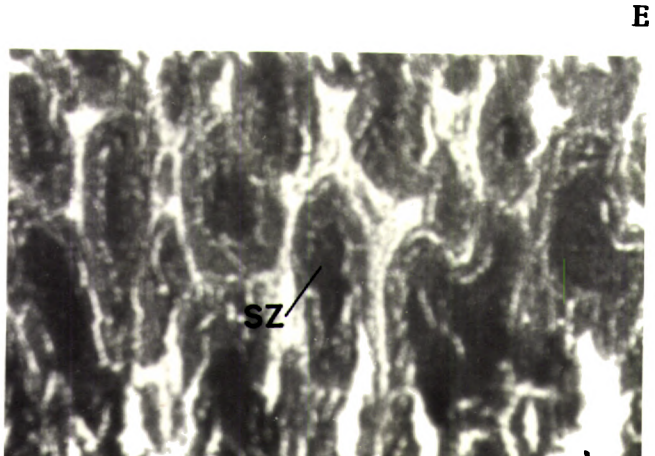

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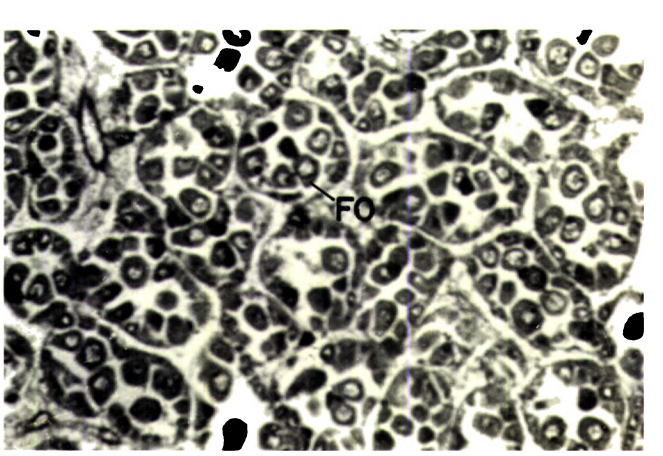


January 1992 (43.33%); it was moderate in January (33.33%), July (38.70%), October (26.66%) and November (23.33%) 1991, and low ($\leqslant$ 20%) in the other months (Fig.19C). In most of the months the percentage of females in stage I was higher than that of males (Figs. 19A and B).

Oysters in advanced stage of gonad maturation or stage II (Tables 7A and B; Plate V C and D)occurred during November 1990 - March 1991, May August 1991 and November 1991 - January 1992 (Fig. 19C). Their percentage was high in January 1991 (53.33%), February 1991 (46.66%) and January 1992 (40%); moderate in June (33.33%), July (32.25%) and December (30%) 1991 and low ($\leqslant$20%) in the remaining months (Fig.19C).

Oysters in ripe condition or stage III of maturity (Tables 7A and B; Plate V E and F) were recorded throughout the study period at this station except for June 1991 (Fig. 19C). They formed high percentage in March (40%) and August (43.3%) 1991, moderate in February (36.66%), July (25.88%) and September (23.33%) 1991 and low ($\leqslant$16.66%) in the remaining months (Fig. 19C).

Partially spawned or stage IV oysters (Tables 7A and B; Plate VI C and D) occurred from February to May 1991 and August to November 1991 (Fig. 19C). High percentage of this maturity stage was recorded in March (40%) and September (33.33%) 1991, moderate occurrence in April (30%) and August (26.66%) 1991, and low percentage ($\leqslant$16.66%) in the other months (Fig. 19C). It is evident from Figs. 19A and B that, while the appearance of partially spawned males was recorded earlier than that of females, the occurrence of partially spawned females in the monthly samples was extended for a longer duration.

The spent or stage V oysters (Tables 7A and B; Plate VI E and F) were present during March - June 1991 and August - December 1991 (Fig. 19C). Their percentage occurrence was high in April (46.66%) and September (43.33%) 1991, moderate in May and October 1991 (33.33%) and low ($\leqslant$16.66%) in the other months (Fig. 19C).

The oysters with indeterminate gonads or in stage VI of maturity (Table 7A and B; Plate VII A) appeared during November 1990 to January 1991, March to July 1991, and October 1991 to January 1992 (Fig. 19C). Their occurrence was moderate in May (33.33%) and November (30%) 1991, and low ($\leqslant$16.66%) in the other months (Fig. 19C).

II. Station 2:

At this station, the monthly percentage composition of 0 age male, female and sexes pooled oysters, belonging to various stages of gonad maturity are shown in Figs. 20A, B and C, respectively.

The presence of oysters with gonads in stage I (Tables 7A and B; Plate V A and B) was registered for greater part of the study period, namely from November 1990 to January 1991 and April 1991 to January 1992 (Fig. 20 C). Their percentage was high in November (46.66%) 1990 and December 1991 (50%), moderate in July (30%), September to November (33.33% to 36.66%) 1991, and January (26.66%) 1991, and low ($\leqslant$ 16.66%) in the remaining months (Fig. 20C). Though maturing male oysters occurred more frequently in the monthly samples, the percentage of maturing females was in general higher than that of males at this station (Figs. 20A and B).

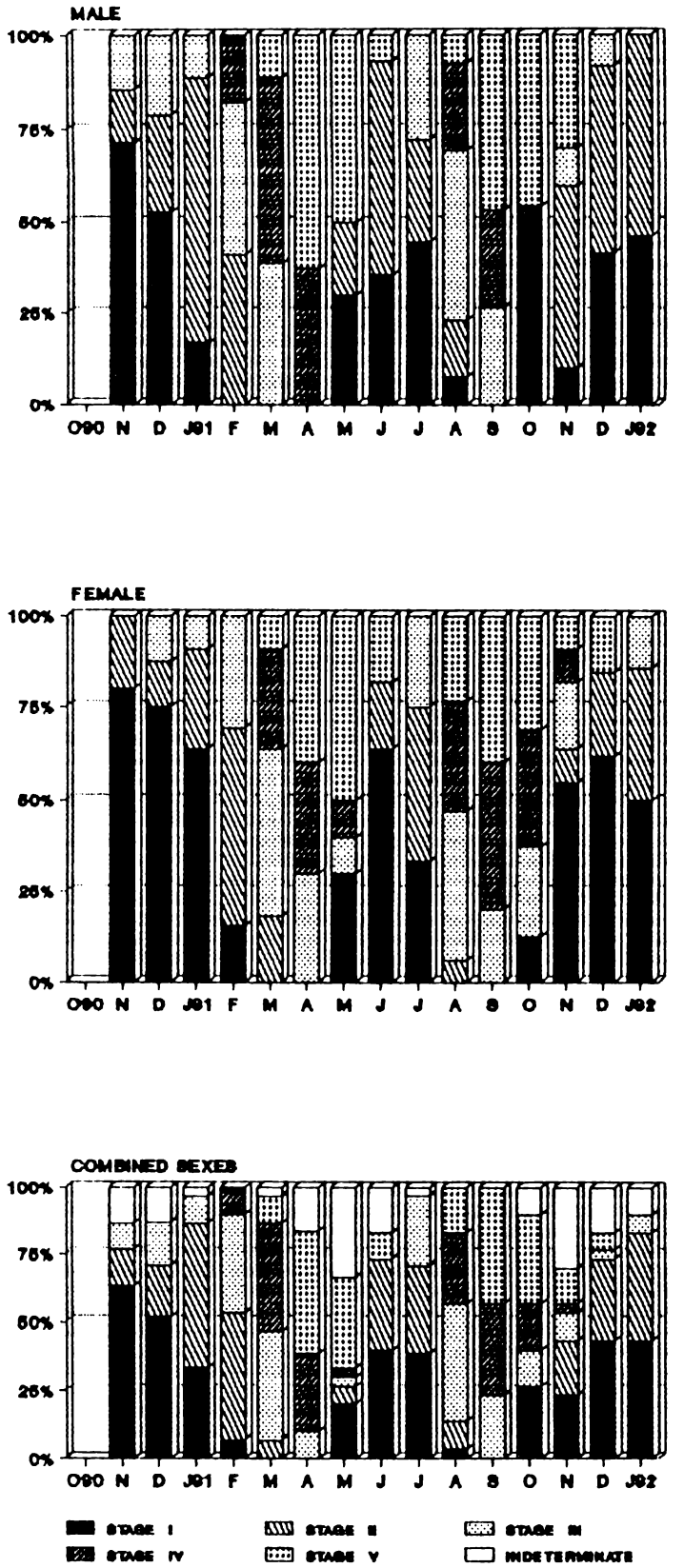


Fig. 19. Monthly percentage occurrence of different maturity stages of 0 age oysters at station 1.

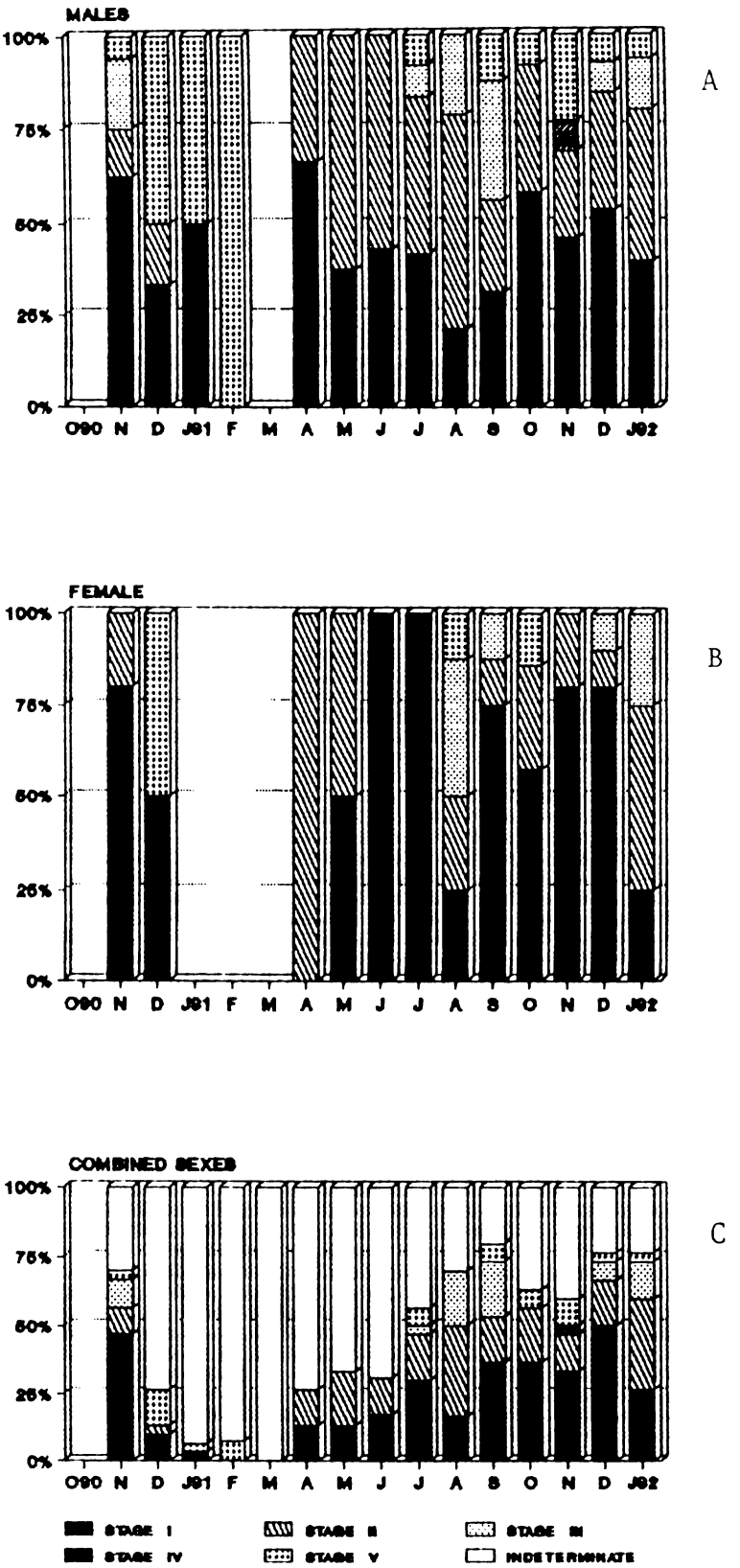


Fig. 20. Monthly percentage occurrence of different maturity stages of 0 age oysters at station 2.

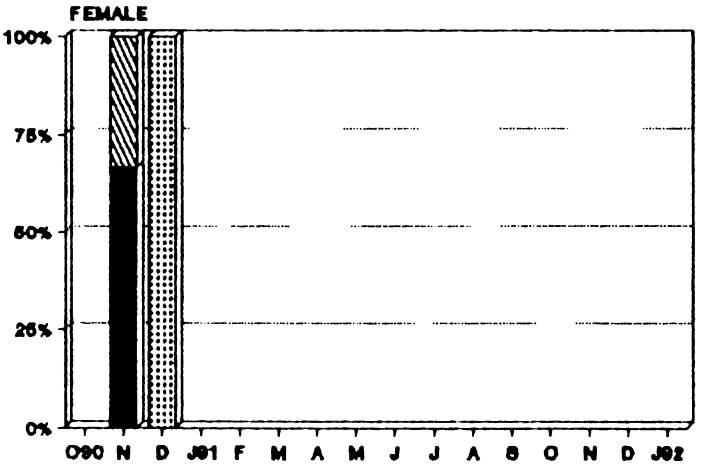
Oysters in stage II (Tables 7A and B; Plate V C and D) were found during November December 1990 and April 1991 - January 1992 (Fig.20C). Their occurrence was moderate (33.33%) in August 1991 and January 1992, and low ($\leqslant$ 20%) in the other months (fig. 20C).

In contrast to station 1, at this station the monthly occurrence of oysters in stage III of gonad maturation (Tables 7A and B; Plate V E and F) was observed only during November 1990, July - September 1991 and December 1991 - January 1992 (Fig. 20C). Their percentage occurrence remained low ($\leqslant$ 20%) in all the months (Fig. 20C). The oysters in stage IV (Tables 7A and B Plate VI C and D) were found only in November 1991 (Fig. 20C) and all these oysters (3.33%) were males (Fig. 20A). The occurrence of oysters in stage V (Tables 7A and B; Plate VI E and F) was recorded during November 1990 to February 1991, July 1991, and September 1991 to January 1992 (Fig. 20C). The percentage composition of spent oysters at this station was low ($\leqslant$ 13.33%) in all the months (Fig. 20C).

The occurrence of oysters in stage VI (Tables 7A and B; Plate VII A) was recorded throughout the study period at this station. Their percentage composition was very high (66.66% to 100%) during December 1990 to June 1991, high (40 to 43.33%) in July and November 1991, moderate (30 to 36.66%) in November 1990, August and October 1991, and low ($\leqslant$ 23.33%) in the other months (Fig. 20C).

III. Station 3:

The gametogenic activity of 0 age oysters at this station was very poor and was restricted to the initial three months of the experiment



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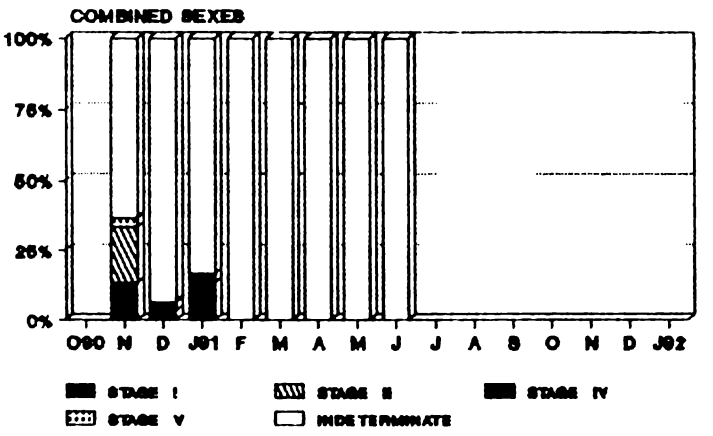


C

Fig. 21. Monthly percentage occurrence of different maturity stages of 0 age oysters at station 3.

only (Figs. 21A, B, and C). Stage I oysters (Tables 7A and B; Plate V A and B) in small numbers ($\leqslant$13.33%) were recorded from November 1990 to January 1991 (Fig. 21C). The occurrence of oysters (20%) in stage II (Tables 7A and B; Plate V C and D) was observed in November 1990 only (Fig. 21C).

Oysters in ripe condition were not observed at this station. The oysters in stage IV of gonad maturity (Tables 7A and B; Plate VI C and D), which formed a very low percentage (3.33%) were recorded only during December 1990 (Fig. 21C). Similarly, the occurrence of oysters in stage V (Tables 7A and B; Plate VI E and F), was low (3.33%) in November and December 1990 (Fig. 21C).

Oysters in stage VI (Tables 7A and B) were recorded throughout the study period (November 1990 to June 1991) at this station. These oysters formed the most dominant group (63.33 to 100%) in all the monthly samples (Fig. 21C).

B. 1+ age oysters:

The monthly variations in the occurrence of 1+ age oysters belonging to various stages of gonad maturity at stations 1 to 3 are described under the following sub-headings.

I. Station 1:

The monthly percentage composition of males, females and the sexes pooled oysters belonging to different stages of gonad maturity are shown in Figs. 22A, B, and C, respectively.

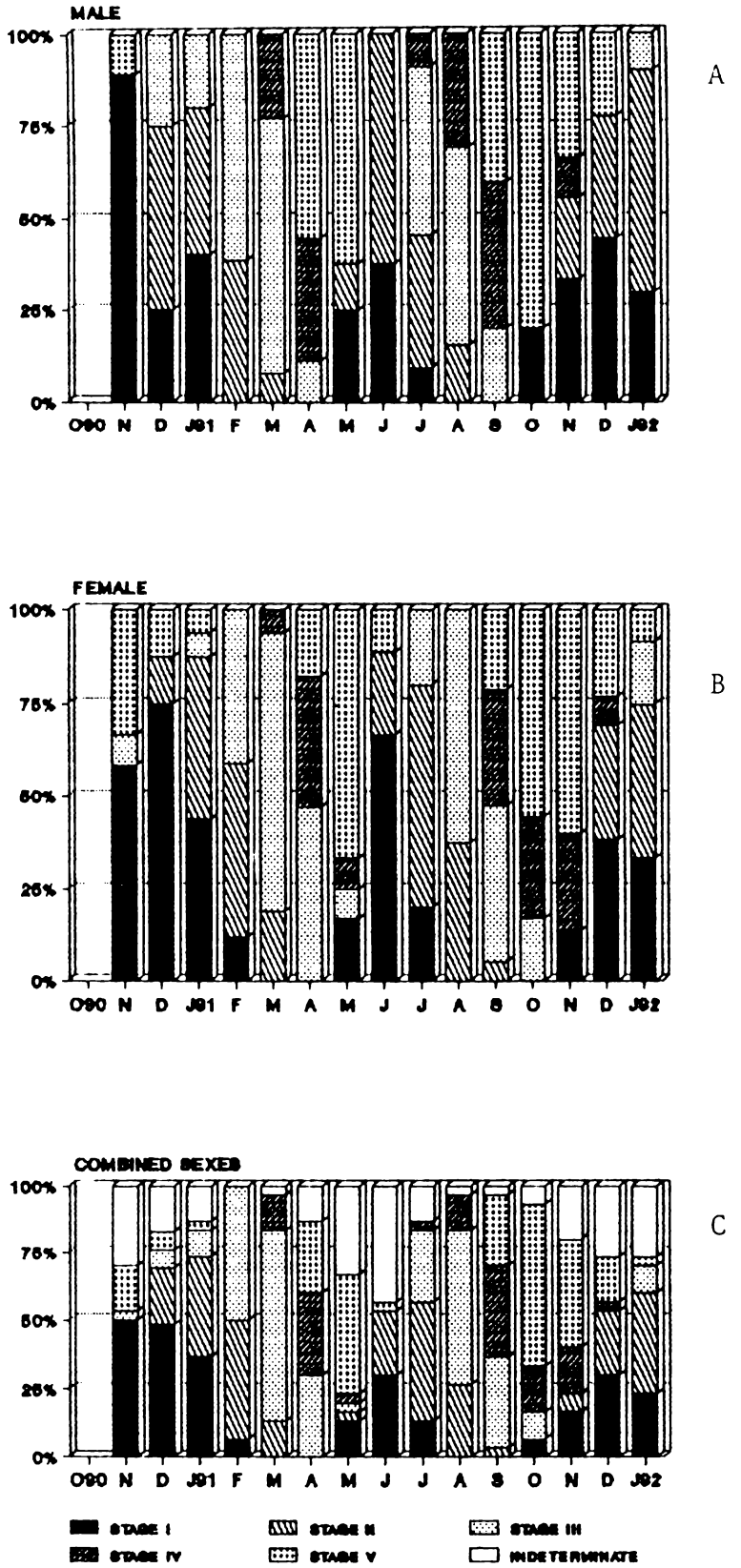


Fig. 22. Monthly percentage occurrence of different maturity stages of 1+ age oysters at station 1.

Stage I oysters (Tables 7A and B; Plate V A and B) were observed from November 1990 to February 1991, May to July 1991, and October 1991 to January 1992 (Fig. 22C). Their percentage was high in November (50%) and December (46.66%) 1990, moderate in January (36.66%), June (30%), December (30%) 1991 and January (23.33%) 1992, and it was low ($\leqslant$ 13.33%) during the other months (Fig. 22C).

The oysters in stage II of maturity (Tables 7A and B; Plate V C and D) were recorded during December 1990 - March 1991, May - September 1991, and November 1991 - January 1992 (Fig. 22C). Their percentage was high (43.33%) in February and July 1991, moderate in January (36.66%), June (23.33%), August (26.66%), December (23.33%) 1991 and January 1992 (36.66%), and low ($\leqslant$9.33%) in the other months (Fig. 22C).

Oysters in stage III (Tables 7A and B; Plate V E and F) were observed during November 1990 - May 1991, July - October 1991, and in January 1992. Their occurrence was high during February (50%), March (70%) and August (56.66%) 1991, moderate in April (30%), June (26.66%) and September (33.33%) 1991, and low ($\leqslant$ 10%) in the remaining months (Fig. 22C).

Oysters in stage IV of gonad maturity (Tables 7A and B: Plate VI C and D) were recorded during March - May 1991 and July - December 1991 (Fig. 22C). Their occurrence was moderate (30 to 33%) in April and September 1991, and low ($\leqslant$16.66%) in the other months (Fig. 22C). As seen in the Figs. 22 A and B, during the second half of the study period, stage IV males were recorded earlier than females. Oysters in stage V of maturity (Tables 7A and B; Plate VI E and F) were recorded

PLATE VI

A. Male gonad in ripe stage (stage III). x 250

B. Female gonad in ripe stage (stage III). x 250

C. Male gonad in partially spawned stage (stage IV). x 125

D. Female gonad in partially spawned stage (stage IV). x 125

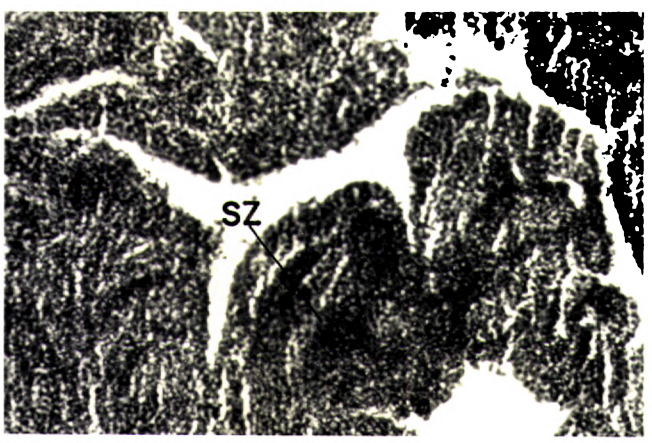
E. Male gonad in spent stage (stage V). x 125

F. Female gonad in spent stage (stage V). x 125

FW follicular wall; SZ spermatozoa;
RS residual spermatozoa; FO - free oocyte;
RO - residual oocyte; CT - connective tissue

PLATE VI

A



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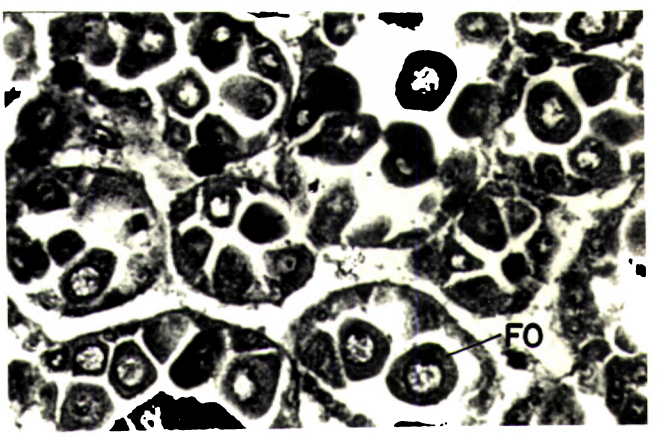

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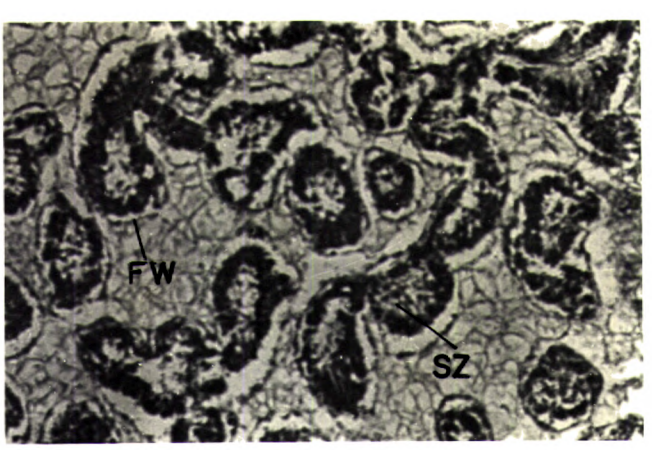
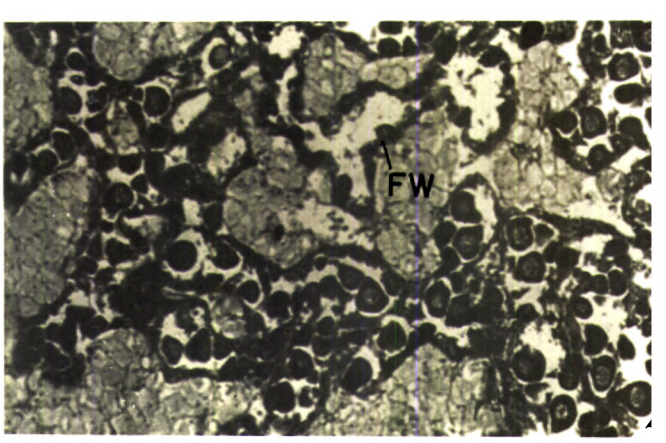
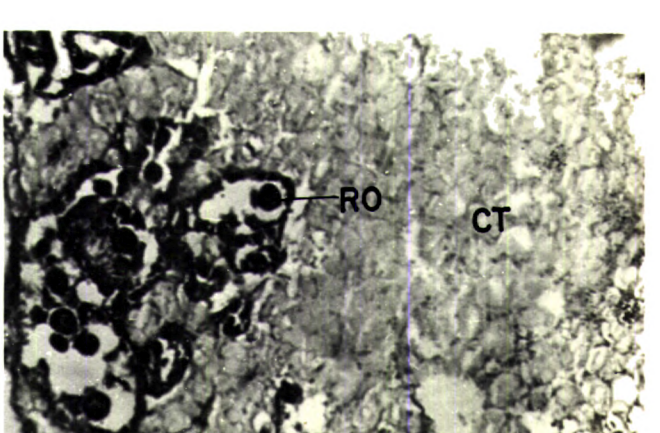


D



E

F



from November 1990 to January 1991, April to June 1991 and September 1991 to January 1992 (Fig. 22C). Their percentage composition was high in May (43.33%), October (60%) and November (40%) 1991, moderate (26.66%) in April and September 1991 and low ($\leqslant$16.66%) in the other months. Oysters in stage VI of maturity (Tables 7A and B; Plate VII A) occurred in all the monthly samples except in February 1991. Their percentage composition was high (43.33%) in June 1991, moderate in November (30%) 1990, May (33.33%) 1991, December (26.66%) 1991 and January (26.66%) 1992, and low ($\leqslant$20%) in the other months (Fig. 22C).

II. Station 2:

The monthly percentage composition of males, females and the sexes pooled belonging to various stages of gonad maturity are presented in Figs. 23A, B and C, respectively.

Oysters in stage I (Tables 7A and B; Plate V A and B) were recorded from November 1990 to January 1991, May to August 1991 and October 1990 to January 1992 (Fig. 23C). Their percentage was high (40 to 50%) in November 1990, December 1990, June 1991 and December 1991, moderate (33.33% to 36.66%) in January 1991, November 1991 and January 1992, and low ($\leqslant$13.33%) in the other months (Fig. 23C).

Oysters in stage II of gonad maturity (Tables 7A and B; Plate V C and D) were observed during November 1990 - March 1991, June - September 1991, and November 1991 - January 1992 (Fig. 23C). They occurred in high numbers (46.66%) in January and July 1991, moderate (23.33 to 26.66%) in December 1990 and June 1991, and low ($\leqslant$20%) in the remaining months (Fig. 23C).

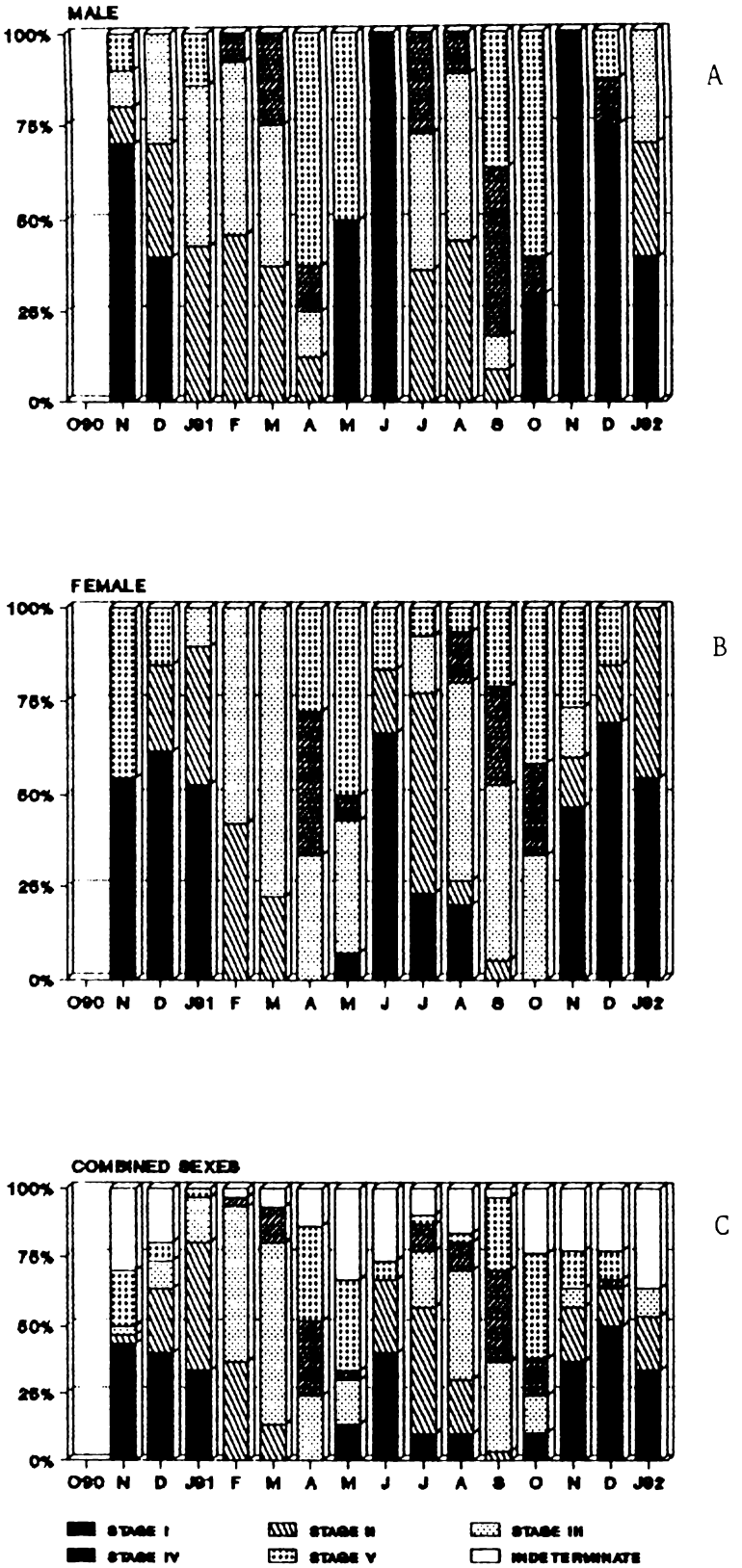


Fig. 23. Monthly percentage occurrence of different maturity stages of 1+ age oysters at station 2.

