Nature and Ecological Significance of Nutrient Regeneration in Different Prawn Culture Fields

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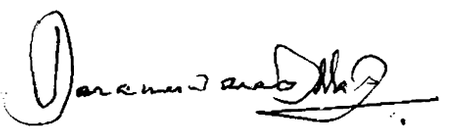
CERTIFICATE

This is to certify that the thesis entitled **"Nature and Ecological significance of Nutrient Regeneration in Different Prawn Culture Fields"** is the bonafide record of the research work carried out by Shri. **Joshi K.K.,** under my guidance and supervision in the Centre of Advanced Studies in Mariculture, CMFRI, and that no part thereof has been presented for the award of any other degree.



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DECLARATION

I hereby declare that this thesis entitled **"Nature and Ecological significance of Nutrient Regeneration in Different Prawn Culture Fields"** has not previously formed the basis of the award of any degree, diploma, associateship or other similar titles or recognition.

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PREFACE

Nutrient regeneration in its broadest sense, covers the entire field of biological oceanography, as it links the two bio-ecological processes such as the primary production and re-mineralisation. As such, all the major unresolved questions in quantitative marine ecology can be traced back to this central issue. No general agreement exists about such basic questions as the structure of food webs, the interaction of their component populations, or whether current methods successfully measure rates of ecosystem processes. Critical appraisal of this situation have been made from a variety of sub-disciplines of which some are phytoplankton, microbial, zooplankton ecology, nutrient regeneration, magnitude of primary production and pelagic/benthic coupling.

Studies concerned with the culture ecosystem in the past were concentrated mainly in determining the identity of the system, abundance of fauna and their relationship to environmental variables. More recent investigations have been concerned with subjects such as productivity, faunal diversity and ecophysiology of individual taxon. The synthesis of organic compounds from the inorganic constituents of water by the activity of organisms is termed as production. The raw materials are water, Co_2 and various other substances, the nutrients being chiefly inorganic ions, principally nitrate and phosphate. Eventually, as a result of respiration and excretion, dead and decomposed organic materials become broken down and return to the water as simple substances which plants can utilize in primary production. In this way, matter is continually cycled from inorganic to organic form and back to inorganic state. However, only limited studies

have been made in the past on the distribution and seasonal variation of phosphates, nitrate and silicate, fractions and circulation of phosphorus and nitrate, nutrients productivity relations in the prawn culture fields. In the context of rapidly developing coastal aquaculture in the country and considering the importance of inter-relationships between environmental parameters, nutrients, metals and productivity of the culture ponds, the present investigation was taken up to study the spatial and temporal distribution, seasonal availability and regeneration of nutrients, and primary productivity in selected prawn culture fields of Narakkal near Cochin during January 1986 to December 1987 along with important environmental parameters and metals which influence their distribution and availability.

The present work "Nature and Ecological Significance of Nutrient Regeneration in different Prawn Culture Fields" was undertaken to understand the seasonal variation of nutrients, nutrient cycling and primary productivity of the prawn culture systems. The main emphasis was to find the qualitative and quantitative estimates of distribution of total phosphorus, inorganic phosphorus, organic phosphorus, total nitrogen and nitrogen fractions in the water. The effect of nutrient cycling on primary productivity and concentration of metals also form one part of the study.

The entire thesis comprise of only one major chapter with sub-chapters such as, Introduction (1), Review of Literature (2), Material and Methods (3), Results (4), Discussion (5), Executive Summary (6) and Bibliography (7). 'Introduction' in which explanation for importance of aquaculture, the nature of ecosystem, purpose of taking up the present work, the details of the relevant work carried out by other workers in relation to water and sediment in different prawn culture fields. 'Material and Methods' including

the techniques of sampling and preservation of water and sediment samples from the ecosystem and methods of analyses of various physico-chemical characteristics, primary productivity and metals. The 'Results' section is concerned with the seasonal variation of environmental parameters, nutrients, primary productivity and dissolved metals. In 'Discussion', the results of environmental parameters, nutrients are presented followed by the discussion and comparison of the results related to primary productivity. The 'Executive' of the contents of research work has been reported after 'Discussion'. The 'Bibliography' forms last part of the thesis.

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1. INTRODUCTION

Prawn form a prominent export commodity among marine products. Prawn fishery also plays a vital role in providing livelihood for thousands of families by way of extending employment opportunities. During the past five years the average landing of prawns from the wild is around 1,02,000 mt despite of increasing fishing effort. The growth and survival of the prawn industry depend on the uninterrupted production and supply of prawns. It is highly essential to safeguard the production trend against any fluctuation or decline.

The prawn fishery of the south-west coast of India is largely confined to the coastal regions and estuaries, which are normally turbid. The very forceful monsoon and excessive landrunoff are mainly responsible for increasing the turbidity of these waters. Since in turbid waters the euphotic zone becomes shallow, the phytoplankton organisms are easily removed from the favourable zone of illumination. They thus keep settling to the bottom as detritus. The large assemblage of prawns below the euphotic zone in these waters, may therefore, be a consequence of their direct link with the primary production through plant detritus and through animal matter. Conditions for detritus feeders are greatly improved if such areas happen to have a seasonal outburst of primary productivity and there is much evidence to suggest that coastal areas of the south-west coast of India are extremely fertile because of upwelling which occurs during the monsoon months.

In this situation farming of commercially important species of prawns could be adopted as an alternative measure for increasing prawn production. It is estimated that India has 2.6 million ha of backwaters, lagoons and estuaries out of which 3 lakh ha can be utilized for culturing prawns. But at present only about 10,000 ha are being utilised for culturing prawns employing the traditional methods. There is thus great scope for expanding prawn culture activities in India. Even by using the extensive type of culture in the additional acreage to be brought under prawn cultivation, the prawn production from culture operations along could be easily be increased to 1,00,000 tonnes annually (Muthu, 1978). As the prawn industry is export oriented, the additional yields from culture operations will bring in more foreign exchange and also improve rural economy of the country.

In Kerala, the total brackish water resources including the lower reaches of rivers, the brackish water lakes, the backwaters and the adjacent low-lying fields and mangrove swamps which are estimated at about 2,43,000 hectares. A traditional system of prawn farming in paddy fields popularly known as prawn filtration is prevalent in more than 4,500 hectares of low-lying coastal brackish water fields adjoining the Vembanad lake in Kerala State. These fields ranging in size from less than 0.5 ha to more than 10 ha and lying along the coastal villages of Trichur, Ernakulam, Alleppey and Kottayam districts are confluent with the Vembanad lake through canals and are subjected to tidal influence. The farming system involves entrapment of juveniles prawns brought in by the tidal water, in the fields and catching them by filtration at regular intervals.

About 4,500 hectares of low-lying coastal areas in the districts of Ernakulam, Alleppey and Trichur are utilised for growing paddy during the south west-monsoon season and prawns during the rest of the year. During the south west-monsoon season the heavy precipitation makes the waters of the Vembanad lakes almost fresh and the paddy fields are also inundated by fresh water. During this period (June-September) a special variety of paddy called "Pokkali" which is tolerant of salinities upto 6-8 ppt, is grown in these fields.

After the paddy is harvested, the fields are leased out to prawn culturists from October to April-May. During this period salinity of the water in the feeder canals increase and so paddy cannot be grown. The paddy stumps are allowed to decay in the water to form a good organic manure that stimulates the growth of phytoplankton and zooplankton. The juveniles of marine prawns are found naturally in the backwater system enter the fields along with the tidal water. At the end of the lease period (April-May) the prawn and other fishes are fished out and are returned to the owners for paddy cultivation.

In addition to the pokkali fields, there are relatively deeper brackish water impoundments which are not suitable for growing paddy. These are used for growing prawns throughout the year. The method of stocking and harvesting the similar to those adopted in the case of seasonal fields. Since such area are deeper the bottom portion of the water column will be saline making it suitable for the growth and survival of prawns during the monsoon periods also. These fields ranging in size from 0.5 to 2 ha are called perennial fields.

The penaeid prawns belonging to the genera Penaeus and Metapenaeus spawn in the sea but the post larvae enter the estuaries and backwater areas in large numbers and grow rapidly. Brackish water areas serve as a natural nurseries for the juveniles. The euryhaline nature of these prawns enables them to colonize in the estuaries and backwaters. In the traditional culture operations these naturally occuring post larvae and juveniles are trapped in tidal impoundments and allowed to grow for short periods before they are caught. These ponds are constructed in the coastal brackish water areas where there is a good tidal range and with abundant supply of prawn seed.

The area of present investigation includes the backwaters running almost paralled to the Arabian sea from Alleppey in the South to Azhikode in the north of Kerala. The depth varied from 1.5 to 10 m and total area of water spread is about 300 sq. km. On the northern half there are two permanent passages to the Arabian sea, one at Cochin and the other at Azhikode. Six rivers empty into the backwaters, each through their tributaries and branches. On the southern half the rivers Muvattupuzha, Manimala, Meenachil, pampa and Achancoil join the lake, while the Periyar river joins at the northern half. All these rivers empty large quantity of flood waters during the monsoon season enriched with the nutrients and considerable quantity of silt.

Narakkal is an important fishing village in the island of Vypeen. The latter stretches northwards for a distance of about 19 miles from the Cochin Harbour entrance. It is washed by the Arabian sea on the west and on the east by the Cochin Backwater. The distance from coast to

coast at the widest point of the island may not exceed about 3 miles, it may be reduced to about a couple of furlongs at the narrowest. Traversing the island from east to west are a number of canals running perpendicular to the backwaters, most of them connecting at their inner ends with canals that run paralled to the length of the island and thus forming a complex net work. All of them join the backwaters at their eastern extremities, but none reach the sea on the other side. Bunder canal at Narakkal is one such transverse canal passing westwards for a little over 3 furlongs to join a long canal running north to south.

A knowledge of the biotic and abiotic factors affecting the cultivable species of prawns is a prerequisite for their successful culture. Of the various abiotic factors, the physical and chemical characteristics of the media in which prawns thrive have profound influence on the successful breeding, growth and survival. Ecological relationships are manifested not in a vaccum but in physico-chemical settings, sets of non living or abiotic environmental substances and gradients. These include basic inorganic elements and compounds such as calcium and oxygen, water and carbondioxide, carbonate and phosphate and also an array of organisms activity. It is against this abiotic backdrop that biotic components, plants, animals and microbes interact in a fundamentally energy-dependent fashion. The two processes occuring concurrently in ecosystems, results the movement of energy and of nutrient elements. The former has been said to be unidirectional and non-cyclic, the implication of decomposer mineralisation activity is that the movement of nutrients is cyclic. Estimates of nutrient fluxes have clearly shown that external nutrient inputs (rainfall, river flow) can account for less than 1% of annual nutrient requirements for primary production.

Almost all required nutrients come from internal recycling. Although remineralization of nutrients from organic matter through photochemical processes occurs, biological transformation is the predominant mechanisms. Furthermore, most of the primary organic production is probably consumed by planktonic herbivores which recycle nutrients either directly or indirectly through their excretory activity. In addition to the dynamic interchanges of nutrients that occur within ecosystem among its atmospheric, soil and biotic components, there is an exchange of nutrients between ecosystem resulting from geological meterological and biological forces. In the process of converting radiant energy into chemical energy by photosynthesis, the green plants also incorporates into its protoplasm a variety of inorganic elements and compounds. Among the important once are the direct components of the photosynthetic reaction, Co_2 and water and that are critical to photosynthesis, notably nitrogen, phosphorus and some fifteen other essential nutrients.

Because several properties of the coastal environment usually vary together, the effects of variation in single factors are seldom evident in natural conditions. The differences of distribution are associated with differences of penetration and absorption of solar radiation, and therefore with gradients of temperature, illumination and to a lesser extent salinity. The distribution of a species is consequently associated with complex of variables and it is not easy to assess the role of each parameter independently. The effects of variation in single factor can be studied to some extent in controlled conditions in the laboratory but in this unnatural environment the response may be abnormal.

Depending on the water conditions the sites suitable for prawn farming can be classified as marine, estuarine and fresh water. Marine farms are salt water farms located in the coastal areas which are largely free from the influence of river discharge. Estuarine farms are situated in the vicinity of the confluence of the river and sea. One of the most prominent characteristics is the dynamic nature of the process taking place which result in marked changes in temperature, salinity and pH. Towards the seaward end, the physical and chemical conditions are more or less marine. But these conditions change with the season, fresh water conditions prevailing during the monsoon because of the rain-fed rivers. The shallow estuarine muddy bottom and tidal marshes are of particular importance to the fish farmers, since they are regarded as the most fertile areas, their biological production rating as high as twenty times that of the open sea.

It is well-known that most of the penaeid prawns begin their life in the open sea and migrate to shallow coastal areas and estuaries at post larval stages. They stay in these environments and then return to the sea on reaching or nearing adulthood/maturity. This ontogenic movement is associated with abilities acquired at different stages to withstand the changes in environmental conditions. In the sea, the changes are relatively less and many vital activities such as maturation, breeding, early metamorphosis are accomplished here. The conditions in the estuary, on the other hand, are very complex and dynamic and the juvenile life of prawn is endowed with more power to tolerate the extreme fluctuations in physico-chemical factors of such surroundings.

Temperature has a pronounced effect on chemical and biological processes. The rates of chemical and biological reactions are doubled for

every 10°C increase in temperature (Q_{10} rule). Prawns are known to tolerate wide range of temperature, the highest range recorded being 2.6 to 38°C (Panikkar, 1968) but culture practices are easier at temperature above 15°C. The influence of temperature on the survival and growth of post larval and juvenile population is relatively more when compared with optimal salinity conditions. The term salinity refers to the total concentration of all dissolved ions in a natural water expressed in milligrams per litre Salinity is the most important factor influencing the life history of penaeid prawns. It influences many functional responses such as metabolism, growth, migration, osmotic behaviour and reproduction.

The oxygen content of the water has profound influence on the general metabolism and growth of the prawns. In the estuaries, the oxygen requirements of Penaeus indicus changes as the prawn grows and the metabolism is related to body weight, the heavier forms showing greater dependency on the oxygen content of the water. The photosynthesis by phytoplankton is the primary resource of dissolved oxygen in a prawn culture system. The primary losses of dissolved oxygen from a pond include respiration by the phytoplankton prawns, and by other organisms and diffusion of oxygen into the air. Concentration of dissolved oxygen decreases with increasing temperature and salinity.

The pH is a measure of the hydrogen ion concentration and indicates whether the water is acidic or basic in reaction. Phytoplankton and other aquatic vegetation remove carbondioxide from the water during photosynthesis, so the pH of a body of water rises during the day and decreases during the night. Water with pH value of above 6.5 to 9.0 at day break are

considered best for prawn production (CMFRI, 1984). The total alkalinity refers to the total concentration of bases in water expressed as milligram per litre of equivalent calcium carbonate. The availability of carbondioxide for phytoplankton growth is related to alkalinity.

Many of the nutrients are minor constituents of the brackish water, present only in very low concentration and their supply excerts a dominent control over production. Nitrogen and phosphorous are of special importance. Where the quantities of these ions are known, theoretical estimates of the potential productivity of the water generally accord well with observed values. Iron, zinc and copper are the essential nutrients, silicon is required by diatoms The absorption of nutrients by the phytoplankton reduces the concentration of these substances in the surface layers, and this limits the extend to which the plant population can increase. A certain amount of nutrients absorbed by phytoplankton may be regenerated and recycled with in the lighted zone, but plants are continually being lost from the surface layers through death, sinking and by consumption by zooplankton which move to deeper levels during day-time.

Of all the nutrients in the brackish water, phosphorous is likely to be the most important ecologically because the ratio of phosphorus to other nutrients in the brackish water tends to be considerably greater than the ratio in the primary sources of the biological elements. A deficiency of phosphorus is therefore more likely to limit the productivity. The important categories of phosphorus are inorganic phosphorus, organic phosphorus and particulate phosphorus.

The ultimate source of the nitrogen, which plays a fundamental part in the metabolism of organism is certainly the molecular nitrogen of the atmosphere. · Biochemical changes in the concentration of molecular nitrogen thus involve nitrogen fixation, assimilation and denitrification. Nitrogen, either nearly fixed or assimilated as nitrate or ammonia, is incorporated into proteins or other compounds in organisms. The production of ammonia, nitrite and nitrate in this regular order, from dead diatoms suspended in sea water in the dark.

The forms of nitrogen present in lake waters may be roughly through conveniently grouped as molecular nitrogen, organic nitrogen, ammonia and particulate nitrogen. Three possible sources of nitrogen compounds are fixation in the ponds, precipitation and sediments. The loss of nitrogen compounds by diffusion of volatile nitrogen compounds from its surface by denitrification in the lake and in the formation of permanent sediments. Minute amounts of nitrite are some times found even in unpolluted oxygenated surface water of lakes, though any appreciable nitrite content in surface water has long been regarded as a warning of sewages contamination. Since reduction of nitrate to nitrite is well known in cultures of diatoms and of Chlorella in the laboratory, such an explanation of the minute amounts of nitrite often observed in unpolluted and well-oxygenated surface water is very reasonable.

The oxidation of ammonia to nitrite and nitrite to nitrate is accompanied by a fall in free energy, these reactions are available as energy sources to any organisms which can activate them. The observed concentration of nitrate will naturally depend on the balance of biochemical production and destruction. The activities of nitrifying bacteria account for the bio-

chemical production of nitrate in lakes the destruction of nitrate is accomplished in two major ways. In the presence of organic matter, therefore both the reduction of nitrate to nitrite and the reduction of nitrite to hyponitrite or free nitrogen are processes which are capable of providing energy to organisms.

Ammonia, underwhich term NH_3, NH_4 + and NH_4OH will be included, is the major nitrogenous end product of the bacterial decomposition of organic matter, and is important excretory product of invertebrate animals also. Ammonia in aqueous solution is present mainly as NH_4 + and as undissociated NH_4OH . The proportions of these two forms will depend greatly on the pH, and this variation may be of considerable ecological importance.

Silicon is present in the brackish water chiefly as silicate, ions and possibly some times nitrate traces of colloidal silica. It is a constituent of the diatom cell wall and in some radiolarian skeletons. The concentration of silicate at the surface is usually low, but increases with depth. Although much of the silicate incorporated in the diatom cell wall is probably returned to the water quickly after death, as siliceous deposits of planktonic origin. Iron is an essential plant nutrient, and also has various roles in animal physiology. The amount of iron in the solution seems inadequate to support rapid plant growth, and it is possible that marine plants can utilise particulate iron in someway, perhaps gradual solution of particles absorbed on the cell-wall, or even by actual ingestion by certain plants which have exposed protoplasm.

The synthesis of organic compounds from the inorganic constituents of water by the activity of organisms is termed as production. It is effected

almost entirely by the photosynthetic activity of marine plants with traces of organic matter also formed by chemosynthesis. The raw materials are water, Co_2 and various other substances, the nutrients mainly inorganic ions, principally nitrate and phosphate. Chlorophyll contain plants, by making use of light energy, are able to combine these simple substances to synthesis complex organic molecules. This is termed "Gross Primary Production". The chief products are three major categories of food materials, namely carbohydrate, protein and fats.

Eventually as a result of respiration, excretion,death and decomposition, organic materials become broken down and returned to the water as simple substances which plants can utilise in primary production. In this way, matter is continually cycled from inorganic to organic forms and back to inorganic state. The initial synthesis of organic material involves the in take of energy to the system, and this is supplied by sunlight. The rate of photosynthesis increase with rising temperature up to a maximum, but then diminishes sharply with further use of temperature. Different species are suited to different ranges of temperature. Seasonal variation of production rate are related to changes of both temperature and illumination. Apart from its direct effect on rate of photosynthesis, temperature also influences production indirectly through its effect on movements and mixing of water and hence on the supply of nutrients to the euphotic levels.

Many of nutrients are minor constituents of water, present only in very low concentration, and their supply exerts a dominant control over production. The absorption of nutrients by the phytoplankton reduces the concentration of these substances in the surface layers and this limits the

extent to which the plant population can increase. A certain amount of nutrients absorbed by phytoplankton may be regenerated and recycled in the ecosystem.

Although the interactions between plant and animal populations are difficult to elucidate, the grazing rate of the herbivorous zooplankton is certainly one of the factors which regulates the size of the standing stock of phytoplankton, and therefore influences the production rate. The quantity of zooplankton generally correlates more closely with the quantity of plant nutrients in the surface layers than with the size of stock phytoplankton, indicating how greatly grazing reduces the number of plants in fertile water. In the long term, the primary productivity of an area must determine the size of the animal population it supports, butin the short term these are often wide, and sometimes rapid, changes in both numbers and composition of population due to variety of causes.

Interaction between carbon, nitrogen, silicon and phosphorus have been particularly significant in ecosystems where increase in level of carbon, nitrogen, silicon and phosphorus are associated with the use of improved pasture technology. Interactions have been less important in ecosystem where carbon, nitrogen, silicon and phosphorus levels have declined but even here some changes in the ratios of carbon, nitrogen, silicon and phosphorus in the various organic pools and the rates of transfer between them vary greatly between environments and are affected by the prawn culture practices used.

Inputs of phosphorus and nitrogen as fertilizers can greatly increase the amount of plant biomass in soils where these nutrients are deficient.

This allows adapted species such as phytoplankton to grow and persist and results in an increased animal input of nitrogen to the system. The increased levels of carbon, nitrogen, and phosphorus in the biomass can result in relatively high levels of carbon, nitrogen and phosphorus in soil organic matter acts as a sink for carbon, nitrogen and phosphorus in these situations.

The main pathways of loss are in product removal, gaseous losses and leaching. After death, the tissue of plants and animals become converted gradually by certain degree into soluble form. Dissolution may be initiated by a autolysis, the tissue being broken down by the dead organisms own enzymes, but decomposition is brought about mainly by bacterial action. Free living bacteria are abundant on the surface of organisms and detritus and are specially numerous in the uppermost layer of bottom deposits,bacterial metabolism converts soil organic matter into organic solutes and eventually into organic form. Phosphorus compounds are regenerated as phosphate. On the death and decay of animals the phosphorus in their body tissue returns to the water very quickly as phosphate, indicating that decomposition of phosphorus compounds is probably mainly by autolysis. Nitrogenous organic materials are broken down more slowly, mainly by bacterial activity, regenerated at first as ammonia, and then further oxidised to nitrite and finally to nitrate.

Nutrients released through benthic community metabolism have been considered an important source for primary producers in coastal waters (Rowe et al., 1975). The importance of zooplankton in regeneration of nutrients for primary production is not quantitatively considered until relatively recently. From early estimated of feeding efficiency it was apparent that a significant fraction of the ingested organic matter would be mineralised through respiratory and excretory activity.

Microheterotrophs are represented by protozoans, metazoans, (nauplii, copepods) and bacteria. They account for the bulk of planktonic respiration, phytoplankton grazing and nutrient regeneration. Protozoans excretes dissolved inorganic phosphorus one to two orders of magnitude more rapidly than macrofauna. Bacteria are important in recycling phosphorus only indirectly through their conversion of dissolved organic matter into bacterial biomass for subsequent utilisation as a food source by protozoans. Protozoans then excrete inorganic phosphate as a waste product of their metabolic product. From field studies it was seen, microheterotrophs appear to account for the largest fraction of regenerated nitrogen in most environments.

Phytoplankton excrete, on the average, about 10-20% of their production as dissolved organic matter. Phytoplankton have been shown to excrete significant quantities of dissolved organic phosphorus. Natural phytoplankton population excretes as much as 10% of the inorganic nitrogen they assimilate with the doubling of population time.

2. REVIEW OF LITERATURE

A series of papers reviewing the hydrography of backwaters are available mainly based on temperature and salinity distribution (Balakrishnan, 1957; George and Kartha, 1963; Ramamritham and Jayaraman, 1963) and on seasonal abundance of zooplankton (George, 1958). Considerable work on the hydrography has been carried out by Qasim et al. (1967, 1968 and 1969) on the various aspects of productivity, solar radiation, tidal range, chlorophyll and nutrients. The plankton production and environmental parameters have been reported by Pillai et al. (1975) and Nair et al. (1975).

The importance of physical and biotic scaling to the experimental simulation of a coastal marine ecosystem have been studied by Perez et al. (1977). The environmental characteristics of the seasonal and perennial prawn culture fields in the estuarine systems have been studied by several workers (Suseelan, 1978; Gopinathan, et al., 1982). Effects of various physico-chemical factors on pond productivity was studied by Singha (1983).

A series of papers reviewing the abundance and distribution of nutrients are available (Atkins, 1930; Cooper, 1933; Ryther and Dunstan, 1971; Bodungen, 1986). Nutrients and plankton of the Killai backwater and the adjoining waters were studied by Sundararaj and Krishnamurthy (1973). While a large amount of data have accumulated on hydrography and nutrients in the Narangasett Bay (Oviatt, Perez and Nixon, 1977), at Sanich Inlet British Columbia (Takahashi et al., 1975), at Loch Ewe, Scotland (Davies et al., 1975), the work has been done by investigators in the marine

microcosms. Recent studies (Propp, 1977) based on large number of samples, reported the exchange of energy, nitrogen and phosphorus between water, bottom and ice in a nearshore ecosystem of the sea of Japan.

The work of Redfield et al. (1937) in the Gulf of Maine and of Armstrong and Harvey (1950) in the English channel provide the basic information of the three fractions of phosphorus containing materials in the sea. In India, investigations on the seasonal variations : the phosphate content of the coastal waters have been conducted by Jayaraman (1951) and Ramamurthy (1953) at Madras, Jayaraman (1954) in the Gulf of Mannar and Palk Bay, George (1953) and Subrahmanyan (1959) at Calicut and Qasim et al. (1969) in the Cochin Backwater and recently by Nair (1972) in the Gulf of Mannar. Phosphorus in the sediment may be found in pore water, absorbed to particles, bound to calcium, chemisorbed by ironoxy hydroxides in distinct iron compounds and contained in organics (Syers et al., 1973; Nriagu and Dell, 1974; Williams et al., 1976; Nissenbaum, 1979; Krom and Berner, 1981; D'Silva and Bhosle, 1990).

Although silicate is closely linked to nitrogen and phosphorus in nutrient biological cycles (Richards, 1958; Carlucci et al., 1970), laboratory studies have focussed primarily on re-solution kinetics associated with physico-chemical properties. Grill (1970) have modelled the distribution of silicate in the ocean on the basis of laboratory derived relationship between dissolution and physico-chemical properties. Kinetics of silicate re-solution are similar in magnitude to those of nitrogen and phosphorus had been stated also be species-related (Kamatani, 1971; 1979). Recently Anirudhan and Nambisan (1990) studied the relation between silicon and salinity in the estuarine system of Cochin.

2. REVIEW OF LITERATURE

A series of papers reviewing the hydrography of backwaters are available mainly based on temperature and salinity distribution (Balakrishnan, 1957; George and Kartha, 1963; Ramamritham and Jayaraman, 1963) and on seasonal abundance of zooplankton (George, 1958). Considerable work on the hydrography has been carried out by Qasim et al. (1967, 1968 and 1969) on the various aspects of productivity, solar radiation, tidal range, chlorophyll and nutrients. The plankton production and environmental parameters have been reported by Pillai et al. (1975) and Nair et al. (1975).

The importance of physical and biotic scaling to the experimental simulation of a coastal marine ecosystem have been studied by Perez et al. (1977). The environmental characteristics of the seasonal and perennial prawn culture fields in the estuarine systems have been studied by several workers (Suseelan, 1978; Gopinathan, et al., 1982). Effects of various physico-chemical factors on pond productivity was studied by Singha (1983).

A series of papers reviewing the abundance and distribution of nutrients are available (Atkins, 1930; Cooper, 1933; Ryther and Dunstan, 1971; Bodungen, 1986). Nutrients and plankton of the Killai backwater and the adjoining waters were studied by Sundararaj and Krishnamurthy (1973). While a large amount of data have accumulated on hydrography and nutrients in the Narangasett Bay (Oviatt, Perez and Nixon, 1977), at Sanich Inlet British Columbia (Takahashi et al., 1975), at Loch Ewe, Scotland (Davies et al., 1975), the work has been done by investigators in the marine

Most experimental work on remineralisation of nutrients from particulate and dissolved organic matter has dealt principally with laboratory decomposition studies, beginning with the classical work of Brand, et al.(1937) More direct support for in situ recycling came from observed cyclic appearance of known regenerative forms of these nutrients. In addition, their distribution suggested sites of regenerative activity (Redfield and Keys, 1938). Later studies dealt more quantitatively with the location and magnitude of nutrient regeneration (Riley,1956; Menzel and Ryther, 1960; Ketchum and Corwin,1965). Recent work on the nutrient regeneration and production models (Dugdale,1967; Walsh, 1975; Dugdale, 1977; Jamart et al., 1977) introduced a conceptual frame-work for nutrient limitation of primary production. In India earlier work by Panikkar and Jayaraman (1956) reported distribution and seasonal cycle of nutrients. Variation in the nutrient regenerative and utilization processes in Vellar Estuary have been elucidated (Rajendran and Venugopalan, 1973) using the concept of "preformed" nutrients.

The nutrient regeneration have been studied by several workers (Dugdale and Goering, 1967; Mc Carthy, 1972; Mac Isacc and Dugdale, 1972; Hattori and Wada, 1974). More recent estimates of regenerative fluxes have also relied heavily on indirect methods (Harrison and Hobbie, 1974; Haines, 1975). Eppley et al. (1979) have demonstrated that the "regenerated" production increases simultaneously with new production when upwelling brings nitrate into the euphotic zone of coastal waters. Much of our present knowledge of the location and degree of nutrient cycling in the ocean has come indirectly from observations of the distribution of particulate and dissolved organic matter. This work has been the subject of a number of recent reviews (Riley, 1970; Menzel, 1974; Wangresky, 1978). Within the coastal and oceanic water columns grazing by herbivorous zooplankton has been

considered the most important mechanism for nutrient recycling from particulate organic matter (Steele, 1972; Riley, 1970), although direct microbial degradation may also be important.

Seasonal patterns of nutrient cycling in the coastal ecosystems, are primarily driven by seasonal changes in the physical environment (Wyatt, 1980). Within these constraints, biological process in the pelagic and benthic and geochemical reactions at the sediment water interface take different shape of various extent in the nutrient distribution in water column (Morris et al., 1981). Rutgers Vander Loeff and Es Van (1981) has determined the relationship between oxygen and nutrient exchanges and to qualitatively evaluate the influence of these exchanges on the nutrient budgets of the estuary. Recent work on nutrient regeneration (Wangresky and Wangresky, 1980; 1981), suggest that the transport of nutrients from deeper, nutrient-rich water column is discontinuous and occurs largely during mixing events. Estimates of regeneration often expressed as percentage of nutrient requirements of pelagic autotrophs, vary over a wide range (Fisher et al., 1982).

Wangresky and Wangresky (1983) has suggested the concept of competitive exclusion has little real meaning in a universe where success is gaining and using nutrients depends upon distance from sources of regeneration. Nutrient regeneration in the Deep Baffin Bay with consequence for measurement of the conservative tracer NO (Nutrient-Oxygen relationship) and fossil fuel Co_2 in the oceans has been studied by Jones et al. (1984) Nutrient cycling in a microflagellate food chain has been studied by Goldman et al. (1985), Caron et al. (1985). Investigations carried out in shallow water areas in the Northern Wadden sea (Asmus, 1986) showed nutrient flux. Recent work on the annual cycle of nutrients in relation to biological process

and seasonality of the physical environment of a coastal ecosystem (Bodungen, 1986) has showed distinct pattern of nutrient cycling.

