ECOBIOLOGY OF RAFTGROWN GREEN MUSSELS *PERNA VIRIDIS* L.

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BY

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DEDICATED TO

MY PARENTS

CERTIFICATE

Shri Chandrashekher Umanath Rivonker has been working under my guidance since 1987. The Ph.D. thesis entitled "Ecobiology of raft-grown green mussels *Perna viridis* L." submitted by him contains the results of his original investigations on the subject. This is to certify that this thesis has not been the basis for the award of any other research degree or diploma of any University.

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(Chandrashekher Rivonker)

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CHAPTER I

INTRODUCTION

Seafoods, a traditional source of high quality nutrition supplement have assumed great importance, as a potential source for human nutrition. Their importance of late has further been enhanced by the lack of sufficient food supply from agriculture and inland water resources. Despite the awareness of the contribution of the world's ocean to man's diet, which stems largely from hunting and gathering of fish and shellfishes, it should be borne in mind that wild stocks of aquatic organisms are limited. Further, ecological reasoning suggests that we must eventually reach a ceiling on the rate of harvest of aquatic organisms.

Thus the need for a comprehensive resource management together with a wise and optimum utilization become paramount in the face of mounting population pressure. In view of the above, it is apparent that a greater thrust has to be laid on research on mariculture.

Mariculture or seafarming, involves growing of economically important marine organisms under partially controlled conditions so that the yield is of high quality and can be predicted, well ahead of harvesting. This branch of marine science, has the potential of producing large quantities of low cost protein-rich food, inturn its production is influenced to a great extent through the production of unicellular algae. Molluscs, especially edible bivalves, are considered suitable for culture as they have a high growth rate, high yield per total weight, high nutritional value and moreover a good export potential.

Among molluscs, edible bivalves especially mussels, oysters and clams are an important source of nutrition in the coastal states of India. Goa with a coastline of about 106 kms has vast resources of the above mentioned marine animals. At present most of the shellfisheries of Goa are based on harvesting of wild stock from estuaries and rocky coastal areas. In the past, inadequate information on biotic and abiotic characteristics of shellfish resources acted as a major constraint for the management and cultivation of shellfish resources through mariculture. The green mussel *Perna viridis* L. offers an excellent scope for cultivation in the Indian coastal ecosystem because of its cosmopolitan distribution, fast growth rate and disease resistant properties, (Qasim *et al*., 1977). Mussels being sedentary and filter feeders, predominantly phytoplankton - the primary producers, do not exhaust their energy in search of food and moreover, feed at low trophic level in the food chain. Thus, they are better convertors of food as compared to terrestrial animals, thereby helping in the building up of highly proteinaceous meat which is directly utilizable by man as food.

Taking into consideration, the above, Parulekar *et al*.(1984) explored the possibility of culturing these mussels by adopting "off bottom culture" method using a wooden floating raft. The benthic animals were suspended in the water column on the ropes, which acted as a substratum. Thus a three dimensional system was made available to the mussels for optimum utilization of food material in a tropical subtidal biotope. In this method, it was observed that the competition for space and food was comparatively less and further the quality of mussel meat was consistently higher, than in mussel population from natural environs.

Here, a brief account of review of earlier work conducted on mussels with respect to ecobiology and growth is given. Biochemical composition and trace metal distribution in mussel tissue is presented herewith following the order of the chapters dealt in the present thesis.

Historical Review

Along the west coast of India, three seasons namely, premonsoon (February-May), monsoon (June-September) and postmonsoon (October-January) have been identified (Wyrtki, 1971). There is a good deal of information available on the physico-chemical and biological characteristics of the three seasons along the west coast of India (Bal and Pradhan, 1946; Rao and Madhavan, 1964; Noble, 1968; Sankarnarayanan and Qasim, 1969; Haridas et al., 1973; Devassy and Bhattathiri, 1974; Kumaran and Rao, 1975; Sathyendranath and Varadachari, 1982; Shetye, 1984; Verlencar and Qasim, 1985; Verlencar, 1987). Estuarine ecosystems are known to be dynamic due to influx of fresh water, and their characteristics keep on changing with time. In Goa, particularly in the Zuari estuarine region, significant contributions have been made on the studies of physico-chemical and biological characteristics (Dehadrai, 1970; Sankarnarayanan and Jayaraman, 1972; Parulekar et al., 1973; Parulekar and Dwivedi, 1974; Cherian et al., 1975; Anon, 1978; Parulekar et al.,1980; De Souza *et al*., 1981; Qasim and Sen Gupta, 1981; Verlencar, 1982; De Souza and Sen Gupta, 1986). The detailed physical characteristics of the estuarine region of Goa coast have been studied and described by Das *et al*. (1972) and Murthy and Das (1972). This estuarine ecosystem is fringed by mangroves which influences to a great extent the formation of detritus and supports organisms that are detritivorous (Untawale and Parulekar, 1976). The phytoplankton also play an important role as primary producers, although the ecosystem is essentially detritus based (Goes, 1983).

The benthic fauna are an important component in the trophic structure of the ecological pyramid, and exhibit wide variations in their abundance. In this context, a detailed account on the ecological characteristics with relevance to the densities of benthic fauna has been provided by Parulekar and Dwivedi (1974), Parulekar *et al*. (1980) and Ansari *et al*. (1986). Recently, Ansari (1988) conducted a long term study on the ecology of meiobenthos in two estuaries of Goa. He suggested that the pattern of seasonal variations in environmental parameters in both the estuaries were similar. The information on environmental characteristics play an important role in undertaking aquaculture practices.

Although commercial cultivation of shellfishes has very high prospects, with high returns, it is an equally risk oriented venture. Qasim and Achari (1972) reported the success of mussel culture for the first time in India. Jones and Algarswami (1973) presented a detailed account on the availability and the resource potential of the mussel fishery which was estimated to be around 1000 tonnes. For successful culture of mussels, a proper knowledge of their biology is essential. Rao et al. (1975) made an effort to study the biology of the green mussel, *Mytilus viridis* and highlighted the scope for undertaking mussel culture operations around Goa. Various studies on the aspects of spawning, fertilization and larval development in green mussel, *Mytilus edulis* L. were done by Rao et al. (1976). In this regard, mention of another species of mussel locally called as weaving mussel, *Modiolus metcalfei* should be made. This species was studied and discussed by Parulekar et al. (1978), emphasizing the possibilities of its culture. Qasim et al. (1977) carried out studies on the culture aspects of green mussel *Mytilus edulis* L. on ropes hanging from floating rafts, and provided baseline information on the methodology of raft culture, cost-benefit analysis and its adoption in India. Also mentioned were the advantages and constraints encountered in undertaking raft culture of mussels. Further, studies on the impact of environment on physiological variations in raft-grown green mussel were conducted by Parulekar et al. (1982), and the results suggest that these animals have a compensatory mechanism for growth and survival depending upon their external osmotic balance. A recent study by Parulekar et al. (1984) brought out the possibilities of culture of edible bivalves around Goa and highlighted the importance of green mussel as a potential organism for mariculture.

Mention should also be made of the work carried out in temperate waters. Studies on the growth of blue mussel were initiated by Coulthard as early as 1929 and reported that temperature was an important factor that controls growth. Fox and Coe (1943) studied nutrition, metabolism, growth and calcium deposition in the Californian mussel and concluded that organic detritus supplies large quantity of food materials. The growth of mussels is variable and is known to be affected by environmental factors prevailing in the particular area. The factors affecting growth and the data on biology of the mussel has been studied and discussed earlier (Bohle,1965; Baird,1966; Sandykhova,1967; Thiensen, 1968) and it has been documented that improved feeding conditions rather than low salinities have significant effect on growth. A much detailed study on ecology and other related seasonal changes such as growth and mortality of <u>Mytilus</u> <u>edulis</u> L. has been reported by Seed (1969a;1969b;1976). He stated that growth varies considerably according to age, size and environmental conditions, and further demonstrated that population structure of these mussels show erratic distribution on rocky shores.

Growth and mortality rates in natural populations on rocky shores provide in general, the abundance of mussel density, their degree of resistance towards varying environmental stress. Jorgensen (1976) carried out studies on growth efficiency and described the factors responsible for controlling size in some mytilid bivalves, especially <u>Mytilus</u> <u>edulis</u> L.. He reported that shells have lower organic content than soft tissues and shell growth may have only partial dependence on metabolic carbon. Sivalingam (1977) carried out experiments on feasibility of culture of green mussel in Malaysia. He used rope culture technique and found it to be the most productive. Further he used different types of spat collectors and found that meshed nylon netting, although expensive was a promising material. Achari (1980), Mahadevan (1980) and Rangarajan (1980) studied the areas of spatfall, seed collection, production and provided details of economic aspects of raft culture in India. Algarswami et al. (1980) and Nagappam Nayar (1980) have described the status of mussel culture and exploitation of its resources in India. These authors highlighted the possible sites of exploitable resources of mussels and for standardization of the technique for raft culture were projected with the purpose of adopting the same in our country.

Allometry, deals with relationship of one body parameter to another, which varies with growth, season and ecological factors. Allometric relationships in molluscs have been studied as early as 1936 by Huxley and Tessier. Coe (1946) made attempts to apply the concept of allometry and studied the resurgent population of the Californian bay mussel, Mytilus edulis. Rao (1953) documented a linear relationship between shell weight and tissue weight in Mytilus californianus and further illustrated that wide range of variation is expected within a given population of the same species. Biometric studies on the mussel population have been made by Schaefer et al. (1985) in three species of Astarte in Kiel bay. He opined that an isometric growth of shell length and shell breadth was noticed for A. borealis, while A. montagui exhibits positive allometric shell growth and changes its shape during life cycle. Seed (1968) conducted studies on the factors influencing shell shape in Mytilus edulis L. and stated that shell shape and thickness is influenced by calcium content of the surrounding medium. Furthermore, he described absolute and allometric growth in the mussel Mytilus edulis. Jones et al. (1978) described in detail the seasonal and the annual variations in allometric relationships in shell and soft body characters of Patella vulgata L. and established a formula relating internal shell volume to external; linear dimensions which could be were used to compute condition index. Hilbish (1986) studied the growth trajectories of shell and soft tissue in bivalves. He demonstrated that uncoupled rates of shell and tissue growth seriously affect adjusted weight cycles. Borrero and Hilbish (1988) carried out studies on temporal variations in shell and soft tissue growth of the mussel, Guenkensis demissa and stated that growth of shell and soft tissue do not occur coincidentally at all times.

In India, studies on allometric relations have been carried out in wild and cultured populations of green mussel by earlier authors (Shafee and Sundaram, 1975; Shafee, 1976; Ansari et al., 1978; Mohan, 1980) wherein they reported different types of relationships depending upon their application and have emphasized that, allometric relationships are an essential tool to have a better understanding of the growth parameters in green mussel.

In recent years much emphasis have been focussed on the nutritive aspects of marine organisms and among these, the molluscs are preferred as they have high nutritive value and are also easy to cultivate on a commercial scale. Research on biochemical composition of the marine molluscs in the decade 1950-60 highlights the pioneering work in this field (Korringa, 1956; Lee, 1956; Baird, 1958; Fraga, 1958; Lubet, 1959; Dare and Edwards, 1975) and emphasizes that the changes in body weight are mainly due to changes in carbohydrate content. In India, early studies in this field were carried out by Venkataraman and Chari (1951) who reported that high lipid content in mussel tissue was found to coincide with intensive feeding. Studies on the biochemical composition of the mussel were carried out by Williams (1969) who documented that seasonal changes in lipid content of Mytilus edulis showed an inverse correlation with glycogen content. A review of a new approach to study the biochemical composition of the molluscs was presented by Giese (1969).

The physiological changes in Mytilus edulis induced by temperature and nutritive stress, and the biochemical ecology of molluscs have been studied in temperate waters by Gilles (1972), Bayne (1973) and Gabbot and Bayne (1973) who concluded that temperature influences biochemical constituents to a certain extent. Pieters et al. (1979) studied the changes in glycogen, protein, total lipid and energy metabolism in Mytilus edulis and discussed it in relation to environmental factors and the reproductive cycle. Telembici and Dimoftache (1972) made a comparative account of the dynamics of general biochemical composition and discussed the same in some of the bivalves of Romanian Black Sea. Seasonal changes in flesh weight and biochemical composition of the scallop, Chlamys opercularis have been conducted by Taylor and Venn (1979), and stated that seasonal cycle of weight and biochemical composition of the gonad, closely follow the spawning cycle. They further emphasized that the variation of protein and lipid in above mentioned species was because of the variation in gonad composition.

Studies on biochemical composition and its influence on reproductive cycle have been conducted in detail by Pieters et al.(1980) and studies with reference to energy metabolism and gametogenesis have been carried out by Zandee et al. (1980) demonstrating that no seasonal variations in free amino acids occur in total tissue and different organs. Shafee (1981) carried out the studies on seasonal changes in the biochemical composition and calorific content of the Black scallop Chlamys varia L. from Louveoc, Bay of Brest to understand the relationship between reproductive cycle, storage and utilization of food reserves. Walter (1982) conducted studies on growth and reproduction in tropical mussel, Perna viridis and stated that spawning occurred year round, but was not with consistently repetitive peaks. Recently Deslous-Paoli and Heral (1988) carried out studies on biochemical composition and energy value of Crassostrea gigas (Thunberg) cultured in Bay of Marennes Oleron and opined that the quality of food available during phytoplankton bloom is linked with reserve of energy mainly as glycogen.

From Indian coast, Nagabhushanam and Mane (1975; 1978) conducted studies on reproduction and seasonal variation in biochemical composition in estuarine mussel, Mytilus viridis from Ratnagiri region, west coast of India. They suggested that the level of major biochemical constituents such as protein, fat and glycogen showed correlation with the reproductive cycle of the mussels. Studies conducted by Qasim et al. (1977) on culture aspects of green mussel on a floating raft, wherein they studied the biochemical composition and inferred that total caloric content of cultured mussels is higher than those from natural beds. Shafee (1978) conducted studies on the variations in biochemical composition of the green mussel, Perna viridis L. from Ennor estuary, Madras and remarked that peak calorific values coincided with peak protein values. Seasonal changes in biochemical constituents in edible molluscs were also conducted by earlier workers along the Indian coast (Suryanarayanan and Alexander, 1972; Wafar et al., 1976) suggesting that high values of caloric content were recorded during pre-spawning season and a steady decline was observed as spawning progressed. More recently, Mohan and Kalyani (1989) conducted studies on seasonal variations in biochemical composition of the green mussel, Perna viridis L. and found that males and females do not differ significantly in biochemical constituents.

Mussels are known to accumulate high concentration of trace metals in their soft tissue, and are often considered to be a sentinel for monitoring water quality. Studies on the distribution of trace metals in marine ecosystem were conducted by earlier workers in different parts of the world (Riley and Tongudai,1967; Sen Gupta and Pylee,1968; Abdullah et al.,1972; Preston et al., 1972; Sen Gupta, 1972; Riley and Taylor, 1972; Carpenter and Manella, 1973) and documented that trace metal distribution in different areas vary to a considerable effect with local conditions and geochemical processes. A synoptic survey on dissolved trace metal levels in Baltic waters has been conducted by Sen Gupta (1972). He compared the water quality with reference to trace metal in two main watermasses i.e. Baltic and North Sea. Young et al. (1979) studied the vessel related contamination in the Southern Californian harbours by copper and other metals suggesting that harbour-related activities can be as important a source as coastal wastewater discharges in the contamination of the nearshore marine ecosystem. In Danish waters, Magnusson and Rasmussen (1982) conducted investigations on trace metal levels in coastal waters and found that metals are found predominantly in dissolved and labile form except for iron, found mainly in particulate phase.

In Indian waters, Sreekumaran et al. (1968) studied major and minor elements along the west coast of India, and stated that there exists a close relationship between chemical composition of marine organisms and sediments. Sen Gupta et al. (1978) carried out studies on few trace metals in the Arabian Sea and obtained higher values for few stations nearshore, indicating possible addition from land. Calcium and Carbonate dissolution in North western Indian Ocean has been reported by Naqvi and Naik (1983). These authors suggested that high calcium flux from the rivers in a relatively small areas influences Ca:Cl ratio in the upper layers of the region. Trace metals and major elements distribution in the areas of Laccadives and Bay of Bengal were studied by Naqvi and Reddy (1979); Sanzgiri and Moraes (1979); Braganca and Sanzgiri (1980), and reported that dissolved calcium showed decrease in concentration with depth, whereas iron and manganese showed a marked increase at a depth of 500 m. Naik and Moraes (1982) studied the distribution of major elements in the waters off central west coast of India and discussed the depthwise distribution of these elements.

Exhaustive published literature, on trace metal content variations in marine molluscs, is available (Phillips, 1976a; 1977a; 1977b; 1978; 1979; 1980). Goldberg et al. (1978) initiated a world wide monitoring programme "The mussel watch" to assess the degree of pollution in aquatic ecosystem using marine mussels. Segar et al. (1971) carried out studies on the distribution of the major and some minor elements in marine molluscs and inferred that generally the highest concentration of these elements were in gut and digestive gland and the lowest in muscle and shell of the molluscs. Boyden (1974; 1977) conducted studies on trace metal contents and its relationship with size in the molluscs and made an attempt to establish different relationships among the above parameters. Eisler et al. (1978) carried out survey work on the marine clam, *Pitar morrhua* collected near an electroplating plant, Rhode Island and observed a decrease in copper content with increasing body weight. Pentreath (1973) studied the accumulation of certain trace metals from water by the mussel Mytilus edulis and reported that diet play an important role in the uptake of trace metals than surrounding medium. The occurrence of trace metals in coastal organisms is studied earlier by several workers (Graham, 1972; Bryan, 1973; Leatherland and Burton, 1974; Fowler and Oregioni, 1976; Sankarnarayanan et al., 1976; Watling and Watling, 1976; Talbot et al., 1985; Talbot, 1986; Bruegman and Lange, 1988). These workers reported that the mussels are ideal test organisms for pollution monitoring in aquatic ecosystems due to their size, sessile nature and short life. Further they also stated that electroplating plants, ironworks and waste outfalls were almost always associated with elevated iron residues in molluscs. Gordon et al. (1980) conducted studies on Mytilus californianus as a bioindicator of trace metal pollution and stated that degree of variability was not the same. Individuals of Mytilus edulis, sampled from less than 1km transects exhibited dramatic variations in the metal concentration (Pophan et al., 1980). Metal concentrations in the mussel, collected from estuaries in South eastern Australia were studied and discussed by Wotton and Lye (1982), and provided information on variability in the concentration of several metals in Mytilus edulis collected from different areas.

Ecotoxicological testing with marine molluscs was conducted by Calabrease (1984), who presented a review on toxicity tests with marine molluscs, and further inferred that toxicity test can be from inexpensive to expensive depending on length of the test. Chan (1988; 1989) studied the accumulation and tolerance of some metals in green mussels, Perna viridis and confirmed the ability to accumulate dissolved copper, lead and cadmium in proportion to exposed concentrations. Julshaman (1981) conducted studies on major and minor elements and the variation of ten elements in oysters, mussels and seaweeds. Calabrease et al. (1984) conducted studies on long term exposure to silver and copper on growth, bioaccumulation and histopathology in the blue mussel, Mytilus edulis. These authors reported that mussels accumulated significant amount of silver only at highest test concentrations, and the silver exposed mussels accumulated more amount of Cu than control animals. Further, histopathological studies showed yellowish to black deposition in the basement membrane and connective tissues of various organs.

Zingde et al. (1976) conducted studies on variations of various trace metals in marine flora, fauna and estuarine waters around Goa and suggested that amongst these, seaweeds accumulate high concentration of manganese. Studies on variations in trace metals in two populations of green mussel Mytilus viridis L. from Goa were conducted by Bhosle and Matondkar (1978) and stated that the rope cultured animals showed higher concentration of metals than those from natural beds. Sankarnarayanan et al. (1978) analysed some of the heavy metals in the oyster, Crassostrea madrasensis from Cochin region and discussed the pattern of variation of these metals. D'Silva and Kureishy (1978) conducted experimental studies on the accumulation of copper and zinc in the green mussel, and highlighted that metal uptake is linear in the initial periods of the experiment. Lakshaman and Nambisan (1983) studied seasonal variations in trace metal contents in bivalve molluscs and stated that the concentration were well below the permitted limits recommended for marine products.

From the above review, it appears that much of the work conducted in Perna viridis L. and related species is connected to samples collected from the natural rocky environments. Not much work has been undertaken to study the degree of dependence of growth on environmental/hydrobiological factors, seasonal changes in the growth parameters as well as the dynamic pattern of changing body dimensions in a partially controlled environment, cultured under submergence from a floating raft. Further, studies on biochemical changes mentioned earlier are mainly from natural populations. However, with few exceptions (Qasim et al., 1977; Parulekar et al., 1982) no systematic information on the changing pattern of these constituents in a partially controlled environment is available. Although exhaustive information on trace metal composition is available in mussels from natural conditions, no attempts have been made earlier to study trace metal variation in mussel tissue with advancement of growth in the cultured population.

The present investigation was mainly initiated to have a better understanding of the ecobiological factors affecting the biology of the raft grown mussel population. The environmental parameters were estimated, primarily to observe the existence of any direct dependence of growth on these factors and to estimate the degree of dependence of some of the important biological factors. A second aim was to report seasonal variability of these parameters and the effect of the same on growth. Growth studies were mainly conducted to observe the seasonal pattern of variation in the raft-grown mussel population. The allometric relationship in mussels was also studied to observe the seasonal changes in different body parameters and to compare the same during the complete period of culture. Changes in biochemical composition are known to occur seasonally, hence, these constituents of soft tissue were estimated to relate the same to the reproductive cycle of the mussel. The bioaccumulation studies were mainly designed to understand the impact of transportation of mining ore by barges thereby creating turbulence, and its effect on the raft grown mussels as the site happened to be near to the route of these barges transporting the ore. The above mentioned topics are discussed in details in the thesis.

OBJECTIVES

The present study was undertaken mainly with following objectives:

1. Growth pattern in the raft-grown green mussel population during different seasons.
2. The impact of seasonal variations in hydrobiological factors on the raft-grown green mussel, Perna viridis L.
3. Changes in allometric relationships with reference to size in

the raft-grown population of the green mussel.

4. Changes in proximate biochemical composition of raft-grown green mussels in relation to culture biology, reproductive cycle and environmental factors.

5. Bioaccumulation of trace metals and major elements in raft-grown mussels in relation to the chemistry surrounding waters.

CHAPTER II

MATERIALS AND METHODS

DESCRIPTION OF STUDY AREA:

A semi-enclosed area, in the Dona Paula bay, located at the mouth of the river Zuari (15° 27' N lat. and 73° 47' E long.) was chosen as the study site (Fig. 1). The Zuari river, originates in Dighi ghats of the Sahayadri mountain ranges (Western Ghat) in Karnataka, and after a prolonged flow of 67 kms, empties into the Arabian sea at Dona Paula. The average runoff of Zuari estuary is 9.0 km^3 $annum^{-1}$ (NIO, Tech. report, 1979). Dona Paula bay is protected towards north, east and the south by rocky promontories and is less than 2.0 kms upstream of the opening of Zuari river in the Arabian sea.

The tidal influence in the study area has been reported by Singbal (1973) to be comparatively low in monsoon (June - September) upto 2.0 m (Dehadrai, 1970). Similarly, the wave action is reported to be minimum, thus facilitating protection and steady growth of culture animals round the year (Parulekar *et al.*, 1982). The bottom deposits in Dona Paula bay (Parulekar *et al.*, 1974) are firm, thereby allowing proper anchorage and maintaining the steady position of the raft. Low siltation and clear water in this region except during monsoon make it an ideal site for off-bottom culture experimental trials in the field. In general, this culture site was found to be ecologically and biologically suitable for experimental and partially controlled field studies.

DETAILS OF RAFT FABRICATION:

Raft used for the experimental culture of green mussel *Perna*

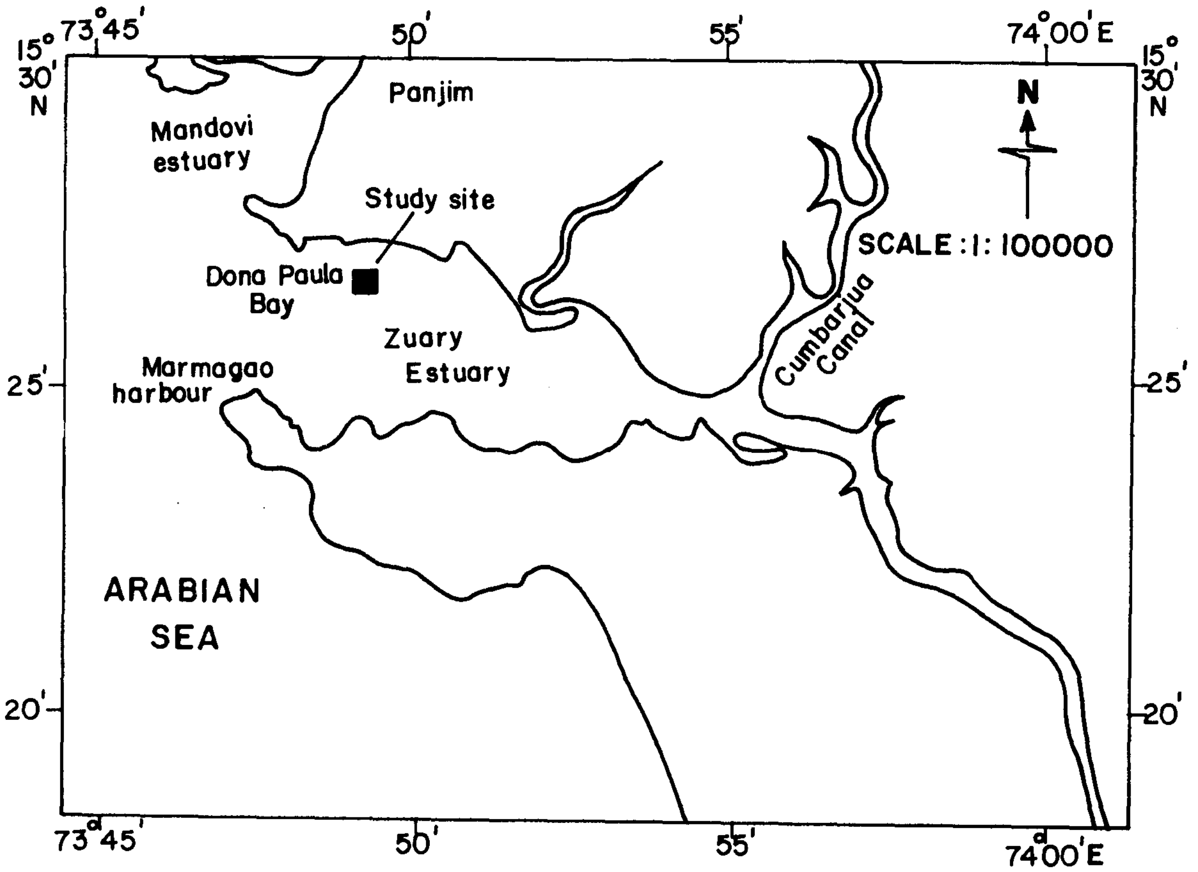

Fig. 1. Map showing site of raft culture

viridis L. was fabricated indigenously after assembling the material near the culture site. Wooden poles were used for fabrication of frame (4.0 x 4.0 m) (plate I). The bamboo poles were placed equidistant from each other, from which, ropes with mussel seed were suspended in the water column. The bamboo poles were tied using nylon ropes (5.0 mm diameter).

The fabricated raft was mounted on four (Poly Vinyl Chloride (PVC) drums (200 L capacity) which were tied to the frame with the help of nylon ropes. The gross weight of the raft of dimension 4.0 X 4.0 m inclusive of PVC drums was about 0.75 tonnes and covered 16.0 m^2 surface area. The raft was towed to the site at a desired depth where human interferance was minimum. The raft was then moored by using two cement anchors weighing about 70.0 kg each, with a thick nylon rope (40.0 mm diameter). The average depth at the culture site was 7.0 m. The raft was in good condition till the termination of experimental period of 12 months from October 1987 to September 1988.

SURVEY OF MUSSEL SEED / COLLECTION OF SPAT:

The hatchery system of mass production of seed, confers specific advantages, like production of fast growing and disease resistant strains through cross breeding and immunization. However, for large scale production, the application of this technique was not felt necessary as spats are available in abundance along the rocky shores of west coast of India. A survey for identifying the spatfall area in Goa and Karnataka was undertaken during August-September, 1987, which coincides with

Plate I . Raft used in present study

the spawning season of green mussel in these areas. Along the Goa coast, major rocky shore areas like Anjuna, Baga, Chapora and Arambol, which are supposed to support large population of mussel seed (Qasim *et al*., 1977) were surveyed. But during the present survey no settlement of spat was observed in these areas. Dense settlement of spat was observed at Keni in Karnataka (14° 40' N lat. 74° 25' E long.; Plate II and III) on a rocky shore in between the mid tide and the low tide marks. The size of mussel seed ranged from 3.0-8.0 mm when the spat was about 2-3 weeks old. The density of the mussel spat was approximately 1200 m^{-2}. This seed was removed by scraping with the help of an iron chisel and scraper, then washed with seawater. The mussel seed was then transported live to the culture site. During transportation the water was changed twice.

TRANSPLANTATION OF MUSSEL SEED:

The mussel seed was transplanted on the coir rope with the help of a mosquito cloth strip. The length of the coir rope used was 6.0 m whereas mosquito cloth strip was 5.0 m and the width 0.25 m. The mussel seed were spread along the length of the rope leaving half a meter on free ends (Plate IV and V). The density of the mussel seed per metre rope was about 300. The mosquito net cloth was stitched around the rope with mussel seed in it and a thin twine was wrapped around the stitched mosquito net clothing. The mussel seed gets attached to rope within few days (Plate VI). For each rope a sinker was tied to the end so that the ropes with mussel seed should not entangle when submerged from the raft due

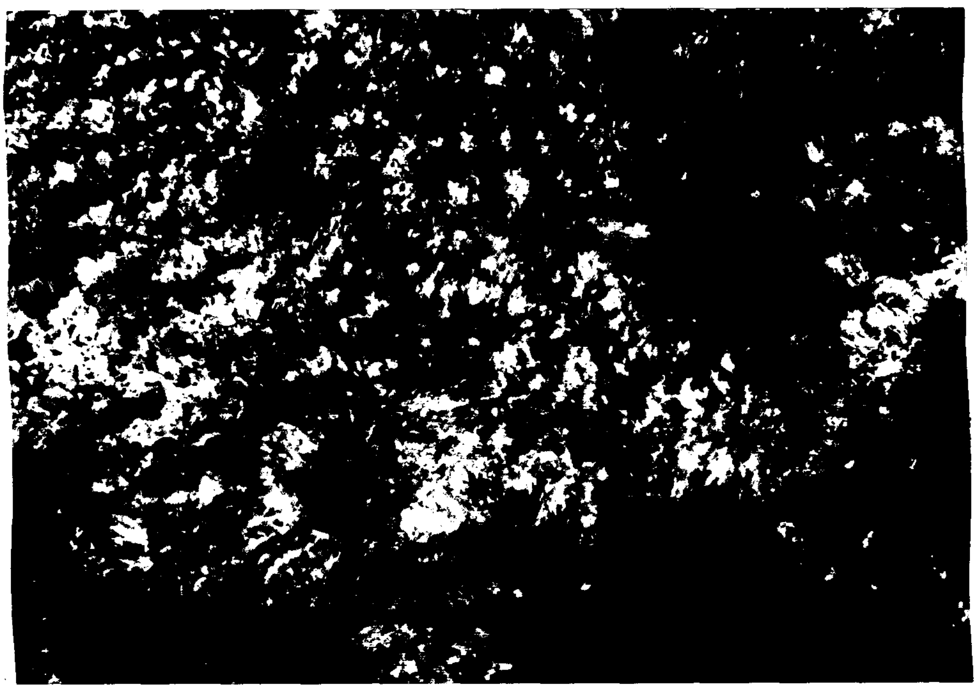

Plate II Natural bed of mussel spat

Plate III. Collection of mussel spat from the natural bed.

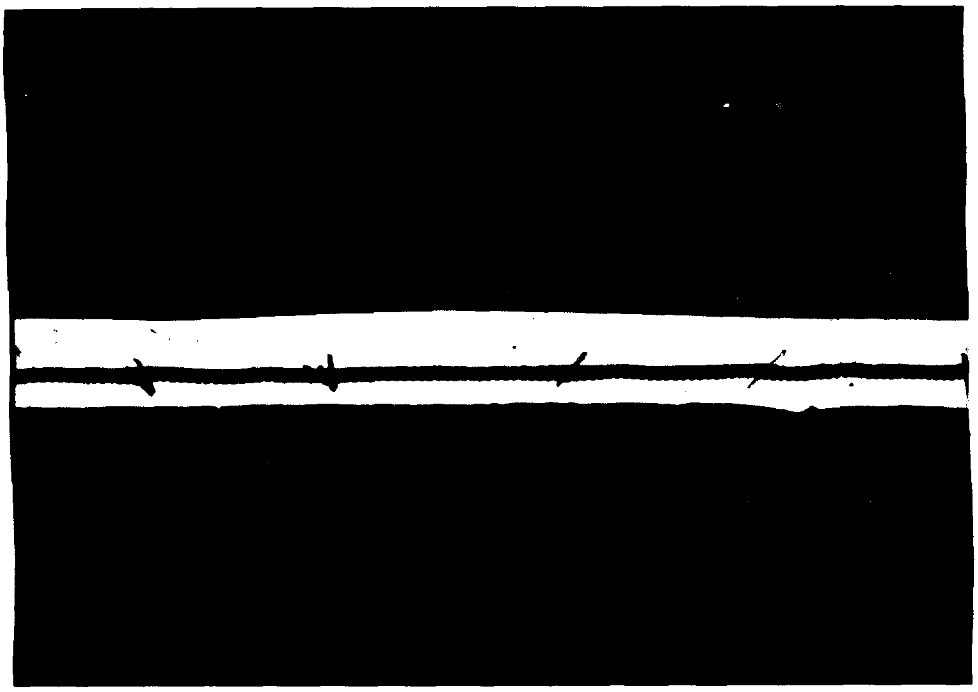

Plate IV. Mosquito clothing with rope ready for transplanting spat.

Plate V. Mussel spat on mosquito clothing with rope

Plate VI. Mussel spat attached to rope

to the influence of wave action and currents.

As soon as the ropes with mussel seed were ready, they were transferred for submergence from the wooden raft. About 0.5 m of the top part of the rope was left without seeds to enable to tie it to the raft. The ropes containing the mussel seed were submerged upto 5.0 m deep water column which form a part of euphotic zone. These seed got attached to the coir rope with byssus threads within 48 hrs after transplantation. The mosquito net covering the mussel seed took around 10-15 days to disintegrate. The spat transplanted on ropes began growing immediately after settlement. During the growth period, mortality observed was negligible (about 5.0 %).

SAMPLING:

Water samples at the site of culture were collected from October 1987 to September 1988, covering three seasons viz. post monsoon (October 1987 - January 1988), pre-monsoon (February 1988 - May 1988) and monsoon (June 1988 - September 1988) at fortnightly interval for hydrobiological parameters at three depths (0, 4.0 and 6.0 m). Niskin bottle of 5.0 litre capacity was used for water sampling. These samples were transported to the laboratory immediately for chemical analysis. Details of sampling dates and time of collection are shown in Table 1.

MUSSELS:

Mussel samples were also collected fortnightly for observations on growth, morphometry, biochemical composition and

Table 1. Sampling programme at the site of raft culture during the period of study

Sr. No.	DATE			TIME (HRS)
	DAY	MONTH	YEAR	
1.	8TH	OCTOBER	1987	0945 - 1045
2.	23RD	OCTOBER	1987	1110 - 1155
3.	8TH	NOVEMBER	1987	1210 - 1250
4.	24TH	NOVEMBER	1987	0930 - 1015
5.	10TH	DECEMBER	1987	1000 - 1045
6.	26TH	DECEMBER	1987	1405 - 1450
7.	10TH	JANUARY	1988	1220 - 1305
8.	25TH	JANUARY	1988	1005 - 1050
9.	10TH	FEBRUARY	1988	0910 - 1000
10.	24TH	FEBRUARY	1988	0950 - 1030
11.	7TH	MARCH	1988	0830 - 0915
12.	22ND	MARCH	1988	1500 - 1540
13.	7TH	APRIL	1988	1025 - 1105
14.	22ND	APRIL	1988	1135 - 1210
15.	6TH	MAY	1988	0920 - 1005
16.	23RD	MAY	1988	1010 - 1050
17.	7TH	JUNE	1988	1345 - 1430
18.	22ND	JUNE	1988	1205 - 1430
19.	7TH	JULY	1988	1415 - 1500
20.	26TH	JULY	1988	1245 - 1330
21.	10TH	AUGUST	1988	1015 - 1100
22.	25TH	AUGUST	1988	1105 - 1200
23	10TH	SEPTEMBER	1988	1425 - 1515

trace metals analysis. Mussels were removed manually from ropes hung from the raft. During each sampling, 30-35 mussels were collected. The sampled mussels were cleaned externally to remove mud, dirt particles and any fouling organisms attached to the shell.

MORPHOMETRIC CHARACTERISTICS:

25 mussels were taken randomly from the fortnightly collections, and were examined for various morphological characters. The mussel were measured for shell length (anterior - posterior axis), breadth (lateral axis) and height (dorso-ventral axis) with the help of a Vernier calliper to 0.1 mm. The terminology used is illustrated in Fig. 2. Total weight was determined to the accuracy of 0.1 mg after removal of excess water. Thereafter, each organism, was immersed separately in boiling water for 30 secs., to separate the meat from the shell. The meat from each mussel was placed on blotting paper to remove excess water and then weighed to record soft tissue wet weight (STWW). The shell weight (SW) was determined by drying each shell at 40-50 ^{o}C for about 30 minutes. After recording STWW, the soft tissue of individual mussel was allowed to dry separately in an oven at 80 ^{o}C as followed by Borrero and Hilbish (1988). The drying was continued until the difference between two successive weighings remained near 0.1 mg. The volume of the mantle cavity was determined using displacement method.

BIOCHEMICAL ANALYSIS:

The dried meat samples were powdered with mortar and pestle.

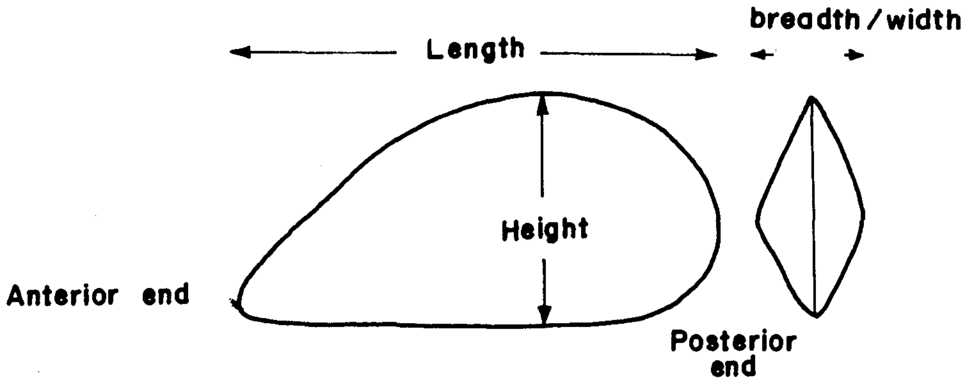

Fig. 2. Terminology used in present study to describe mussel shell.

This powder was used for the analysis of biochemical components such as protein, carbohydrate, lipid and total organic carbon. Protein was estimated following the method described by Herbert et al. (1971). 5 mg of powdered sample was taken in a dried test tube and homogenized in 0.5 ml of 1N NaOH and 2.5 ml of distilled water. This was heated at 80 ^{o}C in a water bath for 30 minutes to extract the protein. After cooling, 0.5 ml of 1N HCL was added to neutralize it and subsamples were transferred to other test tubes. 2.5 ml of mixed reagent (carbonate - tartrate - copper solution) was added, followed by 0.5 ml of 1N Folins-ciocalteau reagent. The solution was mixed well, allowed to stand for 30 minutes and then centrifuged. The absorbance was measured at 750 nm using spectronic 1001, spectrophotometer. Appropriate blanks and standards (bovine serum albumin) were similarly treated to prepare standard curves. All concentrations are expressed as mg/g dry weight of animal tissue.

Carbohydrate was estimated using Phenol-sulphuric acid method (Dubois et al., 1956), modified by Hitchcock (1977). To a 5 mg of dried sample, 2 ml of 80% sulphuric acid was added and digested for 18 hrs at room temperature. To this 2 ml of phenol reagent (5%) and 5.0 ml of concentrated sulphuric acid were added. The mixture was centrifuged and the absorbance measured at 490 nm. Standard curve was drawn with the help of analar grade D-glucose. All concentrations are expressed as mg/g dry weight of animal tissue.

Lipid was estimated following the method described by

Parsons et al. (1984). The dry powdered sample (10 mg) was placed in homogenizer with 8 ml chloroform-methanol mixture (1:2:0.8 v/v of chloroform, methanol and distilled water respectively). This mixture after filtering through an ignited (450 ^{o}C for 3 hrs) GF/C filter paper, was transferred to a separating funnel. Extraction of lipid was made by 2 ml of distilled chloroform and 4 ml of distilled water by continuous shaking for 10 minutes. The chloroform layer was separated and evaporated to dryness in vacuum. 2 ml of 0.15% potassium dichromate reagent was added and the tubes were kept in boiling waterbath for 15 minutes. 4 ml of distilled water was added to this, and after cooling the tubes, absorbance was measured at 440 nm. Blanks and standards (stearic acid) were treated similarly and standard graph was plotted. All concentrations are expressed as mg/g dry weight of the animal tissue.

Total organic carbon in the animal tissue was determined by wet oxidation method as mentioned by Parsons et al. (1984). To a known quantity of the dried sample powder, 1 ml of phosphoric acid and 1 ml of distilled water were added in order to prevent the chloride interference and kept in a boiling waterbath for 30 minutes. Sulphuric acid dichromate reagent was added (10 ml) to these tubes and the samples were digested in a boiling waterbath for a period of 1 hour. Therefore, each sample was diluted with distilled water to 50 ml. Subsamples (approximately 10 ml each) were centrifuged at 4000 rpm for 20 minutes and absorbance was measured on a spectrophotometer at 440 nm. Blanks and standards (D-glucose) were treated similarly and the standard curve was plotted. Concentrations are expressed as mgC/g dry weight of the animal tissue.

TRACE METALS IN SEAWATER:

Collection and storage of samples:

The essential criteria in the trace metal analysis is that the samples should be devoid of any external contamination. The sample containers themselves form one of the potential source of metal contamination. Much of the analytical accuracy will depend upon the choice of container materials and the procedure adopted to clean them. Adequate precautions for cleaning sample containers and other glasswares were taken. Polythene bottles used for storage of water samples were allowed to stand with analar grade HCL at room temperature for 3 days. These containers were then rinsed with distilled water and dried at 55 ^{o}C. The collected water samples were then stored by reducing the pH below 4 using 1N HCL.

PREPARATION OF TISSUE FOR METAL ANALYSIS:

The mussels, after collection, were cleaned and kept in filtered seawater in an aquarium for 48 hrs to defecate. The mussel meat was removed by using clean scissors and forceps under hygienic conditions so as to avoid any contamination. The scissors and forceps were cleaned with distilled water before and after use. The mussel meat was then kept in an oven and dried at 80 ^{o}C for 24 hrs. The dried meat was stored in glass vials, previously cleaned with concentrated hydrochloric acid.

ANALYSIS OF WATER SAMPLES:

Trace metals were analysed by using the method of Brooks et al. (1967), modified by Sen Gupta et al. (1978). 500 ml of filtered seawater was taken and to this 10 ml of an aqueous 2% ammonium pyrrolidine dithiocarbonate (APDC) solution was added which acts as useful chelating agent for various metals and was also effective in wide pH range (Brooks et al., 1967). To this 25 ml of methyl isobutyl ketone (MIBK) was added and the samples were vigorously shaken for 10 minutes, and the phases were separated via separating funnel.

To prepare a standard working curve, the extracted seawater samples were re-extracted to ensure that they were free of trace metals. Aliquotes (500 ml each) were then taken and known concentration of trace metals were added (0, 1, 2 and 3 ppm) using micropipette. These standards were extracted in a similar way as mentioned above. All these samples were run into an Atomic Absorption Spectrophotometer (model Varian Spectra AA 30) and the concentration expressed as ppm.

TRACE METALS IN MUSSEL TISSUE:

Analysis of trace metals (Fe, Cu, Zn and Mn) and major elements (Ca and Mg) in the total mussel tissue were undertaken. The metals were estimated by the method described by Leonard (1971). A known weight of each dried powdered sample (pooled for each day of collection) was taken in a glass beaker. To this 70% nitric acid was added and subjected to digestion on an electric hot plate until the brownish fumes completely disappeared and the residue turned whitish in colour. The residue was allowed to cool at room temperature. Then, 2 ml of perchloric acid was added and digested for about 10-15 minutes on an electric hot plate to dryness. The dried residue was treated with 10 ml dilute HCl and measured by atomic absorption spectrophotometry (AAS model Perkin and Elmer, 5000). Appropriate dilutions were made depending upon the sensitivity of detection in these samples. Reported concentrations of metals are expressed as ppm. Appropriate blanks and standards were also prepared by using the same method.

ANALYSIS OF HYDROGRAPHIC DATA:

Water samples were analysed for hydrographic parameters, such as temperature, salinity, dissolved oxygen, pH, total suspended matter, particulate organic carbon, chlorophyll a and phytoplankton cell count at fortnightly intervals.

Temperature of the water samples was measured with the help of a mercury thermometer immediately after the collection. The values are expressed in ^{o}C.

Salinity of the water samples was estimated following the method as described by Strickland and Parsons (1968). This involves determination of chlorinity by the Mohr Knudsen titration method with standard silver nitrate solution, using potassium chromate as an indicator. Salinity values are expressed as parts per thousand (%.).

Dissolved oxygen concentration of water samples was monitored using Winkler method. This method involves the fixation of dissolved oxygen using Winkler A and B reagent, followed by the titration against standard sodium thiosulfate solution using starch as indicator. The concentration was expressed as ml/litre of the sea water. For pH measurement digital pH meter (Phillips, PP 9046) was used.

The total suspended matter was determined by filtering 1 litre of water sample through preweighed millipore membrane filter paper (0.45 u). The residue was dried in an oven at 70 °C and weighed on an electric balance (Mettler AE 200). The concentrations are expressed as mg/litre (dry weight) of sea water. Particulate organic carbon was estimated following the method of wet oxidation using sulfuric acid-dichromate reagent as described by Parsons _et al_. (1984).

Chlorophyll _a_ estimation was done spectrophotometrically (Spectronic 1001). About 500 ml to 1 litre water sample was filtered through a GF/C filter paper followed by an extraction with 90% acetone in dark bottles at low temperature i.e. <5 °C (Yentsch and Menzel, 1963). The values are expressed as ug/litre of seawater.

Phytoplankton cell count was done by taking a known volume of water sample and enumerating under the microscope for dominant groups. The phytoplankton cell count is expressed as cells x 10^3/litre.

CHAPTER III

ENVIRONMENT

INTRODUCTION:

Dona Paula bay (Fig. 1) provides numerous advantages for the culture of edible bivalves. The site is well protected against human interference, pollution, wave action, occurrence of algal bloom, siltation and unpredicted variation in tidal amplitude.

However, field studies in estuaries must contend with spatial and temporal variations as well as chemical variations, caused by such factors as variable river discharge, tributaries with different input composition and flux of materials at the sediment water interface (Toole et al., 1987). A great deal of information is available on hydrographic features of this area (Dehadrai, 1970; Das et al., 1972; Cherian et al., 1975; Qasim et al., 1977; Qasim and Sen Gupta, 1981). The complex interrelationship between light, temperature, nutrients and various other environmental conditions together determine the relative success of different phytoplankton species (Raymont, 1980). Parulekar et al. (1982) discussed the importance of hydrographic factors influencing physiological changes occurring in raft-grown green mussels. However, at a given time, environmental conditions and hydrographic features may together influence certain biological processes (growth, physiology, reproduction, etc.) in the raft-grown population. Thus, studies on environmental and hydrographic parameters were felt necessary to have better understanding of ecobiological interrelations with raft-grown mussel *Perna viridis* L.