Oysters in stage III of maturation (Tables 7A and B; Plate V E and F) were recorded during November 1990 - March 1991, July November 1991, and in January 1992. Their distribution was high in February (56.66%), March (66.66%) and August (40%) 1991, moderate (23.33% to 33.33%) in April and September 1991 and low ($\leqslant$ 20%) in the rest of the months (Fig. 23C). The oysters in stage IV (Tables 7A and B; Plate VI C and D) appeared in the monthly samples of February to May 1991, July to October 1991, and December 1991 (Fig. 23C). Their occurrence was moderate (26.66 to 33.33%) in April and September 1991 and low (13.33%) in the other months (Fig. 23C). As was observed at station 1, stage IV male oysters occurred at this station earlier than the females (Figs. 23A and B).

Oysters in stage V of maturity (Tables 7A and B; Plate VI E and F) were recorded during November 1990 to January 1991 and April to December 1991 (Fig. 23C). They occurred in moderate numbers (26.66 to 33.33%) from April to May and September to October 1991, and in low numbers ($\leqslant$ 20%) in the remaining months (Fig. 23C).

Stage VI oysters (Tables 7A and B; Plate VII A) occurred in all the monthly samples (Fig. 23C). Their abundance was moderate (23.33 to 36.33%) in November 1990, May to June 1991, and September 1991 to January 1992, and low ($\leqslant$20%) in the other months (Fig. 23C).

III. Station 3:

The monthly percentage composition of males, females and sexes pooled oysters, belonging to various stages of gonad maturity are

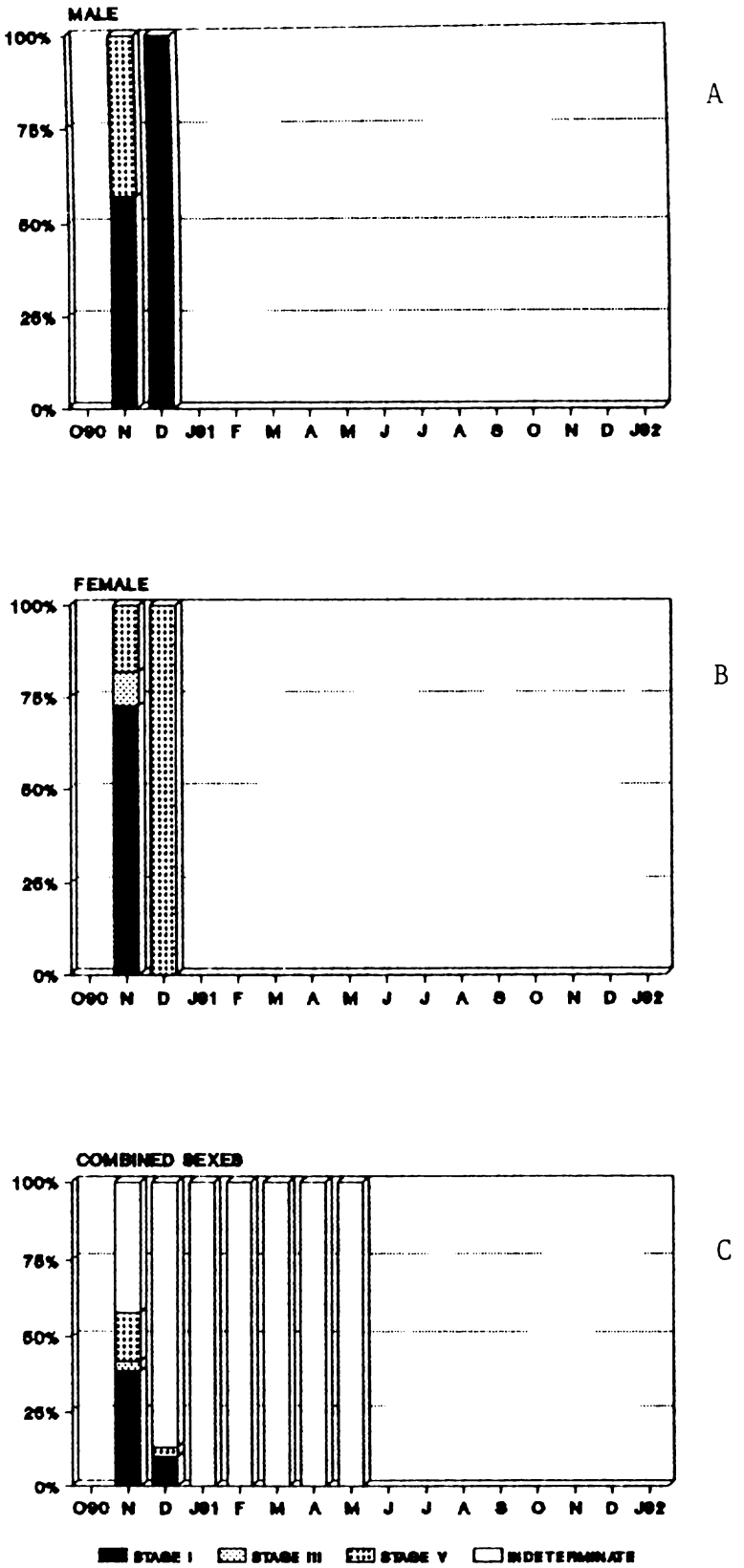


Fig. 24. Monthly percentage occurrence of different maturity stages of 1+ age oysters at station 3.

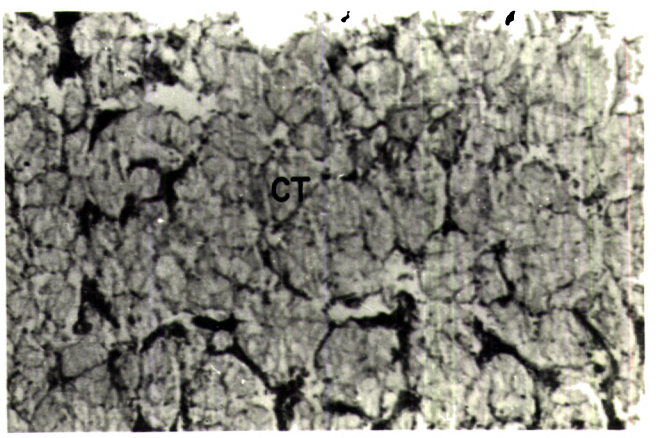
PLATE VII.

A. Gonad in indeterminate stage (stage VI). x 125

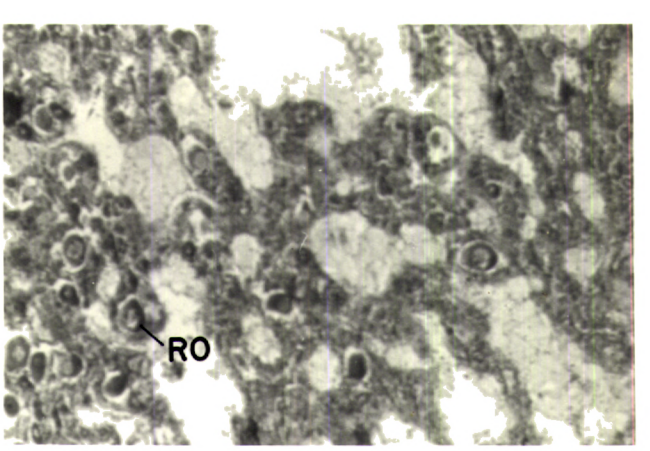
B. Active reabsorption of gametes in female gonad (stage V). x 125

RO - residual oocyte; CT - connective tissue

PLATE VII



A



B

presented in Figs. 24A, B and C, respectively. As was described in the case of 0 age oysters of this station, the reproductive activity of 1+ age oysters was equally poor and was restricted to the initial two months of the experiment only.

Oysters in stage I (Tables 7A and B; Plate V A and B) were the dominant group among the gametogenically active oysters during November and December 1990 and they accounted for 40% and 10% of oysters in the pooled samples, respectively (Fig. 24C). The oysters in stages II and IV did not occur in any of the monthly samples at this station. Stage III oysters (Tables 7A and B; Plate V E and F) formed a very low (3.33%) proportion and were observed in November 1990 (Fig. 24C). These oysters were all females (Fig. 24B).

Occurrence of spent or oysters with gonads in stage V (Tables 7A and B; Plate VI E and F) was recorded in November (3.33%) and December (16.66%) 1990 (Fig. 24C).

The indeterminate oysters (stage VI); (Tables 7A and B) occurred in all the months with a very high contribution of 43.33 to 100% (Fig. 24C).

SEX RATIO:

The monthly sex ratio for both the age group of oysters at stations 1 and 2 was worked out and data were subjected to chi-square test analysis. At station 3, since the sex of both age groups was not discernible during most of the study period, no attempt was made to analyse the sex ratio. The monthly variations in sex ratio of 0 age and

1+ age oysters at stations 1 and 2, and the results of chi-square test analysis are presented under the following headings.

A. 0 age oysters:

The monthly variations in sex ratio of 0 age oysters at station 1 and 2 are described under the following sub-headings.

I. Station 1:

Oysters at this station showed a male dominance from November 1990 to April 1991 and June to July 1991 (Fig. 25A). Starting with a male: female ratio of 81:19, the ratio reached equal proportion of sexes (50:50) in May 1991, and from August 1991 onwards upto the end of the study period, females marginally dominated (Fig. 25A). The overall ratio of male: female at this station was 56:44.

The results of chi-square test showed that at 5% probability there was no significant departure from the expected 1:1 ratio in any of the months, except November (X^2 = 9.8; d.f.=1) and December (X^2 = 4.48; d.f. = 1) 1990. The test of homogenity between months with respect to sex ratio (X^2 = 16.99; d.f.= 14) revealed that there was no significant ($P \leq 0.05$) difference from the expected 1:1 ratio.

II. Station 2:

Among the oysters which could be sexed at this station, males invariably outnumbered females in all the months. The male:female ratio ranged from 80:20 in May 1991 to 57:43 in December 1991 (Fig. 25B). The

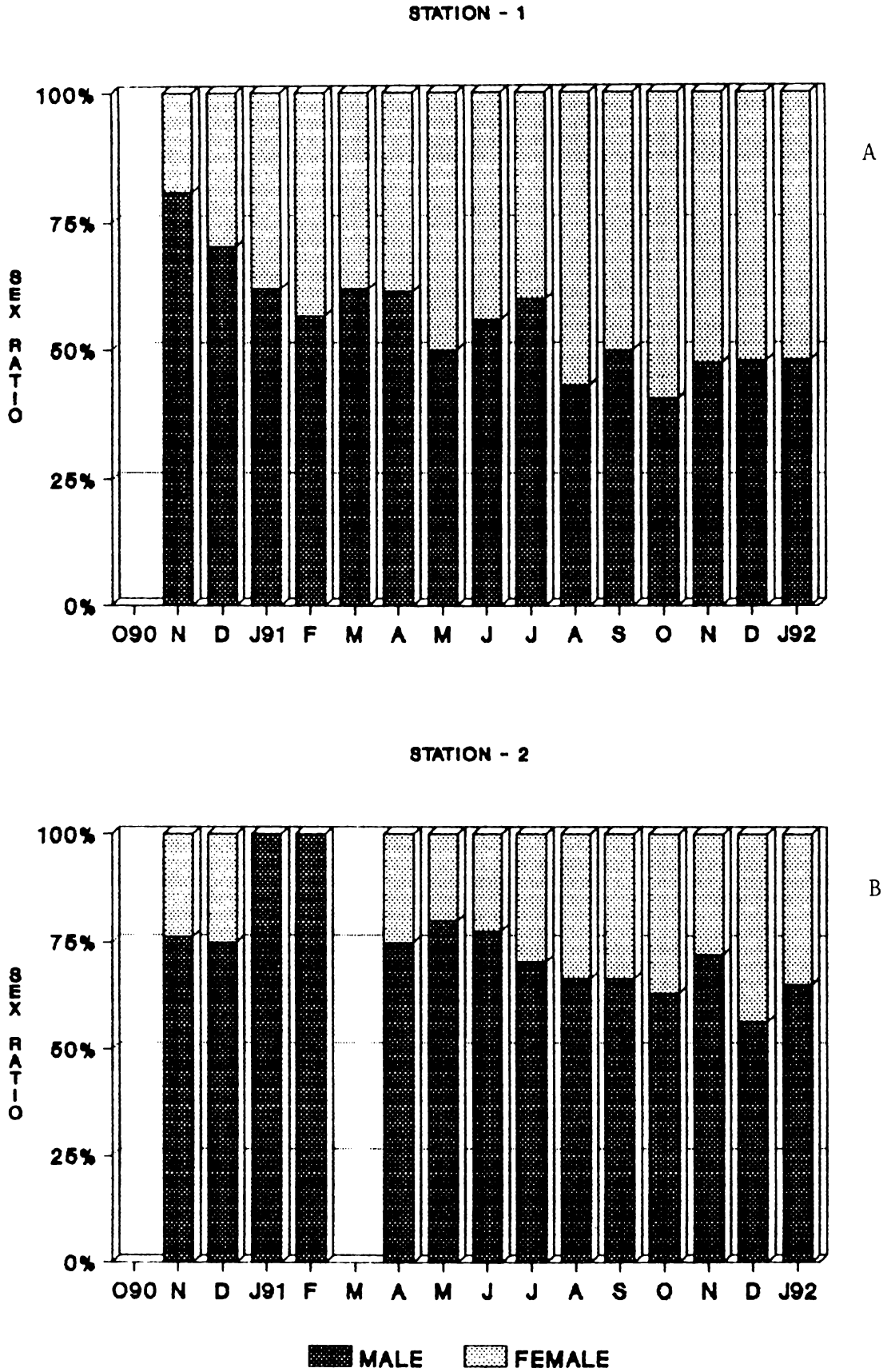


Fig. 25. Monthly sex ratio of 0 age oysters.

overall male:female ratio was 69:31 for 0 age oysters at this station. The monthly data of January and February 1991 in which all the oysters which could be sexed were males and data of March 1991 in which all the sampled oysters were in indeterminate stage, were not included in the chi-square test analysis at this station. Except for November 1990 (X^2 = 5.76; d.f.= 1), the results of chi-square test did not show any significant ($P \leqslant 0.05$) variation from the theoretical 1:1 ratio in any of the months. The test of homogenity between monthly sex ratio data revealed no significant departure from the hypothetical 1:1 ratio (X^2 = 3.95; d.f.= 11) at this station.

B. 1+ age oysters:

The monthly variations in sex ratio of 1+ age oysters at stations 1 and 2 are presented under the following sub-headings.

I Station 1:

In contrast to 0 age oysters, the monthly sex ratio of 1+ age oysters at this station showed a female dominance throughout the study period (Fig. 26A). The monthly male:female ratio ranged from 33:67 in December 1990 to 47:53 in June 1991 (Fig. 26A). The overall male: female ratio was 40:60.

The results of chi-square test applied to monthly sex ratio data revealed no significant ($P \leqslant 0.05$) departure from the expected 1:1 ratio. Similarly the test of homogenity between months with respect to sex ratio (X^2 = 2.72; d.f.= 14) showed no significant ($P \leqslant 0.05$) departure from the hypothetical 1:1 ratio.

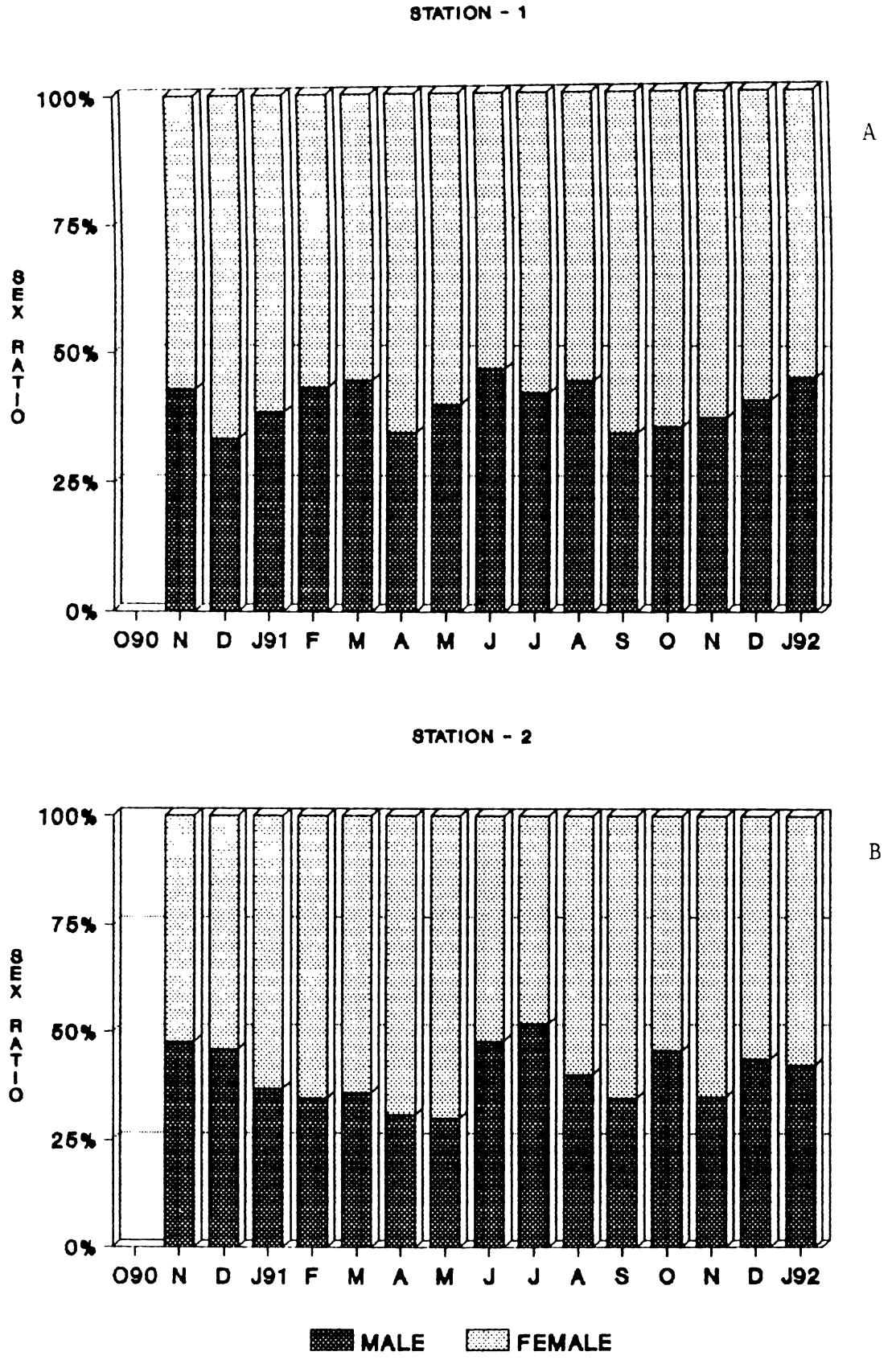


Fig. 26. Monthly sex ratio of 1+ age oysters.

II. Station 2:

The monthly sex ratio of 1+ age oysters at this station, except in the month of July 1991, showed a female dominance throughout the study period (Fig. 26B). The monthly male:female ratio ranged from 30:70 (April and May 1991) in favour of females to 52:48 (July 1991) in favour of males. The overall male:female ratio was 40:60.

The result of chi-square test showed that there was no significant ($P \leqslant 0.05$) deviation from the expected hypothetical 1:1 ratio in any of the months, except in April 1991 ($X^2 = 3,84$; d.f.= 1). The test of homogenity between months with respect to sex ratio ($X^2 = 6.23$; d.f.= 14) revealed no significant ($P \leqslant 0.05$) departure from 1:1 ratio.

MORTALITY:

The mortality among the two age group of oysters at all the three stations are presented as percentage, on fortnightly basis. Fortnightly calculations of percentage mortality were corrected for population reduction caused by removal of oysters for condition index and stages of gonad maturity analyses. The fortnightly variations in mortality of both age group of oysters at each station are as follows:

A. 0 age oysters:

In general the mortality of oysters was comparatively very low, moderate and very high at stations 1, 2 and 3, respectively. At station 1 the mortality was comparatively higher during October 1990 and October 1991 to January 1992. During the rest of the study period mortality remained very low at this station (Fig. 27A).

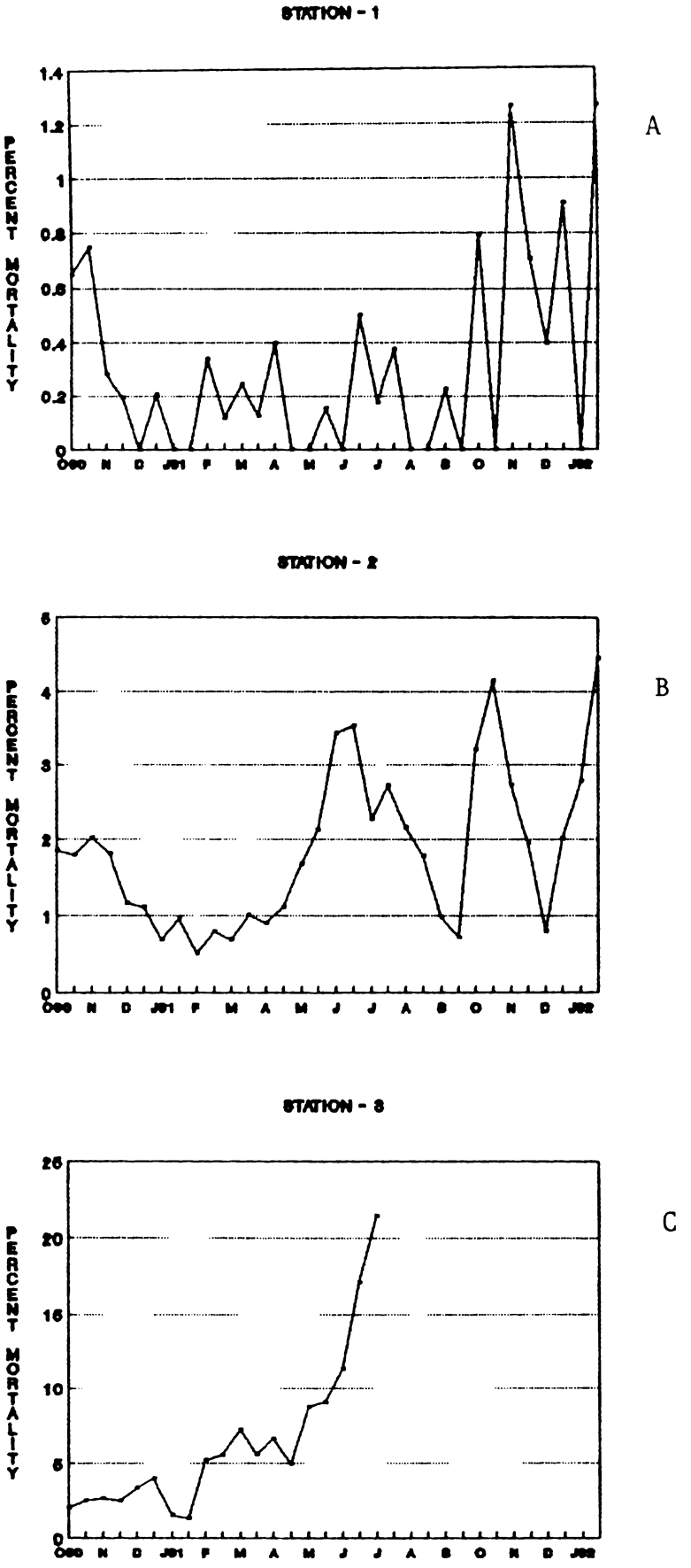


Fig. 27. Fortnightly percentage mortality of 0 age oysters.

At station 2, 0 age oysters had comparatively moderate mortality in the initial months of October and November 1990, and thereafter a decline in percentage mortality values was recorded from December 1990 to April 1991. In the subsequent months, high mortality was recorded during May - August 1991, October - November 1991 and January 1992. During the months of September and December 1991 mortality remained low to moderate (Fig. 27B).

At station 3, except a moderate decrease in mortality during the month of January 1991, the fortnightly mortality values were on the rise throughout the study period (Fig. 27C).

The overall mortality of 0 age oysters during the entire period of the experiments, calculated as percentage of initial number of oysters stocked at each station, were 5% at station 1, 25.64% at station 2 and 50.74% at station 3.

B. 1+age oysters:

As in the case of 0 age oysters, the fortnightly mortalities were in general low, moderate and very high at station 1, 2 and 3, respectively.

At station 1, despite sharp fortnightly fluctuations in percentage mortality values, no distinct periodical variations was observed in the mortality of 1+ age oysters (Fig. 28A). At station 2, the fortnightly mortality values remained comparatively low during October 1990 April 1991. An increase in values to moderate and then to high levels was observed during May to July 1991, followed by a sharp drop to low levels

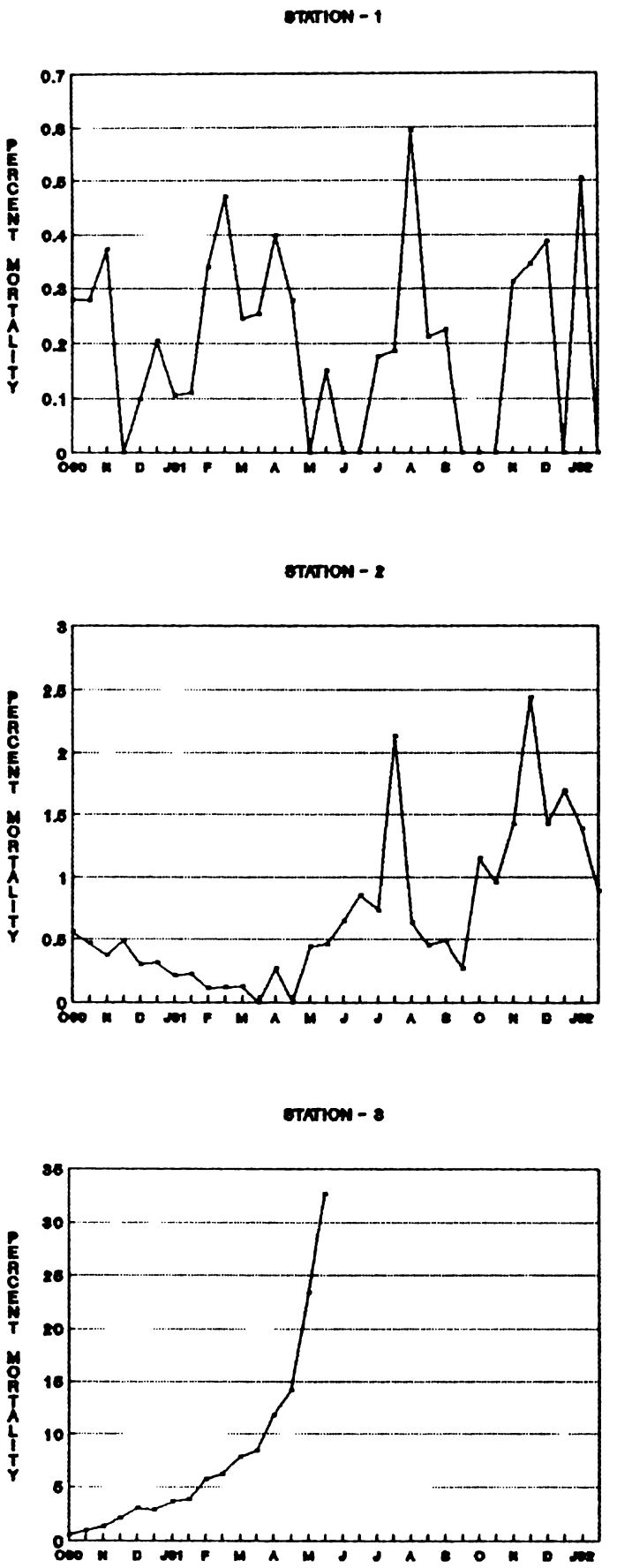


Fig. 28. Fortnightly percentage mortality of 1+ age oysters.

in August and September 1991. In the following months, once again a sharp increase to high mortality levels was noticed during October and November 1991, which was followed by a decrease to moderate levels in December 1991 to January 1992 (Fig. 28B).

At station 3, a sharp and continuous increasing trend was observed in the fortnightly mortality values from the beginning upto the date of termination of the experiment (Fig. 28C).

The overall mortality of 1+ age oysters, calculated as percentage of initial number of oysters stocked at each station, were, 3.98% at station 1, 9.16% at station 2 and 52.40% at station 3.

ENVIRONMENTAL PARAMETERS:

The seasonal variations in mean fortnightly values of various environmental parameters studied during the period October 1990 to January 1992 at station 1 and 2, and October 1990 to July 1991 at station 3, are presented under the following headings. The data were classified for monsoon (October to December), postmonsoon (January to March), summer (April to June) and premonsoon (July to September) following the classification of seasons on the east coast of India by Rao (1956), and Jagadeesan and Ayyakkannu (1992). The seasons mentioned are cyclic phenomena influenced by north east monsoon.

I. Salinity:

The seasonal variations in fortnightly mean salinity values followed a more or less comparable trend at all the stations. A steep

decline in salinity values during monsoon (1990) season, was followed by a gradual increase to peak values through postmonsoon and summer seasons. The high salinity values were maintained with minor fluctuations during premonsoon season. Thereafter, a sharp drop in values was recorded from the beginning upto the mid-monsoon (1991) season at stations 1 and 2. During the remaining period of study the salinity values were once again on the rise (Fig. 29A).

The minimum and maximum mean salinity values recorded during the period of study were, 26.53ppt (S.D.=±0.54; second fortnight of November 1991) and 37.31ppt (S.D.=±0.41; second fortnight of September 1991) at station 1, 23.02ppt (S.D.= ± 0.92; second fortnight of November 1991) and 37.31ppt (S.D.= ±0.82; first fortnight of May 1991) at station 2, and 30.31ppt (S.D. = ± 0.69; first fortnight of November 1990) and 36.44ppt (S.D.= ± 0.78; second fortnight of May 1991) at station 3 (Fig. 29A).

II. Water temperature:

As in the case of salinity, seasonal variations in fortnightly mean temperature values at all the stations followed a similar seasonal trend. A gradual drop to minimum values was observed during monsoon (1990). Thereafter, the values were on the rise throughout postmonsoon and reached peak levels by mid-summer. In subsequent months of summer, a decrease in temperature values was followed by an increase in the values from the beginning upto the end of the premonsoon season. The water temperature values at station 1 and 2 showed fluctuations during

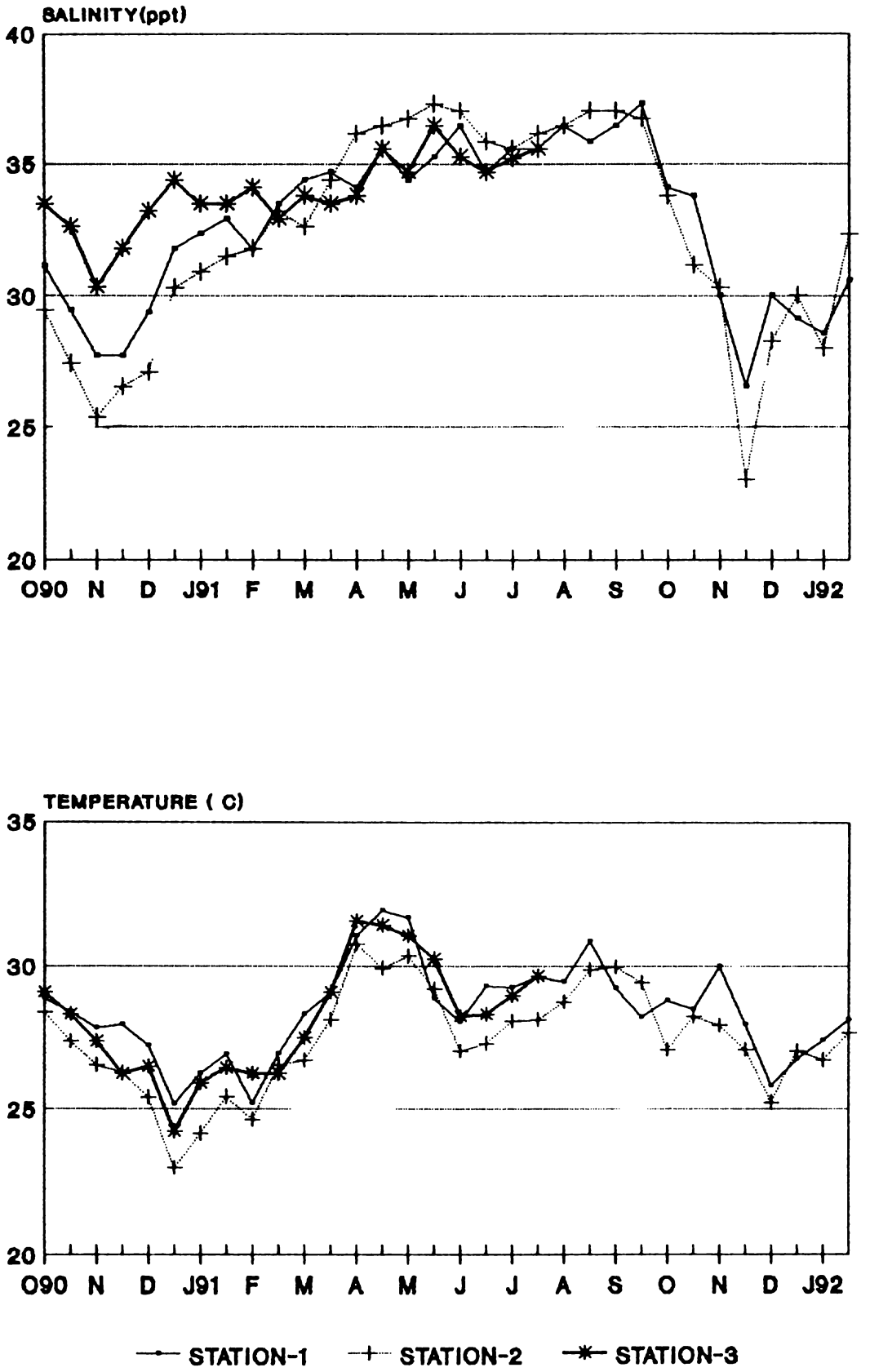


Fig. 29. Fortnightly variations in (A) Salinity and (B) Water temperature.