In aquatic systems, the limiting material resource is a dissolved nutrient (N, P and C) which is converted to particulate form by plant growth. Transport of the dissolved element can only be effected by movement of the environment itself whereas particles can move selectively through the environment. In aquatic systems, all essential materials can potentially be recycled between primary and secondary producers in the productive surface layers (Smetacek, 1985b). Recent work on the nutrient enrichment in the laboratory with surface water from Laholm Bay (Graneli et al.,1986) indicated the phytoplankton is nitrogen limited. At longer time scales, the entire ocean is a recycling system through which a flux of material from one part of the lithosphere to another runs. In this the organisms have had a profound influence in changing the chemistry of the atmosphere and oceans over a Geological time scale (Holland et al., 1986).

Phosphorus is one of the nutrients limiting plant growth in natural waters contrary to the open ocean, phosphorus cycling in estuaries and coastal sea areas are influenced by river in put in both dissolved and particulate form, contribution of sewage and the intensive contact of water masses with the underlying sediments. Thus phosphorus in shallow sea areas is subject to both biological and the physico-chemical control (Einsele, 1938). In recent years there has been an increasing awareness that eutrophication may occur in coastal areas and even in open parts of semi-enclosed seas. Oxygen deficiency in the deeper parts of the Baltic Sea is probably, to a large extent caused by man through a several-fold increase in the input of phosphorus and nitrogen (Larson et al., 1985).

The dynamics of this "regenerative" system were described for nitrogen regeneration in the Long Island sound by Harris (1959). Several reviews have done on the nitrogen cycling, dealing with individual cycling, individually with mineralisation (Klump and Martens, 1983), nitrification (Kapalan, 1983) and denitrification (Hattori, 1983), rates of nitrification, denitrification and nitrogen fixation (Blackburn, 1986). Literature values on benthic denitrification span a wide range (Hattori, 1983; Seitzinger and Nixon, 1985). Nitrogen fixation adds algal available nitrogen to the ecosystem. Capone (1983) has gathered measurements made in estuarine sediments.

In Narrangasett Bay the increase in phosphate in summer, when inorganic nitrogen is still virtually zero, is more marked than in Laholm Bay (Kremer and Nixon, 1978). Smith (1984) and Smith et al. (1986) have argued that degree of nitrogen versus phosphorus limitation of net production in the ecosystem reflects the degree of confinement of the system. The fundamentals of the sedimentary nitrogen cycles are well known. Phytoplankton cells fall to the sediment surface, the sinking of diatom bloom is thought to be a normal part of diatom life cycles (Smetacek, 1985). The cellular organic-N is mineralised to ammonium some ammonium is oxidised to nitrate, ammonium and nitrate leave the sediment and are potentially available to allow further phytoplankton growth to occur nitrogen being a limiting nutrient (Wheeler, 1983). The rate of organic-N sedimentation is usually measured by the use of sediment traps (Wassman, 1985).

Dissolved organic nitrogen (DON) is a component which is widely discussed among the Baltic sea oceanographers. It consists of an unknown mixture of organic compounds, mainly formed by the autolysis of cells, exudation and excretion, and also from the land-based humic substances

(Pountanen, 1985). Jackson and williams (1985) have estimated that the labile fraction is only five to twenty percentage of dissolved organic nitrogen. Leppanen et al. (1986) studied changes in dissolved inorganic nitrogen, particulate nitrogen and dissolved organic nitrogen.

Recent work on the inorganic N/P(nitrogen/phosphorus) ratio (Chiaudani and Vighi, 1974; 1976; Forsberg, et al., 1978) have suggested an inorganic-N/P ratio of less than 11 indicates nitrogen limitation of phytoplankton biomass, between 11 and 27 both elements or another factor limit and for N/P 27, P is limiting. Explanation for the apparent storage of nitrogen in the bay may be that the element is lost through denitrification. This is indicated by a low N/P-flux ratio from sediments in the Kattegat, although these measurements were made outside the area investigated by Nixon (1981) and Blackburn and Henriksen (1983).

the fact that N:P ratio only vary about a factor of two in the world's ocean is a reason for surprise if one considers the widely differing geochemistries of these elements. Biological maintenances of this ratio is generally accepted, particularly by geologists who consider phosphorus distribution to be primarily controlled by its geochemistry but that nitrogen geared to phosphorus by organisms (Smith, 1984). Besides benthic denitrification zooplankton grazing may cause a lowering of the inorganic-N/P supply ratio in surface waters. Bamstedt (1985) found an N/P excretion ratio of 9.2 for zooplankton from the Swedish west coast.

The energy flow in marine benthic environments is fuelled by the input and degradation of organic matter. These processes have been evaluated in order to describe the cycling of organic carbon in coastal sediments of the Baltic sea (Smetacek et al.,1978). Recent work on benthic regeneration

to nitrogen requirements for primary production (Martin, 1968; Carpenter et al., 1969; Whiteledge and Packard, 1971; Jawed, 1973; Eppley et al., 1973; Nixon et al., 1976; Biggs, 1977; Rowe et al.,1975;Smith and whiteledge 1977; Smith, 1978; Walsh, et al., 1978; Dag et al., 1980). Nutrients released through benthic community metabolism have been considered an important source for primary producers in coastal waters (Davies, 1975; Rowe et al., 1975; Hartwig, 1976; Rowe and Smith, 1977).

Earlier work (Panikkar and Jayaraman, 1956) reported problems of productivity and compared the production of the two coast lines of India. The effect of light on photosynthesis has been studied by various authors notably by Steele (1962), Vollen Weider (1965), Bannister (1974) and more recently Hameedi (1977). The physical environment has an important influence on the size composition of primary producers in plankton communities (Landry, 1977). Van Es (1977) made comparison between in situ primary production, import from natural sources and organic waste discharge in terms of organic carbon. Recent work on primary production and organic matter, fluctuations in biomass (De Wilde and Kuipers, 1977) in a large indoor tidal mud flat ecosystem reveals the systems to be self pertaining and fairy stable. The coastal zones have long been known as regions of higher productivity and with a faster cycling time for the organic materials produced, but very little increase in standing crop of dissolved organic carbon. Studies have shown that phytoplankton may decompose more rapidly than zooplankton or zooplankton faecal material (Iturriga, 1979).

Recent research on the cycle of organic carbon in sea water (Wangresky, 1983) have brought into estimates of several important rates. According to him the current estimates of the rate of primary production

and nutrient regeneration may be too low, at least in past probably because of under estimate of the rate of exudate release by phytoplankton. The actual value found for primary productivity may depend largely on the time since the last episode of turbulent mixing.

Pomeroy and Johannes (1966), Johannes (1968) were first to suggest that microplankton were an important component of planktonic metabolism in the marine ecosystem. The importance of zooplankton in regeneration of nutrients for primary production was not quantitatively considered until recently (Harris, 1959; Ketchum, 1962). Corner and Davies (1971) have published review of research on the physiology of zooplankton excretion. Recent work on the Algal excretion (Hellebus, 1965; Fogg, 1966; Prochazkova et al., 1970; Mc Carthy and Eppley, 1972; Schell, 1974; Williams, 1975; Wangresky, 1978) have suggested that phytoplankton appear to have a relatively minor direct role in nutrient cycling in the marine ecosystem. Recent studies in productive inshore waters have not sh own the important macrozooplankton contribution earlier described by Smith (1978). Smetacek (1985a) reviewed the literature that deals with the causes and effects of the sinking out of phytoplankton.

Smetacek (1985b) has argued that diatom blooms commence rapid sinking following mucous secretion and resultant enmeshment of the chains into loose aggregates with higher sinking rates than individual chains. Support for this assumption is derived from numerous observations of the rapidity with which bloom diatoms and their identifiable remains vanish from the surface layer following the bloom crash (Smetacek, 1984; Davis and Payne, 1984). Most of the work on plankton bloom and sedimentation has been reported by Smetacek (1979; 1980; 1981; 1985a; 1985b), Smetacek et al.(1984).

The general implication that microheterotrophs accounts for the bulk of planktonic respiration, phytoplankton grazing and nutrient regeneration have been supported in more recent studies (Harrison, 1978; King et al., 1978; Caperon et al., 1979; Jackson, 1980). A detailed investigation of production, sedimentation and plankton biomass and composition in relation to the physico-chemical environment was conducted by Noji et al. (1986). Investigation on copepods by Smetacek and Pollenhe (1986) suggested that copepod feeding is the primary source of the detritus and that establishment of this pool is of survival value to the copepod population.

Many organisms have been shown to return simple inorganic nutrients to the oceans (Pomeroy et al., 1963; Johannes, 1964; 1965; Barlow and Bishop, 1956; Hargrave and Green, 1968; Jawed, 1969). In the long run, bacterial activity must be the most important factor in nutrient regeneration. The few studies which have been made certainly demonstrate the importance of bacteria to normal phytoplankton growth through much of the year (Watt and Hayes, 1963; Sen Gupta, 1968). Recent work on the role of bacteria in nutrient regeneration (Johannes, 1965; Banse, 1974; Faust and Correl, 1976; Eppley, et al., 1977; Sorokin, 1978) have suggested that bacteria are important in recycling of nutrients.

Pomeroy (1974) drew attention to the necessity of changing the simple food chain paradigm by stressing the importance of bacteria in the system. Bacterial break down of carbohydrate can only proceed in the presence of sufficient essential elements (Fenchel and Blackburn, 1979); thus, if there are in short supply, bacterial growth is also limited by the same elements limiting phytoplankton growth; in both cases, energy supply is in excess. Evidence has been obtained from enclosure experiments with natural

populations suggesting that bacterial activity in regenerating system can well be regulated by the rate of supply of the limiting element (Smetacek et al., 1982).

Ever since the early work by Putter (1909), the question of uptake and use of dissolved organic matter by the larger organisms has been debated in the literature. Wangresky (1977) was given a detailed account of distributions of particulate matter in the oceans, both in time and space. Recent work on the dissolved organic matter (Ogura, 1970; Menzel, 1974; williams, 1975) have suggested that although dissolved organic concentrations are 10 to 20 times higher than particulate concentrations, the bulk of the dissolved constituents are refractory. Most of the work on particulate carbon, organic carbon, particulate carbon, organic matter has been studied and reported in a series of papers by Wangresky (1974; 1977; 1978) and Gordon et al. (1979). Following the decline in total particulate carbon in the after math of the bloom detritus level increase significantly and constitute the bulk of organic carbon in the ensuing regenerating system (Smetacek and Hendriksen 1979). Remineralisation and accumulation of organic matter in the peru upwelling region has been studied by Henrichs and Farrington (1984). Biodegradation rates for organic matter were based on concentration changes of dissolved oxygen and nutrient ions in bell jar experiments and were deduced from flux models (Balzer, 1984; 1985).

3. MATERIAL AND METHODS

The different types of prawn culture farms falling under three broad categories were selected for sampling of water and sediment. They are perennial fields (Station I and II), canals in the coconut grove fields (Station IV and V) and Pokkali fields (Station III and VI). Six stations were selected in the prawn culture fields to collect water and sediment samples at fort-nightly intervals for the period of two years (from January 1986 to December 1987). The investigation was carried out at Narakkal (76°14'E; 10° 03'N) about 10 km north west of Cochin, Kerala (Fig. A). The water samples were analysed for temperature, hydrogen ion concentration, salinity, dissolved oxygen, total alkalinity, total phosphorus, inorganic phosphorus, organic phosphorus, particulate phosphorus, total nitrogen, total inorganic nitrogen, dissolved organic nitrogen, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, particulate nitrogen, primary productivity, chlorophylls, copper, zinc and iron. Sediment samples were analysed for zinc, copper and iron.

The perennial fields chosen were the ponds of Marine Prawn Hatchery Laboratory (MPHL) of CMFRI (Presently Narakkal Research Centre of CIBA), which is separated from Arabian Sea by about 280 m of land strip and is connected by a canal to the Cochin Backwater. The average depth of the perennial field is about 1 m. Two collection sites representing the approximate total area of the perennial fields were selected, keeping in view of various factors, to carry out the seasonal variation studies. These were station I and station II (Fig. A).

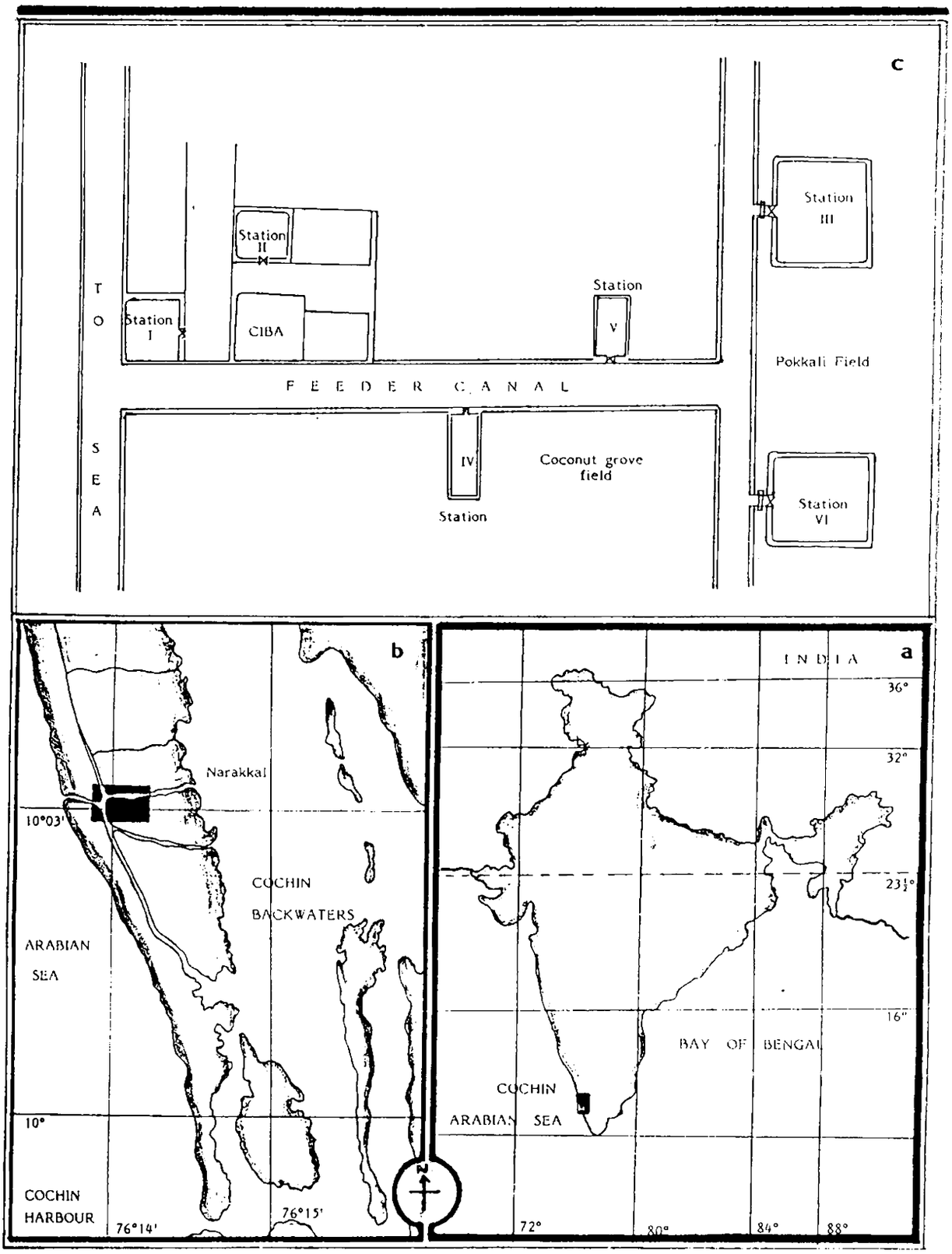

Fig.A. A general lay out of the sampling stations (**c**) Narakkal showing the location of sampling stations (**b**) and map of India showing location of Narakkal (**a**).

The pokkali field is an earthern field, where prawns and paddy are cultured seasonally following the traditional method. The pokkali fields chosen were the ponds with a central canal with an average depth ranging from 0.5 to 1 m at NARAKKAL. Two stations i.e. station III and station VI (Fig. A) were identified for regular sampling of water and sediment in the pokkali field. In the case of pokkali field the sampling was done directly from the prawn culture fields during the months of October to May and rest of the period it was done from the feeder canals, which have been connected to the fields.

The canals in the coconut grove is a typical brackish water environment in a coastal plantation of about 1.5 hectares located at Narakkal. This is connected to Cochin Backwaters through a net work of few canals. The coconut grove canal field had a water depth of 0.50 to 0.75 m. Two statioons representing the environment were selected to carry out the seasonal variation studies. These were station IV and station V (Fig. A).

SAMPLING STRATEGY

Samples of water and sediment were collected sequentially, every fortnight, from each prawn culture fields during high tide period only, as copper concentration is known to vary on a tidal basis (Young et al.,1977). The values for each fortnight were averaged to find the monthly mean at each station.

SAMPLING OF WATER

For oxygen analysis, 125 ml 'Corning' reagent bottle with a BOD stopper was used. The bottles were washed twice with ambient water before

sampling. Care was taken to ensure filling of water into the bottle with air-bubble free unagitated water. Then, the bottle was stoppered inside the water column, 1 ml of winkler A (20% aq w/v Manganese sulphate) and 1 ml of winkler B (4.1 g NaOH + 75 g KI in 100 ml water) were added immediately after removing the stopper of the bottle. Subsequently, the BOD stopper was secured without trapping any air-bubble and the precipitate was dispersed uniformly throughout the bottle by shaking.

Water samples for net primary productivity studies were collected in the same wasy as for the dissolved oxygen but for the addition of winkler A and B using 'light and dark' bottle method. The bottles were stoppered inside the water-column without trapping any air-bubble. Reagent bottles of 125 ml capacity were used as light and dark bottles.

Water samples for temperature, hydrogen ion concentrtation, salinity total alkalinity, phosphorus, nitrogen and silicate were collected in a 2 litre narrow mouth polypropylene bottles precleaned twice with the ambient water. Water sample for chlorophyll was collected in 2 litre wide mouth polypropylene bottles precleaned twice with the ambient water. Samples for copper, zinc and iron were also collected similarly except that these samples were acidified to about pH 4 capped, stored in an ice box (FAO, 1975).

Water samples were analysed for pH immediately after reaching the laboratory. There after water samples were analysed as early as possible for various parameters. Light and dark bottles for primary productivity studies were kept in the shade near window for 3 and 24 hours before analysis

SAMPLING OF SEDIMENT

Sediment samples for copper, zinc and iron were collected with the help of van veen grab lowered from the Dinghy using polypropylene rope. The grab was hauled up once it penetrated the bottom. There upon, sediment samples were collected and stored in polythene bag.

Sediment samples were dried in hot-air oven at 100°C for 24 hours. There upon, sediment samples were cooled to room temperature, powdered with agate mortar, put into small polythene bags properly labelled, sealed and stored in a desicator for metal analysis.

ANALYTICAL METHODS

TEMPERATURE

Temperature of the water body was determined by the help of centi-grade thermometer, graduated in 0-50°C. Thermometer was dipped into water contained in narrow mouth polypropylene bottle, immediately after its sampling at the prawn culture fields and the temperature was recorded.

HYDROGEN ION CONCENTRATION (pH)

Electrometric method with electrically operated Elico-pH meter having a glass electrode and Calomel electrode was used for determination of hydrogen ion concentration values with greater accuracy.

Water samples collected in 2 L polypropylene bottles were used for the determination of hydrogen ion concentration. The instrument was calibrated with the help of pH buffers. After taking pH-meter reading, the *in situ* pH was calculated using the formula (FAO, 1975).

pH in situ = pH measured + 0.0118 (t_2-t_1)

Where,

t_1 = Temperature in situ

t_2 = Measured temperature

SALINITY

Salinity was estimated by precipitating the chloride ions in the water as silver chloride by titrating with standard silver nitrate (FAO, 1975). Water samples collected in 2L polypropylene bottles were used for salinity estimation. It was determined by classical Mohr's titration method. The outline of the method is as follows:

10 ml of water sample was titrated against the silver nitrate solution with potassium chromate as an indicator. Care was taken to arrive at the exact end-point colouration in all the samples and the standardisation titration. Silver nitrate solution was standardised during every set of titration using the standard sea water supplied by the Oceanography Institute, Copenhagen, Salinity was calculated as follows.

$$\text{Salinity of the sample} = \frac{V_1 \times S}{V_2}$$

Where,

V_1 = Volume of silver nitrate for 10 ml standard sea water

V_2 = Volume of silver nitrate for 10 ml sample

S = Salinity of standard sea water.

DISSOLVED OXYGEN

Dissolved oxygen was estimated by Winkler method modified by

Carrit and Carpenter (1966). The outline of the method is as follows (FAO, 1975).

The sample was treated with manganous sulphate and a strongly alkaline iodide reagent. the manganous hydroxide formed reacts with the dissolved oxygen in the sample to form a brown precipitate,manganic hydroxide ($MnO(OH)_2$). Upon acidification in the presence of iodide, iodine is liberated to an amount equivalent to dissolved oxygen originally present. The iodine is then titrated with standard sodium thiosulphate.

125 ml corning reagent bottles having precipitated water sample were used for oxygen analysis. The precipitate was dissolved in the laboratory using 1 ml of 1+1 Sulphuric acid. The sample was titrated against sodium thiosulphate solution. Starch was used as an end-point indicator. Sodium thiosulphate solution was standardised during every set of titration using 0.005 N potassium iodate. Then the dissolved oxygen concentration was calculated using the formula.

$$\text{Oxygen (ml/l)} = \frac{V_1 \times N \times 8 \times 1000 \times R}{V_2 \times 1.429}$$

Where,

V_1 = Volume of sodium thiosulphate

N = Normality of Sodium thiosulphate

V_2 = Volume of water sample taken for titration against the sodium thiosulphate.

R = Correction factor equal to 1.01.

TOTAL ALKALINITY

Alkalinity is defined herein as the quantitative capacity of an aqueous medium to react with hydrogen ions. Total alkalinity was determined by

titration with standard sulphuric acid (APHA, 1980).

To the 20 ml sample solution 3 drops of phenolphthalein indicator was added. If pink colour develops the sample was titrated with 0.02 N H_2SO_4 till it appears colorless (pH 8.3). Volume of H_2SO_4 required for titration was noted (A). Then 3 drops of methyl orange indicator was added to the same sample, titrated with standard sulphuric acid (0.02 N) till orange colour changed to pink. Volume of sulphuric acid required for titration was noted (B). The total alkalinity was calculated as follows:

$$\text{Total alkalinity} = \frac{\text{Total volume of titrant (A+B) x 1000}}{\text{ml of sample}}$$

TOTAL PHOSPHORUS

All phosphorus compounds occuring in sea water was oxidised with peroxy disulphate to phosphates. Different modifications of the procedure were given by Murphy and Riley (1962) and Koroleff (1965). The modified method of Grasshoff (1976) was followed for total phosphorus. The outline of the method is presented below:

To 35 ml sample in a 100 ml Erlenmeyer Flask, 0.35 g of potassium peroxy disulphate was added, and boiled gently in a electric heating mantle until the volume is 5 ml. After cooling it to room temperature, the solution is diluted to 35 ml again with distilled water. Added to it, 1 ml of the acid-molybdate solution (prepared by mixing 200 ml of 9.1 N sulphuric acid with 45 ml of 0.073 m ammonium heptamolybdate solution and then adding 5 ml of 0.1 m potassium antimonyl tartarate solution) and mixed well. Then 1 ml of the ascorbic acid solution was added to it. The blue colour of the sample was measured in the ECIL senior spectrophotometer GS 865D at 882 nm after 5 minutes.

INORGANIC PHOSPHORUS

The phosphate in the water is allowed to react with ammonium molybdate, forming a complex heteropoly acid. This acid is reduced by ascorbic acid, to a blue coloured complex, the light absorption of which is measured in a spectrophotometer. The procedure given below was given by Murphy and Riley (1962).

To 35 ml filtered sample, 1 ml of acid-molybdate solution was added. 1 ml of ascorbic acid solution was added to it. The blue colour of the sample was measured in the ECIL senior spectrophotometer at 882 mm after 5 minutes.

PARTICULATE PHOSPHORUS

Particulate phosphorus was obtained from the difference between the total phosphorus concentration in unfiltered and filtered sample. The method described here is an application of the techniques outlined by Strickland and Parson (1968) and Grasshoff (1983).

Water samples collected in polypropylene bottles were used. Inverted the polythene bottle containing water sample into the millipore filtering equipment containing a 47 mm Millipore filter paper (Pore size of 0.45 micron) under $\frac{1}{2}$ atmosphere pressure vaccum. Drained the filter thoroughly with suction and collected the water for total phosphorus estimation. Total phosphorus estimation. Total phosphorus estimation was carried out using this 'filtered' water sample; same was also done using the unfiltered water sample. The methodology for estimation of total phosphorus was given in the total phosphorus section. Difference between the two readings were recorded as the particulate phosphorus value

ORGANIC PHOSPHORUS

Dissolved organic phosphorus was calculated from the difference between the total phosphorus and inorganic phosphorus concentration in filtered sample. The modified methods of Grasshoff (1976) for total phosphorus and Murphy and Riley (1962) for inorganic phosphorus, were followed.

TOTAL NITROGEN

A method for determination of total nitrogen, the oxidation of organic nitrogen compounds with potassium peroxidisulphate was introduced by Koroleff (1976) and subsequently become recommended procedure for total nitrogen. The basic principle is that the organic and inorganic nitrogen compounds are oxidised under pressure by potassium persulphate in alkaline solution to nitrate. The nitrate is reduced to nitrite and determined spectrophotometrically. The outline method is presented below (Grasshoff, 1983).

Pipetted 15 ml of the sample into an oxidation bottle ("Rollrand flasche mit Bugelverschluss"). Then 10 ml of the oxidation reagent (prepared by dissolving 5 g potassium persulphate, in 0.15 m sodium hydroxide and then diluting it to a volume of 500 ml with the same solution), was added to the sample, was sealed and mixed well. The bottle was kept in the pressure cooker and boiled under pressure for 30 minutes. Then 0.5 ml of 1.25 M sulphuric acid was added to the sample. The cooled sample was added to 50 ml volumetric flask and one drop of bromothymol blue indicator was also added. Samples were neutralised using the 0.15 M sodium hydroxide. Then were diluted to 50 ml and proceeded the nitrate determination (Nitrate determination is presented below).

NITRATE NITROGEN

To 50 ml of the sample and the blank, 2 ml buffer [prepared by mixing 25 ml phenol solution (prepared by dissolving 46 g phenol in 100 ml of water) and 25 ml of sodium hydroxide solution (prepared by dissolving 29 g of sodium hydroxide in 2000 ml of water) and 1 ml reducing agent (prepared by mixing 25 ml of copper sulphate solution (prepared by dissolving 100 mg of copper sulphate in 1000 ml of water) and 50 ml of hydrazine sulphate solution (prepared by dissolving 14.5 g of hydrazine sulphate in 2000 ml of water] rapidly. The flasks were kept away from sunlight in dark place for 20 hours.

To the reduced solution added 2 ml acetone after two minutes added 0.5 ml of sulphanilamide solution (prepared by dissolving 8 g of sulphanilamide in a mixture of 80 ml of concentrated hydrochloric acid and 420 ml of water). After 2 minutes 0.5 ml of N-(1 Naphthyl) ethylene diamine solution (prepared by dissolving 800 mg of N N E D in water and making up to 500 ml) was added to the sample. The absorbance was measured against the blank in the ECIL Senior Spectrophotometer GS 865D at 545 nm.

PARTICULATE NITROGEN

Particulate nitrogen was concentrated for analysis by filtering 250 ml of water sample through Millipore membrane filter (Leppanen et al.,1986). water samples collected in polypropylene bottles were used. 250 ml water sample were filtered through into the Millipore filtering equipment containing a 47-mm Millipore filter paper (pore size 0.45 micron) under % atmospheric pressure vaccum. After draining the filter thoroughly, the filter was used for the estimation of particulate nitrogen. The analysis was made in the

same way as for total nitrogen described by Koroleff (1976).

NITRITE NITROGEN (No_2-N)

Water samples collected in polypropylene bottles were used. Nitrite was determined by the Azo-dye method (Bendschneider and Robinson, 1952). The determination is based on the classical Griess's reaction in which the nitrification at pH 1.5-2.0 is diazotised with Sulphanilamide, resulting in a diazo compound, which in turn is coupled with N-(1-Naphtyl)-ethylene diamine to form a highly coloured azo-dye with an absorption maxima at 545 nm that is measured spectrophotometrically.

To 25 ml of the sample and blank sample, 0.5 ml sulphanilamide reagent was added. After 3 minutes 0.5 ml N N E D was added to the sample. The absorbance was measured against blank in the ECIL senior spectrophotometer GS 865D at 545 nm.

AMMONIA NITROGEN (NH_3-N)

Ammonia was determined following the phenol-hypochlorite method (Soloranzo, 1969). In a weakly alkaline solution ammonia reacts with hypochlorite to form monochloramine, which in the presence of phenol, catalytic amounts of nitroprusside ions and an excess of hypochlorite yields indophenol blue. The following methodology was employed in the analysis.

To 50 ml of the sample and blank, successively, 2 ml of phenol solution (prepared by dissolving 10 g of phenol in 100 ml methanol) and 2 ml of 0.5% sodium nitroprusside solution (prepared by dissolving 1 g sodium nitroprusside in 200 ml distilled water) were added. To the sample 5 ml

oxidizing reagent (prepared by mixing 100 ml alkaline solution (prepared by dissolving 100 g trisodium citrate and 5g of sodium hydroxide in 500 ml of water) and 25 ml of sodium hypochlorite solution which was more than 1.5 N) was also added mixing thoroughly after each addition. The colour was allowed to develop at room temperature for 1 hour. The absorbance was measured against the blank in the ECIL senior spectrophotometer GS 865D at 640 nm.

TOTAL INORGANIC NITROGEN (TIN)

Total inorganic nitrogen was calculated from the sum of nitrate nitrogen, nitrite nitrogen and ammonia nitrogen. The formula was taken from Leppanen et al. (1986) and Bodungen (1986).

$$\text{Total Inorganic Nitrogen(TIN)} = \text{Nitrate nitrogen } (No_3\text{-}N) + \text{Nitrite nitrogen } (No_2\text{-}N) + \text{Ammonia nitrogen } (NH_3\text{-}N)$$

DISSOLVED ORGANIC NITROGEN (DON)

Dissolved organic nitrogen was calculated from total nitrogen by substracting the sum of total inorganic nitrogen and particulate nitrogen. The formula for the calculation of dissolved organic nitrogen was taken from Leppanen et al. (1986).

$$\text{Dissolved Organic Nitrogen(DON)} = [(\text{Total Nitrogen (TN)} - \text{Total Inorganic Nitrogen (TIN)} + \text{Particulate nitrogen(PN)}]$$

SILICATE (SIO)

The estimation of dissolved silicon compounds in natural waters is based on the formation of a yellow silicomolybdic acid, when a more or less acidic sample is treated with a molybdate reagent. The method described here was basically taken from Mullin and Riley (1955).