This chapter deals with vertical variations in ecobiological factors (temperature, salinity, chlorophyll a, dissolved oxygen, suspended load, particulate organic carbon, phytoplankton cell count, etc.) in the water column at the site of raft culture.

RESULTS

CLIMATE:

Annual variation in hydrographical factors could be divided into three periods such as (1) Pre-monsoon (February - May) (2) Monsoon (June - September) and (3) Post-monsoon (October - January). The average maximum atmospheric temperature observed during pre-monsoon 1988 period was 32.85 ^{o}C with a peak value in May (35 ^{o}C) (Fig. 3). Relative humidity was about 80% during the period of study, except during the monsoon when values as high as 93% were recorded. During south-west monsoon Goa receives the major part of its annual rainfall, amounting to a total of 3453 mm.

The combined effect of cloud cover restricts the incoming solar radiations and precipitation and thereby helps in lowering the summer temperature maxima. The average air temperature during monsoon was 29 ^{o}C. The mean air temperature varied from 24.5 to 31 ^{o}C. Some rain showers are also observed during post monsoon (Fig. 4) period. Practically no rainfall was observed from January to March and May. The maximum atmospheric temperature during the study period (October 1987 to September 1988) was observed in November and May (35 ^{o}C), whereas minimum temperature value was reported in February (17 ^{o}C).

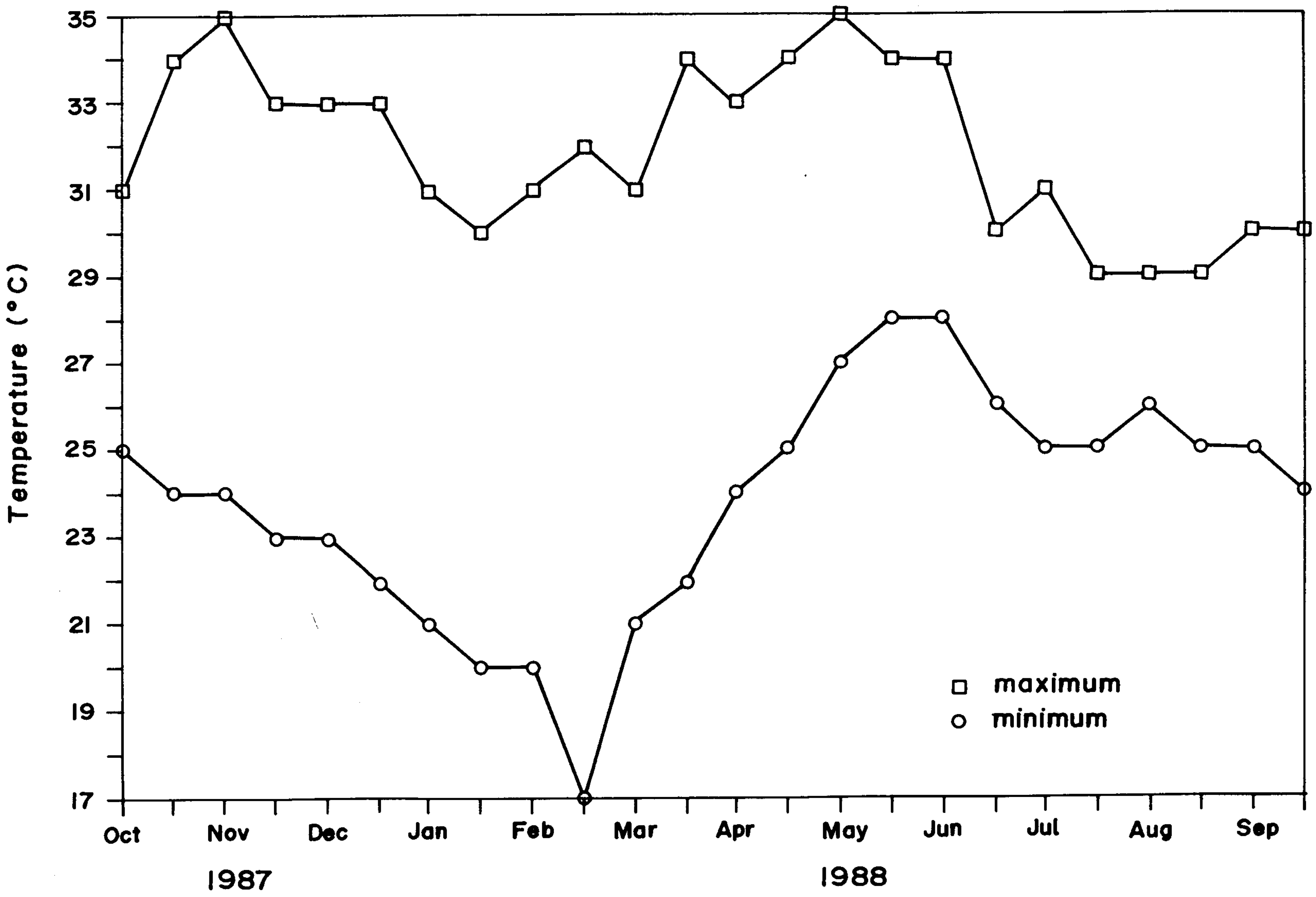

Fig. 3. Fortnightly changes in atmospheric temperature at the site of raft culture

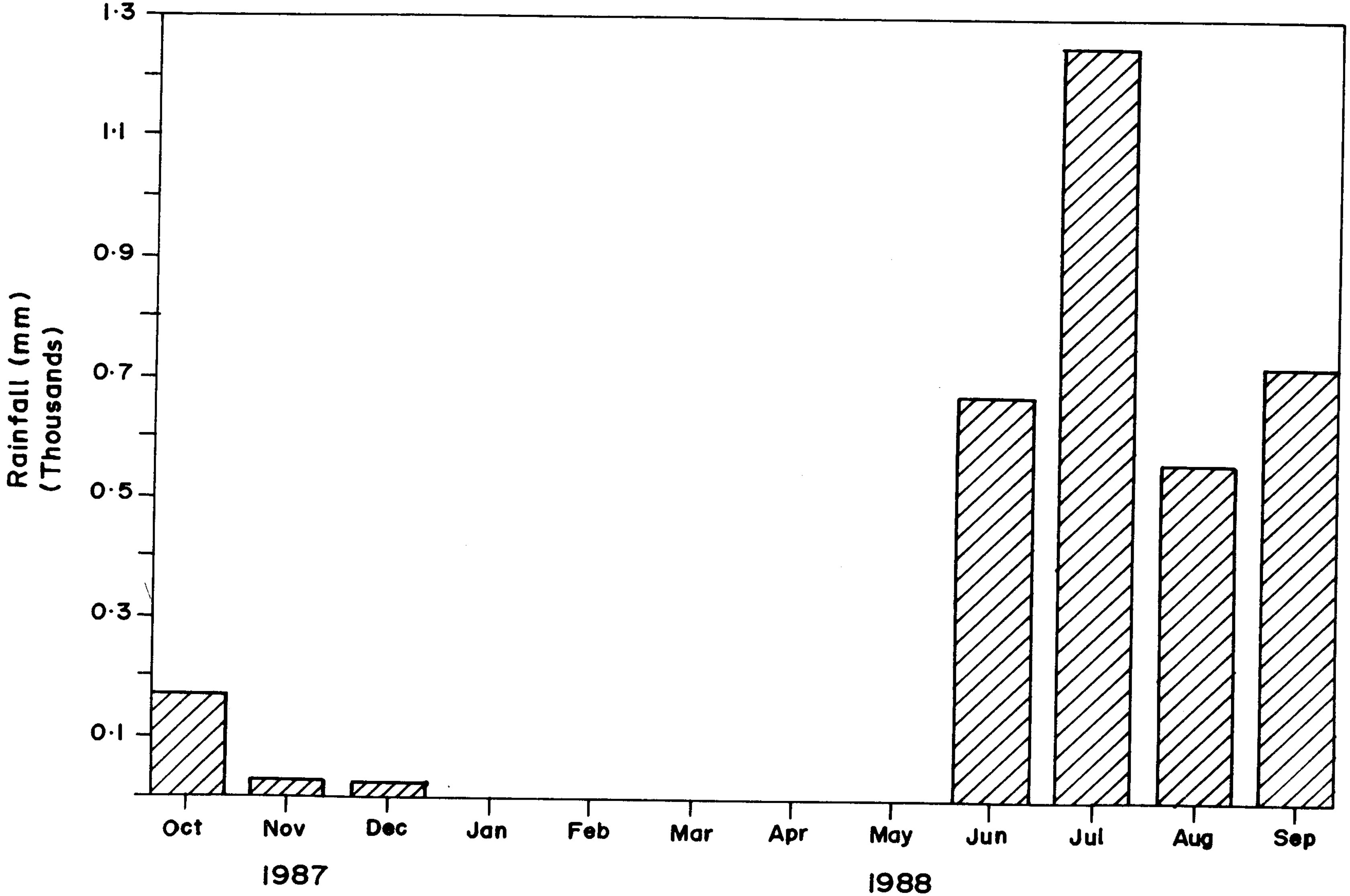

Fig. 4. Monthly variations in rainfall at the site of raft culture

HYDROBIOLOGICAL PARAMETERS

TEMPERATURE:

The temperature of water column at the raft culture site, varied between 26.7° and 31.5°C, the range of variation throughout the study period being 4.8°C. The surface water temperature was high from April to June, with a peak value of 32.0°C in June (Fig. 5). A sharp fall in temperature of 5.2°C was observed in July with a minimum of 26.8°C. Another peak in surface water temperature was noticed in April (31.5°C). Gradual increase in water temperature was observed from July to September. The temperature during October-December varied between 29.3 and 30.0°C, and in November-December, the surface water temperature registered lower values compared to mid-depth and near bottom waters. The average surface water temperature recorded during the present study was 29.13°C.

Water temperature at mid-depth in the area of study ranged from 26.5 to 31.5°C. The maximum and the minimum temperatures were recorded in April and January, respectively. Stable temperature regime (30 $\pm$ 0.2°C) was observed from October to December. In January, a sudden fall in temperature was noticed. The temperture difference from December to January was to the tune of 3.5°C. Since then, temperature increased and then a low value of 27°C was observed in March. Then onwards a steep rise in temperature was noticed with maximum value in April. In May, slight decrease in temperature was recorded, followed by peak value of 31.5°C in June. From July to September, temperature was

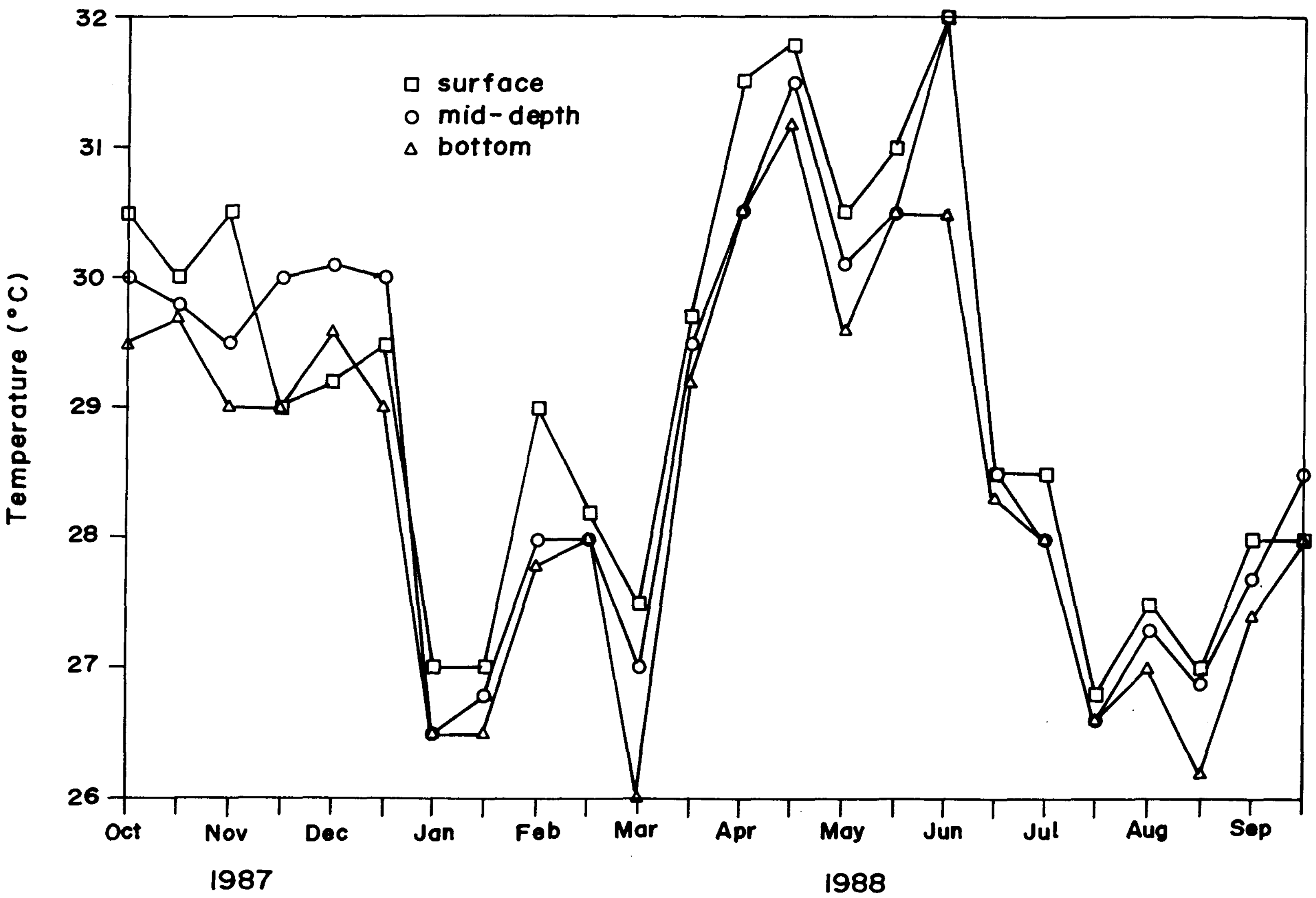

Fig. 5. Fortnightly changes in water temperature at the site of raft culture

in the range of 26.6 to 28.5 °C. The average mid-depth water temperature being 28.87 °C for the study period.

Near bottom waters were colder as compared to surface and mid-depth water during the period of study except during October-December. The water temperature in the bottom water was in the range of 26.6 to 31.2 °C. Maximum water temperature value was recorded in April and the minimum in July. The average temperature in bottom waters being 28.5 °C with high values in October and a decrease in November. Thereafter, a slight increase was observed in December. A steep fall in temperature was seen in January which gradually increased till April. From July onwards, the temperature slowly increased till September i.e. end of the study period.

SALINITY:

In the present study, highest (35.82 ppt) and lowest (21.02 ppt) value for water column was recorded in June and August, respectively (Fig. 6). The salinity values indicate that the water column was more saline during the period from November to June, the variation in salinity being from 33.87 to 35.82 ppt.

The surface water salinity at the raft culture site, with low values in October, registered a steep increase in November. Salinity of surface water from November onwards was high, with slight variations till May, reaching its peak value (36.06 ppt) in June (Fig. 6). Towards the end of June, a sudden fall in salinity was noticed. The salinity gradient being 7.38 ppt.

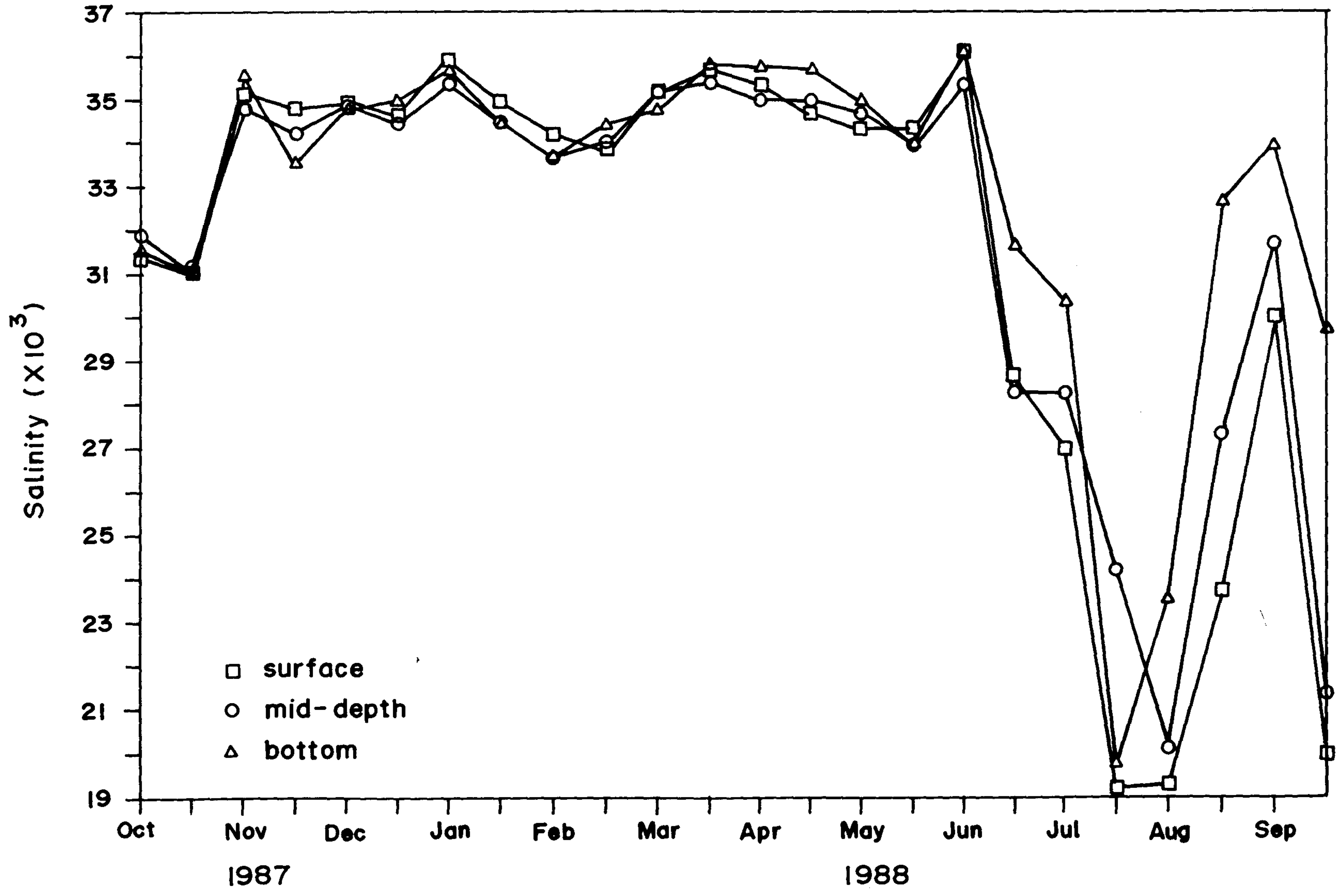

Fig. 6. Fortnightly fluctuations in Salinity at the site of raft culture

From June onwards, decreasing trend in salinity was observed till August. Thereafter, salinity increased upto the first week of September attaining a value of 30.00 ppt, whereas a sudden fall in salinity was observed in last week of September registering a value of 20.00 ppt. The annual average salinity for surface water was found to be 31.43 ppt.

Mid-depth water salinity followed the same pattern of variation as observed for surface water from November to May period. An increase in salinity was observed from October to November, with the rate of change being marginal. Salinity values were highest during March (35.39 ppt) and the lowest in August (20.13 ppt). Thereafter, the values showed a gradual increase till September. However, in the latter part of September, a sudden decline upto 9.28 ppt was recorded. The average salinity value for the complete period of study was 31.86 ppt.

The salinity distribution in the nearbottom waters indicated generally higher values from February to June, except during the last week of May. Near bottom waters, with low salinity values in October, increased in November and remained steady till May (33.5 to 35.5 ppt). The maximum and the minimum values were observed in June (36.6 ppt) and July (19.29 ppt) respectively. In July, the fluctuations in salinity were observed upto a level of 10.57 ppt. Later, salinity values increased gradually till the begining of September and a slight fall was noticed during latter half of September. In general, nearbottom waters were more saline as compared to surface and mid-depth waters, with 32.85 ppt as an average annual salinity value.

DISSOLVED OXYGEN (DO):

Variation in dissolved oxygen at the site of raft culture is shown in Fig. 7. The DO values in the area of study indicate optimum levels throughout the period of study. The maximum value was observed in the month of July (6.01 ml/l) and the minimum value in June (3.02 ml/l) for the surface water. The peak value in July remained steady with minor variations in monsoon season. Since October, the values increased gradually and attained peak in January and then onwards was steady with small variations till July. The average value for surface water was 4.04 ml/l for the entire period of study.

A similar trend in the distribution was observed for mid-depth, thus indicating saturated waters for the complete period of study at the site of raft culture. DO content was low with slight variations from begining of the study period till July. Relatively low values were observed as compared to surface waters. The maximum value was observed in July (5.92 ml/l) and the minimum in February (2.98 ml/l). After attaining a peak value in July, a gradual fall was recorded till September. The average DO content for the period of study was 3.94 ml/l.

In July, the maximum DO content (5.64 ml/l) in the near bottom waters was observed. The DO content in near bottom waters was low as compared to surface and mid-depth levels. The DO

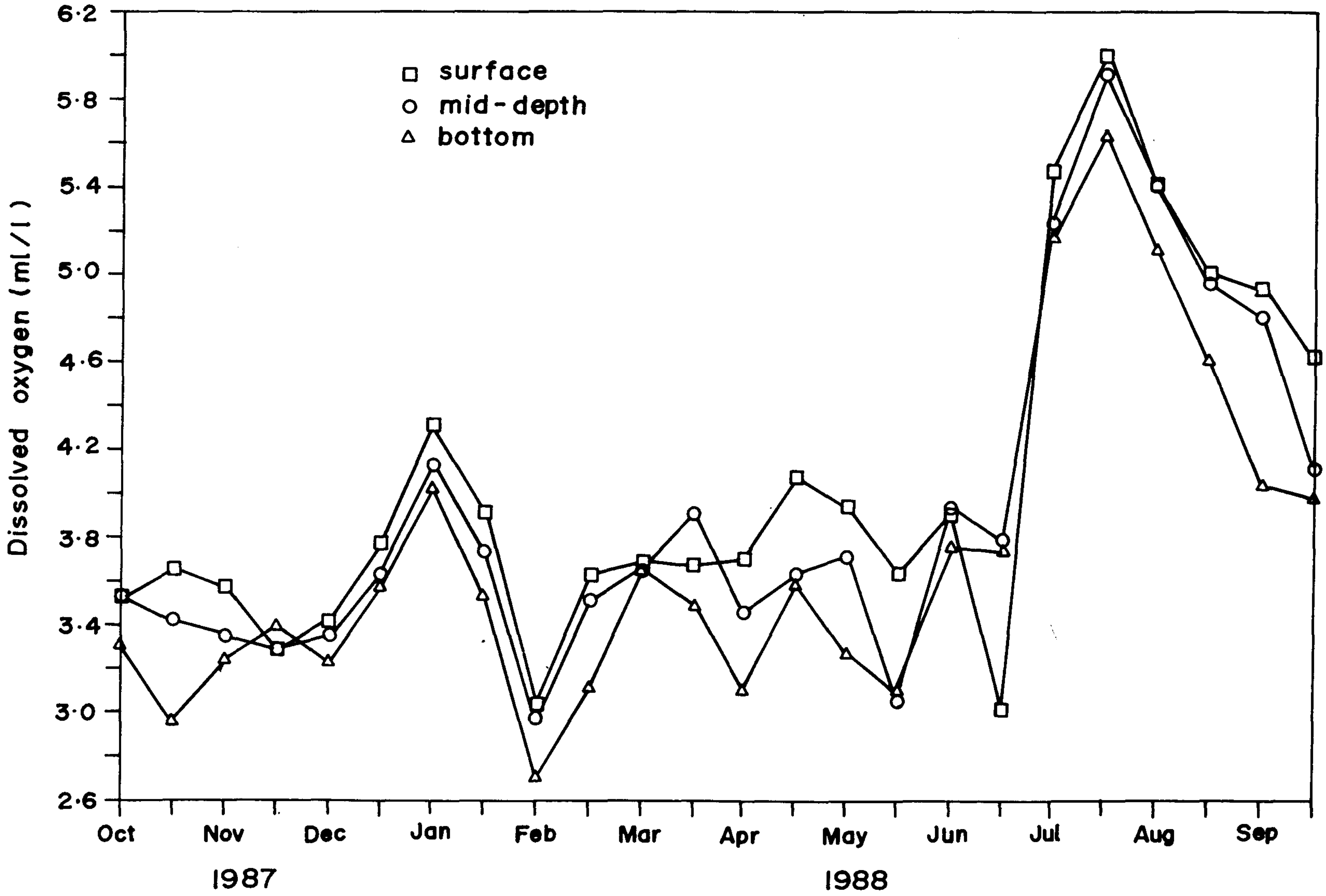

Fig. 7. Fortnightly changes in DO at the site of raft culture during the present study

content was high only during the monsoon months. The minimum value of DO for near bottom waters was observed in the month of October (2.97 ml/l). Since June, DO content increased till August followed by a slight fall in September. The average dissolved oxygen value was observed to be 3.75 ml/l.

pH:

The hydrogen ion concentration (pH) did not show any marked variations during the period of study at the raft culture site. The annual pH range of water column varied from 7.67 to 8.44 (Fig. 8). Generally near bottom waters registered higher pH values than the surface and mid-depth waters. Variations in pH values for surface, mid-depth and near bottom waters were from 7.04 to 8.34; 7.40 to 8.49 and 7.50 to 8.51 respectively. The maximum and the minimum values of pH were observed in the month of July and April respectively. Comparatively higher values of pH were recorded during the period of July-August at all the depths.

SUSPENDED LOAD:

Fig. 9 presents variations in suspended load at the site of raft culture.

Annual average value for the water column at the raft culture site highlighted that the suspended matter was low and uniform throughout the year except for the months of August and September. The maximum value was observed during September (1075.47 mg/l) and the minimum in the month of April (33.8 mg/l).

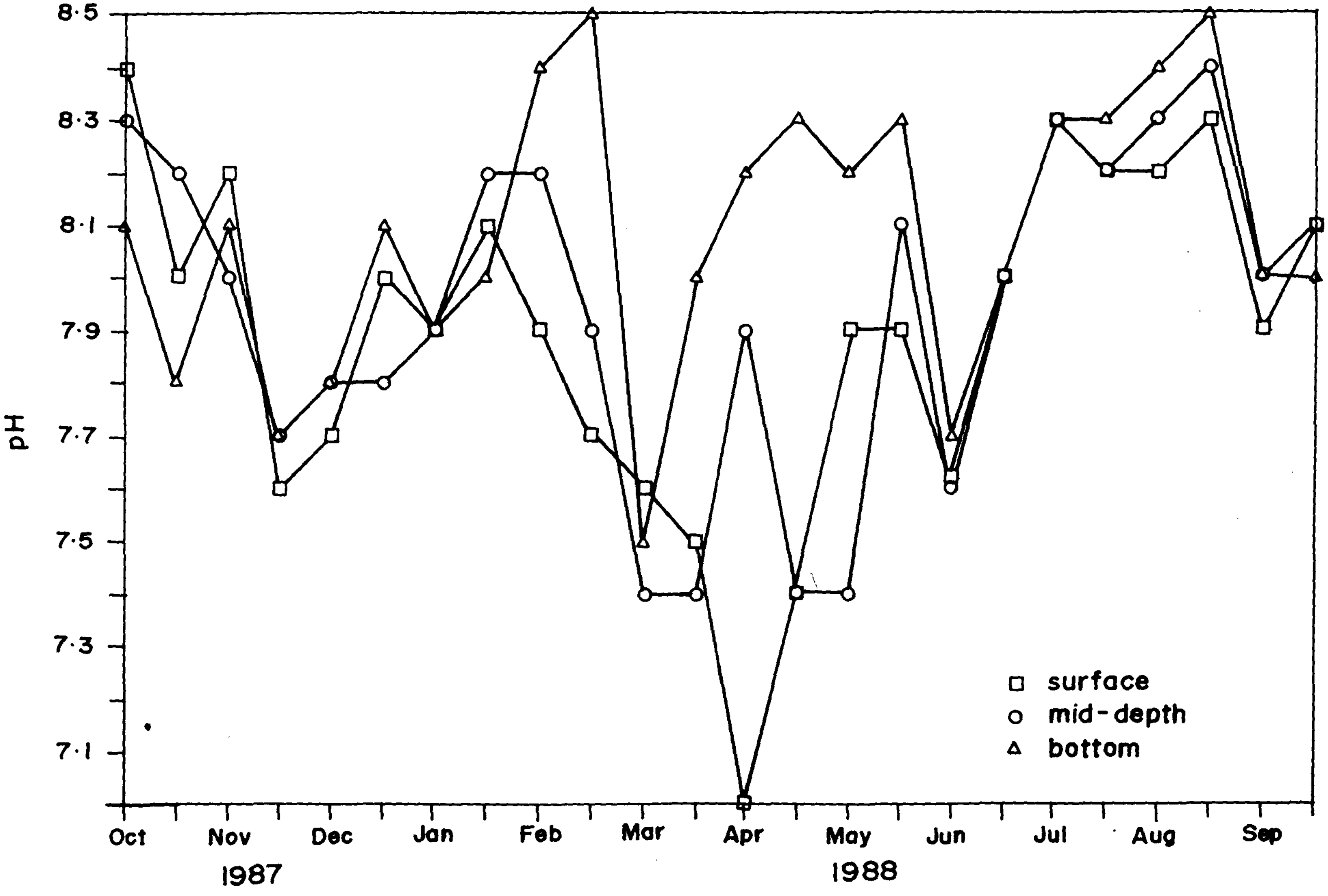

Fig.8. Fortnightly variations in pH at the site of raft culture.

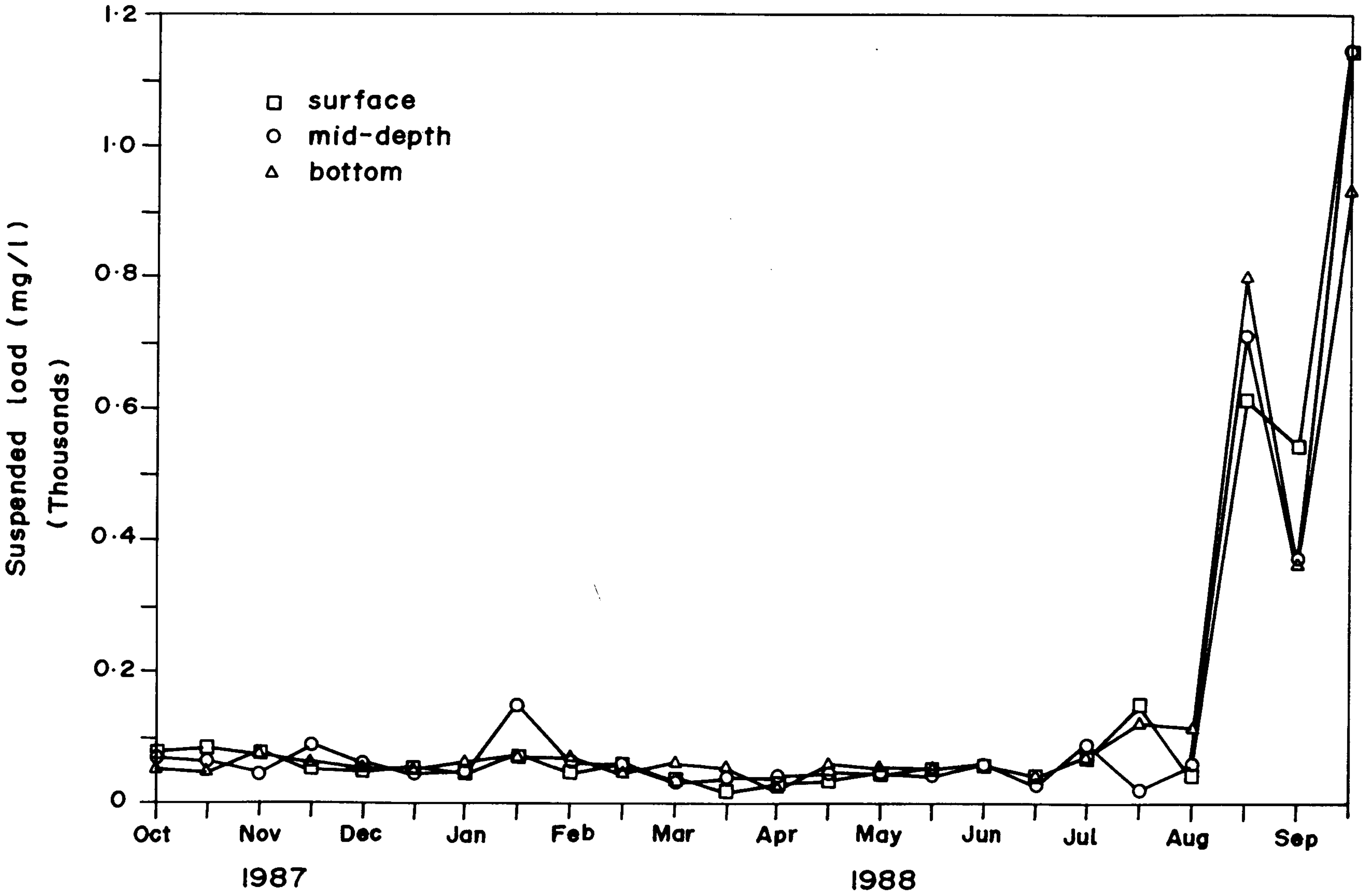

Fig. 9. Fortnightly changes in suspended load at the site of raft culture

In surface water, the suspended load observed was low to moderate throughout the period of study except in July, August and September. During these months, suspended load was very high reaching its peak in September (1143.8 mg/l). Suspended matter was found to be the least in the latter half of March (19.4 mg/l). An ascending trend in suspended load values was observed from June to September, except a low value in August (43.0 mg/l). The annual average value for the surface water was 146.84 mg/l.

In the present study, suspended load varied from a minimum value of 22.4 mg/l in July to a maximum of 1150.6 mg/l in September for mid-depth water at the site of raft culture. The suspended matter from October, 1987 till the first half of August, 1988 was from low to moderate in the range of 22.4 to 152.0 mg/l. In the latter half of August and September, the suspended load was high, recording its peak value in September. The annual average for mid-depth water was computed to be 144.09 mg/l.

In near bottom waters, the suspended matter followed the same pattern of variation as that of surface and mid-depth water especially from October, 1987 to June, 1988 with minimum values in April (26.2 mg/l). As compared to the values during these months a slightly higher value was observed in the last week of July (124.4 mg/l). From August, an increase was observed attaining maximum value in September (932.0 mg/l). The average annual suspended matter at the raft culture site for near bottom water was 143.4 mg/l. The annual average values at each depth revealed high suspended matter in surface water than mid-depth and near bottom waters. However, the difference was not significant.

PARTICULATE ORGANIC CARBON (POC):

Fortnightly variations in particulate organic carbon (POC) are depicted in Fig. 10.

The POC values indicate that the water column at the site of raft culture presented an uniform distribution of POC increasing with depth, except for some period (February to April and June). The maximum POC content was in July (5348.45 µg/l) and the minimum in February (432.17 µg/l).

POC in the surface water at the raft culture site, showed a gradual decrease from October to November. Since then, a steady increase was noticed till the end of December. The POC content was low for the period from January to April (316.93 - 802.32 µg/l). In May, a sudden rise in POC content was observed, which decreased in June registering a value of 478.63 µg/l. A slightly higher value in POC content in the first week of July, with a sudden rise recording its maximum value (5276.14 µg/l) was observed in the last week of July. However, in August the value observed was much less (1364.75 µg/l) and thereafter gradually increased till September. The minimum value was observed in April (316.93 µg/l). The annual average value was found to be 1323.62 µg/l for the surface waters.

A decreasing trend in POC content was observed from the

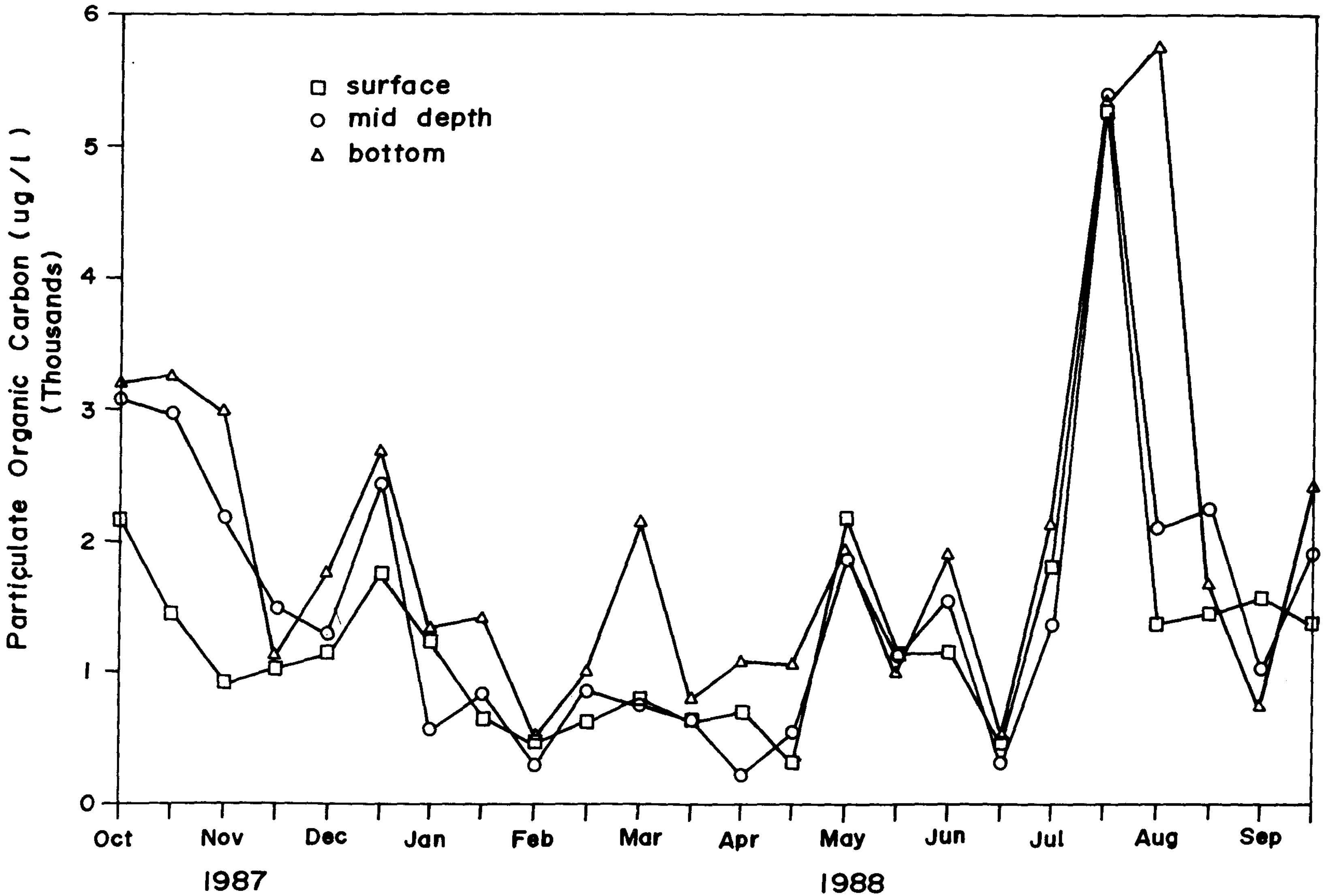

Fig. 10. Fortnightly changes in Particulate Organic Carbon at the site of raft culture

beginning of the study (October and November) at the raft culture site for mid-depth waters. A high value was noticed in the last week of December. For the period from January to April, POC values were low ranging from 232.85 to 873.20 µg/l. The minimum value was observed in April (232.85 µg/l). Since then, upto the end of the study period, except in the last week of June, the POC content was high with its peak value in the month of July (5400.78 µg/l). The POC content in mid-depth waters was high as compared to surface water. The annual average for mid-depth water being 1550.89 µg/l.

At the near bottom waters, during the present study, maximum value of POC content was observed in August (5756.52 µg/l) and the minimum value in February (507.41 µg/l). During the complete period of study, the nature of distribution of POC at the raft culture site was higher as compared to surface and mid-depth waters. No specific pattern, either ascending or descending, was observed even for a period of two months in continuity. There was homogenous distribution of POC in near bottom waters for the total period of study except for slightly lower values in March, June and September. The annual average POC content for near bottom water was 1996.40 µg/l.

Chlorophyll a:

Fig. 11 represents variations in chlorophyll a content at the site of raft culture.

The chlorophyll a content for the water column was observed

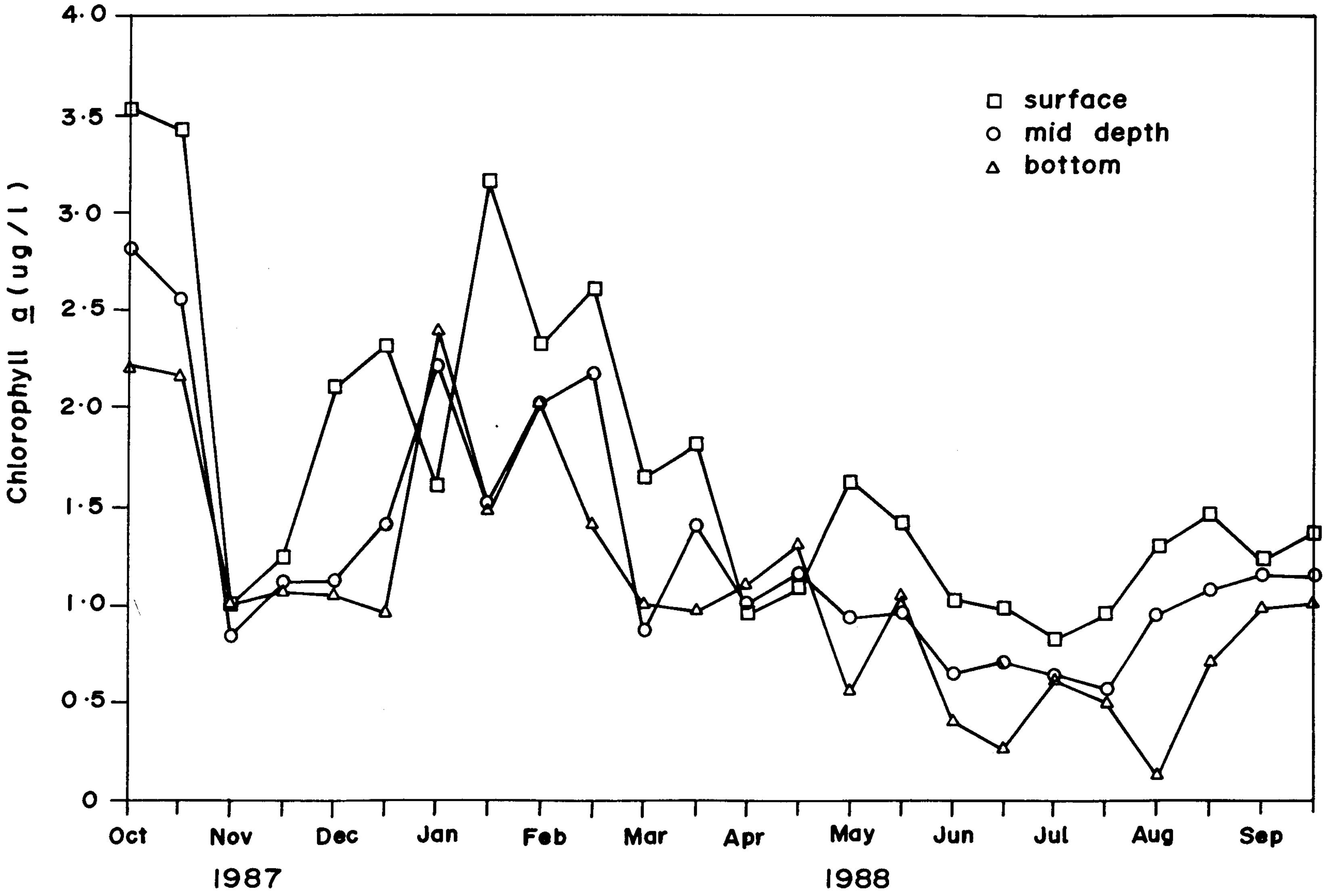

Fig. 11. Fortnightly variation in Chl. a at the raft culture site

to be maximum in October (2.85 µg/l) and minimum in the month of June (0.65 µg/l). During the monsoon months i.e. June-August, chlorophyll a content was low as compared to other periods.

Chlorophyll a content observed for surface water was maximum in October (3.53 µg/l), showed a fall in November, followed by gradual increase, attaining a second peak in January (3.16 µg/l). Thereafter, chlorophyll a values were low during remaining part of the study. In monsoon months, major fall in chlorophyll a values was noticed in the study area. Minimum value of chlorophyll a content was observed in July (0.83 µg/l). A small increase in chlorophyll a content was observed at the end of the monsoon season i.e. September. An annual average value for surface water was found to be 1.7 µg/l.

Variations in chlorophyll a concentration for mid-depth water followed a similar pattern as observed for surface waters registering low chlorophyll a values from May to August, with mamixum value in October (2.82 µg/l). Low values of chlorophyll a content were observed from November to June with minute variations. In July, the minimum value of chlorophyll a was noticed (0.57 µg/l). The annual average values of chlorophyll a for mid-depth water was found to be 1.29 µg/l.

In near bottom water, the chlorophyll a concentration from May to August was low as compared to the remaining part of the study. The highest chlorophyll a content was observed in April (2.4 µg/l) and the lowest (0.14 µg/l) during the month of August. A steady fall in the chlorophyll a content was observed from October to December. During January and April the near bottom waters registered higher values than surface and mid-depth waters. The annual average value in the nearbottom waters at the site of raft culture was observed to be 1.1 µg/l.

PHYTOPLANKTON CELL COUNT:

Monthly variations in phytoplankton cell count for surface and sub-surface waters are shown in Fig. 12. Table 2 and 3 presents abundance of various species of phytoplankton in the water column. In general, phytoplankton cell count was more in surface water as compared to sub-surface waters except in April. Higher values of phytoplankton count was observed in October, December, February and September, for the surface and sub-surface waters.

During monsoon season, phytoplankton count was minimum. Low values of phytoplankton count was observed in March and November. Phytoplankton count was observed to be maximum in October (112.75 cell $\times 10^3$/l) for surface waters and in February (95.5 cells $\times 10^3$/l) for sub-surface waters. Minimum value of phytoplankton count was observed in June (17.5 cells $\times 10^3$/l) for surface waters and 12.9 cells $\times 10^3$/l for sub-surface waters.