1991 monsoon, however an overall decline in these values was observed by the end of this season (Fig. 29B).

The fortnightly mean water temperature values ranged from 25.16 °C (S.D. = ± 0.16; second fortnight of December 1990) to 31.93 °C (S.D.= ±0.54; second fortnight of April 1991) at station 1, from 22.96 °C (S.D.= ±0.12; second fortnight of December 1990) to 30.76 °C (S.D.= 0.32; first fortnight of April 1991) at station 2, and from 24.23 °C (S.D.= ± 0.20; second fortnight of December 1990) to 31.56 °C (S.D.= ±0.32; first fortnight of April 1991) at station 3 (Fig. 29B).

III. Dissolved Oxygen:

While the dissolved oxygen values at stations 1 and 2 followed a comparable seasonal pattern, much wider fluctuations were observed in these values at station 3. An increase in dissolved oxygen values was recorded at all the stations during 1990 monsoon season, and the rate of increase was considerably higher at station 3. At stations 1 and 2, a gradual decrease to minimum values was recorded throughout the postmonsoon and upto the beginning of summer season. Though an overall decreasing trend to minimum dissolved oxygen values was observed during the same period at station 3 also, the fluctations were considerably higher than at other stations. An increase in the mean dissolved oxygen values during the second half of summer season, was followed by a decline in values throughout the premonsoon season at all the three stations. During 1991 monsoon season the values were once again on the rise at stations 1 and 2 (Fig. 30A).

The fortnightly mean dissolved oxygen values ranged from a minimum of 2.86ml/l (S.D.=± 0.14; first fortnight of April 1991) to maximum of 5.01ml/l (S.D.= ± 0.11; first fortnight of June 1991) at station 1, from 3.05ml/l S.D.= ± 0.09; first fortnight of September 1991) to 4.82ml/l (S.D.= ± 0.05; first fortnight of December 1990) at station 2, and from 2.56ml/l (S.D.= ± 0.15; second fortnight of April 1991) to 6.65ml/l (S.D.= ± 0.27; first fortnight of December 1990) at station 3 (Fig. 30A).

IV. pH:

The fortnightly mean pH values were generally on the alkaline side and followed similar seasonal variations at all the stations. A declining trend to low pH values was observed during both the monsoons of 1990 and 1991, upto the mid monsoon seasons. In the following months the values were on the rise throughout the postmonsoon and summer seasons. In premonsoon season, a decrease in the values was observed upto the middle of the season, and thereafter an increase to peak values was recorded upto the end of this season (Fig. 30B).

The fortnightly mean pH values ranged from a low of 7.99 (S.D.= ± 0.06; second fortnight of November 1990) to high of 8.39 (S.D.= ± 0.05; first fortnight of June 1991) at station 1, from 7.83 (S.D.= ± 0.12; first fortnight of November 1990) to 8.42 (S.D.= ± 0.06; second fortnight of September 1991) at station 2 and from 8.07 (S.D.= ± 0.09; first fortnight of November 1990) to 8.37 (S.D.=± 0.03; second fortnight of May 1991) at station 3 (Fig. 30B).

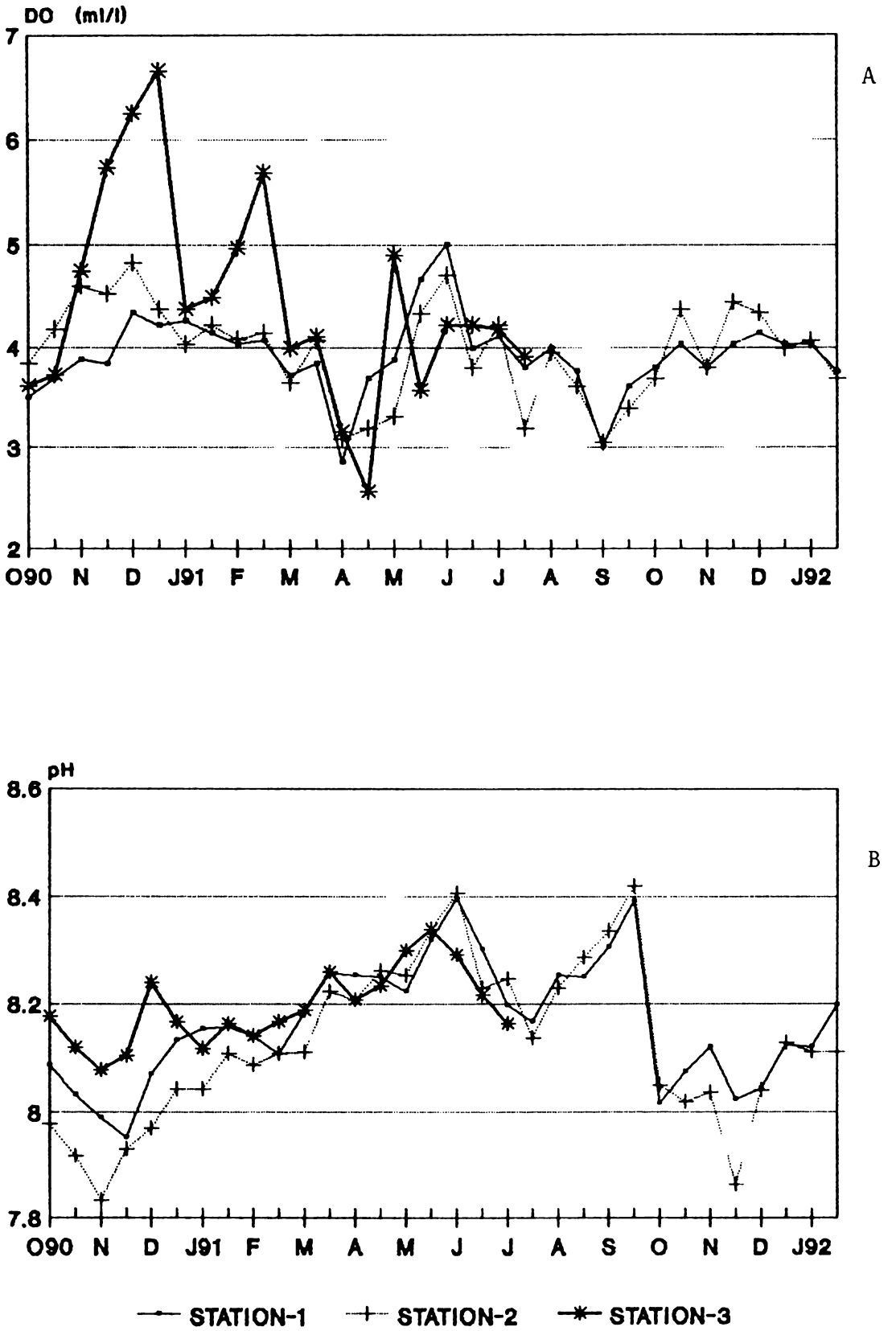


Fig. 30. Fortnightly variations in (A) dissolved oxygen and (B) pH.

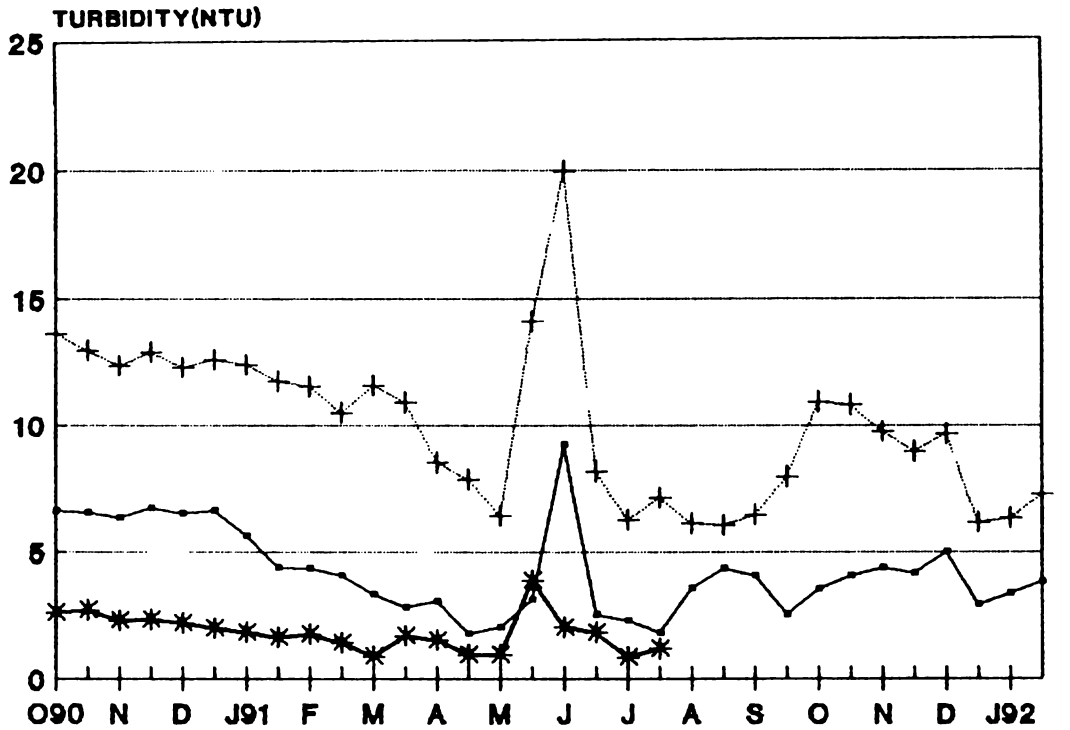
V. Turbidity:

Though there was considerable difference in the level of mean turbidity values between the stations, the seasonal variations in these values followed a comparable trend at all the three stations. A gradual declining trend from high turbidity values observed during the 1990 monsoon season was maintained throughout postmonsoon and upto midsummer season. In subsequent months, a sharp increase to peak values by the end of summer season was followed by a steep decrease to low values in the beginning of premonsoon season. During the premonsoon season the turbidity values remained low with minor fluctuations, and thereafter with the onset of monsoon season (1991) a rise in the values was recorded at stations 1 and 2 (Fig. 31A)

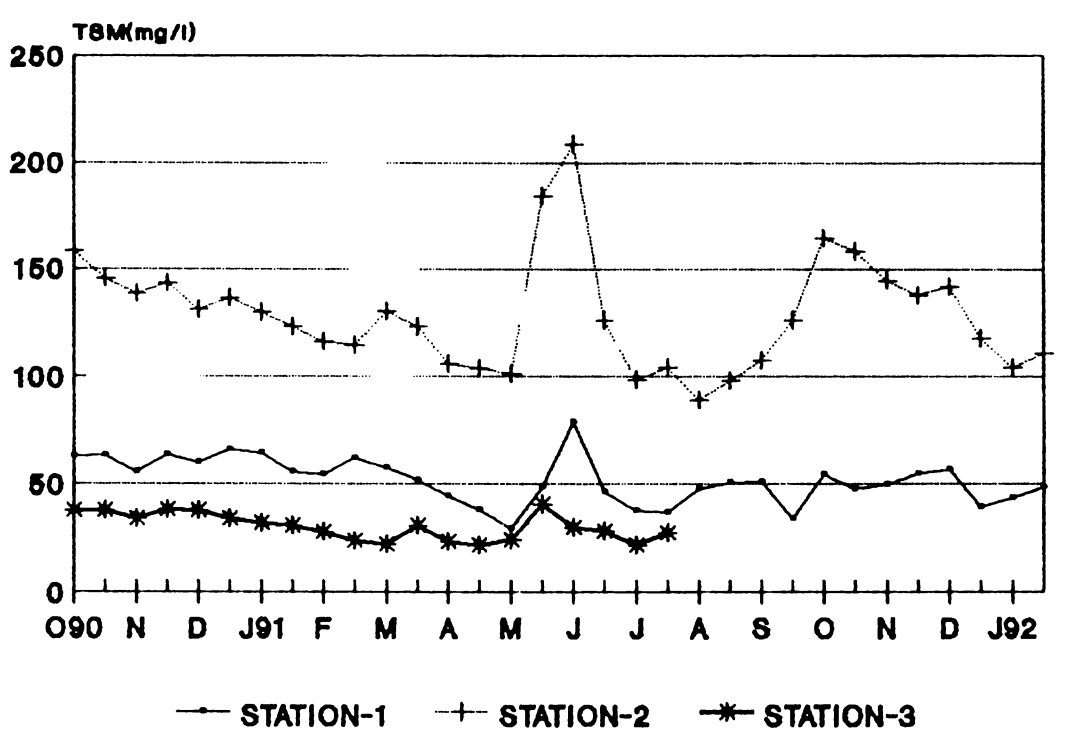
The fortnightly mean turbidity values ranged from 1.78NTU (S.D.= $\pm$ 0.51; second fortnight of April 1991) to 9.22 NTU (S.D.= $\pm$0.62; first fortnight of June 1991) at station 1, from 6.09 NTU (S.D.= $\pm$ 0.70; second fortnight of August 1991) to 19.99 NTU (S.D.= $\pm$ 1.25; first fortnight of June 1991) at station 2, and from 0.86 NTU (S.D.= $\pm$ 0.071; first fortnight of March 1991) to 3.89 NTU (S.D.= $\pm$ 0.70; second fortnight of May 1991) at station 3 (Fig. 31A).

VI. Total suspended micro-matter (TSM):

Mean TSM values followed a similar seasonal trend as was described for turbidity values at all the three stations (Fig.31B). They ranged from a minimum of 29.66mg/l (S.D.= $\pm$ 2.00; first fortnight of May 1991) to a maximum of 78.66mg/l (S.D.= $\pm$ 3.09; first fortnight of June 1991)



A



B

Fig. 31. Fortnightly variations in (A) turbidity and (B) total suspended micro-matter.

at station 1, and from 89mg/l (S.D.= ± 2.86; first fortnight of August 1991) to 208.56mg/l (S.D.= ± 4.32; first fortnight of June 1991) at station 2, and from 21.86mg/l (S.D.= ± 1.85; first fortnight of July 1991) to 40.76mg/l (S.D.= ± 2.34; second fortnight of May 1991) at station 3 (Fig.31B).

VII. Nitrate-nitrogen:

The mean nitrate values followed a more or less similar seasonal trend at all the stations. There were wide fluctuations during monsoon season (1990), and the values increased gradually upto the beginning of postmonsoon season. Thereafter, a continuous decrease to minimum values was recorded upto the beginning of summer season. In the following months the values increased to peak levels by the end of the summer season. Despite wider fluctuations in the mean values, an overall declining trend was recorded throughout 1991 premonsoon and monsoon seasons (Fig. 32A).

The minimum and maximum mean values recorded during the period of study were 0.917 µgat/l (S.D.= ± 0.05; second fortnight of February 1991) and 2.79 µgat/l (S.D.= ±0.26; second fortnight of August 1991) at station 1, 1.06 µgat/l (S.D.= ±0.073; first fortnight of March 1991) and 3.30 µgat/l (S.D.= ± 0.71; first fortnight of June 1991) at station 2, and 0.39 µgat/l (S.D.= ± 0.095; first fortnight of November 1990) and 1.59 µgat/l (S.D.= ± 0.058; second fortnight of May 1991) at station 3 (Fig. 32A).

VIII.Nitrite-nitrogen:

While the seasonal variations in nitrite values at stations 1 and 2 were similar, the trend in fluctuations was different at station 3 during certain seasons. At stations 1 and 2 an overall increase in the values was observed during monsoon (1990) upto the beginning of postmonsoon season. At station 3, the peak value recorded in November (1990) was followed by a sharp drop in the values by the end of this season. During postmonsoon and upto the beginning of summer season, a declining trend in the values was recorded at all the three stations, with a higher rate of decrease at stations 1 and 2. A sharp increase in the values observed in the middle of summer season (May), was followed by a sharp decrease upto the beginning of premonsoon season at all the stations. Towards the end of the premonsoon season (1991) there was a decline in the values, which showed a sudden increase with the onset of monsoon 1991 (Fig. 32B).

The fortnightly mean nitrite values ranged from a minimum of 0.05 µgat/l (S.D.= $\pm$ 0.019; second fortnight of September 1991) to maximum of 0.34 µgat/l (S.D.= $\pm$ 0.37; second fortnight of October 1990) at station 1, from 0.09 µgat/l (S.D.= $\pm$ 0.061; first fortnight of December 1991) to 0.44 µgat/l (S.D.= $\pm$ 0.021; first fortnight of June 1991) at station 2, and from 0.028 µgat/l (S.D.= $\pm$ 0.01; second fortnight of March 1991) to 0.28 µgat/l (S.D.= $\pm$ 0.04; first fortnight of November 1990) at station 3 (Fig. 32B).

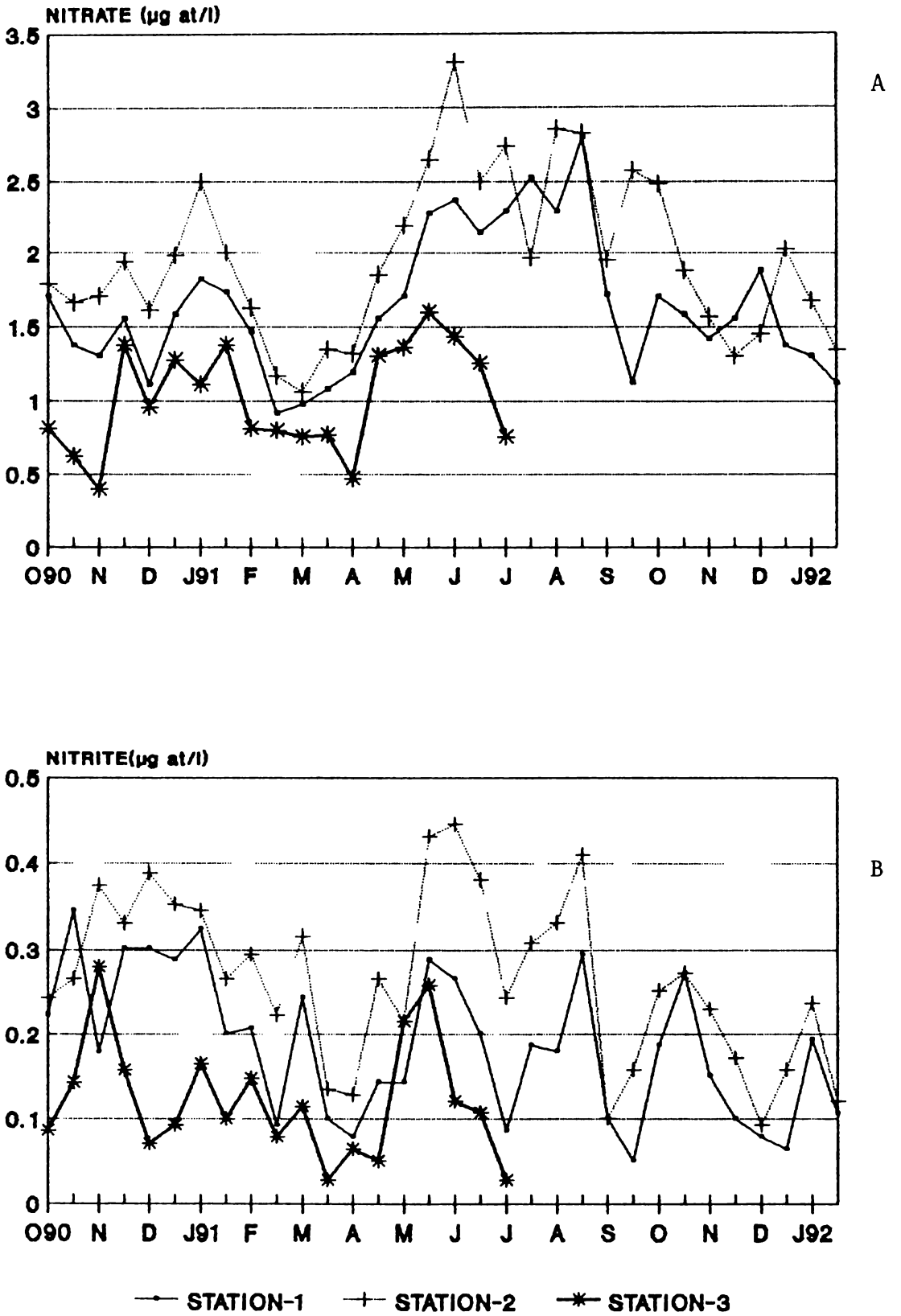


Fig. 32. Fortnightly variations in (A) nitrate and (B) nitrite

IX. Calcium:

The variations in fortnightly mean calcium values followed a comparable seasonal trend at all the stations. A decrease in the values with the onset of monsoon season (1990) upto November was followed by a gradual increase throughout postmonsoon and upto the beginning of summer season. During summer a drop in the values was observed till the beginning of the premonsoon season. There was an increase in the values during premonsoon season, which was followed by a decline with the onset of monsoon (1991) at stations 1 and 2 (Fig. 33A).

The fortnightly mean calcium values ranged from a minimum of 359.38mg/l (S.D.= $\pm$1.89; first fortnight of December 1990) to a maximum of 493.38mg/l (S.D.= $\pm$ 7.03; second fortnight of September 1991) at station 1, from 336.66mg/l (S.D.= $\pm$5.12; second fortnight of November 1991) to 518.36mg/l (S.D.= $\pm$ 3.77; second fortnight of September 1991) at station 2, and from 368.73mg/l (S.D.= $\pm$ 4.98; first fortnight of November 1990) to 448.89mg/l (S.D.= $\pm$ 12.70; second fortnight of April 1991) at station 3 (Fig. 33A).

X. Silicate:

The fluctuations in fortnightly mean silicate values followed almost a similar seasonal trend at all the three stations. A rise in the values upto the midmonsoon season (1990) was followed by a sharp drop by December 1990. The peak values at all the three stations were recorded during the postmonsoon season. There was a sudden decrease by the end of February 1991 and during rest of postmonsoon season and upto the

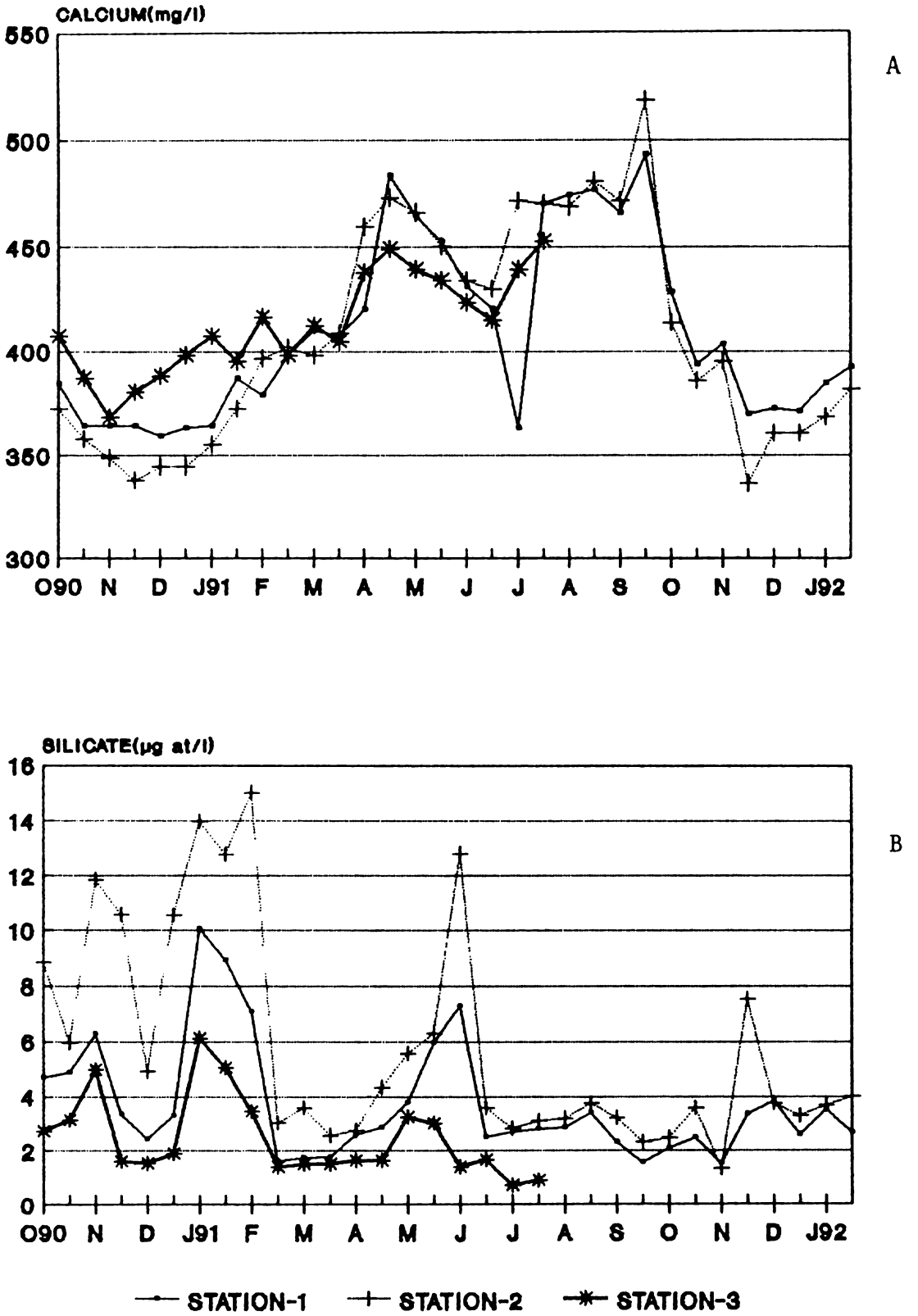


Fig. 33. Fortnightly variations in (A) calcium and (B) silicate

midsummer season, the values remained low with minor fluctuations. In the following months an increase in the values was observed upto the end of the summer. During the premonsoon and monsoon seasons (1991), the values remained low with minor fluctuations, except in the case of station 2 where a sharp increase and decrease was recorded towards the end of the monsoon (Fig. 33B).

The mean silicate values ranged from 1.52 µgat/l (S.D.= ± 0.34; first fortnight of November 1991) to 10.06 µgat/l (S.D.= ± 0.79; first fortnight of January 1991) at station 1, from 1.33 µgat/l (S.D.= ±0.066; first fortnight of November 1991) to 15.02 µgat/l (S.D.= ±0.77; first fortnight of February 1991) at station 2 and from 0.71 µgat/l (S.D.= ± 0.69; first fortnight of July 1991) to 6.11 µgat/l (S.D.= ± 0.75; first fortnight of January 1991) at station 3 (Fig. 33B).

XI. Reactive phosphorus:

The values followed a similar seasonal pattern at all the stations, though wider fluctuations were observed at station 2. A declining trend was recorded during the monsoon (1990) and upto mid-postmonsoon season. A sudden increase in the values during February-March 1991, was followed by a sharp drop in the values throughout the summer season. During premonsoon season the values generally remained low with minor fluctuations. During the remaining period of study, except for a sudden increase and then a rapid fall to the same level in November 1991, the reactive phosphorous values remained at moderate levels (Fig. 34A).

The values ranged from a minimum of 0.87 ugat/l (S.D.= ±0.26; first fortnight of June 1991) to a maximum of 3.77 µgat/l (S.D.= ± 0.081; first fortnight of March 1991) at station 1, from 0.81 µgat/l (S.D.= ± 0.10; first fortnight of August 1991) to 4.25 µgat/l (S.D.= ± 40.12; first fortnight of March 1991) at Station 2, and from 0.44 µgat/l (S.D.= ± 0.045; second fortnight of May 1991 to 2.48 µgat/l (S.D.= ±0.059; second fortnight of February 1991) at station 3 (Fig. 34A).

XII. Ammonia - nitrogen:

The seasonal variations in the mean ammonia values at stations 1 and 2 were considerably higher than at station 3. At all the three stations, a general declining trend to low values was observed during the monsoon season (1990). At station 3 during the rest of the study period values remained low with minor variations. At stations 1 and 2 there was an overall increase in the values during postmonsoon season. In summer the values remained low. Thereafter an increasing trend with wider fluctuations was recorded throughout the premonsoon and upto the midmonsoon season (1991). In the remaining period except a sharp drop from peak to moderate levels during the end of monsoon season (1991), the ammonia values remained at moderate levels with minor variations (Fig. 34B).

The fortnightly mean ammonia values ranged from 0.11 µgat/l (S.D.= ± 0.028; second fortnight of November 1990) to 0.70 µgat/l (S.D.= ± 0.11; first fortnight of November 1991) at Station 1, from 0.13 µgat/l (S.D.=±0.014; second fortnight of April 1991) to 0.83 µgat/l

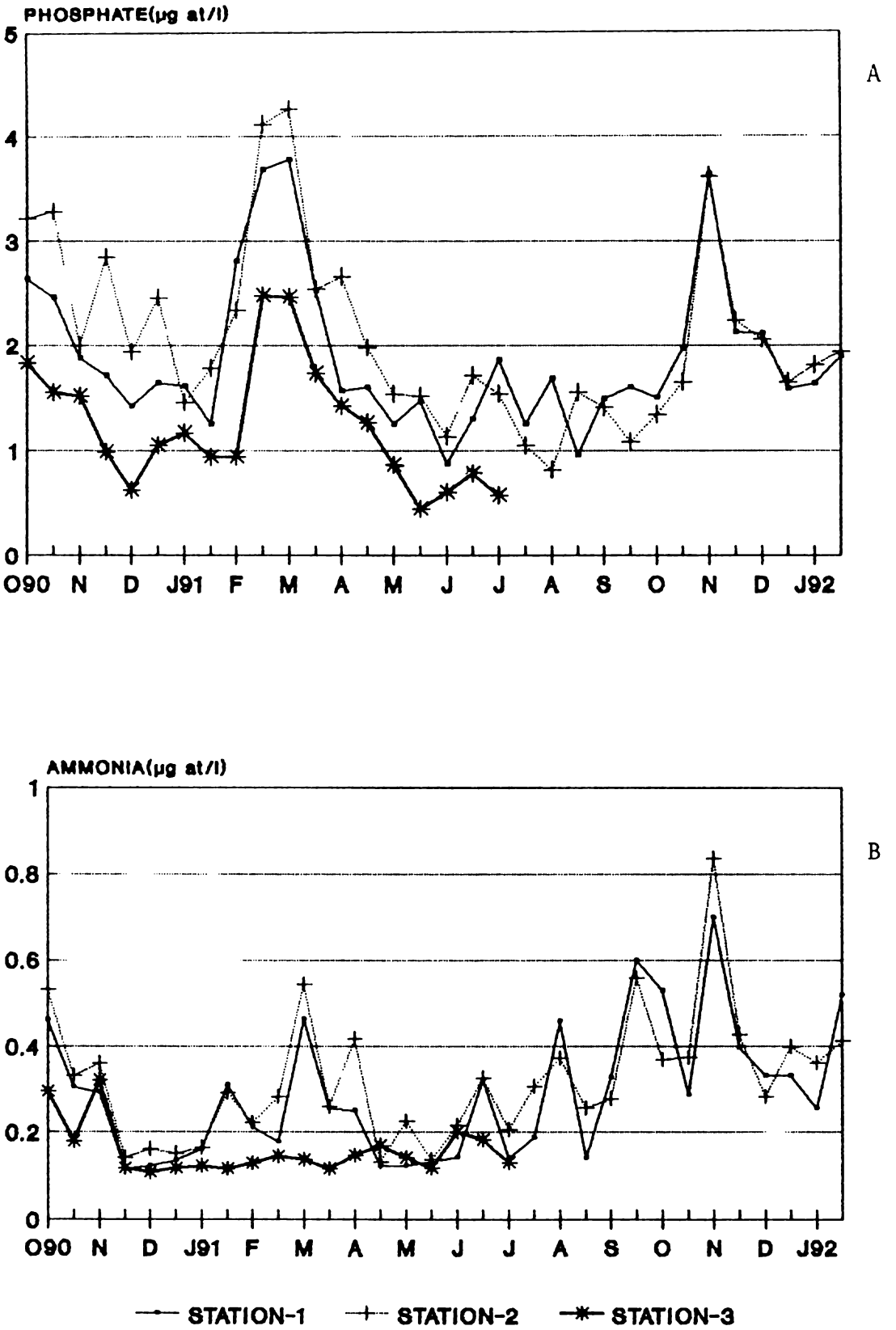


Fig. 34. Fortnightly variations in (A) reactive phosphorus and (B) ammonia.