To 25 ml of the sample and blank, 10 ml of molybdate solution (prepared by dissolving 4.0 g of ammonium molybdate in 300 ml of distilled water and added 12 ml of concentrated hydrochloric acid (12 N), mixed and made to volume of 500 ml with distilled water) was added. After 10 minutes to the sample, the reducing reagent [prepared by mixing 100 ml of metol sulfite in 500 ml of distilled water and added 10 g of metol), 60 ml of oxalic acid solution (prepared by dissolving 50 g of oxalic acid in 500 ml of distilled water) and 60 ml of the 50% sulphuric acid (250 ml distilled water + 250 ml concentrated sulphuric acid)] was added rapidly to made 50 ml. The solution was allowed and to stand for 2 hours to complete the reduction. The absorbance was measured against the blank in the ECIL senior spectrophotometer GS 865D at 810 nm.

METALS

The determination of trace elements in seawater has received increasing attention and use of modern instrumental methods is beginning introduced to produce significant success in this field. Sprague and Slaving (1964) have shown that a number of elements may be separated from 25% of potassium chloride solutions by extraction of their complexes with ammonium pyrollidine dithiocarbamate (APDC) into methyl isobutyl Ketone (MIBK). Metals was determined following the MIBK-APDC extraction method (Brooks et al., 1967).

Perkin-Elmer 2380 Atomic Absorption Spectrophotometer (AAS) incorporated with automatic curve correction microprocessor technology was utilized for metal analysis. The light source used was an intersitron Hollow Cathode Lamp (HCL). Air-acetylene was the oxidant-fuel combination with a compatible 10 cm burner head and an impact bead of pyrex. The instrument was used for analysis subject to the operational as well as standard conditions laid out in the Perkin-Elmer manual.

PREPARATION OF STOCK STANDARD SOLUTIONS

COPPER (1000 mg/L)

1 g of Copper metal was dissolved in a minimum volume of (1+1) HNO_3 diluted to 1 liter with 1% (v/v) HNO_3.

ZINC (500 mg/l)

0.5 g Zinc metal was dissolved in a minimum volume of (1+1) hydrochloric acid and diluted to 1 litre with 1% (v/v) Hcl.

IRON (1000 mg/l)

1.00 g iron metal was dissolved in 50 ml of 1+1 HNO_3 and diluted to 1 litre with 1% (v/v) HNO_3.

PREPARATION OF DILUTE WORKING STANDARD SOLUTION

Prepared suitable dilute standards from the stock solutions described under the standard conditions for each element, adjusting the pH of standard to pH 4.0 with hydrochloric acid. Added incremental amounts of these dilute standards to the distilled water (containing 1% lanthanum in the case

of calcium) to prepared working standards containing 0, 2, 5 and 10 µg/L of the elements of interest.

In case of copper and zinc, the incremental amounts of their dilute standards are added to the extracted seawater to prepare the working standards containing 0, 2, 5 and 10 µg/L of the element of interest. To 750 ml of the working standard, added 20 ml of methyl iso-butyl ketone (MIBK) and then 7 ml of the 1% Ammonium pyrolldine dithiocarbamate (APDC) solution, and equilibrated for 30 minutes on a mechanical shaker. The organic layer in polypropylene bottle was separated and analysed within 3 hour of extraction.

The working standards were prepared fresh every time and were used as calibration as well as check standards.

ANALYSIS OF METALS IN WATER SAMPLES

COPPER, ZINC AND IRON

Acidified water samples (pH 4.0) contained in 2 L narrow mouth polypropylene bottles were used. Water sample was filtered through 47-mm Millipore filter paper (pore size 0.45 micron). An aliquot of 750 ml was taken in 1 L polypropylene flask and added 35 ml of MIBK followed by 7 ml of 1% APDC solution (W/v) in distilled water (prepared the APDC solution with an equal volume of MIBK, allowed the phase to separate and retained the aquous phase and equilibrated for 30 minutes on a mechanical shaker. the organic layer was separated in a polypropylene bottle. It was aspirated and analysed preferably within 3 hours of extraction and the aquous layer was saved for the preparation of standard solutions. The slit width

was 0.7 mm for copper, zinc and iron. The operating wavelengths for copper, zinc and iron analysis were 324.8 nm, 213.9 nm and 248.3 nm respectively. The concentrations were then calculated as follows.

Element (µg/ml) = (µg/ml in sample solution). (d.f.)

Where,

d.f. = dilution factor, if used

$$= \frac{\text{final volume of diluted aliquot}}{\text{volume of aliquot taken for dilution.}}$$

ANALYSIS OF METALS IN SEDIMENT SAMPLES

1 g of the dried and finely powdered sediment sample was ignited in silica crucible at 700°C for 24 hours. Thereafter, sediment was cooled to room temperature and transferred to 100 ml beaker. 10 ml (1+1) of Hcl was added to it and heated at 60-80°C for one hour. Decanted the supernatant into a 250 ml volumetric flask and retained. 10 ml aqua-regia and was added to the residue and evaporated to dryness in a fume-hood. Repeated the addition of aqua-regia and evaporated to dryness. The residue was dissolved in a minimum amount of Hcl and transferred to a 100 ml beaker along with acid extract. Diluted it with distilled water, filtered and made to volume in a 250 ml volumetric flask.

The processed sample solution was diluted, whenever necessary with distilled water to bring the concentration of the element of interest into a suitable concentration range. then APDC-MIBK extraction was carried out. The procedure followed for analysis of copper, zinc and iron was same as described for metal analysis of water.

While carrying out analysis, the following additional precautions were taken:

Interferences (i.e. chemical, ionization and matrix) and background absorption, if any, were corrected after checking the standard conditions. In case of matrix interferences, standards were matched, as closely as possible to the samples. Always used deionised double glass distilled water. Proper number (usually two) of calibration standards were used and also checked the standards (falling in the middle of the range being covered by calibration) to make sure that the analysis was accurate. The blank was a representative of the sample matrix. Whenever sample was digested, the blank contained all the reagents were used in the sample preparation. The burner and the burner head assembly was cleaned regularly.

ESTIMATION OF PRODUCTIVITY

The methods used for the estimation of primary productivity were the light and dark bottle method of Gaarder and Gran (1927) and ^{14}C method of Steeman Nielsen (1952) modified by Wolfe and Schelske (1967). During the first year of study (1986) light and dark bottle method was followed for the estimation of primary production. During the second year (1987) more accurate ^{14}C technique was followed for the estimation of primary production.

(i) LIGHT AND DARK BOTTLE METHOD

Primary productivity was estimated by measuring release of oxygen which dissolved into surrounding water resulting in increase of oxygen during photosynthesis and was computed by measuring the dissolved oxygen at the

beginning and at the end of the incubation period.

After keeping laboratory for 24 hours the water samples collected in light and dark bottles were fixed using Winkler A and Winkler B solutions. the differences between light and initial bottles were taken as net production. The calculation was done as follows:-

$$\text{Net primary production} = \frac{V_{LB} - V_{IB} \times 0.536}{PQ \times N} \text{ mg C/m}^3\text{/day.}$$

Where,

V_{LB} and V_{IB}	=	Quantity of sodium thiosulphate titre values obtained from the titration of light and initial bottles respectively.
N	=	Is the incubation period
PQ	=	Photosynthetic quotient, 1:2
0.536	=	Factor to convert mg of O_2 to mg C

(ii) ^{14}C TECHNIQUE

Primary production was estimated by radioactive carbon technique of Steeman Nielsen (1952) and as modified for scintillation counting by Wolfe and Schelske (1967). A known amount of radioactive carbonate is added to a sample of water of known total carbonate content. After photosynthesis by the endemic phytoplankton population has continued for a specific time period, the phytoplankton cells are filtered on to a membrane filter, washed, and radioactivity from the carbon in the plants is measured with a suitable scintillation counter. The uptake of radioactive carbonate, as a fraction of the whole, is assumed to measure the uptake of total carbonate as a fraction of the whole, and based on this, the rate of photosynthesis was

evaluated. The outline of the method is presentedbelow.

Special apparatus

(i) 25-mm diameter manifold filtering unit, fitted with funnel to hold the entire water sample.

(ii) 25-mm Millipore filter paper (pore size 0.45 micron)

(iii) Scintillation vials (ECIL), suitable for dissolving Millipore filters and with low quenching in the presence of small amounts of water.

(iv) Scintillation counter (ECIL)

Special reagents

(i) Radioactive carbonate 5 Curie (Ci) $Na_2{}^{14}CO_3$ ampoule from BARC.

(ii) Scintillation fluid

Toluene	-	400 ml
Dioxane	-	400 ml
Ethanol	-	240 ml
Naphthalene	-	50 g
P.P.O.	-	45 g
P.O.P.O.P.	-	100 mg

PROCEDURE

Water samples collected in the 125 ml bottles were used. To 125 ml light and dark bottles 1 ml of 1 μ Ci $Na_2{}^{14}CO3$ was added to each bottle. Samples were incubated for 3 hours. At the end of the incubation period, sample bottles were replaced in black bags. All samples were filtered, using a manifold filtering unit capable of simultaneous filtration of 6 samples at once. Suction applied was 1/3 of an atmosphere during filtration. 25mm

25mm Millipore filter paper (Pore size 0.45 micron) was used to collect the plankton and filters was sucked dry and washed with three small aliquots of filtered water.

Filter paper was removed from the holder while maintaining a vaccum and placed in a scintillation vial containing 10 ml of scintillation fluid. They were allowed to stand overnight after shaking the sealed vial. Vials were counted in scintillation counter. Photosynthesis was calculated using the following equation.

$$\text{Primary production} = \frac{R_S - R_B \times W}{R \times N} \quad \text{mg C/m}^3\text{/hr}$$

Where,

R = The total activity (dpm) of bicarbonate added.

N = Number of hours of incubation

R_S = Sample counter (dpm) corrected for quenching.

R_B = Dark bottle (blank) count (dpm) corrected for quenching.

W = Weight of total carbon dioxide present in mg C/m^3

Total carbondioxide calculation from the total alkalinity as given below.

Carbonate alkalinity = Total alkalinity - 0.05.

Total CO_2 (TC) = 0.96 x carbonate alkalinity.

Wt. of total CO_2 = 1200 x TC.

(iii) CHLOROPHYLL

Chlorophyll is one of the algal pigments and found in three forms viz, chlorophyll a,b, and c in planktonic algae. Chlorophyll 'a' constitutes approximately 1 to 2% of the dry weight of organic material in all planktonic algae and therefore preferred indicator for algal biomass estimation. The modified spectrophotometric method for algal pigments in seawater was described by Parson and Strickland (1963) and new spectrophotometric equations were given by Jefferey and Humphrey (1975).

A known volume of seawater is filtered on to a synthetic filter, pigments are extracted from the filter in 90% acetone and their concentration is estimated spectrophotometrically. The outline of the method is as follows:

PROCEDURE

Water sample collected in 2 L polypropylene bottles were used. To the Millipore filtering equipment containing a 47 mm Millipore membrane filter paper (pore size 0.45 micron) 1000 ml of water sample was added. Sample were allowed to filter under 1/2 atmospheric pressure vaccum. 3 drops of $MgCO_3$ solution (prepared by dissolving 1 g of $MgCO_3$ in 100 ml of distilled water) was added to the sample. The filter was removed from the apparatus and placed in 15 ml centrifuge tube, then 10 ml of 90% acetone (prepared by mixing 100 ml distilled water and 900 ml acetone) was added and stored in a Fridge for overnight. The contents of the tube was centrifuged at room temperature for 10 minutes at 2000 rpm. Then the supernatant was decanted into a spectrophotometer cuvette and measured the extinction at the wave lengths; 750, 664, 647 and 630 nm. The extinction

was corrected by substracting the 750 nm of a small turbidity blank from 664, 647 and 630 nm absorption.

The amount of chlorophyll in the sample was calculated using the following equation.

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

Chlorophyll b (Cb) = $21.03\ E_{647} - 5.43\ E_{664} - 2.66\ E_{630}.$

Chlorophyll c (Cc) = $24.52\ E_{630} - 1.67\ E_{664} - 7.60\ E_{647}$

Where,

E = absorbance at different wave lengths.

Ca,Cb and Co = The amount of chlorophyll in µg/ml

$$\text{mg Chlorophyll/m}^3 = \frac{C \times v}{V \times L}$$

Where,

v = The volume of acetone in ml

V = The volume of the water sample in litres.

C = Amounts of chlorophyll Ca, Cb and Cc.

L = Light path of cell in spectrophotometer.

STATISTICAL ANALYSIS

In order to assess the degree of influence of each environmental parameter and nutrients to the primary productivity, the correlation coefficient was calculated using Personal Computer PB 410 (F), Casio, Japan. Theoretically, a satisfactory dimensionless index of correlation could be obtained by dividing the standard error of the estimate, by the standard deviation of the dependent variable s'. The correlation coefficient that is generally used in statistical analysis is a practical simplification of the above ratio. If 'r' is the coefficient of correlation, the relationship to the index ratio described above is as follows:

$$r^2 = 1 - (SEE)^2 - /S'^2$$

This can be simplified to the formula

$$r = \frac{n \quad xy \; - \quad x \quad y}{n^2 \quad S' \quad S''}$$

Where

SEE = Standard error

S' = Standard deviation of y, the dependent variable.

S'' = Standard deviation of x, the independent variable.

When this coefficient of correlation is used, a value of zero indicates no correlation at all, while the limiting values, +1 and -1 indicate either perfect positive correlation or perfect negative correlation. After obtaining the appropriate coefficient of correlation, the null hypothesis was

tested by assuming that the two sets of data are independent. If the probability of obtaining the observed coefficient by chance is very low (i.e. less than 5%), the hypothesis was rejected and concluded that there is a statistically significant correlation.

4. RESULTS

ENVIRONMENTAL PARAMETERS

TEMPERATURE

The temperature values of the water in each month are presented in Tables 1-3. The temperature values of the water showed fluctuation from 28.00° to 31.90°C in different prawn culture systems. The range in temperature value was between 28.00 and 31.80 in the perennial fields (Station I and II); 28.10 and 31.60 in the coconut grove canal (Station IV and V); 28.00 and 31.90°C in the Pokkali fields (Station III and VI) respectively. Maximum value (31.90) was recorded during the month of May and the minimum value (28.00) was noted during July. The temperature was at its maximum during the pre-monsoon months, extending up to May, after which, with the onset of monsoon it began to decline. During the monsoon and in the early post-monsoon periods the temperature was very low (Figs 1, 2 and 3).

HYDROGEN ION CONCENTRATION (pH):

The Hydrogen ion concentration of the water showed fluctuation between 7.40 and 9.10 in the prawn culture fields. The data on the monthly variation in the pH of the prawn culture stations are summarised in Tables 1-3. Maximum value (9.10) was recorded during August and minimum (7.40) during February. The hydrogen ion concentration of the water in all the prawn culture fields were seen increasing gradually from January and reached a maximum value in August. The pH was at its minimum during the pre-monsoon months, extending upto May, after which it began to increase.

During monsoon and in the early post-monsoon months the pH was very high (Figs. 1, 2 and 3).

SALINITY (SAL)

The data on the monthly variation in the salinity of prawn culture fields are summarised in Tables 1-3. Salinity of the water in all the prawn culture fields showed an upward trend from January to June (21.87 to 33.80‰) but it declined to reach the lowest value of 1.08‰ during September. The salinity of the water in the perennial fields (Station I and II), canals in the coconut grove (Station IV and V) and in the Pokkali field (Station III and VI) varied between 1.10 and 33.90; 1.08 and 33.90; 1.20 and 33.92‰ respectively. Maximum value was recorded during September. During the pre-monsoon season, especially during March-April, the salinity at all stations exhibited considerable increase, while during monsoon values showed decrease (Figs. 4, 5 and 6).

DISSOLVED OXYGEN (DIS O_2)

Dissolved Oxygen values were between a minimum of 2.50 ml/l and a maximum of 6.80 ml/l during August and May respectively. The dissolved oxygen value of water in each month are presented in Tables 1-3. In the perennial field dissolved oxygen value was seen fluctuating between 2.50 and 5.25 ml/l. In the Pokkali field, however, it was relatively higher (2.80-6.81 ml/l). Dissolved oxygen showed a distinct pattern of seasonal fluctuation in the prawn culture fields (Figs. 4, 5 and 6).

Table 1. Seasonal Variation of Environmental Parameters at Stations I & II (1986-87). PRM: Pre-monsoon, Mons: Monsoon; POM: Post-monsoon

PARAMETER		PRM (Feb - May) Min	PRM (Feb - May) Max	MONS (June - Sept) Min	MONS (June - Sept) Max	POM (Oct - Jan) Min	POM (Oct - Jan) Max
S T A T I O N - I							
TEMP (°C)	1986	30.90	31.30	28.20	29.30	28.50	30.40
	87	31.10	31.40	28.60	29.10	29.10	30.70
pH	86	7.70	7.90	7.80	9.10	7.60	7.90
	87	7.80	7.90	7.80	9.00	7.80	8.00
SAL (‰)	86	31.20	33.50	2.30	32.60	4.50	26.70
	87	31.40	33.40	2.10	33.80	4.30	15.50
DIS O_2 (ml/l)	86	3.50	5.25	2.80	3.70	3.50	4.20
	87	3.80	4.30	2.50	3.80	3.65	4.15
TAL (meq/l)	86	2.09	2.24	0.15	2.18	0.30	1.78
	87	2.10	2.23	0.14	2.26	0.28	1.03
S T A T I O N - II							
TEMP (°C)	86	30.40	31.40	28.00	31.40	29.00	30.10
	87	30.90	31.80	28.10	29.50	29.20	30.40
pH	86	7.60	7.90	7.60	9.00	7.50	7.90
	87	7.70	7.90	7.70	8.90	7.50	8.10
SAL (‰)	86	28.10	32.10	1.10	31.80	3.40	24.80
	87	29.20	32.40	1.20	32.40	5.40	14.80
DIS O_2(ml/l)	86	3.65	5.20	2.85	3.65	3.60	4.36
	87	3.50	5.15	2.75	3.40	3.45	4.80
TAL (meq/l)	86	1.88	2.15	0.07	2.13	0.30	1.66
	87	1.95	2.17	0.08	2.17	0.36	0.99

SAL: Salinity; DIS O_2 : Dissolved Oxygen; TAL : Total Alkalinity.

Table 2. Seasonal Variation of Environmental Parameters at Stations III & IV (1986-87). PRM: Pre-Monsoon; Mons: Monsoon; POM: Post-Monsoon

		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
PARAMETER		Min	Max	Min	Max	Min	Max
S T A T I O N - III							
TEMP (°C)	1986	30.20	31.10	28.10	29.50	28.40	30.00
	87	30.40	31.60	28.00	29.40	29.20	30.50
pH	86	7.40	7.80	7.80	8.90	7.40	8.00
	87	7.70	7.90	7.90	9.00	7.40	7.90
SAL (‰)	86	31.20	33.90	1.20	33.40	2.40	26.80
	87	30.80	33.40	1.80	33.90	4.80	14.30
DIS O_2 (ml/l)	86	3.85	6.10	2.95	4.30	3.85	5.20
	87	3.95	6.20	2.80	4.20	4.20	5.10
TAL (meq/l)	86	2.16	2.40	0.08	2.19	0.16	1.79
	87	2.06	2.23	0.12	2.27	0.32	0.95
S T A T I O N - IV							
TEMP (°C)	86	30.30	31.20	28.50	30.50	28.60	30.20
	87	30.70	31.40	28.30	30.30	29.30	30.00
pH	86	7.70	7.90	7.80	9.00	7.80	8.00
	87	7.50	7.90	7.70	8.90	7.50	7.90
SAL (‰)	86	31.26	33.60	1.80	32.73	5.40	26.83
	87	31.52	33.53	2.14	33.90	4.20	13.50
DIS O_2 (ml/l)	86	3.85	6.04	3.08	4.07	3.85	4.62
	87	4.18	4.95	2.75	4.18	4.01	4.56
TAL (mq/l)	86	2.09	2.25	0.12	1.91	0.36	1.79
	87	2.11	2.24	0.14	2.17	0.28	0.90

SAL: Salinity; DIS O_2: Dissolved Oxygen; TAL: Total Alkalinity

Table 3. Seasonal Variation of Environmental Parameters at Stations V & VI (1986-87). PRM: Pre-Monsoon; Mons: Monsoon; POM: Post-Monsoon

		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
PARAMETER		Min	Max	Min	Max	Min	Max
S T A T I O N - V							
TEMP (°C)	1986	30.50	31.20	28.20	30.70	28.40	30.20
	87	30.80	31.60	28.10	30.50	29.50	30.60
pH	86	7.40	7.80	7.80	9.10	7.70	8.00
	87	7.70	7.80	7.90	9.00	7.60	7.90
SAL (‰)	86	25.29	28.69	1.90	28.62	3.06	22.32
	87	26.82	29.16	1.08	29.16	4.32	13.32
DIS O_2 (ml/l)	86	3.51	5.23	2.86	3.67	3.86	4.38
	87	3.81	5.17	2.76	3.42	3.46	4.82
TAL (meq/l)	86	1.69	1.93	0.12	2.23	0.20	1.49
	87	1.76	1.95	0.07	1.95	0.28	0.89
S T A T I O N - VI							
TEMP (°C)	86	30.80	31.50	28.10	30.90	28.80	30.50
	87	31.00	31.90	28.00	30.80	29.50	30.70
pH	86	7.70	7.90	7.90	9.00	7.70	8.10
	87	7.70	7.90	7.80	9.10	7.70	8.00
SAL (‰)	86	30.70	33.92	2.50	32.40	2.90	28.14
	87	31.60	33.30	2.10	33.10	3.80	15.60
DIS O_2 (ml/l)	86	4.23	6.71	3.24	4.73	4.23	5.73
	87	4.43	6.80	3.08	4.62	4.62	5.61
TAL (meq/l)	86	2.21	2.72	0.16	2.17	0.19	1.88
	87	2.16	2.23	0.14	2.27	0.25	1.04

SAL: Salinity; DIS O_2 : Dissolved Oxygen; TAL: Total Alkalinity.

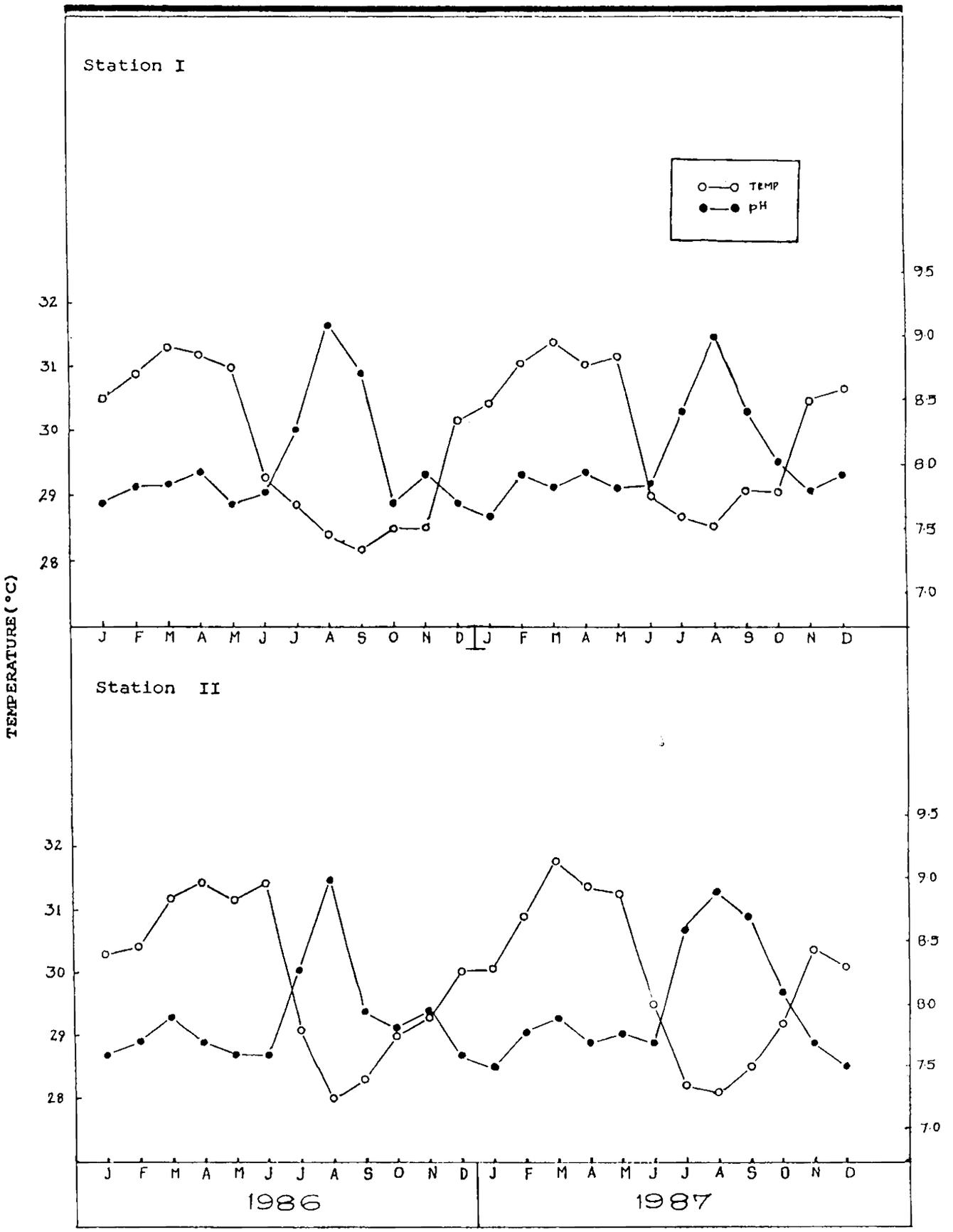

Fig. 1. Seasonal variation in temperature and hydrogen ion concentration (at stations I and II of prawn culture systems during 1986-87.

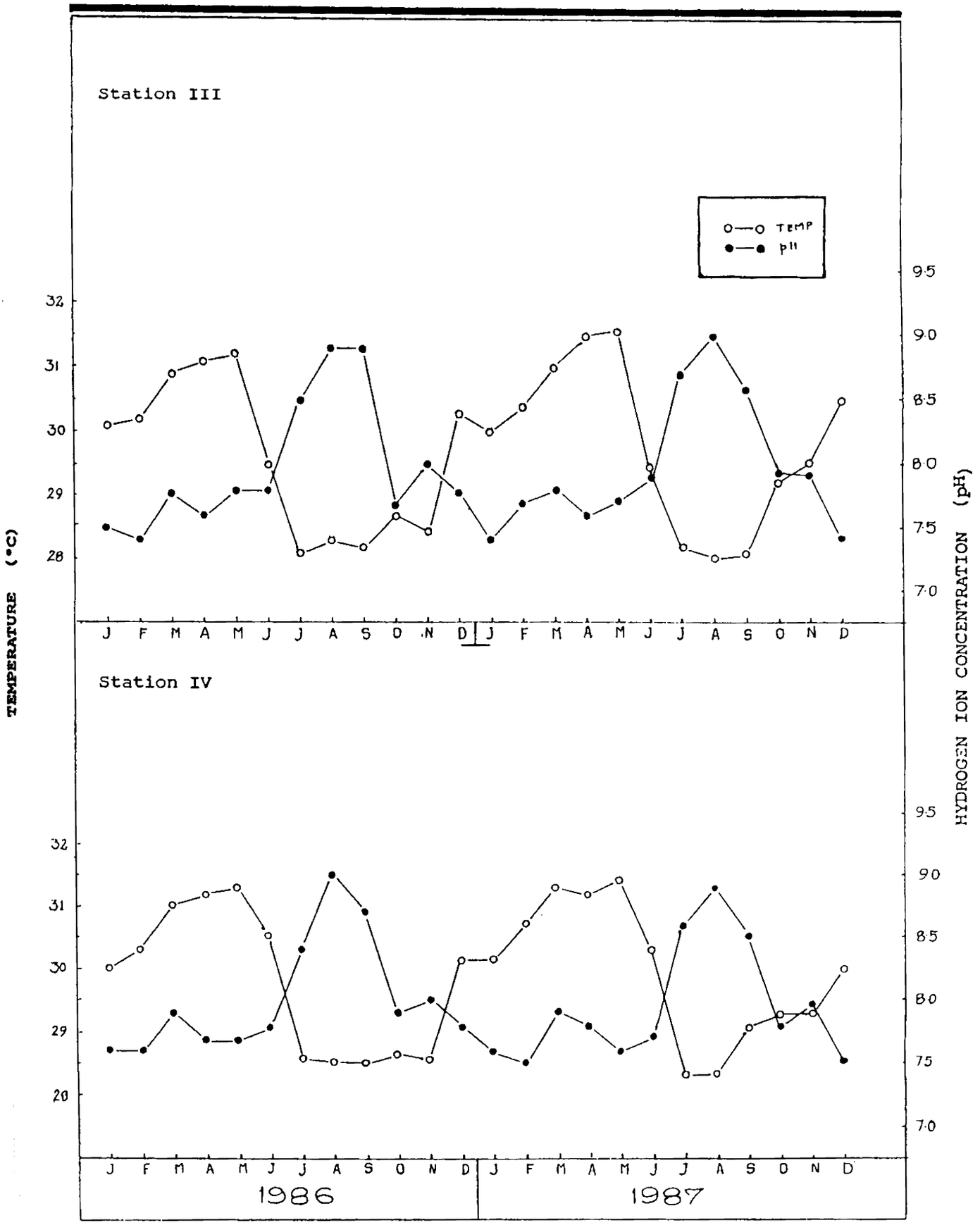

Fig.2. Seasonal variation in temperature and hydrogen ion concentration (pH) at stations III and IV of prawn culture systems during 1986-87.