Major contribution to phytoplankton population was from diatoms followed by dinoflagellates. Among diatoms, <u>Coscinodiscus</u> spp. was present throughout the period of study except in June and July for both surface and sub-surface waters. Occurrence of <u>Trichodesmium</u> spp. was only restricted to the month

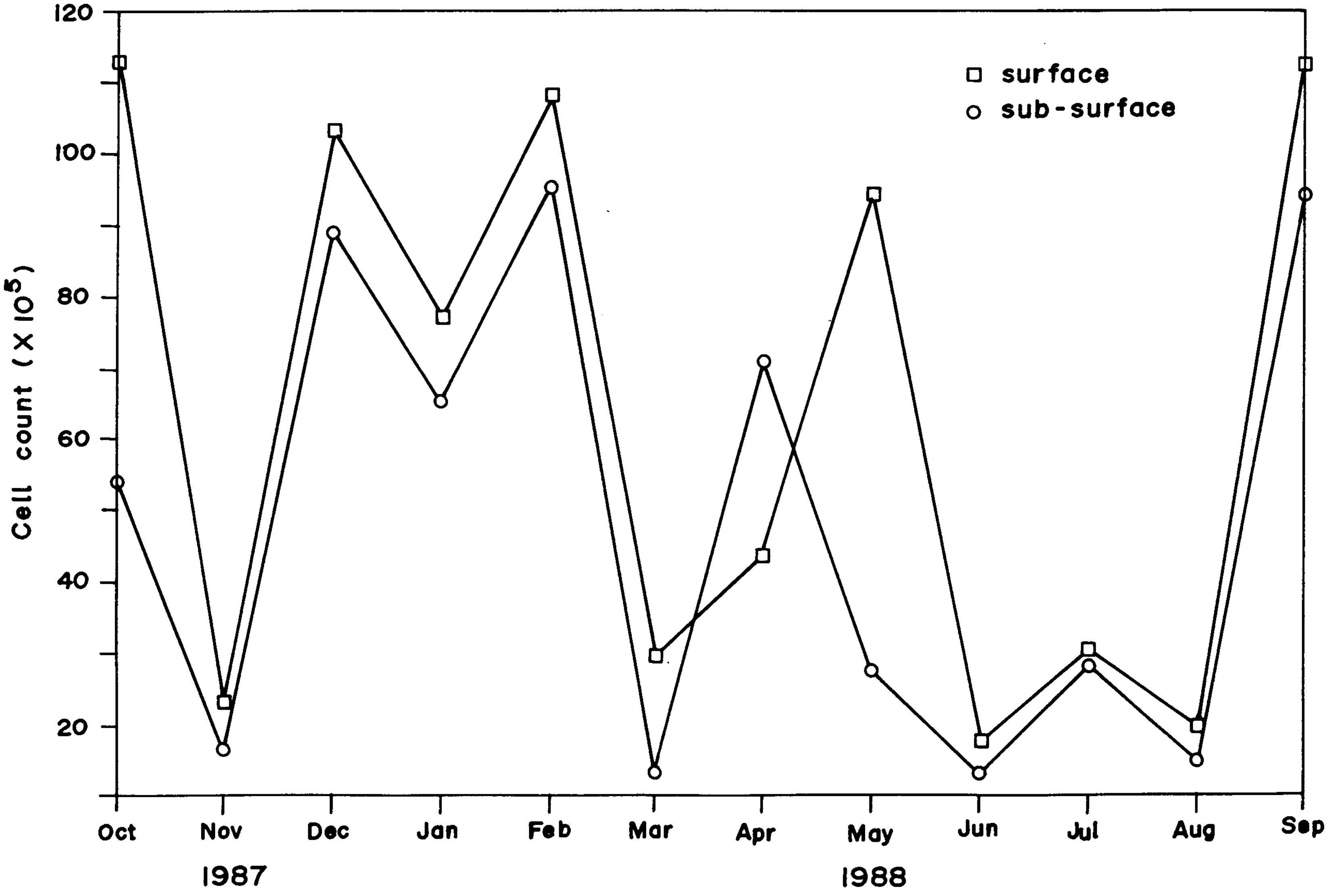

Fig. 12. Monthly changes in phytoplankton cell count at the site of raft culture

Table 2. Distribution of phytoplankton species (cells x 10^3/l) in surface water samples at Dona Paula

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
DIATOMS												
Amphiprora sp.	-	-	-	-	-	-	1.00	1.00	-	-	-	-
Asterionella japonica	-	-	-	-	-	-	1.00	-	-	-	-	-
Bacillaria paradoxa	-	-	-	20.00	-		1.50	12.00	-	-	-	-
Biddulphia sinensis	-	-	-	2.00	8.00		1.50	1.00	-	-	-	-
Biddulphia sp.	-	-	-	1.00	-		-	-	-	-	-	-
Chaetoceros curvisetus	-	-	25.00	-	-		-	-	-	-	-	-
Chaetoceros sp.	-	4.00	-	-	-		1.50	-	1.00	-	-	-
Coscinodiscus perforatus	-	1.00	-	-	-		-	-	-	-	-	1.50
**Coscinodiscus* sp.	2.00	6.00	10.00	5.00	14.00		3.00	22.00	3.00	-	-	-
Ditylum brightwellii	-	-	2.00	-	-		0.50	-	-	-	-	-
Ditylum sol	-	-	-	-	-		0.50	-	-	-	-	-
Ditylum sp.	-	-	2.00	-	3.00		-	-	-	-	-	-
Fragilaria oceanica	76.00	-	-	-	-		-	-	-	-	-	-
Fragilaria sp.	7.00	-	-	-	-		-	-	-	-	-	-
Gyrosigma fascicola	-	-	-	-	1.00		-	-	-	-	-	-
Gyrosigma sp.	-	-	-	-	-		0.25	-	-	-	-	-
Hemiaulus sinensis	-	-	-	-	-		-	-	-	-	-	-

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Hemidiscus sp.	-	-	-	-	-	-	0.25	-	-	-	-	-
Laudaria sp.	-	2.00	-	-	-	-	-	-	-	-	-	0.50
Leptocylindrus danicus	-	0.50	14.00	15.00	-	-	-	-	-	-	-	-
Licmophora sp.	-	-	-	-	0.50	-	-	-	-	-	-	-
Melosira nummuloides	-	-	-	-	2.00	-	-	-	-	-	-	-
Melosira momiliformes	-	-	-	1.00	1.50	-	-	-	-	-	-	-
Melosira sp.	12.00	-	-	-	3.00	-	1.50	10.00	-	-	-	-
Navicula directa	0.50	-	-	-	3.00	-	0.25	-	0.50	-	-	-
Navicula distans	-	-	-	-	7.00	-	-	-	-	-	-	-
Navicula sp.	-	1.50	10.00	3.00	3.00	-	1.00	4.00	4.00	0.50	8.50	-
Nitzschia bilobata	-	-	-	10.00	-	-	2.50	-	-	-	-	-
Nitzschia closterium	-	-	2.00	4.00	-	8.00	-	-	-	0.50	-	2.50
Nitzschia longissima	-	-	-	1.00	-	-	-	-	-	-	-	-
Nitzschia migrans	-	-	-	-	-	6.00	0.50	-	-	-	-	-
Nitzschia seriata	-	2.00	15.00	2.00	38.00	-	-	-	-	-	-	-
Nitzschia sp.	-	2.00	1.00	1.00	-	4.00	4.00	4.00	2.00	-	1.25	-
Pleurosigma angulatum	-	-	-	-	2.00	1.00	-	-	-	-	-	-
Pleurosigma elongatum	-	-	1.00	-	0.50	-	0.25	-	-	-	-	-
Pleurosigma sp.	-	-	-	3.00	1.00	-	2.00	26.00	2.00	0.25	6.25	-
Pinnularia sp.	0.50	-	-	3.00	-	-	-	-	-	-	-	-

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Rhizosolenia styliformis	-	-	1.00	-	-	-	-	-	-	-	-	-
Rhizosolenia sp.	-	-	7.00	3.00	-	-	0.25	-	-	-	-	3.50
Schroederella delicatula	-	-	10.00	-	-	-	-	-	-	29.00	-	-
Skeletonema costatum	-	-	-	-	13.00	-	3.00	-	-	-	-	-
Stephanophysis palmerianni	-	-	-	2.00	-	-	-	-	-	-	-	-
Thallasiosira sp.	-	-	-	-	-	-	-	-	-	1.00	-	-
Thallasiothrix sp.	6.00	-	-	-	-	-	0.25	-	3.00	-	-	-
DINOFLAGELLATES												
Ceratium furca	1.00	-	-	-	-	-	-	-	-	-	-	95.00
Ceratium lineatum	-	-	-	-	-	0.50	-	-	-	-	-	-
Ceratium macroceros	0.50	-	-	-	-	-	-	-	-	-	-	-
Dinophysis sp.	0.25	-	-	1.00	-	-	3.00	-	-	-	-	6.00
Exuviella sp.	-	1.00	-	-	0.50	-	-	-	-	-	-	-
Gonyaulax sp.	2.00	-	-	-	-	-	-	-	-	-	-	-
Gymnodium sp.	0.50	-	-	-	-	-	-	-	-	-	-	-
Noctiluca sp.	1.00	-	-	-	-	-	-	-	-	-	-	-
Peridium sp.	3.00	2.50	3.00	-	5.00	0.50	-	-	-	-	-	2.00
								11.00				
Prorocentrum sp.	0.50	-	-	-	-	-	-	-	-	-	-	1.00
Unidentified forms	-	0.50	-	-	2.00	-	3.00	3.00	2.00	-	-	-
BLUE GREEN ALGAE												
Trichodesmium sp.	-	-	-	-	-	-	11.00	-	-	-	-	-

Table 3. Distribution of phytoplankton species (cells x 10^3/l) in subsurface water samples at Dona Paula

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
DIATOMS												
Amphiprora sp.	-	-	-	-	-	-	0.25	-	-	-	-	
Aulocodiscus sp.	-	-	-	-	-	-	-	-	-	-	-	1.00
Bacillaria paradoxa	-	-	-	8.00	9.00	-	3.50	-	-	-	-	
Bacterioriva sp.	-	-	-	-	2.50	-	-	-	-	-	-	
Biddulphia aurita	-	-	0.50	-	-	-	-	-	-	0.25	-	
Biddulphia sinensis	-	0.50	-	-	4.00	-	2.00	-	-	-	-	
Biddulphia sp.	-	-	-	-	-	-	0.25	0.50	0.25	-	-	
Chaetoceros curvisetus	-	-	19.00	-	-	-	-	-	-	-	-	
Coscinodiscus marginatus	-	1.00	-	-	-	-	0.25	-	-	-	-	1.00
Coscinodiscus sp.	1.00	1.00	9.00	5.00	9.00	2.50	3.00	6.00	-	4.00	2.50	2.00
Cyclotella striata	-	1.00	-	-	-	-	-	-	-	-	-	
Denticula sp.	-	-	-	-	-	-	-	-	-	0.25	-	
Ditylum brightwellii	-	-	0.50	-	-	-	-	-	-	0.50	-	
Ditylum sol	-	-	-	-	-	-	0.25	-	-	-	-	
Eucampia sp.	-	-	-	-	-	-	-	-	-	-	-	0.50
Fragilaria oceanica	43.00	-	-	-	-	-	-	-	-	-	-	64.00
Gyrosigma sp.	-	-	-	-	-	-	0.50	-	-	-	-	
Hemiaulus sinensis	-	-	-	-	3.00	-	9.50	-	-	-	-	

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Laudaria annulata	-	-	-	3.00	-	-	-	-	-	-	-	-
Leptocylindrus sp.	-	3.00	13.5	-	-	-	0.50	-	-	-	-	-
Melosira nummuloides	-	-	-	-	9.00	3.00	-	-	-	-	-	-
Melosira moriliformis	-	-	-	-	2.00	1.00	-	-	-	-	-	-
Melosira sp.	6.00	-	-	-	-	-	17.00	-	3.00	-	-	-
Navicula directa	-	-	-	-	-	1.00	2.50	-	-	-	-	-
Navicula distans	0.25	-	-	-	5.00	-	-	-	-	-	-	-
Navicula sp.	-	0.50	11.50	9.00	-	-	1.00	2.00	0.50	-	3.75	0.50
Nitzschia bilobata	-	2.50	-	6.00	0.25	-	2.00	1.50	1.00	-	-	-
Nitzschia closterium	-	2.00	3.00	16.00	3.00	3.00	0.50	2.00	-	-	5.00	-
Nitzschia delicatessima	0.25	-	-	-	4.50	-	-	-	-	-	-	-
Nitzschia migrans	-	-	-	-	0.50	1.00	0.25	-	-	-	-	-
Nitzschia panduriformis	-	-	-	-	-	-	0.25	0.50	-	-	-	-
Nitzschia seriata	-	2.00	11.00	5.00	22.00	1.50	14.50	1.00	1.50	-	-	-
Nitzschia sp.	-	0.50	-	-	4.00	-	-	0.75	0.25	-	1.25	-
Pleurosigma angulatum	-	-	-	-	0.50	-	-	0.50	-	-	-	-
Pleurosigma elongatum	-	-	1.00	-	-	0.50	1.50	-	-	-	-	-
Pleurosigma sp.	-	-	0.50	5.00	1.00	-	3.50	10.00	-	1.00	2.50	-
Rhizosolenia sp.	-	1.00	7.00	-	-	-	0.25	-	-	-	-	-

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Schroderella delicatula	-	-	5.00	-	-	-	-	-	-	-	-	-
Skeletonema costatum	-	-	0.50	-	7.00	-	1.50	-	1.15	21.00	-	2.00
Stephenophyxis sp.	-	-	-	1.00	-	-	-	-	-	-	-	1.00
Thallasionema sp.	-	-	-	-	-	-	0.50	-	-	1.00	-	-
Thalassiosira subtilis	-	-	-	-	2.00	-	-	-	-	-	-	-
Thallasiothrix sp.	3.00	1.00	-	2.00	-	-	1.50	-	3.00	-	-	-
DIANOFLAGELLATES												
Ceratium furca	-	-	-	-	-	-	-	-	-	-	-	15.00
Ceratium sp.	-	-	1.00	-	5.00	-	-	-	-	-	-	-
Dinophysis sp.	-	-	-	-	-	-	-	-	-	-	-	1.00
Exuviella sp.	0.50	0.50	0.50	1.00	0.25	-	-	-	-	-	-	0.50
Gonyaulax sp.	-	-	-	-	-	-	-	-	-	-	-	1.00
Noctiluca sp.	-	-	-	-	-	-	-	-	-	-	-	0.50
Peridinium sp.	-	-	5.00	-	2.00	-	1.50	0.50	0.50	-	-	1.00
Prorocentrum sp.	-	-	-	-	-	-	-	-	-	-	-	1.00
Tetraselmis sp.	-	-	0.50	4.00	-	-	-	-	-	-	-	2.00
Unidentified forms	-	-	-	-	-	-	2.00	2.00	1.75	-	-	-

of April. Other dominant diatoms were Navicula spp. and Nitzschia spp. in surface waters and Navicula spp, Nitzschia closterium, and Nitzschia ceriata in sub-surface waters during the period of study.

DISCUSSION:

Raft culture site at Dona Paula bay, in Zuari estuary is subjected to fluctuations in hydrobiological and environmental parameters within a small magnitude of time. An extensive account of work carried out on hydrographical parameters of this area is available (Dehadrai, 1970; Das et al., 1972; Dehadrai and Bhargava, 1972; Goswami and Singbal, 1974; Cherian et al., 1975; Parulekar et al., 1975; Dalal, 1976; Parulekar et al., 1980). Detailed investigations were also undertaken during pollution survey of Mandovi-Zuari estuarine system (Anon, 1978). Qasim and Sen Gupta (1981) studied the hydrographical features and compared the estuaries of Goa. Chemical properties and nutrient distribution in estuarine complex of Zuari estuary has been studied by De Souza et al. (1981) and Verlencar (1982). Variations in interference by exogenous factors and their effects on growth, reproduction and physiology of the raft-grown green mussel Perna viridis L. has been discussed by Parulekar et al. (1982). The most recent observations on variation in environmental factors in Zuari estuary with respect to density of benthic organisms has been discussed by Ansari et al.(1986).

The above review suggests that the estuarine region in Zuari is prone to less variation as compared to Mandovi, however seasonal variations in various hydrobiological parameters follow the same pattern of fluctuations. In Zuari estuary changes are not significant except in monsoon. During monsoon, salinity declines, however, the degree of reduction in salinity due to precipitation and inflow of river runoff is not to such an extent that freshwater influx could dominate. In the present study, most of the hydrographic parameters appeared to be adopted to seasonal rhythms, showing marked changes, particularly influenced by the south-west monsoon.

Temperature at the site of culture was the highest in April and June. Higher temperature during this period in the water column was attributed to higher atmospheric temperature prevailing at that time (Dehadrai, 1970). A fall in temperature was observed in May, since the observations were made soon after the first pre-monsoon showers. During monsoon period i.e. from June to September, temperature in the water column was low. Lower temperature during this time was due to precipitation and freshwater influx which brings cooler waters from the upper reaches of river Zuari, especially during the receding tides. The near bottom waters were also cooler, which could be due to thorough mixing of the water column influenced by wind and tidal currents (Cherian et al., 1975).

Surface water registered lower temperature as compared to mid-depth and near bottom waters during November-December. The low temperature in surface water was mainly due to low atmospheric temperature and could also be influenced by intrusion of cold waters as a result of upwelling (Pritchard, 1967). Similar low temperature for surface water was earlier reported by Parulekar et al. (1975). In January, water temperature observed was very low, which coincided with low atmospheric temperature and cooler winds prevailing in the area of study at this time. Dehadrai and Bhargava (1972) also reported such low temperature in this area. The thermal condition of the water in this estuarine complex appears to be influenced by atmospheric temperature (Dehadrai and Bhargava, 1972).

During the period of study except monsoon months, salinity values were higher and uniform with minute variations. Low magnitude of variation was mainly attributed to negligible freshwater inflow at the raft culture site (De Souza et al., 1981). Higher salinity values during major period of study may be due to higher temperature values of the water column prevailing during this period except in January and March. High atmospheric temperature leading to rapid rate of evaporation ascends salinity values. Higher salinity values at this time were also reported by earlier workers (Dehadrai and Bhargava, 1972; Parulekar et al., 1973; Ansari et al., 1986). Less saline waters dominated only in the monsoon season. The obvious reason for less saline water in these months, being precipitation and inflow of freshwater from riverine system of Zuari (Dehadrai and Bhargava, 1972; Parulekar et al., 1973; Ansari et al., 1986).

The salinity gradient during monsoon was observed upto a degree of 10.57 ppt. However, the fall in salinity value in this estuarine complex was not significant. This could be attributed to the thorough mixing of water resulting from intense tidal action and negligible influx of freshwater from the river which contributes to more saline nature of water body in this area (Cherian et al., 1975). Comparatively low salinity values were noticed in October, which were mainly due to the effect of post monsoon showers. During this period mixing of water is due to formation of internal waves and other mixing forces such as wind and tidal currents (Qasim and Sen Gupta, 1981). Such low values of salinity were also reported by Parulekar et al. (1982). Maximum value of salinity was observed in June, prior to the onset of monsoon. Higher salinity value in this month was due to higher water temperature influenced by air temperature and negligible runoff from the river Zuari. The appearance of salinity gradient during monsoon has been reported as a regular phenomena by earlier workers (Sankarnarayanan and Qasim, 1969; De Souza et al., 1981; Verlencar, 1982; Nair et al., 1984; Ansari, 1988) along the west coast of India.

The dissolved oxygen (DO) content in the water column was well saturated with maximum values in monsoon months, i.e. from July to September. The variation pattern of DO during the period of study showed inverse relationship with salinity. This observation corroborates the findings of earlier workers (Sankarnarayanan and Jayaraman, 1972; Haridas et al., 1973; Singbal, 1976; Qasim and Sen Gupta, 1981; De Souza and Sen Gupta, 1986). The highest DO content for the water column was observed in July. The higher value of DO was mainly due to precipitation and influx of oxygen rich freshwater from riverine runoff.

Similar high concentrations of DO were also reported by De Souza and Sen Gupta (1986). Lower values of DO were reported in June before the onset of monsoon, resulting in low solubility. The gross factors controlling the solubility of DO are salinity, temperature and humidity (Verlencar, 1982). The average surface, mid-depth and near bottom DO content shows that surface waters were well saturated with DO than mid-depth and near bottom water. Higher values of DO in surface water might be due to high rate of photosynthesis in clear water, whereas probable cause of low DO in nearbottom water could be reduced photosynthetic activity due to turbid waters (De Souza and Sen Gupta, 1986).

In the present study, pH values at the site of raft culture varied from 7.04 to 8.51 for the water column. Higher pH during monsoon may be due to dilution of seawater by alkaline fresh water of river (Dehadrai and Bhargava, 1972). High values of pH coincided with higher values of DO indicating a direct relationship between pH and DO. Such relationship has been earlier observed by Rao and Madhavan (1964) whereas an inverse relationship was reported by Noble (1968) and Nagrajaiah et al. (1983) in brackish water ponds along Netravati estuary, Mangalore. In certain months i.e. October, November, 1987 and September, 1988 surface water reported slightly higher pH values as compared to sub-surface waters. The probable cause for this could be the concomitant effect of shallow depths and turbidity associated with it and more photosynthetic activity in the euphotic zone (Rao and Madhavan, 1964; Skirrow, 1975). During the process of photosynthesis, carbon dioxide is utilized, as a result it increases the pH value. The distribution of suspended matter was uniform from October to July, highlighting the abundance of food material. Comparatively low level of suspended load in the water column during postmonsoon season could be due to high sedimentation rate by the process of flocculation caused by differences in salinity (Murthy and Das, 1972). The magnitude of suspended load in the water column is also determined to a great extent by tides (Das et al., 1972).

Concentration of suspended matter was high in surface water, which could be due to low saline waters carrying more suspended matter in suspension as suggested by Das et al. (1972). In December, February and July, mid-depth water were observed to have high suspended load as compared to surface waters which coincided with higher salinity values for surface water, indicating that higher salinity may lead to flocculation and lower the capacity of carrying suspended load in suspension. Das et al. (1972) also observed similar relationship between salinity and suspended load and suggested that suspended load does not seem to be influenced by tidal current speed and largely depends on salinity.

Suspended matter in monsoon season was maximum for the water column. These high values of suspended load in monsoon could be due to strong wave action and tidal influence which enhances turbidity (Untawale and Parulekar, 1976). However, it is difficult to assess the exact causes of this increase because of interaction of various environmental factors like sediments, tidal flow, currents, etc.

Observations on particulate organic carbon (POC) show that POC content was high during monsoon months. Similar trend in distribution of POC during monsoon months was reported by earlier workers (Untawale and Parulekar, 1976; Krishnakumari et al., 1978; Goes, 1983). Organic matter in coastal and shelf environments is both, allochthonous from terrestrial materials and autochthonous from in-situ aquatic production (Degens and Ittekkot, 1985; Nelson et al., 1987). In the present study, this high content of suspended living carbon in monsoon cannot be due to autochthonous materials since during this period chlorophyll a values and phytoplankton count were low. The main source of higher POC values was due to the allochthonous materials brought down by riverflow runoff from luxurious mangrove swamps (Untawale and Parulekar, 1976; Krishnakumari et al., 1978). During remaining part of the study the distribution was uniform with minor variation. A second peak of POC value was observed in December-January. This high content of POC was mainly contributed by autochthonous materials as observed from higher Chlorophyll a values and phytoplankton count in the present study. Goes (1983) observed increased level of POC in non-monsoon months which coincided with high chlorophyll a values.

Chlorophyll a concentration was observed to be low in monsoon months. This low content of chlorophyll a was mainly due to increased turbidity in the water column, leading to reduction in light penetration and reduced availability of light for photosynthesis by primary producers. Similar trend of variation in chlorophyll a was earlier reported by Goes (1983).

General trend of variation in chlorophyll a reveals that the content at the surface was higher than mid-depth and near bottom waters except in January and April. The low concentration of chlorophyll a at this time may possibly be due to increased solar radiations. A descending trend in surface chlorophyll a content was observed from February to April, which might be due to gradual heating of surface waters during this period. Cook (1963) demonstrated that chlorophyll a synthesis was inhibited with high light intensities. Gauf (1974) and Gauf and Horne (1975) reported that inhibition of chlorophyll a synthesis in surface water was a result of solar heating, whereas Qasim et al. (1969) stated that temperature does not have direct effect on primary production, however, rise in temperature increases metabolic rate in smaller organisms, thereby increasing respiration rate and hence affect primary production of the area. Chlorophyll a values were maximum in October, coinciding with high phytoplankton count. The probable reason for this could be a sudden increase in salinity which is believed to be an important stimulus for favoring phytoplankton production (Raymont, 1966; Qasim et al., 1969).

The standing crop of phytoplankton in the study area was influenced to a large extent by the onset of the south west monsoon. The reduction in salinity and replenishment of waterbody by influx of riverflow and heavy rainfall were responsible for the decrease in standing crop. These observations were in contrast to those made by Subrahmanyan and Sarma (1965), Devassy and Bhattathiri (1974) and Joseph and Pillai (1975). These authors noticed a bloom of marine phytoplankton during south west monsoon period. During their studies, majority of the species observed were freshwater forms. However, in the present study, it has been observed that, lowering of salinity was not of high magnitude even during the monsoon season. The advent of monsoon inactivated the marine flora by lowering salinity and replacing them with freshwater/brackish water species like Skeletonema costatum, thus giving different picture during monsoon season. During post monsoon season, blooming of phytoplankton takes place. This happens to be a general phenomena which could be due to reduced turbidity of the water column and other favourable conditions (Goes, 1983).

Observations on species composition indicate a pronounced seasonal succession of species. In tropical environment, the floristic changes that occur may be related to changing environmental conditions. During monsoon, when the bay is dominated by low saline conditions, the euryhaline forms like S. costatum, dominated the study area. Kumaran and Rao (1975) observed marine blooms of S. costatum in Cochin backwaters which appear to be favoured by low saline conditions. During post-monsoon period, with decrease in rainfall and attaining optimum conditions (decrease in turbidity, clear sky and an increase in surface salinity) appeared to favour the growth of dianoflagellates Ceratium furca which accounted for about 95% of the total standing crop of phytoplankton.

With an increase in salinity, the population of C. furca was steadily replaced by chain forming diatom Fragillaria oceanica, which was the dominant form during the month of October. During the remaining part of the year, the population in the bay consisted of mixed flora with no form dominating. Diatoms accounted for a major percentage of population during the period of study. Coscinodiscus sp. was present in the study area throughout the period of study. Many diatoms are more or less cosmopolitan, appearing almost anywhere in the world's ocean and becoming locally important, even dominant, when conditions are suitable (Raymont, 1980). In the present study, the phytoplankton population was mainly dominated by diatoms, which confirms the cosmopolitan nature of this group.

CHAPTER IV

GROWTH OF MUSSELS

INTRODUCTION

Studies on growth in bivalve molluscs, use increase in shell length or weight over a given period of time, as an estimate of growth. Mussels as a source of recovering proteins from aquatic environment are known for their high degree of conversion rate per unit area making them efficient and economically feasible for commercialization. Much of the earlier work on growth of green mussel Perna viridis L. (Rao et al., 1975; Shafee and Sundaram, 1975; Shafee, 1976; Sivalingam, 1977; Qasim et al., 1977; Parulekar et al., 1982; Chatterjee et al., 1984) suggests that the growth in this species is much dependent on food availability and local environmental condition such as sheltered waters and salinity gradients. Various attempts have been made to analyse seasonal growth in mussels of different size groups in different local conditions as in cages (Coulthard, 1929; Coe and Fox, 1942; Coe, 1945; Bohle, 1965; Baird, 1966; Sadykhove, 1967; Seed, 1969b). However, it has been demonstrated that cages did not appear to hinder growth in sublittoral population (Harger, 1970a).

Growth in mussels is known for its variable rate, with changes in environmental factors not only between localities but also within same size and age group in the same population (Bayne, 1976). Although, mussel biomass may be increasing at approximately equal rates, their growth in terms of other morphological parameters may vary to a great extent due to local environmental conditions prevailing at that time. Studies by Parulekar et al. (1982) provide a detailed information on growth of green mussel with reference to environmental physiology along the Goa coast, India. However, in the present investigation, efforts were made to study the influence of various physical and hydrobiological parameters when considered alone and or combined affecting growth, and also to study seasonal variation in growth.

RESULTS

Fortnightly samples of 25 cultured green mussels were randomly collected from the raft at sampling site. All the individuals were examined for morphometric characteristics measured to the nearest 0.1 mm using Vernier callipers and the weights were determined using a Mettler balance (model AE 200). The mean (each mean represents 25 individuals) was calculated at each time and used to determine specific growth rate (%). The mean values of length and weight were used to compute growth parameters by using Von Bertalanffy's growth equation.

FITTING OF GROWTH EQUATION TO LENGTH:

Ford (1933) and Walford (1946) suggested graphical method of plotting L_{t+1} against L_t, which was followed to fit Von Bertalanffy's growth equation. The values of growth parameters; coefficient of catabolism (k), assymptotic length (L_{∞}) and arbitrary origin of Length (t_o), were calculated as indicated in Fig. 13 and 14 and were also crosschecked by using analytical method as suggested by Ricker (1958). The values of growth parameters calculated by the two methods mentioned above did not show much difference. The computed values of growth parameters

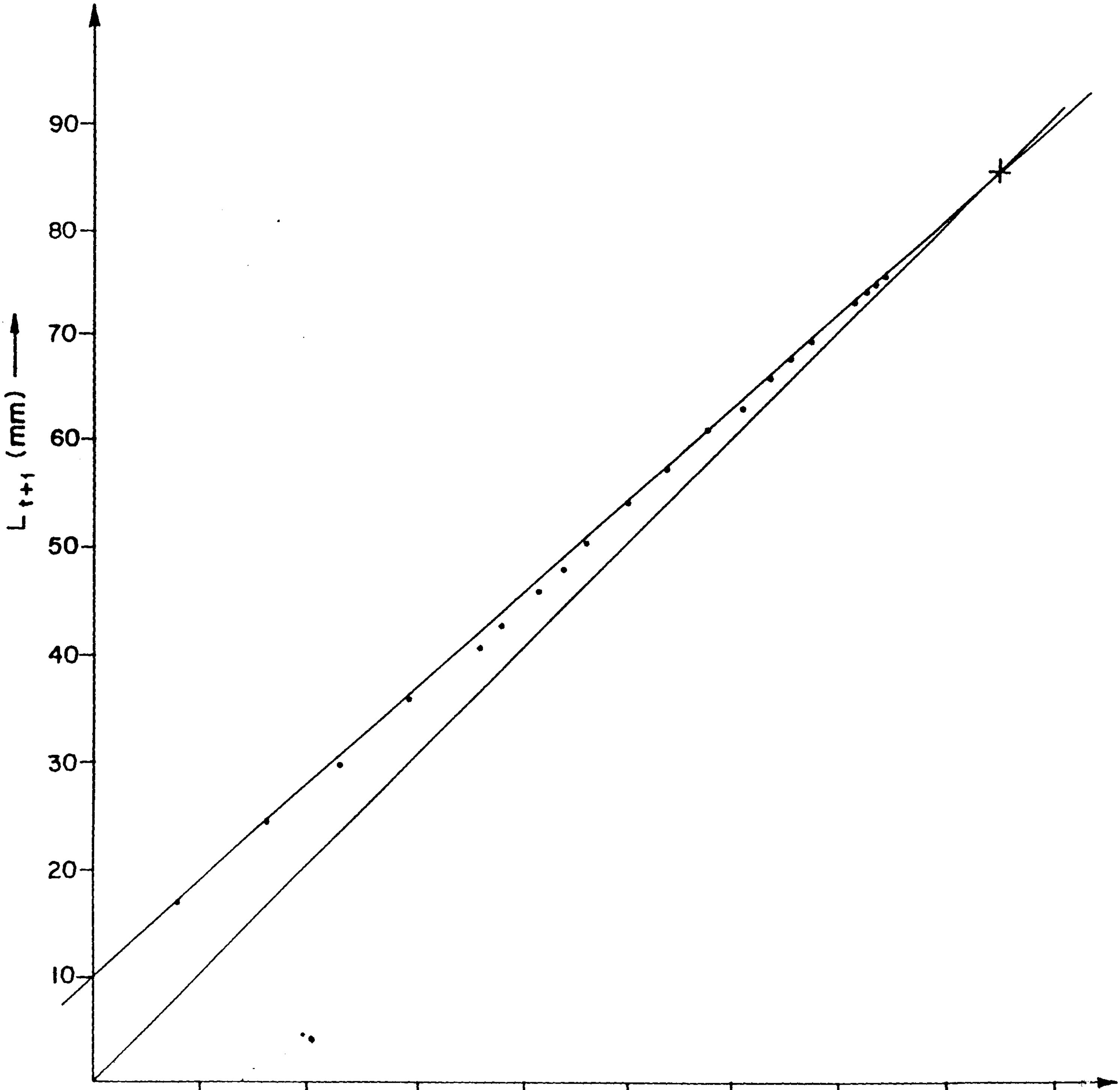

Fig.13. Ford-Walford plot of Growth of *Perna viridis* L.

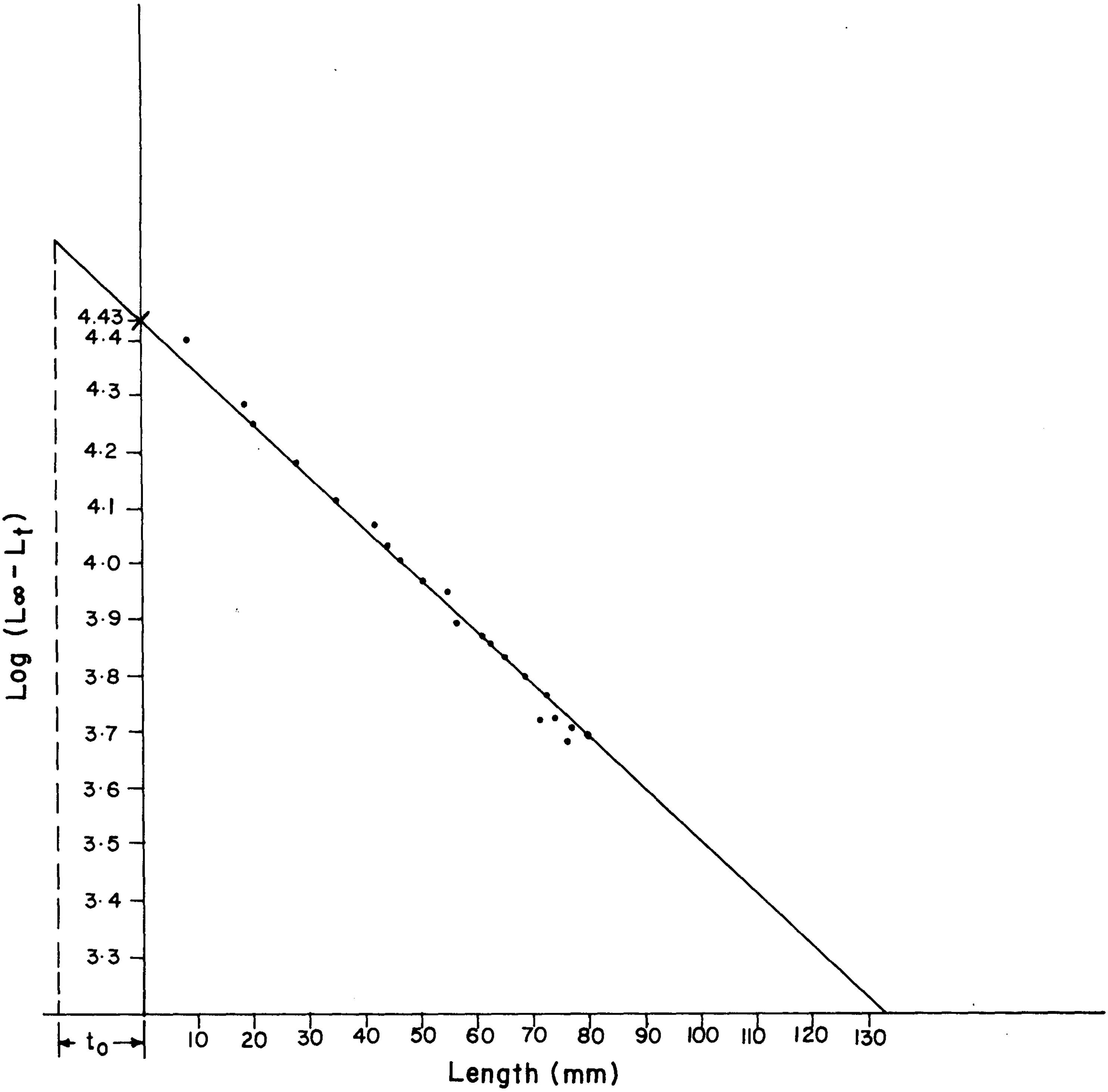

Fig. 14. Log ($L\infty - L_t$) plotted against length to determine 't_o' in *Perna viridis* L.

in Von Bertalanffys growth equation.

$$Lt = L_{\infty}\left[1 - e^{-k(t-t_o)}\right] \quad .... \quad (I)$$

are as follows:

L_{∞} = 85 mm

k = 0.1014

t_o = -0.1153

The assymptotic length (L_{∞}) was obtained graphically at a point where length at L_t equals length at L_{t+1}. A line is drawn at 45^o through the zero point intersecting the curve and the point of intersection indicated as L_{∞} (Fig. 13). 't_o' is calculated by using following formula as described by Ricker (1958).

$$t_o = \left[(\log_e L_{\infty} + kt_o) - \log_e L_{\infty}\right]/k \quad .... \quad (II)$$

The value of $\log_e L_{\infty} + kt_o$ is the y-axis intercept (4.43) in Fig. 14 where $\log_e (L_{\infty}-Lt)$ is plotted against mean lengths. Substituting these values in above equation (II), we have, t_o = -0.1153 and the growth equation (I) in the present study thus appears as:

$$L_t = 85\left[1-e^{-0.01014(t+0.1153)}\right] \quad ... \quad (III)$$

Using equation (III), the theoretical lengths at each time were determined and are given in Table 4. The calculated theoretical lengths were in close agreement with the actual observed values of length.

Computation of specific growth rate (%) was done by using mean lengths. Specific growth was calculated by following the formula as suggested by Bal and Jones (1960).

$$G = \left[(\log L_2 - \log L_1)/T_2 - T_1\right] \times 100 \quad \ldots \quad (IV)$$

Where L_2 and L_1 represent the lengths at time T_2 and T_1 respectively. The values of specific growth rate computed during different periods of the present study are given in Table 4.

FITTING OF GROWTH EQUATION TO TOTAL WEIGHT:

The Von Bertalanffys growth equation was fitted to total weight by calculating growth parameters using analytical method as suggested by Ricker (1958). The calculated values of growth parameters in the Von Bertalanffys growth equation.

$$W_t = W_\infty \left[1 - e^{-k(t-t_o)}\right]^3 \quad \ldots \quad (V)$$

are given as follows:

W_∞ = 37.34 (assymptotic weight)

k = 0.0699 (coefficient of catabolism)

t_o = -2.4305 (arbitrary origin of weight)

The above equation (V), then, could be expressed as:

$$W_t = 37.34 \left[1-e^{-0.0699(t+2.4305)}\right]^3 \quad \ldots \quad (VI)$$

Using equation (VI), the theoretical weights were determined at different times and are given in Table 5, alongwith observed weights at different time of sampling. The actual observed weights and the calculated theoretical weights were in close agreement with observed values except at few times.

Table 4. Average observed length, theoretical length and specific growth during the period of study.

YEAR	MONTHS		OBSERVED LENGTH (mm)	THEORETICAL LENGTH (mm)	SPECIFIC GROWTH (%)
1987					
	OCT	(i)	8.14	9.51	138.52
		(ii)	16.27	17.81	73.28
	NOV	(i)	23.47	24.11	48.10
		(ii)	28.68	30.36	41.36
	DEC	(i)	35.27	36.02	17.68
		(ii)	38.53	41.13	12.28
1988					
	JAN	(i)	40.97	45.74	14.40
		(ii)	44.03	49.91	9.25
	FEB	(i)	46.11	53.68	15.44
		(ii)	49.11	57.09	14.52
	MAR	(i)	53.56	60.16	13.78
		(ii)	57.38	62.94	9.55
	APR	(i)	60.18	65.46	3.08
		(ii)	61.11	67.73	5.67
	MAY	(i)	62.87	69.78	11.50
		(ii)	64.82	71.63	7.54
	JUNE	(i)	67.31	73.31	2.04
		(ii)	68.00	74.82	8.75
	JULY	(i)	71.04	76.19	1.86
		(ii)	71.70	77.42	0.74
	AUG	(i)	71.96	78.54	3.96
		(ii)	73.40	79.55	5.22
	SEPT	(i)	75.34	80.46	-

Table. 5. Average observed weights with respective calculated theoretical weights during period of study.

YEAR	MONTHS		OBSERVED WEIGHT (gms)	THEORETICAL WEIGHT (gms)
1987				
	OCT	(i)	0.49	0.48
		(ii)	0.77	0.70
	NOV	(i)	1.44	1.17
		(ii)	1.46	1.77
	DEC	(i)	2.64	2.48
		(ii)	3.56	3.29
1988				
	JAN	(i)	4.68	4.20
		(ii)	4.79	5.18
	FEB	(i)	7.05	6.22
		(ii)	8.43	6.92
	MAR	(i)	9.02	8.43
		(ii)	13.85	9.57
	APR	(i)	10.01	10.73
		(ii)	10.70	11.89
	MAY	(i)	14.48	13.04
		(ii)	14.65	14.18
	JUNE	(i)	16.31	15.31
		(ii)	16.03	16.41
	JULY	(i)	22.52	17.48
		(ii)	17.71	18.52
	AUG	(i)	15.29	19.52
		(ii)	14.81	20.49
	SEPT	(i)	15.52	21.42

GROWTH OF TRANSPLANTED MUSSEL SEED:

Growth of different parameters of the transplanted green mussels grown on raft is shown in Figs. 15 to 24. From these figures it appears that the growth increment with time (absolute growth) was of ascending order. During some periods, the growth rate was reported to be of a larger magnitude, however in certain cases less values were observed which was mainly due to inaccessibility to collect submerged mussels from the ropes due to rough sea conditions.

SHELL LENGTH:

The fortnightly shell length increment during the period of present study are shown in Fig. 15. Mussel spat (3-8 mm in size) were transplanted on ropes hung on raft, anchored at sampling site in October, 1987. From this time, the progression in mean shell length was fast (10.1 mm/month) till December. The average increment in length during this period was 6.03 mm. From December to March, the growth progression was at a much lower rate as compared to the initial growth rate. The average length increment during this phase of growth was about 50% less when compared to the initial rate of growth. During the remaining part of the study till harvest, mussels, showed much less growth rate. At the time of harvest, length was observed to be increasing as seen from Fig. 15. However, during the latter period of growth at the time of harvesting, i.e. from April to September, the observed length increment was 2.56 mm/month..

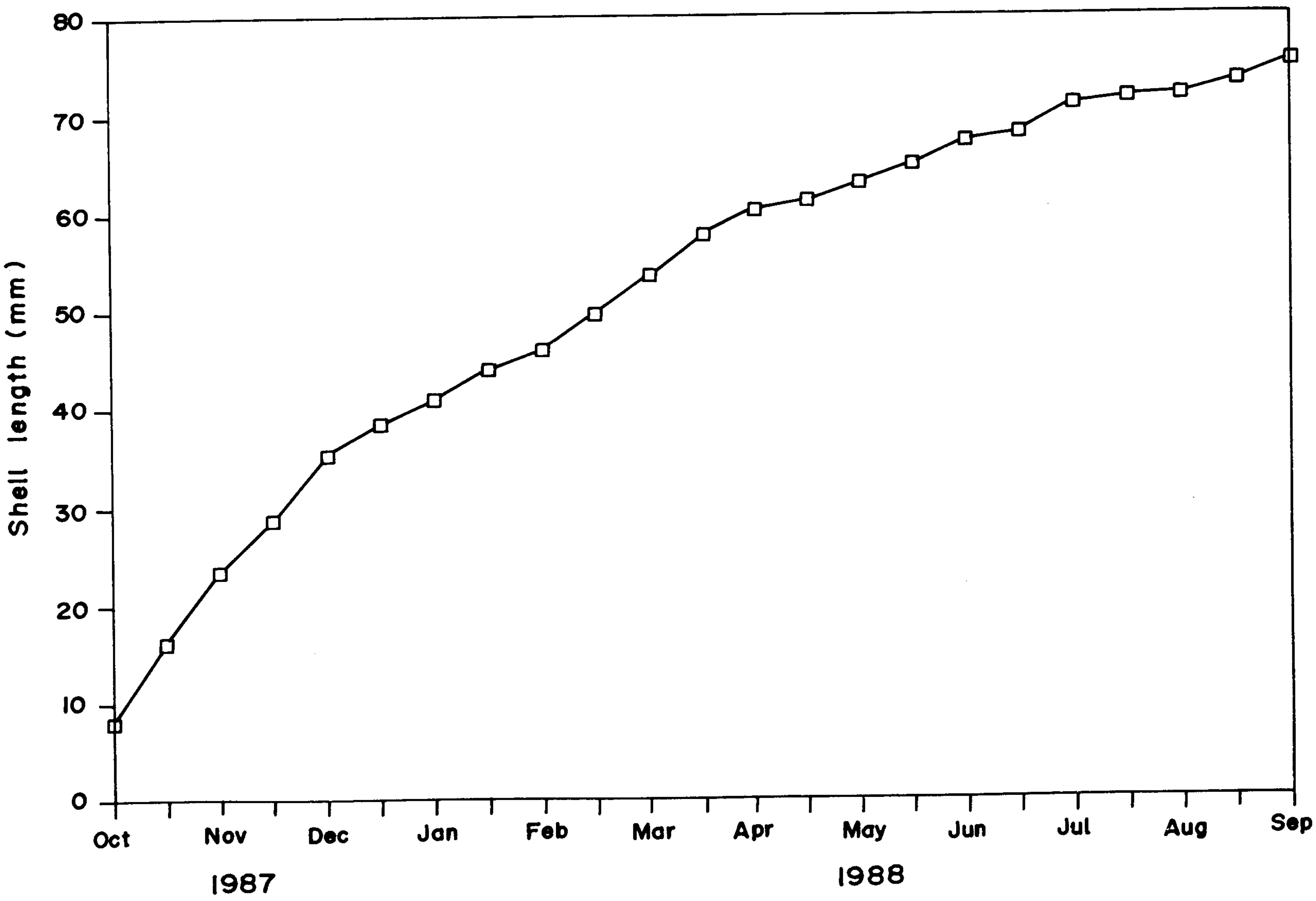

Fig. 15. Growth in shell length of raft-grown *Perna viridis* L.

Specific growth rate (SGR) expressed as percentage was calculated by using the formula as mentioned in equation (IV) and the variations in SGR are tabulated in Table 4. The SGR in raft-grown green mussel was found to vary from 0.75 to 138.52% . During initial growth, SGR was very high and in the range from 17.68 to 138.52% . Thereafter, i.e. from January to April SGR showed abrupt variations with time in the range from 3.08 to 15.44% . For the remaining part of the study, the SGR values were as low as 9% .

SHELL HEIGHT:

Fortnightly increase in shell height is depicted in Fig. 16. Shell height increment followed an increasing trend upto December from the time of transplanting mussel spat in October. The shell height increased at a much faster rate in the initial period of growth i.e. during October-November. The mean growth rate in shell height during this period was found to be 4.71 mm/month. From November to December, increase in mean shell height was 0.63 mm/month. A fall in shell height increment was observed during second half of December and January followed by an increase upto March with relatively higher growth rate (4.65 mm/month). From March to June progression in shell height was consistent with less variations. Thereafter, shell height observed a fall in growth till July. However, towards the end of study (from July to September), shell height increased at a much slower rate of 0.83 mm/month.