(S.D.= ± 0.058; first fortnight of November 1991) at station 2, and from 0.10 µgat/l (S.D.= ± 0.021; first fortnight of December 1990) to 0.32 µgat/l (S.D.= ± 0.064; first fortnight of November 1990) at station 3 (Fig. 34B).

XIII. Chlorophyll-a:

Though the values followed a similar seasonal trend at all the three stations, the magnitude of fluctuations in these values was much higher at stations 1 and 2. At these two stations chlorophyll-a values indicated three seasonal peaks, first during the second fortnight of December 1990 to January 1991, second during May to the first fortnight of June 1991, and third during the second fortnight of July to August 1991. The magnitude of the second peak was much higher than the other peaks. At station 3, only one distinct peak was observed during the second fortnight of May 1991.

At stations 1 and 2, moderate and low chlorophyll-a values were recorded during 1990 and 1991 monsoon seasons, respectively. At these two stations a declining trend from high to low values was observed from the start of the postmonsoon till the beginning of summer season. At station 3, no distinct seasonal variations in the level of chlorophyll-a was observed (Fig. 35A).

The mean values ranged from a minimum of 1.16µg/l. (S.D.= ±0.15; first fortnight of November 1991) to a maximum of 16.39 µg/l (S.D.= ± 0.41; first fortnight of June 1991) at station 1, from 1.19 µg/l (S.D.= ± 0.14; first fortnight of November 1991) to 23.05 µg/l

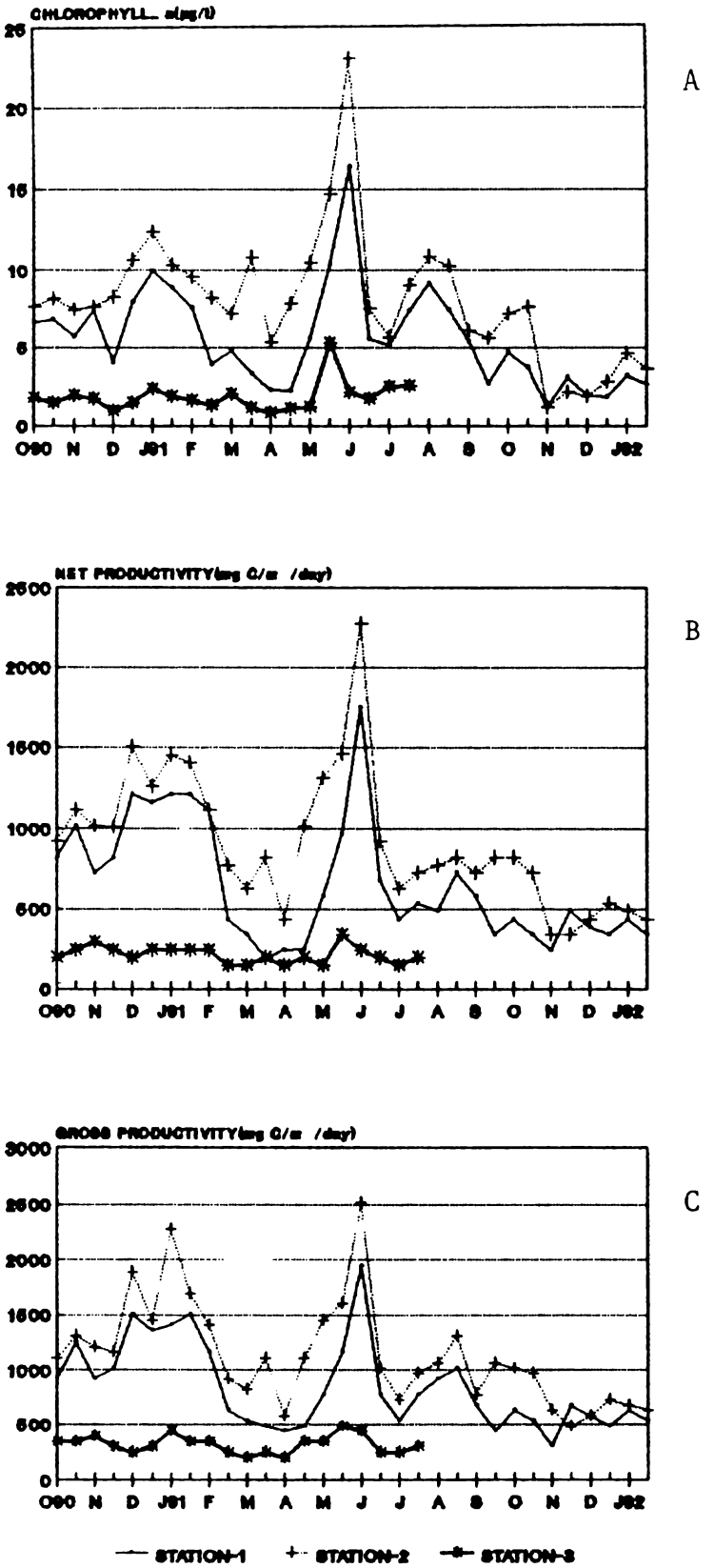


Fig. 35. Fortnightly variations in
(A) Chlorophyll-a,
(B) net primary productivity and
(C) gross primary productivity

(S.D.= ± 1.88; first fortnight of June 1991) at station 2, and from 0.83 µg/l (S.D.= ± 0.051; first fortnight of April 1991) to 5.27 µg/l (S.D.= ± 0.67; second fortnight of May 1991) at station 3 (Fig. 35A). It is evident from the ANOVA table (8A) that there was a significant ($P \leqslant 0.01$) variation in the level of chlorophyll-a concentration among the stations.

XIV. Net primary productivity:

Similar to the chlorophyll-a values, fortnightly variations in the mean net primary productivity values followed a comparable seasonal trend at stations 1 and 2. At these stations two distinct peak periods were observed, first during December 1990 to first fortnight of February 1991 and the second of a higher magnitude during May to first fortnight of June 1991. At these two stations, high and moderate levels of net primary productivity were recorded during monsoon (1990) and premonsoon (1991) seasons, respectively. From the second half of postmonsoon to the beginning of summer season and throughout the monsoon season (1991), the net primary productivity remained low at these two stations. At station 3, net primary productivity values remained low with minor variations (Fig. 35B).

The values ranged from a minimum of 193.95mgC/m^3/day (S.D.= ± 10.00; second fortnight of March 1991) to maximum of 1745.58mgC/m^3/day (S.D.= ± 96.95; first fortnight of June 1991) at station 1, and from 339.41mgC/m^3/day (S.D.= ± 48.46; first fortnight of November 1991) to 2278.96mgC/m^3/day (S.D.= ± 68.56; first fortnight of

Table 8A. ANOVA table showing the level of significance in variations of chlorophyll-a between stations.

Source	Degree of freedom	Mean square	Average	F-value	Probability
Stations	2	207.396	5.522	17.707	$P \leqslant 0.01$
Error	74	11.713	8.004		
			1.830		

Table 8B. ANOVA table showing the level of significance in variations of net primary productivity between stations.

Source	Degree of freedom	Mean square	Average	F-value	Probability
Stations	2	2593322.30	633.696	19.718	$P \leqslant 0.01$
Error	74	131523.241	902.015		
			211.064		

Table 8C. ANOVA table showing the level of significance in variations of gross primary productivity between stations.

Source	Degree of freedom	Mean square	Average	F-value	Probability
Stations	2	3638557.07	827.53	22.775	$P \leqslant 0.01$
Error	74	159760.23	1129.77		
			310.895		

June 1991) at station 2 and from 145.46mgC/m^3/day (S.D.= ±40.44; first fortnight of April 1991) to 339.41mgC/m^3/day (S.D.= ±48.49; second fortnight of May 1991) at station 3 (Fig. 35B).

The result of analysis of variance (ANOVA) test revealed significant ($P \leqslant 0.01$) difference in the level of net primary productivity among the stations (Table 8B).

XV. Gross primary productivity:

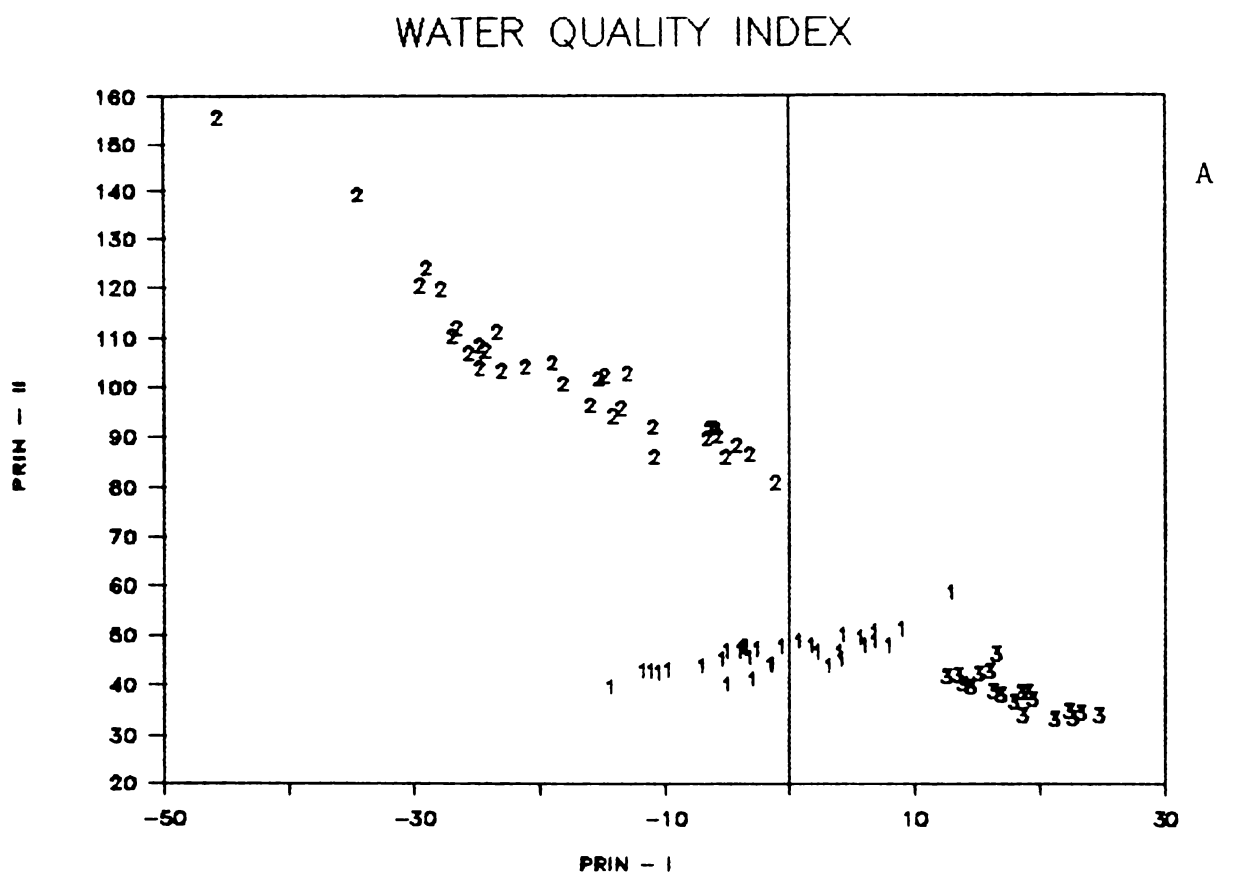
The variations in the level of gross primary productivity followed a similar seasonal trend as was described for net primary productivity at stations 1, 2 and 3.

The values ranged from a minimum of 290.93mgC/m^3/day (S.D.= ±40; first fortnight of November 1991) to a maximum 1939.53mgC/m^3/day (S.D.= ± 96.97; first fortnight of June 1991) at station 1, and from 484.88mgC/m^3/day (S.D.= ±96.98; second fortnight of November 1991) to 2521.41mgC/m^3/day (S.D.= ±145.46; first fortnight of June 1991) at station 2 and from 193.85mgC/m^3/day (S.D.= ± 10.000; first fortnight of April 1991) to 484.88mgC/m^3/day (S.D.= ±96.78; second fortnight of May 1991) at station 3 (Fig. 35C).

The analysis of variance (ANOVA) test showed that there was a significant ($P \leqslant 0.01$) difference in the level of gross primary productivity among the stations (Table 8C).

Results of Principal Components Analysis (PCA):

Principal Components Analysis (PCA) was carried out on hydrological (salinity, water temperature, pH, dissolved oxygen, turbidity and total



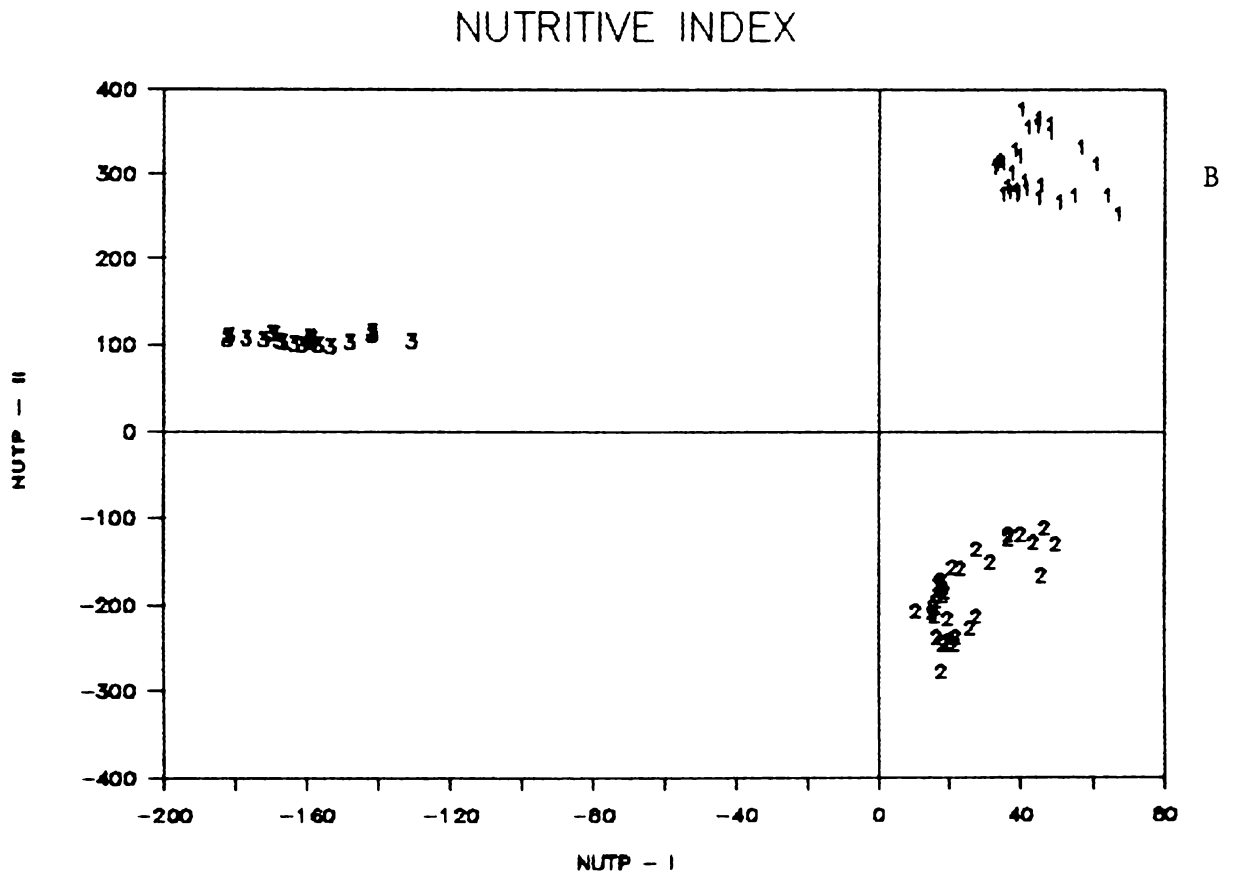


Fig. 36. Principal components analysis of (A) hydrological descriptors and (B) nutritive descriptors.

Table 9A. The coefficients for hydrological descriptors in the PCA.

Variables	Station 1		Station 2		Station 3	
	P-I	P-II	P-I	P-II	P-I	P-II
Salinity	-0.378	0.545	0.429	0.417	0.423	0.281
Water temperature	-0.449	-0.002	0.442	0.133	0.513	0.099
Diss: Oxygen	0.322	0.414	-0.472	0.097	-0.471	-0.008
Turbidity	0.473	0.269	-0.373	0.519	-0.225	0.641
Total suspended micro-matter	0.463	0.317	-0.322	0.561	-0.372	0.545
pH	-0.338	0.599	0.394	0.464	0.384	0.451
Variance %	53	24	57	27	48	31

Table 9B. The coefficients for nutritive descriptors in the PCA.

Variables	Station 1		Station 2		Station 3	
	P-I	P-II	P-I	P-II	P-I	P-II
Calcium	0.069	0.720	0.200	0.621	-0.423	0.176
Nitrate-N	0.473	0.358	0.563	-0.233	-0.189	0.616
Nitrite-N	0.426	-0.299	0.428	0.280	0.528	0.362
Ammonia-N	-0.444	0.202	-0.399	-0.279	0.487	-0.136
Silicate	0.417	-0.355	0.277	0.575	0.504	0.276
Phosphorus	-0.468	-0.313	-0.473	0.289	0.121	-0.603
Variance %	41	24	41	30	34	30

Table 10A. Correlations between hydrological descriptors and principal components.

Variables	Station 1		Station 2		Station 3	
	P-I	P-II	P-I	P-II	P-I	P-II
Salinity	-0.50	0.136	0.417	-0.093	0.566	-0.159
Water temperature	-0.651	-0.349	0.434	-0.186	0.708	-0.215
Diss:oxygen	0.395	0.390	-0.667	0.477	0.615	0.176
Turbidity	0.911	0.765	-0.884	0.859	-0.708	0.934
Total suspended micro-matter	0.969	0.903	-0.967	0.993	-0.882	0.985
pH	-0.442	0.071	0.347	-0.045	0.335	0.060

Table 10B. Correlations between nutritive descriptors and principal components.

Variables	Station 1		Station 2		Station 3	
	P-I	P-II	P-I	P-II	P-I	P-II
Calcium	0.088	0.976	-0.323	-0.900	-0.879	0.573
Nitrate-N	0.442	0.286	0.251	-0.267	-0.028	0.253
Nitrite-N	0.403	-0.277	0.474	0.237	0.505	0.313
Ammonia-N	-0.323	0.144	-0.427	-0.190	0.202	-0.032
Silicate	0.937	-0.462	0.991	0.789	0.770	0.542
Phosphorus	-0.417	-0.240	-0.130	0.277	0.208	-0.380

suspended micro- matter) and nutrient (calcium, phosphorus, nitrate, nitrite, ammonia and silicate) descriptors. Separate analysis was carried out for each station and discrimination between stations was made based on the first two principal components only.

The two principal components derived for each station for the above set of descriptors are presented in Table 9A. It is seen that the principal components together account for more than 60% of variations in all the stations. The descrimination between the stations based on these two sets of descriptors are given in Figs.36A and B. From the figures it is clearly evident that these three stations are distinct from one another, with respect to the hydrological and nutritive characteristics. The correlation between the hydrological and nutritive descriptors with their respective principal axes were computed for each station and the results are presented in Tables 10A and B. It is seen from these tables that turbidity and total suspended micro- matter in the case of hydrological descriptors, and silicate and calcium in the case of nutritive descriptors, have highly significant correlation with their respective principal components. This suggests that, possibly these parameters are the determining factors of discriminations between the stations.

METEOROLOGICAL PARAMETERS:

The mean monthly meteorological data on atmospheric temperature, rainfall and wind velocity during the period October 1990 to January 1992, are presented in Figs. 37A, B and C, respectively. The data were collected from the meteorological station, Port Trust, Tuticorin.

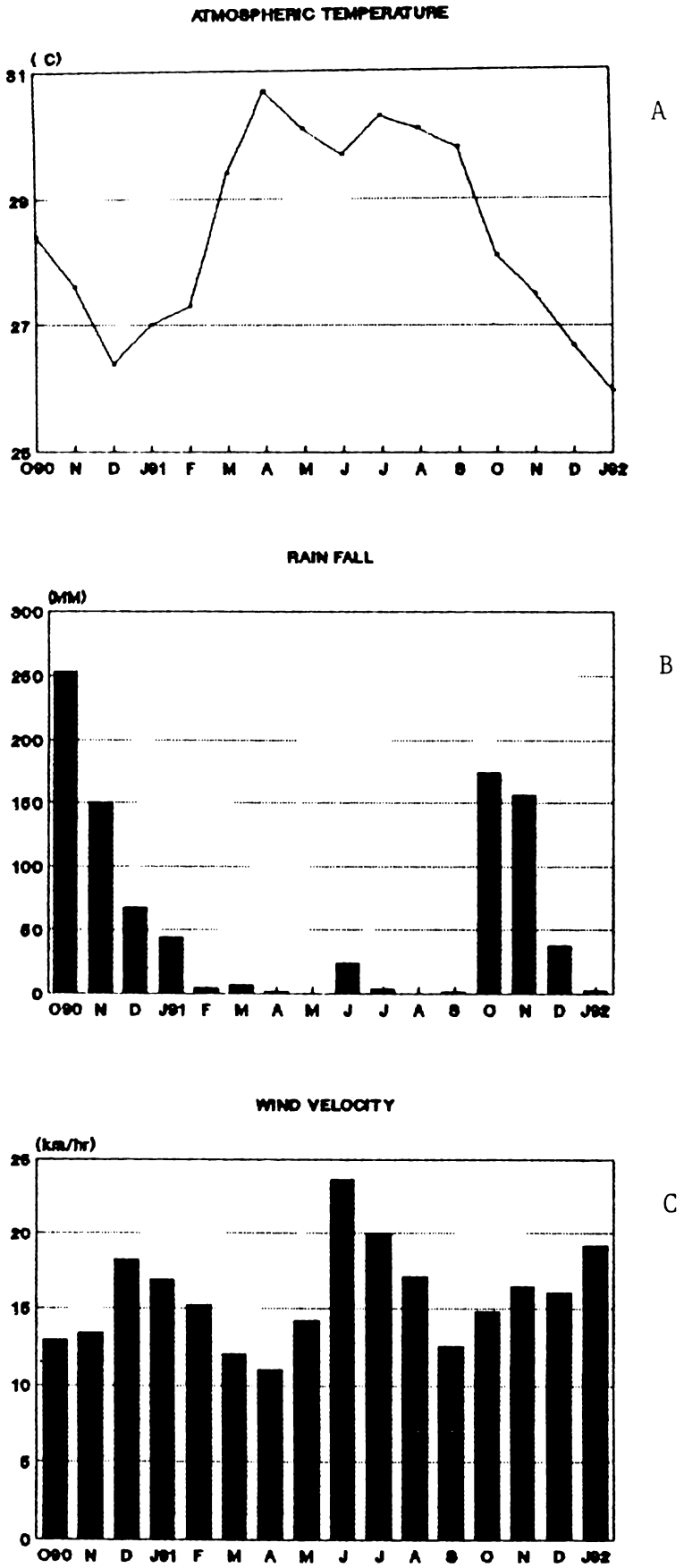


Fig. 37. Monthly variations in (A) atmospheric temperature, (B) rain fall and (C) wind velocity.

The mean monthly atmospheric temperature ranged from a minimum of 26 °C (January 1992) to a maximum of 30.7 °C (April 1991); mean monthly rainfall ranged from 0.10mm (May 1991) to 253.40mm (October 1990), and the minimum and maximum mean monthly wind velocity recorded were 11 Km/hr (April 1991) and 23.60 Km/hr (June 1991), respectively (Figs. 37A, B and C).

CHAPTER 1

SECTION IV

DISCUSSION

The edible oyster C. madrasensis (Preston) has been the subject of many studies conducted in different regions along the Indian coast. The comparison of the results of present study on growth, with the results of previous studies is difficult, because besides different ecological conditions prevailing at the experimental sites, other factors like methods used in calculating growth rates, the source of oysters used in the experiments, the initial oyster size, season of stocking, seasons during which experiments were conducted, culture technique followed etc., do play an important role in the final results obtained. However, for a general comparison the results of some of the growth studies on this species are presented. Paul (1942) observed that in Madras harbour, C.madrasensis attains 66mm shell height in 9 months. Rao and Nayar (1956) reported an average shell height of 50.6mm in 13 months and 63.7mm in 17 months in Adyar estuary. Dhulked and Ramamurthy (1980) reported an average growth of 69-85mm in shell height and 7.2-7.6g wet meat weight in Mulki estuary within 7 months. Somasekar et al. (1982) found that in Vellar estuary this species grows to 51.4mm in one year, 85.7mm in two years and 109.7mm at the end of the third year. In Mulki estuary it attained 72mm in 7 months, 91.5mm in one year and 142mm in two years (Joseph and Joseph, 1983; 1985), and in Bheemunipatnam backwater it was found to reach an average size of 81.8 mm in one year (Reuben et al., 1983). Rao et al. (1983; 1987) found that in Athankarai estuary this species attains shell height of 86.7mm in one year, 89.6mm in 14 months, 112.5mm in three years, and mean whole weight of 112g and an average wet meat weight of 9g at the end of one year. In Cochin

backwater it has been reported to attain an average shell height of 50.3 to 61.75mm in 6 months (Purushan et al., 1983). Narasimham (1987) reported shell height growth of 58-66mm in a period of one year in Kakinada canal. In the Karapad creek, opening into the Tuticorin Bay, Nayar and Mahadevan (1983) found that intertidal rack and tray cultured oysters of almost similar initial size as 0 age oysters of the present study, attained an average growth of 84mm in shell height, 120-130g in whole weight and 8 g in wet meat in one year. Same authors conducted similar culture experiments in the Tuticorin Bay (designated as station 1 in the present study), though no specific report has been published regarding the growth of oyster body variables, they stated that the over all production in terms of yield per hectare was less than the one achieved in the Karapad creek. More recently, Chhaya et al. (1993) reported that hatchery produced spat grown in cages laid in the intertidal zone in Gujarat coastal waters, showed an average growth of only 29mm and 30g in one year. Therefore considerable variation does exist in the growth performance of C. madrasensis at different regions along the Indian coast.

Though experimental variables do play an important role in causing such variations, keeping in view the significantly different growths obtained in the present study in which most of the experimental variables were similar for all the three groups of oysters, one can say that it is the variations in environmental conditions prevailing at each site which ultimately play the most important role in bringing about such differences in the overall performance of the animal. Such significant site specific variations in growth have been reported for

other species of bivalves too. Mallet and Haley (1983) studying the growth rate and survival in pure population matings and crosses of the oyster C. virginia at two locations, suggested that in growth the effect of locality is significantly manifested, and its contribution to the total variance is greater than that of genetic groups. Incze et al.(1980) related the growth and mortality of experimentally-rafted M. edulis of known age at 7 locations in a temperate Northern estuary, to water temperatures and the presence or absence of various potential food sources. Fernandez and Bodoy (1987) monitored individual growth of two age group of oyster, Ostrea puelchana, for two years at two sites in Argentina, and explained the variations in growth between sites in terms of differences in ranges of temperature and food availability. Wilson (1987) grew oysters (O. edulis) and scallops (Pecten maximum) in lantern nets at three stations in Birterbuy Bay, Co.Galway, Ireland. He explained differences in growth between stations in terms of differences in temperature, organic carbon content of the seston and current speeds. Utting (1988) compared growth and survival of hatchery reared oysters O. edulis spat at three sites in North Wales, and attributed the differences in growth to food supply and probable role of particulate inorganic material (PIM) in the water. Brown and Hartwick (1988a) while studying the influences of various environmental parameters upon the suspended culture of the Pacific oyster, C. gigas, measured growth of seeded oysters at 10 locations in British Columbia over a 14 month period. They defined three catagories of site-related growth by comparison of growth curves for different body variables, and stated that available food and variations in salinity and temperature were the

main factors causing such significant variations among the growth of oysters at different sites.

As revealed by the results of statistical analysis applied to environmental data of all the three stations in the present study, the parameters which contributed significantly to variations in ecological conditions of these sites are food availability indices, turbidity, total suspended-micro matter (TSM), calcium and silicate-silicon. Joseph and Joseph (1983) attributed the high rate of growth of C. madrasensis on the west coast of India to abundant food supply. Rao et al. (1987) stated that higher productivity of waters on west coast than on east coast, could be the determining factor in rapid growth of oysters obtained on the west coast. However, no attempt was made by both the authors to analyse the food availability. For that matter, food availability index has not been included in the list of ecological parameters studied during most of the experimental work carried out on C. madrasensis by various workers. Rao (1956) stated that food availability is probably one of the most important factors affecting the growth of C. madrasensis.

It is known that in the natural environment, the ration of suspension feeding bivalves in general comprises a mixture of algal cells, detritus and inorganic silt (Bayne and Newell, 1983). Thangavelu (1988) studying the stomach content of C. madrasensis from Pulicat lake, southeast India, reported that the stomach content of this oyster was composed of diatoms, detritus, inorganic animal matter, and that diatoms formed the major food component. However, a fundamental problem

still largely unresolved, concerns the true nature and energy values of the suspended particulates in coastal and estuarine environments. But despite such problems, food availability indices like quantitative and qualitative phytoplankton analyses, measure of suspended particulate organic matter, estimation of chlorophyll-a and primary productivity have been reported to be suitable indicators of food availability for bivalves. Brown (1988) reported that particulate organic matter (POM) concentration generally follows chlorophyll-a levels, from which a usable food ration for suspension feeders can be estimated. Widdows et al. (1979) and Soniat et al. (1984) utilized a food measurement for suspension feeders which was the sum of measured lipids, carbohydrates, and proteins. In both studies chlorophyll-a concentration well corresponded to food levels.

Significantly higher absolute growths obtained in different body variables of 0 age oysters at station 1, which are also comparable with higher ranges of growth reported for the same species from other regions along the Indian coast, were associated with elevated levels of chlorophyll-a, net and gross primary productivity and non-stressful ranges of other environmental parameters. On the other hand, the percentage growth increments in various body variables of 1+ age oysters at this station was considerably lower than that of 0 age oysters. To explain such wide variations in growth of two age groups of oysters exposed to similar environmental conditions, the effect of age and size on growth efficiency and the concept of scope for growth (Warren and Davis, 1967) should be taken into consideration. Somasekar et al.

(1982), studying the age and growth of C. madrasensis, reported a life span of 3-4 years for this oyster in Vellar estuary. Bayne (1976) suggested that, longevity in bivalves may be reduced in areas of rapid growth. He cited evidence suggesting that Mytilus sp. from Greenland are longer lived (18-24 years) than those from White Sea (9-10 years), or North Sea (6-7 years) or Black Sea (4-5 years). The rapid growth of C. madrasensis under non-stressful conditions along the Indian coast is a well known phenomenon and therefore such a short life span reported for C. madrasensis is not surprising.

The effect of age and size on overall performance of bivalves has been studied by many authors. Brown (1988) while studying the growth of two age groups of oysters, stated that initial size had a considerable affect on growth rates, because growth efficiency in bivalves declines with increasing age and size. Rodhouse (1978) monitored the changes in relative importance of vaious components of the energy budget of oyster O. edulis with time and reported a rapid drop in total net growth efficiency over the first five to six years, caused by diversion of an increasingly large fraction of absorbed energy into maintenance requirements expressed as respiration. He explained that as somatic growth in this oyster declines after about the fifth year and gonad output continues to increase, the total net growth efficiency tends to level off as the asymptotes for the gonad output and respiration curves are approached, and that net growth efficiency for somatic tissue declines exponentially through the entire course of the oyster's life and tends to zero as maximum size is approached. Bayne (1976) describing the growth curves for Mytilus sp. from various localities,

stated that increasing age is accompanied by a decline in growth rate. This may occur to such an extent that in very old individuals growth in length may virtually cease. He explained the factors in terms of reduced metabolic activity in older mussels. Bayne and Newell (1983) reviewing the affect of age and size on growth of molluscs, stated that the most important factor that ultimately sets a limit on growth and size is allocation of all available surplus energy to the production of gametes. Jørgensen (1976) reviewing the growth efficiency and factors controlling size in some Mytilid bivalves, concluded that high growth efficiency can be maintained at a constant level upto a certain critical size above which the maximum growth efficiency declines with increasing size. He argued that declining growth efficiency above a critical body size results from decelerating mean rate of water transport leading to reduction in food uptake, which he considered as the main factor determining the maximum size the species or an individual can attain. Therefore, taking into consideration the role of all the factors mentioned above and the initial age and size of 1+ age oysters at the time of stocking, it should be expected that at the same level of concentration of food in the water, the fraction of food available for growth should decrease with increasing body size, and maximum growth efficiency should decline exponentially with body size and age. The significant reduction in growth of C. madrasensis from the second year onwards, has been reported by Nayar and Mahadevan (1983) and Rao et al. (1983, 1987).