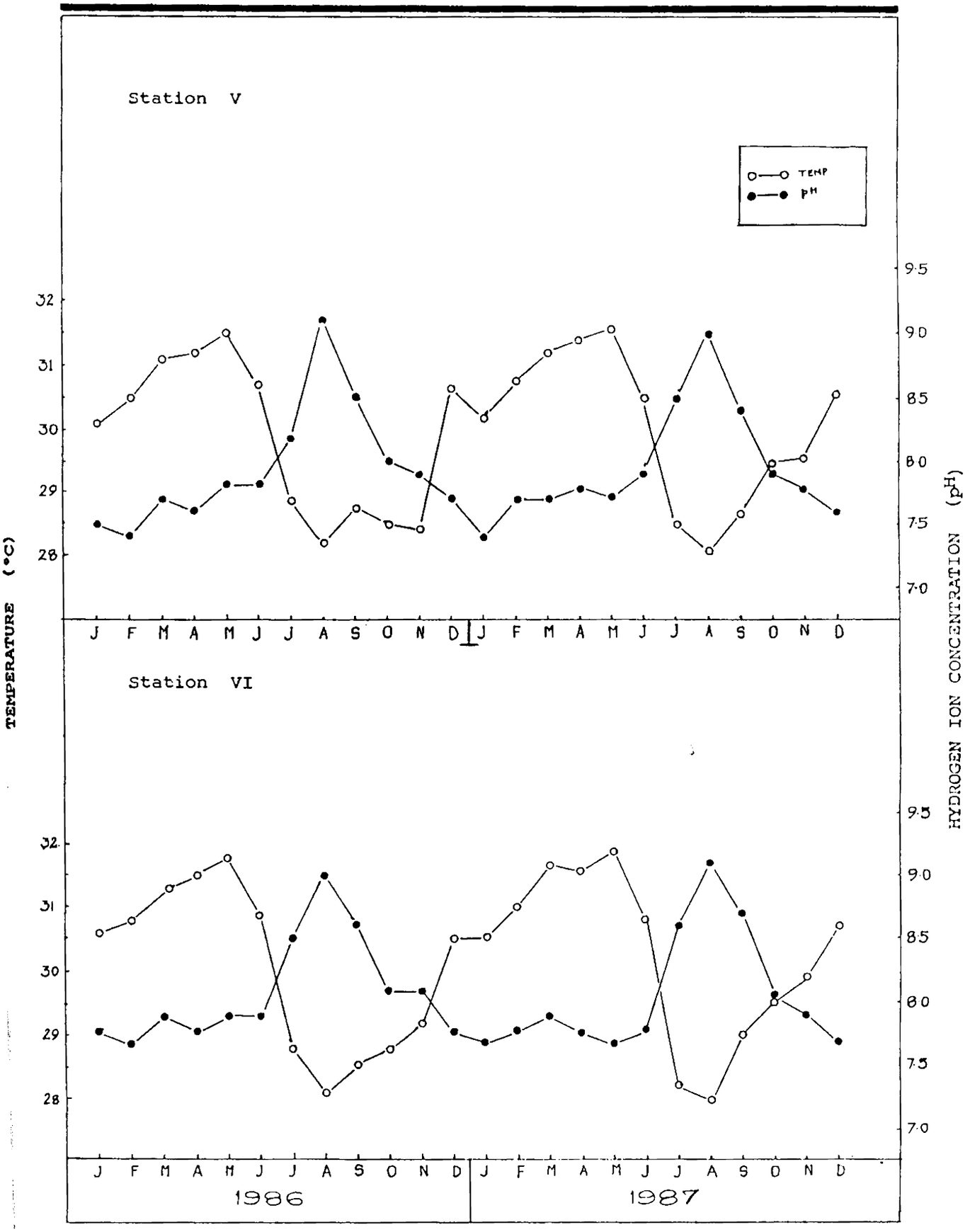

Fig. 3. Seasonal variation in temperature and hydrogen ion Concentration (p^H) at stations V and VI of prawn culture systems during 1986-87.

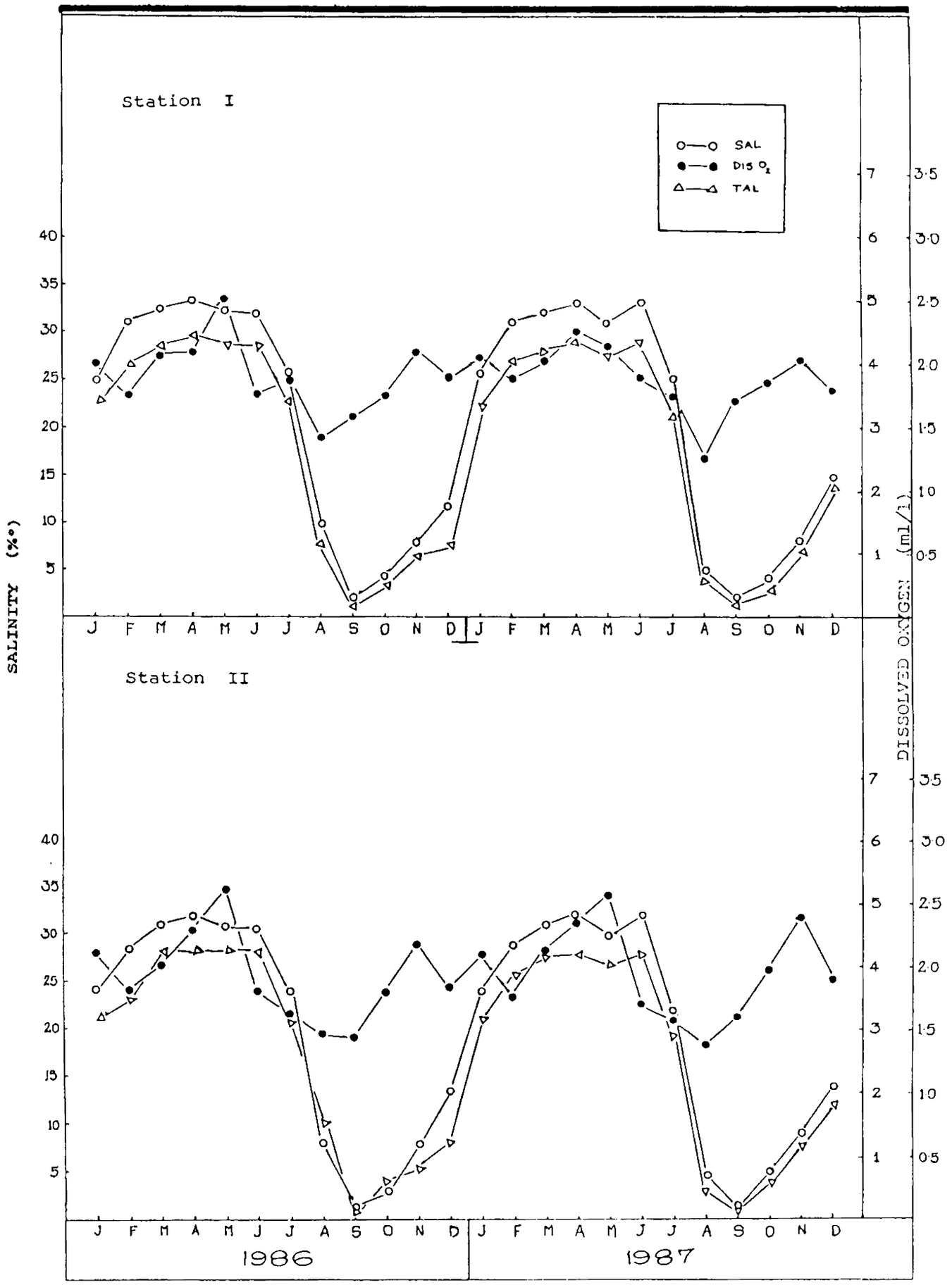

Fig. 4. Seasonal variation in salinity (SAL), dissolved Oxygen (DIS O_2) and total alkalinity (TAL) at stations I and II of prawn culture systems during 1986-87.

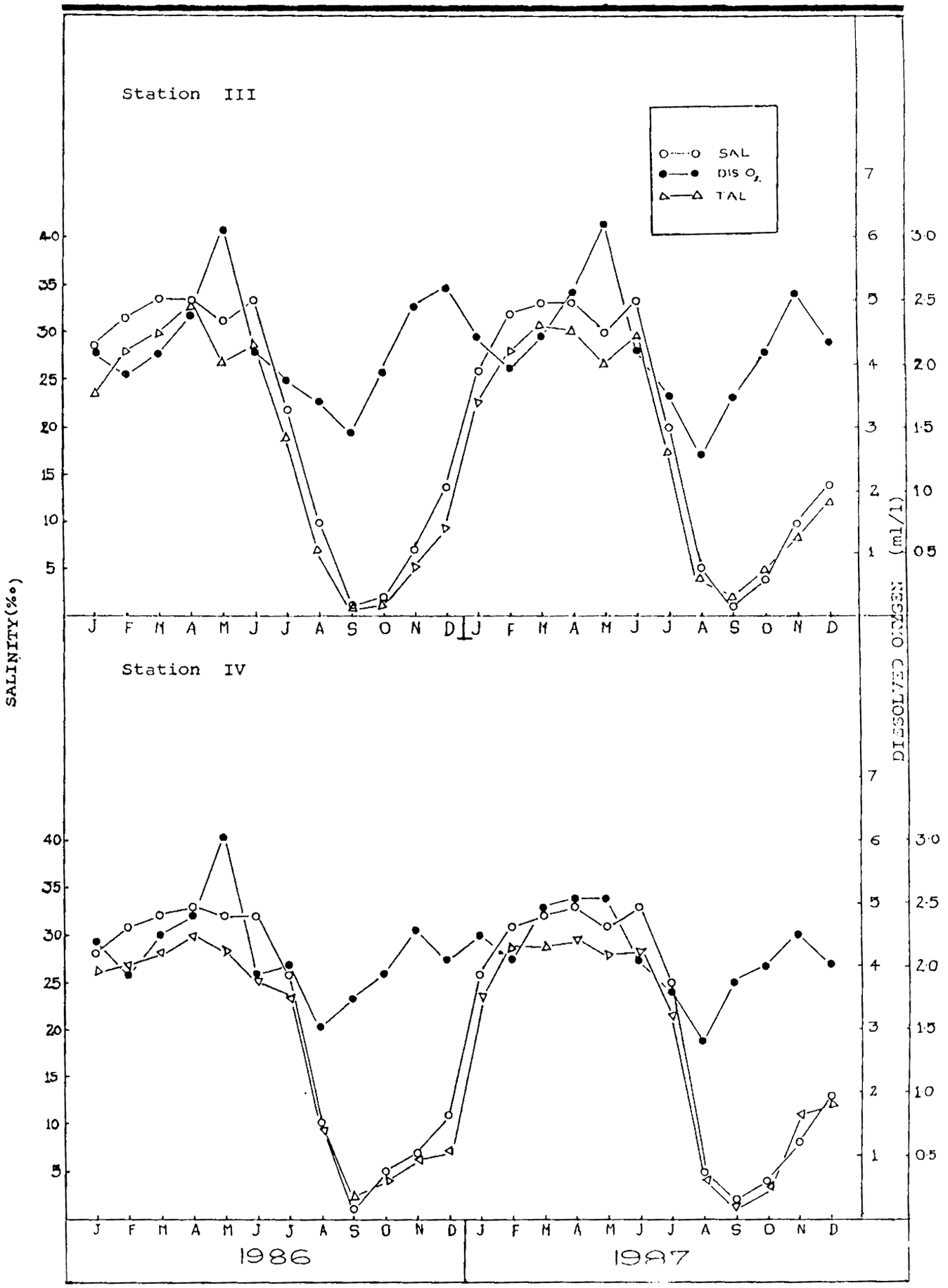

Fig. 5. Seasonal variation in salinity (SAL), dissolved Oxygen (DIS O_2) and total alkalinity (TAL) at stations III and IV of prawn culture systems during 1986-87.

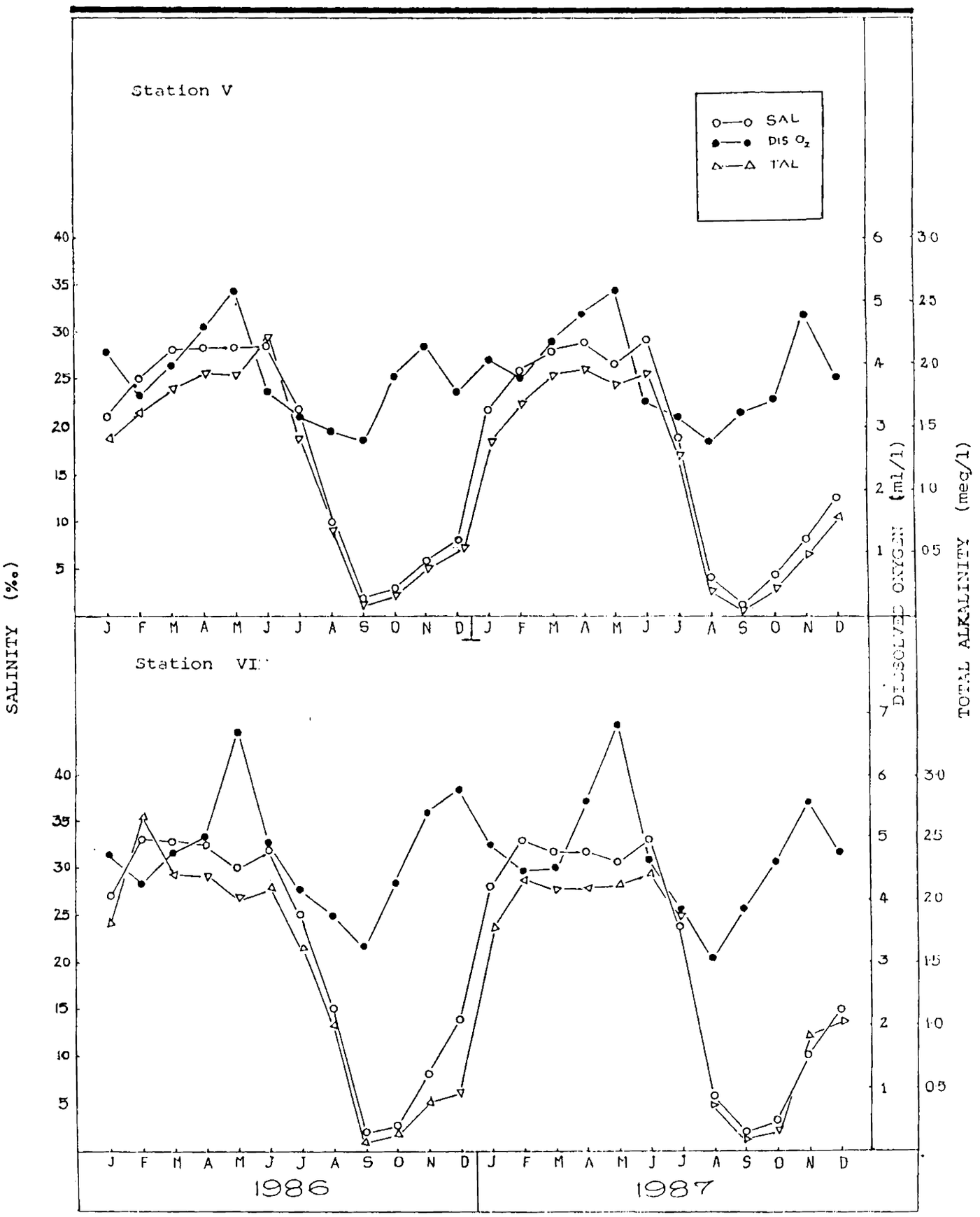

Fig. 6. Seasonal variation in salinity (SAL), dissolved Oxygen (DIS O_2) and total alkalinity (TAL), at stations V and VI of prawn culture systems during 1986-87.

TOTAL ALKALINITY (TAL)

The total alkalinity value of the water in each month are presented in Tables 1-3. The values showed fluctuation from 0.07 to 2.72 meq/l in different prawn culture fields. Maximum value was recorded in the pokkali field during February and minimum value was noted at station V (coconut canal field) during September. The values were found to be high during the pre-monsoon and monsoon months and low during post monsoon months (Figs. 4, 5 and 6).

NUTRIENTS

TOTAL PHOSPHORUS (T.P)

The concentrations of phosphorus in water samples of prawn culture fields are shown in Tables 4-6. The range of variation of total phosphorus varied from 1.06 to 13.76 /ug at/l. In the perennial field maximum total phosphorus value (7.72 /ug at/l) was recorded in July and minimum (1.06 /ug at/l) in January. the values showed fluctuation from 2.79 to 13.76 in the coconut grove canal station; 2.14 to 12.40 /ug at/l in the pokkali field. The total phosphorus was at its maximum during the monsoon months, extending up to September after which it began to decline. During the pre-monsoon and post-monsoon months the total phosphorus was very low. (Figs. 7, 8 and 9).

INORGANIC PHOSPHORUS (I.P)

Inorganic phosphorus of water in all the prawn culture fields showed fluctuation between 0.16 and 8.80 /ug at/l during the period of study.

The data on the monthly variation in the inorganic phosphate concentration of prawn culture stations are summarised in Tables 4-6. In the perennial field, maximum value (4.20) was recorded during June and minimum value (0.16) during the month of January, while in the coconut grove canal the maximum value (8.80) and minimum value (1.00) during the months of July and May respectively. In the pokkali field, relatively high values were recorded throughout the period as compared to other fields. During the monsoon season, especially during June-July the inorganic phosphorus at all the stations exhibited considerable increase, while during pre-monsoon and post-monsoon period values showed decrease (Figs. 7, 8 and 9).

ORGANIC PHOSPHORUS (O.P)

The concentrations of dissolved organic phosphorus in water samples of prawn culture fields are shown in Tables 4-6. Organic phosphorus of the water showed fluctuation between 0.40 and 3.68 µg at/l. The concentration of the organic phosphorus of the water in the perennial fields, canals in the coconut grove and in the pokkali field was varying between 0.40 and 3.04; 0.43 and 3.22; 0.49 and 3.68 respectively. Maximum value was recorded in June-July and minimum in January and April. In general, the higher values were recorded during monsoon period, the lowest during pre-monsoon season (Figs. 7, 8 and 9). During monsoon season organic phosphorus at all the stations exhibited considerable increase while during post-monsoon season values showed decrease.

PARTICULATE PHOSPHORUS (P.P)

Data on particulate phosphorus of the water are shown in Tables

Table 4. Seasonal Variation of total phosphorus (TP), inorganic phosphorus (IP), organic phosphorus (OP) and particulate phosphorus (PP) at Stations I & II (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
S T A T I O N - I							
TP	1986	2.09	2.81	2.70	6.48	1.06	2.01
	87	2.02	3.11	2.26	4.66	1.55	1.92
IP	86	0.19	1.64	0.87	3.64	0.16	1.08
	87	0.98	1.52	0.91	3.28	0.80	1.03
OP	86	0.40	1.75	1.00	2.46	0.54	0.73
	87	0.90	1.21	0.78	1.37	0.54	0.85
PP	86	0.21	0.48	0.38	0.72	0.16	0.24
	87	0.24	0.62	0.28	0.86	0.19	0.27
S T A T I O N - II							
TP	86	2.21	2.89	3.30	7.72	2.34	4.04
	87	2.86	3.32	3.60	5.45	2.11	3.56
IP	86	0.22	1.54	1.30	4.20	0.98	2.17
	87	1.28	1.62	1.50	2.03	0.99	2.05
OP	86	0.84	1.77	1.15	3.04	1.06	1.37
	87	0.94	1.54	1.24	3.02	0.92	1.12
PP	86	0.22	0.43	0.38	0.68	0.28	0.50
	87	0.31	0.50	0.35	0.83	0.20	0.38

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 5. Seasonal Variation of total phosphorus (TP), inorganic phosphorus (IP), organic phosphorus (OP) and particulate phosphorus (PP) at stations III & IV (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
S T A T I O N - III							
TP	1986	2.14	3.85	2.99	6.81	2.35	2.88
	87	2.19	3.19	2.76	5.26	2.44	2.70
IP	86	0.19	1.85	0.98	3.64	0.64	1.82
	87	0.22	1.75	1.05	2.40	1.12	1.94
OP	86	0.84	2.44	1.20	2.76	0.64	1.50
	87	0.68	1.57	1.04	2.56	0.49	1.08
PP	86	0.20	0.44	0.32	0.72	0.20	0.33
	87	0.33	0.52	0.28	0.90	0.24	0.27
S T A T I O N - IV							
TP	86	3.42	4.66	4.69	11.81	2.79	3.40
	87	3.82	5.48	3.95	7.55	2.81	3.40
IP	86	1.32	1.85	2.54	7.85	1.40	1.95
	87	1.25	2.92	2.05	5.42	1.22	2.52
OP	86	1.55	2.33	1.16	3.06	0.91	1.64
	87	1.03	2.30	1.20	.09	0.43	1.23
PP	86	0.36	0.83	0.73	0.96	0.24	0.54
	87	0.48	0.84	0.70	1.12	0.35	0.48

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 6. Seasonal Variation of total phosphorus (TP), inorganic phosphorus (IP), Organic phosphorus (OP) and particulate phosphorus (PP) at Stations V & VI (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
S T A T I O N - V							
TP	1986	3.83	5.23	6.44	13.76	4.34	6.80
	87	4.74	5.79	6.27	8.26	4.31	6.27
IP	86	1.00	2.45	2.05	8.80	1.40	4.65
	87	1.68	3.10	2.92	4.35	1.68	3.35
OP	86	1.86	3.22	1.48	2.20	1.26	3.02
	87	1.84	2.92	1.48	3.06	2.03	2.20
PP	86	0.42	0.92	0.80	1.08	0.44	0.89
	87	0.68	0.85	0.76	1.16	0.60	0.86
S T A T I O N - VI							
TP	86	3.71	6.40	5.04	12.40	3.95	6.33
	87	4.91	5.73	4.84	7.08	4.18	5.54
IP	86	1.25	2.35	1.70	7.50	1.15	4.62
	87	2.15	2.75	2.48	3.15	1.92	2.55
OP	86	1.84	3.62	1.77	3.68	0.88	2.70
	87	1.60	2.65	1.13	3.26	1.70	2.42
PP	86	0.43	0.91	0.68	1.39	0.42	0.67
	87	0.64	1.19	0.57	1.37	0.56	0.64

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

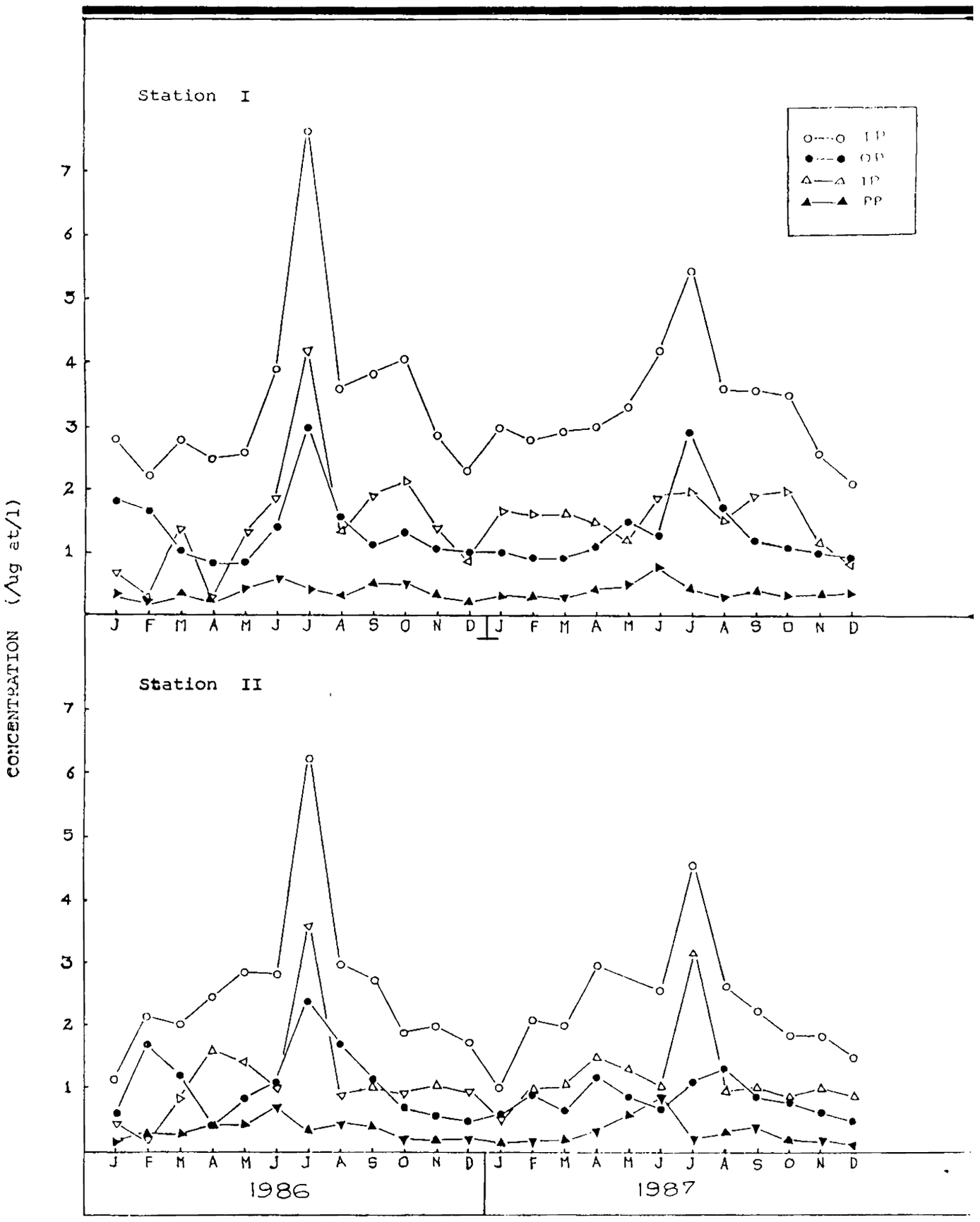

Fig. 7. Seasonal variation of total phosphorus (TP), inorganic phosphorus (IP), organic phosphorus (OP) and particulate phosphorus (PP) concentrations in the water at the stations I and II of prawn culture systems during 1986-87.

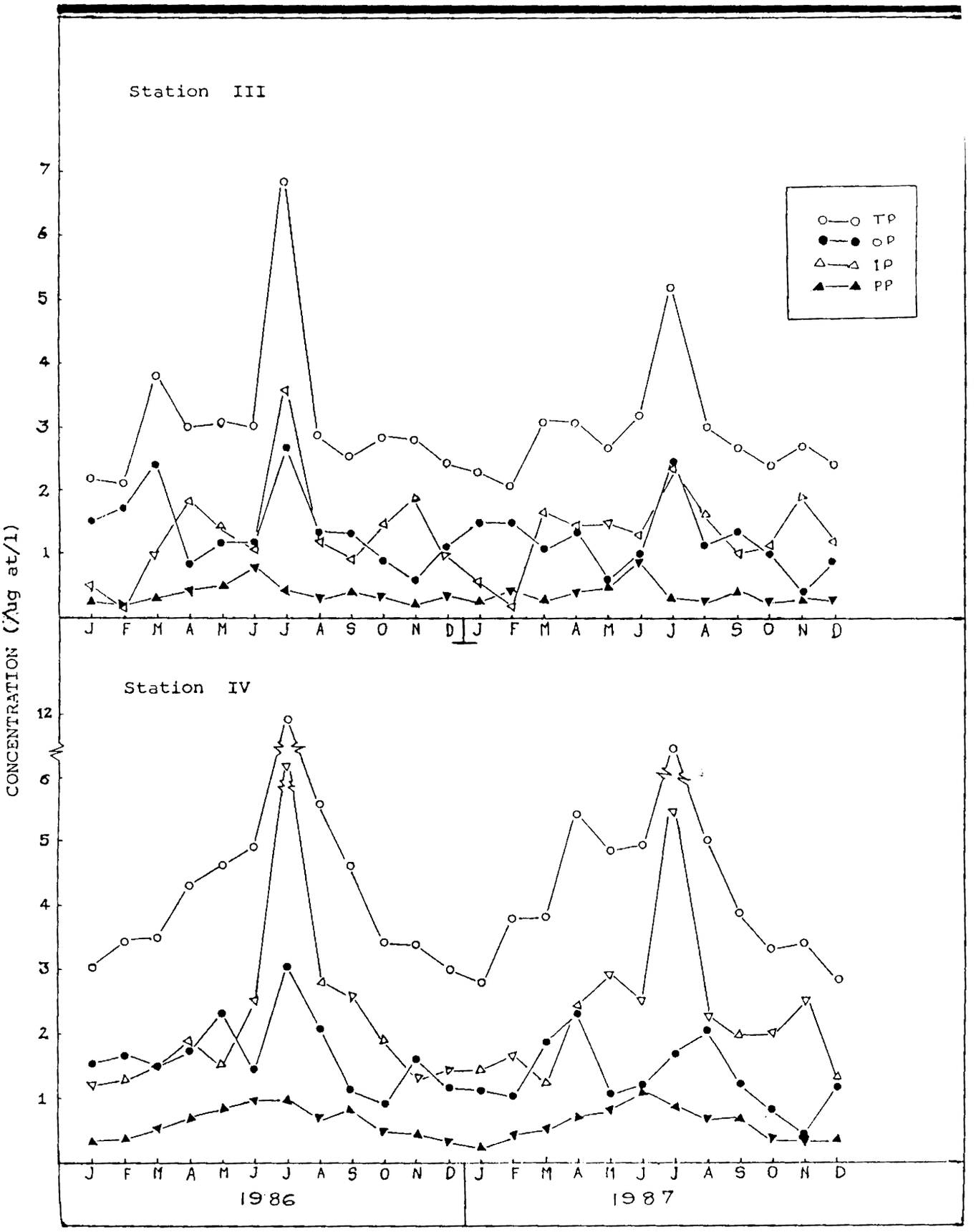

Fig. 8. Seasonal variation of total phosphorus (TP), inorganic phosphorus (IP), organic phosphorus (OP) and particulate phosphorus (PP) concentrations in the water at the stations III and IV of prawn culture systems during 1986-87.

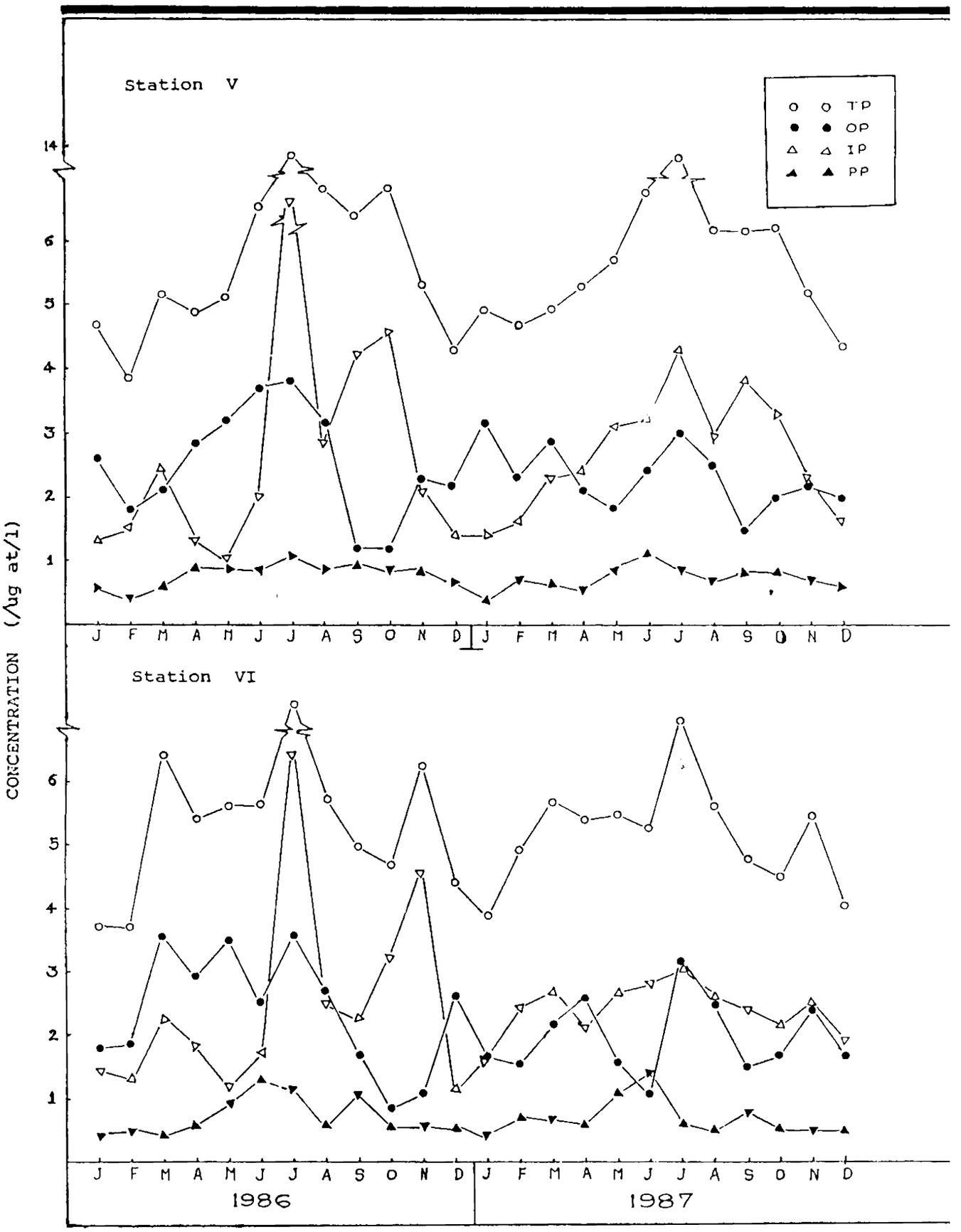

Fig. 9. Seasonal variation of total phosphorus (TP), inorganic phosphorus(IP) organic phosphorus (OP) and particulate phosphorus (PP) concentrations in the water at stations V and VI of prawn culture systems during 1986-87.