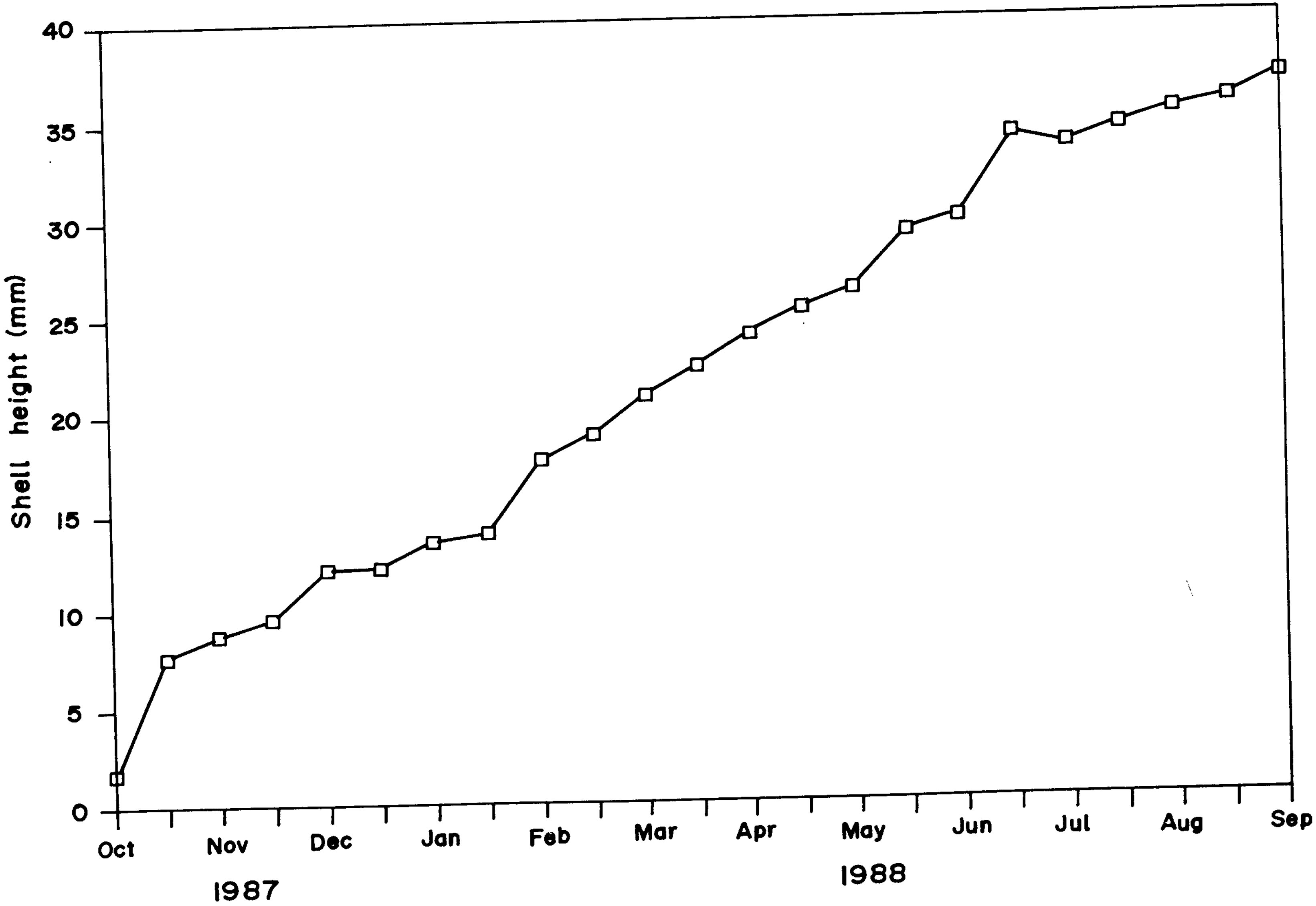

Fig. 16. Growth in shell height of raft-grown *Perna viridis* L.

SHELL BREADTH:

Variations in mean shell breadth increment with time are shown in Fig. 17. Mean shell breadth, in raft-grown green mussels increased steadily throughout the period of study. The monthly shell width increment in the initial growing stage was as high as 5.95 mm. A steep increase in shell breadth increment was observed in January-February (3.74 mm) and June (3.59 mm). However, in general, the rate of rise in increment was found to be reduced as the mussels grew older. During the remaining part of growth period the shell width increment was comparatively low with progression of time and ranged between 0.04 mm (July) and 2.94 mm (May).

TOTAL WEIGHT:

Increase in the mean total weight of the raft-grown green mussels are shown in Fig. 18. The pattern of variation was characterized by two peaks in weight increment. The primary peak was observed in March, with an increment upto 4.83 g, whereas, the secondary peak was noticed in June-July when the monthly increment was 4.81 g. Increase in total weight in the initial period (October to November) was 0.47 g. Thereafter, during the period from November to begining of January the growth rate was 0.81 g. From February to the end of March, the increase in total weight was relatively high (1.76 g) followed by a decline during the period from April to June, with mean growth increment of 1.23 g. In July, growth rate was maximum with an increment of 3.22 g, thereafter, the growth in total weight declined significantly,

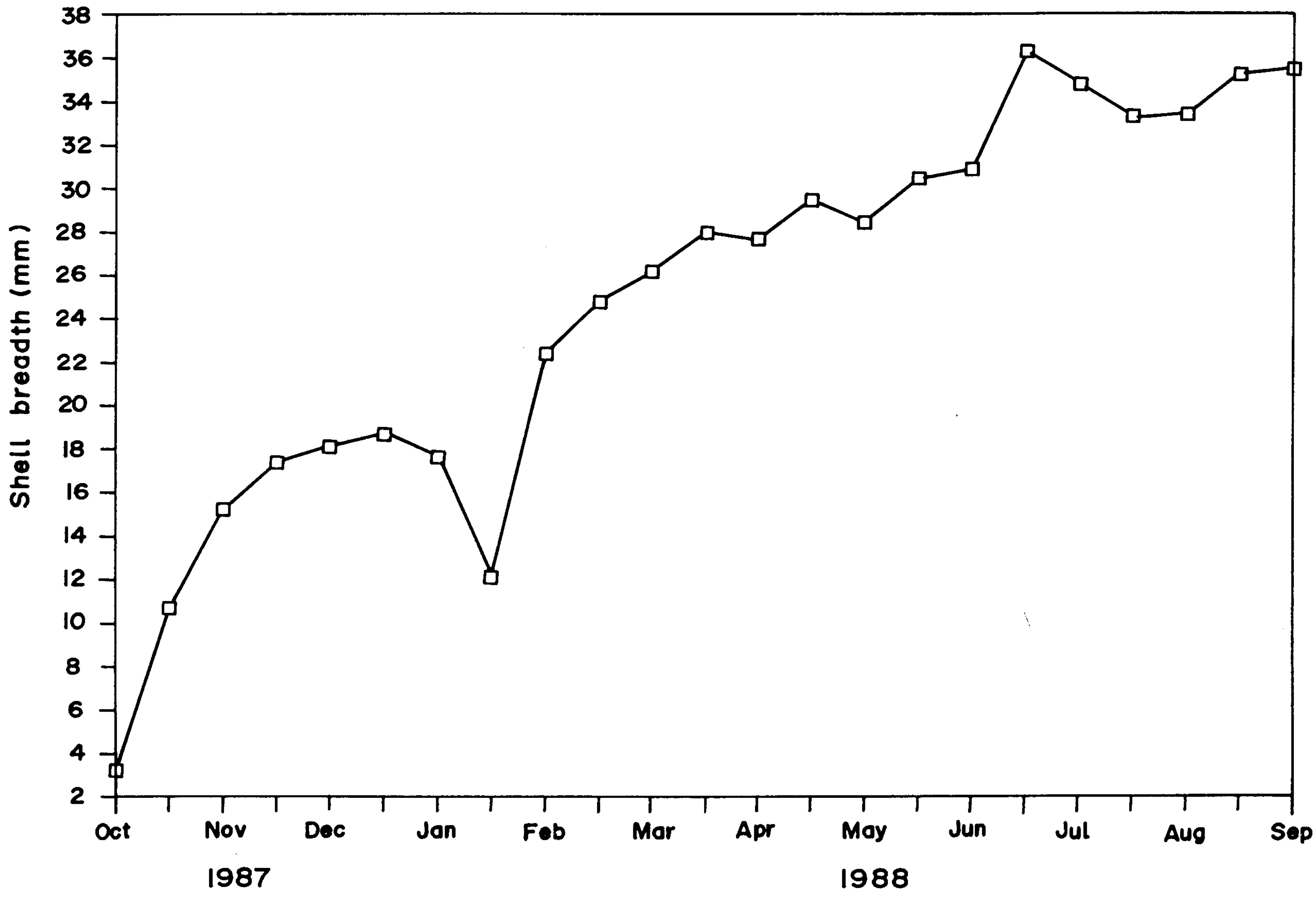

Fig. 17. Growth in shell breadth of raft-grown *Perna viridis* L.

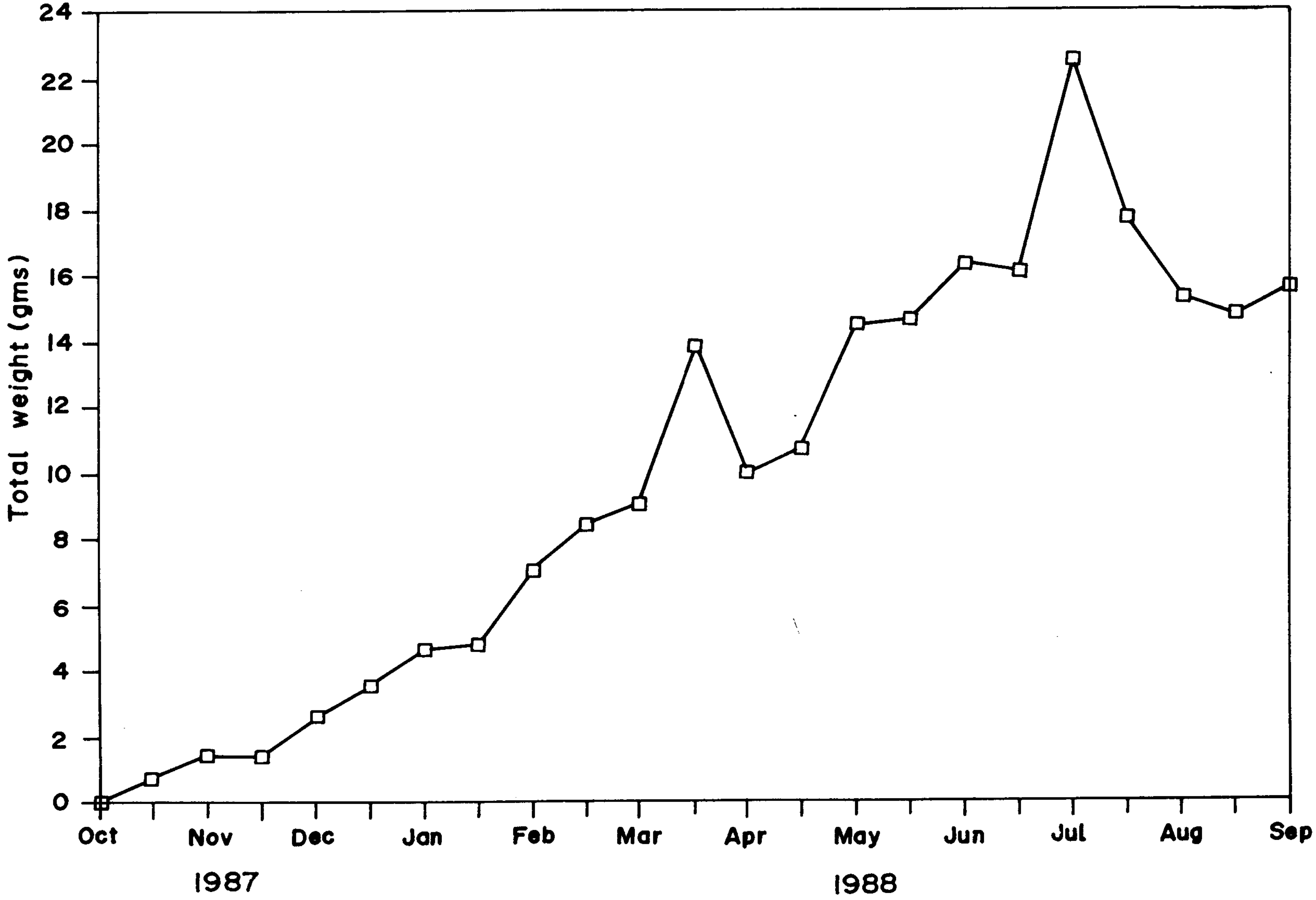

Fig. 18. Growth in total weight of the raft-grown *Perna viridis* L.

upto August. During September, a minor increase in total weight was observed (Fig. 18).

MEAT AND SHELL WEIGHT:

Annual changes in meat and shell weight are shown in Figs. 19 and 20 respectively. A gradual increase in meat weight was observed from October to March, whereas increase in shell weight showed increasing trend till first half of January. A fall was noticed in the shell weight during second half of January, which got enhanced till March. However, in April, the meat weight and the shell weight showed decrease. Thereafter, the meat weight increased upto June and then remained steady till July. The variations in shell weight were inconsistent during the period from April to June, registering peak value in the first half of July coinciding with higher values of meat weight. Thereafter, till August, both meat and shell weight decreased followed by an insignificant increase in meat and shell weight in September.

MEAT: SHELL WEIGHT RATIO:

The variations in meat:shell weight ratio are shown in Fig. 21. The meat shell weight ratio in the present investigation varied between 0.65 and 1.8 in the months of January and June respectively, indicating higher meat yield in June. Higher values of meat:shell ratio were also observed in October, February and from April to August. Generally, these ratios were nearer to one except in January and March, when the shell weight dominated the total weight or meat yield was at its low.

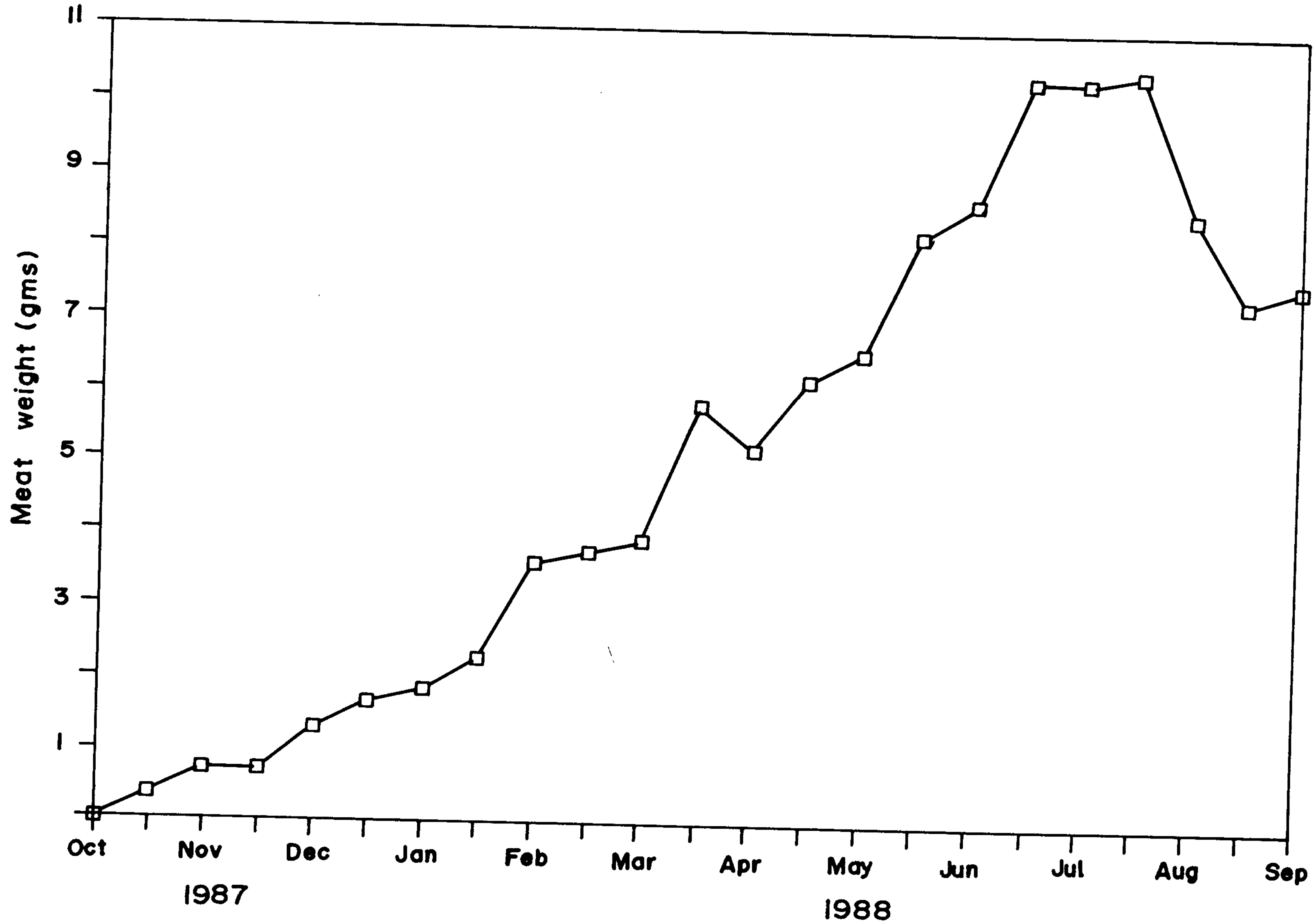

Fig. 19. Growth in meat weight of the raft-grown *Perna viridis* L.

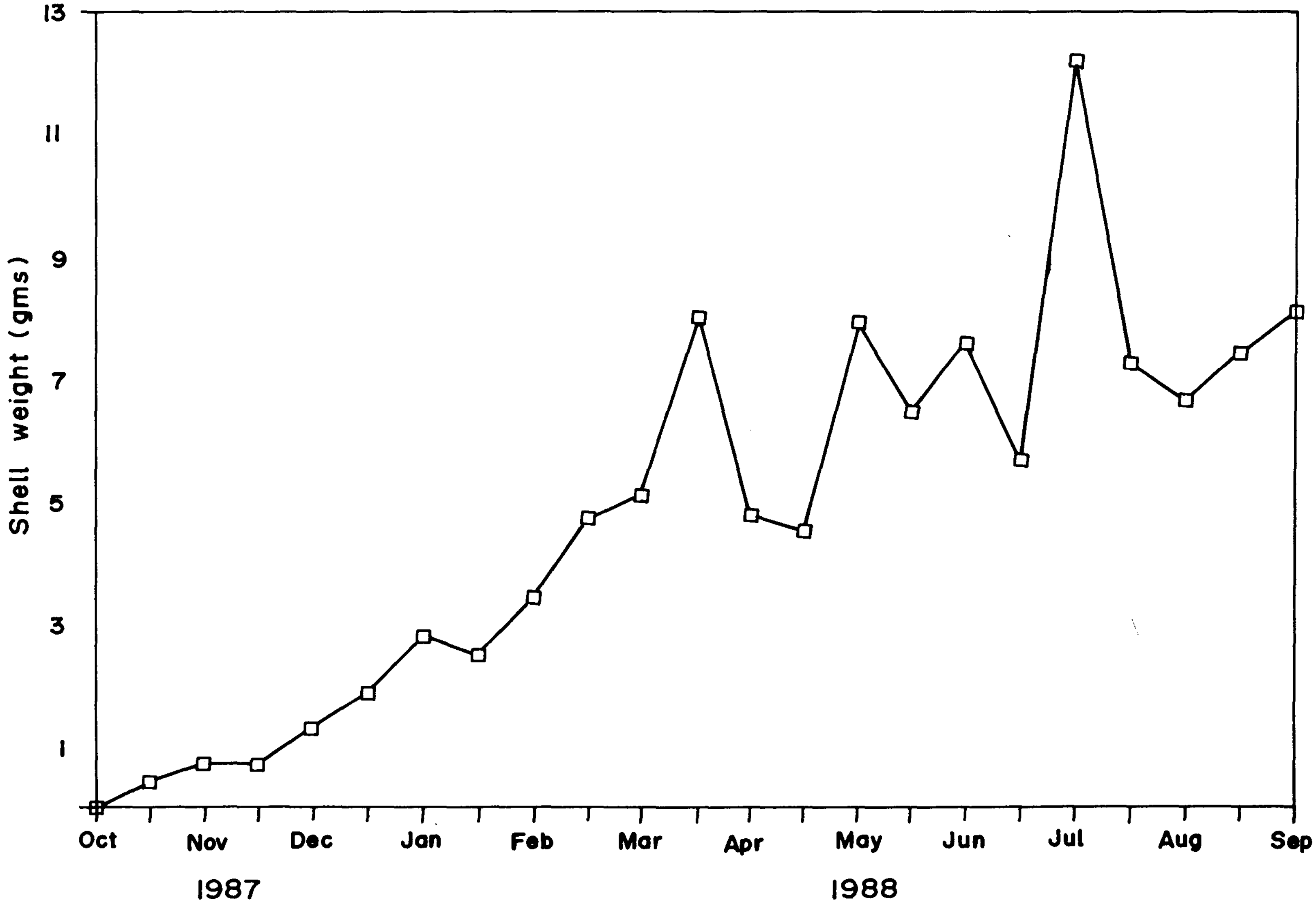

Fig. 20. Growth in shell weight of the raft-grown *Perna viridis* L.

DRY MEAT WEIGHT:

Dry meat weight variations are shown in Fig. 22. The variation in dry meat weight did not follow ascending pattern during the period of study. The dry meat weight values in the present investigation varied between 0.003 to 3.4 g with the lowest value in October and the highest value in March. The dry meat weight displayed conspicuous rise from February to March. Thereafter, the dry meat weight showed inconsistent values from March to August. However, slight increase was observed during second half of August and September. The average dry meat weight during monsoon months was found to be 1.08 g (June-August).

SHELL VOLUME:

Variation in shell volume of the raft-grown green mussels is shown in Fig. 23. The mean shell volume in the cultured mussels varied from 0.015 to 26.11 cm^3. Shell volume increased at a much reduced rate in the initial stages of growth i.e. upto January. From February to June, increase in shell volume was at a much faster rate as compared to initial growth rate. In July, the increase in volume was at a higher rate, thereafter, decreasing gradually in successive months. From August onwards, the shell volume was found to follow ascending order.

CONDITION INDEX:

The variation in the condition index values are shown in Fig. 24. In the present study, the condition index values were found to vary from 0.55 to 1.56. The minimum and the maximum

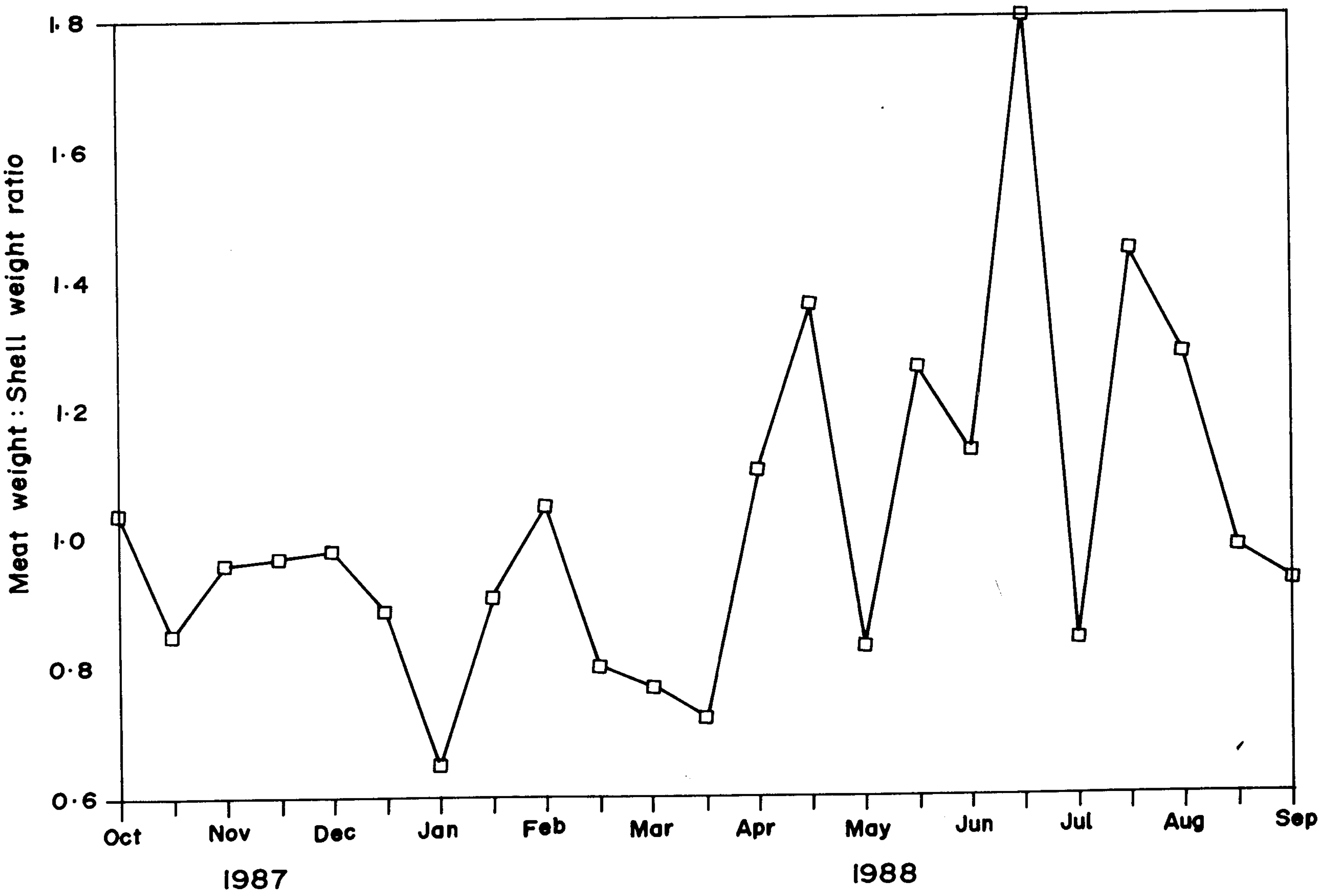

Fig. 21. Variation in meat weight : shell weight ratio of the raft-grown *Perna viridis* L.

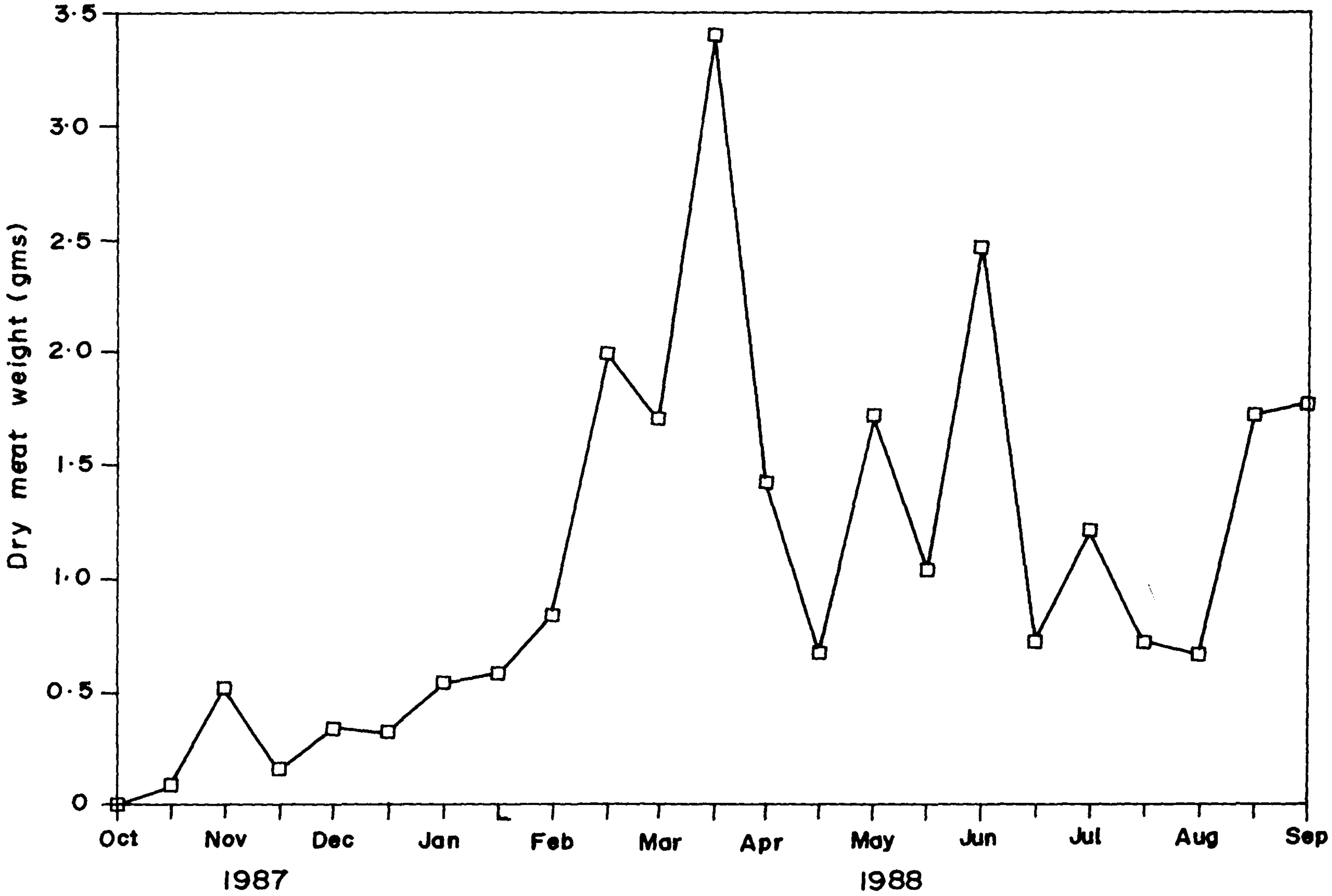

Fig. 22. Variations in dry meat weight of raft-grown <u>Perna viridis</u> L.

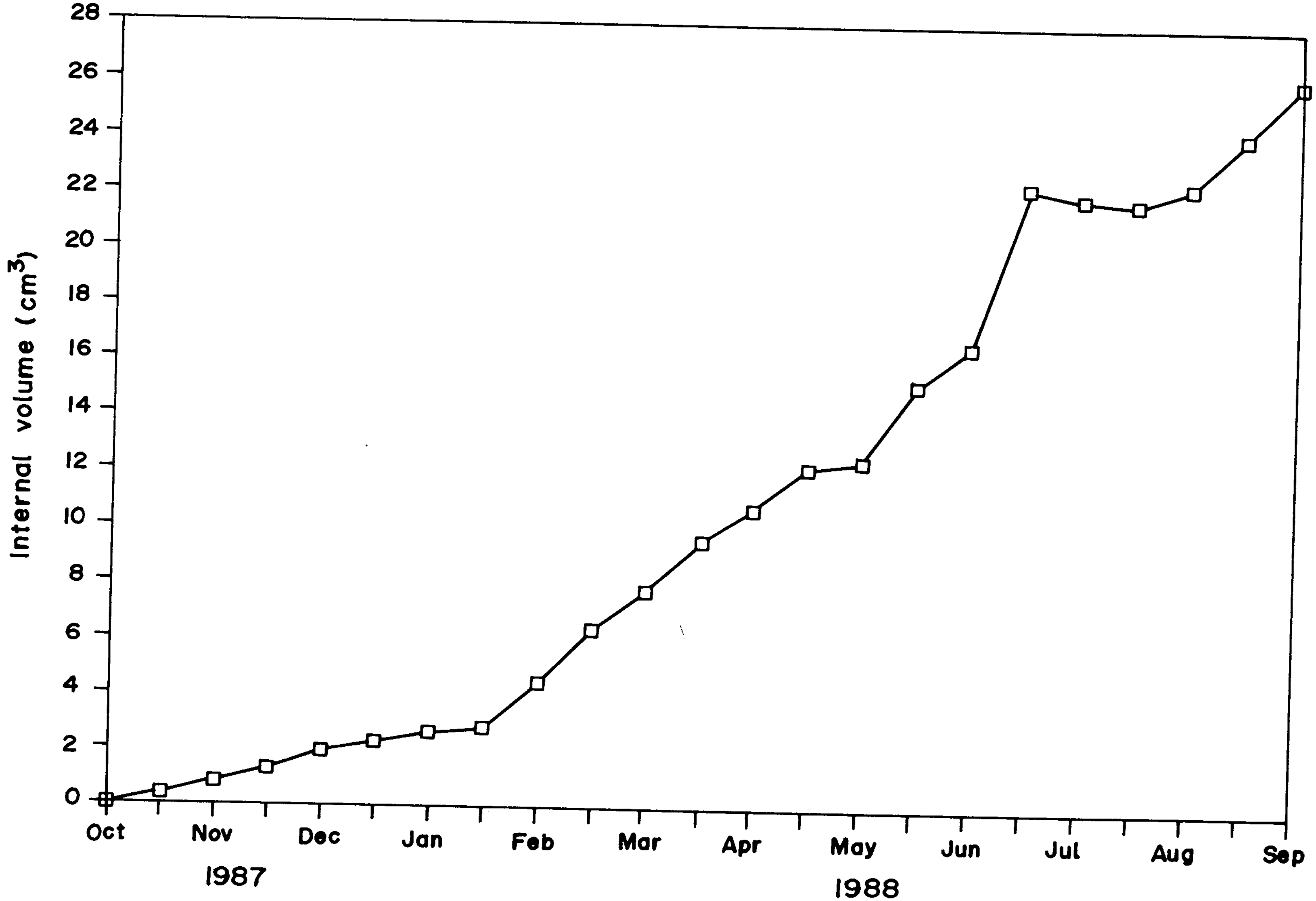

Fig. 23. Variation in internal volume of raft-grown *Perna viridis* L.

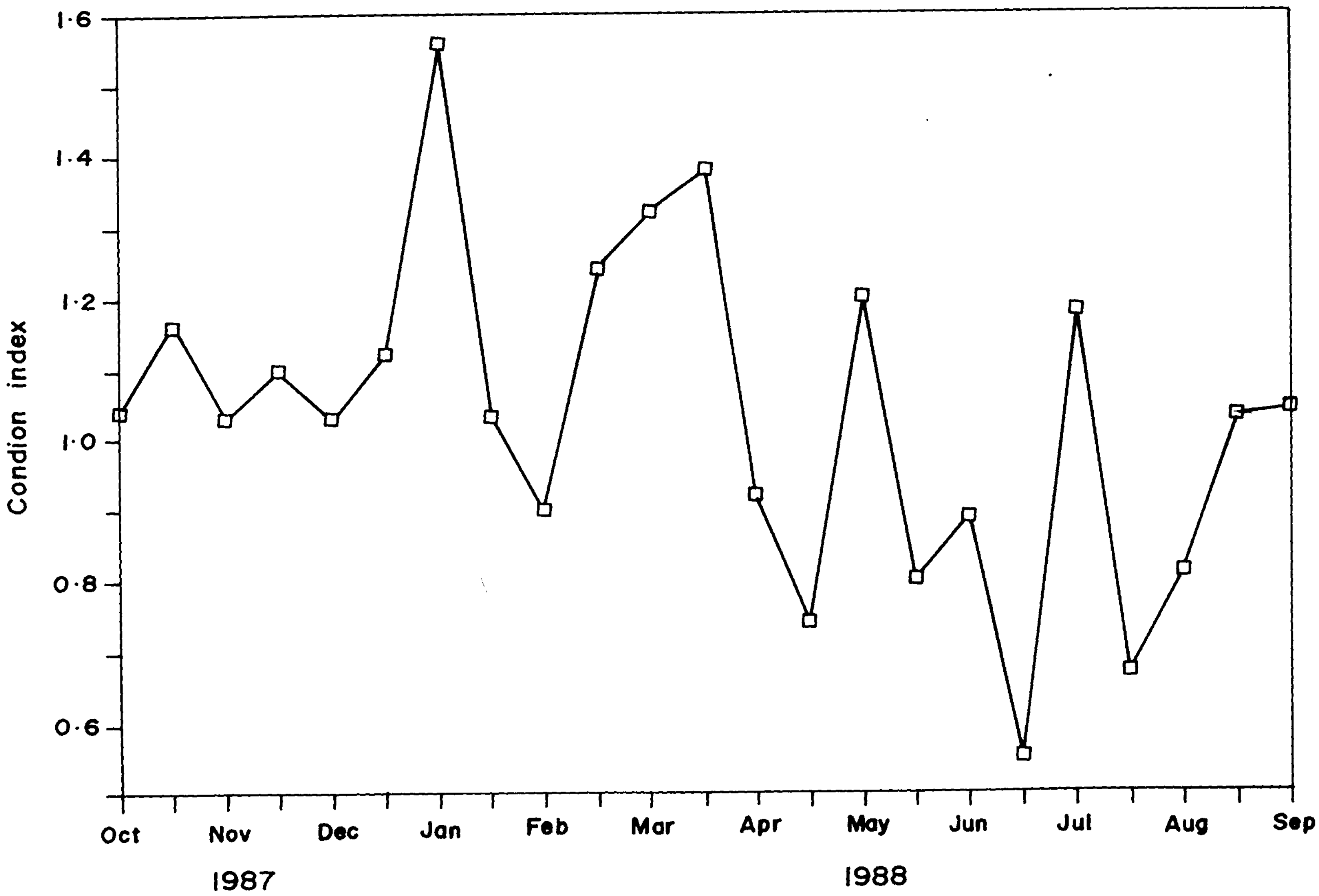

Fig.24. Fortnightly variation in condition index of the raft-grown Perna viridis L.

values were observed in June and January respectively. The general pattern of variation showed higher values for more or less every alternate collections from January to the end of the study period i.e. September 1988.

GROWTH IN RELATION TO HYDROGRAPHICAL PARAMETERS:

The distribution and variation in hydrological parameters has been discussed in earlier chapter. Here, these parameters are considered only to assess the possible interaction of some of these important factors on the growth of green mussels in terms of length and weight increment. Efforts have been made to elucidate the extent and magnitude of detrimental effects, if any, on growth. Further, efforts are made to find out statistically the degree of dependence of growth on hydrological characteristics. The various statistical analysis made were: determination of correlation coefficient (simple and multiple) and fitting of sequential multiple regression equation with all these parameters to explain the possible interdependence of growth on all or some of the hydrological features of the study area.

From Table 6, it could be seen that, among hydrological features, only DO, salinity and chlorophyll a showed a significant effect on growth (level of significance indicated in Table 6). The growth expressed as total weight was found to have a negative correlation with salinity and thus enhancing growth rate with reduced salinity, particularly during southwest monsoon season. A good positive and significant correlation was found

Table 6. Simple correlation coefficient (r) of growth (total weight increment) and various abiotic factors for the raftgrown green mussel <u>P. viridis</u> L.

PARAMETERS	TEMP	SAL	POC	Chl <u>a</u>	SUSP. LOAD	DO	TOTAL WT.
TEMPERATURE		0.472 *	-0.213 NS	-0.086 NS	-0.312 NS	-0.521 **	-0.125 NS
SALINITY			-0.707 ***	0.286 NS	-0.217 NS	-0.787 ***	-0.452 *
POC				-0.076 NS	0.041 NS	0.598 ***	0.074 NS
CHL <u>a</u>					0.14 NS	0.456 *	0.705 ***
SUSP. LOAD						0.423 *	0.252 NS
DO							0.633 ***

NS - not significant

* - significant at 10%

** - significant at 5%

*** - significant at 1%

between DO and chlorophyll a thus highlighting the importance of these parameters in influencing growth of the green mussel P. viridis L., when grown under a constant submerged estuarine environment on a floating raft.

Amongst the various hydrobiological factors, temperature and salinity were found to be positively correlated during the present investigations. However, salinity was negatively correlated with POC and DO. Other hydrobiological factors like POC, Chlorophyll a and suspended load indicated positive correlation with DO at various levels of significance (Table 6). Temperature and salinity were found to be negatively correlated with DO, thus indicating that fall of temperature and salinity has pronounced effect on DO content.

Apart from the above analysis, difference in each parameter from two successive collections was calculated. These values were treated for correlation-regression analysis. However, these values did not show any variations from the above calculated values of simple correlation coefficient (r), although regression coefficient values were different.

In order to have a better understanding, data on fortnightly length and weight measurements was tested as a function of temperature (T), salinity (S), particulate organic carbon (POC), chlorophyll a (Chl), suspended load (SL) and dissoslved oxygen (DO). Data were subjected to sequential multi-regression of the relation of length (L) and weight (W) as dependent variable with each of the above mentioned hydrobiological factors as independent variables, separately by using the following regression equation.

$$L = b_1 T + b_2 S + b_3 POC + b_4 Chl + b_5 SL + b_6 DO + C \qquad \text{...(VII)}$$

where,

L - predicted value of dependent variable.

b1, b2, b3, b4, b5 and b6 - partial regression coefficient and

C - intercept.

From the sequential multi-regression analysis (Table 7) length and weight was found to be influenced mostly by chlorophyll a, when considered as a single independent variable, whereas in combination with POC and DO, it showed significant effect, but to a much lesser extent, on length of the raft-grown green mussels. However, the weight was influenced significantly by the combined effect of chlorophyll a and DO. Other hydrobiological factors did not show any significant effect on growth (expressed either as length or weight), when considered alone or in combination with other hydrobiological factors (Table 7 and 8). Although, some of these parameters may appear as irrelevant in predicting the length or weight values, however, from the regression equations in Tables 7 and 8, it can be seen that these factors do play a role in influencing length and weight of the raft-grown green mussels.

DISCUSSION

Growth, in bivalves, is defined as an increase in body size, weight or volume might be the most appropriate parameter

Table 7. Multiple regression equation for predicting length from hydrobiological factors alongwith F ratios.

REGRESSION EQUATION	MULTIPLE CORRELATION COEFFICIENT	F VALUE BASED ON VARIANCE RATIO
L = 22.334 Chl a	0.733	24.44**
L = 17.877 Chl a + 8.073 DO	0.787	4.27 NS
L = 0.0083 POC + 1.42 Chl a + 1.66 DO	0.868	10.35**
L = -0.638 SAL + 0.0096 POC + 14.24 Chl a + 15.04 DO	0.873	0.58 NS
L = 1.06 T - 0.726 SAL + 0.0102 POC + 13.15 Chl a + 16.6 DO	0.875	0.28 NS
L = 1.06 T - 0.716 SAL + 0.01 POC + 13.29 Chl a + 0.0036 SL + 16.16 DO	0.875	0.04 NS

NS - not significant

** - significant at 5%

*** - significant at 1%

Table 8. Multiple regression equation for predicting weight from hydrobiological factors alongwith F ratios.

REGRESSION EQUATION	MULTIPLE CORRELATION COEFFICIENT	F VALUE BASED ON VARIANCE RATIO
W = 7.15 Chl a	0.705	20.75 **
W = 5.33 Chl a + 3.29 DO	0.787	6.40 *
W = 0.00198 POC + 4.312 DO	0.829	4.13 NS
W = 0.843 T + 0.0023 POC + 3.638 Chl a + 6.78 DO	0.843	1.44 NS
W = 0.837 T + 0.0025 POC + 3.505 Chl a + 0.00357 SL + 7.28 DO	0.846	0.32 NS
W = 0.908 T - 0.164 SAL + 0.00285 POC + 3.41 Chl a + 0.0038 SL + 7.082 DO	0.848	0.25 NS

NS - not significant

** - significant at 5%

*** - significant at 10%

for its measurement. Shell is such a prominent feature in bivalve that the growth is generally measured as an increase in linear dimensions, however, there are certain advantages in measuring growth in terms of weight (Haskin, 1964). There are two major methods of assessing growth, firstly, the size of whole organisms can be related to age, when this represents cumulative increase with time, it is termed as absolute growth, while the percentage increment per unit time is termed as relative growth. Secondly, allometric growth, the rate of growth of one parameter related to that of another, can also be measured.

Variation in rate of growth, not only between localities but also within similar size and age groups in same population is the most characteristic feature in growth of bivalve (Younge, 1968). Cultured mussels may be increasing in biomass at approximately equal rates, their growth in terms of other parameters such as length, width or height may vary considerably according to time and changing local environmental conditions. However, published work on marine bivalves in tropical and temperate waters (Rao, 1973; Shafee, 1976; Parulekar et al.,1982; Chatterjee, et al., 1984, Parulekar et al., 1978; Seed, 1976; Edwards, 1968; Seed, 1969), suggests that the growth rate in bivalves varies greatly and is influenced to a great extent by local environmental and hydrological factors and food availability.

QUANTITATIVE EXPRESSION OF GROWTH:

Estuarine environment seems to impose upper size limit on mussels by prevailing physical and biotic conditions (Seed, 1969). Fast growing individuals approach this limit relatively quicker, whereas in areas of slow growth this limit may be approached only by much older individuals. In the present case, the maximum potential size predicted by Von Bertalanffy's growth equation was 85 mm and 37.34 g, for length and weight respectively.

However, regression by "least squares" are generally used to fit such data, their use may be inappropriate since these parameters are not independent of each other. Thiensen (1973) suggested that Von Bertalanffy's growth equation may only be valid for Mytilus sp. above one third of their maximum size. This equation does not reflect seasonal variations in growth, caused by changes in temperature. However, it should be noted that equation mentioned above are based on determinate growth whereas growth in many bivalves is frequently indeterminate, at least over their normal life span and may not therefore cease at any fixed adult size (Yonge, 1976). From the predicted values, using Von Bertalanffy's growth equation, it can be said that the growth rate in the raftgrown mussels is high and relatively large size mussels can be produced in a short time.

The growth, in terms of increase in shell length was at much higher rate in the intial period of culture. The high rate of increase in shell length was accompanied by other morphological characters, although not proportionately. The high growth rate in the initial stages was mainly attributed to the high metabolic activity in small sized mussels. Hickman (1979) observed that the growth rate was faster at an early age than in later stages of life cycle. This could also be due to less ability to react rapidly to improved feeding conditions in later stages of life cycle i.e. as mussels grew older. Studies conducted earlier (Shafee, 1976; Qasim et al.,1977; Parulekar et al., 1978; Parulekar et al.,1982; Chatterjee et al., 1984) reported higher rate of growth at early age in tropical waters, whereas in temperate waters at certain time, due to low temperature, growth is not realised for about 4-5 years in some individuals (Seed, 1969).

Decrease in growth rate (length) as individuals grow older is well documented for various mussel species (Jorgensen, 1976). In the present study, for the successive period of growth, shell length increased at a lower rate as can be seen from Fig. 15. The reason for this reduced growth rate may be the reduction in metabolic activity with age, which accounts for decreased growth rate as seen from reduction in specific growth rate (Table 4). Salinity itself, however, is not always the primary cause of reduced growth since transplantation of old non growing mussels to more favourable situations can often result in renewed growth (Seed, 1968). Slower growth rate of larger mussels has been demonstrated in temperate waters (Seed, 1969). It is likely that physiological adaptations to slow growth, resulting from reduced feeding time and stress conditions are more pronounced in larger mussels (Baird, 1966). Similarly, shell breadth and height, also increased in initial stages, but the rate of increase was not proportionate to length. However, the shell breadth increased with time to a much lesser extent than length, whereas increment in shell height, although less in initial stages, increased with greater proportions as mussels grew older. These variations in growth of different parameters could be attributed to physiological state of the mussels and also to the local environmental conditions prevailing at that time.

Growth as total weight increment in the raftgrown green mussel did not show maximum rate in initial stages of growing period. This could possibly be due to improper acclimatisation of the green mussels, transplanted from rocky intertidal habitat to submerged ecosystem. Seed (1969) while working in temperate waters stated that in many mussel populations, maximum growth occurs immediately after settlement, whilst in others maximum growth is not realised until perhaps the fourth or fifth year in life. Furthermore, lower growth rate even in the smallest transplanted mussels, suggests that adaptations may take place at an early age. It may also indicate genetic growth differences in the populations (Hickman, 1979). Total weight increase was high in March, which was attributed to increased metabolic activity due to higher temperature resulting in faster growth at that time. Similar increase in weight during March was also earlier documented by Parulekar et al. (1982) and Chatterjee et al. (1984).

A sudden rise in growth rate during June-July was mainly due to abundance of food material, improved feeding and optimum conditions in hydrographic parameters prevailing at that time. Qasim et al. (1977) and Parulekar et al. (1982) also reported high growth rate in June-July, in the case of raftgrown green mussels. Similar increase in growth rate during this period was observed by Hilbish (1986) in Mytilus edulis L.. The total weight declined after attaining peak value in June, and as expected, the meat and shell weight also decreased. The decrease in weight during this period indicates that mussels at this size group are less resilient than smaller sized mussels, and reduced ability to react rapidly to utilize available food material due to improved feeding conditions.

The meat:shell ratio (Fig. 21) indicates that, it was nearer to one during most of the study period. This implies that the meat:shell ratio weight was almost proportional, thereby indicating 50% yield. In January and March, the ratio was observed to be low, demonstrating that much of the food consumed at this time was used for shell formation thereby reducing the yield, although total weight was on progressive increase. Maximum value was observed in June, indicating that yield was maximum in this month.

The dry meat weight was observed to be high in March, indicating less moisture content in the mussel tissue. The high dry meat weight values coincided with higher values of condition index. The high condition index suggests that food availability was not a limiting factor. In June, lower dry meat weight coincided well with low condition index values. Qasim et al. (1977) also reported similar relationship between these parameters in raft-grown green mussel, Perna viridis L. The higher values of condition index in March reflects on better state of health and fatness at this time.

Zuari estuary, constitutes a complex ecological system with strong interaction of various physical and hydrobiological factors, which play an important role in determining growth of green mussels grown on a floating raft. Earlier studies have shown that this estuary is highly productive (Dehadrai, 1970; Goes, 1983). These brackish water areas are more suitable for mussel culture as the mussels are euryhaline and can thrive well in such systems. Estuaries are practically advantageous for culture activity because of higher production rate and thereby leading to improved feeding conditions (Thiensen, 1968; Bohle, 1972).