At station 2, though the level of chlorophyll-a and primary productivity was observed to be significantly higher than at other

stations, the absolute growth in various body variables of 0 age oysters at this station was significantly lower than the 0 age oysters of station 1. Rao (1956) stated that the rate of growth is dependent not only upon the availability of food in the environment, but also upon the ability of the organism to secure it. Comparatively much higher levels of turbidity and total suspended-micro matter (TSM) prevailing at station 2 through most of the study period, appear to be the most important factor preventing the optimum utilization of available ration by 0 age oysters. A study of the literature shows that efforts directed towards understanding the biology of C. madrasensis have not been equally distributed; but confined to selected fields. For example, while salinity and temperature and their effects upon this oyster have been described and discussed by many authors, studies on the effects of other environmental factors such as turbidity, have been virtually neglected. This lack of interest has persisted even though C. madrasensis is an inhabitant of the shallow waters of estuarine, coastal and backwater regions, where turbid conditions are often resulted by river discharge, wind action, wave action etc. Some information available in this regard, which is mostly based on casual observations and not based on detailed studies, include those of Purushan et al. (1983) who stated that besides fluctuation in salinity in Cochin backwater, other important factors adversely influencing the growth and survival of edible oyster C. madrasensis are silting and turbidity. Reuben et al. (1983) noted mortality of C. madrasensis whenever muddy water flowed persistently in the bed area for a week or more. Joseph and Joseph (1983) reported that during southwest monsoon, the larger scale natural mortality of oyster

in feral population of Mulki estuary is probably due to the result of unfavourable environmental conditions, especially very low salinity and high turbidity prevailing in the estuary. Thangavelu (1988), studying the natural food of C. madrasensis of Pulicat lake, reported a significant reduction in feeding intensity of oyster during the periods of high turbidity, despite abundant availability of phytoplankton. The results of present study and the ones reviewed provide evidence of sensitivity of C. madrasensis to high levels of turbidity.

The reports on the effect of high levels of turbidity and particulate suspended matter on other species of oysters include those of Hughes-Games (1977) who attributed the reduction in growth rate of C. gigas grown in sub-tropical fish ponds, to the presence of excessive silt in the water. Bernard (1983) reported that particulate inorganic matter above 75 mg/l can limit oyster growth, and Utting (1988) in his field experiments on growth of O. edulis at different sites, attributed the low growth of oyster spat at a particular site to high levels of particulate inorganic matter (PIM), and stated that high levels of PIM causes reduction in assimilation efficiency in the animal.

In order to understand the precise effect of turbidity on bivalves, many laboratory studies have been conducted by various workers. Loosanoff and Tommer (1948) and Loosanoff (1961) designed and conducted a series of critical experiments on effects of turbidity creating substances upon the behaviour of the American oyster, C. virginica. They reported that when the turbidity of water is noticeably increased by addition of live micro-organisms or inorganic matter such as fine

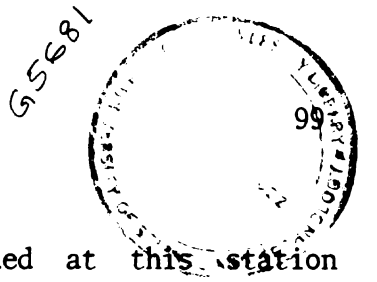
silt, Kaolin, calcium carbonate or Fuller's Earth, the oysters begin to react to it by decreasing their rate of water pumping and by changing the character of shell movements, indicating that oysters are seriously disturbed physiologically. Their results showed an average reduction of 57 to 94% in pumping rate of oysters in concentrations of 100 to $400 mgl^{-1}$ of silt, and no pumping in still higher concentrations. Increasing sediment load appears to exert a negative effect on clearance rate of many other bivalves too. Møhlenberg and Kiørboe (1981) found that clearance rate of Spisula subtruncala was independent of sediment concentration upto $25 mgl^{-1}$ At $40 mgl^{-1}$ of silt the clearance rate of M. merceneria was reduced by 52-53% (Bricelj and Malouf, 1984). Widdows et al. (1979) found that clearance in M. edulis declined by ca $0.007\ l h^{-1}$ (0.5%) for every mgl^{-1} increase in natural suspended sediments, in the range of 370 mgl^{-1} Similarly, Kiørboe et al. (1980) noted that clearance rate of M. edulis was reduced by about 0.6% for every 1 mgl^{-1} increase in sediment load between 10 and 56 mgl^{-1} Reduced clearance in response to silt, inevitably results in a decrease in algal food ingested, and above a threshold seston concentration, many bivalves reject excess filtered material as pseudofaeces. By raising the concentration above this threshold, suspended sediments may result in "dilution" of the available food and a consequent decline in the energy avaialble for production (Widdows et al., 1979; Griffiths, 1980). There is some evidence that bivalves may be able to selectively reject PIM and prevent considerable loss of algae in pseudofaeces (Kiørboe and Møhlenberg, 1981; Newell and Jordan, 1983; Bricelj et al; 1984). However, in high concentrations of PIM, effective elimination of

material of poor nutritional value, without reduction in the ingestion of nutritious particles, requires both high degree of selectivity and abundant pseudofaeces production, which in turn would require substantial amount of energy (Bricelj and Malouf, 1984; Utting, 1988).

Keeping in view the lower growth rate in various body variables of 0 age oysters at station 2, compared to the corresponding age group of oysters at station 1, one can say that while the juvenile oysters at station 2 were capable of selectively rejecting particulate inorganic matter, they could not carry out this function with high efficiency at such levels of total suspended micro-matter (TSM), and this inefficiency is most probably the major factor which has lead to suppression in growth of this group of oysters. On the other hand, while various biological activities of 0 age oysters of station 2 appear to have been highly suppressed by high levels of suspended micro- matter, the 1+ age group of oysters exposed to similar turbid conditions, appear to have much higher degree of tolerance to such conditions. Their performance as revealed by comparison of growth curves was significantly better than that of the same group of oysters at other stations. According to Jørgensen (1955) and Loosanoff (1961), different species or different group of the same species of bivalves are not equally sensitive to the same amount of turbidity in sea water. Same species may show a difference in tolerance towards the suspended silt, depending upon the conditions of their normal habitat before transplantation. More recently, Kiørboe and Møhlenberg (1981) while studying the particle selection in ten suspension feeding bivalves, reported that all the

species examined in turbid waters of different concentrations exhibited particle selection but with different efficiencies, and that selection efficiency is directly correlated with the size of the labial palps. That is, larger the labial palps, higher is the selection efficiency of the animal. Such correlations between turbidity and palp size has been reported by Theisen (1977) too. Both the above factors cited in literature for higher tolerance and efficiency of bivalves to cope up with turbid conditions in sea water, could be taken into consideration to explain the better performance of 1+ age oysters at station 2. While the 0 age oysters were produced and grown in the hatchery for a few weeks in filtered and clear seawater before transplantation, the 1+ age oysters were procured from the oyster farm, located in the bay. Therefore, 1+ age oysters were from a habitat with comparitively much higher turbid conditions than 0 age oysters. And, if indeed there is a direct correlation between palp size and efficiency of the animal to cope up in turbid waters, then it could be said that 1+ age oysters of station 2 being much larger than 0 age ones, have tremendous advantage of using their larger labial palps to make better use of the available ration in the sea water, despite high load of suspended micro- matter.

At station 3, the performance of both the age groups of oysters was extremely poor in all the biological activities monitored, indicating stressfull conditions at this site, that too at such high levels so as to ultimately lead to large scale mortality of the oysters. The principal hydrological parameter which most probably could be responsible for causing such stressfull conditions for animals at this site, is the low food availability, revealed by significantly low levels



of Chlorophyll-a and primary productivity recorded at this station compared to the other two stations. Growth has been stated to result when energy acquisition is in excess of energy expenditure. If, on the other hand, energy intake is less than the expenditure, negative growth occurs and endogenous reserves of energy are utilized to maintain the body in a viable condition. During the shortage of food, the metabolic rate indicates the rate of weight loss as energy reserves are utilized to maintain viable cell conditions (Bayne and Newell, 1983). Such situations of food shortage leading to partial starvation commonly occur for bivalves during the winter months in temperate environments. The weight loss of approximately 0.5% to 1.0% of body weight per day during winter months in south western England was reported for M. edulis (Bayne and Widdows, 1978) and for Cerastoderma edule (Newell and Bayne, 1980). This weight loss occurred despite the fact that the metabolic rate measured as rate of oxygen consumption was lowest in the winter and animals were described to be under cold coma, that is, the energy expenditure was minimum (Newell and Bayne, 1980). Bernard (1983) stated that low food level at lower temperatures is not critical to bivalves, because metabolic requirements of oysters are reduced.

On the other hand, high temperatures as prevailed at station 3, are known to increase the level of metabolic requirements of the bivalves (Widdows and Bayne, 1971; Ansell and Sivadas, 1973). Bayne et al. (1976) in their experiments on M. californianus held at various temperatures between 13 to 26 ^{o}C and provided with two levels of food, demonstrated that the metabolic energy expenditure of mussels which were

given a very low ration was less than half of that observed in well fed mussels (adaptive response). But their respiratory losses were twice that of absorbed ration leading to negative scope in growth which doubled from 13 to 26 °C. Therefore, besides low availability of food, higher temperatures prevailing at station 3 can be considered as another major factor contributing to stressful conditions for oysters at this station.

In suspension feeding organisms, feeding is found to be associated with two to three fold increase in oxygen consumption (energy expenditure) compared with the standard rate of quiescent animal (Thompson and Bayne, 1972). Winter (1973) found that in M. edulis, filtration rate was the highest at lower algal cell concentrations, but the actual ingestion of food was not affected by differences in cell concentration. He concluded that bivalves apparently have a maximum rate of ingestion, which is modulated by changes in the rate of filtration over a rather wide range of concentration of particles. Epifanio and Ewart (1977), studying the maximum ration of four algal diets for the oyster C. virginica supported the finding of Winter (1973) and stated that, the high rate of filtration in oysters exposed to low level ration indicates an increased rate of pumping in response to relatively low concentrations of algae. But nevertheless, the oysters were unable to filter maximum quantities from water. The relatively small amounts of food removed from suspension at this low concentration, combined with increasing energy expenditure to maintain a high filtration rate, would undoubtedly have a negative effect on the growth of the shellfish. Temperature is also known to effect the filtration

rate in bivalves. Walne (1972) while studying the filtration rate in five species of bivalves reported that filtration rate increased with increase in temperature. Therefore, higher activity (filtration rate) of oysters at station 3 caused by low food availability coupled with high temperatures leading to excessive loss of energy against the energy gained, could be cited as another factor resulting in poor performance of these animals.

Similar situations of no or negative growth in bivalves due to food shortage coupled with high temperatures have been reported by many researchers. Malouf and Breese (1977) studied the effect of seasonal changes in environmental parameters on the growth of the Pacific oyster C. gigas and observed an inverse relationship between temperature and growth rate at low levels of food availability. They stated that biological implications of such a relationship include the possibility that animals have increased metabolic cost at higher temperatures, and these costs are reflected in weight loss when food is scarce. An alternative explanation presented was that, food consumption relative to availability is reduced at high temperatures. A third alternative was that, the assimilation efficiency is inversely related to temperature, so that less energy is available for growth at higher temperatures. A fourth possibility quoted by them was that, the observed relationship is caused by a combination of the alternatives suggested above. Beukema and Desprez (1986) studying two populations of tellinid bivalve, Macoma balthica, attributed the nil growth in shell height and decline in weight of one population to lower availability of food during the

periods of high temperature, and stated that low chlorophyll-a concentrations of approximately 1 to 3mgm^{-3} prevailing at their study site during the low growing season, does not provide enough energy for growth. The rate of chlorophyll-a levels recorded at station 3 is comparable to what was reported by the above authors. Other similar reports cited in literature include those of Gillifilan et al. (1977) for Mya arenaria, Shafee (1980) for Chlamys varia, Thompson and Nichols (1988) and Harvey and Vincent (1990) for M. balthica.

When the absorbed ration exactly balances the metabolic demand and energy losses due to excretion, and when growth efficiency is zero, this ration level is called the maintenance ration. From literature it is known that the maintenance ration is a function of body size and is affected in different ways by various endogenous and exogenous factors (Bayne and Newell, 1983). Winter and Langton (1976) demonstrated that in M. edulis, the maintenance ration decreases with increase in body size and explained that higher maintenance ration in smaller individuals reflects their higher metabolic rate. The results of the present study obtained at station 3, does not agree with this phenomenon, since the performance of 0 age oysters was better than that of 1+ age oysters exposed to similar conditions. As revealed by the results of various biological parameters of these two age group of oysters, it is apparent that in comparison to 1 + age group, the 0 age oysters are better able to cope up with stressfull conditions prevailing at this site. Vahl (1981) recorded a similar phenomenon in different age classes of the Iceland scallop C. islandica, where, because of seasonal differences in the amount of food available, the larger individuals were forced into

negative growth for a greater part of the year than the smaller animals. Similarly, better performance of smaller individuals compared to larger ones during the periods of food shortage was recorded for C. edule (Newell and Bayne, 1980) and M. edulis (Bayne and Worall, 1980). There is evidence in earlier reports indicating that smaller individuals are more efficient in utilizing the available ration for maintenance than are larger individuals. Thompson and Bayne (1974) suggest a maintenance efficiency that declines in mussels from 60% in small individuals to 15% in the larger individuals. Therefore, the better performance of o age group of oysters at station 3, can be attributed to their higher efficiency to utilize the available ration for body maintenance, despite higher metabolic rate.

The monthly instantaneous growth rates were calculated for all the body variables of 0 age oysters only. Such calculations were not carried out for 1+ age oysters of station 3 and for wet and dry meat weight data of 1+ age oysters of stations 1 and 2. Because in the former case as evident from the absolute growth data, apparently no growth had not taken place in any of the body variables and in the latter case, data on absolute wet and dry meat weight growth were not normally distributed, and normal distribution of data has been stated to be one of the conditions for such analysis (Fernandez and Bodoy, 1987). The monthly instantaneous growth rates for other body variables of 1+ age oysters of station 1 and 2 were worked out, but no significant correlation could be obtained between these growth rates and environmental parameters. As already mentioned and evident from the results, growth efficiency and

scope for growth has been highly reduced in 1+ age oysters. Therefore, very low percentage growth increments as a result of highly reduced growth efficiency and preferential diversion of available energy to reproductive activity, could be considered as the major factors affecting the response (in terms of growth) of these older oysters to fluctuations in the environmental variables. Keeping in view the above factors, the discussion on probable influence of various endogenous and exogenous factors on periodical variation in growth rate are restricted to results obtained from the analyses carried out on 0 age group of oysters only.

It should be noted that the high morality rate, especially among the o age oysters of station 3 and to some extent among the oysters of station 2, could have lead to certain minor error in periodical mean growth measurements of the population, in turn affecting the results of correlation analysis. The high rate of mortality is the most probable factor resulting in negative growth rate values obtained in shell height of the oysters during periods of very low or no growth. Among all the body variables, the effect of mortality is likely to be the highest on shell height measurements, since the individual variations in shell height within the population of these juvenile oysters is comparitively much higher than the other body variables, as evident by higher standard deviation obtained for mean shell height values. This variation can be explained by assuming that within the population of these juvenile oysters the mortality in the larger sized oysters is higher than that of the small sized ones.

As evident from the monthly instantaneous growth rates considerable periodic variations in growth rate of all the body variables of o age oysters was observed at each site. This seasonality in the growth rate of bivalves has been stated to be the result of complex interactions among environmental variables, reproductive activity and energy balance (Bayne and Newell, 1983). The influence of the above variables, particularly environmental variables on growth rate of oysters have been studied in field oriented experiments (Brown, 1988; Utting, 1988).

Besides environmental factors, age and size have been reported to play important role in bivalve growth rate. Brown (1988), analysing the role of environmental factors on seasonal growth variations in the Pacific oyster, C. gigas, stated that bivalve growth rate is known to be a function of size and age, and that these factors can play a considerable negative role on oyster growth rate. In the present study, while the negative role of age and size is very obvious and evident in the case of 0 age oysters of station 1, their impact is considerably reduced at stations 2 and 3. The higher or equal growth rate observed in almost all the body variables of 0 age oysters at station 2 and 3 during the later periods of the experiments, indicates that these animals which were a few months older and grown to certain extent were capable of attaining equal or higher growth rate in shell as well as soft tissue, compared to their growth rates when they were few months younger. Jørgenson (1976) reviewing and interpretting the results of studies carried out on growth efficiencies and factors controlling size in some Mytilid bivalves, reported that transplantation has given an important tool in revealing factors which determine growth characteristics in

different population of bivalves. He reported that, fishermen in England and Netherlands transplant small mussels stagnant in growth from the intertidal level to an area below the tidal level, where they rapidly grow to marketable size. He further referred to more systematic observations on growth of transplanted mussels made by Seed (1968), who had observed the same degree of enhanced growth in growth-retarded groups of 7-8 years and 14-15 years old mussels of equal size, when transplanted from their native stressful environment to environments with conditions favourable for growth. He concluded, that it is the size rather than age that determines the rate of growth of the transplanted mussels and that, potential for growth remains intact for many years in mussels, prevented from exploiting it owing to unfavourable environmental conditions. In the light of above informations and the results of present study it can be concluded that, while both age and size play important roles in reduction in growth rate of C. madrasensis under non-stressful conditions, as observed in the case of 0 age oysters of station 1, in the case of oysters under the influence of unsuitable environmental conditions, as observed in the case of 0 age oysters at station 2, it is the predominant role of size on growth efficiency rather than age, that determines the rate of growth when environmental conditions turn more suitable for growth.

According to correlation coefficient analysis, food availability indices were closely related to the monthly growth rate of o age oysters at station 1. The correlations with net and gross primary productivity were high and significantly positive in the case of whole weight, whole

volume and meat weight. In the case of shell height, though the correlations were high and positive, they had not attained significant levels. These differences in the level of correlation between monthly variation in food indices and growth rate of body variables is because, growth in shell height, whole weight and soft tissue did not occur simultaneously. As evident from the figures representing the observed monthly instantaneous growth rates, it can be seen that oysters maintained very high shell height growth rates during the initial three months of the experiment, and thereafter, the shell height growth rates dropped considerably and were maintained at the same level with minor monthly fluctuations. On the other hand, in the case of other body variables particularly in the case of soft tissue, though the growth rates were high during the initial months, considerable variations were observed during the later periods of study. Such high shell height growth rates during the initial months of growth experiments followed by a considerable drop in the growth rate have been reported for C. madrasensis (Paul, 1942; Nayar and Mahadevan, 1983). Similarly, Quayle (1952) while studying the seasonal growth of C. gigas in Ladysmith Harbour, reported that rate of growth in shell height, width, thickness and volume did not occur simultaneously. Uncoupled growth patterns particularly in shell and soft tissue seem to be a general phenomenon in marine bivalve populations. Hilbish (1986) showed that growth in shell and soft tissue did not occur simultaneously in M. edulis. Peterson and Fegley (1986) found that there was little tendency for M. mercenaria to grow simultaneously in shell volume and somatic mass. Mechanisms reported by which shell and soft tissue may be

uncoupled are (1) different growth rates of these components,(2) loss of weight due to spawning and (3) loss of tissue weight due to periods of negative energy balance.

Food availability has been observed to play an important role in bivalve growth rates. Brown (1988) found a significant correlation between chlorophyll-b as an index of food availability and shell height growth rate of C. gigas. Utting (1988) related the growth (in terms of whole weight) of O. edulis spat directly to flagellate concentration in the water. Beukema et al. (1977) linked differences in the annual growth of M. balthica in Wadden Sea to inter-annual differences in the primary production of microalgae and the time available for feeding. Similarly, Hummel (1985 a, b) showed that both growth initiation and growth rate in M. balthica can be related to chlorophyll-a concentration. Thompson and Nichols (1988) studying the growth rate in shell height and changes in dry tissue weight of the same species in San Francisco Bay, California, stated that growth rate and variation in tissue weight can be attributed most strongly to differences in chlorophyll-a levels. The shell height growth rate as dependent variable has been positively related to chlorophyll-a concentration by Kautsky (1982) and Page and Hubbard (1987) in M. edulis, to chlorophyll-a and primary productivity by Bodoy and Plante-Cuny (1984) in Ruditapes decussatus and Plante-Cuny and Bodoy (1987) in Donax trunculus, and to phytoplankton concentration by Lelong and Riva (1976) in Ruditapes philippinarum. Dry meat growth was directly and positively related to chlorophyll-a concentrations by Deslous-paoli et al. (1982) and Heral et al. (1984) in C. gigas. Direct positive

correlation between wet meat growth and particulate organic matter (POM) was reported by Wildish and Kristmanson (1984) in M. edulis.

However, as mentioned before, the variation in growth rate of bivalves in nature is the result of complex interactions among many factors and cannot be restricted to one factor alone. The probable role of other factors along with food availability, on periodical fluctuations observed in the growth rate of 0 age oysters at station 1 are discussed. Uninterrupted and rapid growth of oysters during the initial four months of the experiment, particularly in the case of shell height, could be attributed to availability of adequate ration which ranged from 6.69 to 9.43 µg chl-a/1, comparatively lower ranges of temperature (28.46 to 26.53 °C), apparently non-stressful level of particulate suspended matter in water column (63.2 to 60.20mg/1), and the high growth efficiency of the animals due to their young age and small size. Sharp decrease in shell growth rates and negative growth rates observed in soft tissue indicating weight loss during February to April 1991, could be strongly attributed to the combined effect of sudden drop in ration (5.73 to 2.28 µg chl-a/1), rise in temperature (26.05 to 31.50 °C), and high energy demand of gametogensis and spawning. Negative effect of drop in the available food, coupled with rising and high temperastures on growth have been discussed earlier in this section (Malouf and Breese, 1977). As evident from the results of maturity stage studies, the above period is marked by high gametogenic and spawning activity among this group of oysters. The periods of high reproductive activity in bivalves have been stated to be periods of high energy demand (Soniat and Ray, 1985; Ruiz et al., 1992). In the case of

reduction in exogenous energy sources during this period, animals turn to their endogenous reserves to meet the energy requirement needed for growth and reproduction (Bayne and Newell, 1983), which could lead to depletion of accumulated reserves and weight loss in soft tissue.

Increase in all body growth rates (except in shell height), and in particular a very sharp increase in soft tissue during May to June 1991, coincides with sharp increase in food levels (7.99 to 10.98 µg chl-a/1) and marginal drop in mean monthly water temperatures (30.28 to 28.66 ^{o}C), which could be considered as two principal factors responsible for creating high scope for growth during this period. It should be noted that a sharp increase in total suspended micro-matter (39.11 to 62.5mg/1) during the same period did not appear to interfere with growth. As revealed by the results, July to October 1991 is once again a period of high reproductive activity and is marked by a decrease in body growth rates (excluding the shell height growth rates) and weight loss in soft tissue. If the first (February to April) and second (July to October 1991) periods of intensive reproductive activity and spawning are compared, it can be seen that, despite higher availability of food (8.31 to 4.18 µg chl-a/1) during the second period, the energy diverted for gametogensis and spawning by oysters appears to be higher than the first phase, as evident by higher weight losses recorded in dry meat of these organisms during the second phase. Studies on C. varia by Shafee (1980) allow a detailed analysis of the reproductive effort in different seasons of the year. He observed that in the Bay of Brest this species was found to spawn twice in the year (June and September). Gametes

spawned in June were reported not to have been produced at the expense of food reserves stored in the somatic-tissue, because somatic and gonadal tissue growth occurred together. For the September spawning, however, food reserves in the body were utilized in the production of gametes, as was indicated by decline in the weight of somatic tissue. Therefore, reproductive effort was reported to be greater for the second spawning. In the present study the oysters had been exposed to periods of high food availability prior to both periods of intensive reproductive activity, and during the second phase the level of food availability was even greater than the previous one. But the cost of shell growth and reproductive effort, as reflected in dry meat weight losses, appear to have been higher in the second phase. One probable factor for increase in energy requirements of oysters in the second phase of reproduction could be the effect of older age and larger size of these organisms (when compared to the first phase) on reproductive activity. Reproductive capacity or fecundity (Hughes and Roberts, 1980) and reproductive effort, which is a term used to refer to the level of energy allocated for reproduction (Dame, 1972; Rodhouse, 1978; Griffiths, 1980) have been demonstrated to have a direct relationship with size and age respectively.

Regarding the growth of bivalves in relation to periods of intensive reproductive activity and spawning, conflicting statements have been made by different workers. Coe (1947) in the Pismo clam, Tivela stultorum, observed that growth diminishes appreciably during spawning season. In C. virginica, while Needler (1941) reported that growth stops during the period of reproductive activity, Loosanoff and

Nomejko (1949) observed that it is continued throughout the period without interruption during spawning. In Gryphae angulata, kept in the claries or fattening ponds with abundant food, Ranson (1949) observed practically continuous growth, but not in those reared in the parks where the growth was interrupted during the period of spawning. Korringa (1953) stated that in waters rich in food, spawning hardly leads to interruption of growth, but in waters constantly or temporarily poor in it, the oysters show an interruption of shell growth during the season of reproduction. Bayne and Newell (1983), reviewing and interpretting the results of various experiments carried out on growth and reproduction in bivalves, concluded that if food supply is in surplus, the somatic and gonadal growth continue simultaneously and in the case of food shortage, the shell and gonadal growth may continue at the cost of utilization of endogenous energy reserves leading to loss of soft tissue weight. Kautsky (1982) studying the growth of M. edulis reported that, while at first analysis no correlation was found between growth rate and phytoplankton biomass, a good correlation was obtained after the spring values of the reproductive period were excluded. He attributed this to energy supplied during the reproductive period being canalized more or less directly into gonad growth resulting in low shell growth despite abundant food. In contrast to the above study, since in the present study drop in food availability indices coincided with reproductive period, the drop in growth rate during this period which must have been partly due to diversion of energy for reproduction, did not upset the correlation between growth rates and food availability indices. Therefore, in the light of the above reports, and the results

of the present study, it can be stated that it is the level of food availability and overall condition of oysters in terms of endogenous reserves that determine the growth performance during reproductive period; age and size add a further dimension to the complexity of this relationship.

Nayar and Mahadevan (1983) while conducting growth experiments on C. madrasensis of almost similar initial size as the present experimental oysters and following similar culture technique, reported higher growth for these oysters in the Karapad creek (opening into the Tuticorin Bay) than the growth achieved in the present study (Station 1). Also the range of environmental parameters (water temperature, salinity, dissolved oxyge and pH) recorded by them during the experimental period are comparable to the range recorded during the present study. Therefore, most probable environmental factor which could have been responsible for causing such variation in the growth of experimental oysters in these two localities could be the level of food availability, which was not studied by them. Lower growth can be taken as an indication that the 0 age oysters of station 1 were not exposed to optimal levels of their food requirement to achieve their highest potential for growth in various body variables studied.

Brown and Hartwick (1988c) constructed a habitat suitability index (HSI) model for suspended tray culture of the Pacific oyster, C. gigas, from the available information on oyster environment relationships. In the model, biophysical data are to rate aquaculture potential of coastal areas on a scale from 0.0 to 1.0, where 1.0 represents optimal

conditions for growth and survival, and 0.0 represents totally unsuitable habitat conditions. Optimum level of available food for growth of C. gigas was reported to be 12 µg chl-a/l, corresponding to optimum temperature range of 15-18 °C. The mean chlorophyll-a level calculated for the entire study period at station 1 is 5.59 µg/l, which when matched against the suitability index graph of chlorophyll-a presented by above authors for C. gigas, corresponds to an approximate value of 0.40, which is considerably lower than the optimum value of 1.0. Unfortunately, no data are available on the level of available food during various growth experimental studies carried out on C. madrasensis. But as mentioned earlier, judging by growth performance of 0 age oysters of station 1 in comparison to better performance of these oysters in the earlier experiments carried out in the same geographical region, there is every reason to state that the range of food availability recorded in the present study is below the optimal level. Taking into consideration the level of chorophyll-a recorded during the periods of high growth in the present study and the optimal ranges reported for Crassostrea sp., it can be said that, the optimum range of chlorophyll-a required for high and near maximal growth rate in C. madrasensis during the first year of growth, under similar environmental conditions prevailing at station 1, most probably lies above 10 µg/l. However, more detailed studies are required to determine the optimum range. It should be noted that the lower range of optimum ration is of greater importance, since for a given temperature, bivalve growth rates have been reported to be asymptotic beyond certain concentration of food particles (Kirby-Smith and Barber, 1974; Malouf

and Breese, 1977; Bayne and Widdows, 1978). Therefore, higher levels of chlorophyll-a within the optimum range are unlikely to cause any problem for C. madrasensis, since at high levels of available ration bivalves are known to be capable of ingesting optimum amount of food by adjusting their filteration rate (Winter, 1978). The optimum range of chlorophyll-a suggested for C. gagas by Brown and Hartwick (1988c) is from 12 to 55 µg/1.

The negative correlation obtained between water temperature and the growth rate of all the body variables of 0 age oysters at station 1, is due to the fact that during most of the study period an inverse relationship was recorded for this environmental and biological variables. However, during the entire study period mean fortnightly water temperature fluctuated in a narrow range, and varied from 25.16 °C to 31.93 °C and the fortnightly fluctuations were very gradual. On the other hand, high growth rates were also recorded during October to November 1990 and May to June 1991, which were periods marked with high water temperatures. From November 1991 onwards despite a declining trend in water temperature, the growth rate remained low. Therefore, it is unlikely that temperature fluctuating in a narrow range could alone have had any major influence on growth rates and its effect is prominent only during periods of low food availability. The effect of temperature on scope for growth has been the subject of many studies. Buxton et al. (1981) studying the scope for growth in juvenile O. edulis in relation to temperature, reported maximum scope for growth to be between 15 and 20 °C, and that brief exposure to higher temperatures further enhanced

the growth potential. They concluded that gradual warm acclimation during the summer months, together with brief exposure to higher temperatures, which possibly occur in shallow waters during low tide, represent optimal conditions for production in this species. Widdows (1976) while comparing the growth of mussels from two populations found that, individuals which experienced elevated temperatures in their natural habitat were better able to grow at higher temperatures, and that exposure to higher temperatures ($>20^{o}C$) in a fluctuating regime enhanced the scope for growth in both sets of animals. This was mainly due to the maintenance of high filtration rates without increase in respiration as a result of adaptation to temperature cycle. Shafee (1980) reported that the effect of high temperatures during summer, in the Bay of Brest, on growth efficiency of C. varia is slight due to abundance of food. Elvin and Gonor (1979) concluded that food levels explained 96% of the seasonal variance in scope for growth in M.californianus, and average tissue temperature explained only 3%. Bayne and Newell (1983) in a review concluded that, it is the combined effects of ration and temperature that have the most profound influences on physiological energetics of bivalves in the natural habitat. Therefore, on the basis of the present study and the information available, it can be concluded that water temperatures ranging from 25 to $32^{o}C$ is unlikely to have any significant effect on the growth of C. madrasensis during the periods when optimum ration is available.

The considerably high and positive correlation of turbidity and total suspended micro-matter with growth rates of various body variables could be due to two factors. First, the variation in total suspended

micro-matter indicates the variation in particulate organic matter which is a known indicator of ration of bivalves. Secondly, low levels of resuspended particulate inorganic matter which is most likely to contribute significantly to loads of total suspended micro-matter in shallow coastal waters (Bricelj and Malouf, 1984), and presence of which has been observed in the gut content of C. madrasensis (Thangavellu, 1988), has been reported to enhance growth in many bivalves. Winter (1976) observed increased growth in M. edulis upon addition of 12.5mg/1 of oxidized silt to pure algal diet. Growth of C. virginica was stimulated by the addition of kaolinite clay to an algal diet, supplemented with yeast and rice starch (Urban and Langdon, 1984). Kiørboe et al. (1981) reported an increase of 30 to 70% in growth rate of mussels by addition of 5mg silt/l^{-1} to pure algal suspension. Similar reports include those of Ali (1981) and Møhlenberg and Kiørboe (1981). This positive effect of low levels of suspended sediments have been attributed to: (a) an increase in clearance rate; (b) utilization of sedimentary organics and (c) an increase in absorption efficiency of algae through a grinding effect by sediment particles in the bivalve's stomach. However, these authors have not been able to distinguish the mechanism invoked. Though the present study does not warrant to draw any conclusion regarding the precise effect of low levels of total suspended micro-matter on the growth rate of C. madrasensis, it can be stated that loads of micro-suspended matter within the range of 29.66 to 78.66mg/1 is unlikely to have any negative effect on the growth of this oyster, and the possibilities of its positive effect requires further research.