4-6. Particulate phosphorus of the water in all the prawn culture fields showed an upward trend from January to July but it declined to reach lowest value during November. In the perennial fields maximum particulate phosphorus value (0.86 µg at/l) was recorded in June and minimum (0.16 µg at/l) during January. In the coconut grove canals the concentration was seen fluctuating between 0.24 and 1.16 and in the pokkali field maximum value (1.39) was recorded in June and minimum (0.60) during august. The particulate-P was at its maximum during the monsoon months, extending upto August, after which it began to decline. During pre- and post-monsoon periods the particulate-P value was very low (Figs 7, 8 and 9).

TOTAL NITROGEN (T.N).

The data on the monthly variation in the total nitrogen of prawn culture stations are summarised in Tables 7-12. Total nitrogen of the water in all the prawn culture fields were seen increasing gradually from January to reach a maximum value 94.54 µg at/l in July. The range of variation of total nitrogen varied from 15.83 to 94.54 µg at/l. The range in the concentration was between 15.83 and 71.72 in the perennial field; 17.23 and 87.87 in the coconut grove canal and 26.48 and 94.54 µg at/l in the pokkali field. Maximum value was recorded in the pokkali field during July and minimum value in the perennial field during January. During the monsoon season, especially during June-July the total-N in all the station exhibited considerable increase, while during pre- and post-monsoon values showed decrease (Figs. 10, 11 and 12).

TOTAL INORGANIC NITROGEN (TIN)

The concentration of total inorganic nitrogen in water samples of prawn culture fields are shown in Tables 7-12. Total inorganic nitrogen of the water in the perennial field, canals in the coconut grove and in the pokkali field was varying between 3.63 and 26.68, 3.89 and 30.55 and 6.76 and 32.90 µg at/l respectively. There was a gradual increase in the concentration from February to July followed by a fall during August-September. Maximum value was recorded in the pokkali field during July and minimum value was noted during January. In the coconut grove canals relatively lower values were recorded throughout the period as compared to the other fields. The TIN values were found to be high during the monsoon months and low during pre- and post-monsoon periods (Figs. 10, 11 and 12).

DISSOLVED ORGANIC NITROGEN (DON).

Data on dissolved organic nitrogen values are shown in Tables 7-12. Dissolved organic nitrogen value of the water showed fluctuation from 8.94 to 52.64 µg at/l in different prawn culture fields. The concentration in the perennial field, in the coconut grove canal and in the pokkali field was ranging between 8.94 and 40.02, 9.63 and 51.24, 14.53 and 52.64 µg at/l respectively. maximum value was recorded during the month of July and minimum during January. In the pokkali field, relatively higher values were recorded throughout the period as compared to coconut grove canal stations. The DON values were at its maximum during monsoon months, extending upto July, after which it began to decline. during the pre- and post monsoon periods the DON was very low (figs. 10, 11 and 12).

NITRATE NITROGEN (NO_3-N)

The concentrations of nitrate nitrogen in water samples of prawn culture fields are shown in Tables 7-12. The nitrate nitrogen of the water in all the prawn culture fields were seen increasing gradually from January to reach a maximum value in July, thereafter the values showed decrease in the concentration. The range in concentration was between 1.14 and 22.40 µg at/l in the perennial field 1.28 and 25.20 in the coconut canal field and 1.38 and 21.60 µg at/l in the pokkali field. Maximum concentration was recorded during June-July and minimum during January-February. In general, the higher values were recorded during monsoon period, the lowest during pre- monsoon season (Figs. 13, 14 and 15).

NITRITE NITROGEN (NO_2-N)

Nitrite nitrogen in each month are presented in Tables 7-12. Nitrite nitrogen of the water in all the prawn culture fields showed an upward trend from March to July but it declined to reach the lowest value in October The range in nitrite nitrogen value was between 0.1 and 2.4 µg at/l in the perennial fields; 0.20 and 3.60 in the coconut grove canal; 0.10 and 4.20 µg at/l in the pokkali fields. Maximum value was recorded in the pokkali fields during July and minimum value was recorded in the perennial field during October. The nitrite-nitrogen was at its maximum during the monsoon months, extending upto July, after which it becan to decline. During the pre- and post-monsoon periods the temperature was very low. (Figs. 13, 14 and 15).

PARTICULATE NITROGEN (PN)

The data on the monthly variation in the particulate nitrogen of prawn culture stations are summarised in Tables 7-12. The range in particulate nitrogen value in all the prawn culture fields was between 1.60 and 12.04 µg at/l. In the perennial field maximum value (10.35 µg at/l) was recorded during June and minimum values (1.05 and 1.60 µg at/l) during the month of January and November, while in the coconut grove canal the concentration was seen fluctuating between 1.70 and 11.40 µg at/l. In the pokkali field, relatively high values were recorded throughout the period as compared to other fields. The particulate-N was at its maximum during the monsoon months, extending upto June, after which it began to decline. During pre- and post-monsoon periods the particulate-N was very low (Figs. 13, 14 and 15).

AMMONIA NITROGEN (NH_3-N)

The concentrations of ammonia nitrogen in water samples of prawn culture fields are shown in Tables 7-12. Ammonia of the water in the perennial fields, canals in the coconut grove and in the pokkali fields was varying between 1.35 and 12.75 µg at/l, 1.02 and 13.50 and 0.45 and 10.75 µg at/l. In the perennial field maximum concentration was recorded in December and minimum in March. In the coconut grove canal maximum value was recorded in December and minimum in February. But in the pokkali field maximum value was noted in June and minimum during September Ammonia-nitrogen was not showed a distinct pattern of seasonal fluctuations during the pre- and post-monsoon season (Figs. 16, 17 and 18).

Table 7. Seasonal Variation of total nitrogen (TN), Total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station I (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	15.83	27.10	23.60	66.57	24.66	45.35
	87	21.45	47.50	23.41	70.69	19.63	42.89
TIN	86	3.89	7.05	4.40	25.55	6.72	15.30
	87	5.68	13.70	3.63	23.45	5.60	17.50
DON	86	8.94	14.38	11.00	38.32	15.43	25.70
	87	11.92	26.30	9.43	37.52	11.98	20.42
NO_3-N	86	1.14	5.20	2.00	20.00	2.80	9.60
	87	3.20	10.60	3.20	10.80	4.40	11.20
NO_2-N	86	0.30	0.70	0.40	2.40	0.10	0.40
	87	0.45	0.85	0.20	2.20	0.20	0.45
NH_3-N	86	1.35	3.15	1.80	3.82	1.35	5.40
	87	2.03	7.65	0.23	12.75	0.90	5.85
PN	86	3.00	7.20	2.70	8.40	2.05	4.35
	87	3.85	7.50	3.70	10.35	2.05	4.95
SIO	86	7.92	36.30	10.56	49.50	16.50	39.60
	87	7.50	34.80	11.55	54.45	15.84	35.64

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 8. Seasonal Variation of total nitrogen (TN), total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate-nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonia nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station II (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	19.21	28.71	30.10	69.25	24.94	61.51
	87	20.98	56.48	29.87	71.72	41.14	56.36
TIN	86	5.10	7.70	7.05	26.68	7.53	18.28
	87	5.45	15.40	5.90	15.43	10.83	21.53
DON	86	10.96	16.06	15.15	40.02	15.81	38.38
	87	12.53	33.88	13.92	25.30	20.73	28.69
NO_3-N	86	1.20	5.30	5.20	22.40	2.80	11.20
	87	3.05	12.80	4.00	13.60	6.40	14.40
NO_2-N	86	0.30	0.75	0.50	1.35	0.45	0.78
	87	0.60	0.90	0.10	1.80	0.60	0.90
NH_3-N	86	1.35	3.15	1.35	5.85	2.25	6.30
	87	1.80	5.28	1.80	6.53	2.70	6.23
PN	86	3.15	6.90	2.55	7.90	1.60	4.85
	87	3.00	7.20	2.55	10.05	1.05	5.10
SIO	86	4.62	37.20	6.60	42.90	14.84	32.67
	87	5.61	36.70	7.26	39.60	17.16	32.34

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 9. Seasonal Variation of total nitrogen (TN), total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia-nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station III (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	26.49	55.97	34.44	80.34	27.27	56.06
	87	27.08	62.74	39.60	74.40	47.86	53.03
TIN	86	6.76	11.25	9.22	28.30	7.63	19.05
	87	7.59	19.28	8.60	25.07	15.53	23.73
DON	86	14.53	34.12	19.82	47.54	15.64	32.00
	87	16.39	35.66	21.50	33.84	23.90	33.38
NO_3-N	86	1.71	13.60	4.00	19.20	3.50	12.00
	87	3.60	14.40	4.40	14.00	11.60	16.00
NO_2-N	86	0.10	0.65	0.10	2.80	0.10	0.90
	87	0.80	1.15	0.50	2.40	0.50	0.80
NH_3-N	86	2.06	4.95	1.12	6.75	0.45	6.75
	87	3.15	7.88	0.90	9.67	2.23	6.98
PN	86	5.20	7.20	3.75	10.50	2.15	5.01
	87	3.10	7.80	4.50	9.50	3.25	5.40
SIO	86	5.28	36.30	7.20	41.25	11.55	39.60
	87	9.24	35.40	8.25	47.85	13.20	31.68

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 10. Seasonal Variation of total nitrogen (TN), total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station IV (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	20.01	36.04	24.38	85.34	23.53	54.22
	87	17.23	61.30	24.07	87.87	23.50	44.11
TIN	86	4.38	10.05	4.29	30.50	6.33	18.07
	87	4.85	16.38	3.89	25.35	6.37	20.18
DON	86	9.63	18.59	10.29	51.24	13.60	30.35
	87	10.18	34.72	11.28	34.22	14.68	24.65
NO_3-N	86	1.28	8.10	2.25	23.40	2.00	10.80
	87	2.10	12.55	3.60	11.60	4.90	12.60
NO_2-N	86	0.45	1.55	0.50	3.50	0.20	1.15
	87	0.50	1.55	0.03	3.20	0.45	0.95
NH_3-N	86	1.50	3.50	2.04	4.34	1.50	6.12
	87	2.25	8.50	0.26	13.50	1.02	6.63
PN	86	6.00	9.60	3.60	11.20	2.45	5.80
	87	2.20	10.20	3.60	11.40	2.45	6.60
SIO	86	10.50	48.40	14.08	66.00	22.00	52.80
	87	10.12	38.50	15.40	72.60	21.12	47.52

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon ·

Table 11. Seasonal Variation of total nitrogen (TN), total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station V (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	21.71	46.65	34.95	75.19	27.35	61.93
	87	21.93	55.91	32.73	74.60	41.26	57.02
TIN	86	5.65	12.60	8.13	30.55	7.77	20.72
	87	6.20	16.25	7.30	17.00	12.29	24.64
DON	86	11.86	26.46	20.32	41.24	16.78	35.01
	87	13.33	30.06	19.63	34.00	24.85	31.95
NO_3-N	86	1.35	9.85	5.85	25.20	2.90	12.60
	87	4.00	13.15	4.50	16.10	7.20	16.20
NO_2-N	86	0.45	0.90	0.75	2.25	0.12	0.98
	87	0.20	1.05	0.50	2.80	0.75	1.05
NH_3-N	86	1.50	3.50	1.53	6.63	2.55	7.14
	87	2.00	4.75	2.30	8.10	3.06	7.39
PN	86	4.20	9.20	3.10	9.00	2.70	6.20
	87	2.40	9.60	5.80	10.25	1.70	6.80
SIO	86	6.16	49.72	8.80	57.20	19.80	43.56
	87	7.48	48.50	9.68	52.80	22.80	43.12

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 12. Seasonal Variation of total nitrogen (TN), total inorganic nitrogen (TIN), dissolved organic nitrogen (DON), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonia nitrogen (NH_3-N), particulate nitrogen (PN) and silicate (SIO) at Station VI (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ug at/l		Min	Max	Min	Max	Min	Max
TN	1986	31.98	45.37	32.43	94.54	30.40	61.13
	87	27.35	74.54	42.79	76.52	47.10	65.31
TIN	86	7.93	12.39	10.43	32.90	7.20	20.35
	87	7.55	21.03	9.32	28.55	17.10	19.30
DON	86	16.65	25.07	17.20	52.64	19.00	34.18
	87	16.15	43.11	21.43	38.97	20.68	42.66
NO_3-N	86	1.38	9.45	4.50	21.60	3.30	13.50
	87	3.80	14.95	4.50	15.75	10.00	14.40
NO_2-N	86	0.68	1.10	0.15	4.20	0.15	1.20
	87	0.25	1.12	0.20	3.60	0.15	1.40
NH_3-N	86	2.26	5.50	1.28	7.50	0.51	8.65
	87	3.50	8.75	1.02	10.75	2.55	7.90
PN	86	7.20	9.40	4.80	9.40	3.40	6.60
	87	3.65	10.40	9.00	12.04	3.40	7.80
SIO	86	7.04	48.40	9.68	55.00	15.40	52.80
	87	12.32	48.05	11.00	63.80	17.60	42.24

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon

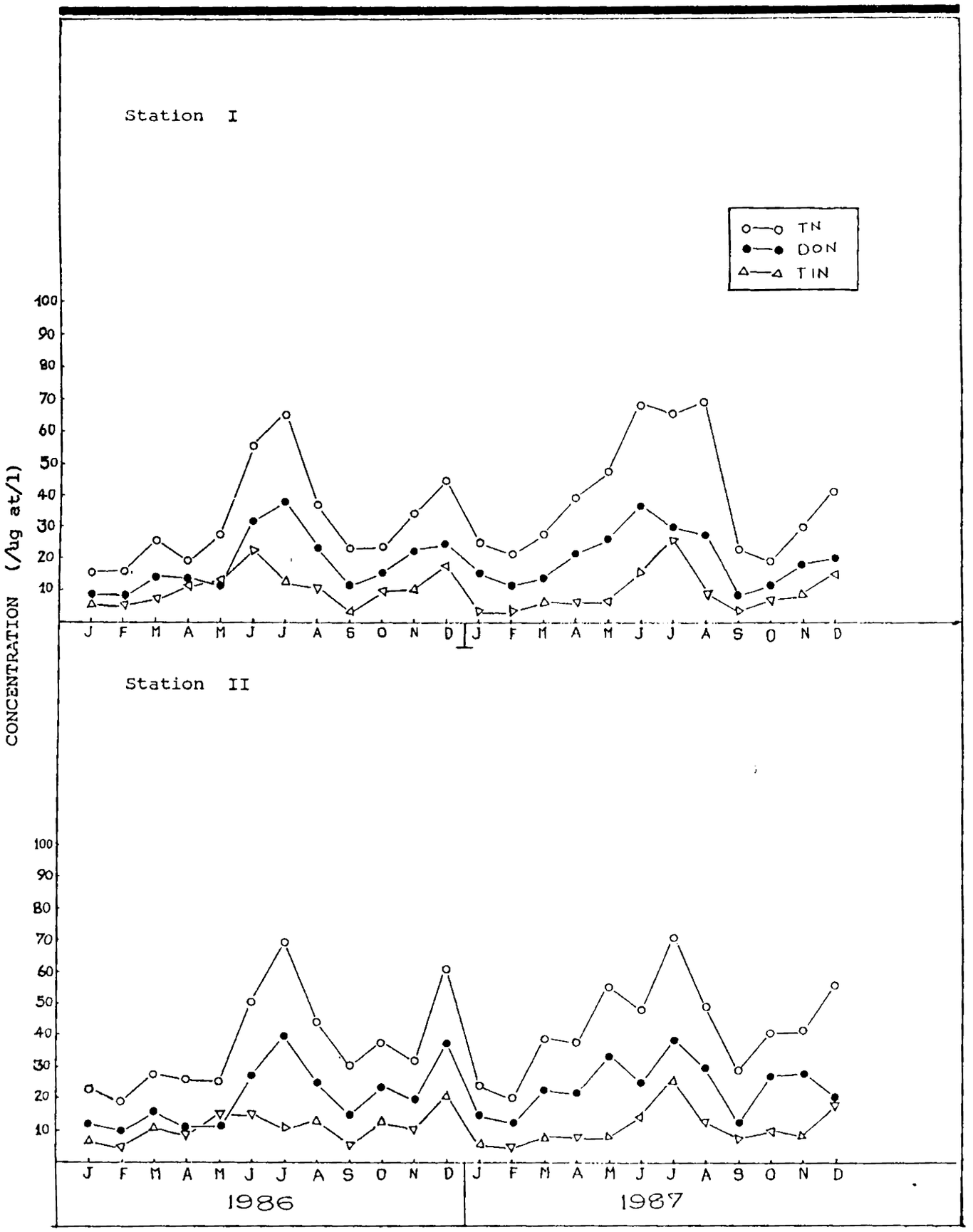

Fig. 10. Total nitrogen (TN), total inorganic nitrogen (TIN) and dissolved organic nitrogen (DON) concentrations in the water at stations I and II of prawn culture systems during 1986-87.

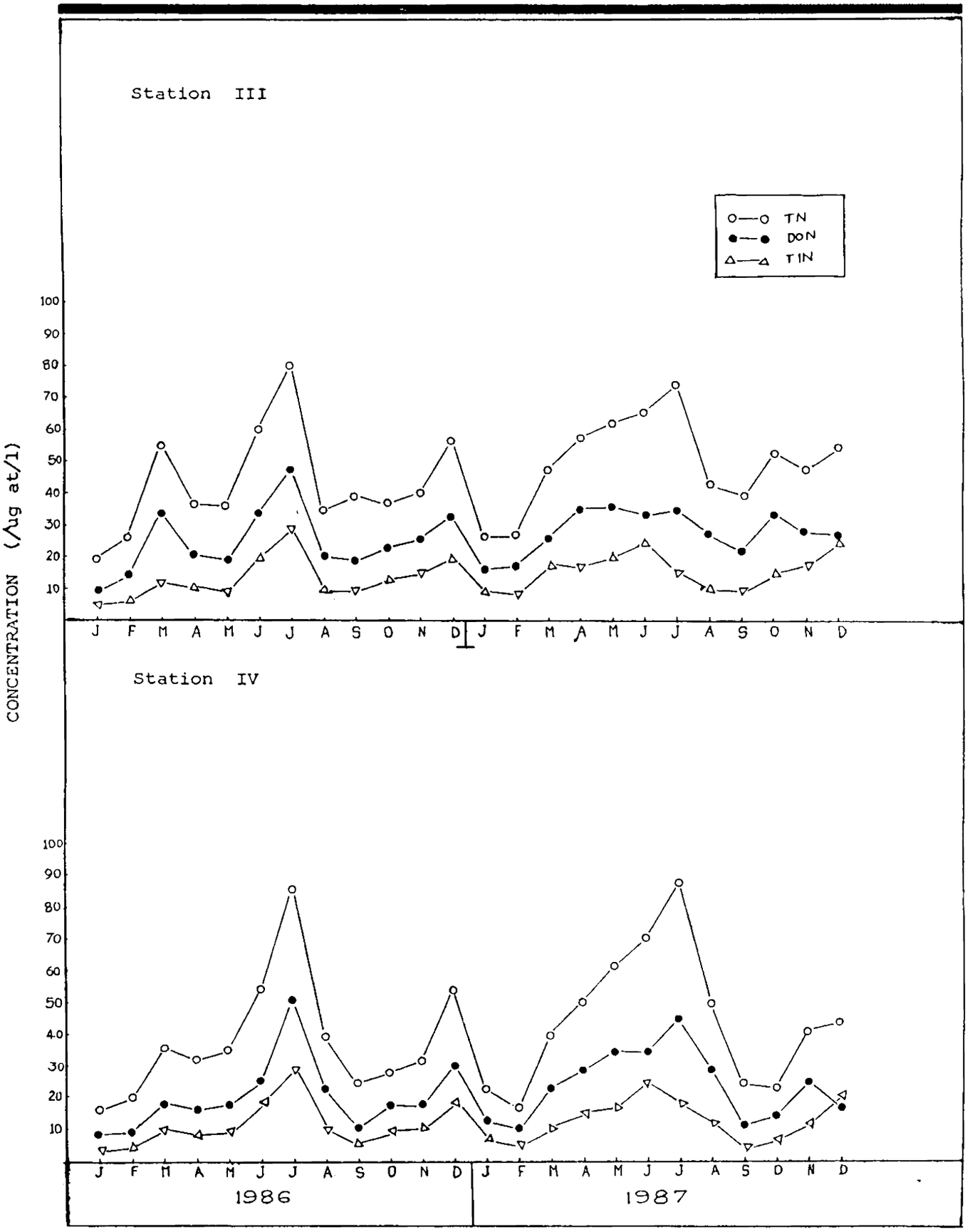

Fig. 11. Total nitrogen (TN), total inorganic nitrogen (TIN) and dissolved org nitrogen (DON) concentrations in the water at stations III and IV of prawn cu systems during 1986-87.

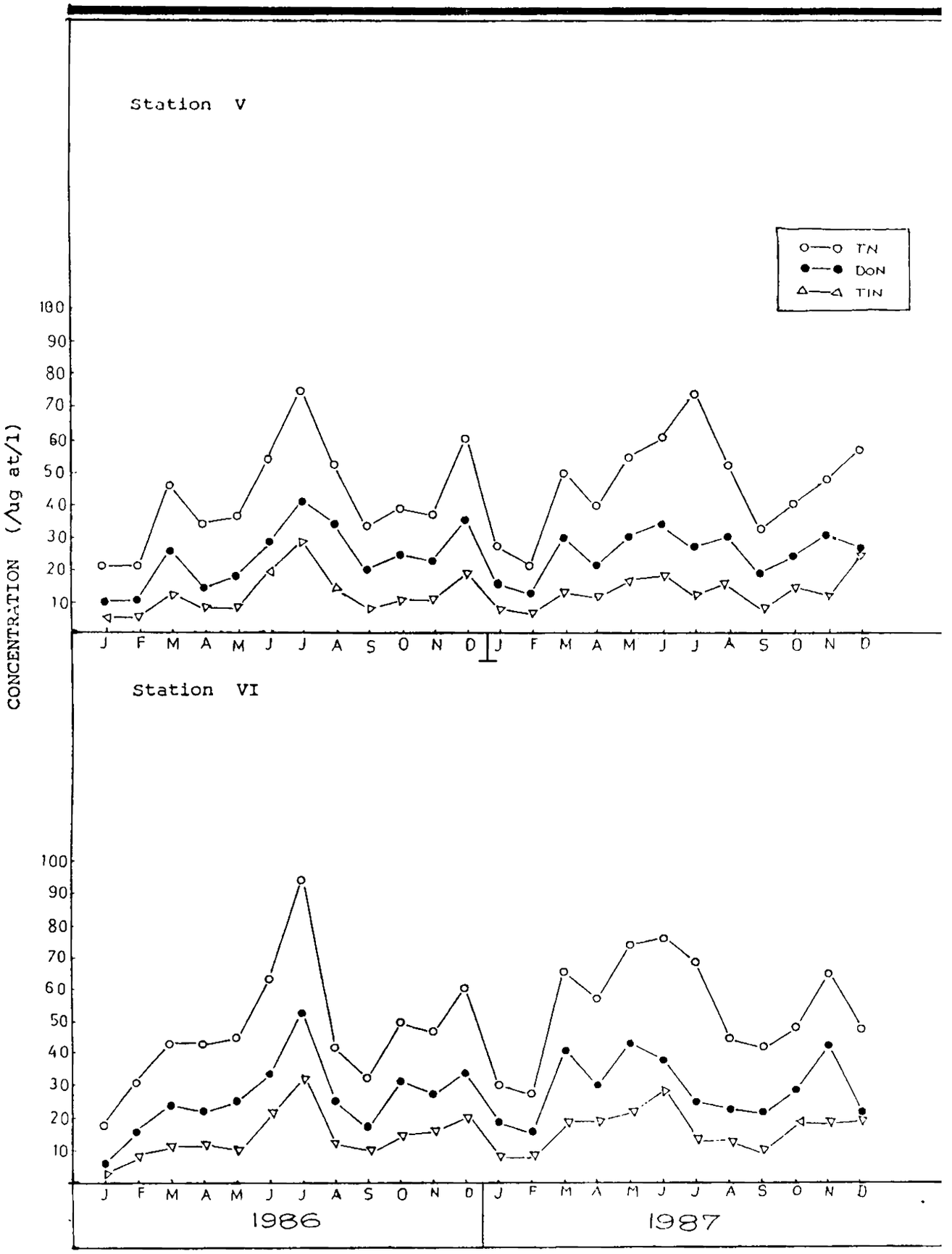

Fig. 12. Total nitrogen (TN), total inorganic nitrogen (TIN) and dissolved organic nitrogen (DON) concentrations in the water at stations V and VI of prawn culture systems during 1986-87.

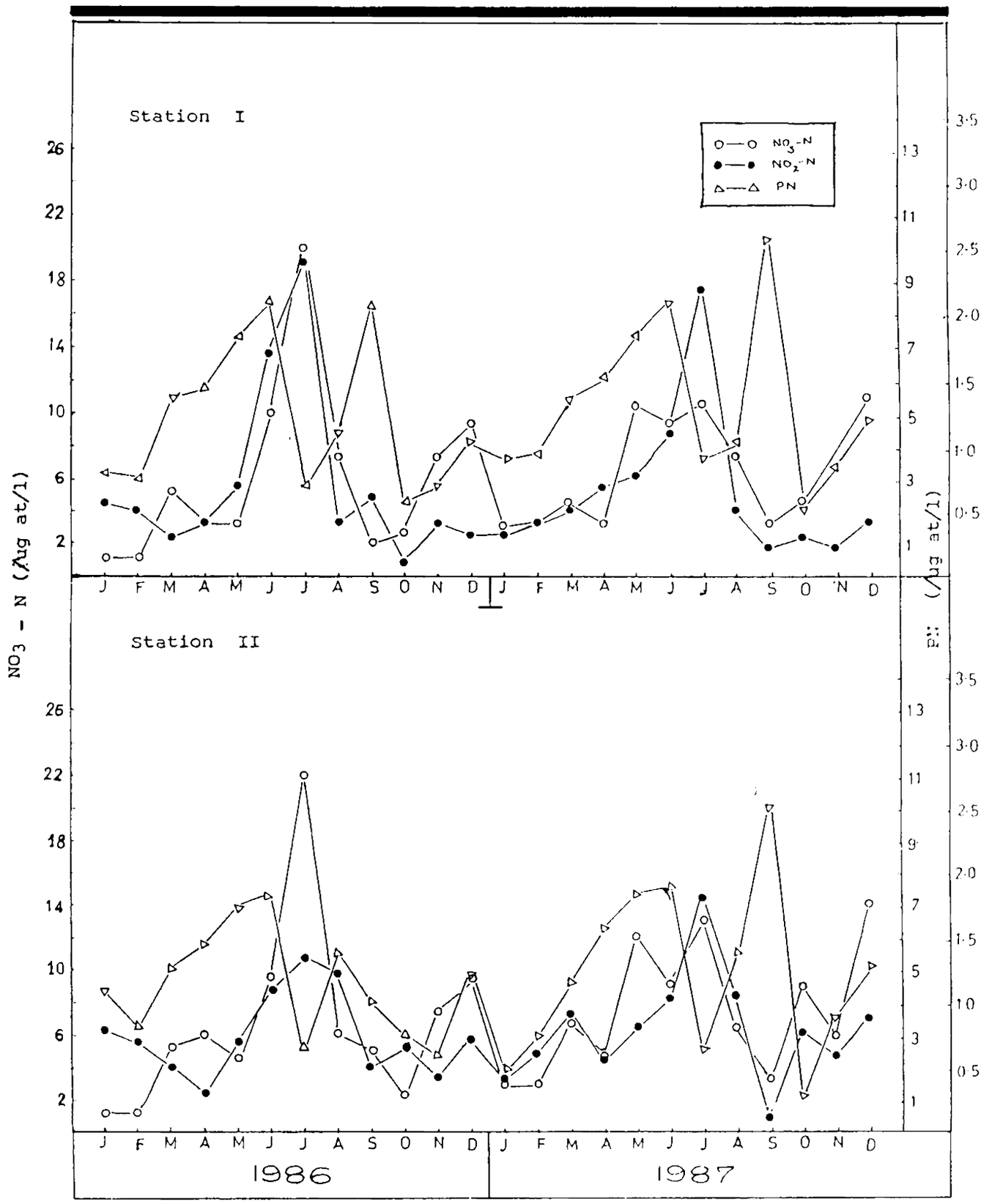

Fig. 13. Nitrate-nitrogen (NO_3 - N), nitrite - nitrogen (NO_2 - N) and particulate - nitrogen (PN) concentrations in the water at stations I and II of prawn culture systems during 1986-87.