Table 6 shows the effect of various environmental parameters on growth (as increase in weight) as deduced from simple correlation coefficient. From Table 6, it can be seen that among environmental parameters, temperature had positive correlation suggesting that the increase in temperature resulted in higher salinity values at the study site. This can be attributed to the higher rate of evaporation during increased solar radiation. However, temperature was found to have negatively significant correlation with DO, indicating that decrease in temperature resulted in increased DO concentration, during southwest monsoon season. Another possibility for high Do content at this time could be due to fresh water influx.

Salinity displayed a strong negative correlation with POC and DO. Such relationship implies that reduction in salinity exerts significant effect on POC and DO, which was more pronounced during southwest monsoon. The high suspended load coinciding with higher values of DO could be due to river runoff which brings huge quantity of suspended load in southwest monsoon, resulting in thorough mixing of water column, responsible for higher DO content.

Considering the importance of the effect of hydrobiological factors on growth, simple correlation coefficient (Table 6) indicated that only chlorophyll a and DO had positive significant relationship ($r = 0.705$ and $r = 0.633$; $P<0.01$). In the present case, growth was taken as an increase in weight since hydrobiological factors were found to have no significant effect on length. However, salinity had negative significant effect ($r = -0.452$; $P < 0.01$) on weight, indicating reduction in salinity enhances growth rate. Such increase in growth rate has been reported earlier by Qasim et al. (1977) and Parulekar et al. (1982) in the raft-grown green mussel, which could have been due to more favourable environmental conditions accompanied by high food production with improved feeding efficiency.

Table 7 shows combined influence of different hydrobiological factors on length and weight, respectively. From Table 7, it can be concluded that among hydrobiological factors, only chlorophyll a either singly or in combination with POC and DO had significant effect on growth, in terms of length ($r = 0.733$; $P < 0.01$ and $r = 0.868$; $P < 0.01$). The increased growth in shell length could be due to improved feeding conditions and food availability at the time coinciding with favourable environmental conditions. However, Parulekar et al. (1982) reported negative correlation of temperature, salinity, DO and suspended load with shell length in raftgrown mussels. Hence, it can be stated that, the dependence of growth on the environmental factors cannot be wholly explained due to some endogenous factors that influence physiological state of the mussels.

The influence of combined effect of hydrobiological factors on weight, as seen from Table 7 indicate that chlorophyll a and its combination with DO exerted significant effect on growth ($r = 0.705$; $P < 0.01$ and $r = 0.787$; $P < 0.05$). Other hydrobiological factors did not show much detrimental effect on growth in the raft-grown green mussels *P. viridis* L., though, in an earlier study, Parulekar et al. (1982), reported that only temperature in combination with salinity had significant effect ($r = 0.62$; $P < 0.05$).

High value of variance ratio in the case of chlorophyll a indicates that the growth in raftgrown green mussels is primarily dependent on food availability, generated by primary productivity, provided environmental conditions are favorable. Low variance ratio in case of other hydrobiological factors may indicate that in a tropical ecosystem, variations in abiotic factors are too wide or data collected on these parameters are not sufficient to establish a valid relationship.

CHAPTER V

ALLOMETRIC RELATIONSHIPS IN MUSSELS

INTRODUCTION

Allometry is described as the study of relationship between increase of one body parameter to the other. Earlier, several authors, have applied the concept of allometric growth to mussels (Coe, 1946; Mason, 1957; Seed, 1968; 1973; Parulekar et al., 1973; Ansari et al., 1978; Mohan, 1980; Parulekar et al., 1982; Borrero and Hilbish, 1988) however, this concept allows only two parameters to be compared at any one time.

It is known that animals changing their body proportions may also change their shapes. Allometric relationship provides an important information regarding comparative growth of various body parameters. A proper understanding of allometry in shell and soft tissue of bivalves is essential to define the growth of a species. The use of regression analysis to explain such relationship between various morphometric characters has been considered suitable (Gould, 1966; Brown et al., 1976). The morphometric characters and their allometric relationships are to a large extent, influenced by age, local environmental conditions and the population density of the species (Hickman, 1979; Schaefer et al., 1985).

The present study was taken up primarily in terms of expressed interests in commercial exploitation of the green mussel P. viridis L. Here, an attempt is made to describe the seasonal changes in allometric growth relationship of different morphological parameters with reference to length as dependent variable of known size animals from a raft grown population under continuous submergence in a subtidal estuarine biotope.

RESULTS

The data on morphological parameters were treated for regression analysis after transforming to logarithms in order to get an exponential equation form. Computation of **r** value (correlation coefficient) was done using computer programme. The best fits were fitted for normal data as shown in figures (25a to 33d). Transformed data was used only to get an exponential equation.

The relationship is expressed, either linear or exponential depending upon its relevance or application. The equations for different relationships along with r values are given in the respective figures. Data was coupled for different collections and was grouped depending upon size categories. This data was treated for regression analysis to see if there exists any significant differences in allometric relationship with different growth rates. Efforts were made to compare these relationships with those for complete period of study.

TOTAL WEIGHT-SHELL LENGTH RELATIONSHIP:

The total weight-shell length relationship is depicted in Figs. 25a to 25d for different growth phases during the study period. Total weight increase with shell length displayed an ascending order. In smaller sized mussels (<40 mm), usually the growth in terms of weight was fast, but in the present study, during initial stages of growth after transplanting mussel seed

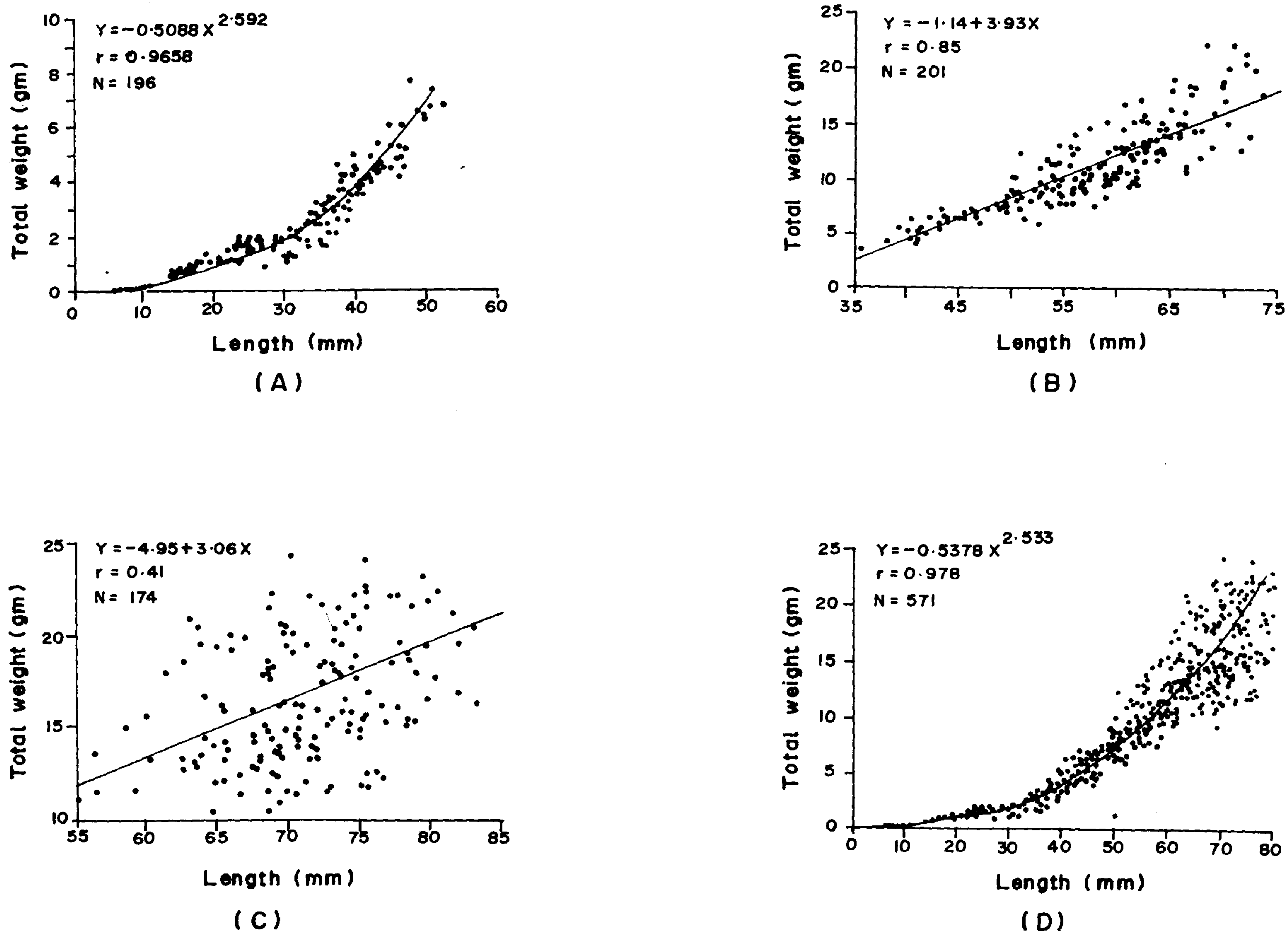

Fig. 25. Shell length-total weight relationship during different seasons and for complete period of study in raft-grown mussels P. viridis L.

from natural rocky shore to subtidal ecosystem, the increase in weight was of reduced magnitude. The weight increment upto a length of 40 mm size was only to the tune of about 3.0 gms. In medium size group (40-60 mm) the rate of increase in weight in shell length was much higher when compared to smaller sized mussels. The increase in weight in this size range was upto 8.0 gms, which was much higher than the growth increment observed in the initial growth period. As the mussels became older attaining size of 60 mm and above, the rate of increase in weight slightly reduced as compared to medium size group (about 6.0 gms).

An exponential relationship was noticed for the initial growing period upto a size of 55 mm. During next growth period, linear relationship was exhibited, whereas in the last stages of growth, when mussels attained a size of 70 mm and above, no specific relationship within these parameters was observed, although a linear fit was fitted with low value of determination.

TOTAL WEIGHT-SHELL HEIGHT RELATIONSHIP:

The total weight-shell height relationship is shown in Figs. 26a to 26d. In the present study, the rate of increase in weight was very low as compared to height in the initial period of growth. The increase in height upto 18.0 mm reflected only an increase of about 4.0 gms in weight. During next growing phase, increment in height upto 15.0 mm resulted in rapid advancement in weight upto an increase of about 12.0 gms. However, towards the end of the growing period, weight did not show any marked increase (Fig. 26d).

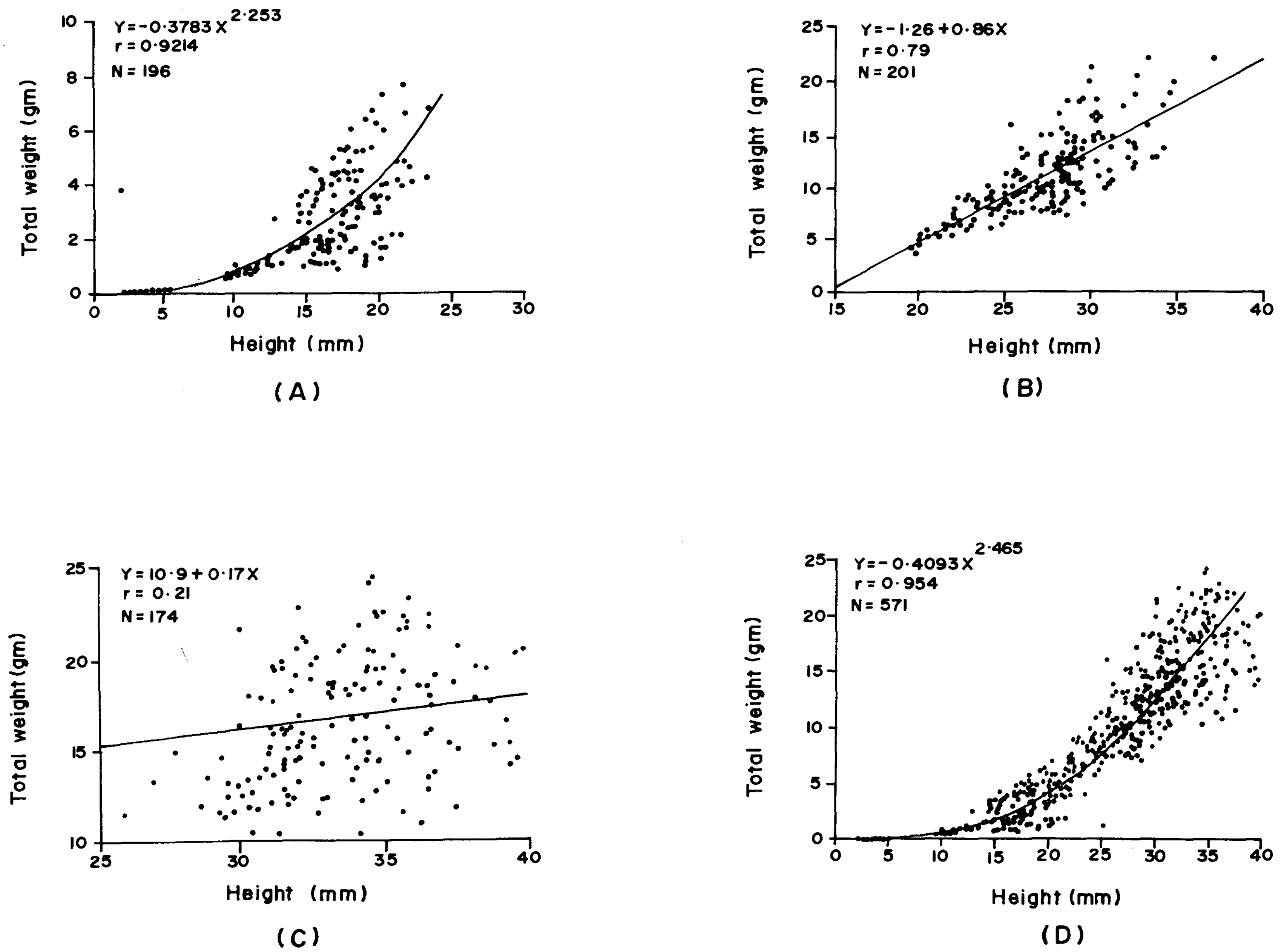

Fig. 26. Shell height-total weight relationship during different seasons and for complete study period in raft-grown mussels P. viridis L.

Generally, in these parameters, for the period of study, exponential relationship was observed. When considered separately, with different growth phases, during the initial period, it showed an exponential relation. In the next size group (20-35 mm height), the weight exhibited linear relationship. In the final stages of growth, no specific relationship could be observed, although regression equation of first order could be fitted (Fig. 26d).

TOTAL WEIGHT-SHELL WIDTH RELATIONSHIP:

Total weight-shell width relationships are shown in Figs. 27a to 27d for the complete data of the study period. During early stages of growth, increase in weight with corresponding shell width followed similar pattern of variation as that of shell height and showed an increase of only about 4.0 g with shell width progression upto 15.0 mm. In the succeeding phase of growth, the shell width increased from 15.0 to 30.0 mm, while, weight showed sharp rise upto an increment of about 11.0 g in this size range. For the remaining part of the study, no noteworthy increase in total weight with corresponding shell width increase was observed.

A linear relationship was observed during the initial period of growth in total weight and shell width. During the next phase of growth, the relationship observed was exponential, suggesting that increase in weight was of higher magnitude in shell width range of 5.0 - 15.0 mm, whereas during the final stages of growth, non-linear relationship was observed. The same data,

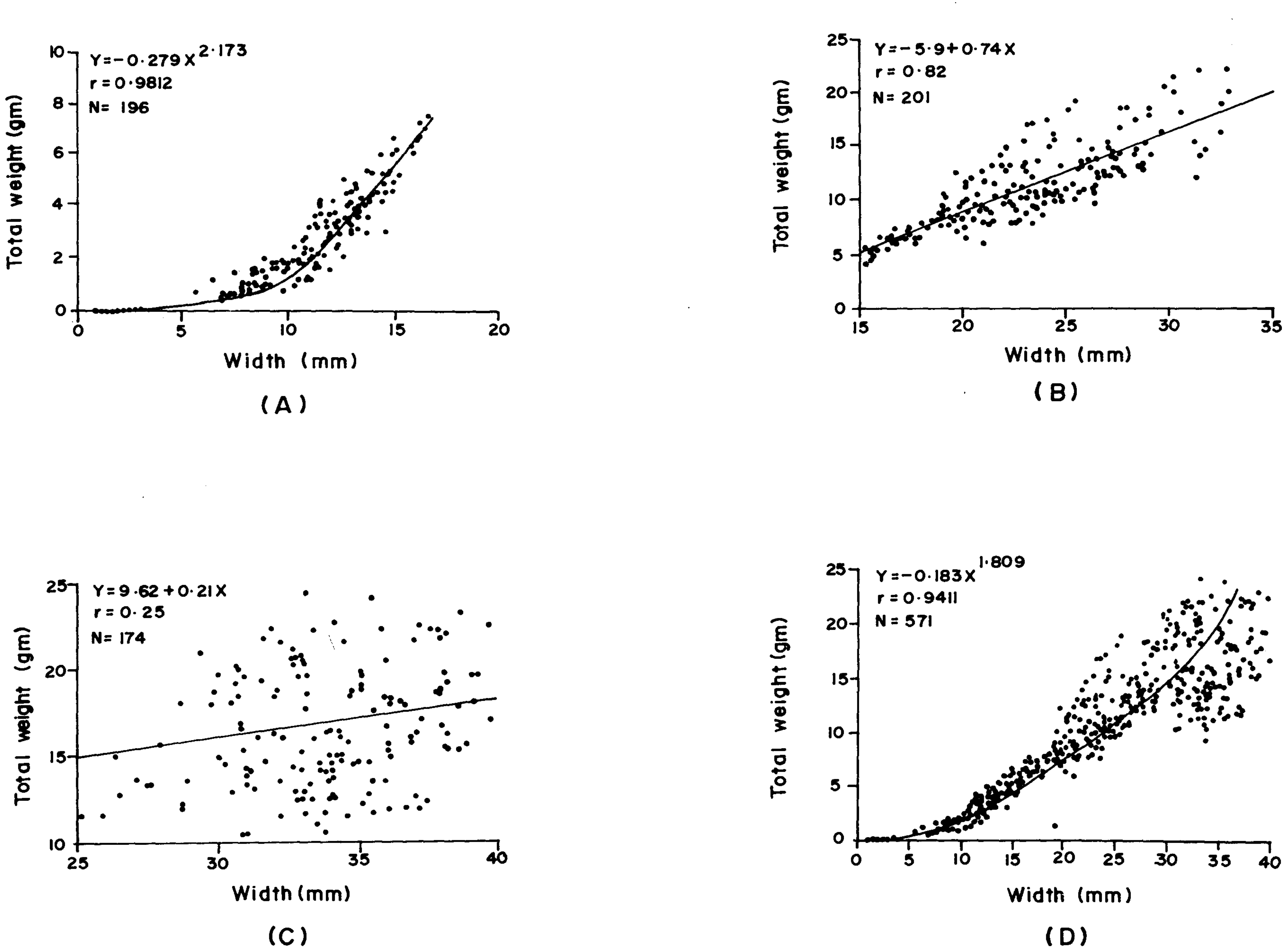

Fig. 27. Shell breadth-total weight relationship in different seasons and for complete study period in raft-grown green mussel P. viridis L.

considered for complete period of investigation showed an exponential relationship (Fig. 27a).

SHELL HEIGHT-SHELL LENGTH RELATIONSHIP:

Shell height-shell length relationship for different growing periods and for complete period of investigation are depicted in Figs. 28a to 28d. Shell height with reference to shell length was constant and proportionate throughout the period of study. However, the rate of increase in height in small sized mussels (<40 mm) was at a much increased rate. In large sized category of mussels (>50 mm) the growth in shell height per unit time decreased but was not significant. In the mussels of 35-45 mm size group, the shell height increment did not show an ascending order. In the mussels of size group 70-75 mm, the shell height was observed to be equal to shell width. The ratio of shell width/shell length was found to vary from 0.22 to 0.50. The higher values of shell height/shell length ratio were noticed in the initial period of growth. As the mussel size increased, these values were observed to be low, which indicate less increase in shell height with corresponding increase in shell length. However, during the complete period of study, the ratios did not show much variations indicating proportionate increase in shell height when compared to increasing shell length.

The shell height/shell length relationship was observed to be linear for complete period of study. When considered separately, with varying growing stages upto a size of 70 mm, the observed relationship was also linear, however, towards the end

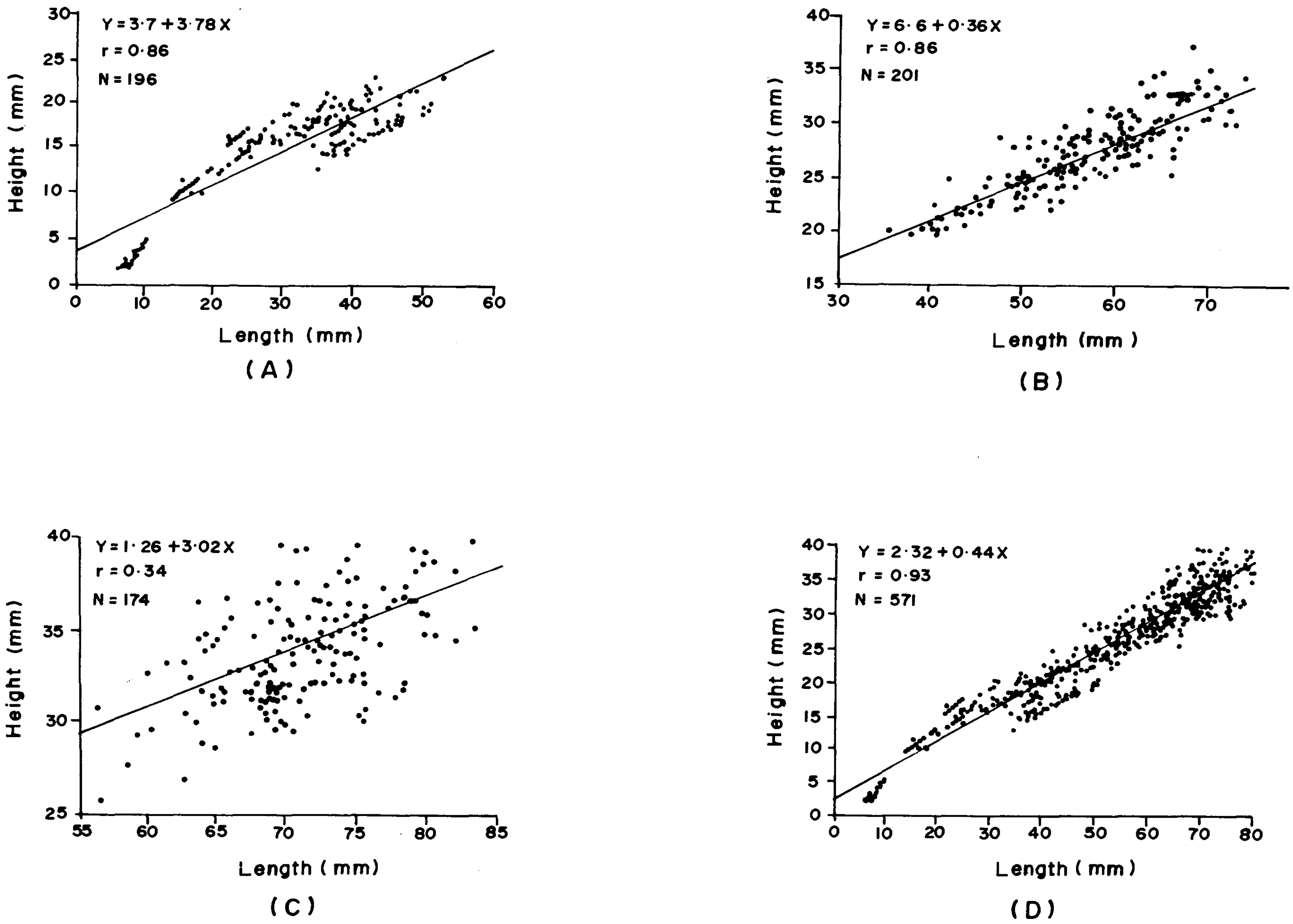

Fig. 28. Shell length-height relationship in different seasons and for complete study period in raft-grown mussels *P. viridis* L.

of the growing period, no specific relationship could be seen from the regression plot (Fig. 28d).

SHELL WIDTH-SHELL LENGTH RELATIONSHIP:

The variations in shell width with shell length are shown in Figs. 29a to 29d. A corresponding increase in shell width and shell length was observed to be of an increasing order i.e. as mussels grew older the increment per unit time was more in shell width as compared to younger mussels. In the initial stages of growth when these mussels were small and growth was relatively faster, the shell width did not increase in proportion with shell length. The rate of increase of shell width in small sized mussels was moderate, whereas, in large sized mussels (>60 mm) the increase in shell width was at faster rate and uniform upto the termination of the experiment. The ratio of shell width/shell length in the present study ranged from 0.27 to 0.66. The changes in the ratio of shell width/shell length did not show much variations. The ratio was found to increase as mussel growth advanced.

An exponential curve was fitted for the above parameters for the total period of study (Fig. 29a). However, for different growing period, when considered separately, the relationship was observed to be linear for all size groups.

SHELL WEIGHT-SHELL LENGTH RELATIONSHIP:

Figs. 30a to 30d represent relationship between shell weight and shell length. The variations in shell weight with reference

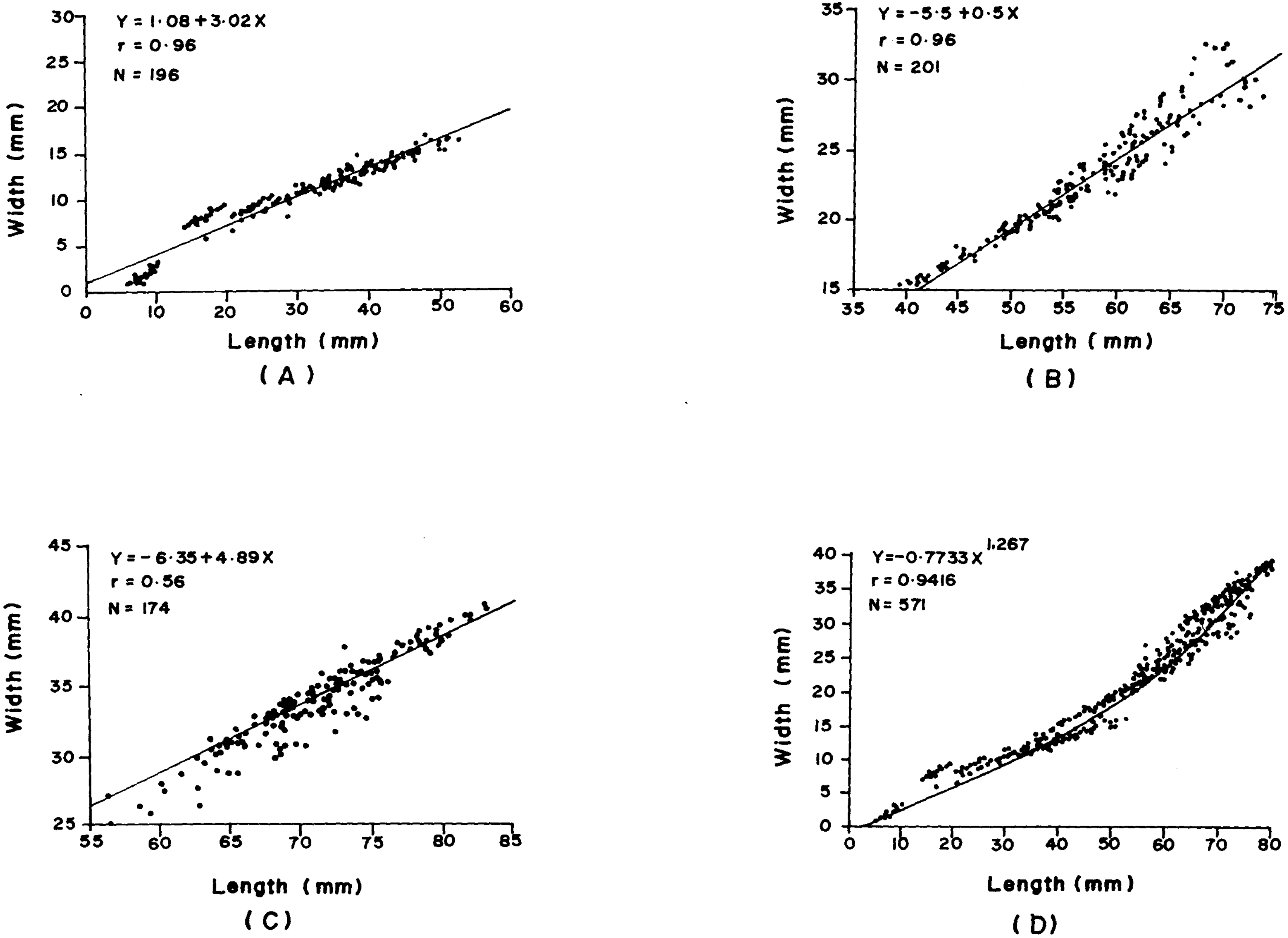

Fig. 29. Shell length-breadth relationship during different seasons and for complete study period in raft-grown mussels P. viridis L.

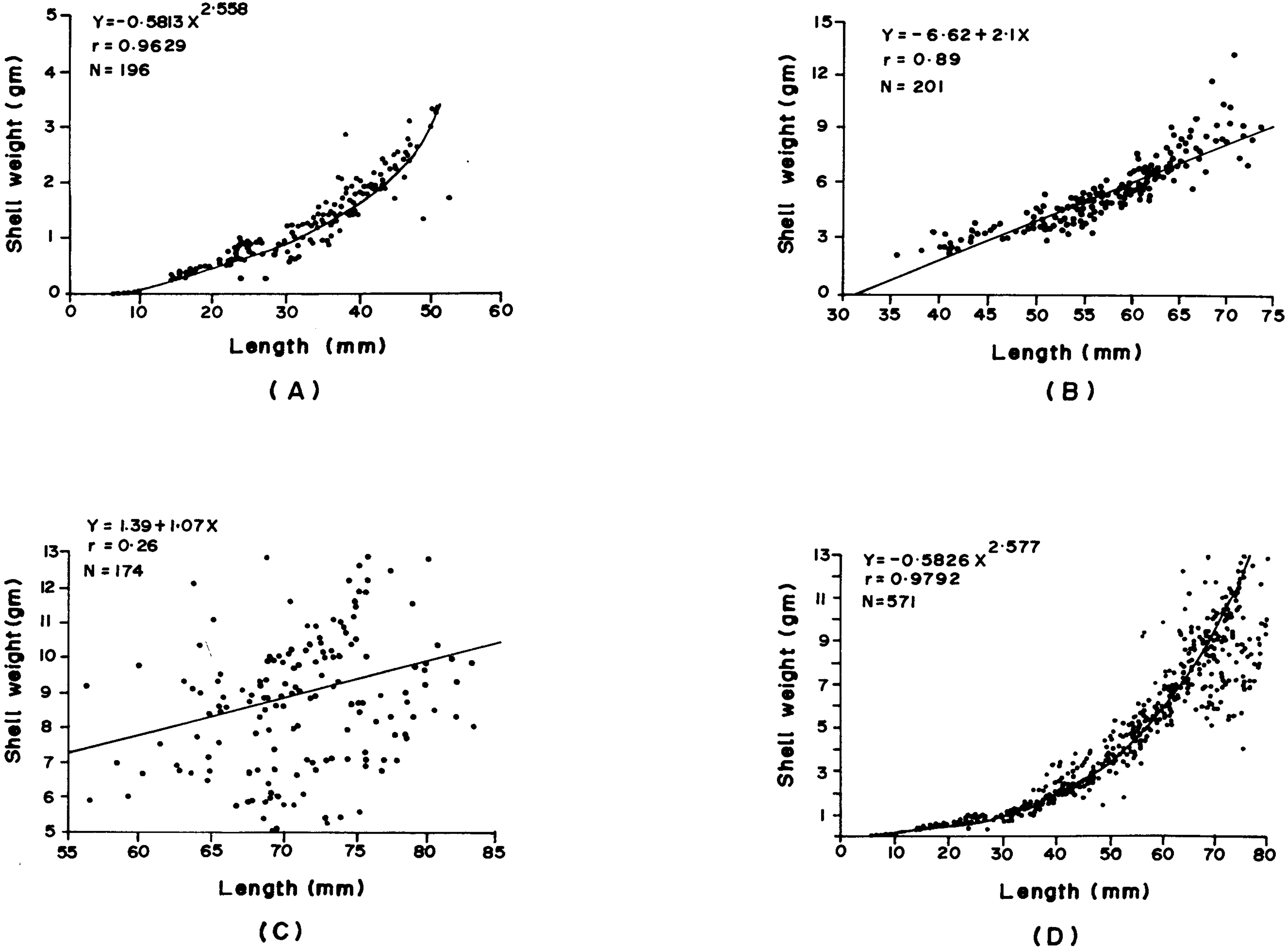

Fig. 30. Shell length-shell weight relationship during different seasons and for complete study period in raft-grown mussels P. viridis L.

to shell length indicate that the increase in shell weight was of very low magnitude upto a size of about 30 mm. In next size category (30-60 mm), the increase in shell weight with shell length showed steep rise. The increment in shell weight in this size category was about 7.0 g. In this size group the increase in shell weight was observed to be uniform with growth, except at a size of 60 mm where a sudden increase in shell weight in relation to shell length was observed. However, the increase in shell weight was only upto the order of about 4.0 g. In larger size group (>70 mm) the corresponding shell weight was observed to be very high, attaining a shell weight of about 12.0 g.

From the regression plots (Figs. 30a to 30d), it was observed that the above parameters exhibited curvilinear relationship during the period of study, indicating that shell weight increases relatively faster as compared to shell length. In the present study, during initial period of growth upto a size of 55 mm, the mussels, exhibited exponential relationship which became linear during next phase of growing period. However, during the time of termination of experiment, no specific relation was noticed.

MEAT WEIGHT-SHELL LENGTH RELATIONSHIP:

The relationship in these parameters is shown in Figs. 31a to 31d. Meat weight increment followed an ascending order with shell length. In small sized mussels (<40 mm), the increase in meat weight with shell length was low as compared to other size groups. In medium sized mussels (40-60 mm) the increment in meat

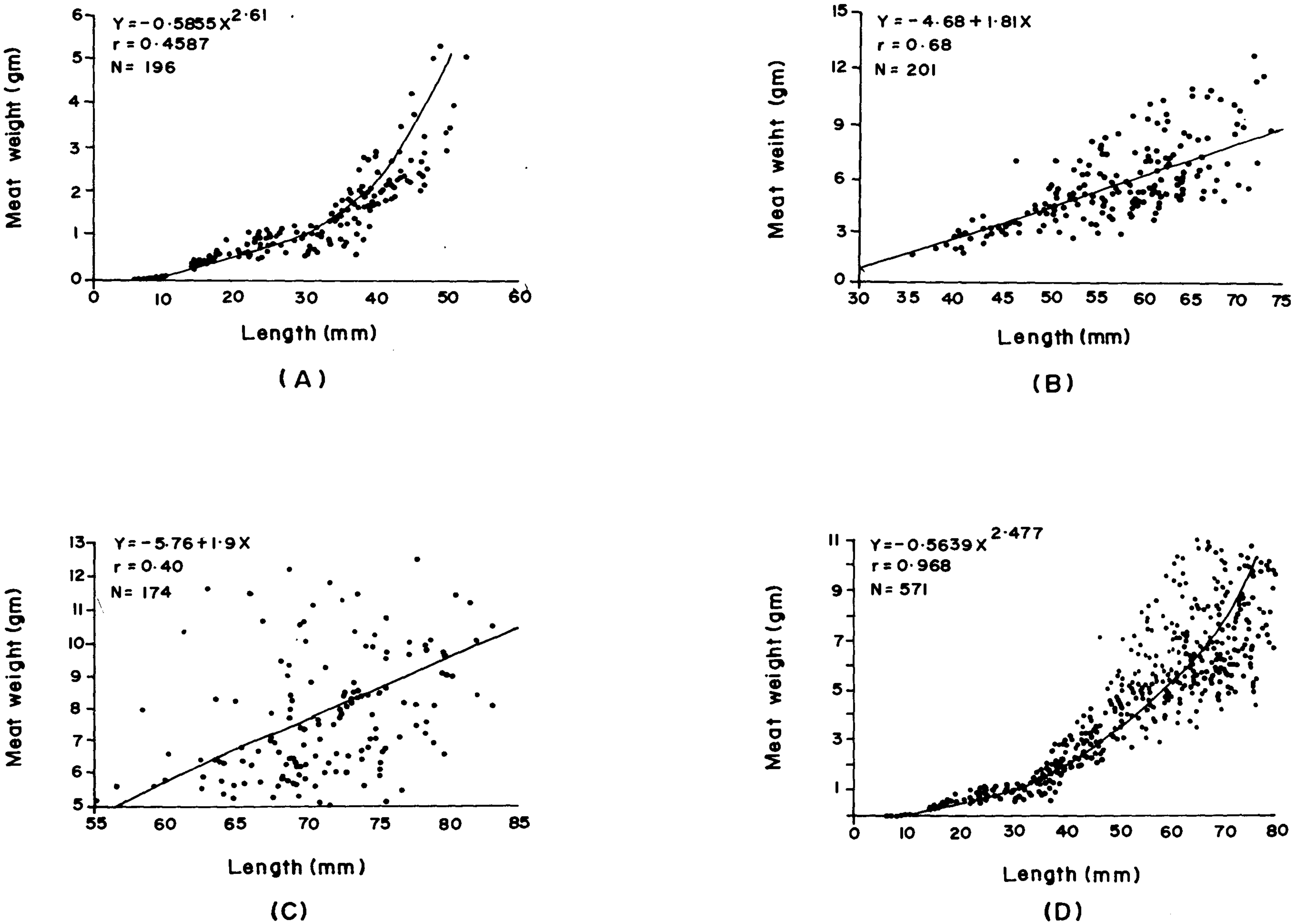

Fig. 31. Shell length-meat weight relationship in different seasons and for complete study period in raft-grown mussels P. viridis L.

weight was higher as compared to smaller size groups. The growth increment in medium size group was about 4.0 g. The increase in meat weight with shell length in this size group was uniform. In large sized mussels (>60 mm) the meat weight was observed to increase with shell length and was upto the tune of 4.5 g, the increment in meat weight being higher than the medium size group. During the period of investigation, the increase in meat weight was found to follow consistent pattern with the shell length.

During the complete period of study, the regression analysis between above parameters was observed to be of an exponential nature. A curvilinear relationship was recorded in the initial period of growth upto a size of 50 mm and as the growth advanced, upto 75 mm size, linear relationship persisted (Figs. 31b to 31d). Mussels, during rest of the growing period showed neither linear nor exponential relationship.

DRY MEAT WEIGHT-SHELL LENGTH RELATIONSHIP:

Dry meat weight-shell length relationship for the different growth phases and for the complete period of study are shown in Figs. 32a to 32d. The changes in dry meat weight with reference to shell length was not found to follow any uniform pattern. The dry meat weight increased gradually with increase in shell length attaining maximum value (3.5 g) at a size of about 55 mm. In a size group of 65 mm, a second peak value (2.5 g) in dry meat weight was observed. In general, the dry meat weight in large sized mussels decreased and was found to be low as compared to their respective shell length group.

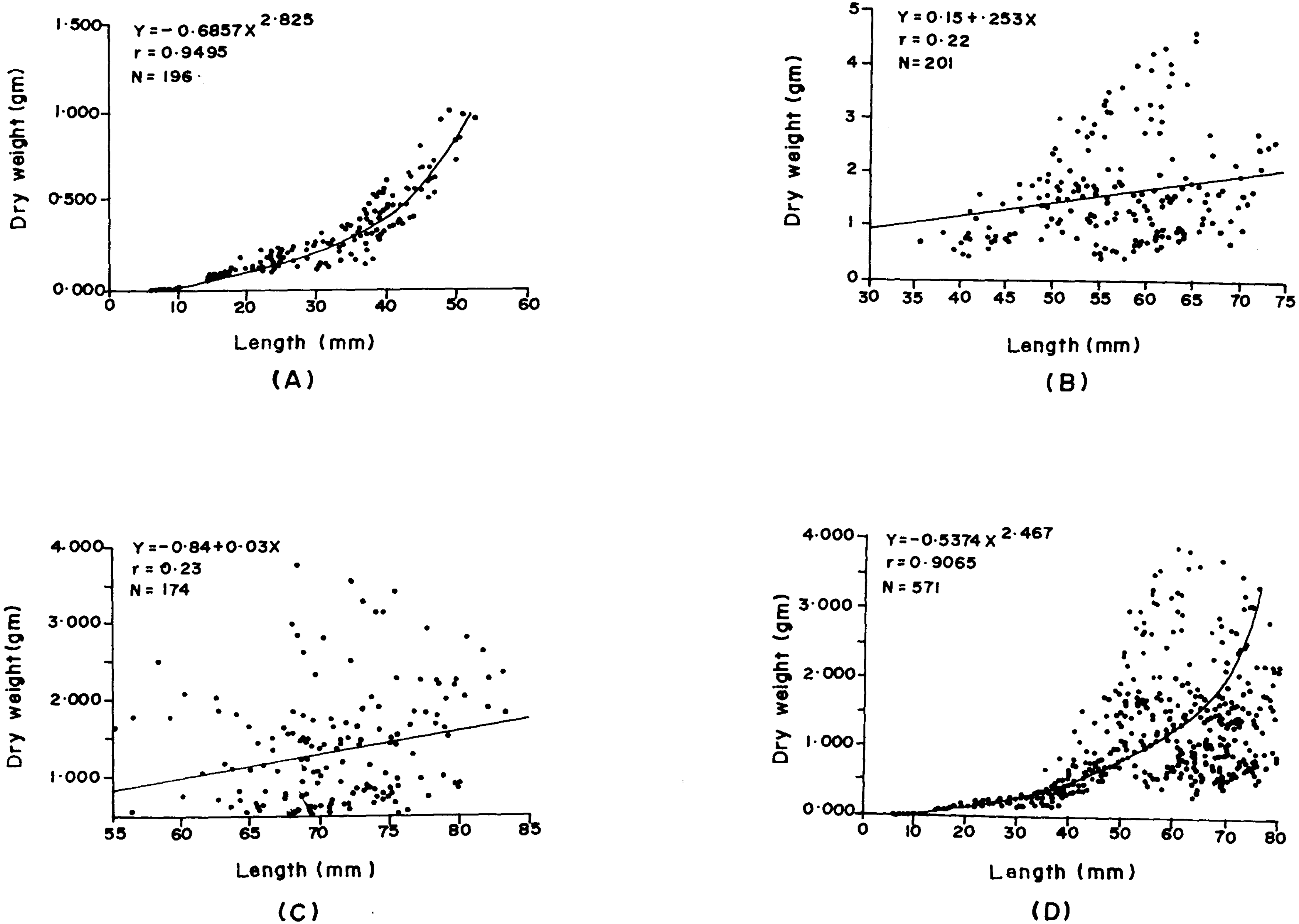

Fig. 32. Shell length dry meat weight relationship in different seasons and for complete study period in raft-grown green mussel P. *viridis* L.

The relationship of above mentioned parameters, was reported to be of an exponential order for total period of study. During initial period of growth, an exponential relationship was observed, whereas, no specific relationship during remaining part of the study could be observed. However, the regression plots (Figs. 32c and 32d) indicate fitted regression equation of first order with very low significance.

SHELL VOLUME-SHELL LENGTH RELATIONSHIP:

The variations in shell volume-shell length relationship during the period of study are depicted in Figs. 33a to 33d. Shell volume increase with respect to shell length upto a size of 40 mm was of very low order registering only an increase of 3 cm^3. In large sized mussels (>40 mm) the shell volume was found to increase at much faster rate. The mussels of 70 mm size group showed steep increase in shell volume from the earlier size group i.e. upto a tune of about 6 cm^3. For the present study, increase in shell volume in relation to shell length was observed to follow an uniform pattern.

The shell volume-shell length showed an exponential relationship for the study period. In the beginning of the growth period, an exponential relationship was observed upto a size of 50 mm, whereas during the remaining part of growth period, the relationship was linear. However, the degree of determination of linearity was not the same.

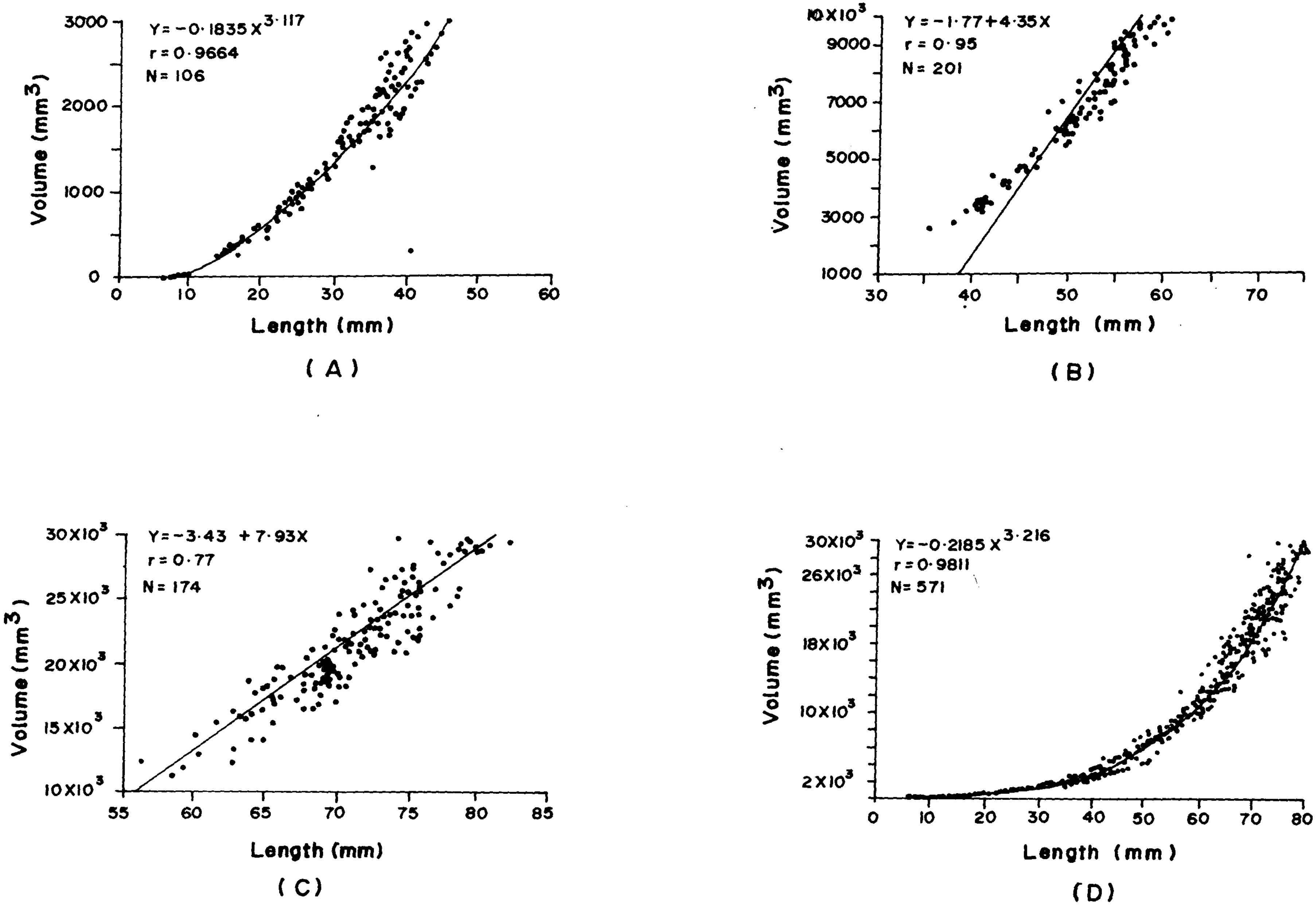

Fig. 33. Shell length-volume relationship during different seasons and for complete study period in raft-grown mussels P. *viridis* L.