Most of the growth studies carried out on C. madrasensis have been conducted in the estuarine and backwater ecosystems along the west and east coast of India. These estuaries and backwaters are characterised by wide fluctuations in salinity. Therefore, it is not surprising that salinity has been often referred to as the most important factor influencing the growth rate and survival of this oyster. On the west coast, sudden drop in salinity levels to almost fresh water conditions during southwest monsoon has been reported to result in cessation of growth and lead to heavy mortality among the experimental as well as the natural populations of this oyster (Purushan et al., 1979, 1983; Joseph and Joseph, 1983). On the east coast, low salinities due to northeast monsoon and high salinities due to excessive evaporation in summer months, when the connection between the sea and estuary is closed, have been reported to have similar effects of retardation in growth rate and heavy mortalities among the oyster populations (Rao and Nayar, 1956; Rao et al., 1983, 1987; Reuben et al., 1983, Narasimham, 1987). Joseph and Joseph (1983) recorded salinities as low as 0.27ppt in the Mulki estuary on the west coast, and stated that in the case of any culture practise in such estuaries, the oysters will have to be harvested before the onset of the southwest monsoon. Rao et al. (1987) reported salinities as high as 71 ppt in the Athankarai estuary on the east coast, and suggested that in the case of any culture practise, the racks holding the oysters will have to be shifted to nearby coastal waters to avoid mortalities during very low or high salinity periods.

Medcof and Needler (1941) reported that rapid fluctuations in salinity can reduce the tolerance of bivalves to changes in other

environmental variables. While Quayle (1969), Bernard (1983), and Brown and Hartwick (1988c) found that salinity below 20ppt leads to reduction in growth of C. gigas, King (1977) and Huges-Games (1977) observed very high growth rates for the same oyster cultured in ponds with high salinity ranges of 40 to 41 ppt, respectively. Other reports include those of Nell and Holiday (1988) who observed that the Sydney rock oyster (S. commercialis) had the highest growth rates at salinities of 23-39ppt.

In the present study mean fortnightly salinity values ranged from 26.53 to 37.31ppt at station 1, and the fortnightly and seasonal variations occurred gradually. Since high growth rates were observed during low as well as high salinity periods, and keeping in mind the non-stressful salinity regimes reported for other oyster species, it can be said that the salinity range observed at station 1 is not likely to act as the limiting factor for rapid growth of C. madrasensis.

As was mentioned earlier, in the coastal waters, seasonal fluctuations in dissolved oxygen and pH values have been reported to usually fall within the tolerance range of the oysters (Westley, 1964; Kuwanti and Nishii, 1969; Davis, 1975). The values of these parameters may reach unfavourable levels due to poor water circulation or pollution (Menzel, 1979). The ill effect of seawater with pH $\leq$ 7.0 (Bamber, 1990) and effect of hypoxic and anoxic conditions (Baker and Mann, 1992) on growth and various other biological activities of bivalves were presented in the introduction section. Brown and Hartwick (1988c) stated that pH and dissolved oxygen do not effect growth and survival,

provided the values fall within the tolerance zone of the oyster. At station 1, the mean fortnightly pH values ranged from 7.97 to 8.35, and the mean fortnightly dissolved oxygen values from 2.86 to 5.01ml/1, which are within the tolerance zone of the bivalves. However, an interesting observation revealed by the present study is that, the periods of high growth rates during the major part of the experiment at station 1 (except the last four months), coincided with periods when the dissolved oxygen levels of sea water were very close to the upper range of this parameter, which in turn corresponds to the optimum level of dissolved oxygen recommended for the culture of C. gigas by Brown and Hartwick (1988c). This point and the strong positive correlation of dissolved oxygen with the growth rate of all body variables (except shell height), can be taken as an indication that besides other environmental parameters, higher dissolved oxygen levels also contributed in creating suitable environmental conditions for obtaining high growth rates in oysters at this station.

The role of calcium in shell formation of bivalves, and sea water as its main source of supply, has been highlighted by many authors (Fox and Coe, 1943; Belvander and Benzer, 1948; Belvander, 1952; Galtsoff, 1964; Epifanio et al; 1975). Calcium concentration has been positively related to salinity (Riley and Chester, 1971). Brown and Hartwick (1988a) stated that low salinity (<20ppt) can lead to reduction in minerals such as calcium which in turn can lead to reduction in the growth of oysters. In the present study also, it was observed that calcium levels closely follow the periodical fluctuations in salinity, and since no significant reduction in salinity was observed at any of

the sites, it may be said that most probably there was no shortage of calcium for growth of oysters at any of the sites.

High concentrations of ammonia and nitrite can be toxic to bivalves. During the present study the concentration of these micro-nutrients remained within the safe range reported for oyster and clam culture systems by Epifanio et al. (1975). As far as other micro-nutrients monitored in the present study are concerned, they are unlikely to have any major direct impact on growth rate of the oysters, and their effect is likely to be reflected through their influence on the standing crop of phytoplankton at each site. The relationship between these set of micro-nutrients and food availability indices monitored is discussed in the later part of this section.

At station 2, though the level of food availability indices were significantly higher than that at station 1, the growth rate of 0 age oysters in all the body variables were considerably lower than that of the corresponding age group of oysters at station 1. As discussed earlier, the suppression in growth rate was most likely due to the high levels of suspended particulate matter recorded at this station.

Vahl (1980) while studying the seasonal variation in seston and growth rate of C. islandica reported that in spite of abundant particulate organic matter (POM as food index), high levels of particulate inorganic matter (PIM) in the water column reduced the potential growth rate in this bivalve, and growth rate increased only during periods of very low PIM. He suggested that differences in periodical growth rates observed are essentially the results of

differences in nutritional condition of water, defined by the relationship between PIM and POM. That is, lower the ratio of PIM:POM, higher would be the scope for growth. Similar observations were made for the same species cultured at different depths by Wallance and Reinsnes (1985).

At station 2, though the periodical differences in growth rate could be mostly explained in terms of variation in food availability indices and level of total suspended micro- matter (TSM), it cannot strictly be restricted to chlorophyll-a: TSM ratio. The conclusion drawn by the above authors, when applied to the results of prsent study, holds good only during periods when the relationship between food availability indices and TSM was inverse (October 1990 to January 1991).

As evident from the results of monthly instantaneous growth rates, the 0 age oysters at station 2 had very low shell growth rates during the initial stocking month of the experiment.This undoubtedly would have been caused due to sudden exposure of these oysters from comparatively clear waters (hatchery, outdoor tanks and bay waters) to very high level of turbidity prevailing at this site during the stocking month. From October 1990 till January 1991, despite monthly fluctuations in growth rates, in general and in comparison to the initial month, an increasing trend in growth rate of all the body variables was observed. This increasing trend could be attributed to the periodical decrease in the level of TSM, coinciding with a simultaneous increase in the level of food availability indices recorded during this period. Another factor which could have contributed positively is the gradual but continuous drop in the water temperature. A comparison of the growth rates of

these oysters during these initial months of the experiment, with the growth rates of 0 age oysters of staton 1 during the same period, provides a clear evidence of supression in feeding rate of oysters at station 2, caused by higher levels of total suspended micro-matter. During February - March 1991, the shell growth rates were on a decline, and a sharp drop in soft tissue growth rates was recorded. The reason for the sudden decline in soft tissue growth rates to negative levels, particularly in February is not clear. Because, the level of total suspended micro-matter recorded during this month was considerably lower than previous months, and at the same time, while there was no increase in the water temperature, the level of food availability indices though marginally decreased, were comparable to previous months. Such conditions should have actually enhanced growth, instead of having a negative impact particularly on soft tissue growth rates. Here another factor which should be mentioned, and which is applicable to the entire study period but could have shown its prominent effect during this period, is the activity of coastal fishermen in the shallow waters adjacent to the pond. Since the area adjacent to the pond (station 2) is bound on three sides by land, fishermen often engage in fishing in this area, and at times they also enter the pond and wade through it with their spread out nets, disturbing the extrmely slushy and loose sediments of the pond bottom, resulting in high turbidity, which would have in turn forced the oysters to close their valves and stop feeding. Such activities was not a regular phenomenon, because maximum care was taken to control it. Therefore, such temporal variations in turbidity levels, which would have eluded the sampling programme, would have

possibly caused such unexplainable fluctuations in growth rates. In April 1991, though the level of available food was comparatively lower than in the previous months, due to considerable reduction in the level of suspended particulate matter, the oysters appear to have utilized this condition for growth, as evident by sharp increase in shell height and soft tissue growth rates. The fluctuation in most of the environmental parameters of stations 1 and 2, including the food availability indices followed a comparable trend, probably because these two stations are very close to each other. During May and June 1991, both the stations were characterised by peak food availability. While the above period was marked by high growth of 0 age oysters at station 1, it was marked by almost no growth in whole weight, whole volume and negative growth in soft tissue of 0 age oysters at station 2. This period provides strong evidence for negative impact of high levels of suspended micro-matter on growth rate of various body variables of 0 age oysters, particularly soft tissue. Thangavelu (1988) studying the natural food of C. madrasensis, reported that during periods of high turbidity, the oysters suspend feeding despite the availability of abundant food in the environment. In the present study, during the above period another factor which would have added to the negative impact of environmental conditions on growth of these oysters, which were already faced with poor feeding conditions, is the higher ranges of temperature prevailing at the site. However, the growth in shell height recorded during the second month (June) of above period, could have taken place at the cost of utilization of endogenous reserves, increasing the degree of negative scope for growth in soft tissue (Bayne

and Newell, 1983). High growth rates recorded in July and August for all the body variables (except shell height), more so in July, could be attributed to comparatively very low levels of total suspended micro-matter and moderately high levels of food availability indices. Such high growth rates, particularly in the case of whole weight and soft tissue, could be taken as an indication that these oysters with suppressed growth rates due to stressful environmental codnditions, could regain their high potential for growth if exposed to favourable environmental conditions (Jørgensen,1976). The reason for the variations in growth rates of most of the body variables during the rest of the study period, particularly in the months of September, November and December 1991 is not very clear. However, the factors which provide appropriate evidence regarding the negative influence of high levels of particulate suspended micro-matter on growth rate of 0 age oysters at station 2 are; (a) overall reduction in absolute and monthly growth rates of these oysters, when compared to the 0 age oysters of station 1, (b) trend of periodical variation in growth rate of these oysters in relation to fluctuations in the level of total suspended micro-matter and food availability indices, (c) poor statistical correlation between growth rates and food avaibility indices when compared to station 1 and (d) negative correlation between total suspended micro-matter and growth rates. Other reports besides the ones already presented, include those of Deslous-Paoli *et al*. (1982), Heral *et al*. (1983), Desolus-Paoli and Heral (1984), who observed a negative correlation between the levels of suspended particulate inorganic matter and dry meat weight growth rate of spat and adult of *C. gigas*.

The negative correlation between water temperature and growth rate of o age oysters at station 2 was already discussed. As far as other parameters like salinity, pH, dissolved oxygen and calcium are concerned, they are unlikely to have any major influence on growth rates of any of these groups of oysters, since the ranges of fluctuations in these parameteres at stations 2 and 3 generally fall within the tolerance range of oysters.

At station 3, the main environmental parameters responsible for very poor performance of oysters are the significantly lower levels of food availability coupled with high water temperatures prevailing at this site throughout the experimental period. The chlorophyll-a levels recorded at this site ranged from 0.78 to 5.54 µg/1 with mean value of 1.84 µg/1 over the entire study period. If this mean value of chlorophyll-a is matched against the site suitability index graph proposed by Brown and Hartwick (1988c) for the culture of C. gigas, it corresponds to a value indicating most unsuitable site for culture as far as chlorophyll-a levels are concerned. However, there could be some variation in the level of food requirement of these two species of Crassostrea.

Victor and Velayudhan (1987) studied the hydrological parameters of the same site (station 3), in slightly deeper regions, for a period of about 2 1/2 years. They reported chlorophyll-a levels ranging from 0.26 to 6.94 mg/m^3 [($\mu g/1 = mg/m^3$) (Strickland and Parsons, 1968)], with mean values of 1.86 mg/m^3 and 1.16mg/m^3 at surface and bottom levels, respectively. The range of chl-a reported by them is within the range

observed in the present study. On the other hand a group of oysters (C. madrasensis) which were placed in this area a few years back, as a part of site testing experiments by the Research Institute (C.M.F.R.I), had not shown any growth and they did not survive for more than a few months (Personal communication, Dr. Ramdoss, scientist Molluscan Division TRC of CMFRI). Therefore, the above reports indicate that this site is characterised by very low levels of food availability and that such a situation prevailed in the earlier years also.

Seed (1976) stated that if food is scarce, growth will be retarded regardless of all other conditions. Therefore, at station 3 food supply is the most important single factor determining growth rates. However, positive but not significant correlation between food availability indices and growth rates at this station, could be taken as an indication that whatever growth had taken place in the body variables, it had occurred during the periods of increase in the level of food indices.

The volumetric condition index analysis (Hopkins, 1949) used in the present study has been proposed for assessment of ecophysiological status of oysters (Quayle, 1980, Lawerence and Scott, 1982). The comparison of condition index (C.I.) values recorded during the present study with previous reportes on C.I. values for C. madrasensis is difficult because of different techniques used in C.I. analysis.

At station 1, though the oysters were exposed to similar environmental conditions, the 0 age oysters maintained higher mean C.I. values than the 1+ age oysters during most of the study period. Similar

observations was made by Nascimento and Pereira (1980), who reported a significant difference between the average C.I. values of two size classes of mangrove oyster C. rhizophorae. However, inspite of such differences, the periodical variations in mean C.I. values of these two age groups of oysters followed a more or less similar trend, and such variations were significantly correlated with periodical fluctuations in food availability indices at this station. C.I. has been related to food availability in the oysters, C. gigas (Westely, 1964; Brown and Hartwick, 1988b; Jones and Iwama, 1991), S. commercialis (Maguire et al., 1981) and C. madrasensis (Rajapandian et al., 1990).

Besides food availability, reproductive cycle of oyster has been reported to play an important role in seasonal fluctuations of C.I. (Quayle, 1969). A detailed analysis was carried out by Joseph and Madhyastha (1982) to study the relationship between gonadal cycle of C. madrasensis and variation in meat weights, which they stated to show the same trend as the condition index. They observed a strong correlation between the variations in meat weight and annual gonadal cycle, and reported an increase in weight from moderate to high levels during the development and proliferation of gonad, followed by a sharp decline during periods of intense spawning. And then again a marked increase to highest levels was found as the oysters pass into indeterminate stage.

The C.I. values of both age groups of oysters at station 1 remained at high levels in the initial months (November 1990 to February 1991). This could be attributed to a rising trend in food availability, gradual drop in water temperature and an increase in the percentage occurrence

of oysters in advanced and ripe stages of maturation. A decline in C.I. of both age group of oysters from February to April 1991 could be attributed to intense spawning activity during this period. However, a sharper and earlier drop in C.I. values of 1+ age group of oysters could have been due to higher negative impact of drop in food availability indices coupled by increasing water temperature on the somatic tissue of these oysters. A sharp increase in C.I. values in May and June 1991 could be attributed to a rapid increase in food availability indices, along with a simultaneous increase in total suspended micro- matter. Increase in the percentage occurrence of oysters with indeterminate gonads in the monthly samples of the above period, could be considered as another factor contributing to such an increase in C.I. values (Joseph and Madhystha, 1982). A gradual decline in mean C.I. values from July to November 1991, could be attributed mainly to spawning activity and partly to a general declining trend in food availability indices.

Since the ranges of salinity, pH and dissolved oxygen levels recorded at all the three stations fall within the tolerance zone of the oysters in general, these parameters are unlikely to have any marked influence on the C.I. values of the experimental oysters. Similarly, the correlation obtained between C.I. values and the level of micro-nutrients must be due to their direct relationship with food availability indices, which has been discussed at the end of this section.

The variation in mean C.I. values of 0 age oysters at station 1 follow periodical trends in growth rates, indicating that the C.I.

values present a true picture of their physiological status. The lower C.I. values recorded for the 0 age oysters at station 2 indicate their overall poor physiological condition. But the periodical variations in these values do not appear to reflect a true picture of their physiological status, because such variations do not follow the trends in growth rates, particularly in the case of meat weight growth rates. As the results indicate, while during the period from November 1990 to January 1991, comparatively higher growth rates were recorded for these oysters, their mean C.I. values were at the lowest level. During February March 1991, while a drop in growth rates was observed, the C.I. values were higher than that of previous months. Though the increase in C.I. values during April 1990 correspond to an increase in meat weight and shell height, the reason for further increase in May 1991 is not clear, because a simultaneous drop in growth rates of all body variables was recorded during this month. The drop in mean C.I. values in June could be related to a decrease in growth rates, particularly in the meat weight. But, inspite of sharp increase in growth rates in July, the C.I. values remained at the same level. An increase and then a decrease in C.I values observed during August and September 1991 could be attributed to similar fluctuations in meat weight growth rates during these months. While an increase in the values from October to December 1991 could be related to positive growth rates observed, further rise in the values to levels equal to that of 0 age oysters of station 1, in the last month of the experiment can not be explained.

Brown and Hartwick (1988b) stated that volumetric condition index values may not present a true picture of physiological status of oysters under certain stressful environmental conditions. The explanation presented is that, stressful environmental conditions can lead to abnormal variation in shell and body tissue growth rates or a simultaneous reduction in body tissue and shell growth rate, which in turn could result in misleading volumetric condition index values. Based on their suggestion some of the C.I. values obtained for 0 age oysters of station 2, which do not follow the trends in growth rates could be partly explained. High C.I. values in the months of March, May 1991 and January 1992, could possibly be due to a simultaneous decrease in both shell and tissue growth rates. However, since C.I. values do not seem to present the true physiological status of this group of oysters, their correlation with environmental parameters can not be taken into consideration.

The mean C.I. values of 1+ age oysters at station 2 fluctuated between moderate to high levels during most of the experimental period. The periodical variations in these values showed low positive correlation with food availability indices and low negative correlation with turbidity and total suspended micro-matter values. Low positive correlation with food availability indices possibly indicate that food levels at this station must have remained at adequate levels for these oysters throughout most of the study period. Low negative correlation with turbidity and total suspended micro-matter could be due to high tolerance of these oysters to such turbid conditions. The periodical trend in mean condition index of these oysters appears to be mainly

influenced by their reproductive cycle. An increasing trend in C.I. values from November 1990 to March 1991 could be attributed to a simultaneous increase in percentage occurrence of oysters in ripe and advanced stage of maturation in the monthly samples of this period. Drop in C.I. in April 1990, can be attributed to intense spawning activity during this month. A gradual increase in C.I. from May to August 1991, could be due to a sharp increase in food availability indices in May-June, and an increase in number of oysters with ripe and well developed gonads in July and August. However, the magnitude of rise in C.I. values of these oysters during May and June, was lower than the rise in C.I. of 1+ age oysters of station 1 during the same period. This could be due to a sharp increase in the level of particulate suspended micro-matter during the above period at station 2, which would have most probably had a negative impact on the feeding rate. The C.I. values dropped to low levels in September and October 1991 when majority of the oysters were in partially spawned or spent condition. From November 1990 till the termination of the experiment, though an increase was recorded in C.I. values, in general the values remained at low to moderate levels. During this period, the food availability indices were at the lowest levels and total suspended micro-matter and turbidity at high levels. Fall in C.I. of C. madrasensis following spawning was observed by Rao (1956) and Narasimham (1987). Drop in C.I. values due to increase in the level of particulate suspended matter has been reported for C. rhizophorae (Nascimento and Periara, 1980) and the clam M. mercenaria (Bricelj et al., 1984).

Among the three stations, the lowest C.I. values were recorded for both the age groups of oysters at station 3. Such low values indicate very poor physiological status, which could only be attributed to low food availability at this site. The positive correlation between periodical variations in the condition index of 0 age oysters and food availability indices (at significant level with net primary productivity), indicate their higher efficiency to respond to any improvement in the environmental conditions. On the other hand, a gradual and continuous drop in C.I. values of 1+ age oysters, demonstrates their fast rate of tissue weight loss, most probably due to utilization of endogenous reserves. Calculated on the basis of initial (November 1990) and final (May 1991) mean wet meat weight, the 1+ age oysters at this station had lost 60.56% of their body weight. Kautsky (1982) observed weight losses of upto 78% in mussels subjected to severe food shortage during high summer temperatures. He further reported that if mussels in poor conditions are supplied with adequate food, they can recover and grow again. However, in the present study, indications of improvement with increase in food availability was observed in the case of 0 age oysters only.

The sex ratio in natural population of C. madrasensis from different regions has been reported to be in favour of males for a part of the study period (Rao, 1956; Stephen, 1980) and in favour of females throughout the study period (Rajapandian and Rajan 1983; Narasimham, 1987). In the present study, while the percentage of males was higher among the 0 age oysters for most of the study period, in the case of 1+ age oysters the proportion of females was invariably higher for most of

the experimental period. However, as revealed by chi-square test analysis, there was no significant deviation from 1:1 ratio for both the age groups of oysters.

Rao (1956) stated that the occurrence of a few transitional hermaphrodites and fluctuation in percentage of different sexes in C. madrasensis before and after the indeterminate phase of the gonad, could be taken as evidence of reversal of sex. He further stated that rare occurrence of individuals with reproductive elements of both sexes is an indication that hermaphroditism is not a regular feature. In the present study monthly fluctuations in sex ratio were observed in both the age groups of oysters. But since no transitional hermaphrodites could be detected, sex reversal could not be corroborated by this study.

Reproduction in natural populations of C.madrasensis has been studied either by examination of gonad or by monitoring of spat fall. Mainly two variable peaks of intense gametogensis and spawning has been reported for this species along the west and east coasts of India. The peak sexual activity in estuaries and backwaters has been associated with wide fluctuations in salinity (Hornell, 1922; Rao, 1951, 1956; Rao 1974; Stephen, 1980; Joseph and Madhyastha 1982; Joseph and Joseph, 1983). On the other hand, peak spawning in oyster beds situated in coastal and backwater areas which are not characterized by wide fluctuation in salinity, has been mainly attributed to periods of higher water temperatures (Nayar and Mahadevan, 1983; Rajapandian and Rajan, 1983; Thangavelu and Sundaram 1983; Narasimham, 1987). In the present study normal and regular gametogenic activity was observed among both

the age groups of oysters at station 1, and in 1+age oysters at station 2. The 1+age oysters with ripe or spent gonads occurred in most of the months indicating almost continuous spawning among the larger size group of experimental oysters. However, spawning among both the age groups of oysters was intensified during February - May 1991 and July - December 1991, as evident by occurrence of high percentage of ripe, partially spawned and spent oysters in the monthly samples during the above period. Intensive spawning commenced among the 0 age oysters earlier (March and August) than the 1+age oysters (April and September) .Initial spawning period had a short duration and reached its peak in April 1991, when water temperature and salinity values were at high levels at both the stations (31.5 ^{o}C; 35.86 ppt). Second spawning period was comparatively of longer duration and reached its peak in September and October 1991, and intensive spawning continued upto November 1991 among the 1+ age oysters of station 1. During the second spawning period water temperature (29.70 to 27.46 ^{o}C) and salinity (36.87 to 26.67 ppt) were on a decline at both the stations.

Rise in temperature has been reported to be the chief stimulating factor in inducing spawning in the American oyster, C. virginica (Loosanoff and Davis, 1952). Rao (1951) stated that under tropical conditions of Indian coast, the water temperatures of the sea or backwaters are high throughout the year and do not fall at any time below the optimum level reported for European and American oysters. However, experimental studies by Nayar et al.(1984) have shown that conditioned oysters were stimulated to spawn by increasing the temperature of sea water by 2-4 ^{o}C above the ambient temperature. From

the present observations it is clear that though high temperatures appear to play a major role in spawning, the effect of drop in salinity levels can not be ruled out, since comparatively high intensity spawning occurred among the 1+age oysters of station 1 in November and December 1991, when salinity values were comparatively low.

Along the southeast coast of India two peak spawning periods following more or less comparable trend as was observed in the present investigation, has been reported for C.madrasensis from Madras Harbour (Rao, 1951), Muttukadu backwater, Madras (Sarvesan, 1990), Vagai estuary (Rao, 1974) and Tuticorin coast (Nayar and Mahadevan, 1983; Rajapandian and Rajan, 1983; Thangavelu and Sundaram, 1983; Rajapandian et al., 1990). Though the magnitude of spawning peaks reported do vary, the close similarity in the timings of peak spawnings observed over several years can be taken as a strong indication that peak spawning in the above geographical region is a regular annual phenomenon, which occurs more or less during the same period.

Other environmental variables which appear to play important role in reproductive activity in the present study are the food availability indices. The initial peak period of food availability (December to January 1991) coincides with initial peak period of gametogenic activity. Similarly other months of high food availability (May to June, August 1991) were marked by intensive gametogenesis and spawning activity among the reproductively active group of oysters at stations 1 and 2. Thangavelu (1988) studying the feeding intensity of this oyster in a natural bed along the east coast (Pulicat Lake), reported high

feeding intensity (on natural phytoplankton crop) during the periods of active gametogenesis and also immediately after spawning. He attributed the initial high feeding intensity period to the requirement of high energy for formation of gametes and the second, to the recovery of energy lost in releasing gametes during spawning. He concluded that the reproductive status of C.madrasensis is mainly determined by feeding intensity. Reports on other species of bivalves which strongly correlate periods of phytoplankton blooms with active gametogesis, intensive spawning and building up of energy reserves after spawning, include those of Kautsky (1982) and Starr (1990) for mussles, Soniat and Ray (1985) and Ruiz et al. (1992) for oysters.

Also the occurrence of phytoplankton blooms along the southeast coast of India appears to be another regular annual phenomenon and the periods of maximum phytoplankton production observed in the Gulf of Mannar (Prasad, 1954) and along the Tuticorin coast (Marichamy et al., 1985; Rajapandian et al., 1990; Gopinathan and Rodrigo, 1991) more or less follow a similar trend as was observed in the present study. Therefore, the role of such regular phytoplankton maxima corresponding to peak periods of reproductive activity in C. madrasensis deserves importance while analyzing the influence of environmental parameters in the reproduction of this oyster.

On the basis of this study, it can be concluded that, probably the most important environmental variables which are likely to influence the gametogenesis and spawning of this oyster in coastal and backwater areas with narrow range of variation in salinity, appear to be

food availability, water temperature and to some extent variation in salinity.

The reproductive activity was poor among o year class oysters of station 2 and almost absent among both the age groups of oysters at station 3. At station 2, the o year class oysters showed very poor gametogenic activity in the initial phase of the experiment, and most of the oysters had gonads in indeterminate stage. Though accumulation of connective tissue was evident, the gonads were not fully filled and did not possess a healthy look in most of the cases. This could be attributed to negative impact of high levels of total suspended micro-matter and turbidity on the feeding rate of these oysters. Probably these young oysters, due to their higher growth efficiency, preferred to divert the energy in excess of maintenance to growth rather than reproduction. During the second phase of the experiment, gametogenic activity had increased among the above group of oysters. Though the reason for such a sudden increase in the reproductive activity is not clear, it could probably be due to comparatively favourable environmental conditions in July and August 1991, manifested by moderate food availability and decrease in the level of turbidity indices. The other assumption could be that there is certain degree of increase in the tolerance of these oysters to high turbid conditions, due to adaptive measures. Bayne and Newell (1983) reported disproportionate suppression of gamete production in a population of mussels exposed to unseasonal thermal stress and stated that environmental factors acting on the components of energy budget, may have a considerable impact on the energetics of reproduction. They further explained that while certain reproductive characteristics of a

species such as mean egg size, unit energetic cost of gamete production and age related increase in reproductive effort may be maintained across a wide range of environmental changes, other properties like timing of gametogenesis, spawning, fecundity and maximum reproductive effort attainable by individual are more prone to environmental changes.

At station 3, gametogenic activity was almost absent among both the age groups of oysters and throughout the study period the gonad was shrunken and filled with fluid. This could be only attributed to the utilization of energy reserve due to very low food availability at this site. Kautsky (1982) related the absence of gametogenesis and spawning in a population of mussels during a part of the year to shortage of available food in the environment.

Percentage mortality as well as over all mortality was the least among both the age groups of oysters at station 1, when compared to the oysters at other stations. Low rate of mortality reflects the non-stressful environmental conditions prevailing at this site.

At station 2, the periodical as well as over all percentage mortality of o year class oysters was comparatively higher than the o age oysters of station 1. Higher rate of mortality among these oysters could be attributed to stressful conditions of high levels of total suspended micro-matter and turbidity at this station. The mortality was higher during the second half of the experimental period and the reasons are unknown. Loosanoff (1961) stated that oysters subjected to high and prolonged exposure in turbid waters die because of clogging of the gill

with silt or other materials, which interfere with normal respiration and feeding. The percentage rate and over all mortality of 1+age oysters at station 2 was not high. However, as in the case of 0 age oysters, the mortality rate among this group of oysters also was comparatively higher in the second phase of the experiment for which the reasons are not clear.

The highest mortality of oysters among the three stations was recorded at station 3. This could only be attributed to the shortage of food at this station. Incze et al. (1980) recorded increased mortality in natural populations of M. edulis when conditions of reduced food availability coincided with increased temperatures, resulting in a negative scope for growth and rapid depletion of endogenous energy reserves. Kautsky (1982) studying a natural as well as experimental population of mussels, stated that during periods of food shortage mortality occurs due to utilization of energy reserves and also found that shell growth slows down and stops long before death.

All the hydrological variables monitored during the present study showed a distinct periodical variation which followed a more or less comparable trend at all the three stations, particularly at stations 1 and 2 which were situated very close to each other. Periodical variation in salinity closely followed the trends of water temperature and exhibited a bimodal cycle of distribution. The peak values correspond to hot periods of summer (April-May) and premonsoon (August-September), when atmospheric temperature was at the highest level. Minor drop in the values during June and comparatively rapid decline during November-

December, have been associated with indirect impact of southwest monsoon and direct effect of northeast monsoon respectively. Prasad (1954) reported that the Gulf of Mannar being wide open, its waters are subjected to considerable influence of water currents from the Indian ocean and adjacent seas. With the onset of southwest monsoon a coastal current commencing from the southern part of Arabian Sea, sweeps along the east coast and the direction of this current has been reported to reverse (north to south) with the onset of northeast monsoon (Prasad, 1954; Marichamy and Pon Siraimeetan, 1979).

The periodical trend and range recorded for the above parameters during the present study is comparable with the earlier reports from this coast (Malu Pillay, 1962; Marichamy and Pon Siraimeetan, 1979; Nayar and Mahadevan, 1983; Marichamy et al.,1985; Victor and Velayudhan, 1987; Rajapandian et al., 1990; Gopinathan and Rodrigo, 1991).

Dissolved oxygen registered a fall in March-April and August-September. During the northeast monsoon seasons and May-June period the values were higher. An inverse relationship between dissolved oxygen and water temperature, atmospheric temperature and salinity was observed in most of the months. Prasad (1956) stated that the probable factor contributing to higher levels of dissolved oxygen in the Gulf of Mannar is the existence of coral reefs and hence higher quantities of coral zooxanthellae which produce considerable amount of oxygen during photosynthesis. Probably, the same factor could account for higher levels of dissolved oxygen at station 3, since this area has a considerable population of corals. The dissolved oxygen range reported

by Victor and Velayudhan (1987) for this area is comparable to that obtained in this study.

Marginally higher pH and calcium values were recorded at station 3. At all the three stations, these two parameters in general remained at lower levels during monsoon seasons. The range in the values of pH and calcium reported by Victor and Velayudhan (1987) can be compared with the present observations.

The considerable difference in the level of turbidity and total suspended micro-matter among the three stations could be mainly attributed to the texture of their bottom sediments. The bottom of the pond (station 2) was extremely slushy with very fine loose top layer which would get dispersed easily. The bottom of the area adjacent to the earthen pond (in the bay) has almost similar texture. Normal coastal wave action and regular tidal currents keep the loose bottom sediments in suspension, as evident by the muddy appearance of water body in this area. The pond is connected to its adjacent area directly through an opening without a sluice gate. The tidal movement besides dispersing bottom sediments of the pond, carries muddy water into the pond also. At high tide the action of the water against the already eroded mud pond walls, breaks free more sediments from the wall into the pond. Another factor which further increases the muddy conditions in the adjacent water body to the pond is regular fishing activities of coastal fishermen. The water body adjacent to the pond is bound by land on three sides and therefore it forms a suitable fishing ground for coastal fishermen, who in turn disperse a lot of bottom sediments as they wade

through the water. The bottom of stations 1 and 3 are firm, and dense growth of sea grass at station 3 further prevents dipersal of bottom sediments.