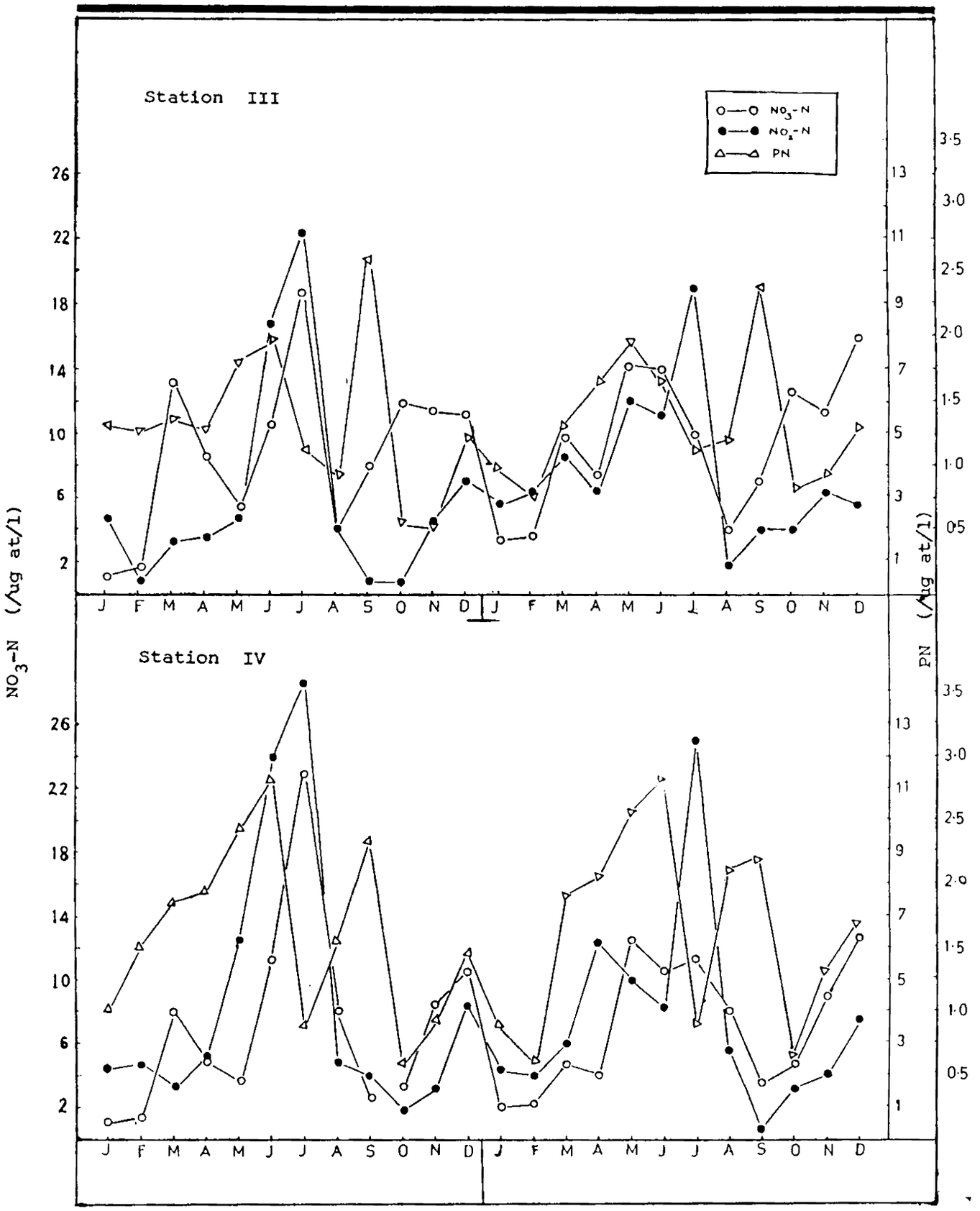

Fig. 14. Nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) and particulate-nitrogen (PN) concentrations in the water at stations III and IV of prawn culture systems during 1986-87.

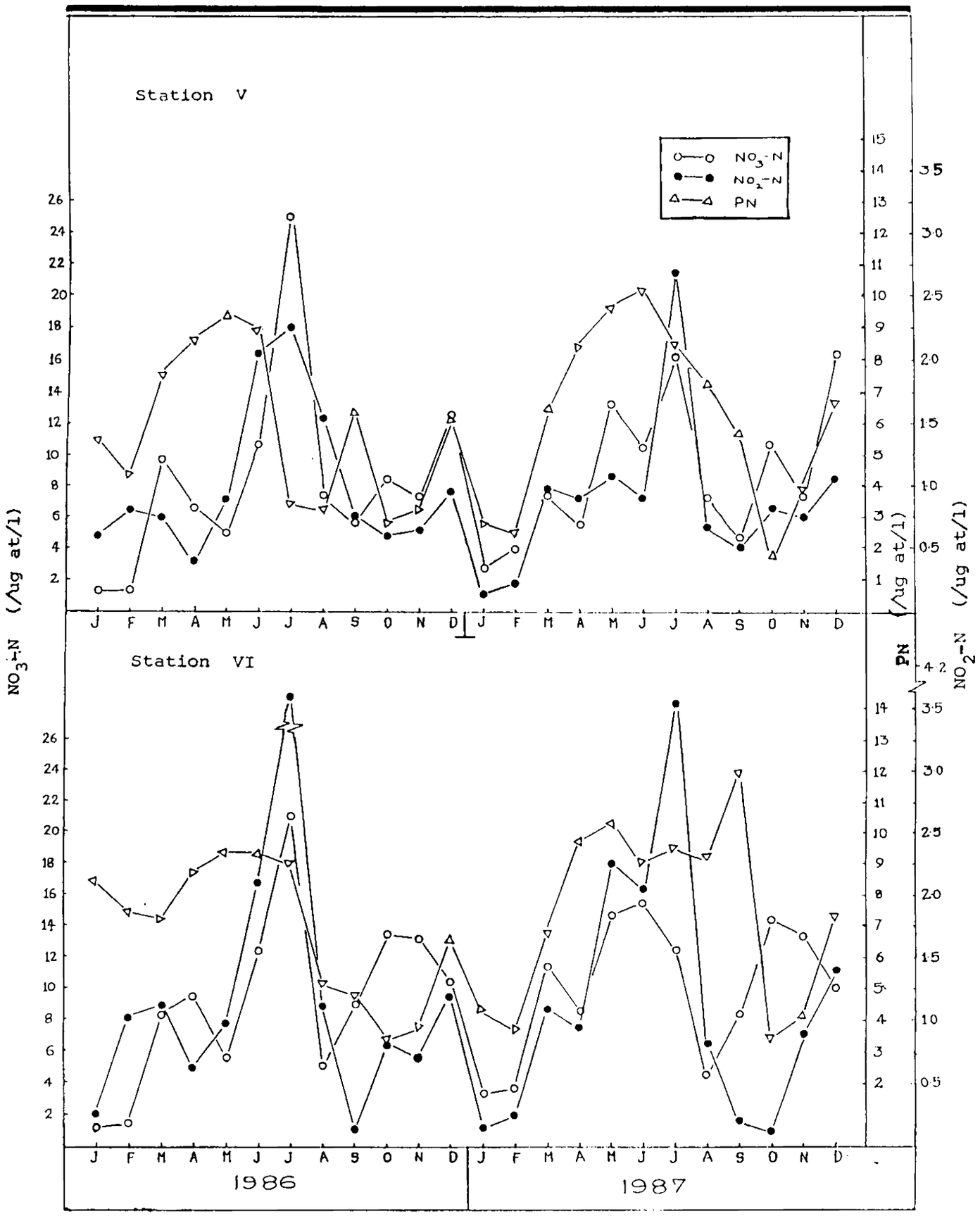

Fig. 15. Nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) and particulate-nitrogen (PN) concentrations in the water at stations V and VI of prawn culture systems during 1986-87.

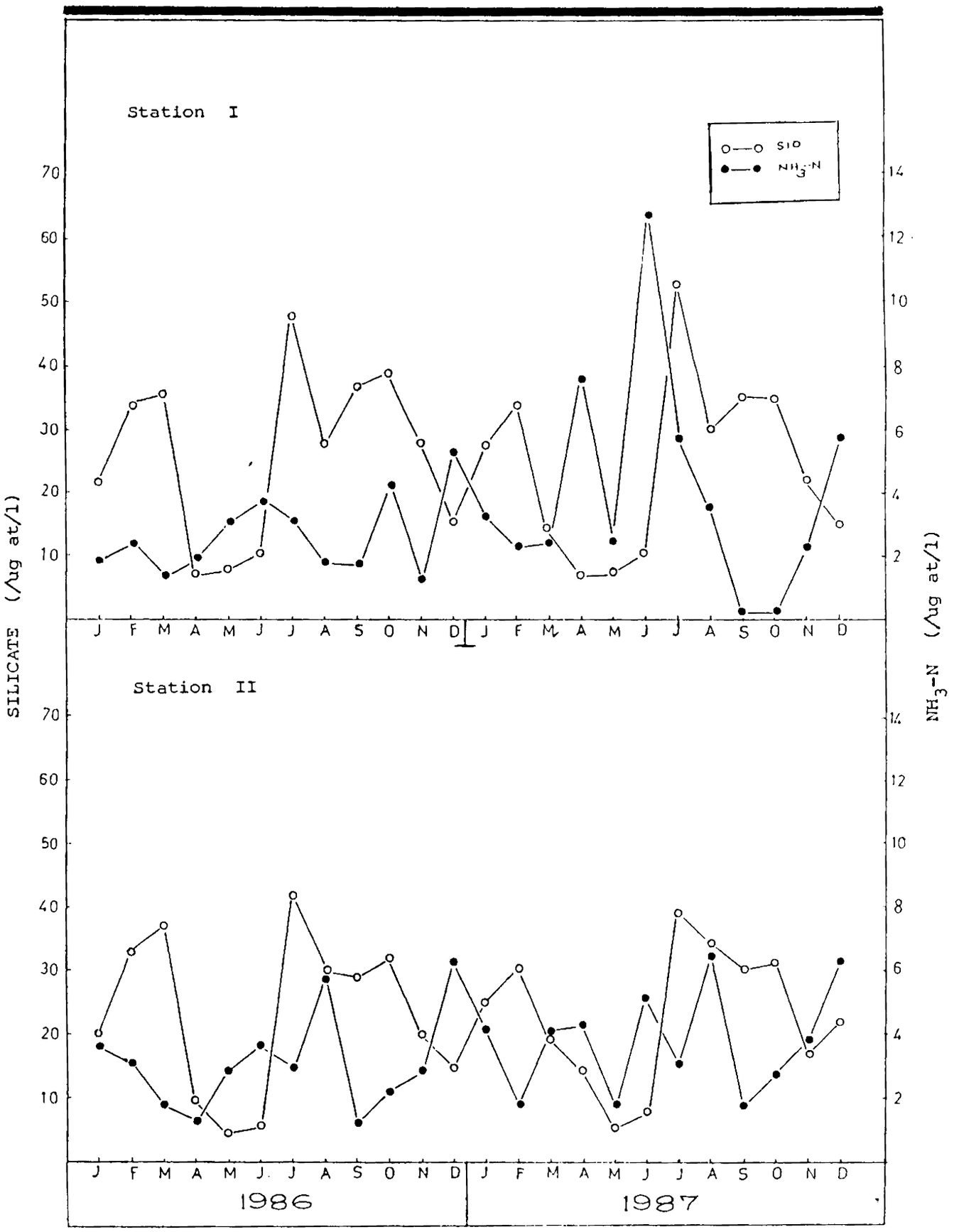

Fig. 16. Ammonia-nitrogen (NH_3-N) and silicate (SIO) content of the water column at stations I AND II of prawn culture systems during 1986-87.

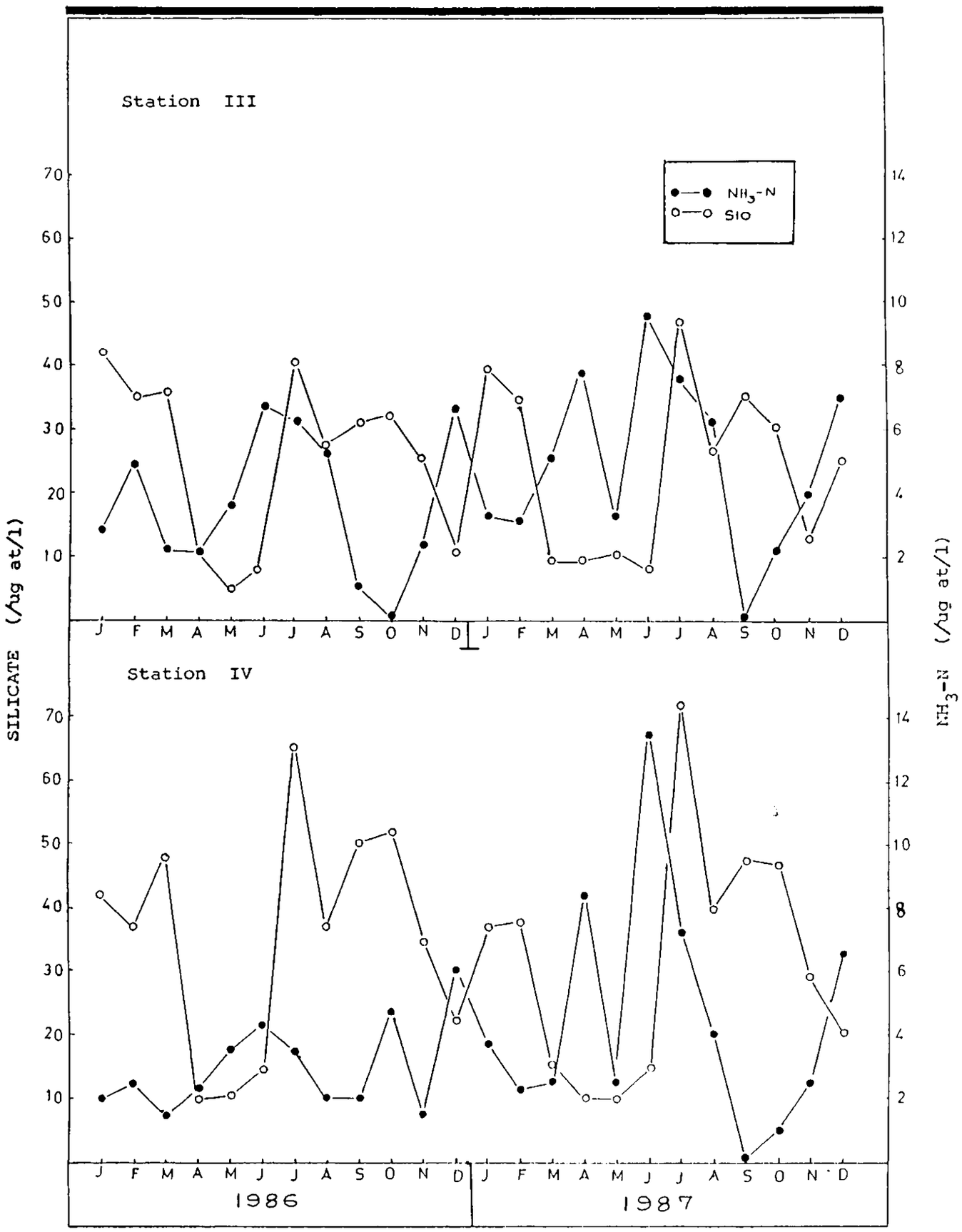

Fig. 17. Ammonia-nitrogen (NH_3-N) and silicate (SIO) content of the water column at stations III and IV during 1986-87.

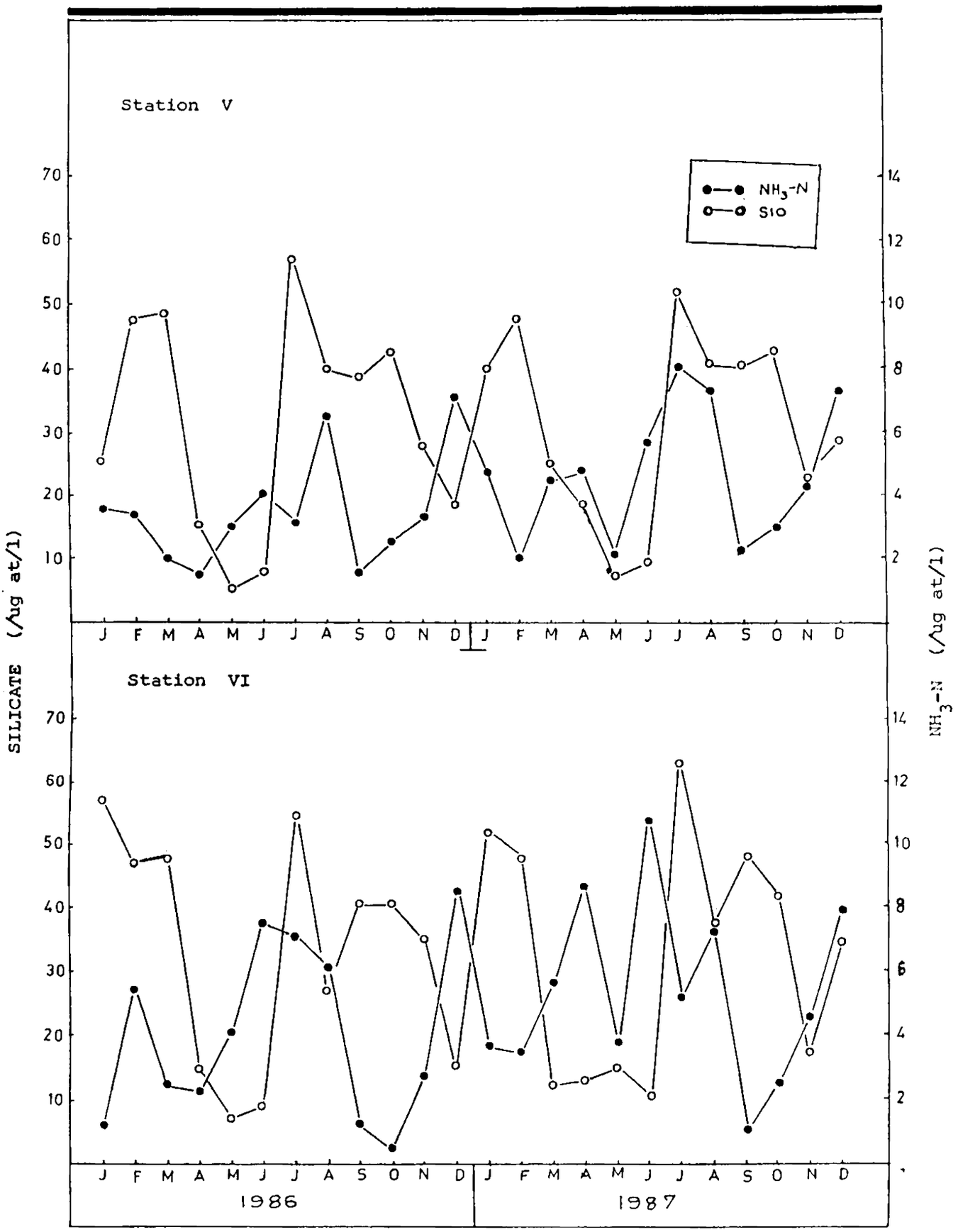

Fig. 18. Ammonia-nitrogen (NH_3-N) and silicate (SIO) content of the water column at stations V and VI during 1986-87.

SILICATE (SIO)

The concentrations of silicate in water samples of prawn culture fields are shown in Tables 7-12. Silicate showed a wide range of fluctuation from 4.62 to 72.60 /ug at/l. The silicate values of water showed fluctuation from 5.61 to 54.45 in the perennial field; 6.16 to 72.60 in the coconut grove canal; 5.28 to 63.30 /ug at/l in the pokkali field. Maximum value was recorded during the month of May. Silicate showed an upward trend from April to July but it declined to reach the lowest value during December-January. The silicate values were found to be high during the monsoon months and low during pre- and post-monsoon periods (Figs. 16, 17 and 18).

PRODUCTIVITY

PRIMARY PRODUCTIVITITY (PRP)

Data on primary productivity are shown in Tables 13-15. Primary productivity values of the water showed fluctuation from 642.00 to 1246.00 in the perennial field; 636.00 to 1283.75 in the coconut grove canal and 587.50 to 1403.75 mg C/m^3/day in the pokkali field. In the perennial field maximum production was recorded during the month of May-June and minimum recorded in the month of December-January. In the pokkali field relatively high production was recorded throughout the period as compared to coconut grove canal and perennial fields. In general, the higher primary productivity values were recorded during monsoon and post-monsoon periods, the lowest during pre-monsoon season (Figs. 19, 20 and 21).

CHLOROPHYLL 'a' (Chl a)

The concentrations of chlorophyll 'a' in water samples of prawn culture fields are shown in Tables 13-15. Chlorophyll 'a' concentration of the water in the perennial field, canals in the coconut grove and in the pokkali field was varying between the 0.36 and 9.69; 0.68 and 10.80 and 0.10 and 11.70 mg/m^3 respectively. Maximum values were recorded in the pokkali field during May-June and the minimum values were recorded in the same fields during November. During the monsoon season, especially during July-August, the chlorophyll 'a' at all stations showed considerable increase, while during post-monsoon values showed decrease(Figs.19,20 and 21).

CHLOROPHYLL 'b' (Chl b)

The data on the monthly variation in the chlorophyll 'b' of prawn culture stations are summarised in Tables 13-15. Chlorophyll 'b' concentration of the water showed fluctuation from 0.01 to 4.95 mg/m^3 in all the prawn culture fields. In the perennial field maximum value of 4.18 mg/m^3 recorded during the month of August, while in the coconut grove canal it was seen fluctuating between 0.02 and 4.18 during the month of August and April respectively. In the pokkali field, relatively high values were recorded throughout the period as compared to other stations (Figs. 22, 23 and 24).

CHLOROPHYLL 'c' (Chl c)

Data on chlorophyll 'c' are shown in Tables 13-15. The range in chlorophyll 'c' concentration value was between 0.06 and 6.98 mg/m^3.

Table 13. Seasonal Variation of Primary productivity (PRP), Chlorophyll a,b and c (Chl a, Chl b and Chl c) at Stations I & II (1986-87).

		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
PARAMETER		Min	Max	Min	Max	Min	Max
STATION I							
PRP mg/C/m^3/D	1986	679.00	1022.50	932.40	1027.00	653.25	982.50
	87	642.00	1122.00	983.33	1246.60	651.00	986.67
Chl a mg/m^3	86	2.06	4.67	3.60	9.69	1.28	3.21
	87	1.35	8.42	3.41	6.61	1.22	4.79
Chl b mg/m^3	86	0.27	2.77	0.01	4.18	0.29	2.49
	87	0.03	1.99	0.01	1.14	0.41	2.10
Chl c mg/m^3	86	0.21	4.26	0.62	4.69	0.09	1.02
	87	0.36	4.82	0.35	6.98	0.36	0.88
STATION II							
PRP mg/C/m^3/D	86	683.75	1002.50	676.00	962.50	712.50	895.20
	87	684.00	982.00	656.85	948.16	852.33	892.14
Chl a mg/m^3	86	3.03	4.68	0.36	7.22	0.47	2.59
	87	1.12	8.50	0.68	7.10	0.46	2.60
Chl b mg/m^3	86	0.08	2.78	0.03	0.47	0.89	1.74
	87	0.01	2.75	0.42	2.35	0.38	1.07
Chl c mg/m^3	86	0.52	3.13	0.15	3.21	0.15	1.26
	87	0.44	2.85	0.06	2.73	0.11	0.54

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon; D: Day ·

Table 14. Seasonal variation of Primary productivity (PRP), Chlorophyll a,b and c (Chl a, Chl b and Chl c) at Stations III & IV (1986-87).

STATION III							
		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
PARAMETER		Min	Max	Min	Max	Min	Max
PRP mg/C/m^3/D	1986	587.50	1035.00	911.80	983.00	618.50	814.40
	87	732.40	1106.00	825.83	969.16	737.16	1038.75
Chl a mg/m^3	86	2.01	5.69	1.20	7.97	0.10	2.72
	87	1.56	9.14	2.81	6.62	0.13	4.19
Chl b mg/m^3	86	0.33	2.27	0.02	3.65	0.82	2.58
	87	0.04	1.58	0.05	4.76	0.17	2.50
Chl c mg/m^3	86	0.78	3.82	0.08	1.22	0.26	1.28
	87	0.83	3.94	0.96	4.47	0.12	1.83
STATION IV							
PRP mg/C/m^3/D	86	730.00	985.75	978.00	1011.64	684.10	1038.30
	87	746.40	1075.00	996.50	1281.00	689.16	969.00
Chl a mg/m^3	86	3.10	6.64	2.70	9.10	1.92	4.82
	87	2.07	7.53	5.05	9.91	1.84	5.82
Chl b mg/m^3	86	0.41	3.82	0.02	3.87	0.42	3.73
	87	0.16	2.99	0.35	1.71	0.61	3.15
Chl c mg/m^3	86	0.32	4.18	0.93	5.82	0.13	1.53
	87	0.54	1.75	0.52	1.13	0.39	1.34

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon; D: Day.

Table 15. Seasonal variation of Primary productivity (PRP), Chlorophyll a,b and c (Chl a, Chl b and Chl c) at Stations V & VI (1986-87).

STATION V							
		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
PARAMETER		Min	Max	Min	Max	Min	Max
PRP mg/C/m^3/D	1986	687.00	1022.50	651.80	982.50	714.20	1033.50
	87	636.00	1113.75	668.33	957.33	906.33	1014.66
Chl a mg/m^3	86	4.05	7.28	5.40	8.60	0.78	3.88
	87	3.72	10.80	0.68	10.60	1.20	5.40
Chl b mg/m^3	86	0.43	4.18	0.04	0.71	1.33	2.61
	87	0.27	4.12	0.63	3.53	0.57	1.57
Chl c mg/m^3	86	0.78	3.98	0.22	4.82	0.23	1.90
	87	1.21	4.27	0.10	4.05	0.16	0.81
STATION VI							
PRP mg/C/m^3/D	86	807.00	1282.50	1054.00	1175.00	754.33	973.00
	87	812.00	1403.75	983.35	1170.00	828.14	967.50
Chl a mg/m^3	86	5.08	8.54	3.16	7.30	1.81	4.09
	87	4.22	11.70	2.43	9.42	1.62	2.34
Chl b mg/m^3	86	0.61	3.14	0.02	4.28	1.24	3.87
	87	0.72	2.38	0.54	4.95	0.26	2.65
Chl c mg/m^3	86	0.48	3.95	0.12	1.83	0.40	1.91
	87	1.08	3.88	0.10	6.71	0.18	2.75

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon; D: Day .

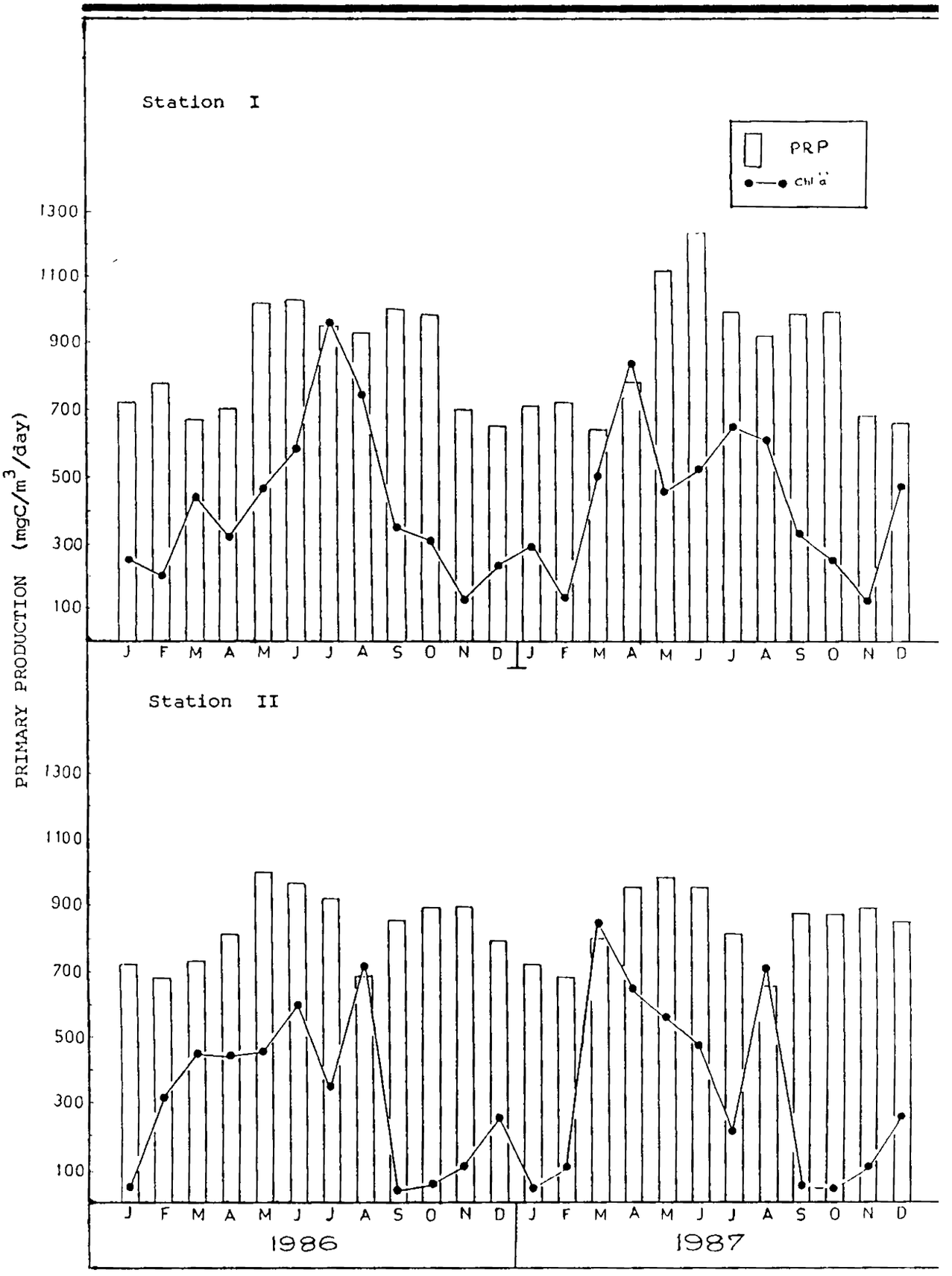

Fig. 19. Monthly primary production (PRP) data and monthly chlorophyll 'a' (Chl a) concentration at the stations I and II of prawn culture systems during 1996-87.