DISCUSSION

The concept of allometry was first postulated by Huxley and Tessier (1936) and since then it has been extensively applied to many bivalves like Mytilus californianus (Coe and Fox, 1942; Fox and Coe, 1943), Mytilus edulis (Genovese, 1961; Hancock, 1965b; Seed, 1968), Perna canaliculus (Hickman, 1979), Perna viridis (Shafee and Sundaram, 1975; Ansari et al., 1978; Mohan, 1980; Parulekar et al., 1982). These studies suggest that allometric relationships in bivalves play an important role in understanding comparative morphometrics and emphasize the care that must be exercised in using different bivalve population. However, the use of this concept is somewhat limited and has been criticised by some authors (Holme, 1961; Wilbur and Owen, 1964). Although, knowingly that the changes in the form of an animal cannot be described satisfactorily by such relationships, they are, however, useful in comparison of shell dimension of animals of known size within a locality which is a primary concern of this study. An understanding of the allometric relationships in shell and soft body characters is therefore essential to fully understand the growth of a species. The use of regression analysis to define such relationships has been considered most suitable (Gould, 1966; Brown et al., 1976).

Total weight-shell length relationship suggests that in early stages, growth rate was less. However, for certain size groups, an exponential relationship was recorded, indicating that increase in total weight was at a rapid rate with respect to shell length. The reduced rate of progression during early period of growth of the transplanted mussels could mainly be due to improper acclimatisation to subtidal ecosystem and to varying environmental conditions prevailing at that time. Earlier, Seed (1968) reported that in some populations of blue mussel, growth increase is not realised until fourth or fifth year of life. In medium size group (40-60 mm), the weight increase was of a high magnitude. The increase in the total weight coincided with higher rate of increase in meat weight suggesting that contribution of soft tissue to the total weight was significant. This could probably be due to increased feeding efficiency and food availability for the raftgrown mussels. Seed (1969) also reported higher contribution of meat weight and stated that this increase in tissue weight occurs through the deposition of fat and glycogen in the tissue. In the case of large size mussels (60-80 mm), rate of increase in total weight decreased with length as compared to medium size group. Earlier studies (Jorgensen, 1976; Hickman, 1979) have reported that, as the mussels grew older, in the later stages of growing period, growth rate decreases with increase in size. In the present study, for different growing periods, varying relationships were observed, suggesting that rate of change in body dimensions does change with different growing periods. The _Perna viridis_ L. from Mangalore (west coast of India) was found to exhibit linear relationship in body characters after logarithmic transformation (Mohan, 1980). However, Ansari _et al_. (1978) reported an exponential relationship in above parameters of the green mussel _P. viridis_ L., from Goa, also along the west coast of India.

Considering the importance of shell height to predict other biomass parameter (Dame, 1972; Ansari et al., 1978) a relationship between total weight with shell height and shell width were studied to assess whether any of these parameters play an important role in the morphometric of green mussel. Neither shell height nor shell width was found to be useful in predicting other biomass parameters.

The total weight-shell height relationship showed an exponential trend indicating that increase in total weight was at a low magnitude in the initial stages of growing period. After certain size, the rate of increase in total weight was much faster and linear, indicating proportionate increase in total weight with shell height increment. Seed (1969) reported a linear relation in Mytilus edulis of large and small size categories, whereas, Mohan (1980) noticed non-linear relationship in the green mussel, Perna viridis L.

For the complete study period, total weight-shell width displayed an exponential curve, implying that the total weight increase was not proportionate with the shell width. Ansari et al. (1978) reported an exponential relationship in these parameters of the green mussel Perna viridis L. During different growing periods, considered separately, an exponential relationship was observed. However linear relationship was observed in the size range of 15-35 mm shell width, thus suggesting a change in the growth pattern of body dimensions with advancement of growth. Most of the earlier studies on allometry (Seed, 1968; 1973; Jones et al., 1979; Hickman, 1979) suggest that such changes in body parameters are likely to occur due to changes in local environmental conditions. Hilbish (1986) demonstrated uncoupled growth in shell and soft tissue in Mytilus edulis L. Towards the end of growth period, as seen from Fig. 27d, no relationship of a particular significance was noticed.

The shell height increase with shell length was found to be proportionate and uniform as indicated by linear relationship (Figs. 28a - 28d) except in case of large size mussels. Furthermore, in small sized mussels, the increase was at a higher level and more linear ($r = 0.93$) as compared to the large size category. The increased rate of height in the initial phase of growth in present study could mainly be attributed to the density of mussels on the rope. Due to increased density of mussels, in the initial period of fast growth, there could have been more scope for height enhancement, thereby suppressing width and length due to competition for space. Seed (1973) and Hickman (1979) have also made similar observations in their experiments on Mytilus edulis L. and Perna canaliculus, respectively. This type of relationship of shell height-shell length may be density dependent and could be explained by the fact that, such conditions of high density coupled with external factors as in the present study, may lead to reduced growth in shell length and shell width and promote shell height. However, Seed (1968) reported that under such conditions, the shell length and height get reduced and promotes shell width.

As mussels grew older, the height increment was stagnant whereas in few cases, width was found to be equal to the shell height. Seed (1968; 1973) and Hickman (1979) in their studies on Mytilus edulis and Perna canaliculus respectively, have also reported similar trend of variation in shell height with shell length. The shell height/shell width ratio was found to follow decreasing trend with the shell length. In large sized mussels (>65 mm) the ratio of shell height/shell width was less than 1, thus highlighting that the increase in shell width was at a faster rate than the shell height during later stages of growth in the present study.

Shell width-shell length relationship in the raftgrown population demonstrated that as mussels grew older, the increment in width per unit length was high. The higher rate of increase of shell width in older mussels was mainly due to increased shell gape in these mussels for feeding. Seed (1973) also reported an increase in shell width with larger shell length categories and further stated that, in Mytilus edulis increased tension in older animals lead to more gape of the valves. This increase in gape could be due to increased feeding efficiency coinciding with abundance of food material (present study) at that time. Shell width increase was proportionate with length in the initial stages, indicating that, in early stages of growth, much of the energy gained from ingested food was used for building up of soft tissue (as seen from meat:shell ratio). The ratio of shell width/shell length was increasing and higher in the later stages of growth as compared to shell height, suggesting that as the animals grow older, they become wider and many a time shell width often exceeds shell height. Seed (1973) made similar observations and stated that as shell length increases beyond a certain limit shell width continues to increase, when increase in height almost ceased. During the course of present study, as well as during different stages of growth, linear relationship of these parameters suggests that, changing growth rates and seasons did not affect the relationship of these parameters. Jones et al. (1979) also reported, no seasonal variations in shell and soft body characters of the limpet, Patella vulgata L..

Shell weight and meat weight with shell length showed similar type of relationship for the period of study as well as for changing growth phases (Figs. 30a to 31d). In early stages of growth, an exponential relationship was observed, which indicates that increase in shell and meat was faster in the size range of 30-50 mm size group. Similar curvilinear relationship in Mytilus edulis was also reported by Seed (1973). During remaining period of growth, relationship was linear, emphasizing, changing pattern of variation in shell weight with respect to shell length. Seed (1969) stated that during unfavourable environmental conditions, cessation of accretionary growth at shell margin occurs, however, growth of shell in terms of thickness continues, thereby resulting in increased shell weight. Rao (1953) also found that subtidal population of mussels had heavier shells, and this he attributed to longer and continuous submergence, leading to calcium deposition which was directly dependent on time of exposure to the calcium source i.e. sea water. In large sized mussels, no such specific relation was observed. From this it could be inferred that, in large sized mussels, total weight, shell weight and meat weight cannot be related to shell length or another possibility could be insufficient data to predict any valid relationship between these parameters. Such non-linear relationship in large size green mussels has earlier been observed by Mohan (1980).

The relationship between dry meat weight and shell length was found to be of an exponential order for complete period of study. When considered separately, no specific relationship could be seen except an exponential relationship in early stages of growth. In large size mussels, some low values of dry weight were reported which could mainly be attributed to environmental conditions prevailing at that time. Similar exponential relationship was earlier reported by Ansari et al. (1978) in Perna viridis. Shell volume exhibited an exponential relationship with shell length indicating that increase in shell volume with respect to shell length was of higher rate in size group of 50 mm and above. However, Seed (1973) in his experiment on Mytilus edulis reported sigmoidal curve for above parameters.

This suggests that the allometric relationship during various stages of growth is important functionally in biology of an organism and practically a predictive tool for ecological investigations. The changes in body dimensions of raft-grown population in the green mussels during different stages of growth indicate that the relationship could indirectly be influenced by population density, feeding efficiency at different size groups, food availability and local environmental conditions prevailing at that particular time. Non-linear growth due to change in direction of body dimensions also play an important role in determining allometric relationships of the raftgrown green mussel population.

CHAPTER VI

BIOCHEMICAL COMPOSITION OF MUSSELS

INTRODUCTION

Today, much of our attention, has been focussed on seafoods as they are one among the major source of protein. Seafoods are known to have high nutritive value and also can earn considerable amount of foreign exchange. Among molluscs, particularly mussels are known to thrive well in estuarine subtidal ecosystem without much maintenance and yields high rate of returns (Qasim et al., 1977).

Earlier studies (Gerritsen and Van Pelt, 1945; Koringa, 1956; Baird, 1966; Giese, 1966; 1969; Williams, 1969; Gabbot and Bayne, 1973; Dare and Edwards, 1975; Pieters, 1979; 1980) suggest that seasonal variations in biochemical composition follow different patterns depending on latitudes and geographic areas and are strongly influenced by temperature and phytoplankton. Zandee et al. (1980) described in detail the seasonal variations in biochemical composition of Mytilus edulis with reference to energy metabolism and gametogenesis. Changes in some of the biochemical constituents are known to associate with different phases of annual cycle of reproduction.

In the present study, an investigation on the proximate biochemical composition of the raft-grown green mussel P. viridis in relation to culture biology with changing growth phases and its variations in relation to reproductive cycle, are discussed. An effort is also made to have better understanding about the impact of some of the important hydrobiological parameters such as temperature and phytoplankton abundance on the biochemical constituents of the body tissue, when grown in an estuarine environment, under continuous submergence.

RESULTS

Annual changes in proximate biochemical composition during the period of study in the raftgrown green mussel Perna viridis L. are shown in Figs. 34 to 40. From the estimated biochemical constituents, the caloric potential was calculated using the conversion factors 5.7, 9.3 and 4.0 Kcal./g for protein, lipid and carbohydrate respectively (Elliot and Davison, 1975). Percentage frequency of animals with different conditions of gonad are depicted in Fig. 41. Regression analysis to establish different relationships among these biochemical constituents were conducted and results are given in Table 9.

WATER:

Changes in water content in tissue (as percentage) during the period of study in the raft-grown green mussel are shown in Fig. 34. In the present investigation, the water content in the mussel tissue varied from 66.86 to 90.12%. Maximum water content was observed in first fortnight of July and minimum in the second fortnight of March. The water content values from the beginning of the study period were low upto first fortnight of February with further decrease till April. The water content during this time ranged from 66.86 to 73.78%. The magnitude of variation being only to the tune of 6.56%. Thereafter, from April, the percentage water content steadily increased upto second fortnight of May, attaining a peak value of 85.15%, followed by a declining

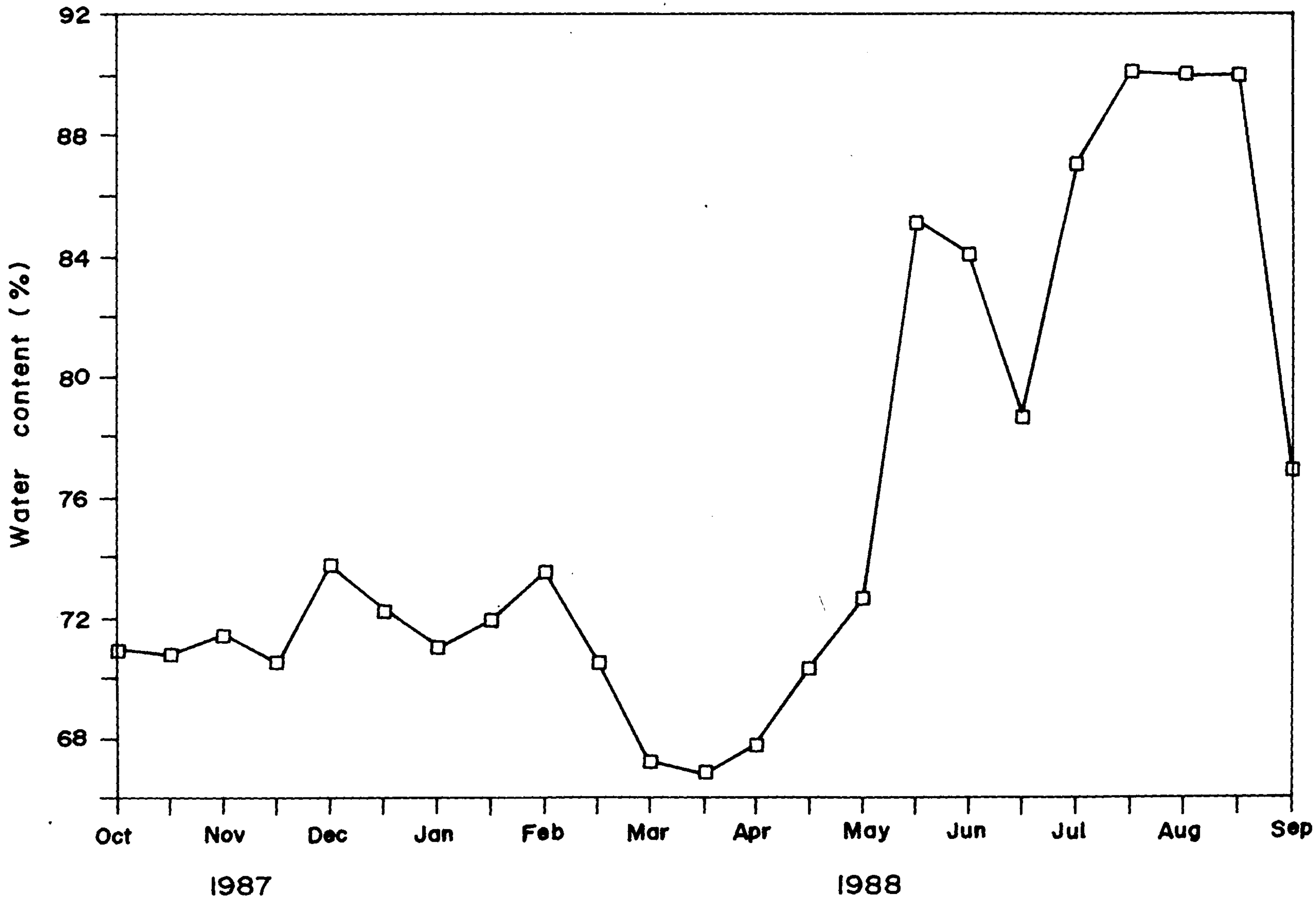

Fig.34. Fortnightly variations in the water content in the raft-grown *P. viridis* L.

trend upto second fortnight of June. Since then, a sudden increase in the percentage of water content was observed, which continued to remain high throughout the monsoon season till August. The high percentage of water content was observed to coincide with low saline waters during south west monsoon period. The higher percentage of water content in mussel tissue coincided with low values of protein, lipid, carbohydrate and ash content.

PROTEIN:

Protein content variation in the raft-grown green mussel P. viridis L. are depicted in Fig. 35. In the present study, the protein concentrations were observed to be generally high, except in the second half of monsoon season, just prior to the termination of the experiment. In small sized mussels, the protein values were low, which suddenly increased in November and then onwards a gradual increase in protein content was noticed upto January. The range of variation from the beginning of study to January was from 600.76 to 609.8 mg/g dry wt. During pre-monsoon season, the protein values were higher and the rate of increase in protein content was also high during the period from February to March. During the above mentioned period, the protein values ranged from 620.72 to 685.84 mg/g dry wt. Since then, upto May, the values remained stable. The maximum value of protein content was observed in first fortnight of March (685.84 mg/g dry wt.). During southwest monsoon, i.e. from June onwards, a decreasing trend in protein content was noticed registering its lowest value in September (457.46 mg/g dry wt.). A slightly

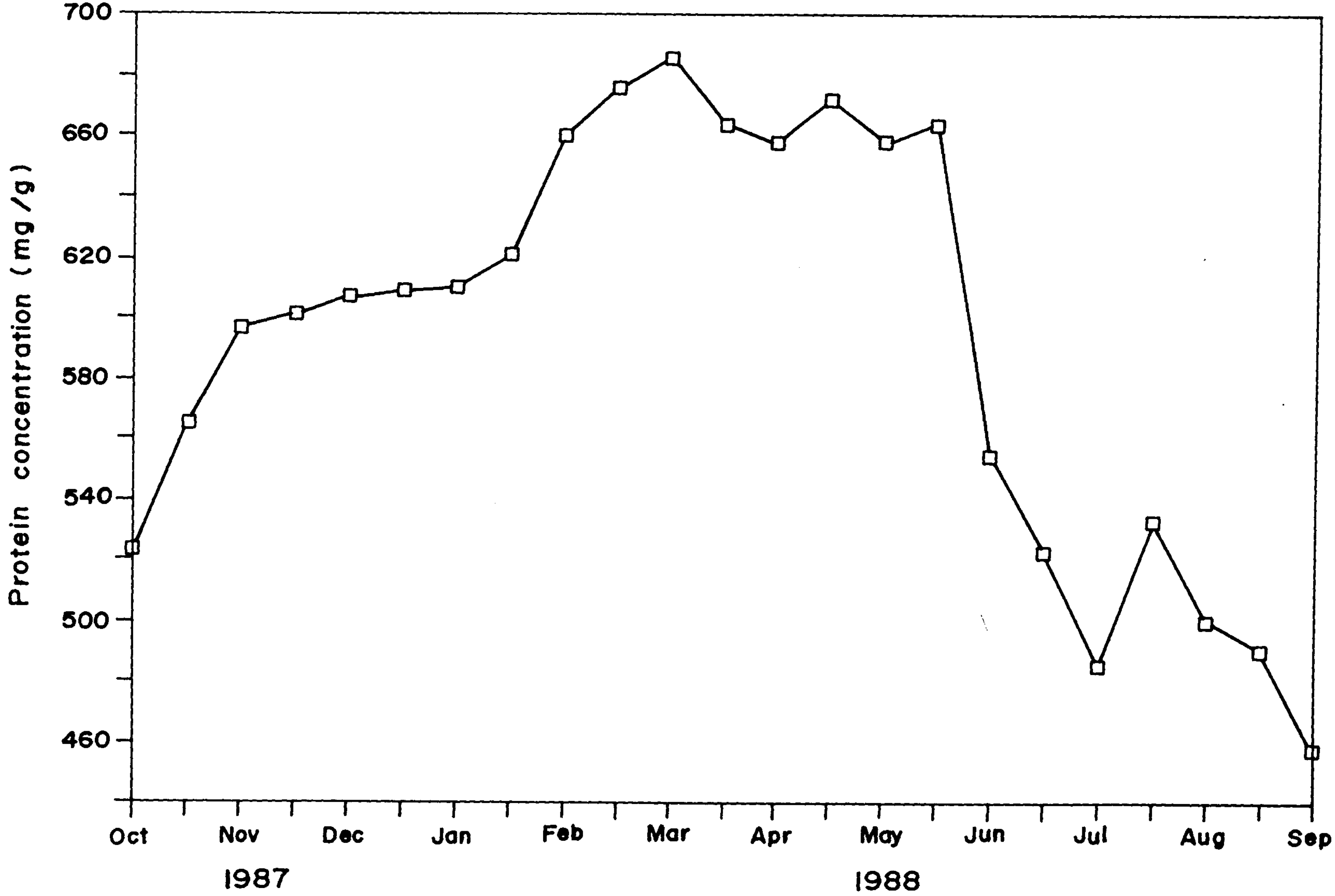

Fig. 35. Fortnightly variations in protein concentration in the raft-grown P. viridis L.

higher value was reported in second fortnight of July (532.55 mg/g dry wt.).

The contribution of protein for total energy (cal/g dry wt) varied from 2584.649 to 3874.996 cal/g dry wt. during the period of study, coinciding with minimum and maximum values of protein in the respective months. The percentage contribution of protein above for total energy production of the raft-grown green mussels varied from 77.45 to 79.09%.

An increase in protein content from February to May was observed to coincide with maturation of gonad. From June onwards the protein level decreased, indicating that much of the energy contributed by protein was used for maturation and spawning. The average value of protein from February to May was 66.73% and during peak spawning period i.e. June-August, it was 51.42% as evidenced from spent gonad conditions. From the examination of gonad condition of the mussels it appears that gametogenesis gets initiated in January and the maturation of gonads lasts till May. In the raft-grown mussels, first gametogenesis occurs at a size group of 15 mm and above. From the observation on gonad, it appears that the spawning was continuous from June onwards to the end of the experimental period i.e. September 1988. From February onwards, three stages of gonadal conditions viz. maturing, mature and spent were found. The reoccurrence of maturing stages of gonad during July to September could mainly be due to intermittent spawning of these mussels. In the present study, the peak period of spawning was observed to be from May to July, although spawning continued at reduced rate in the following months. Thus in an estuarine environment, the mussels not only thrive well, but, also reproduce, over prolonged breeding season.

LIPID:

Variations in lipid content of the raft-grown green mussel, P. viridis during the period of study are shown in Fig. 36. In the early phases of growth, the lipid content observed was high which steadily decreased till the second fortnight of December. The variation in lipid value was in the range of 61.62 to 74.23 mg/g dry wt.. Thereafter, upto June, low value of lipid content was observed. From January to July, the variations in lipid content was not high, but it showed an alternate increase of low magnitude. The lipid content values were in the range of 41.31 and 55.59 mg/g dry wt.. This clearly shows that variation in lipid content during the above mentioned period was not marked. The lower values of lipid content were found to be inversely related to the protein content values. In June, during first fortnight, slightly higher value (62.86 mg/g dry wt.) was observed, which decreased during following fortnight. Thereafter, from July onwards a gradual decrease in lipid content values were observed upto the end of study period. The maximum and the minimum values of the lipid content were observed in October 1987 (74.23 mg/g dry wt) and September 1988 (25.76 mg/g dry wt.) respectively. The difference in minima and maxima during the total period of study being 48.47 mg/g dry wt.. It was also observed that higher values of protein were followed by

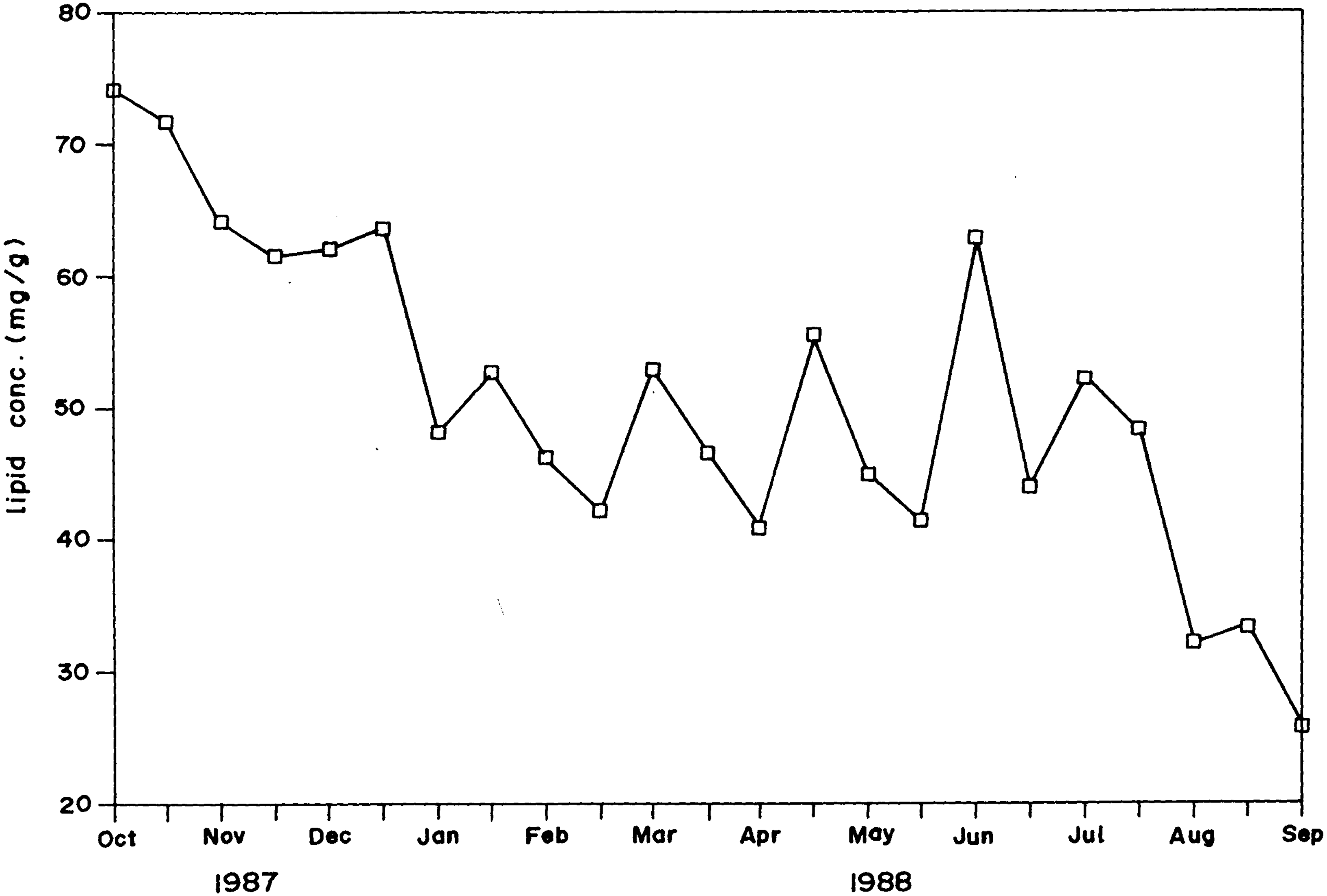

Fig.36. Fortnightly variations in the lipid concentration in the raftgrown *P. viridis* L.

the higher values of lipid in the successive months.

The contribution of lipid content to the total energy varied from 243.432 to 701.475 cal/g.. Percentagewise, contribution from lipid to the total energy potential in terms of calories was from 7.2 to 15.6.

Average lipid content from October to December was 6.63% . Thereafter, during maturation (> 15mm) the lipid content was low as compared to early stages of life (60 to 70 mm size group) with an average value of 4.81% . The lipid content was reported to be comparatively high during pre-spawning period. Soonafter spawning, the lipid content declined and the average value from July to September was 3.83% .

CARBOHYDRATE:

Changes in carbohydrate content in the raft-grown green mussel are depicted in Fig. 37. The carbohydrate content registered its maximum value (198.62 mg/g dry wt.) in the initial stages of culture period. As the growth enhanced, a gradual decrease was observed upto second fortnight of February registering its minimum value of 113.82 mg/g dry wt.. The carbohydrate content increased steeply upto second fortnight of April and remained steady till the first fortnight of May. During second fortnight of May, a slightly low value followed by a decreasing trend was observed upto second fortnight of June. In July, although low, but a slight increase in carbohydrate level was observed which remained constant till the termination of the experiment. At the time of low carbohydrate

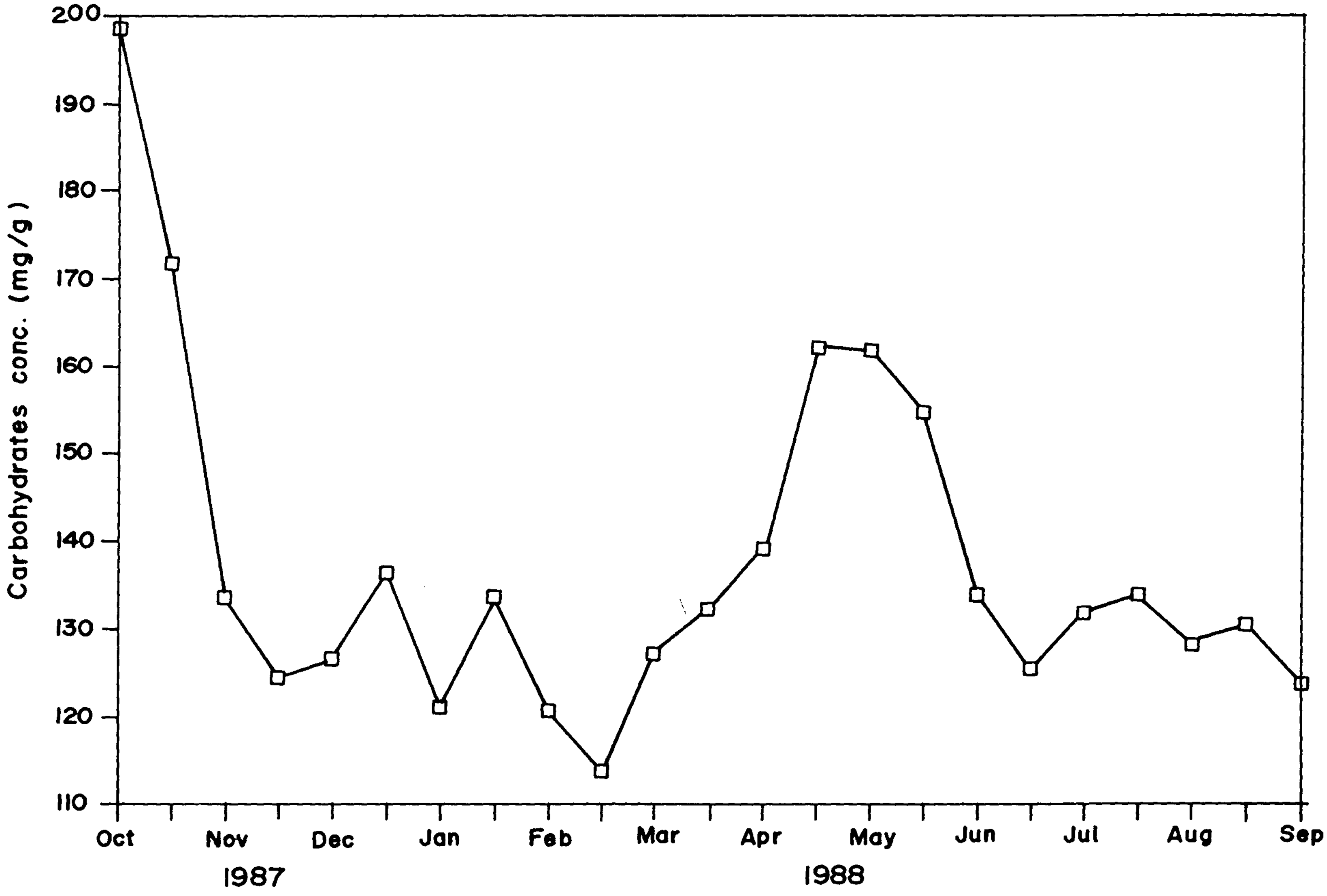

Fig.37. Fortnightly variations in carbohydrate content in the raft-grown P. viridis L.

concentration, the values ranged from 123.89 to 133.86 mg/g dry wt. with little variations. Overall analysis indicate that there is no marked variation in carbohydrate content in green mussel during the complete period of study except a slightly higher value in May. During monsoon season, the lower values of carbohydrates coincided with low values of protein content. It was observed that when the protein content was high the corresponding carbohydrate content was generally low, but, just prior to the monsoon period slightly higher values of carbohydrate were recorded. To the total energy potential, the contribution from carbohydrate was upto the tune of 446.662 to 814.322 cal/g during the months of February and October respectively. The percentage contribution from this biochemical constituent was from 9.9 to 18.2 to the total energy production in the raft-grown green mussels.

During pre-monsoon period, just prior to peak spawning period, high carbohydrate content (161.8 mg/g dry wt.) was observed which coincided with higher protein content. However, during spawning period, the carbohydrate content values were low. In general, carbohydrate values observed were higher in immature mussels which declined in mature mussels.

ASH:

Trends in ash content variations during the period of study in these raft-grown green mussels are depicted in Fig. 38. The ash content varied from 51.86 to 218.37 mg/g dry wt.. During the early stages of growth, the ash content showed higher values

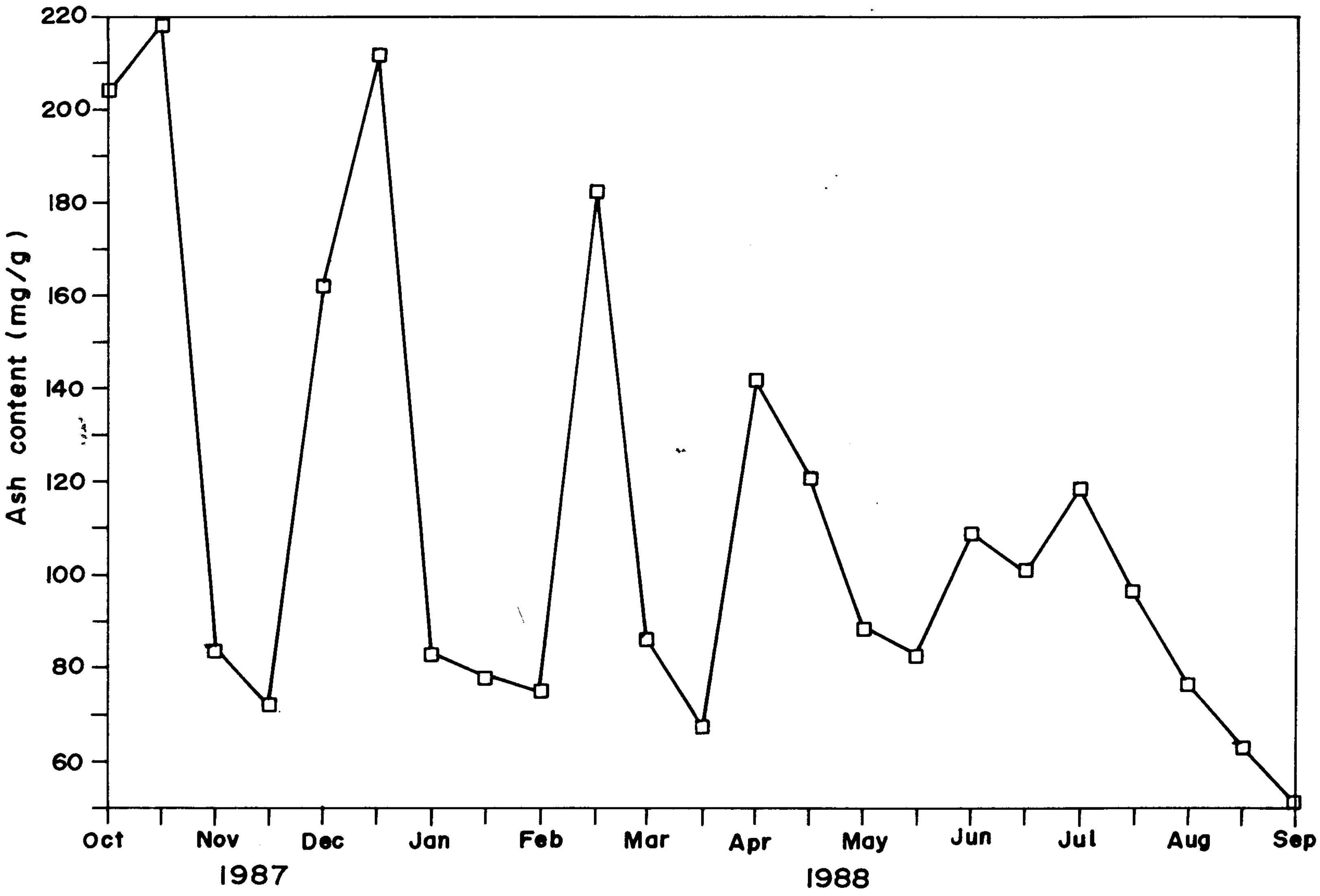

Fig.38. Fortnightly variations in the ash content in the raft-grown P. viridis L.

(218.32 mg/g dry wt.), which declined sharply registering a value of 83.94 mg/g dry wt. in November. In the succeeding months, an increase was observed in December followed by a decrease till first fortnight of February. A high value (182.39 mg/g dry wt.) was observed in second fortnight of February. In April, a sudden rise was noticed which declined in May. Since May, the ash content values in general were low which showed gradual increase till July followed by decreasing trend upto the end of study period. During July-September period, the values varied from 51.86 to 118.52 mg/g dry wt.. Lower values of ash content during this time were found to coincide with low values of lipids and proteins, whereas higher values of ash content coincided with higher values of carbohydrates during the early stages of growth.

ORGANIC CARBON:

The changes in organic carbon content in the raft-grown green mussel during the period of study are shown in Fig. 39. The peak value of 369.7 mg/g was observed in August and the minimum value of 182.4 mg/g dry wt. in March. The annual magnitude of variation was 187.3 mg/g dry wt.. The organic carbon content in the raft-grown green mussel was low in the early stages of growth which increased gradually till second fortnight of December. Thereafter, upto second fortnight of February the organic carbon content was stable in the range of 246.5 - 297.2 mg/g dry wt., which declined in the first fortnight of March registering lowest value (182.4 mg/g dry wt.). In May, the organic carbon value increased and remained stable upto July,

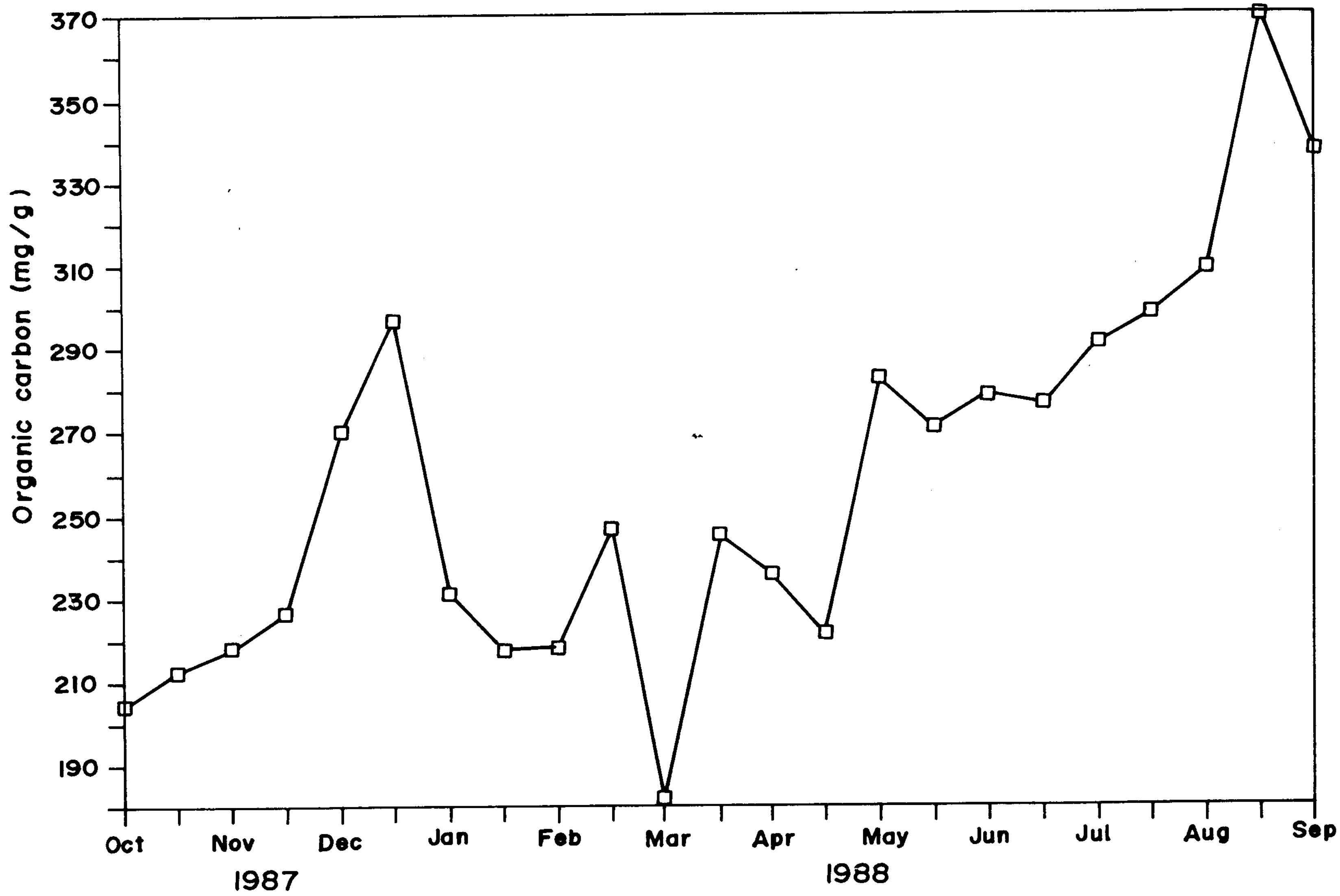

Fig. 39. Fortnightly variations in the organic carbon in the raft-grown P. viridis L.

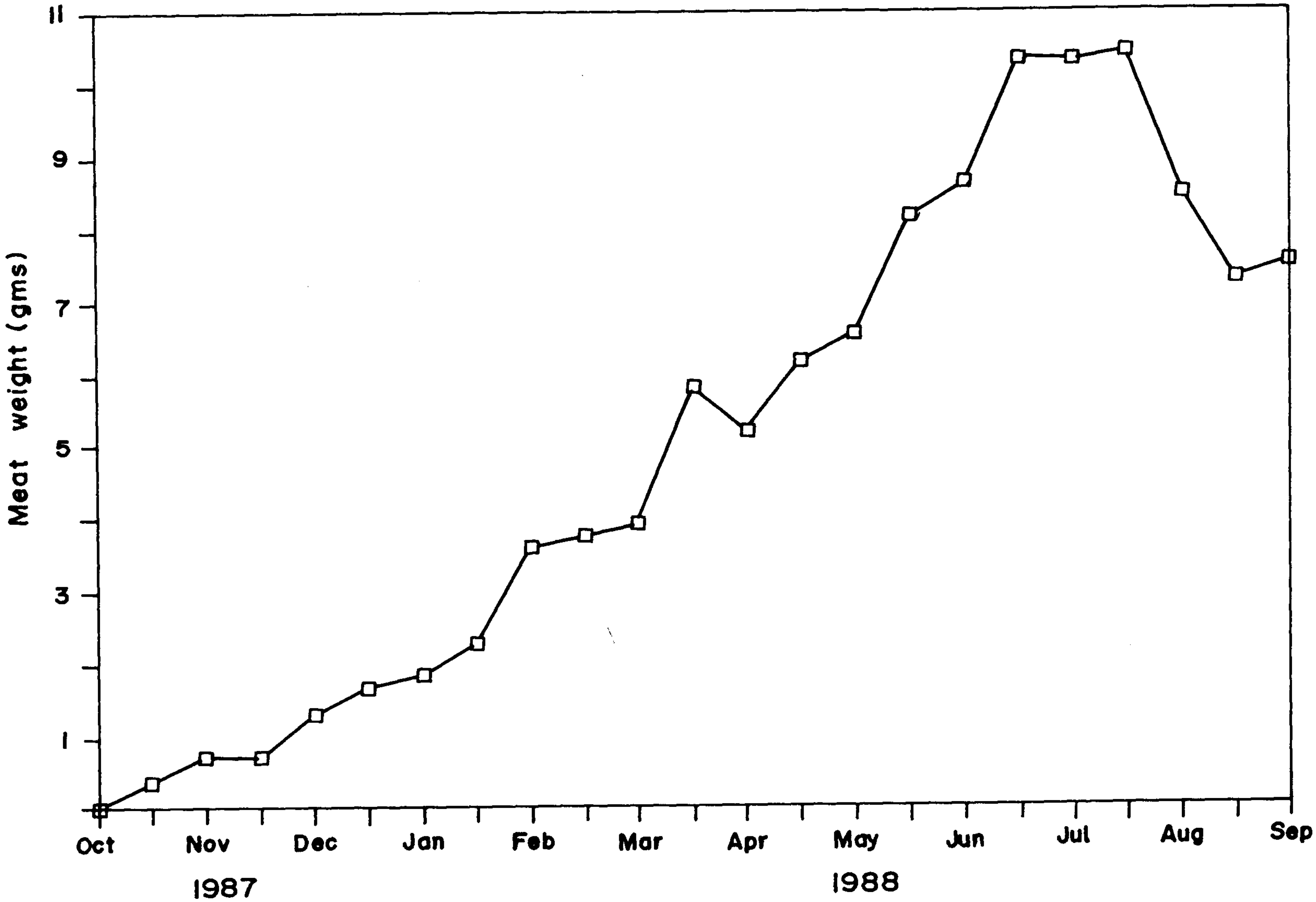

Fig. 19. Growth in meat weight of the raft-grown *Perna viridis* L.

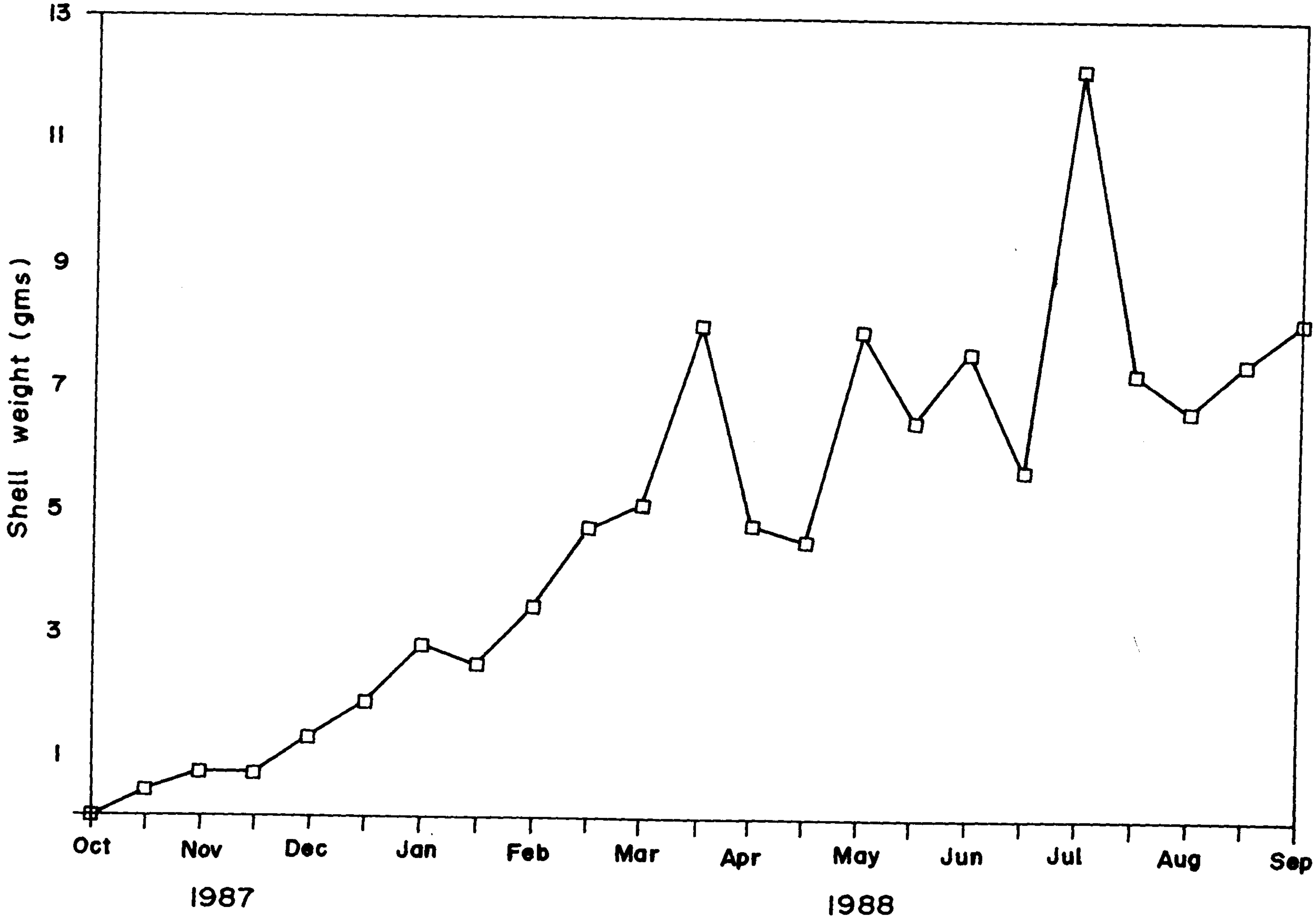

Fig. 20. Growth in shell weight of the raft-grown Perna viridis L.

followed by an increasing trend upto August, thereafter followed by decreasing trend till September. Higher values were inversely related to protein, lipid, carbohydrate and ash content.