A distinct increase in turbidity and total suspended micro- matter to peak levels during May-June at all the three stations could be attributed to factors like increase in turbulence due to coastal currents, strong south winds and rapid increase in phytoplankton crop during the above period. Prasad (1956) stated that with the onset of southwest monsoon (April-May), due to incursion of water currents from adjacent sea into the Gulf of Mannar and owing to strong southwest winds, the water in the Gulf becomes turbulent and that the secchi disc readings showed drastic reduction in visibility due to large quantities of suspended debris. He further explained that, such water currents are generally more rapid in shallow waters and in the proximity of land boundaries. Increase in turbidity along the Tuticorin coast during summer months have been reported by Marichamy et al., (1985) and Gopinathan and Rodrigo (1991).

During the northeast monsoon season, turbidity was high and an increase in the level of total suspended micro-matter and turbidity values was very conspicuous at station 2. This could be due to the direct impact of rain fall on the eroded mud walls of the pond (station 2) and drainage of rain water carrying sediments from the surrounding land. The flow of water currents (north to south) due to the onset of northeast monsoon (Prasad, 1954), could also be considered as a factor. Victor and Velayudhan (1987) monitoring the fluctuations in turbidity of

the Harbour waters (station 3) stated that, the southwest and northeast monsoons when active along the southeast coast of India are associated with large quantities of suspended matter. But, Gopinathan and Rodrigo (1991) reported high clarity (low turbidity) in the inshore waters of Tuticorin coast (10-15 m depth) during northeast monsoon, which is contradictory with the present study. However, the increase in turbidity during the above period was prominent at station 2 only. The range of turbidity (NTU) and total suspended micro-matter obtained in the present study cannot be compared with previous reports from this coast, because of different techniques adopted for analysis of this parameter.

The trend in periodical fluctuations in the standing phytoplankton crop during the present study at stations 1 and 2, are comparable to those of Prasad (1954) for the Gulf of Mannar, Marichamy et al. (1985) and Gopinathan and Rodrigo (1991) for inshore coastal waters of Tuticorin, and Rajapandian et al. (1990) for habitats of oyster beds, namely coastal and mangrove areas around Tuticorin. The level of chlorophyll-a and primary productivity recorded during the present study at stations 1 and 2 are also comparable with the reports by the above authors for waters of Tuticorin coast. However, the peak values of chlorophyll-a observed at station 2 are comparatively higher than the peak values reported for this area. Rajapandian et al., (1990) and Gopinathan and Rodrigo (1991) observed a very close relationship between the trend in fluctuations in chlorophyll-a and primary productivity along the Tuticorin coast. In the present study though the magnitude of production varied between stations 1 and 2, the trend in periodical

fluctuations in productivity indices was similar and a close relationship was observed between periodical variation in chlorophyll-a and primary productivity levels.

The magnitude of primary production and chlorophyll-a levels at station 3 was comparatively very low. As mentioned earlier the range of chlorophyll-a as reported by Victor and Velayudhan (1987) for this area is comparable to the values obtained in this study. The the exact reason for low phytoplankton crop at station 3 is not known. It may be due to high competition between phytoplankton population, dense sea grass and the coral population of this area for available micro-nutrients in the water. Another factor could be the sandy bottom of this area which may not be rich in organic matter. It is also probable that the rate of exchange of Harbour water (bound by long breakwaters) with the open sea being a slow process, the phytoplankton crop carried inside the harbour water gets grazed upon and due to natural morality coupled with low mixing with the open sea, remains at low levels. Based on organic production, Gopinathan et al. (1982) classified the esturine system of Cochin (southwest coast) into low ($<500 mgC/m^3/day$), moderate ($500\text{-}1500 mgC/m^3/day$) and high ($>1500 mgC/m^3/day$) productive areas. They stated that high rate of production has been recorded in the regions where the influx of the inshore water is relatively greater, and where there is least influence by the 'new water', the rate of production is low.

Prasad (1954) stated that nutrient level in the Gulf of Mannar do not show violent fluctuations, as are characteristics of temperate

waters. He reported a general inverse relationship between quantities of phytoplanktons and nutrient salts (silicates, nitrates, and phosphates). During the present study, in general, some micro-nutrients showed direct and others inverse monthly relationship with phytoplankton crop. The seasonal curves of average values of phytoplankton appear to have an overall inverse relationship with that of phosphorus and ammonia, and a direct relationship with silicate, nitrate and nitrite. Above relationships were distinct at stations 1 and 2 only. Rajapandian et al. (1990) and Gopinathan and Rodrigo (1991) reported an inverse relationship between phytoplankton crop (chlorophyll-a and primary productivity) and silicate and phosphate levels and a direct relationship with nitrate and nitrite levels along the Tuticorin coast. Mathews (1990) observed a direct relationship between the levels of micro-nutrients (nitrate-N, nitrite-N, ammonia-N, phosphate and silicate-silicon) and that of primary production values in a salt pan along the Tuticorin coast. Therefore considerable variation in the relationships between the above parameters is evident from year to year. An inverse relationship between seasonal variation in the level of micro-nutrients and phytoplankton crop has been stated to reveal a significant utilization of the particular nutrients during peak periods of phytoplankton blooms (Gopinathan and Rodrigo, 1991), which in turn may depend on preference and requirement of dominant species of phytoplankton.

CHAPTER 2

SECTION I

INTRODUCTION

The culture techniques for most of the bivalves including the oysters, have been broadly classified into two groups, I) bottom and, II) off bottom methods of culture. Bottom culture as the name implies, is the method in which the animals are grown directly on the bottom, and off-bottom culture is a method whereby the growing bivalve is held off the bottom by various means. Suspended bivalves are generally known to grow more rapidly than those on the bottom and have better condition index. Higher food availability, less siltation, reduced fouling and predation are the reasons reported for better growth and condition of off-bottom cultured bivalves (Manzi et al., 1977; Frechette and Bourget, 1985).

Among the variety of off-bottom culture methods, the ones which permit the animals to be placed at a level where they are exposed for brief periods during most tidal cycles (for eg: racks) have been stated to have the advantage of controlling fouling to a considerable extent (Quayle, 1980). Periodic aerial exposure as an ecological parameter has been the subject of a number of studies dealing with intertidal versus subtidal bivalve culture, in order to determine the optimal combination of environmental parameters that will yield the highest rate of growth.

Traditionally it has been accepted that bivalves suspended subtidally grow faster due to extended periods of immersion, during which the animals feed and gain energy for growth. However, Gillmor (1982) in his work on the instantaneous growth rates of various intertidal bivalves aerially exposed for different daily periods,

concluded that in high intertidal forms there may be a degree of optimality associated with periodic exposure. He presented both experimental and theoretical evidence to show that intertidal bivalves could be capable of better growth at certain intertidal levels than at subtidal ones, e.g: Crassostrea virginica and Geukensia demissa. Crosby et al. (1991) in his studies on the effects of immersion time and tidal position on in situ growth rates of Crassostrea virginica stated that, if an intertidal suspension-feeding bivalve species is able to maintain equal (or greater) rates of growth as their subtidal siblings then, a) some degree of adaptive metabolic capacity must exist in the intertidal populations to compensate for shorter feeding periods and/or b) some selective disadvantage such as predation, disease or lower food quality/quantity, must exist in the subtidal populations.

Gillmor (1982) explained that, adaptations to environment are generally divided into two major categories: resistance adaptations and capacity adaptations. While resistance adaptations are related to survival at environmental extremes, capacity adaptations are involved less with lethal limits of an organism and more with maintenance rate of functions at optimal levels over the normal environmental range. He grouped capacity adaptations into those which are energy - conserving and those which are energy-supplementing. Among energy-conserving adaptations the following were reported to be prominent: supression of mechanical activity during emersion, presence of anaerobic pathways more efficient than classical glycolysis (Embden-Meyerhoff-Parnas pathway) for energy production during emersion, or the ability to use atmospheric oxygen for respiration, relative insensitivity of metabolism to

temperature during both emersed and immersed periods, and reduction of physiological energy needs during exposure. He further explained that the focal point of energy-supplementing adaptations in intertidal animals is food assimilation, and more food must be assimilated per unit of time available for feeding if intertidal organisms are to show any compensation for the restrictions placed on this time by tidal exposure.

Elvin and Gonor (1979) on the basis of their experiments using radioactive labelled Isochrysis sp. reported that periods of exposure lead to increased assimilation efficiency in Mytilus californianus. Littlewood (1988) in his experimental studies on subtidal versus intertidal cultivation of mangrove oyster Crassostrea rhizophorae, reported that animals held at mid-intertidal heights attained greater sizes and weights than those grown at lower levels. He suggested that, careful studies on growth and natural tidal preference should be conducted before deciding whether to cultivate bivalves subtidally or intertidally. Crosby et al. (1991) stated that, although numerous combinations of specific metabolic adaptations and selective disadvantage are possible, one need only study rates of growth in intertidal versus subtidal suspension feeding siblig bivalve populations under the same environmental conditions (other than immersion time), to demonstrate whether such adaptive metabolic capacity or selective disadvantages exist for a given species.

The Indian backwater oyster, Crassostrea madrasensis has been experimentally cultured both intertidally (Nayar and Mahadevan 1983; Rao et al., 1983) and subtidally (Purushan et al., 1983); but there exists

no comparative information on the relative efficiency of these methods. In the light of works discussed above, a closer look at growth performance of this oyster occurring intertidally and subtidally in nature is required.

Keeping in view the importance of aerial exposure on growth of intertidally occurring bivalves, the present study was conducted to assess the growth of Crassostrea madrasensis in various intertidal levels and a subtidal level.

CHAPTER 2

SECTION II

MATERIALS AND METHODS

STUDY AREA:

Tuticorin bay (latitude 8° 50'N and longitude 78° 8'E) situated in the southeast coast of India, was chosen as the site for carrying out the experiment (Fig. 38), as the performance of oysters grown at this site (designated as station 1 in the previous experiments) were comparatively good, indicating the suitability for oyster culture. It is a semi-enclosed bay having a shallow shore with water depth ranging from 0.5 to 2.5m. Roughly 100 hectares of such shallow area is available and generally is not subjected to high waves or wind action. The experimental structures were erected in the tidal zone, where the maximum tidal fluctuation is 74cm (Indian tide tables, Department of Survey, Government of India).

EXPERIMENTAL STRUCTURES:

In order to expose the animals to three intertidal levels with different degrees of aerial exposure and one subtidal level, two long wooden poles with one end sharpened to enable them to be easily driven into the bottom, were planted vertically in a line at a distance of 2.5m apart. These two vertical poles were connected horizontally by three wooden cross poles of 4-5cm diameter in the intertidal zone and a cross pole of similar dimensions in the subtidal zone. The cross poles were bound to the vertical poles using coir and 3mm thick synthetic ropes at different precalculated heights on the basis of requirements of the

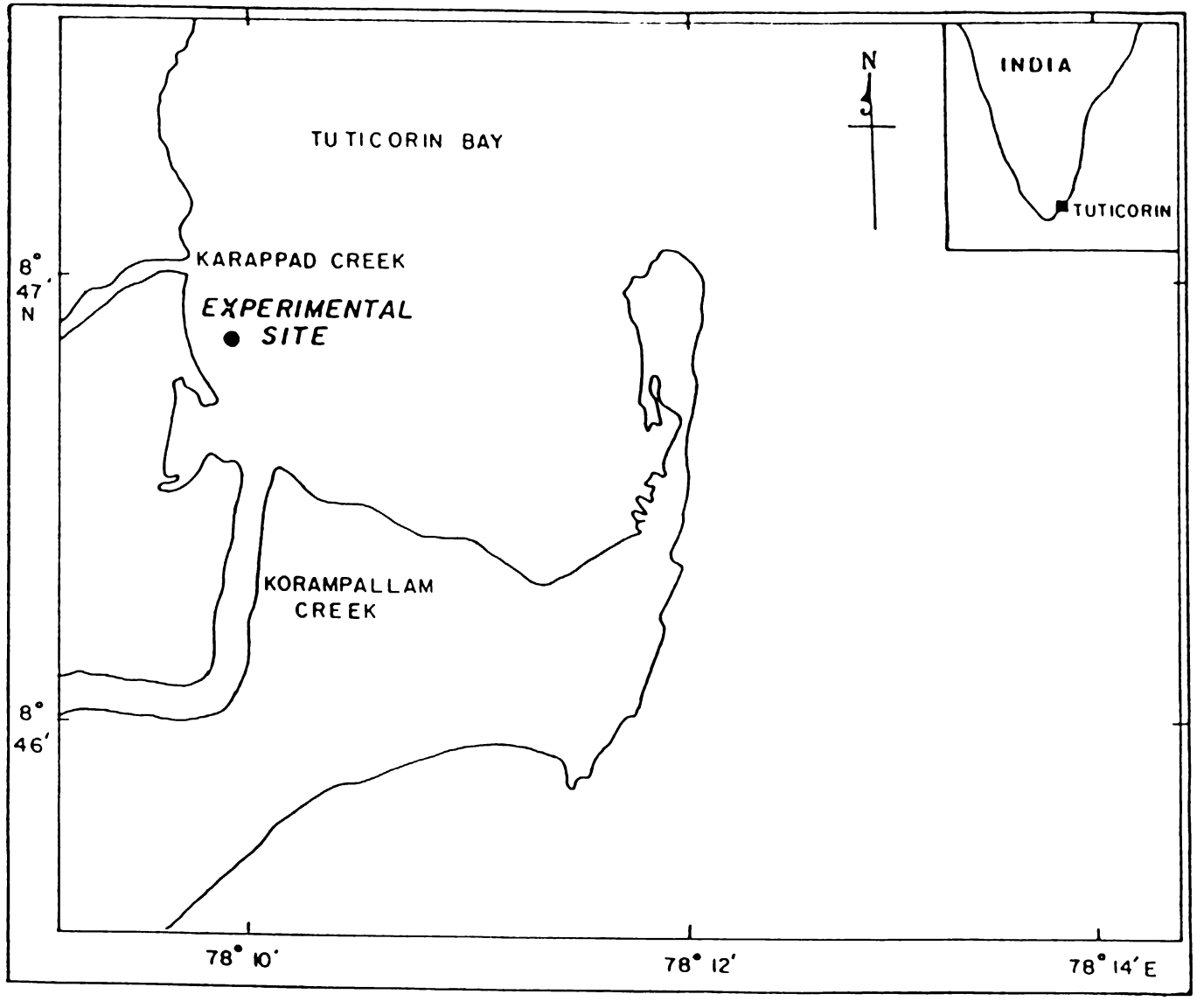


Fig.38. Map showing the experimental site in Tuticorin bay.

experiment. In addition to binding materials, iron nails were inserted into the vertical poles just below the cross poles to provide extra support and prevent shifting of the cross poles from their original position. In this manner four single racks were constructed and were designated from top to bottom as level 1, 2 and 3 in the intertidal zone and level 4 in the subtidal zone (Plate VIII B).

The effects of aerial exposure were separated from the effects of fouling by setting up two sets of cages at each level, one with foulers being removed from experimental oysters and the other with fouling being allowed. Hereafter these two sets will be referred to as cleaned and uncleaned oysters.

The eight cages suspended at all the four levels were tagged and numbered as cages 1 to 8 from top to bottom level, using small aluminium plates. All the eight cages were regularly brush-cleaned to permit maximum water circulation. At weekly intervals, fouling organisms settled on the oysters in cages I, III, V, and VII (cleaned oysters) were removed by scraping and brushing, and oysters in cages II, IV, VI and VIII were not cleaned (uncleaned oysters).

When the cages suspended in the intertidal zone were half submerged, the oysters in these cages were considered fully submerged. The height of the cages measured from the level of mean low tide upto the mid-portion of the cage, and the degree of mean daily aerial exposure the oysters were subjected to are as follows:

PLATE VIII.

A. A view of a natural bed of Crassostrea madrasensis along the Tuticorin coast.

B. Racks for rearing the experimental oysters at three intertidal levels and a subtidal level, (subtidal rack immersed).

PLATE VIII

A

B

Cages I and II (Level 1) were suspended at a height of 46cm (± 2cm) and had a mean aerial exposure of 79.28%, cages III and IV (Level 2) were suspended at a height of 28cm (± 2cm) and had a mean aerial exposure of 42.60%, cages V and VI (Level 3) were suspended at a height of 12cm (± 2cm) and had a mean aerial exposure of 12.32%, and cages VII and VIII (Level 4) were suspended at a height of -15cm (± 2cm) and the oysters in these cages remained submerged always (nil aerial exposure). The mean daily aerial exposure was worked out on the basis of Indian tide table chart, published by the Department of Survey, Government of India.

EXPERIMENTAL OYSTERS AND STOCKING:

The experimental oysters were procured from the oyster farm of the Tuticorin Research Centre of Central Marine Fisheries Research Institute. The seed of the oysters in the research centre's farm were hatchery produced and reared on shell strings suspended from racks. Juvenile oysters belonging to the same batch of spat were detached from the cultch (oyster shells), brush-cleaned and rinsed with filtered seawater. An oyster was classified as damaged, if in the process of separating it from its cultch, the shell had broken in anyway so as to expose its flesh.

The undamaged oysters were divided into eight as equal as possible size groups on the basis of shell dimensions and were stocked in the cages on 11.7.1991 at a rate of 92 to 97 oysters per cage. The mean initial size of the experimental oysters at the time of stocking were as presented:

Cage I oysters had an initial mean shell height of 28.78mm (n=92; S.D.= ± 7.07) and an initial whole weight of 3.87g (n=92; S.D.= ± 1.72), cage II oysters had a mean shell height of 29.45mm (n=93; S.D. = ± 6.95) and mean whole weight of 5.36g (n=93; S.D.= ± 2.10), cage III oysters had a mean shell height of 28.24mm (n=92; S.D.= ± 6.89) and a whole weight of 4.621g (n=92; S.D.= ± 2.08), cage IV oysters had a mean shell height of 28.08mm (n=97; S.D.= ± 6.49) and a mean whole weight of 4.75g (n=97; S.D.= ± 1.95), cage V oysters had a mean shell height of 28.98mm (n=92; S.D. = ± 6.73) and a mean whole weight of 4.26g (n=92; S.D.= ±2.13), cage VI oysters had a mean shell height of 28.19mm (n=92; S.D. = ± 5.87) and mean whole weight of 5.04g (n=92; S.D.= ± 1.79), cage VII oysters had a mean shell height of 28.29mm (n=93.50; S.D.= ± 6.17) and mean whole weight of 5.31g (n=93; S.D.= ± 2.21), and cage VIII oysters had a mean shell height of 28.87mm (n=92; S.D.= ± 5.62) and mean whole weight of 5.13g (n=92; S.D.= ± 1.72).

BIOLOGICAL PARAMETERS:

Regular monthly measurements of shell height, whole weight and mortality counts of oysters was carried out for a period of 7 months from July 1991 upto February 1992. The wet meat weight measurements of 37 to 42 randomly sampled oysters from each cage was carried out only once at the end of the experiment.

All the oysters were brought to the laboratory and kept in separate fibre glass tanks filled with filtered sea water and provided with aerators, prior to measurements.

I. Shell height:

The shell height of all the oysters from each cage were measured individually using vernier calipers, upto the nearest 0.01mm. Shell height was measured as the distance from the end of the umbo to the ventral shell margin (Galtsoff, 1964).

II. Whole weight:

While the whole weight of the cleaned oysters (cages I, III, V and VII) was recorded monthly, the whole weight of uncleaned oysters (Cages II, IV, VI and VIII) was taken only at the beginning and end of the experiment. All the oysters in each cage were brush-cleaned, rinsed with filtered sea water, blotted dry and were weighed to the nearest 0.1g using an electric balance. The oysters were weighed individually only at the beginning and end of the experiment, and the monthly weights were taken for groups of 5 to 10 oysters.

III. Mortality:

Mortality data for both cleaned and uncleaned oysters were collected monthly from counts of left or cupped valves of dead oysters.

IV. Wet meat weight:

The oysters collected from each cage were cut open carefully, the tissue was seperated from the shell and dried using blotting sheets. The tissues were placed individually in labelled and preweighed aluminium foil dishes, and weighed to the nearest 0.01g using an electric Sartorius balance (Type 1712).

CHAPTER 2

SECTION III

RESULTS

The results of biological parameters studied during the period from July 1991 to February 1992 are presented under the following headings.

Shell height:

The observed variations in monthly mean shell height values of cleaned and uncleaned oysters at all the four tidal levels are presented in Figs. 39A and B, respectively.

The final mean shell heights of cleaned and uncleaned oysters recorded in the month of February 1992 were 33.87mm (n=81; S.D.=$\pm$ 4.85) in cage I, 36.52mm (n=84; S.D.=$\pm$ 6.07) in cage II, 54.84mm (n=84; S.D.=$\pm$ 8.45) in cage III, 51.69mm (n=89; S.D.= $\pm$8.23) in cage IV, 61.58mm (n=89; S.D.=$\pm$ 8.9) in cage V, 58.46mm (n=86; S.D.=$\pm$ 8.20) in cage VI, 54.89mm (n=82; S.D.= $\pm$9.91) in cage VII, and 52.77mm (n=82; S.D.=$\pm$ 8.27) in cage VIII (Figs. 39A and B); (Plate IX).

The effect of different degrees of aerial exposure on growth in shell height of cleaned and uncleaned oysters was analysed assuming that the growth over the period of time at each tidal level follows $Y = ax^b$, where Y = shell height and x=time (Table 11). Since there was no significant difference between shell height growth of cleaned and uncleaned oysters at any of the levels, their values were pooled and are presented in Table 12. The analysis of covariance (ANCOVA) was carried out to test whether there was any significant difference between the

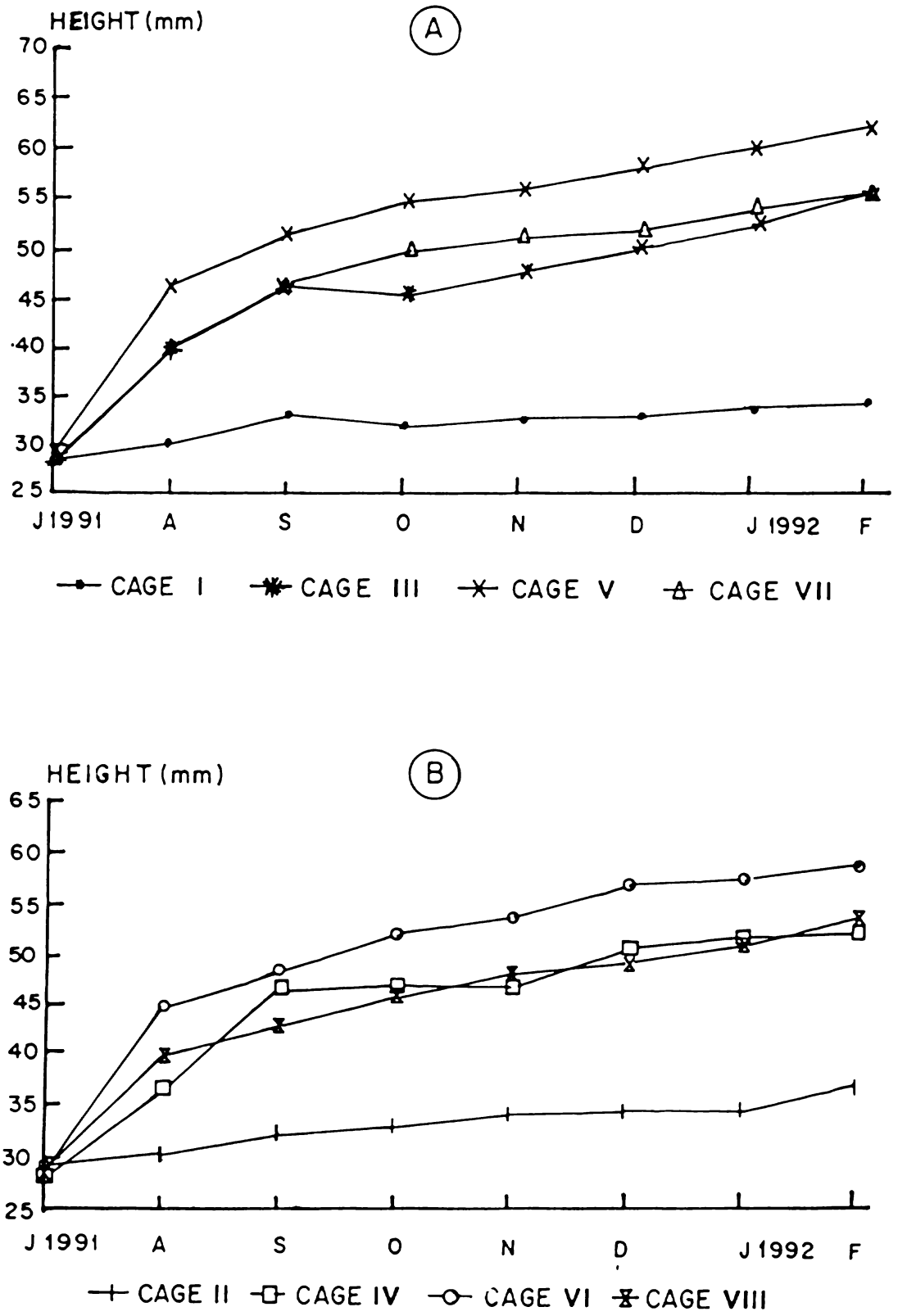


Fig. 39. Monthly variations in mean shell height of (A) cleaned oysters and (B) uncleaned oysters.

Table 11. The shell height parameters of cleaned and uncleaned oysters ($y = ax^b$).

Levels	Cages	a	b	r
1	I	3.3581	0.0893 (± 0.0116)	0.9427
	II	3.3575	0.1000 (± 0.0122)	0.9579
2	III	3.4162	0.2866 (± 0.0307)	0.9672
	IV	3.3951	0.2948 (± 0.0334)	0.9635
3	V	3.4912	0.3277 (± 0.0454)	0.9468
	VI	3.4547	0.3252 (± 0.0423)	0.9528
4	VII	3.4265	0.3016 (± 0.0330)	0.9660
	VIII	3.4248	0.2686 (± 0.0228)	0.9790

Figures in parenthesis denote the standard error.

Table 12. The pooled shell height parameters at the four levels ($y = ax^b$).

Levels	a	b	r
1	3.3578	0.0947 (± 0.0097)	0.927
2	3.4057	0.2907 (± 0.0212)	0.965
3	3.4729	0.3264 (± 0.0299)	0.946
4	3.4256	0.2851 (± 0.0212)	0.969

Figures in parenthesis denote the standard error.

Table 13. The results of analysis of covariance (ANCOVA) test between different levels in respect to shell height.

Source	Degree of freedom	Mean square	F-value
Slopes	3	0.549	77.16**
Error	59	0.007	
Elevation	3	0.079	24.26**
Error	56	0.003	

** Significant at 1% level.

levels with respect to shell height growth. The result obtained (Table 13) revealed that the shell height growth of oysters at level 1 differed significantly ($P \leq 0.01$) from the other three levels, and that of oysters at levels 2 to 4 did not differ significantly.

Whole weight:

The Figs. 40A and B represents the observed monthly variations in mean whole weight values of cleaned oysters at the four tidal levels. The final mean whole weight of cleaned and uncleaned oysters in the month of February 1992 were 12.08g (n=81; S.D.=$\pm$ 3.44) in cage I, 13.06g (n=84; S.D.=$\pm$ 4.60) in cage II, 28.70g (n=84; S.D.=$\pm$ 9.53) in cage III, 28.06g (n=90; S.D.=$\pm$ 8.13) in cage IV, 32.63g (n=89; S.D.=$\pm$ 10.40) in cage V, 30.01g (n=86; S.D.=$\pm$ 8.09) in cage VI, 23.11g (n=82; S.D.=$\pm$7.64) in cage VII, and 21.42g (n=82; S.D.=$\pm$ 7.68) in cage VIII.

Since the mean whole weight of uncleaned oysters was recorded only at the beginning and at the end of the experiment, to assess the effect of different degrees of aerial exposure on whole weight growth, only the monthly data of cleaned oysters were subjected to statistical analysis. As in the case of shell height growth, the whole weight growth of oysters at each level over the period of time follow $Y = ax^b$ (Table 14). The analysis of covariance (ANCOVA) detected no significant difference for whole weight growth of oysters at levels 2 to 4. However, ANCOVA did yield a significant ($P \leq 0.01$) difference between whole weight growth of oysters at level 1 and the other three levels (Table 15).

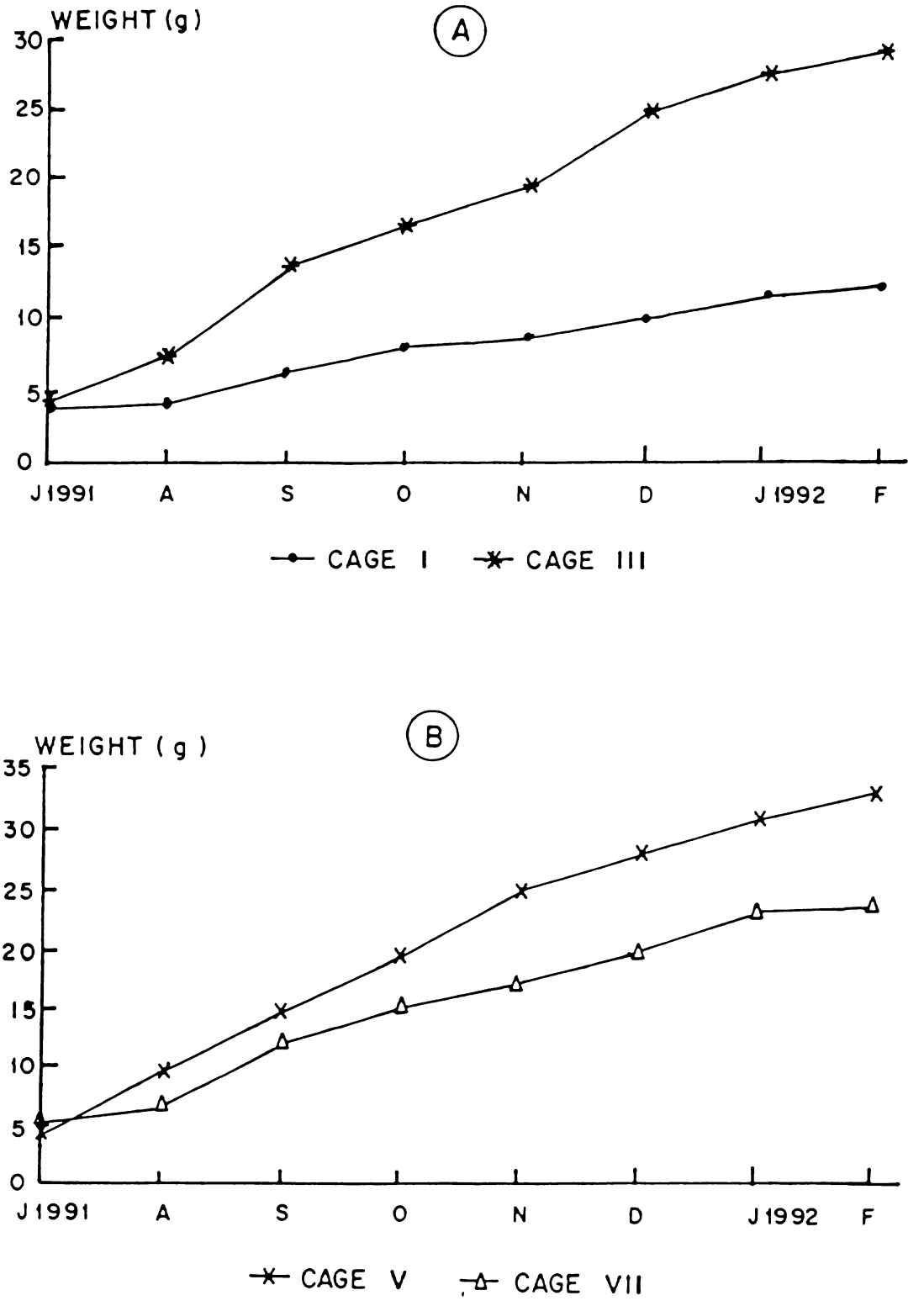


Fig. 40. Monthly variations in mean whole weight of cleaned oysters

Table 14. The whole weight parameters of cleaned oysters ($Y = ax^b$).

Levels	a	b	r
1	1.4575	0.5095 (± 0.0558)	0.925
2	1.5192	0.8929 (± 0.0252)	0.994
3	1.5681	0.9271 (± 0.0308)	0.992
4	1.5927	0.7363 (± 0.0333)	0.986

Table 15. The results of analysis of covariance (ANCOVA) test between levels in respect to whole weight.