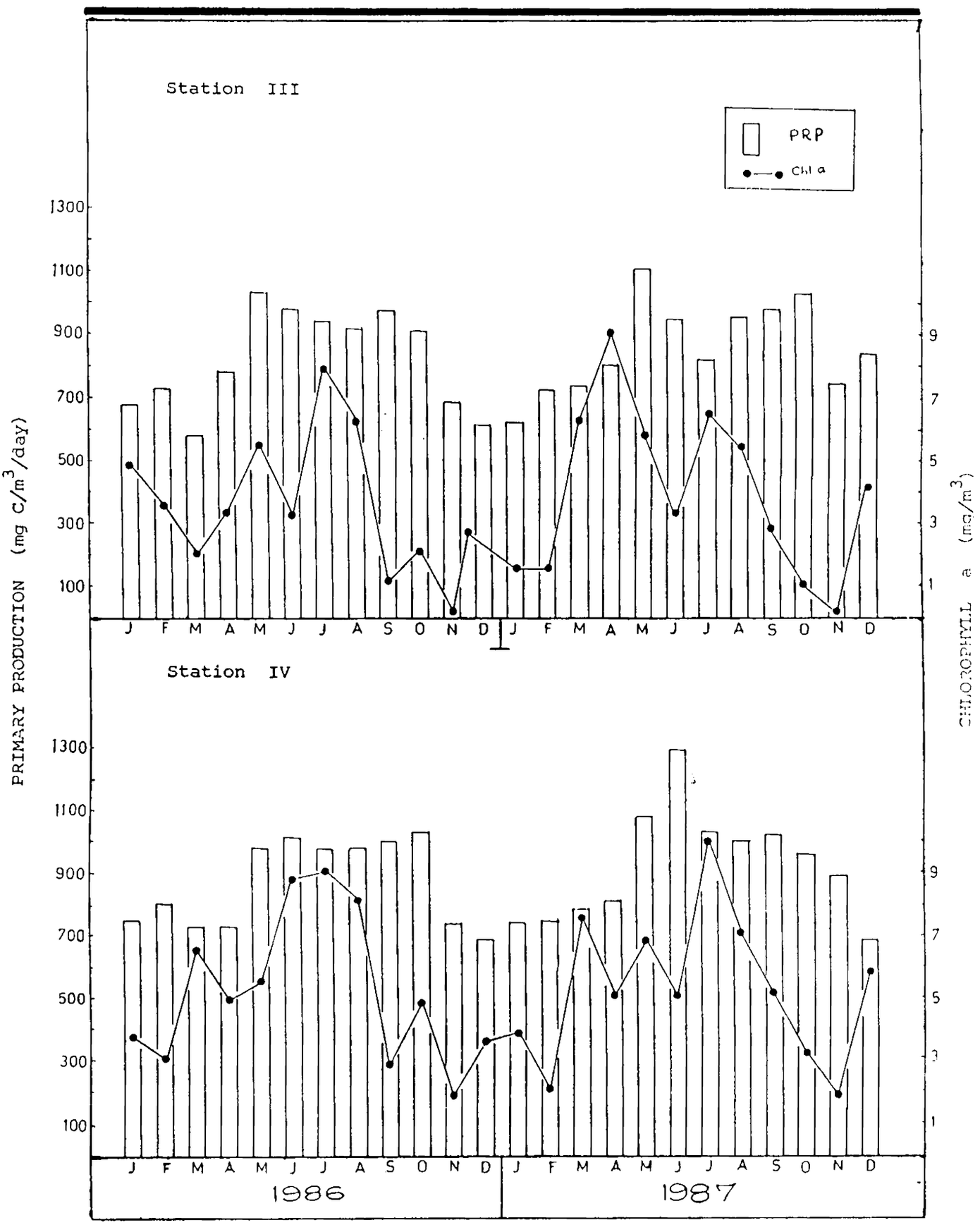

Fig. 20. Monthly primary production (PRP) data and chlorophyll 'a' (Chl a) concentration at the stations III and IV of prawn culture systems during 1986-87.

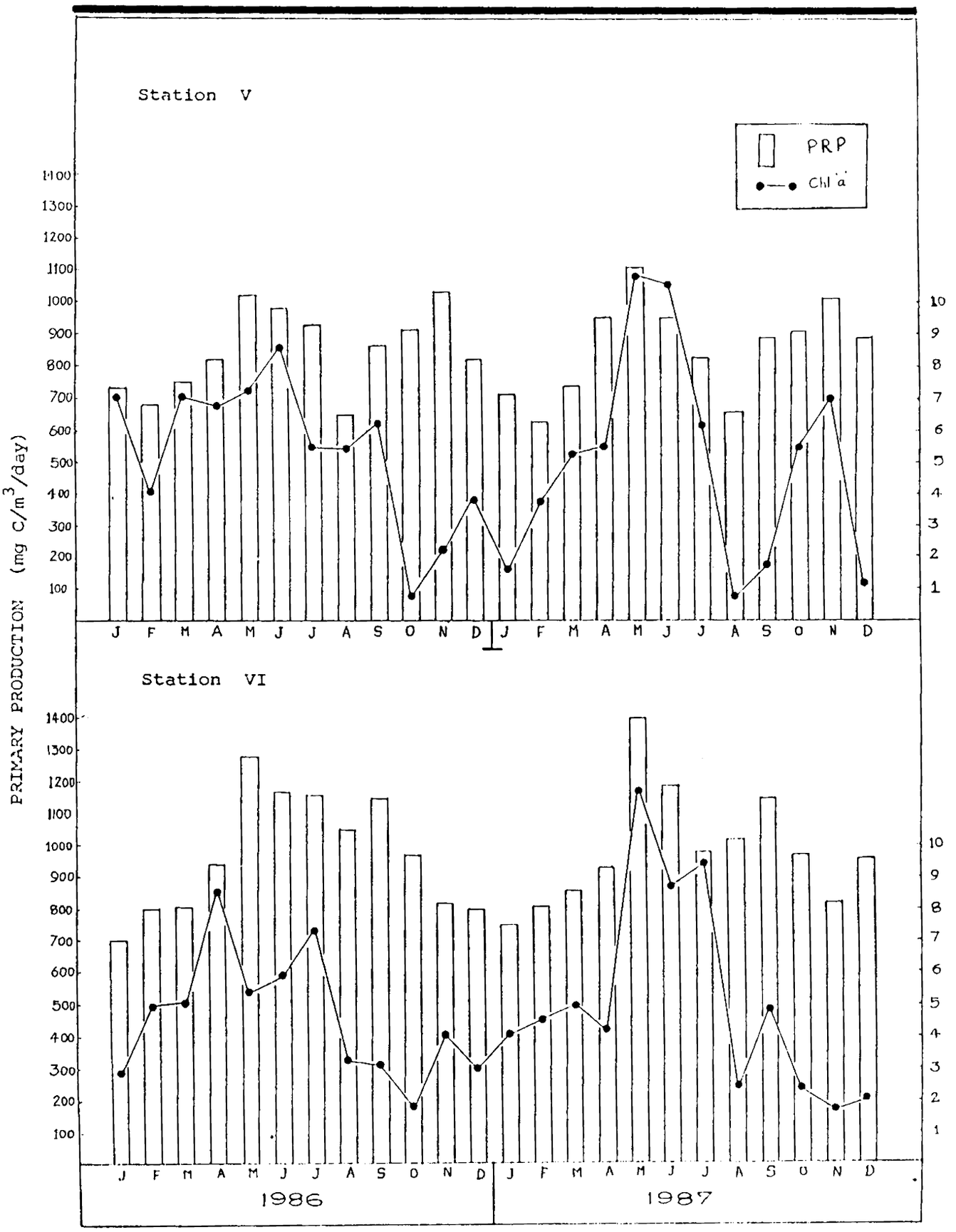

Fig. 21. Monthly primary production (PRP) data and chlorophyll 'a'(Chl a) concentration at the stations V and VI of prawn culture systems during 1986-87.

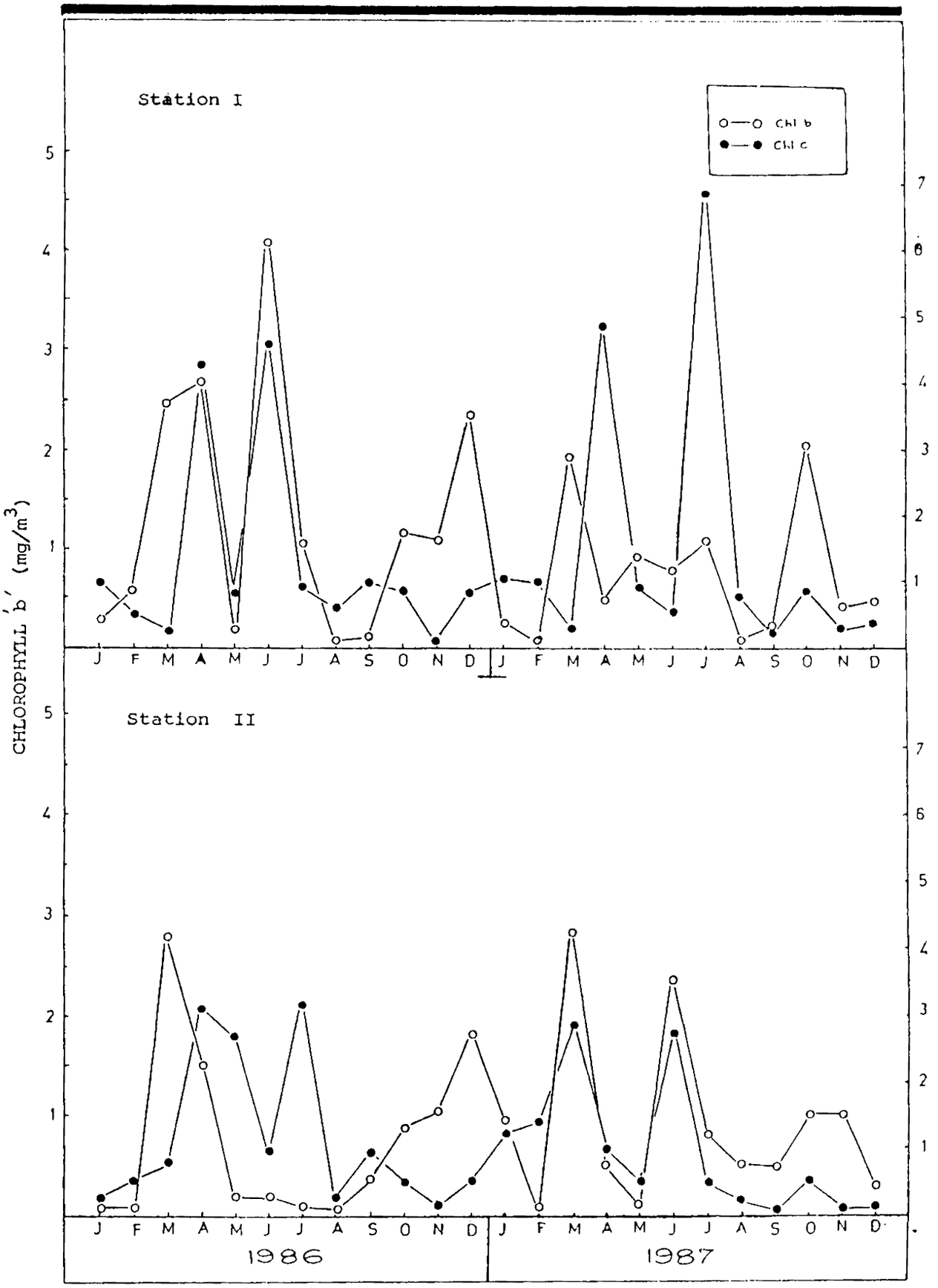

Fig. 22. Monthly chlorophyll'b' (Chl b) and chlorophyll 'c' (Chl c) concentrations at the stations I and II of prawn culture systems during 1986-87.

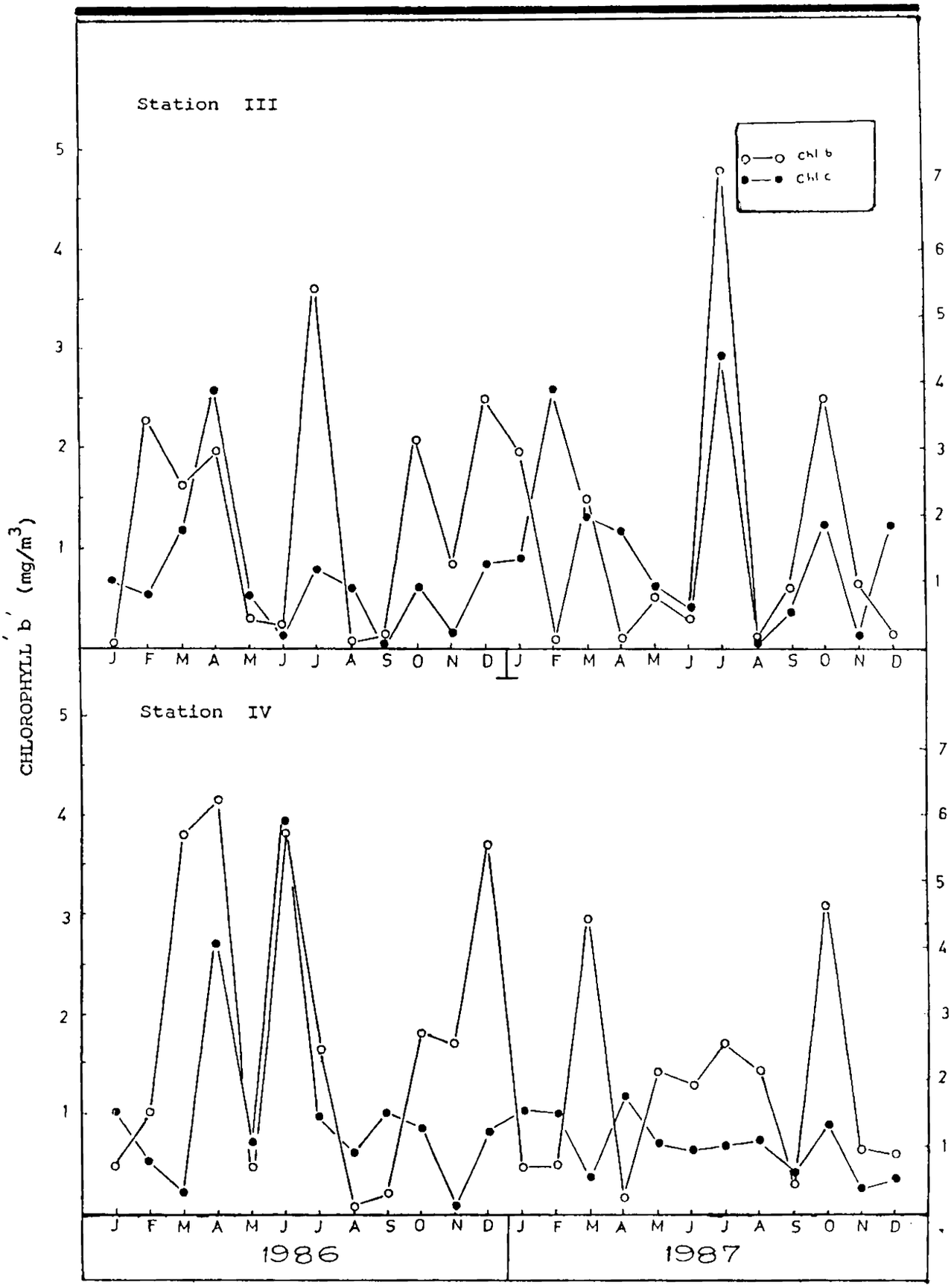

Fig. 23. Monthly Chlorophyll 'b' (Chl b) and chlorophyll'c' (Chl c) concentrations at the stations III and IV of prawn culture systems during 1986-87.

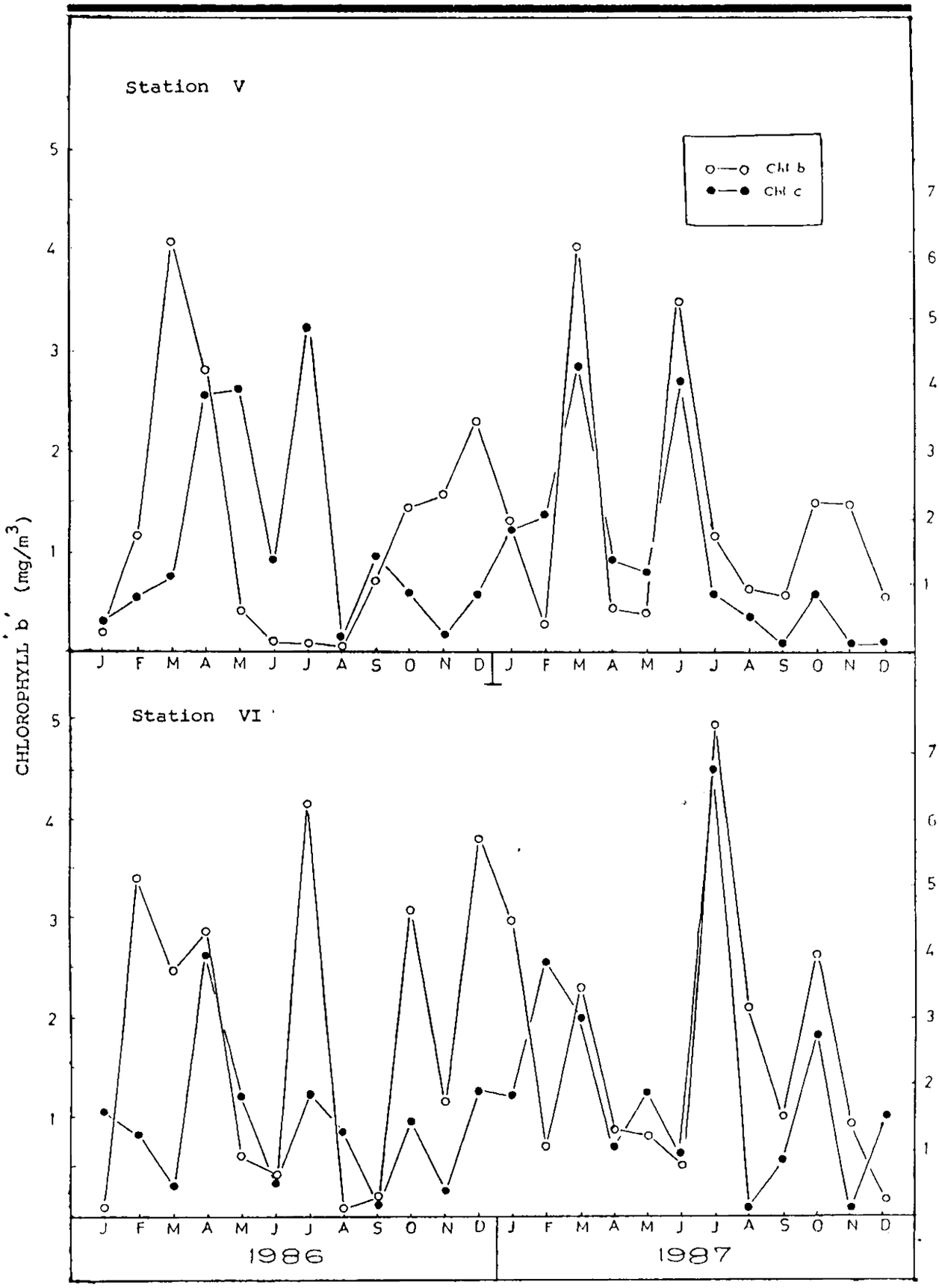

Fig. 24. Monthly chlorophyll 'b' (Chl b) and chlorophyll 'c' (Chl c) concentrations at the stations V and VI of prawn culture systems during 1986-87.

Chlorophyll 'c' concentration of the water in the perennial field, canals in the coconut grove and in the pokkali field was varying between 0.06 and 6.98; 0.10 and 5.82 and 0.06 and 6.71 mg/m^3 respectively. Maximum value was recorded during the month of July and minimum during November (Figs. 22, 23 and 24).

METALS IN WATER

COPPER (Cu)

The concentration of copper in water samples of prawn culture fields are shown in Tables 16-21. copper concentration of the water showed fluctuation from 3.44 to 12.64 ppb in all the prawn culture fields. In the perennial field, maximum value (8.69) was recorded during the month of August, minimum value (3.44) was recorded during March. In the coconut grove canal showed relatively low values recorded throughout the period as compared to that of other fields. The copper value was its maximum during the monsoon months, extending upto September, after which, it began to decline. During the pre- and post-monsoon periods the copper value was very low (Figs. 25, 26 and 27).

ZINC (Zn)

The data on the monthly variation in the zinc of prawn culture fields are summarised in Tables 16-21. Zinc concentration of the water in the perennial fields, canals in the coconut grove and in the pokkali field varied between 4.16 and 9.98; 4.50 and 11.96; 7.80 and 14.72 ppb respectively.

Maximum concentration was recorded during the months of August-September in the pokkali field and the minimum concentration was recorded during May-June in the coconut grove canal. The concentration in all the prawn culture fields were seen gradually increasing from February to reach a maximum in August-September. During the monsoon and post-monsoon season the zinc concentration at all the stations showed considerable increase, while during pre-monsoon values showed a decreaseing trend (Figs. 25, 26 and 27).

IRON (Fe)

The concentration of iron in water samples of prawn culture fields are shown in Tables 16-21. Iron concentration of the water showed fluctuation from the 1.12 to 4.95 in the perennial fields; 1.26 to 5.85 in the coconut grove canal; 2.10 to 7.20 ppb in the pokkali fields. In the perennial field maximum concentration was recorded in October and minimum in March-April,while in the coconut grove maximum concentration was recorded in September and minimum value in April. In the pokkali field, relatively high copper values were recorded throughout the period as compared to that of other fields. The iron values were found to be high during post-monsoon months and low during pre- and monsoon periods (Figs.25, 26 and 27).

METALS IN SEDIMENT

COPPER (Cu)

The concentration of copper in water samples of prawn culture fields are shown in Tables 16-21. Copper concentration of the sediment in the perennial field, canals in the coconut grove and in the pokkali fields was

varying between 28.40 and 55.27; 31.95 and 71.50; 53.25 and 88.00 ppb. Maximum value was recorded in the pokkali field during September and minimum value in the perennial field during March. There was a gradual increase in concentration from March to September followed by a fall during November-December period. During the monsoon season, especially during August-September, the copper at all the stations showed considerable increase, while during the pre-monsoon periods, the values showed decreasing trend (Figs. 28, 29 and 30)

ZINC (Zn)

The data on the monthly variation in the zinc of the sediment are summarised in Tables 16-21. Zinc concentration of the sediment showed fluctuation from 32.08 to 58.29 ppb in the perennial field; 36.09 to 75.40 in the coconut grove canal 60.15 to 92.80 ppb in the pokkali field. Maximum value was recorded during the month of September and minimum during May. The zinc concentration in all the prawn culture fields were seen increasing gradually from May to reach a maximum value in September. The concentration of zinc in the sediment was at its maximum during monsoon months, extending upto September, after which it began to decline. During pre-monsoon and post-monsoon periods zinc concentration was very low (Figs. 28, 29 and 30).

IRON (Fe)

The data on the monthly variation in the concentration of iron in the prawn culture fields are summarised in Tables 16-21. Iron concentration of the sediment was low in all the prawn culture fields upto the

Table 16. Seasonal variation of Copper (Cu), Zinc (Zn) and Iron (Fe) in water and sediment at Station I (1986-87).

PARAMETER		PRM (Feb-May)		MONS (June-Sept)		POM (Oct- Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	5.06	5.50	5.39	8.03	5.61	6.71
	87	4.40	5.28	5.61	8.69	5.61	6.93
Zn in Wat	86	5.77	6.66	6.66	9.21	5.77	9.87
	87	5.99	6.77	7.21	9.98	5.99	7.21
Fe in Wat	86	1.54	3.30	1.76	3.85	3.52	4.95
	87	1.98	2.75	2.42	4.62	2.75	4.18
Cu in Sed	86	35.67	40.70	40.70	50.35	42.00	50.35
	87	36.98	40.80	40.30	55.27	41.20	48.74
Zn in Sed	86	40.30	44.72	42.31	58.29	43.61	56.28
	87	40.70	43.71	43.21	57.28	44.22	55.27
Fe in Sed	86	1.32	2.75	1.54	2.86	2.53	3.20
	87	0.90	2.86	1.48	3.08	2.31	4.18

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon

Table 17. Seasonal variation of Copper (Cu); Zinc (Zn) and Iron (Fe) in water and sediment at Station II (1986-87).

PARAMETER		PRM (Feb-May)		MONS (June-Sept)		POM (Oct-Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	3.68	4.65	3.92	5.84	4.08	5.94
	87	3.44	3.84	4.08	6.32	4.08	5.04
Zin Wat	86	4.16	4.80	4.80	6.64	4.16	7.36
	87	4.32	4.88	5.20	7.20	4.32	5.20
Fe in Wat	86	1.12	2.40	1.28	2.80	2.56	3.60
	87	2.00	1.44	1.76	3.36	2.00	3.04
Cu in Sed	86	28.40	32.40	32.40	40.08	33.44	40.08
	87	29.44	32.24	32.08	44.00	32.80	46.07
Zn in Sed	86	32.08	35.06	33.68	46.40	34.72	44.80
	87	32.40	34.80	34.40	45.60	35.20	44.60
Fe in Sed	86	0.96	2.00	1.12	2.00	1.84	2.32
	87	0.72	2.08	1.08	2.24	1.68	3.04

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon

Table 18. Seasonal variation of Copper (Cu), Zinc (Zn) and Iron (Fe), in water and sediment at Station III (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	6.90	7.50	7.35	10.95	7.65	9.15
	87	6.45	7.20	7.65	11.85	7.65	9.45
Zn in Wat	86	7.80	9.00	9.00	12.00	7.80	13.80
	87	8.10	9.15	9.75	13.50	8.10	9.75
Fe in Wat	86	2.10	4.50	2.40	5.25	4.80	6.75
	87	2.70	3.75	3.30	6.30	3.75	5.70
Cu in Sed	86	53.25	60.75	60.75	65.25	62.70	75.25
	87	55.20	60.45	60.15	82.50	53.35	64.50
Zn in Sed	86	60.15	66.75	63.15	87.00	65.10	84.00
	87	60.75	65.25	64.50	85.50	66.00	82.50
Fe in Sed	86	1.80	3.75	2.10	3.90	3.45	4.35
	87	1.35	3.90	2.02	4.20	3.15	5.70

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 19. Seasonal variation of Copper (Cu), Zinc (Zn) and Iron (Fe) in water and sediment at Station IV (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	4.14	4.50	4.41	6.57	4.59	5.49
	87	3.87	4.32	4.59	7.11	4.95	5.67
Zn in Wat	86	4.68	5.40	4.50	7.47	4.68	8.28
	87	4.86	5.49	5.85	8.10	4.80	5.85
Fe in Wat	86	1.26	2.70	1.44	3.15	2.88	4.05
	87	1.62	2.25	1.98	3.15	2.25	3.42
Cu in Sed	86	31.95	36.45	36.45	45.09	37.62	46.28
	87	33.12	36.27	36.09	49.50	36.90	47.53
Zn in Sed	86	36.09	40.05	37.89	52.20	39.06	50.40
	87	36.45	39.15	38.70	51.30	39.60	49.50
Fe in Sed	86	1.08	2.25	1.26	2.34	2.07	2.80
	87	0.81	2.34	1.21	2.52	1.89	3.42

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon .

Table 20. Seasonal variation of Copper (Cu); Zinc (Zn) and Iron (Fe) in water and sediment at Station V (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	6.11	6.50	6.58	9.49	6.63	7.93
	87	5.59	6.24	6.63	10.27	6.63	7.19
Zn in Wat	86	6.76	7.80	7.80	10.79	6.76	11.96
	87	7.02	7.93	8.45	11.70	7.02	8.45
Fe in Wat	86	1.82	3.90	2.08	4.55	4.16	5.85
	87	2.34	3.25	2.86	5.46	3.25	4.94
Cu in Sed	86	46.15	52.65	52.65	65.13	54.34	63.44
	87	47.84	52.39	52.13	71.50	53.30	55.90
Zn in Sed	86	52.13	57.85	42.40	75.40	56.42	72.80
	87	52.65	56.55	55.90	74.10	57.20	71.50
Fe in Sed	86	1.56	3.25	1.82	3.38	2.99	3.92
	87	1.17	3.38	1.75	3.64	2.73	4.94

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon.

Table 21. Seasonal variation of Copper (Cu); Zinc (Zn) and Iron (Fe) in water and sediment at Station VI (1986-87).

PARAMETER		PRM (Feb - May)		MONS (June - Sept)		POM (Oct - Jan)	
ppb		Min	Max	Min	Max	Min	Max
Cu in Wat	1986	7.36	8.00	7.28	11.68	8.16	9.76
	87	6.88	7.68	8.16	12.64	8.16	10.08
Zn in Wat	86	8.32	9.60	9.60	13.28	8.32	14.72
	87	8.64	9.28	10.40	14.40	8.64	10.40
Fe in Wat	86	2.24	4.80	2.56	5.60	5.12	7.20
	87	2.88	4.00	3.52	6.72	4.00	6.08
Cu in Sed	86	56.80	64.80	64.80	80.16	66.86	82.38
	87	58.20	64.48	64.16	88.00	55.82	68.80
Zn in Sed	86	64.16	71.20	57.20	92.80	69.44	89.60
	87	64.80	69.60	68.80	91.20	70.40	88.00
Fe in Sed	86	1.92	4.00	2.24	4.16	3.68	4.85
	87	1.44	4.16	2.16	4.48	3.36	6.08

PRM: Pre-Monsoon; MONS: Monsoon; POM: Post-Monsoon .

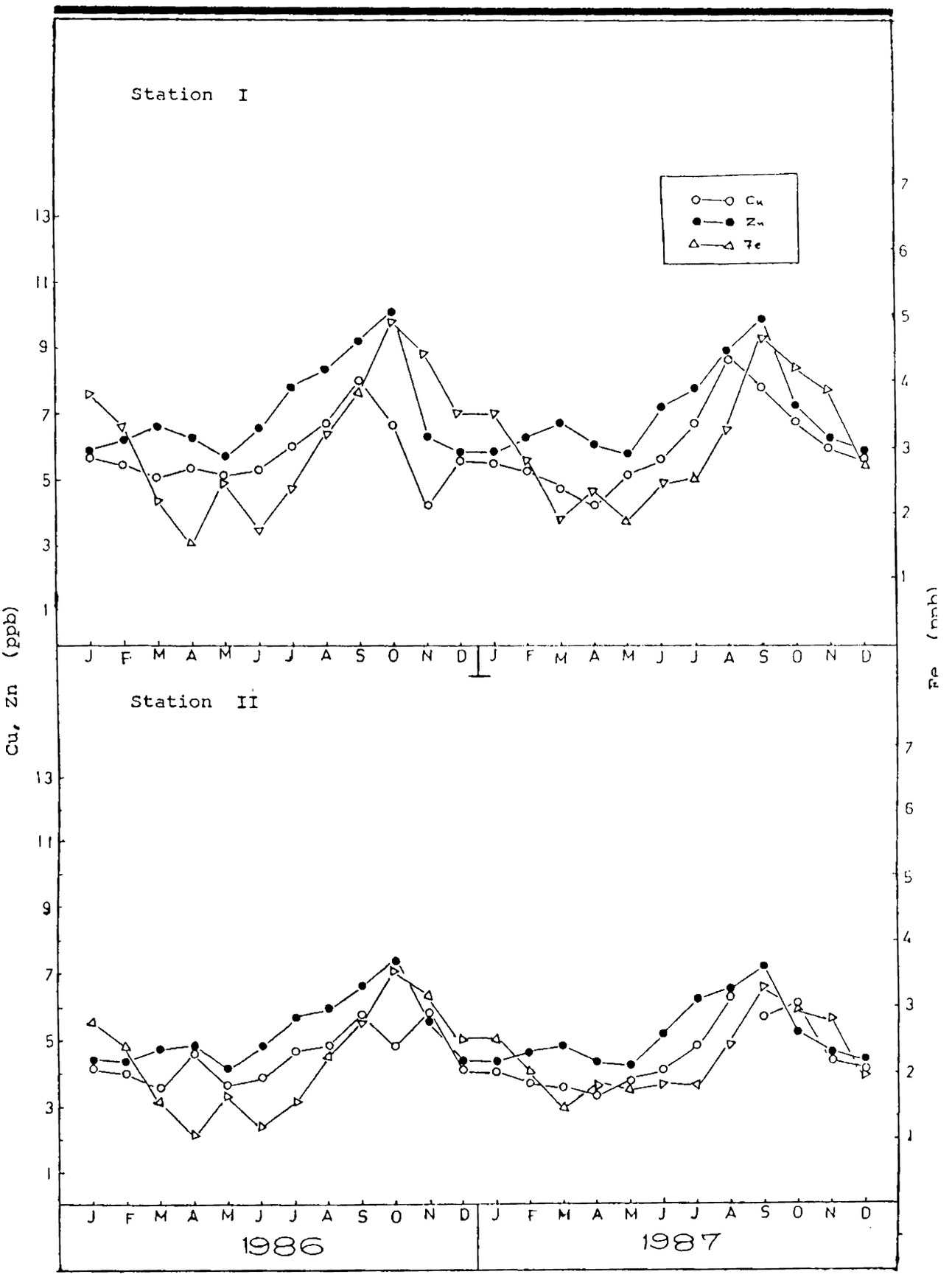

Fig. 25. Copper (Cu), Zinc (Zn) and Iron (Fe) concentrations in the water at stations I and II of prawn culture systems during 1986-87.