CALORIFIC POTENTIAL:

Variations in total calorific values are shown in Fig. 40. From the energy contribution made by major biochemical components, it is evident that in early stages of growth, the energy reserves were generally high. Since the beginning of study period to January, no marked changes in calorific potential were observed. The calorific value during this period was in the range of 4.397 -4.602 Kcal/g.. From January onwards the pattern of variation displayed an increasing trend upto March, and then showed low value in the first fortnight of April. During the period from February to May, the calorific values were high and varied from 4.661 to 4.986 Kcal/g.. Thereafter, the energy content underwent a steady decline, registering lowest value in September (3.336 kcal/g) with an exception in second fortnight of July, when a slightly high value was observed. The maximum energy content during the study period was recorded (4.986 kcal/g) in the second fortnight of April. The maximum values of total energy were found to coincide with higher values of protein, indicating significant contribution made by protein to the total energy content.

To know, whether there exists any relationship among the above biochemical parameters, regression analysis were conducted. The relationship and the levels of significance are given in

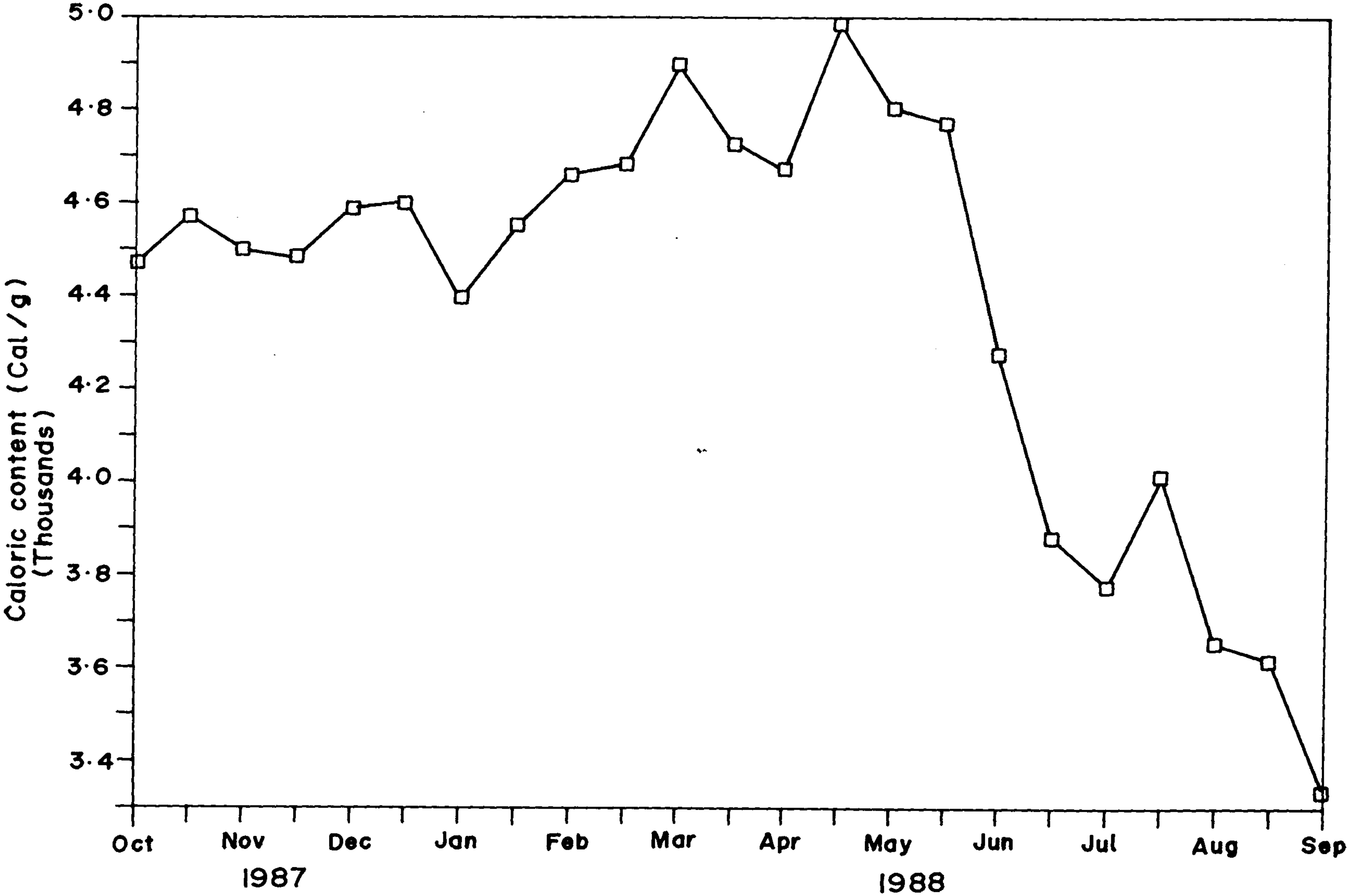

Fig. 40. Fortnightly variations in the caloric content in the raft-grown P. viridis L.

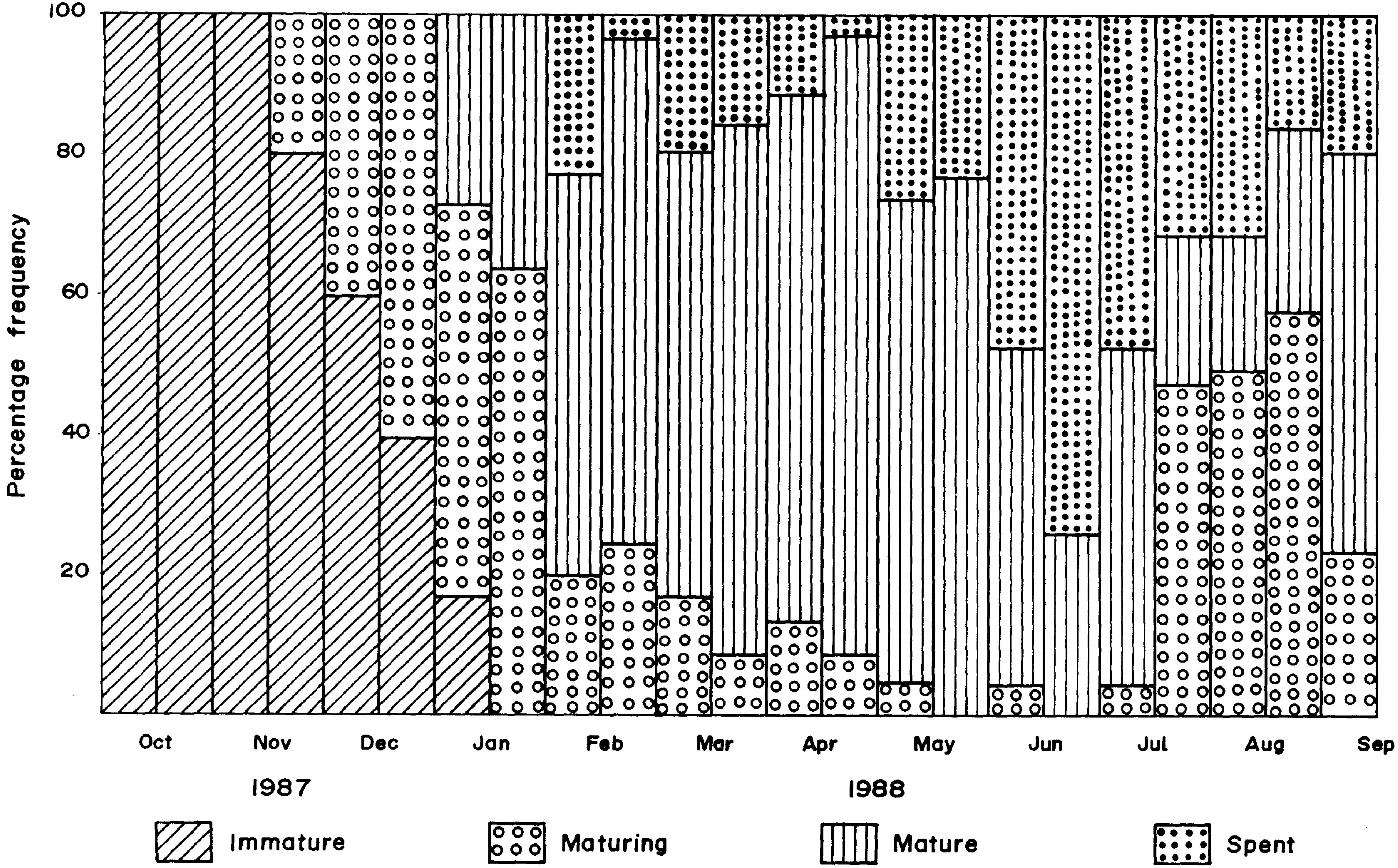

Fig. 41. Reproduction cycle in raft-grown green mussel *Perna viridis* L.

Table 9. From the statistical analysis made, it appears that water content and protein are inversely related with high degree of significance. The contribution of protein to total caloric potential showed a positive correlation with high degree of significance ($r = 0.924$; $p<0.001$). Carbohydrate content showed a significant positive relationship with lipid, whereas the water content and lipid concentration showed a negative relationship, although not significant. The relationship between organic carbon and carbohydrates displayed negative correlation and was significant at 90% level. The share of carbohydrate content for the total energy contribution was significant as seen from correlation coefficient value. However, contribution by lipids to the total energy content was not appreciable as revealed by low value of correlation coefficient. Organic carbon and water content displayed an inverse and significant relation with total energy content at varying level of significance.

DISCUSSION

Studies on variation in biochemical composition in <u>Mytilus sp</u>. have been conducted earlier in the temperate waters (Alvarez, 1968; Giese, 1969; Williams, 1969b; Gilles, 1972a; Dare, 1973a; Gabbot and Bayne, 1973). These studies show that the changes in body weight are mainly due to changes in carbohydrate content. The seasonal cycle for storage and utilization of glycogen reserves reflect the complex interaction between food supply and temperature; and between the growth and the annual reproductive cycle (Gabbot, 1976). Available literature on the biochemical composition of green mussel from tropical waters (Suryanarayanan

Table 9. Regression coefficients of various biochemical parameters showing the relationship alongwith correlation coefficient value (r) and level of significance.

Sr.No.	Relationship	a ± SE	b ± SE	r
1.	Lipid/protein	13.869 ± 1.3	-0.002 ± 0.125	-0.006 NS
2.	Carbohydrate/ protein	3.621 ± 0.83	0.024 ± 0.08	0.136 NS
3.	Organic carbon/ protein	42.455 ± 3.434	-0.294 ± 0.331	-0.375 NS
4.	Water/protein	117.82 ± 3.94	-0.71 ± 0.38	-0.646***
5.	Energy content/ protein	0.89 ± 0.115	0.059 ± 0.011	0.924***
6.	Carbohydrate/lipid	0.65 ± 1.06	0.32 ± 0.254	0.496**
7.	Organic carbon/lipid	32.03 ± 5.32	-0.51 ± 1.27	-0.18 NS
8.	Water/lipid	83.19 ± 7.47	-0.536 ± 1.788	-0.135 NS
9.	Energy content/lipid	3.46 ± 0.42	0.068 ± 1.01	0.292 NS
10.	Organic carbon/ carbohydrate	34.59 ± 4.65	-1.906 ± 1.82	-0.43*
11.	Water/carbohydrate	87.196 ± 6.7	-2.255 ± 2.611	-0.365 NS
12.	Energy content/ Carbohydrate	3.53 ± 0.37	0.17 ± 1.44	0.473*
13.	Water/organic carbon	64.97 ± 4.5	0.434 ± 0.602	0.311 NS
14.	Energy content/ organic carbon	5.368 ± 0.239	0.039 ± 0.032	-0.484**
15.	Energy content/ water	7.48 ± 0.22	-0.041 ± 0.019	-0.700***

n = 23

NS - not significant

* - significant at 10%

** - significant at 5%

*** - significant at 1%

and Alexander, 1972; Nagabhushanam and Mane, 1975; Wafar et al., 1976; Qasim, et al., 1977; Nagabhushanam and Mane, 1978; Shafee, 1978; Parulekar et al., 1982; Mohan and Kalyani, 1989) suggest that information on biochemical composition is essential as it reflects directly on the nutritive value, thereby enabling to establish an ideal time of harvest. Further, it reveals that the changes in biochemical constituents depend on the phases of reproductive cycle.

Nagabhushanam and Mane (1978) discussed seasonal variations in the biochemical composition of Mytilus viridis L. from Ratnagiri, west coast of India, whereas, from Ennore estuary, Madras along the east coast of India, variations in biochemical composition of the green mussel Perna viridis L. have been studied by Shafee (1978). In coastal waters of Goa, the growth of raft-grown green mussel Perna viridis L. was very rapid (Parulekar et al., 1982) due to the abundance of food material and ideal environmental conditions and the mussels adapt biochemically to wide ranging external conditions and also respond appropriately to rapid and irregular variations in these conditions.

Many bivalves are known to increase or decrease the level of tissue water content with respect to change in salinity of the surrounding medium. Galtsoff (1964) reported that during low saline conditions, the water level in oysters rose to 92.5% . In the present study, a noticeable increase in water content during monsoon season i.e. at the time of fall in salinity was observed.

In monsoon, the water content in the raft-grown mussels was upto 90% . Nagabhushanam and Mane (1978) reported the highest percentage of water content (81.17%) during monsoon and the lowest (79.35%) in summer. These authors in their earlier study also found high level of water content in monsoon and low level during the summer months. Present observations corroborate the same. The possible cause of higher percentage of the water content in monsoon may be, that the mussels might have gained water and lost salts as stated earlier by Galtsoff (1964). Parulekar et al. (1982) also observed similar type of relationship between salinity and water content in the raft-grown green mussel and stated that these mussels develop an iso-osmotic internal medium to compensate for considerable lowering of salinity during monsoon season. Furthermore, it was reported that this compensation is achieved by dilution of body fluids, resulting in higher water content in tissues. Minimum water content was observed in March (summer). Such low values of water content in summer were earlier observed by Deshmukh (1972) and Parulekar et al. (1982). Parulekar et al. (1982) stated that these mussels develop an appropriate compensatory mechanism to counteract the increasing salt content in the environment during summer season.

The protein values in the present study indicate that from March to May, the values were higher as compared to other period which coincided with increased food availability and just prior to active spawning period. Such higher concentration of protein during pre-spawning period was earlier observed by Wafar et al.

(1976) and Nagabhushanam and Mane (1978). The increased protein content during pre-spawning season could be a mechanism of storage of reserves to meet spawning requirements. The protein content immediately after peak spawning period was observed to be low in the present study. Galtsoff (1964), Quayle (1969), Nagabhushanam and Mane (1975; 1978) and Wafar et al. (1976) reported decrease in protein content during post-spawning period. Gabbot and Bayne (1973) reported a decrease in total energy during spawning and found that protein accounted for about 75% of the loss and also noticed that fall in protein content of the body tissue was accompanied by an increase in the rate of ammonia-N excretion. This implies that much of the energy spent during active spawning period in the present case was mainly contributed by protein. Further the *Mytilus edulis* can utilise protein as an energy source during winter, when glycogen, the normal reserve, is at minimum level.

The influence of reproductive cycle on biochemical composition depends on timing of gonad proliferation and gametogenesis (Lubet, 1959; De Zwann and Zandee, 1972; Gabbot, 1976). The gonad development in *Perna viridis* causes a reciprocal decline in stored reserves in body tissue and protein from adductor muscle (Comely, 1974). Taylor and Venn (1979) stated that the gametogenesis is supported by reserves of glycogen and protein in temperate waters. However, the extent to which the energy demands are met from stored reserves depend on the level of feeding and energy conversion efficiency.

As the mussel increased in length, during the initial period of growth the protein content was noticed to be increasing at uniform rate. This increase in protein content could mainly be due to increased feeding efficiency associated with food availability. The proper assimilation of ingested food could have resulted in increase in protein content during this time. The increased protein content may also be attributed to better metabolic conditions which prevailed in a subtidal ecosystem (Qasim et al., 1977), thereby increasing assimilation efficiency, directly influencing protein content. Thus it indicates that protein as a source of energy reserves in bivalve, play an important role as compared to glycogen and other intermediary carbohydrate metabolism.

The lipid content, in the raft-grown green mussels, was found to be in the range of 61.62 - 74.23 mg/g dry wt. till December. The high values of lipid content in the initial stages of growth were mainly attributed to increased feeding efficiency. Venkataraman and Chari (1951) correlated high lipid level with intensive feeding and storage of fat before spawning. Earlier workers (Lubet and Longcamp, 1969; Williams, 1969; Telembici and Dimoftach, 1972; Pieters et al, 1979) noticed a peak value in winter and low value in summer. However, in contrast, a reverse pattern reporting higher value of lipid in summer and lower value in winter, is also on record (Renzomi, 1963; Fraga, 1958; Gabbot and Bayne, 1973; Dare and Edwards, 1975).

During January to May, the lipid content values were lower as compared to those in the early stages of life. During this time, the lipid content was somewhat stable with slight variations alternatively. The lipid content during this period was in the range of 41.31 and 52.78 mg/g dry wt.. The low values of lipid were mainly due to utilization of accumulated lipid for building up of tissue material. The low lipid content values were accompanied by faster growth rate of the mussels. Low lipid content values were correlated with faster growth rate in oysters earlier by Venkataraman and Chari (1951). The probable cause for low fat content could also be due to initiation of gametogenesis and utilization of energy reserves for development of gametes. Similar observations were earlier made by Qasim et al. (1977) and Zandee et al. (1980).

In the present study, the lower values of fat content could be correlated to low content of chlorophyll a and phytoplankton biomass at the site of raft culture. Widdows and Bayne (1971), Bayne (1973) and Lucas et al. (1978) stated that presence of large amount of phytoplankton allows the accumulation of lipid and carbohydrate reserves.

During the remaining part of the study i.e. from June till termination of the experiment in September, the lipid content declined. This decline in lipid content was observed to coincide with monsoon season. At this time, the water content in these mussels was observed to be high thus indicating an inverse relationship between lipid and water content. This period of low lipid content coincided with post-spawning season in these mussels. Such a fall in lipid content during post-spawning period has also been reported earlier (Qasim _et al_., 1977; Shafee, 1978; Parulekar _et al_., 1982). Low values of lipid content during post-spawning could be attributed to exhausting of energy resources for spawning activities (Qasim _et al_., 1977). The reduction in fat content during monsoon period could also be due to low water temperature and other unfavourable biotic conditions prevailing at that time. The effect of temperature and nutritive stress can be interpreted as a compensatory change in the seasonal steady state values for metabolic rate resulting in a decline from routine to standard metabolism (Bayne, 1973).

Carbohydrate content in raft-grown green mussel _Perna viridis_ L. showed cyclic variations. In the initial stages of growth, carbohydrate content was found to be very high (198.62 mg/g dry wt.). High carbohydrate content in immature mussels, have earlier been observed by Nagabhushnam and Mane (1975). Lec and Pepper (1956) also reported increased carbohydrate content in immature animals and a drop in gravid animals. Parulekar _et al_. (1982) reported low values of carbohydrate content in small sized mussels. In the present study carbohydrate values remained low during winter period i.e. from December to February. Such low values of carbohydrate during winter season were also reported by Baird (1958; 1966), Gabbot and Bayne (1973), Shafee (1981); Galassi _et al_. (1982) and Parulekar _et al_. (1982). In general the carbohydrate values were stable throughout the period of study, suggesting that during spawning season, energy requirements are met by protein and lipid to a greater extent as compared to carbohydrate contents. Earlier studies (Wafar _et_ al., 1976; Qasim et al., 1977; Shafee, 1981) also demonstrated that during pre-spawning and post-spawning season, protein and lipid increases and decreases respectively thus indicating that these biochemical constituents play a dominant role in gametogenesis.

No conspicuous decrease was observed in carbohydrate content during the period from December to February. The chlorophyll a and phytoplankton biomass at this time was observed to be high. This indicates that no decrease in carbohydrate could result as its metabolic energy demands were met by phytoplanktonic biomass (Brunetti et al., 1983). The carbohydrate content showed gradual increase from March to May registering its second maxima in May, prior to peak spawning season. The increase in carbohydrate content prior to spawning period was earlier observed by Parulekar et al. (1982). However, Nagabhushnam and Mane (1978) reported a fall in carbohydrate content during pre-spawning period. Taylor and Venn (1979) stated that, in green scallop, Chlamys opercularis, gametogenesis is supported by reserves of glycogen and proteins. During remaining period of study i.e. from June to September (monsoon season) the carbohydrate content declined and remained steady (125.54 - 133.86 mg/g dry wt.). Such a decline in carbohydrate content during monsoon months was earlier reported by Mohan and Kalyani (1989) and during post-spawning period low values were reported by Galassi et al. (1982). The decrease in carbohydrate content during monsoon season could be due to low temperature and unfavourable conditions causing stress to raft-grown mussels. Gabbot and

Bayne (1973) reported that, stress in these animals results in utilization of carbohydrate reserves and a decline in the rate of excretion of ammonia-N. Carbohydrate serves as an index of high glycogen metabolism during the period of high environmental stress in monsoon season (Parulekar et al., 1982).

The changes in ash content in the raft-grown green mussels did not show any definite pattern. The ash content was generally high (204.34 mg/g dry wt.) in small sized mussels, inspite of large fluctuations. In large sized mussels, ash content was low (51.86 mg/g dry wt.). Dare and Edwards (1975) measured ash contents in Mytilus edulis and reported to be between 9 and 15%. Paoli and Heral (1988) reported the ash content to vary from 4.4 to 41.2% in the oyster, Crassostrea gigas. Organic carbon content in the present study varied from 182.4 to 369.7 mg/g dry wt.. The higher values of organic carbon were observed during monsoon season, which were found to be inversely related to major biochemical constituents like protein, carbohydrate and lipid. The higher values of organic carbon during monsoon season in the raft-grown green mussel were also earlier reported by Parulekar et al. (1982).

The energy content in the raft-grown green mussels during the beginning of growth stages was high (4.39 - 4.98 Kcal/g) upto May. Higher energy content in mussels was mainly due to higher content of proteins and lipids which directly influenced the total energy content. Shafee (1978) reported energy content in mussels to vary from 5.25 to 5.42 Kcal/g on ash free dry wt. basis, which was higher as compared to energy values observed in the present study. Since May, till the end of the period of study i.e. September, a decreasing trend in energy content was noticed, which was mainly due to low values of major biochemical constituents. It was also noticed that soon after spawning, the energy content were in low range (3.33 - 4.01 Kcal/g). Shafee (1981) reported that energy reserves do not appear to play a significant role in subsequent maturation of gonads.

Present study indicates that major biochemical constituents in raft-grown green mussel, Perna viridis L. are greatly influenced by quality and quantity of food available, exogenous parameters such as temperature which influence metabolic level and reproductive cycle of cultivated mussels. The environmental conditions appear to influence certain biological processes within a population so that the reproductive cycle usually becomes acutely tuned to local seasonal conditions (Walter, 1982). It was also observed that the most appropriate time of harvesting these mussels was at a size group of 65-70 mm, when the major biochemical constituents were at the maximum level, thus yielding higher food value. The present study, has also revealed that, the reproductive cycle to a large extent was associated with the proximate biochemical composition and thus affected the seasonal cycle.

CHAPTER VII

MAJOR ELEMENTS AND TRACE METALS

Introduction

Among molluscs, bivalves are known to be potential test organisms for studying metal pollution (Phillips, 1977; 1980). The mussels have been used internationally as sentinel organisms for monitoring the metal pollution (Goldberg et al.,1978). The concentration of most of the trace metals in the marine environment is at reduced level and poses great difficulty in their measurements. Considering the bioaccumulative properties, the bivalves become more important as indicator organisms in pollution monitoring programme (Phillips, 1976; Goldberg et al., 1978; Talbot, 1987).

Earlier literature (Segar et al., 1971; Graham, 1972; Leatherland and Burton, 1974; Zingde et al., 1976; D'Silva and Qasim, 1979; Gordon et al., 1980; Popham et al., 1980; Wotton and Lye, 1982; Kureishy et al., 1983; Talbot et al., 1985; Talbot, 1985; 1986) provide enough evidence that bivalves can be successfully used in evaluation of water quality and also for rendering the suitability for human consumption. Successful culture of these edible bivalves in an estuarine ecosystem depends on several factors including the water quality, as it plays a key role in the management and protection of marine communities from pollutants. The dynamic process of defining criteria for water quality is never ending, and the estuarine subtidal ecosystems are so complex that man's effort to define it will never attain finite precision. However, in estuaries, the trace metal concentration is the combined impact of anthropogenic and natural inputs, often reduced by scavanger processes and dilution.

Mussels, because of their cosmopolitan distribution, and sedentary habit have been extensively used in toxicology (Coleman, 1980). However, natural population of mussels often exhibit considerable variability in the levels of trace metals, which furthermore complicates an attempt to detect changes resulting from anthropogenic activity (Phillips, 1977a; Westerhagen, et al., 1978; Gordon et al., 1980).

Due to their high food value, these mussels are in great demand in internal as well as external markets. Secondly, the site of raft culture happens to be near the harbour, a place for loading of mining ore throughout the year. The present study was mainly undertaken (October 1987 - September 1988) to determine the concentration and rate of accumulation of trace metals and major elements in the mussel tissue under continuous submergence within an estuarine ecosystem. Based on the results, the seasonal variation in the accumulation of major elements (Ca & Mg) and trace metals (Fe, Cu, Zn and Mn) in raft-grown green mussels has been discussed. Water quality was also assessed by estimating the above mentioned metals to predict the possible relationship between the trace metals in the surrounding water and mussel tissue. An attempt has also been made to define the rate of uptake of these metals by the mussels with enhancement of growth.

RESULTS

WATER:

CALCIUM (Ca): Changes in Ca concentration in the water column at the site of raft culture are shown in Fig. 42. The Ca content in the water column was observed to be homogenous at all the three depths during the major period of study. From the beginning of the study period, a steep rise of Ca level was recorded till first half of November, thereafter it remained high and stable registering its maximum value (424 ppm) in May. During monsoon season (June-September), the Ca concentration was observed to follow a declining trend with minimum value (226 ppm) during first half of July. Towards the termination of the experiment, the calcium content was observed to increase gradually. During the major period of study i.e. upto May, the Ca values at various levels in the water column did not show much variations (365-424 ppm), whereas in monsoon months, changes were relatively larger (226-399 ppm) (Fig. 42). A notable feature observed was that near bottom waters registered higher Ca values when compared with surface and mid-depth levels. In the present study, Ca content values ranged from 226-424 ppm for the entire period of investigation.

MAGNESIUM (Mg): The variations in Mg concentration in seawater at the site of raft culture are depicted in Fig. 43. The maximum (1329 ppm) and minimum (708 ppm) values of Mg were observed in the first half of June and the second half of July (708 ppm), respectively. The Mg content from November to May was observed to be of higher magnitude. During this time, the Mg

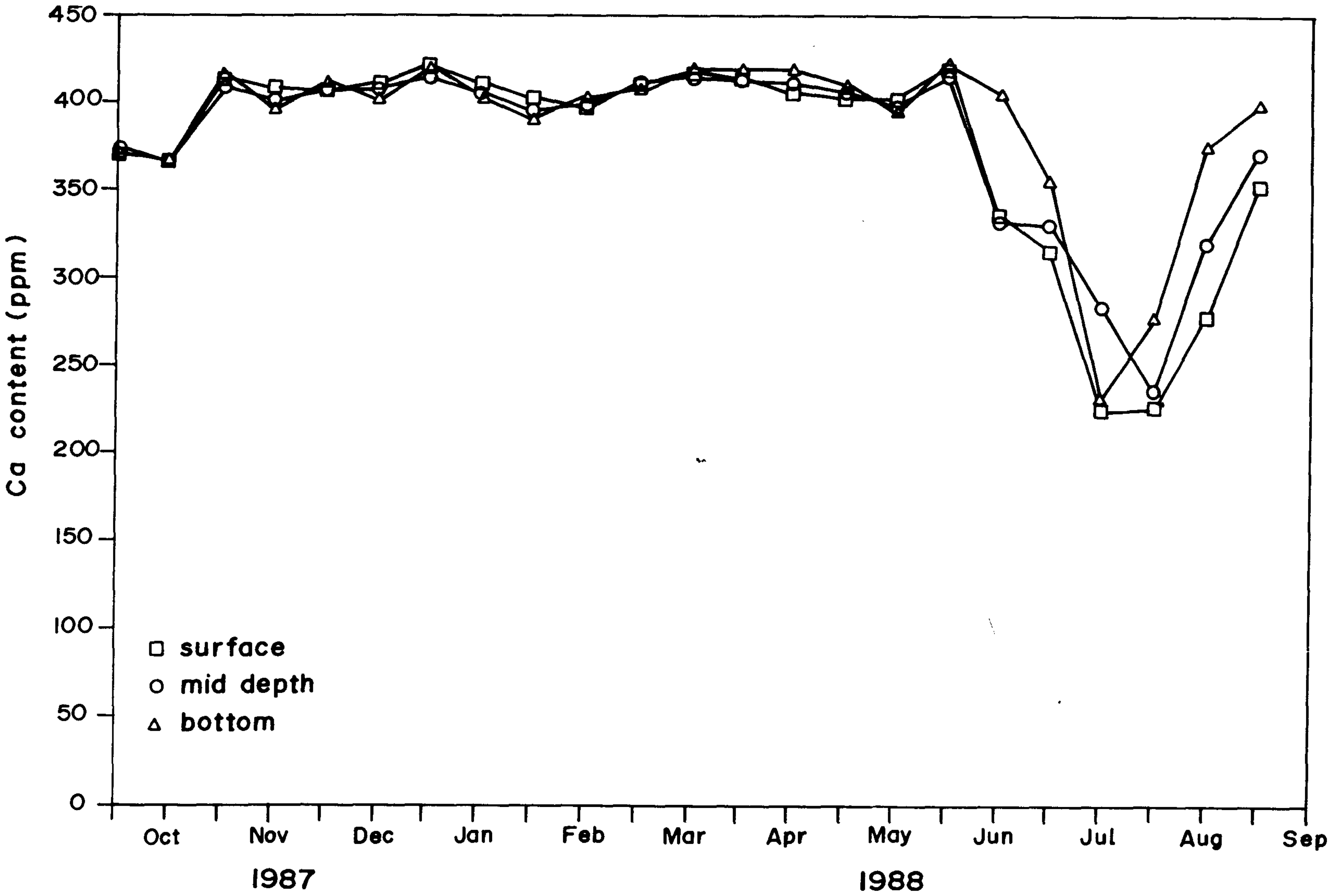

Fig. 42. Fortnightly changes in Ca content in the water column at the site of culture

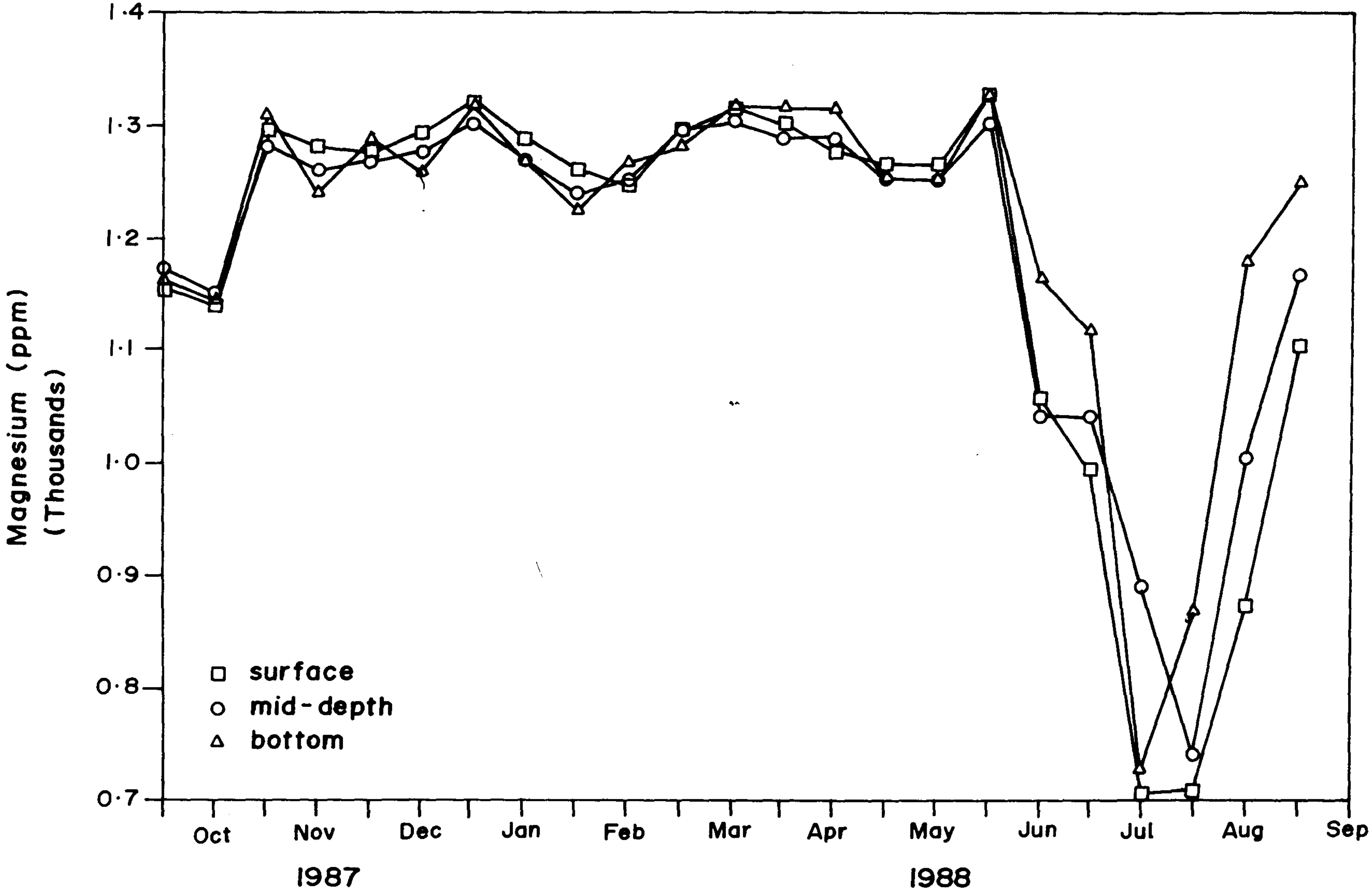

Fig.43. Fortnightly variations in Mg content in the water column at the site of raft culture

concentration at various levels in the water column did not show significant variations and was in the range of 1225 and 1329 ppm. During monsoon, the Mg concentration decreased sharply registering the minimum value in July, which more or less remained the same till August, and then onwards, an increasing trend till the end of the study period, was observed. In monsoon, the near bottom waters registered higher values of Mg as compared to surface and mid-depth waters. From Figs. 42 and 43, it was inferred that the variations in calcium and magnesium content coincided with variation in salinity.

IRON (Fe): The variation pattern in Fe concentration at the site of raft culture is shown in Fig. 44. The Fe content with its low values in the beginning of study period, i.e. October 1987, displayed a sharp increase in nearbottom waters in November. However other two levels (surface and mid-depth) in the water column did not show much variations. From December onwards a sudden increase in Fe content was observed registering its peak value in first half of February, when the mid-depth waters reported maximum value (0.84 ppm) followed by nearbottom (0.40 ppm) and surface waters (0.031 ppm). Since then, the changes in Fe content upto the end of the study period did not show significant variations. During the April -May period, mid-depth waters reported higher Fe content as compared to surface and near bottom waters. In the entire water column the annual range of variation in Fe content was from 0.005 to 0.084 ppm during the entire period of study with its minimum and maximum values in December and February, respectively.

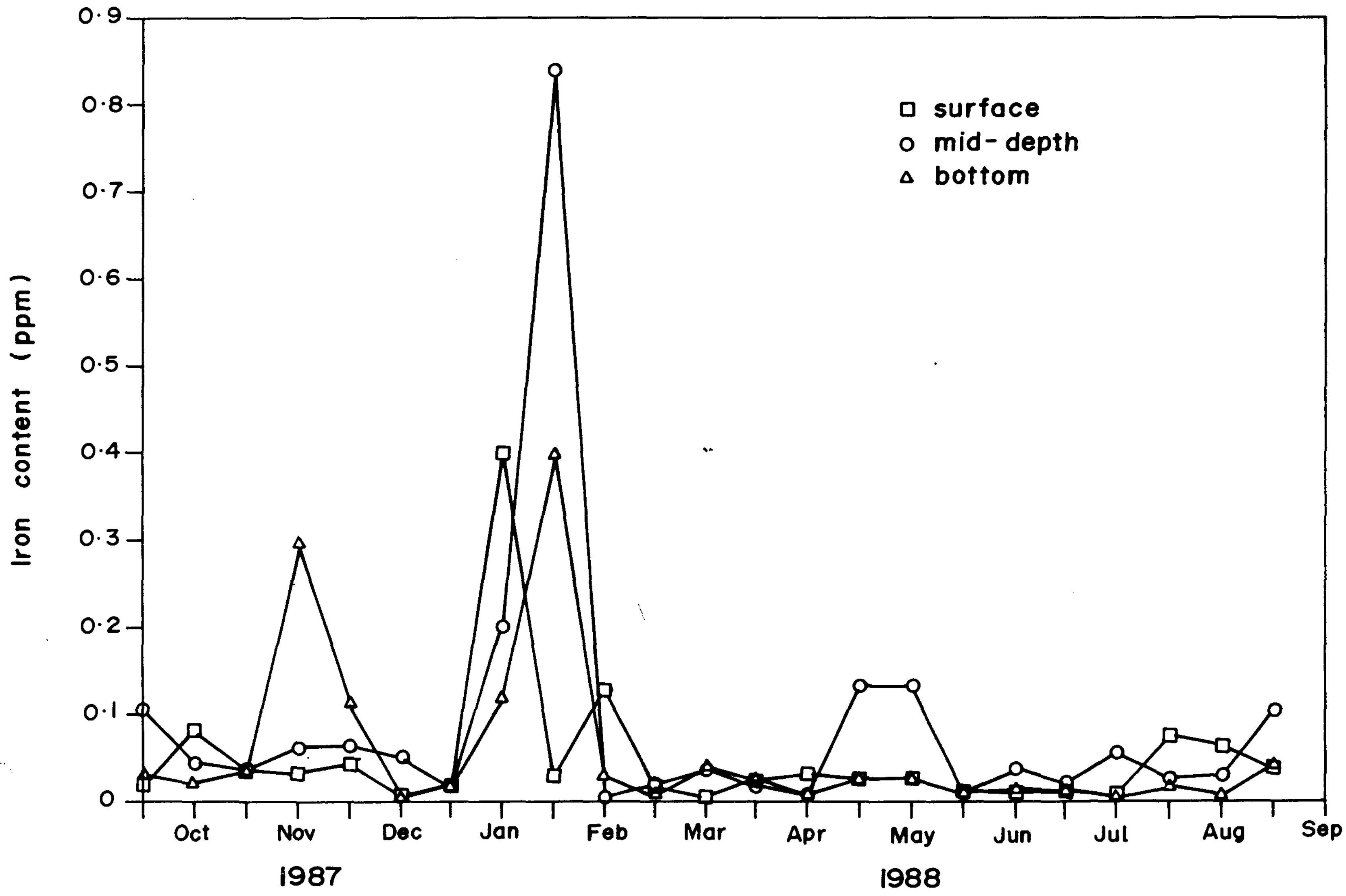

Fig.44. Fortnightly changes in iron content in the water column at the site of raft culture

COPPER (Cu): Changes in Cu values in the water column at the site of raft culture are depicted in Fig. 45. The Cu content for the entire study period ranged from Below Detection Limit (BDL) to 0.042 ppm in November and January respectively for surface water. Mid-depth and near bottom waters recorded comparatively lower values in Cu content. The changes in variations observed in Cu content during the entire study period in the water column were not high except in January (Fig. 45). In the beginning of study period, the Cu content in the water column was observed to be high, decreasing upto first half of November and then reporting slight increase during the second half of November. Thereafter, the Cu content remained stable till the first half of January. During second half of January, a sudden increase in Cu content was reported registering its maximum value at surface (0.042 ppm), mid-depth (.016 ppm) and nearbottom (.021 ppm) waters. Then, a secondary peak in Cu content, for mid-depth waters was registered in March, noticing a steady decline till April. Thereafter, variations in Cu content upto the end of study period were not marked at different levels in the water column at the site of raft culture.

ZINC (Zn): Variations in Zn concentration at the study site are presented in Fig. 46. The Zn level at the culture site observed were in the range of 0.01-0.0375 ppm for the water column, during the first half of October 1987, which slowly decreased upto first half of November. In second half of November a slight increase in Zn content was noticed. The Zn content with its low values in the first half of December steadily increased, attaining its peak

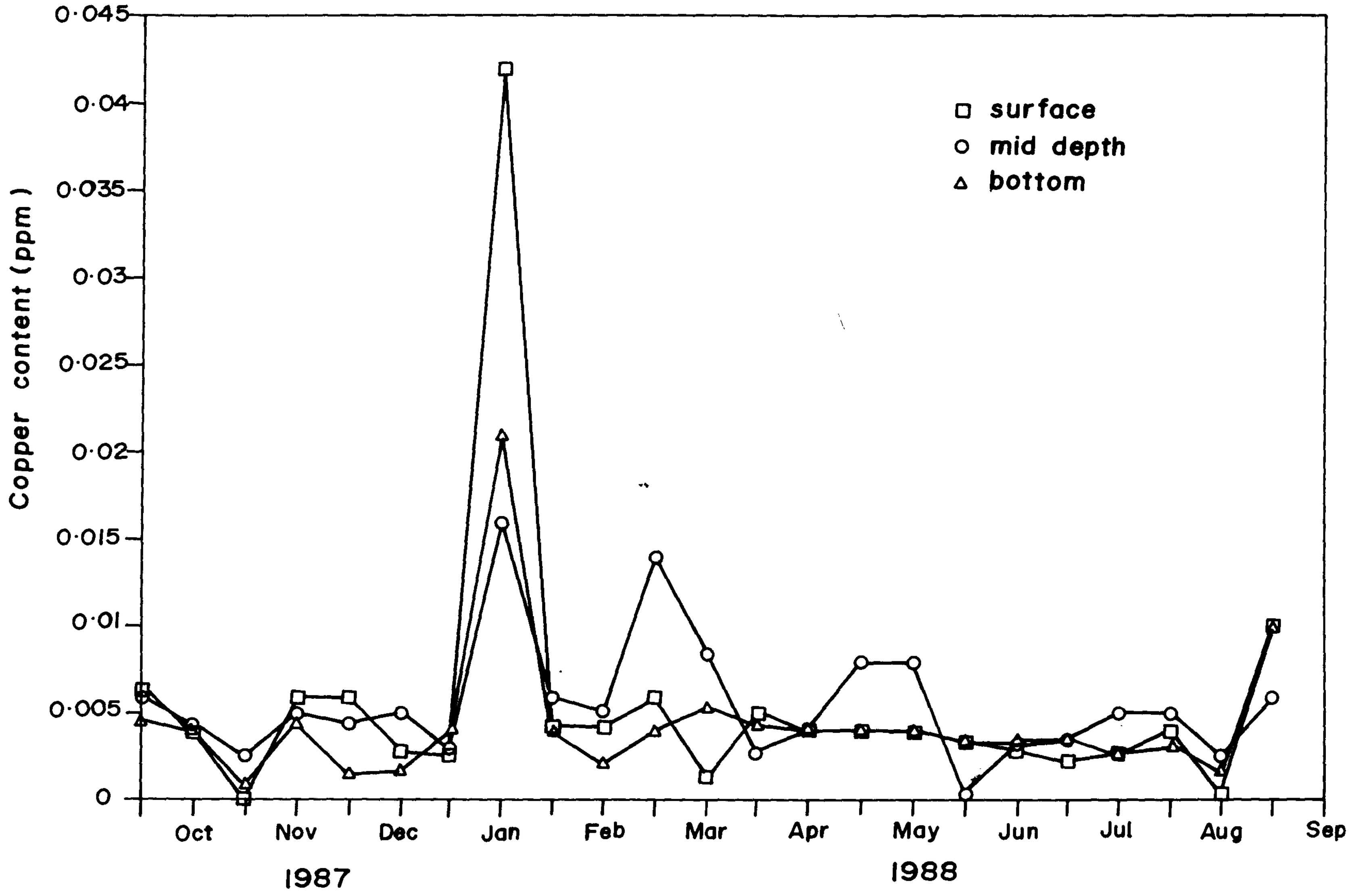

Fig.45. Fortnightly changes in Cu content in the water column at the site of culture

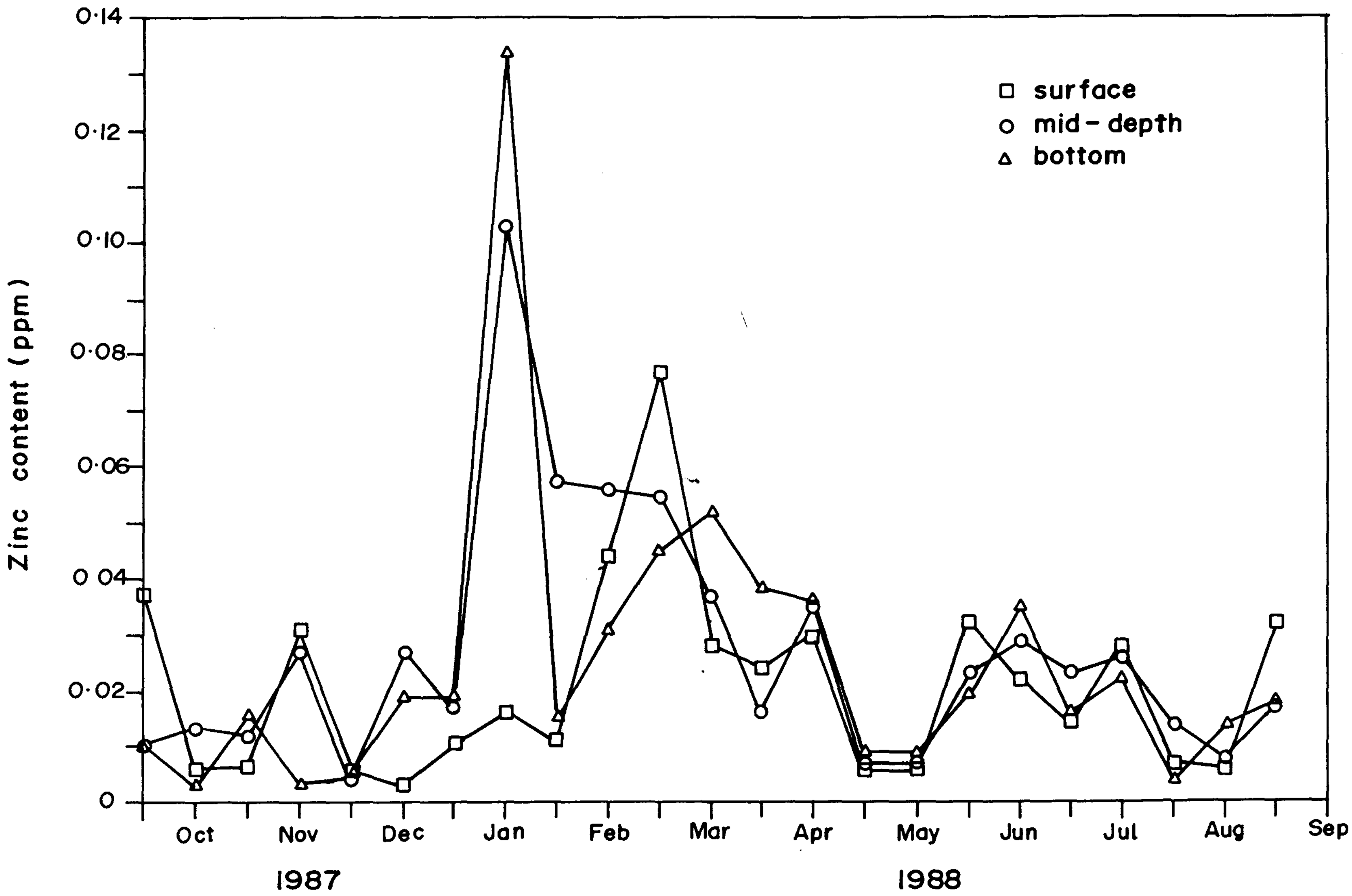

Fig. 46. Fortnightly changes in the Zn content in the water column at the site of raft culture

value (0.134 ppm) for near bottom waters in January. At this time, mid-depth waters also observed high value (0.108 ppm), however, for surface waters the Zn content was low (0.0163 ppm). Thereafter, the Zn values for the water column reported sudden fall in first half of February, and again increased in March. In March, the surface water registered higher value (0.077 ppm) as compared to mid-depth and near bottom waters. Since March a gradual increase in Zn content was observed at all depths, although there were some minor variations. Low values of Zn for all depths were reported in May. The Zn content values increased in June, remained steady till July. Since then, a steady increase in Zn concentration was observed in the water column upto the end of the study period. The Zn values in the water column were in the range 0.004-0.134 ppm, registering its minimum and maximum values in the months of January and August, respectively. Generally Zn concentration during monsoon months was moderately low in the range of 0.0005 to 0.035 ppm.