Source	Degree of freedom	Mean square	F-value
Slopes	3	1.380	61.86**
Error	59	0.022	
Elevation	3	0.251	24.97**
Error	56	0.010	

** Significant at 1% level.

PLATE IX. Samples of oysters collected at the end of the experiment from three intertidal levels (the first three upper rows) and from one subtidal level (the last row).

PLATE IX

Wet meat weight:

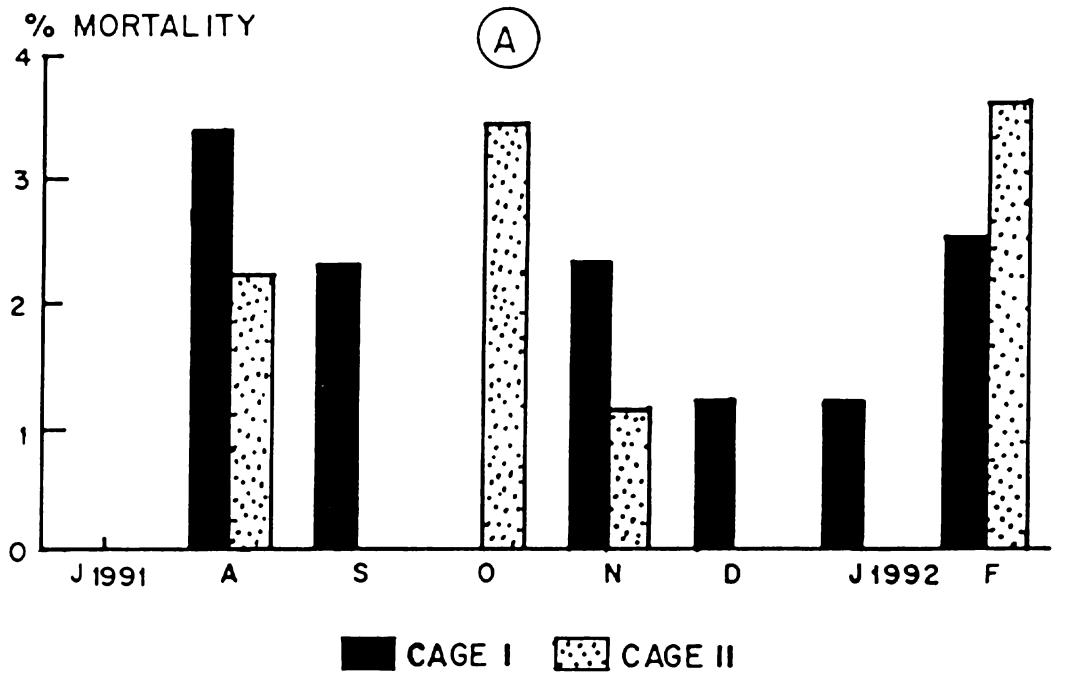
The mean wet meat weight of randomly sampled oysters were recorded only at the end of the experiment.

The final mean wet meat weight values of cleaned and uncleaned oysters were 1.157g (n=40; S.D.=± 0.412) in cage I, 1.10g (n=38; S.D.=±0.34) in cage II, 2.348g (n=42; S.D.= ± 0.85) in cage III, 2.20g (n=41; S.D.=± 0.70) in cage IV, 2.753g (n=39; S.D.= ± 0.78) in cage V, 2.518g (n=40; S.D.= ± 0.46) in cage VI, 1.899g (n=39; S.D.= 0.46) in cage VII and 2.016g (n=37; S.D.= ± 0.47) in cage VIII.

Mortality:

The plots of monthly percentage mortality against time are given in Figs. 41A and B for oysters at levels 1 and 2, and in Figs. 42A and B for oysters at levels 3 and 4. As can be seen in these figures, the oysters grown at highest and lowest levels comparitively suffered greater mortality.

The overall percentage mortality for cleaned and uncleaned oysters were 11.09% in cage I, 9.67% in cage II, 8.69% in cage III, 8.24% in cage IV, 3.26% in cage V, 6.52% in cage VI, 11.82% in cage VII, and 10.86% in cage VIII.



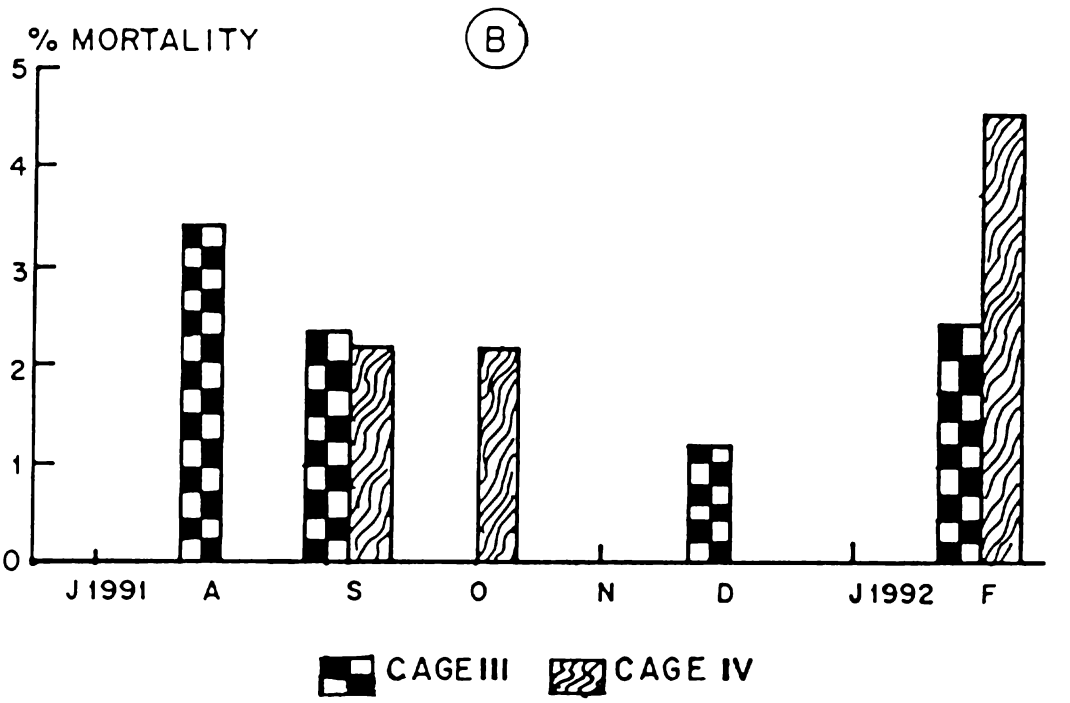
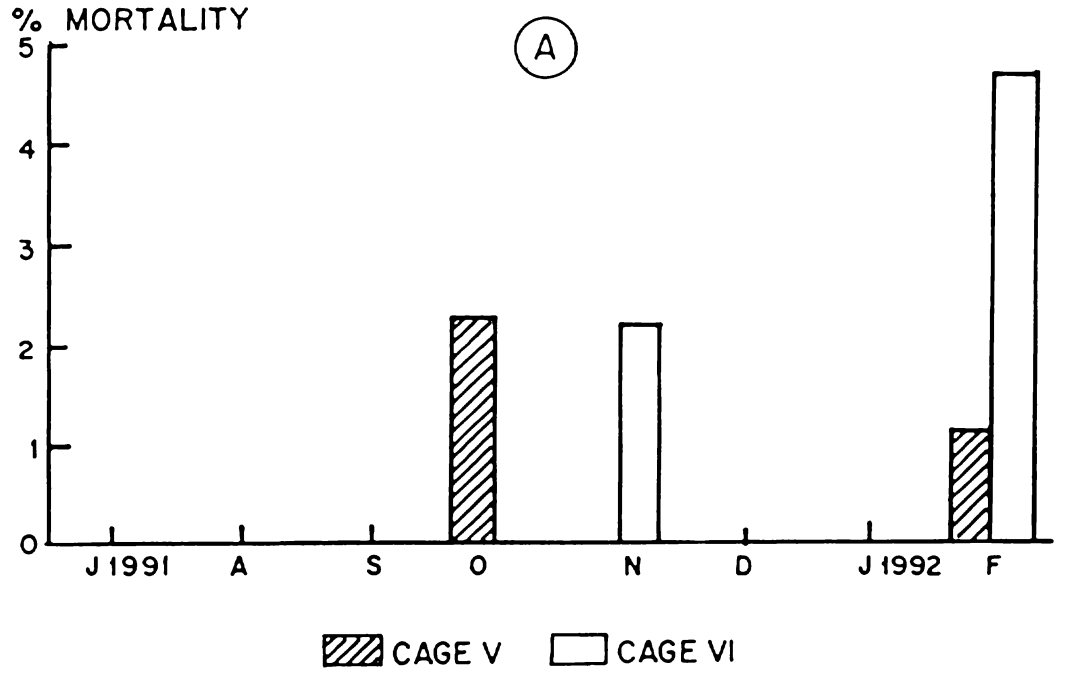


Fig. 41. Monthlyy percentage mortality of oysters at (A) tidal level 1 and (B) tidal level 2.



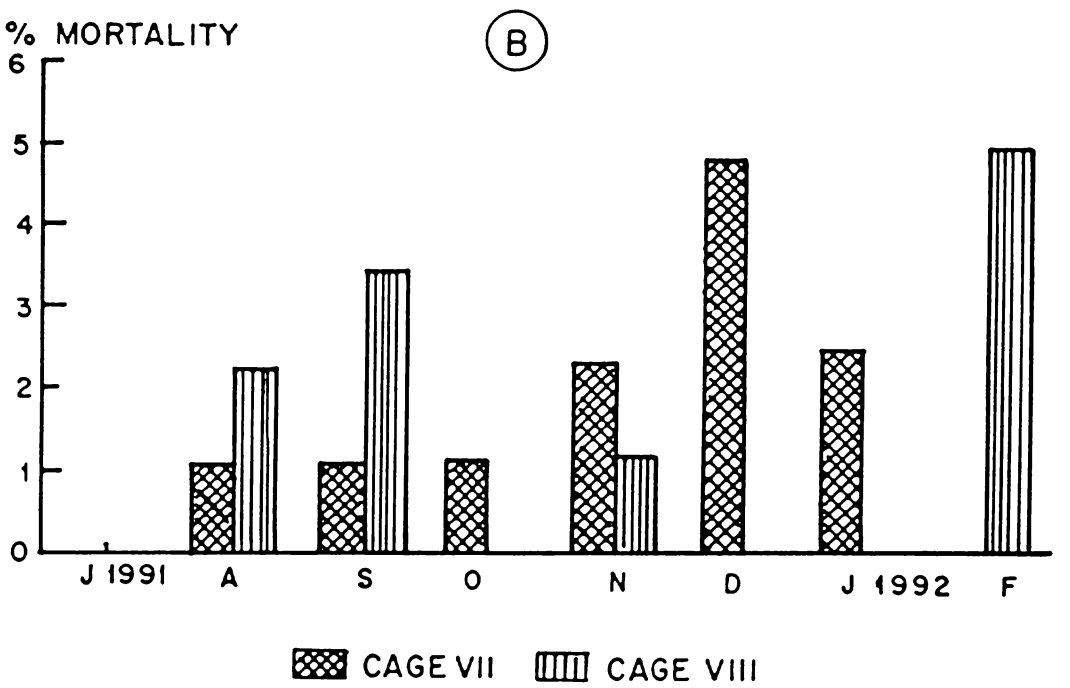


Fig. 42. Monthly percentage mortality of oysters at (A) tidal level 3 and (B) tidal level 4.

CHAPTER 2

SECTION IV

DISCUSSION

The indian backwater oyster, C. madrasensis is known to grow abundantly in the wild forming extensive beds in the form of dense or patchy aggregations in estuaries, creeks, bays and backwaters (Mahadevan, 1987). It is also found in sheltered areas like ports and harbours where it occurs in large numbers attached to pillars, walls of wharves and buoys, and along the open coasts where suitable substrata are present for settlement. It has been reported to occur from mid-littoral zone to a depth of 15-16m (Rao, 1987).

As was mentioned earlier, C. madrasensis has been experimently cultured in subtidal as well as intertidal zones. But there is no information regarding the comparative performance of this oyster in the above zones. One advantage of intertidal oyster culture has been stated to be the reduced settlement of fouling organisms due to aerial exposure (Quayle, 1980). It is evident from the results of the present growth experiments in intertidal and subtidal zones, that fouling did not appear to play an important role, since the absolute growth obtained by cleaned and uncleaned sets of oysters within each tidal level did not differ significantly. However, while fouling was permitted on uncleaned oysters only, the cages of both sets of oysters were not allowed to be fouled (to facilitate free exchange of water), and foulers and predators were removed from both oyster cages. In other words the settlement of fouling organisms was not permitted to occur in the true sense.

Gillmor (1982) assessing the intertidal growth and capacity adaptations in five species of bivalves in laboratory as well as shore

experiments, reported that C. virginica and G. demissa showed abilities to supplement energy input and growth per unit immersion time was better at certain intertidal levels than subtidally. While the growth rate of C. virginica was reported to peak at 20 to 40% aerial exposure in shore experiments, growth data of G. demissa peaked at about 50% mean aerial exposure in laboratory and 20% aerial exposure in shore experiments. The intertidal growth performance of the above bivalves was stated to correspond well with their natural level of occurrence in the shore.

During the present experiment, though no significant difference was observed in the absolute growth (shell height, whole weight) of oysters experiencing 0 to 42.60% mean daily aerial exposure (levels 2 to 4), the oysters grown at level 1 (79.28% aerial exposure) showed significantly reduced mean shell height and whole weight growth. The highest and lowest growth was recorded for oysters at level 3 (12.32% mean aerial exposure) and level 1 (79.28% mean aerial exposure), respectively. The results indicate that C. madrasensis shows improved growth at low intertidal levels when compared to subtidal or mid and higher intertidal levels.

Gillmor (1982) explained the better performance of bivalves in intertidal zone in terms of contribution due to certain physiological adaptations namely energy-conserving and energy-supplementing capacity. Energy-conserving adaptations reported by him were presented in the introduction section. He considered food assimilation as the major point of energy-supplementing capacity adaptations and stated that the intertidal animals must assimilate more food in periods available for

feeding(immersion time) in order to compensate for restriction placed on this feeding period by tidal exposure (emersion time). He related such energy-supplementing adaptations leading to positive energy input to (i) discontinuous feeding due to tidal cycle (ii) enhanced rate of feeding during immersion time and (iii) continuation of digestive activity during periods of emersion. The above phenomena were reported to result in the processing of more food during a tidal cycle. Langton and Mckay (1976) showed that rates of growth of juvenile oyster, C. gigas are higher when they are fed several batches of algae each day, rather than an equal ration at a constant concentration. Epifanio and Ewart (1977) stated that it would appear appropriate in mariculture practises to take advantage of the periodicity in filteration and digestion by offering algae in pulses rather than maintaining a constant supply.

In the light of the above information and the results of the present study it can be said that, C. madrasensis is capable of maintaining a higher positive energy balance to improve growth at certain low intertidal levels, with about 12.32% mean daily aerial exposure. On the other hand, increase in energy loss due to further increase in the period of aerial exposure is demonstrated by reduced growth of oysters at levels 2 and 1 which are placed at higher mean aerial exposure levels of 42.60% and 79.28%, respectively.

The experimental oysters at intertidal levels had comparatively thicker and more cupped shells when compared to the subtidal ones. This could be attributed to exposure to sunlight and higher atmospheric

temperature. The wet meat weight growth of oysters measured at the end of the experiment showed the same trend as in their shell height and whole weight. The highest and lowest mean wet meat weight was recorded for oysters at level 3 and 1, respectively. However, it should be mentioned that while majority of subtidal oysters appeared to be in spent condition at the time of meat weight analysis, the intertidal oysters particularly the ones at level 1 had well developed gonads. The reason for probable earlier spawning among the subtidal oysters is not known. Since in the previous experiments it was observed that spawning leads to weight loss in this oyster, the above factor most probably would have had considerable negative impact on the mean meat weight of subtidal oysters.

Another factor which strongly indicated the presence of high intertidal capacity adaptations in C.madrasensis is the fact that experimental oysters were able to maintain a positive energy balance and to grow even at 79.28% mean daily aerial exposure level. Littlewood (1988) studying the growth performance of C.rhizophorae in intertidal and subtidal levels, reported highest growth for oysters held at mid-intertidal levels and also observed growth in oysters held at 98% mean daily aerial exposure level.

The monthly and over all percentage mortality of cleaned and uncleaned sets of oysters within each tidal level did not show any appreciable difference. However, mortality among the oysters at levels 1 and 4 was comparatively higher than at other levels. Littlewood (1988) attributed the higher mortality among oysters experiencing longer

periods of exposure to increased thermal, respiratory and desication stress. Most probably in the present study also similar factors could have been responsible for higher mortality among the oysters at level 1. Higher mortality among subtidal oysters must have been due to factors not known.

SUMMARY

The meat of the edible oyster Crassostrea madrasensis could be a good source of animal protein for the growing Indian population. Despite several advances made in culture technology of this oyster, no significant commercial attempt has been made in this field. One major factor for such a set back has been pointed out to be the lack of precise information on ecological characteristics of sites suitable for culture of this species. A review of literature on C. madrasensis reveals the existence of considerable disparity in growth, survival and production of this oyster cultured experimentally at different regions along the Indian coast. Absence of risk factors and greater predictability of economics of production can create confidence amongst individuals and agencies interested in taking up oyster culture.

Thorough understanding of environment-species relationship leads to selection and identification of sites suitable for culture of the candidate species. The aim of the present study is towards better understanding of interaction of C. madrasensis with its surrounding environment. The main objective of the study is to develop a back ground for subsequent development of a site suitablility standard index for culture of C. madrasensis along the Indian coast.

To assess the influence of various environmental parameters on the biology of C. madrasensis, two age classes of cultchless oysters designated as 0 age (2 months old after settlement) and 1+ age (19 months old) were transplanted and reared at three sites, having wide

variations in their ecological conditions, along the Tuticorin coast (south east coast of India). Suspended rack and tray/cage culture method was adopted for rearing of the oysters at each site. The experimental structures were erected in shallow waters of Tuticorin bay (station 1), a coastal earthern pond (station 2), and Tuticorin harbour (station 3). The biological parameters such as shell height, whole weight, whole volume, wet meat weight, dry meat weight, condition index, sex ratio, maturity stages of gonad and mortality of both the age groups of oysters, and hyrdological parameters such as temperature, salinity, dissolved oxygen, pH, turbidity, total suspended micro-matter, calcium, nitrite-N, nitrate-N, ammonia-N, reactive phosphorus, silicate, chlorophyll-a, net and gross primary productivity of all the experimental stations were analysed and recorded fortnightly for a period of 16 months (October 1990 - January 1992).

The results of statistical analyses (principal components analysis and analysis of variance test) applied to the environmental data of all the three stations show that the parameters which contribute significantly to variations in ecological conditions of these sites are the level of food availability indices (chlorophyll-a, net and gross primary production), turbidity, total suspended micro-matter (TSM), calcium and silicate. On the other hand, comparisons of polynomial regressions fitted to station specific growth data of both the age groups of oysters show that, 0 age oysters of station 1 and 1+ age oysters of station 2 had significantly ($P \leq 0.05$) higher growth than their corresponding age group of oysters at the other two stations.

Significantly higher growth of 0 age oysters at station 1, which is also comparable with higher ranges of growth reported for this species by earlier workers, was associated with elevated levels of food availability indices and non-stressful ranges of other environmental parameters prevailing at this site. On the other hand, low percentage growth increments of 1+ age oysters of this station which were exposed to similar conditions, could be due to the effect of age and size on growth efficiency.

At station 2, though the level of food availability indices were significantly higher than that of other stations, growth of 0 age oysters was significantly lower than 0 age oysters of station 1. Comparatively higher levels of turbidity (6.09 to 19.99 NTU) and total suspended micro-matter (89 to 208.56 mg/l) prevailing at station 2 appear to be the most important factors preventing the optimum utilization of available ration by this group of experimental oysters. High turbid conditions have been reported to cause reduction in pumping rate, clearance rate and dilution of available food which consequently lead to a decline in energy available for growth. However, significantly higher growth of 1+ age oysters at station 2 indicate their higher tolerance to such turbid conditions. It has been reported that same species of bivalves may show a difference in tolerance towards suspended micro-matter depending upon the condition of their normal habitat before transplantation. There are also reports which relate the selection efficiency of bivalves (in turbid conditions) directly to the size of their labial palps. In the present study, while the 0 age oysters were produced in the hatchery and grown for a few weeks in filtered and clear

sea water before transplantation, 1+ age oysters were procured from the oyster farm situated in the Tuticorin bay. Therefore, 1+ age oysters were from a habitat with comparatively much higher turbid conditions than 0 age oysters. And, if indeed there is a direct correlation between labial palp size and the efficiency of the bivalves to cope up with turbid conditions, then it can be said that 1+ age oysters must have used their larger labial palps to make better use of the available ration despite high loads of suspended micro-matter.

At station 3, growth performance of both the age groups of oysters was extremely poor, indicating stressful ecological conditions. The principal hydrological parameters which most probably could be responsible for causing such stressful condition are the combined effect of low food availability (0.83 to 5.27 µg/l chlorophyll-a; 145.46 to 339.41 mgC/m^3/day net primary production; 193.95 to 484.28 mgC/m^3/day gross primary production) and high water temperatures (24.23 to 31.56 ^oC) prevailing at this station throughout the study period.

Inorder to assess the relationship between the monthly instantaneous growth rates of 0 age oysters and mean monthly environmental parameters, their values were subjected to computer analysis for the estimation of correlation coefficient 'r'. The food availability indices were closely related to the monthly growth rates of 0 age oysters at station 1. Taking into consideration the level of chlorophyll-a recorded during the periods of high growth at station 1 and keeping in mind the optimal ranges reported for other species of Crassostrea, it can be said that the optimum range of chlorophyll-a

required for obtaining high growth rate in C. madrasensis during the first year of growth (under environmental conditions similar to that at station 1) most probably lies above 10 µg/l. However, more detailed studies are required to determine the precise optimum range.

The negative correlations obtained between water temperature and growth rates of all the body variables of 0 age oysters at station 1, indicates an inverse relationship between these variables. However, during the entire study period fortnightly mean water temperature values fluctuated in a narrow range (25.16 to 31.93 °C), and the fortnightly/seasonal fluctuations were very gradual. On the other hand, high growth rates were also recorded during periods of high water temperatures (October - November 1990 and May - June 1991), and from November 1991 onwards despite a declining trend in water temperature values, very low growth rate was observed. Therefore, it is unlikely that temperature fluctuating in a narrow range could have had any major influence on the growth rates singly, and its effect is only prominent during the periods of low food availability.

Considerably high and positive correlation of turbidity and total suspended micro-matter with the growth rates of 0 age oysters at station 1 could be due to the following factors. First, the variations in total suspended micro-matter in turn indicates fluctuations in particulate organic matter (POM) which is a known indicator of ration of bivalves. Secondly, low levels of resuspended particulate inorganic matter, which is most likely to contribute significantly to loads of total suspended micro-matter in shallow coastal waters and presence of which has been

observed in the gut content of C. madrasensis, has been reported to enhance growth in many bivalves. Though the present study does not warrant to draw any conclusion regarding the precise effect of such low levels of total suspended micro-matter on growth rate of C. madrasensis, it is stated that loads of suspended micro-matter within the range of 37 to 64 mg/l is unlikely to have any negative effect on growth of this species, and the possibilities of its positive effect requires further research.

The fortnightly mean salinity values ranged from 26.53 to 37.31 ppt at station 1 and the fortnightly/seasonal variations occurred gradually. Since high growth rates were observed during low as well as high salinity periods and keeping in mind the non-stressful salinity regimes reported for other species of oyster, it can be said that the salinity range observed at station 1 is unlikely to act as the limiting factor for rapid growth of C. madrasensis.

At all the experimental stations the fortnightly mean pH (7.83 to 8.42), and dissolved oxygen (2.56 to 6.65 ml/l) values remained within the tolerance zone of the bivalves. However, an interesting observation made is that, the period of high growth rates during the major part of the experiment at station 1, coincided with periods when the dissovled oxygen levels of sea water were very close to the upper range of this parameter (5.01 ml/l). This in turn corresponds to the optimum level of dissolved oxygen recommended for the culture of C. gigas. This observation supported by high positive correlation of dissolved oxygen with growth rate of all the body variables (except shell height) can be

taken as an indication that besides other environmental parameters, adequate dissolved oxygen levels also contributed in creating suitable environmental conditions for higher growth rate of 0 age oysters at station 1.

Calcium concentration has been positively related to salinity. It has been stated that low salinity (<20 ppt) can lead to reduction in minerals such as calcium, which in turn can lead to reduction in the growth rate of oysters. In the present study also it was observed that at the three experimental stations calcium levels (336.66 to 518.36 mg/l) closely follow the periodical fluctuations in salinity and since no significant reduction in salinity was observed at any of the sites, it may be said that most probably there was no shortage of calcium for growth of oysters at any of the sites.

The concentration of micro-nutrients, particularly ammonia-N (0.10 to 0.83 µg at/l) and nitrite-N (0.028 to 0.44 µg at/l) which can be toxic at high concentrations, remained within the safe range reported for oyster culture systems. The set of micro-nutrients monitored during the present study are unlikely to have had any major direct impact on growth rate of the oysters and their effect is likely to be reflected through their influence on the standing crop of phytoplankton at each site.

At station 2, though the level of food availability indices, chlorophyll-a (1.19 - 23.05 µg/l), net primary productivity (339.41 - 2278.96 $mgC/m^3/day$), and gross primary productivity (484.88

2521.41 mgC/m^3/day), were significantly higher than that of station 1, the growth rate of 0 age oysters were considerably lower than that at station 1. The suppression in growth rate was most likely due to high turbid conditions prevailing at this site.

It has been stated that if food is scarce, growth will be retarded regardless of all other conditions. The level of food availability indices recorded at station 3 does not appear to provide enough energy for normal growth, at such high water temperatures.

The endogenous factors like age, size, intensive gametogenesis and spawning activity were found to play a negative role on growth rates of the experimental oysters.

In the present study, while the percentage of males was higher than females among the 0 age groups of oysters through most of the study period, in the case of 1+ age oysters the percentage of females was invariably higher for most of the experimental period. However, chi-square test analysis revealed no significant deviation from the theoretical 1:1, male:female ratio for both the age groups of oysters. Fluctuations in sex ratio were observed in both the age groups of oysters. But since no transitional hermaphrodites could be detected, sex reversal could not be corroborated by this study.

Normal and regular gametogenic activity was observed among both the age groups of oysters at station 1 and in 1+ age oysters at station 2. The 1+ age oysters with ripe or spent gonads occurred in most of the monthly samples indicating an almost continuous spawning among the

larger size groups of oysters. However, spawning among both the age groups was intensified during February - May 1991 and July - December 1991. Initial spawning had a short duration and reached its peak in April. Second spawing period was of comparatively longer duration and peaked in September - October. On the basis of the results of the present study and information cited in literature, it can be concluded that probably the most important environmental variables which are likely to influence the gametogenesis and spawning activity of C. madrasensis in coastal and backwater areas (with narrow range of variation in salinity) appear to be food availability and water temperature.

The overall percentage mortality among both the age groups of oysters was the least at station 1 (5% and 3.98%). Low rate of mortality reflects the non-stressful environmental conditions prevailing at this site. At station 2 percentage mortality of 0 age oysters (25.64%) was comparatively high. Higher rate of mortality could be attributed to high levels of total suspended micro-matter and turbidity at this station. The percentage mortality of 1+ age oysters at station 2 was 9.16%. Among all the experimental sites, highest mortality of oysters occurred at station 3 (50.74% and 52.40%). This could only be attributed to shortage of food at this site.

All the hydrological variables monitored during the present study showed distinct periodical variations which followed a more or less comparable trend at all the three stations, particularly at stations 1 and 2 which were situated very close to each other.

Periodicial variations in salinity (23.02 - 37.31 ppt) followed the trend of variation in water temperature (22.96 - 31.93 ^{o}C) and exhibited a bimodal cycle of distribution. The periodical fluctuations in dissolved oxygen values (2.56- 6.65 ml/l) showed an inverse relationship with water temperature, atmospheric temperature and salinity during most of the study period.

Calcium and pH values at the three stations ranged from 336.66 to 518.36 mgl/l and 7.83 to 8.42, respectively. The pH and calcium concentration generally remained low during monsoon seasons.

Turbidity ranged from 1.78 to 9.22 NTU at station 1, from 6.09 to 19.99 NTU at station 2, and from 0.86 to 3.89 NTU at station 3. Total suspended micro-matter ranged from 29.66 to 78.66 mg/l at station 1, from 89.00 to 208.56 mg/l at station 2, and from 21.86 to 40.76 mg/l at station 3. The considerable difference in the level of turbidity and total suspended micro-matter among the stations could be mainly attributed to the texture of their bottom sediments.

The chlorophyll-a concentration ranged from 1.16 to 16.39 µg/l at station 1, from 1.19 to 23.05 µg/l at station 2, and from 0.83 to 5.27µg/l at station 3. Net primary productivity ranged from 193.95 to 1745.98 mgC/m^{3}/day at station 1, from 339.41 to 2278.96 mgC/m^{3}/day at station 2, and from 145.46 to 339.41 mgC/m^{3}/day at station 3. Similarly, minimum and maximum gross primary productivity values recorded were 290.93 and 1939.53 mgC/m^{3}/day at station 1, 484.88 and 2521.41 mgC/m^{3}/day at station 2, and 193.89 and 494.84 mgC/m^{3}/day at station 3. The results of analysis of variance (ANOVA) test revealed a significant

($P \leqslant 0.01$) difference in the level of food availability indices among the stations.

Though the exact reason for low phytoplankton crop at station 3 is not known, it may be due to high competition between phytoplankton, dense sea grass and coral population of this area for available micro-nutrients in the water. Another factor could be the sandy bottom of this area, which may not be rich in organic matter. It is also probable that, since the rate of exchange of Harbour water (bound by long break waters) with the open sea being a slow process, the phytoplankton crop carried inside the Harbour water gets grazed upon and due to natural mortality coupled with low mixing with the open sea, remains at low levels.

At the three experimental stations, nitrate-N concentrations ranged from 0.39 to 3.30 µg at/l, nitrite-N from 0.028 to 0.44 µg at/l, ammonia-N from 0.10 to 0.83 µg at/l, reactive phosphorous from 0.44 to 4.25 µg at/l, and silicate from 0.71 to 15.02 µg at/l. The seasonal curves of average values of phytoplankton crop indices (chlorophyll-a, net and gross primary productivity) appear to have an overall inverse relationship with that of reactive phosphorus and ammonia-N, and a direct relationship with that of silicate, nitrate-N, and nitrite-N. The above relationships were distinct at station 1 and 2 only. An inverse relationship has been stated to reveal a significant utilization of the particular nutrients during peak period of phytoplanton blooms, which inturn may depend on preference and requirements of dominant species of phytoplankton.

Though traditionally it has been accepted that bivalves hung subtidally could obtain better growth due to extended periods of feeding, a few recent reports have presented evidences to show that intertidal bivalves could be capable of better growth at certain intertidal levels than at subtidal ones. Indian backwater oyster, C. madrasensis, has been reported to occur from mid-littoral zone to a depth of 15-16 m. This oyster has been experimentally cultured both intertidally and subtidally, but there exists no information on relative efficiency of these methods.

In order to assess the growth and survival of C. madrasensis at three intertidal levels with different degrees of aerial exposure and at a subtidal level (nil aerial exposure), an experimental structure was constructed in the shallow intertidal zone of Tuticorin bay where maximum tidal amplitude is about 76cm. The structure was made of two vertical wooden poles planted in line about 2m apart. Three cross poles in the intertidal zone and one in the subtidal zone were tied across the vertical poles at precalculated heights on the basis of requirements of the experiment.

The experimental oystes (about two months old after settlement) were placed in box type cages, suspended from horizontal poles and reared for a period of 7 months (July 1991 February 1992). Two sets of cages holding almost equal numbers of oysters (n = 92 - 97) were suspended from the horizontal poles at each of the four levels. While one set of oysters at each level was regularly cleaned (cleaned oysters) the other set was allowed to be fouled (uncleaned oysters). The oysters

were subjected to approximately 79.28%, 42.60%, 12.32% and nil mean daily aerial exposure from top (level 1) to bottom (level 4).

Since there was no significant difference between growth (in terms of shell height) of cleaned and uncleaned oysters at any of the levels, their values were pooled. The mean shell height and whole weight monthly data was subjected to statistical analysis. The analysis of covariance (ANCOVA) test detected no significant difference in growth of oysters at levels 2 to 4(42.60%to nil mean aerial exporures). However, ANCOVA did yield a significant difference between growth of oysters at level 1 (79.28% mean aerial exposure) and the other three levels. The results indicate that C. madrasensis shows improved growth (though not at significant levels) at low intertidal level (12.32% mean daily aerial exposure) when compared to subtidal or mid and higher intertidal levels. The oysters at level 1 and level 4 (nil aerial exposure) suffered comparatively greater mortality.

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