MANGANESE (Mn): The pattern of variation in Mn concentration in the water column at the site of raft culture is depicted in Fig. 47. The Mn content with its low values in October increased sharply in first half of November for the water column. In mid-depth waters, Mn concentration was generally low for major study period, except in second half of November when high value was observed. Since then a gradual fall in Mn content was observed upto January. The Mn content, henceforth remained steady with minor variations upto May in the range of 0.00052-0.0025 ppm in the water column at different depth levels (Fig. 47). In June, a

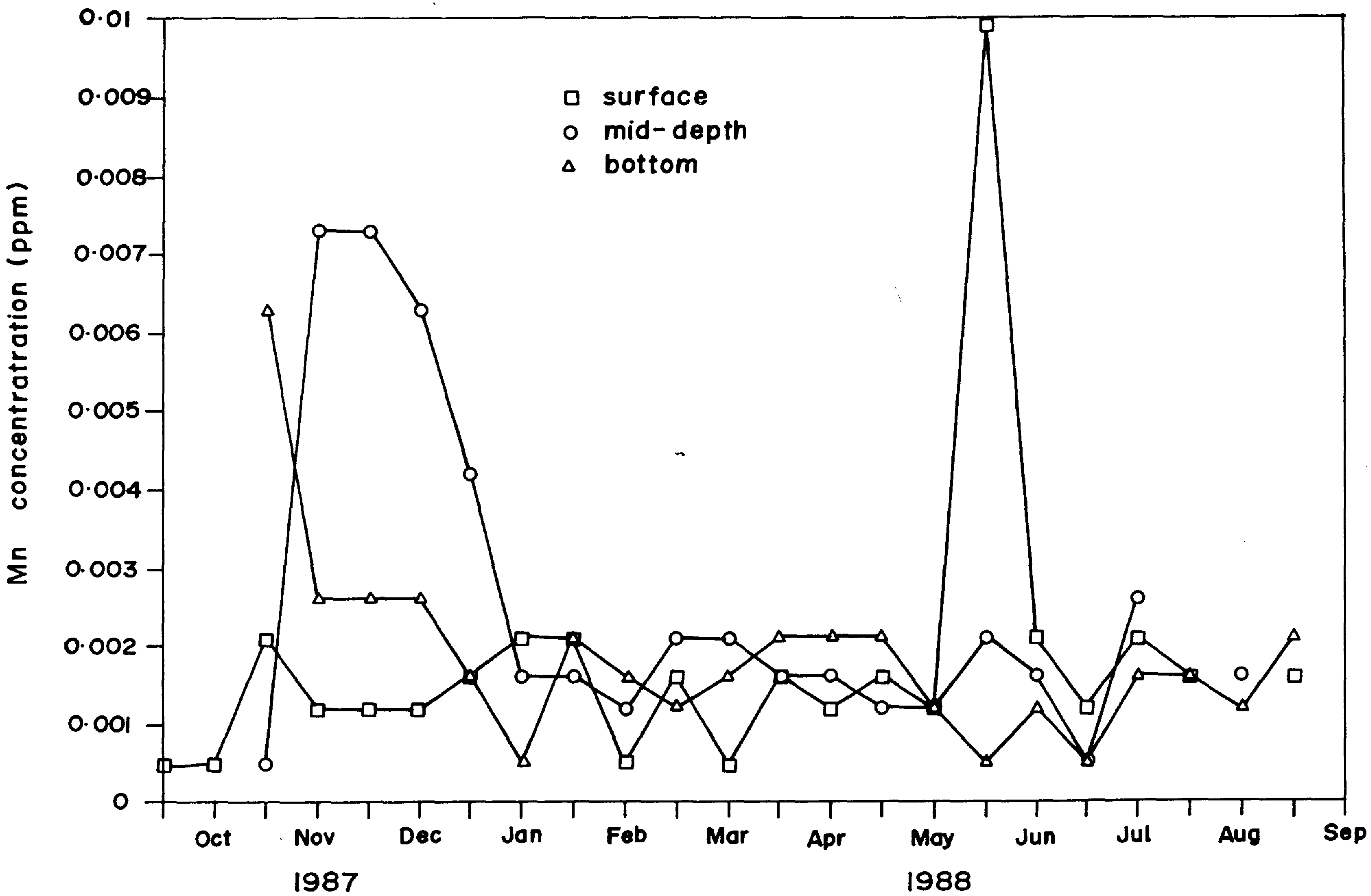

Fig.47. Fortnightly changes in Mn content in the water column at the site of raft culture

sudden rise in Mn content was observed for surface waters. Thereafter, the Mn content values at all depths were in the same range as mentioned above with variations of low magnitude. The maximum value was reported in June (0.0099 ppm) for surface water and the minimum value (BDL) was observed in August, September and October.

MUSSEL TISSUE:

CALCIUM (Ca): The variations in calcium content in the mussel tissue are shown in Fig. 48. Calcium content in mussel tissue was observed to be high in young mussels, which increased and reported peak value in November. Thereafter, the Ca content declined with rapid phase of growth of mussels recording its minimum value in January (1124 ppm). The values increased sharply in the first half of February followed by a steady and proportionate decline with no significant variation till September, when a low value was recorded. In general, it indicates that, decrease in Ca concentration was observed as the size of mussel increased.

MAGNESIUM (Mg): Changes in Mg content in the raft-grown mussel tissue, in general, were high throughout the period of study. The Mg content values were in the range of 984 to 4738 ppm with a minimum and maximum value in January and April, respectively. In young mussels, with higher values of Mg, a steady decrease upto November was observed as the mussels grew. However, in December, high values were observed. Thereafter, the variation in Mg content showed a decreasing trend upto January. During the

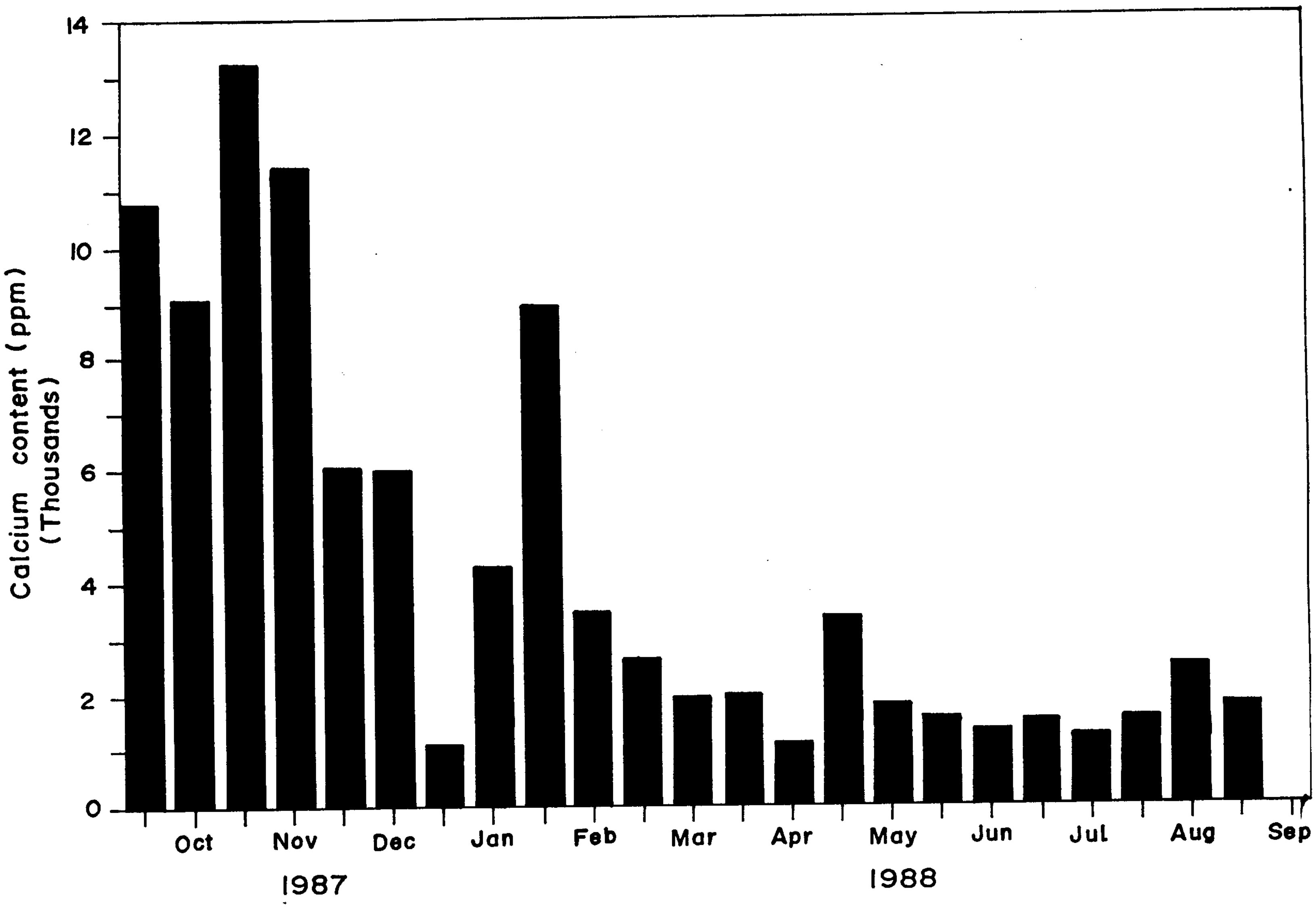

Fig.48. Fortnightly variation in the Ca content in the raft-grown green mussel

period of faster growth rate (February - May) high values of Mg content were in the range of 2825-4738 ppm. Thereafter, upto the end of the study period, the variation in Mg content reported a insignificant gradual increase (Fig. 49). It appears that, as the mussels grew beyond a certain size, not much variation in Mg content was observed.

IRON (Fe): The changes in the Fe content in the raft-grown green mussel during the period of study are depicted in Fig. 50. Fe content with low values in the initial growing period i.e. October, increased steeply recording its maximum value (8621 ppm) in November. Then, a sudden fall in the Fe content was observed in December, which did not vary much upto January. At this time the range of variation in Fe content was 2946-3607 ppm. In February, high values of Iron content were observed. Thereafter, from first half of March to April, a gradual increase in iron content was noticed. In second half of April, a minimum value (1745 ppm) of iron content was observed in the mussel tissue. During the period of second half of May to first half of August, the Fe content was stable, followed by a steady rise upto the end of the study period. In general, the Fe content in mussel tissue for the period of study does not indicate and leads to any particular trend of variation.

COPPER (Cu): The variations in copper content in the raft-grown green mussel are depicted in Fig. 51. The Cu content was observed to be high (39 ppm) in the mussel spat, immediately after transplantation. Then, in November it was below detectable level but showed an increase by second half of December but with

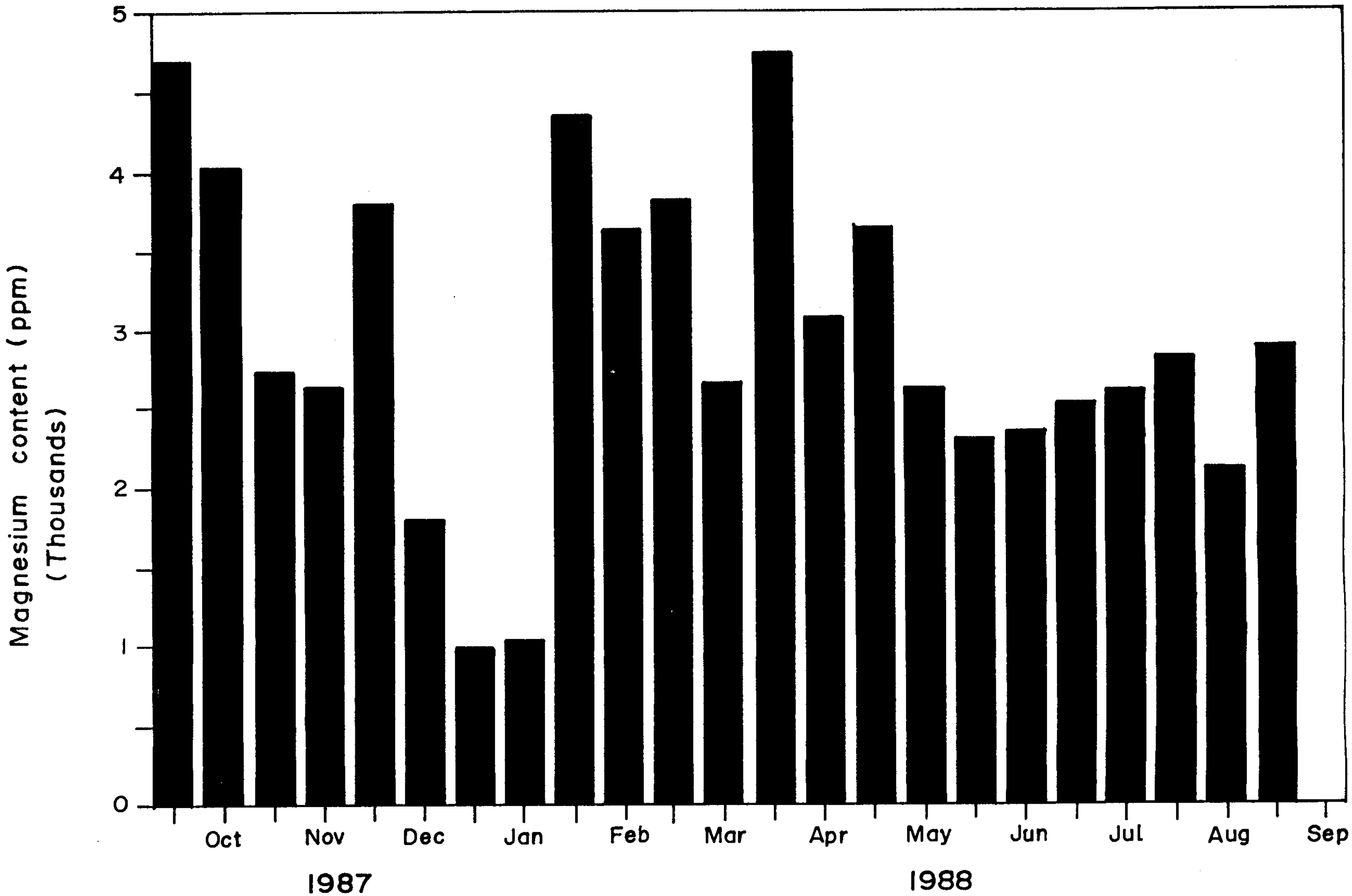

Fig. 49. Fortnightly variations in the Mg content in the tissue of raft-grown green mussel

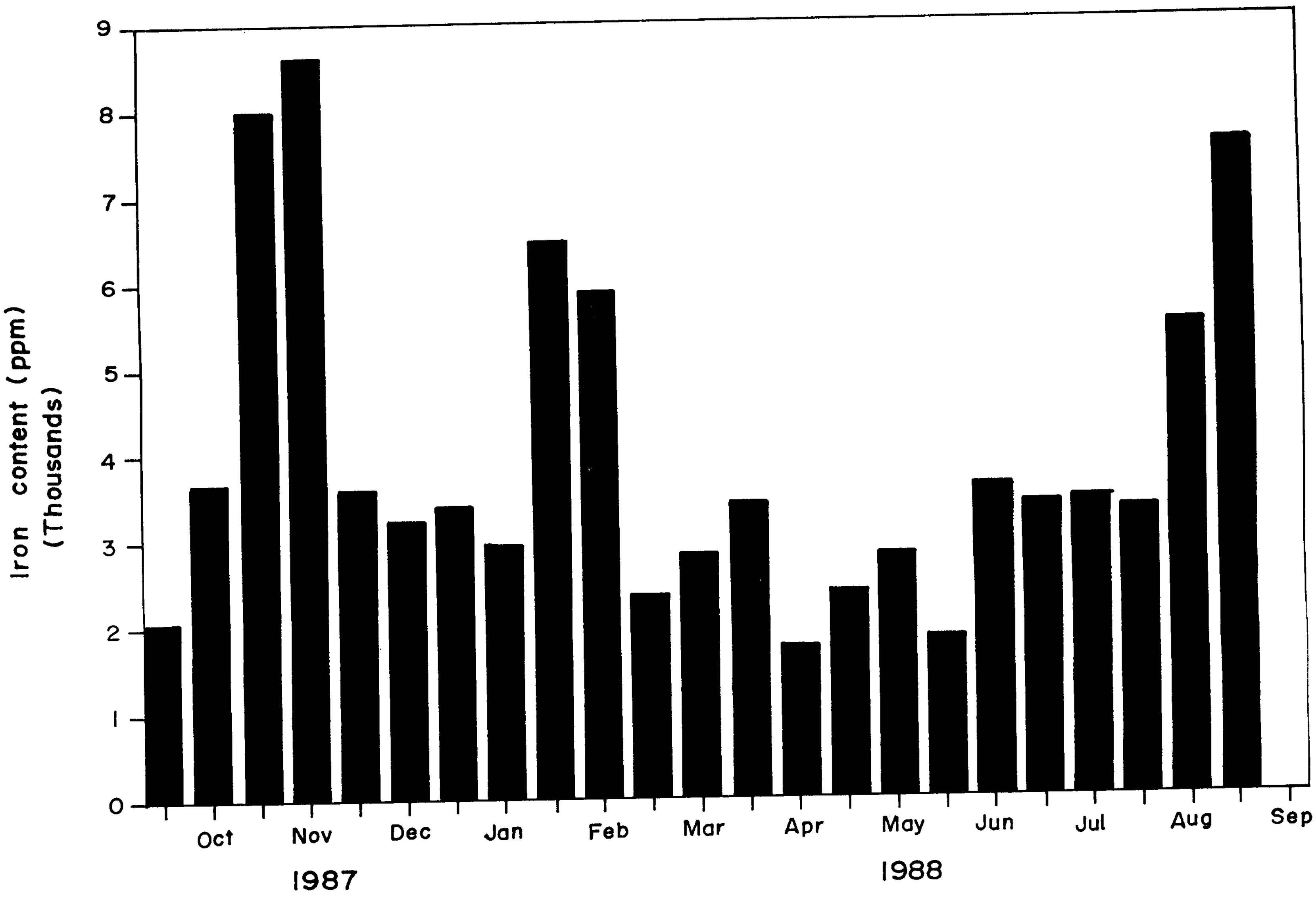

Fig.50. Fortnightly changes in the iron content in the tissue of raft-grown green mussel

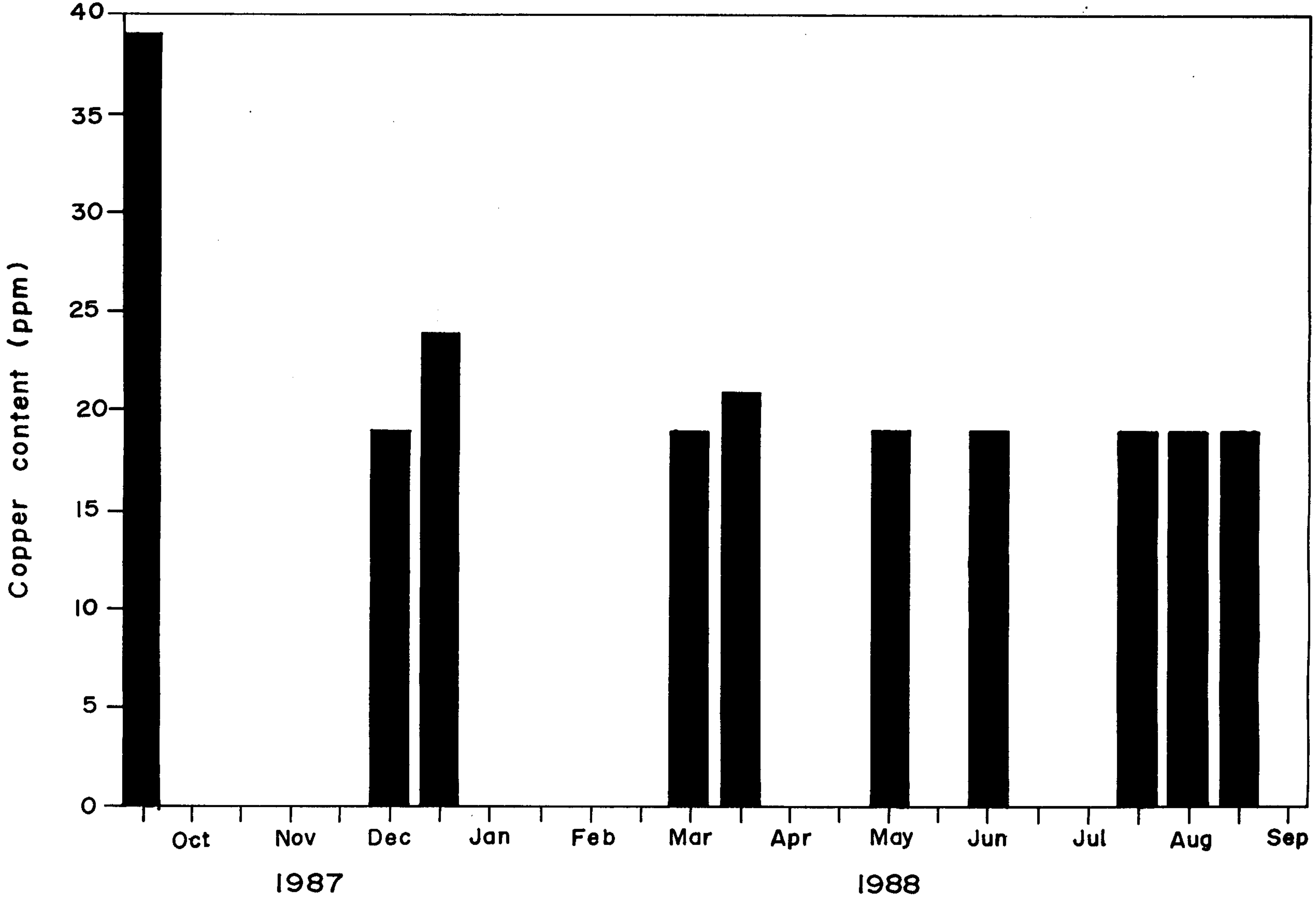

Fig.51. Fortnightly changes in the Cu content in the tissue of the raft-grown green mussel

relatively low values (19 ppm). The Cu content increased in January reporting a value of 24 ppm. During the remaining part of the study, the Cu content was stable within the range of 19-24 ppm, except in the months of January, February, April and July, during which the Cu content was below detectable level.

ZINC (Zn): The variation pattern in Zn content in the raft-grown green mussel is shown in Fig. 52. In the raft-grown green mussel, the Zn content with its higher values in the initial stages of the experiment decreased steadily upto December as the size increased. In January, it attained the peak value (1766 ppm) and then a marked decrease was noticed till first half of February. In March, a further fall in Zn content was recorded which remained steady within the range of 125-202 ppm. Since May onwards, a steady rise in Zn concentration was observed upto the end of the study period. The maximum and the minimum values of Zn content were recorded in January (1766 ppm) and May (82 ppm) respectively. During the rapid growth phase from January to April, the pattern of Zn distribution was observed to be of decreasing nature, thereafter, the Zn content was observed to be of ascending order, however, the degree of increase was of low magnitude.

MANGANESE (Mn): Changes in Mn content in the raft-grown green mussels are depicted in Fig. 53. The maximum concentration was observed in the beginning of the study i.e. October, 1987 as well as in the large sized mussels in August, 1988 (179 ppm). At the begining of the study, the Mn content in small sized mussels was

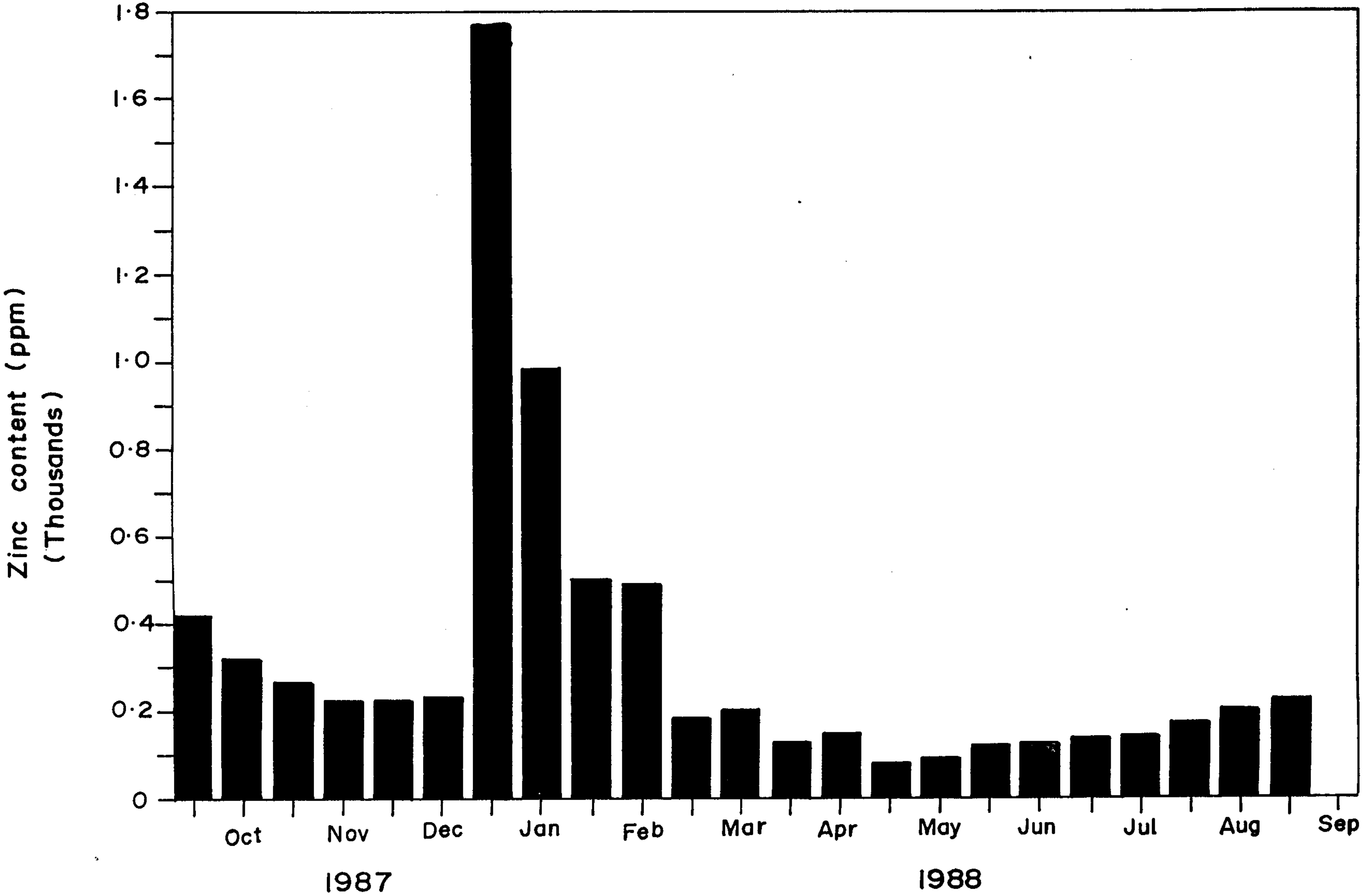

Fig.52. Fortnightly changes in the Zn content in the tissue of the raft-grown green mussel

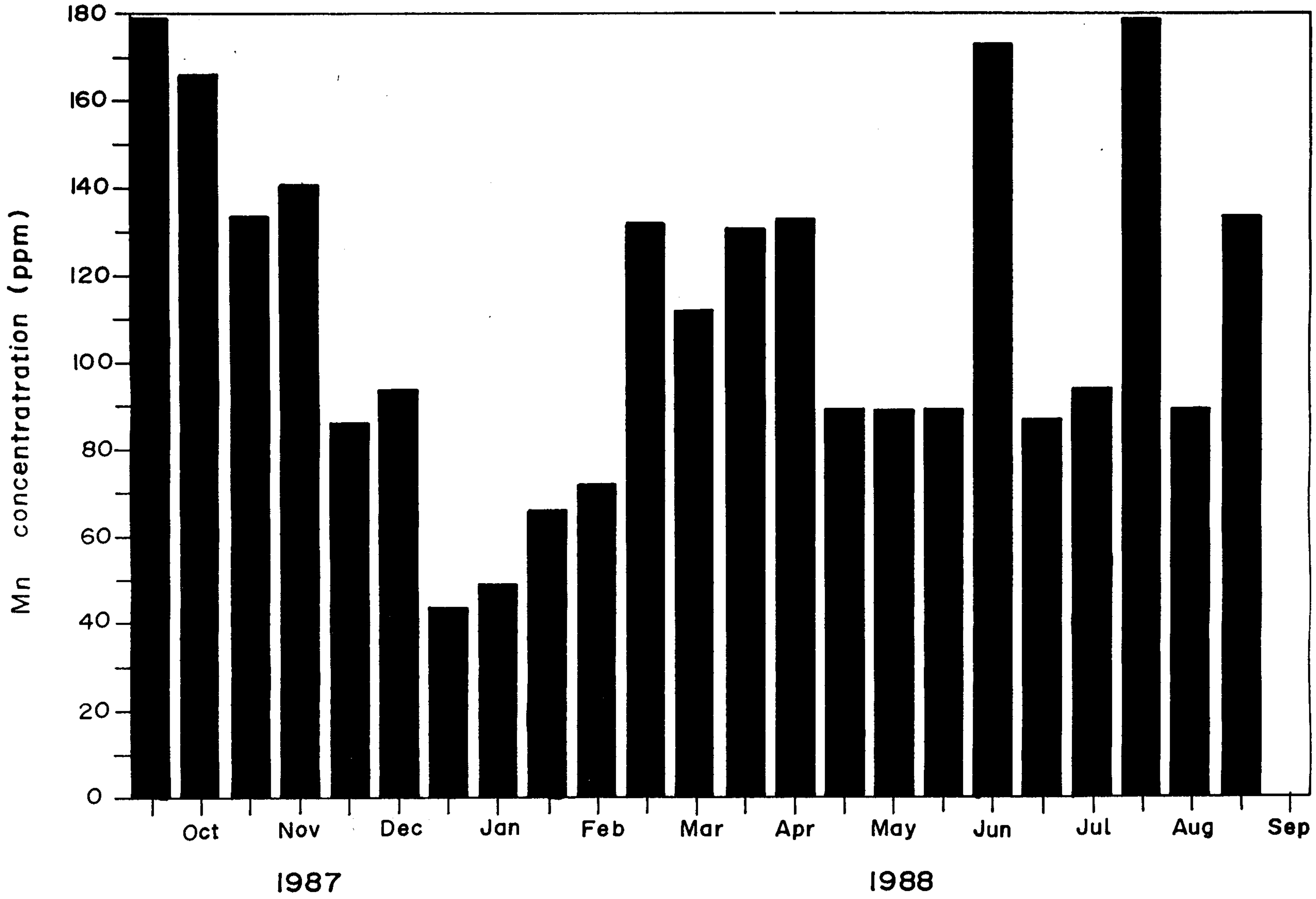

Fig.53. Fortnightly variations in the Mn content of the raft-grown mussel tissue

observed to be high followed by a slow decrease upto first half of November. In the second half of November, a slight increase was observed in Mn content, which further decreased upto January, registering its minimum value (44 ppm). Thereafter, the Mn content in the raft-grown mussels increased with the enhancement of growth upto April. In May, a fall in Mn content was observed and it extended till the first half of June. During second half of June, high value of Mn was reported which further decreased in July. A secondary peak of Mn content in the mussel tissue was observed in the first half of August, which reported steep fall in second half of August. Therafter, a gradual increase in the Mn content was observed upto the end of study period.

In order to know whether there exists any significant relationships, the data on major elements (Ca & Mg) and trace metals (Fe, Cu, Zn and Mn) composition in water column (taken as average of three depth levels) and mussel tissue was statistically analysed for correlation matrix with reference to growth (increase in shell length). From the analysis, it was found that, no significant relationship could be established between the above mentioned parameters.

DISCUSSION

Tropical estuarine ecosystem are known for their wide and abrupt variations in the water quality (Qasim, et al.,1969). The need to understand water quality criteria has become a necessity with respect to aquaculture activities and environment protection, as these coastal ecosystems have been widely used for the purpose of discharging industrial effluents, domestic sewage and human interferance that greatly mark the differences with time.

Most of the earlier studies (Subrahmanyam and Sen Gupta, 1965; Sen Gupta, 1972; Sen Gupta et al.,1976; Sanzgiri and Moraes, 1979; Braganca and Sanzgiri, 1980) in Indian coastal waters suggest that these trace metals in the natural seawater are greatly influenced by local topography and hydrobiological conditions. Furthermore, Sen Gupta et al. (1978) are of the opinion that trace metal composition in an area depend to a large extent on geochemical cycle of the environment.

Studies on major elements in the Indian ocean (Sreekumaran et al., 1968; Naqvi and Reddy, 1978; Sen Gupta et al., 1978; De Souza and Sen Gupta, 1981; Naqvi and Naik, 1983) reveal that these elements, being conservative or semiconservative in properties, their concentration may delineate the characteristics of different water bodies and to some extent these metals also play an important role in biological processes.

Marine bivalve molluscs, especially mussels are widely used in pollution monitoring programme (Calabrease, 1984) and their suitability for pollution studies has confirmed the characteristics, such as, abundance of species, sedentarism, minimal life span, higher degree of sensitivity to pollutants and the large size of adult suitable enough for physiological and biochemical analysis. Many published reports (Williams, 1974; Roberts, 1975; Phillips, 1976; Talbot et al., 1976a; Nair et al., 1977; Goldberg et al., 1978; Orrens et al., 1980; Kureishy, et al., 1983; Lakshamanan and Nambisan, 1983; Calabrease, 1984; Calabrease, et al., 1984; Talbot, 1986; Chan, 1988; 1989) provide exhaustive information on various changing patterns in levels of accumulation of different trace metals in mussels grown either in laboratory or from natural rocky environment. Moreover, Calabrease (1984) stated that accumulation of particular metal can vary even in any one particular population group or species of organisms depending on size, age, sex, reproductive condition, physiological state, seasonal variations, etc.. Further, the condition of the animal is largely influenced by quality of the environment.

WATER:

In the present study, the major elements, Ca and Mg, observed a significant seasonal pattern of variation. The concentration of these elements was observed to be high except in the monsoon season. Such higher values of major elements could mainly be due to more saline waters, and enhanced biological activity, thereby releasing Ca at increased rate from biological sources. Similar results were also earlier reported by Naqvi and Reddy (1979) and Naik and Moraes (1982). In monsoon, low values of Ca and Mg were mainly attributed to dilution and drainage from riverine sources (Sen Gupta et al., 1978). The near bottom values for these elements were higher than other depths. Such higher values for near bottom waters were also reported by earlier authors (Naik and Reddy, 1980; Naik and Moraes, 1982;

Naqvi and Naik, 1983). These higher values for near bottom waters could be due to geochemical processes and more saline waters.

Ca values in the near bottom waters were reported to be higher than surface and mid depth waters. Similar increase in Ca values with increasing depth upto 100 m were reported by earlier workers (Wilson, 1975; Naqvi and Reddy, 1979; Shiller and Gieskes, 1980). Hutchinson (1957) reported that Ca:Cl ratio of river water is much higher than seawater. This could be one of the probable reason for high values in the area of study. However, in contrast, Naqvi and Reddy (1979) noticed that maximum Ca:Cl ratio does not exactly coincide with salinity maxima and stated that it could be mainly due to utilization of Ca in the upper layers by the organisms. Furthermore, Koczy (1956) stated that upper layers upto few meters in the ocean, optimal conditions for lime secreating organisms seem to exist, but exceptions have also been reported (Sen Gupta and Pylee, 1968). The Ca content variation observed in the present study was found to vary with salinity, registering higher values in more saline waters. Along the central west coast of India, Naik and Moraes (1982) also reported similar type of variation in Ca content of sea water.

Large differences in Mg content, as compared to other localities (Riley and Tongudai, 1967; Carpenter and Manella, 1973) could mainly be attributed to negative water balance thereby suggesting excess evaporation over precipitation and land runoff. The Mg content variation in monsoon months was comparatively significant with depth. Sen Gupta *et al*. (1978) reported that this element does not appear to take part in biological cycle, and therefore be more or less constant except in nearshore areas, where freshwater modifies the relationship. Furthermore, in the present context it could be stated that Mg shows wider vertical variation than Ca.

The Fe content in the present study at the culture site was reported to be near stable and registered low values. Similar uniformity in distribution of Fe content was earlier reported by Kremling and Petersen (1984) in Baltic surface waters. During the period of January to February, high values of Fe were observed which could be associated with large ammount of soluble organic matter in the water column (Qasim and Sen Gupta, 1980). In the present study, high suspended matter was observed to coincide with higher Fe content values. However, suspended load in the present study could not be directly related to high Fe content. Another probable reason for high Fe content could be due to terrestrial pollution and anthropogenic local inputs as documented earlier by several workers (Chow and Pattersen, 1966; Danielsson and Westerlund, 1984; Kremling and Petersen, 1984), though no substantial data could be generated, in the present study. Braganca and Sanzgiri (1980) stated that Fe content in coastal waters is a function of freshwater input and is greatly influenced by riverine waters. Relatively low values of Fe were observed during some period of the present study. This could be due to clear waters prevailing at that time, causesd by sinking of biogenic material, thereby reducing metal content (Danielsson and Westerlund, 1984). Such low values in coastal waters of Goa have earlier been also reported by Zingde et al. (1976).

The Cu content at all depths at the site of raft culture was low except in January. Magnusson and Rasmussen (1982) reported minor differences between different stations in Danish waters. Higher values of Cu in January could be attributed to higher rate of dissolution of Cu in the upper layers (Sen Gupta, 1972; D' Silva and Kureishy, 1978; D' Silva and Qasim, 1979). This higher rate of dissolution of Cu at this time was influenced by high content of oxygen as observed in the present study. Earlier authors (D' Silva and Kureishy, 1978; Magnusson and Westerlund, 1980) made a note that low concentration of oxygen is not favorable for dissolution of Cu in upper layers. Therefore, probably low values of Cu observed during the study could be due to low values of oxygen content.

Changes in Zn concentration in the present study indicates that, higher values were observed during the period from January to March and could probably be due to terrestrial contamination, anthropogenic local inputs and or from local sources such as Zn rich rocks and river runoff areas (Abdullah et al., 1972; Preston et al., 1972; Chester and Stoner, 1974; Kremling and Petersen, 1984). During the monsoon, the Zn content values were reported to be low. These low values of Zn in monsoon months were expected due to colloidal and adsorbed form of Zn on suspended matter (Braganca and Sanzgiri, 1980) and another possibility could also be due to less contamination (Danielsson and

Westerlund, 1984).

In the present study, high values of suspended load were reported in monsoon season. The near bottom waters registered higher values than surface waters in January, March, April and June. Such high values for nearbottom waters have also been reported by earlier authors (Riley and Taylor, 1972; Braganca and Sanzgiri, 1980).

The Mn content at the site of raft culture showed two peaks, the primary one in November-December and the secondary in June. The high values of Mn are mainly attributed to transportation of mining ore in this area (Zingde et al., 1976). Except above mentioned periods, the Mn content was low and homogenous. Kremling and Petersen (1984) also reported homogenous distribution of Mn in Baltic waters. Low values of Mn in an estuarine ecosystem suggests that riverine input is not a source of Mn. Similar observations were earlier reported by Braganca and Sanzgiri (1980). Low values of Mn were also recorded in monsoon season thereby indicating that riverine input does not enhance the Mn content of the water body. This corroborates with earlier findings of Branganca and Sanzgiri (1980). The near bottom waters reported higher values as compared to surface and mid-depth waters during certain part of the study period. Redox-potential is known to play an important role in distribution of Mn (Stumm and Morgan, 1970; Braganca and Sanzgiri, 1980).

MUSSELS:

The Ca content in the mussel tissue was observed to be of descending order throughout the study period i.e. as the growth enhanced, a reduction in Ca content was observed thereby indicating that in young mussels uptake of Ca is more as compared to adult mussels. Earlier, Silverman et al. (1987) made similar observations and stated that Ca accumulated by mussels dissapear during reproductive season. Bruegman and Lange (1988) reported that Ca content of mussel tissue is greatly influenced by composition of sediments, acting as substrate for their food materials. Seasonally, in post monsoon Ca content was found to be high, whereas, at other times the Ca content was observed to be of low concentration. Low values of Ca in the present study could be a result of dilution of the medium by precipitation or runoff thereby reducing availability for uptake of this element by the raft grown mussels.

In mussel tissue, the Mg content in the present study did not show any specific pattern of variation. As such the distribution of Mg was almost uniform with minute variations. A noticeable fall in Mg content was reported in December-January. In the beginning of the growth period upto January, a gradual fall in Mg content was recorded and thereafter as mussels grew older, no such variations in Mg content were observed. Julshman (1981) analysed Mg content in soft parts of mussels and compared the same with other marine flora and fauna. Jeffree and Simpson (1984) studied distribution of major elements in freshwater mussel, Valesmio angari and emphasized the importance of these elements.

In the present investigation, the Fe content did not follow any particular rhythm of variation. However, in small sized mussels, soonafter transplantation of mussel spat, Fe content was observed to be low. Since the mussels were transplanted at new site it generally takes some time to acclimate. Therefore, probably the inefficient feeding during this acclimatisation period might have lead to low Fe content of transplanted mussel. In general, Fe content values were reported to be high, with much higher values in the month of November 1987, August 1988 and September 1988. Such high values of Fe content in molluscs have also been reported by earlier workers (Eisler et al., 1978; Fowler and Oregioni, 1978; Sankarnarayanan et al., 1978; Phillips, 1979) who have stated that such elevated values are mainly due to proximity to anthropogenic point sources such as electroplating plants, ironworks and waste outfalls. Zingde et al. (1976) opined that high values of Fe in marine fauna could be attributed to inflow of mine drainage. Moreover, other factors such as sex, salinity, season, water turbidity and depth are also known to influence Fe accumulation in organisms (Watling and Watling, 1976; Phillips, 1978). Seasonwise, low values of Fe content were recorded in winter, however, in contrast, Sankarnarayanan et al. (1978) reported higher values of Fe content in molluscs at this time.

Cu content in the raft-grown mussel tissue was observed to be high in the initial period of growth. i.e. soonafter transplantation of mussels from the natural conditions. Similar observations, reporting high values of Cu in small sized mussel group were earlier made by Watling amd Watling (1976), whereas, Marks (1938) reported low values of Cu. Boyden (1974) reported a positive correlation of Cu content in mussel tissue with increasing body weight. In the present study, the distribution of Cu did not reveal any specific trend of variation. Phillips (1976) stated that Cu uptake in mussels was erratic and seems to be influenced by available concentration of other metals such as Zn, Cd and Pb salts. However, other abiotic factors are also supposed to influence Cu accumulation in mussels such as salinity and proximity to point source (Olson and Harrel, 1973; Young 1977). Higher ability to acumulate Cu by mussels in post monsoon could not be wholly explained by temperature regimes. Possible causes for high acumulation of Cu in October could be due to other factors such as moisture content (Phillips, 1976), availability of food (Bryan, 1973), local pollution (Fowler and Oregioni, 1976) and land drainage (Bryan, 1973; Fowler and Oregioni, 1976; Phillips, 1976). Furthermore, elevated levels of Cu are primarily attributed to proximity to anthropogenic sources and secondarily to various biological and abiotic modifiers capable of modifying Cu uptake and retention in molluscs. A thorough knowledge of these modifiers and relevant interaction effects are essential to have a better understanding of Cu kinetics in marine ecosystem.

The pattern of Zn variation in raft-grown mussels displayed a decreasing trend in size range of 40-62 mm shell length. Such decrease in Zn with enhancement of growth has earlier been reported by Watling and Watling (1976) and Boyden (1977).

However, in the size range of above 62 mm shell length, a reverse pattern was observed. Boyden (1974) documented increase in Zn content with increasing body weight. Phillips (1979) stated that marked variations in Zn content seems to be influenced by season, geographic locale and Zn specific sites of accumulation. In monsoon, increasing trend of Zn content with size was observed in the present study. Zn content in nearshore mussels cooincided with periods of high precipitation and runoff with concomitant increase in suspended particle load in coastal waters (Fowler and Oregioni, 1976).

Mn content in the raft-grown mussels were observed to be of higher magnitude. The Mn values were found to be high in young as well as adult mussels. Such higher values of Mn in mussel tissue are mainly attributed to pollution by automobiles, small crafts and to substrate composition especially muddy substrates (Graham, 1972). The present site of raft culture happens to be in the vicinity of a major port **Marmugao** and is known for high rate of pollution by small crafts operating in this area. Fowler and Oregioni (1976) stated that industrialized port areas exhibit higher Mn values as compared to other areas. In the present study, Mn content in the mussel tissue does not seem to follow a specific trend of variation with size. Downes (1957) reported that Mn concentration in molluscs was not related to age or body weight.

Interpretations made from statistical analysis highlights that no definite as also the significant relationship could exist among the trace metals in seawater medium and mussel tissue with the enhancement of growth. Earlier authors (Bryan, 1973; Pentreath, 1973; Young, 1977) described that diet and food chain presumably play a major role in accumulation of trace metals as compared to seawater medium. Hence, the present study, confirms to a certain extent, that trace metal content in mussel tissue is not regulated by composition of the medium.

CHAPTER VIII

SUMMARY

In the present study, fluctuations in hydrobiological characteristics have maximum effect at the site of raft culture only during the south west monsoon. Most of the hydrological parameters are tuned to seasonal rhythms, especially the south west monsoon playing an important role in changing the water quality. Further, chlorophyll a and standing crop of phytoplankton showed low values during south west monsoon. Among phytoplankton population, diatoms, Coscinodiscus spp. in particular, are found to be present round the year.

Assymptotic length (L_∞) and weight (W_∞) for the raft grown population of the green mussel is computed to be 85 mm and 37.34 g respectively. Specific growth rate is found to be high in the initial phases of growth. Among hydrobiological characteristics, the growth (length and weight) is found to be influenced, statistically, by chlorophyll a, when considered as single independent variable. The chlorophyll a content in combination with particulate organic carbon and dissolved oxygen also showed significant effect on shell length of the raft-grown green mussels. However, the total weight is found to be influenced significantly by the combined effect of chlorophyll a and dissolved oxygen.

Allometric relationships in the present study indicate that within the raft-grown population of the green mussel, Perna viridis L. under identical environmental conditions in an estuarine biotope, the relationships vary considerably from one size group to other. Another important observation is that these relationships do change within a population when considered separately for a particular size group and for overall population.

The major biochemical constituents in the raft-grown mussel population show seasonal variations, influenced largely by breeding behaviour and developmental stages of gonad in the reproductive cycle. It is found that ideal size for harvesting these mussels is 65-70 mm shell length during which the major biochemical constituents in the tissue are at its peak level. Another noteworthy observation is that protein contributes maximum to the energy potential of the raft-grown mussels.

Studies on distribution of major elements (Ca and Mg) and trace metals (Fe, Zn, Cu and Mn) in water column and mussel tissue at the site of raft culture did not bring out any specific relationship between these constituents in water column and the mussel tissue. It is found that to a certain extent the Calcium showed inverse relationship with size. No definite relationship could be established between parameters in water medium and mussel tissue.

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