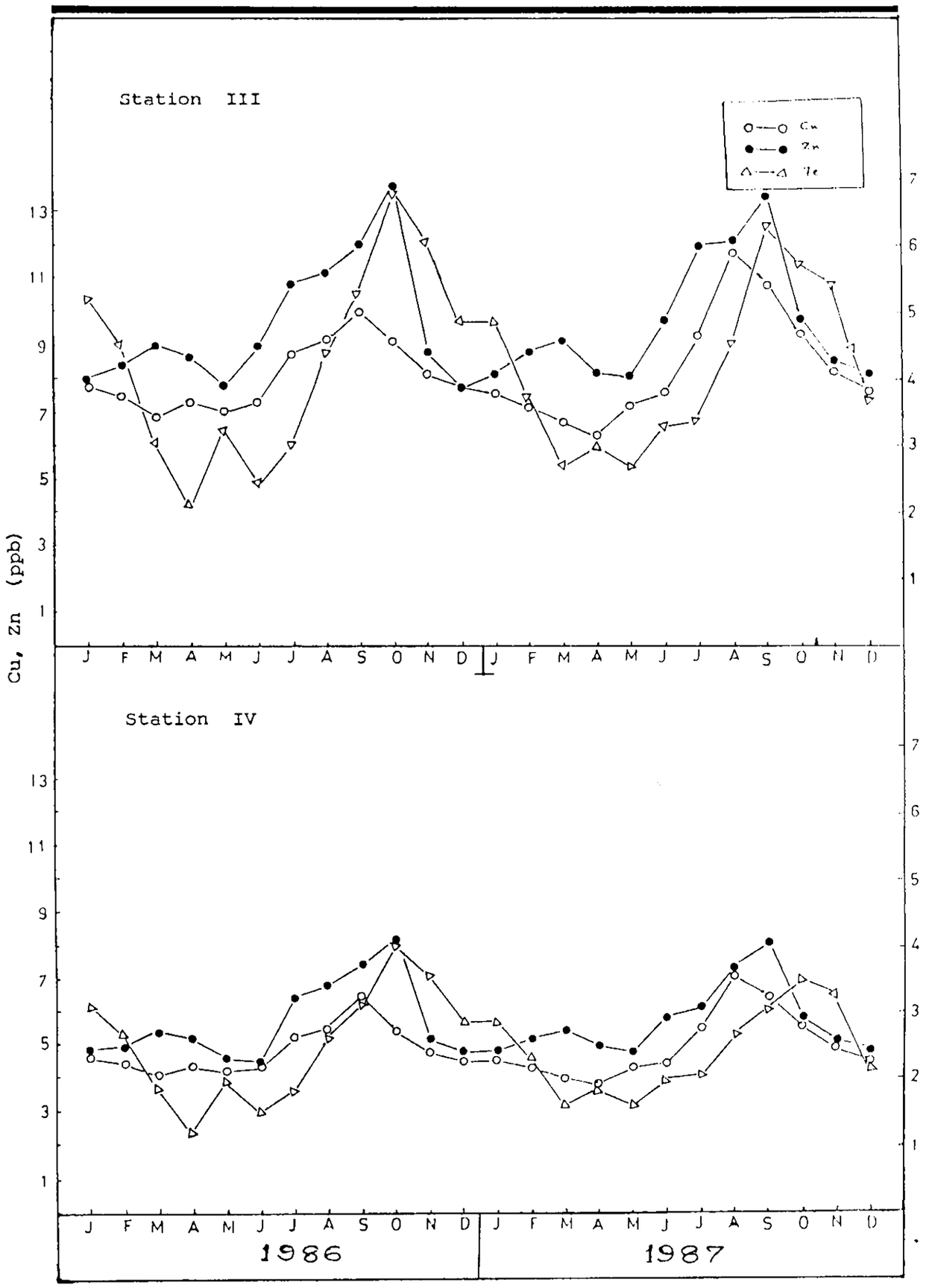

Fig. 26. Copper (Cu), Zinc (Zn) and Iron (Fe) concentrations in the water at stations III and IV of prawn culture systems during 1986-87.

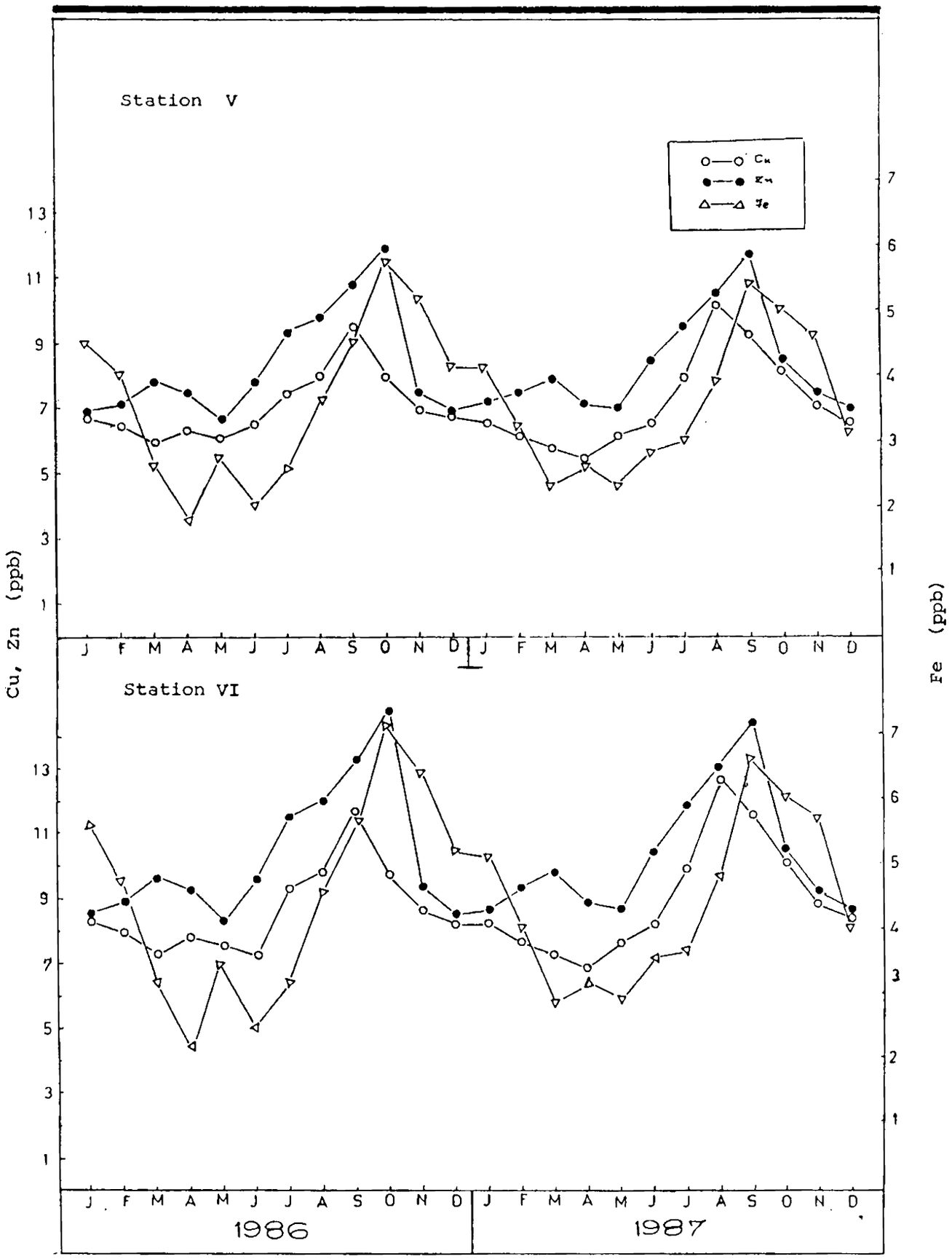

Fig. 27. Copper (Cu), Zinc (Zn) and Iron (Fe) concentrations in the water at stations V and VI of prawn culture systems during 1986-87.

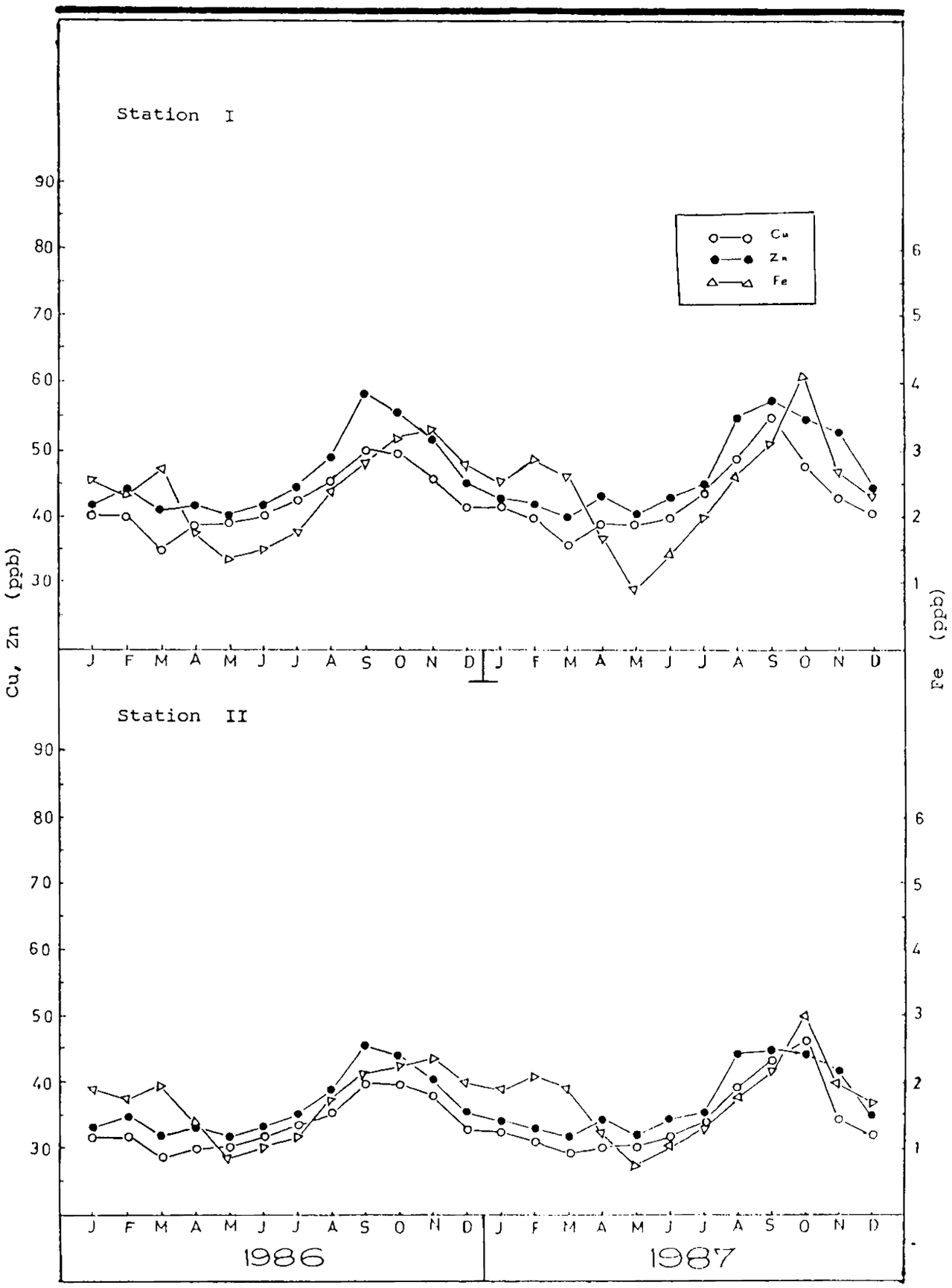

Fig. 28. Zinc (Zn), Copper (Cu) and Iron (Fe) concentrations in the sediment at stations I and II of prawn culture systems during 1986-87.

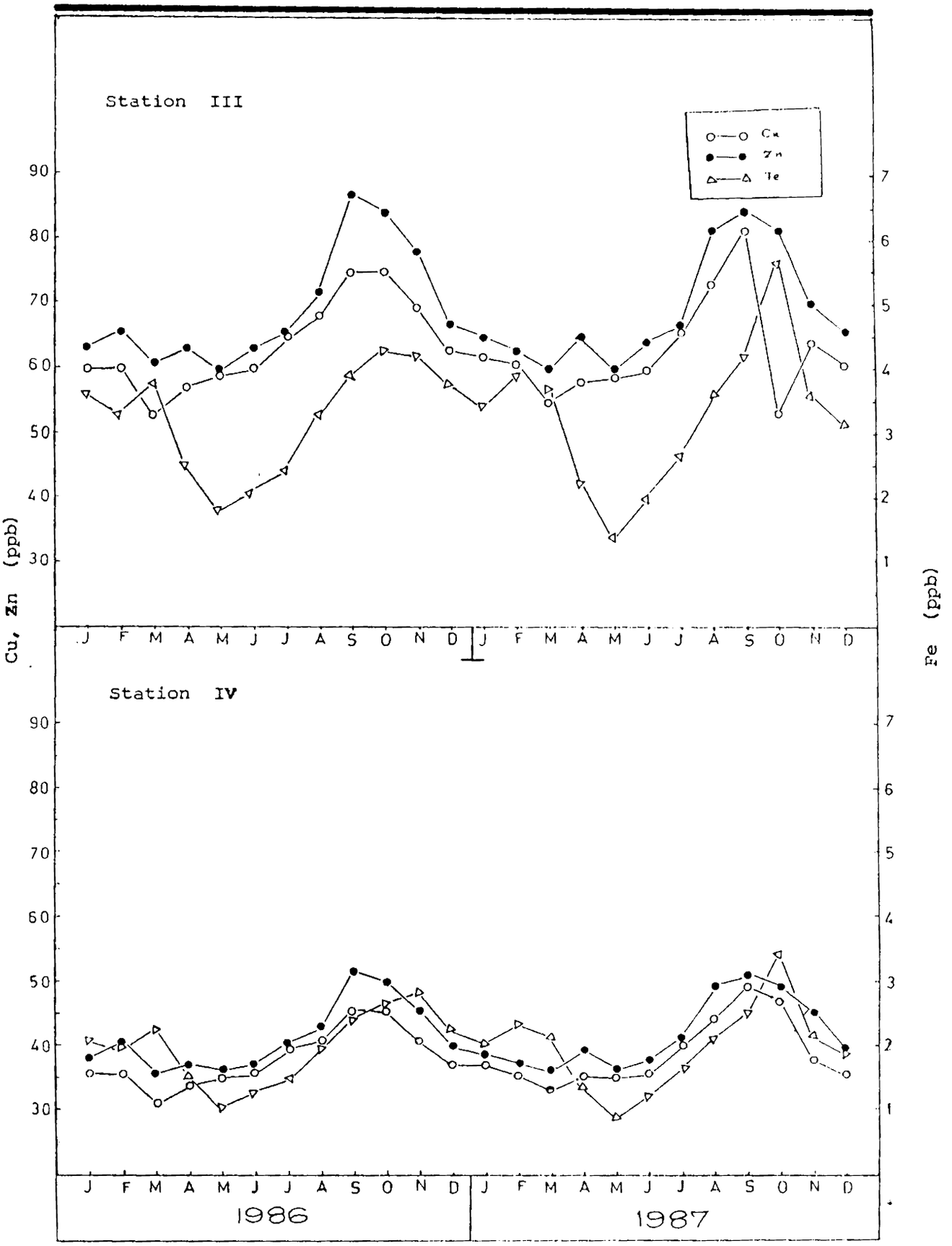

Fig. 29. Zinc (Zn), Copper (Cu) and Iron (Fe) concentrations in the sediment at stations III and IV of prawn culture systems during 1986-87.

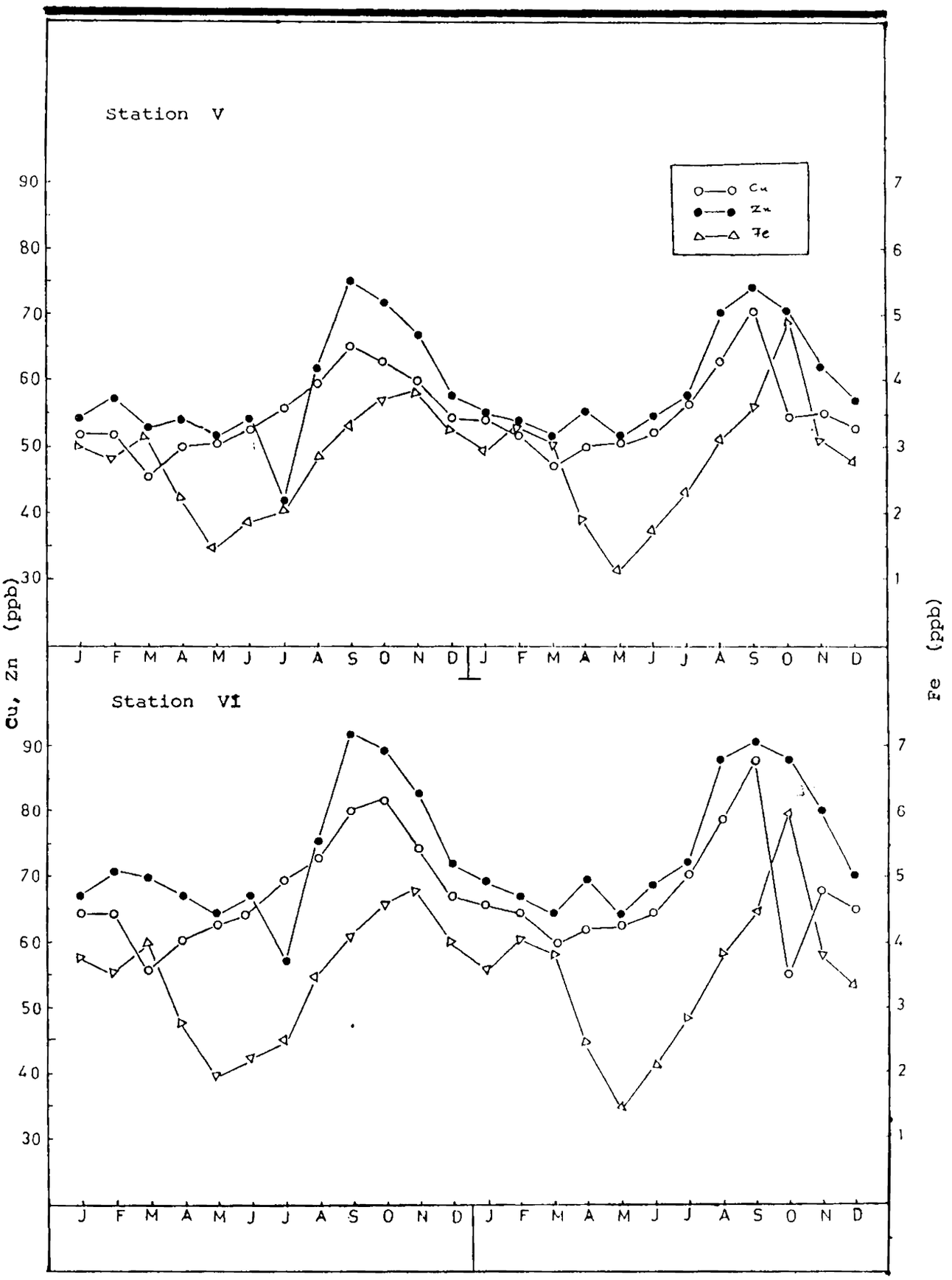

Fig. 30. Zinc (Zn), Copper (Cu) and Iron (Fe) concentrations in the sediment at stations V and VI of prawn culture systems during 1986-87.

end of July and thereafter showed a progressive increase upto October. The range in concentration was between 0.72 and 4.18 ppb in the perennial fields; 0.81 and 4.94 in the coconut grove canal; 1.35 and 6.08 in pokkali fields. Maximum value was recorded during the month of October and minimum during May. The iron concentrations were found to be high during monsoon, post-monsoon months and low during pre-monsoon months (Figs. 28, 29 and 30).

NUTRIENT RATIO

TOTAL NITROGEN/TOTAL PHOSPHORUS (N/P)

The Table 22 lists the values of the total N/P ratio at stations I to VI throughout the period of observation. Total N/P ratio of the prawn culture fields was showed range from 4.48 to 40.40 throughout the period. The ratio in the perennial fields, canals in the coconut grove and in the pokkali fields was varying between 7.33 and 40.40; 4.48 and 22.77; 4.84 and 29.56 respectively. During the months of January to April the ratios were consistently low, but became high during June to August, and have showed no consistancy in fluctuation during September to November.

INORGANIC N/P

The Table 23 lists the values of the inorganic N/P ratio at stations I to VI throughout the period of observation. Inorganic N/P ratio of the water in the prawn culture fields ranged from 1.08 to 22.33 throughout the period. Calculated ratio during June-September was 22.33-3.01 in the

perennial fields; during January-May was 1.40-9.94 in the coconut grove canal and during January-December 1.08-18.14 in the pokkali fields.

ORGANIC N/P

The Table 24 lists the values of the organic N/P ratio at stations I to VI throughout the period of observation. Organic N/P ratio of the prawn culture fields was showed range from 7.96 to 160.21 throughout the period. The ratio in the perennial fields, canals in the coconut grove and in the pokkali fields was found to vary between 9.24 and 74.57; 8.87 and 160.21; 7.96 and 106.11 respectively. Maximum ratio was observed during the month of December and minimum during September.

PARTICULATE N/P

The Table 25 lists the values of the particulate N/P ratio at stations I to VI throughout the period of observation. Particulate N/P ratio of the water in the prawn culture fields have showed a range from 3.01 to 28.53 throughout the period. Calculated ratio during January-July was 24.25-5.30 in the perennial fields; during February-October was 16.66-30.1 in the coconut grove canal and during February-August 28.53-4.68 in the pokkali fields.

Table 22. Seasonal variations in the total nitrogen/phosphorus ratio of the prawn culture fields

STATIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						1 9 8 6						
I	12.87	7.34	12.78	7.68	9.63	20.35	10.26	12.14	8.72	13.13	17.67	26.30
II	7.66	8.65	9.92	10.30	9.59	9.59	9.59	13.53	8.64	9.46	10.95	26.25
III	8.39	12.37	14.51	12.20	11.64	19.87	11.78	11.50	14.65	13.04	14.88	22.51
IV	5.33	5.85	10.02	7.32	7.58	10.96	7.22	6.97	5.19	8.30	9.27	17.65
V	4.48	5.66	8.90	6.84	7.05	8.17	5.46	7.71	5.42	5.81	7.12	14.26
VI	4.84	8.60	6.83	8.06	8.01	11.40	7.62	7.37	6.42	10.62	4.65	13.67
						1 9 8 7						
I	24.33	9.33	13.45	12.86	16.44	25.90	14.41	25.85	10.33	10.19	15.50	40.40
II	8.09	7.33	13.49	12.54	16.97	11.47	13.15	8.29	8.25	11.54	15.97	36.18
III	11.58	12.35	14.82	17.93	23.06	20.03	14.13	13.90	14.32	21.37	17.71	29.56
IV	8.42	7.91	10.54	9.19	12.75	14.27	11.63	9.85	6.08	7.02	12.04	22.77
V	5.57	4.62	10.23	7.71	9.64	8.92	9.03	8.41	5.21	6.57	9.14	17.83
VI	7.69	5.56	11.60	10.77	13.45	14.40	9.80	7.93	8.84	10.67	11.77	13.67

Table 23. Seasonal variations in the inorganic nitrogen/phosphorus ratio of the prawn culture fields

IONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						1 9 8 6						
I	5.77	3.26	9.28	3.71	4.76	14.78	7.01	11.20	4.19	7.89	8.61	15.61
II	3.37	4.16	4.96	5.75	5.64	7.97	6.35	10.69	3.87	4.85	6.65	18.65
III	3.03	5.68	5.54	5.89	6.51	17.58	7.77	7.18	9.40	7.89	8.03	18.14
IV	1.40	1.88	6.70	2.74	3.46	7.33	3.88	3.82	1.62	4.20	4.54	7.52
V	1.43	2.21	3.65	2.63	2.95	4.91	3.47	5.66	1.93	2.51	3.55	8.56
VI	1.08	3.37	2.66	3.24	3.35	8.08	4.38	4.89	4.63	4.55	3.58	6.45
						1 9 8 7						
I	4.72	5.77	7.27	7.59	9.57	22.33	4.20	12.14	3.98	7.00	9.69	21.34
II	4.48	3.38	7.25	6.28	12.03	7.75	5.65	9.32	3.01	6.36	8.46	21.74
III	4.63	6.19	9.33	11.07	12.68	12.03	10.44	6.25	6.60	8.19	13.86	8.47
IV	2.63	2.12	3.30	4.08	5.60	9.94	2.65	5.28	1.89	3.12	4.58	9.49
V	2.25	2.31	3.95	3.20	5.24	3.98	2.75	5.22	1.87	3.38	3.74	9.19
VI	2.58	3.04	4.83	5.79	5.60	10.12	4.12	4.74	3.75	5.32	4.07	6.60

Table 24. Seasonal variations in the organic nitrogen/phosphorus ratio of the prawn culture fields

STATIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						1 9 8 6						
I	20.92	11.92	13.07	32.46	15.06	32.39	15.67	13.34	9.24	21.19	33.96	47.59
II	14.73	14.23	15.29	15.22	12.72	20.26	13.16	15.30	13.17	18.04	21.14	35.70
III	18.28	19.37	23.69	25.71	15.94	27.52	17.22	14.95	15.22	23.85	37.70	28.57
IV	43.05	13.01	11.99	22.52	12.87	16.57	16.74	10.71	8.87	19.35	27.57	118.09
V	27.75	13.79	23.35	17.39	14.95	16.22	10.62	10.39	16.33	19.96	17.14	27.78
VI	17.25	19.82	15.40	23.81	16.71	21.55	14.30	9.34	9.71	36.18	5.44	48.27
						1 9 8 7						
I	21.16	12.95	19.00	18.61	29.09	48.10	28.16	19.97	9.87	14.04	26.94	74.57
II	14.83	13.32	24.74	20.12	22.00	18.33	12.99	17.17	11.18	23.95	26.32	54.05
III	31.28	28.70	23.38	26.07	52.44	32.29	13.63	23.69	15.97	30.90	56.34	45.72
IV	90.66	9.33	23.73	21.69	33.54	26.79	64.55	14.13	9.40	17.77	55.74	160.21
V	16.45	9.80	33.52	18.13	16.33	23.77	8.87	11.67	13.26	23.44	26.44	44.75
VI	25.00	9.67	34.15	18.49	71.85	35.01	7.96	9.45	13.73	39.45	106.11	43.70

Table 25. Seasonal variations in the particulate nitrogen/phosphorus ratio of the prawn culture fields

STATIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						1 9 8 6						
I	23.52	13.88	21.67	12.95	15.00	11.66	7.03	9.37	17.63	8.54	11.87	21.32
II	11.93	14.06	14.20	15.23	15.71	10.80	5.30	13.15	20.57	5.95	6.74	16.84
III	20.70	26.00	14.58	13.00	16.03	11.04	10.81	11.71	25.24	6.69	7.46	15.65
IV	13.88	16.66	13.60	10.15	11.53	11.96	3.75	8.28	10.37	4.50	7.66	14.72
V	8.13	9.95	11.58	10.21	9.91	10.41	3.13	3.87	6.65	3.01	4.00	9.11
VI	17.50	14.01	16.51	13.03	10.30	6.76	7.40	8.38	4.68	5.05	6.25	10.85
						1 9 8 7						
I	19.04	11.53	22.37	14.84	11.61	9.72	9.37	10.93	20.50	7.53	12.72	22.19
II	12.50	10.09	15.24	14.06	13.58	8.83	6.37	14.34	18.99	7.94	7.50	24.25
III	25.48	13.00	16.69	13.00	13.84	8.83	14.80	13.02	28.53	9.37	7.90	18.55
IV	16.39	12.29	12.84	10.59	11.34	10.00	4.32	8.66	13.11	5.10	8.48	16.47
V	12.72	5.96	11.04	12.35	10.79	7.75	3.79	4.03	7.25	3.12	4.16	10.29
VI	20.00	9.63	9.62	13.43	7.89	6.82	13.39	8.85	6.00	5.31	6.59	11.78

COEFFICIENT OF CORRELATION

In order to assess the influence of environmental parameters, nutrients and metals on the primary productivity, the collected data were analysed statistically and the coefficient of correlation are presented in Tables 26 and 27.

ENVIRONMENTAL PARAMETERS

In the prawn culture systems temperature showed positive correlation with salinity (r = 0.7017); dissolved oxygen (r = 0.6604) and negative correlation with pH (r = -0.7265); total phosphorus (r = -0.4275); Silicate (r = -0.5711); Primary productivity (r = -0.2822); Zinc (r = -0.7635); Iron (r = -0.7836). Hydrogen ion (pH) showed positive correlation with total phosphorus (r = 0.3339); total nitrogen (r = 0.2960); Silicate (r = 0.5421); Primary productivity (r = 0.3980); Copper (r = 0.7152); Zinc (r = 0.7039) and negative correlation with salinity (r = -0.2439); dissolved oxygen (r = -0.5635); total alkalinity (r = -0.4692).

Salinity showed positive correlation with dissolved oxygen (r = 0.4238); total alkalinity (r = 0.3438) and negative correlation with Silicate (r = -0.3859); Copper (r = -0.8914); Zinc (r = -0.6123); Iron (r = -0.2797). Dissolved oxygen showed negative correlation with total alkalinity (r = -0.3857); total phosphorus (r = -0.2561); Silicate (r = -0.6564); primary productivity (r = -0.3484); Copper (r = -0.6901); Zinc (r = -0.7276); Iron (r = -0.2797).

NUTRIENTS

Total phosphorus showed positive correlation with inorganic phosphorus (r = 0.9284); organic phosphorus (r = 0.4116); particulate phosphorus (r = 0.6590); total nitrogen (r = 0.6009); total inorganic nitrogen (r = 0.5714); organic nitrogen (r = 0.5704); nitrate nitrogen (r = 0.7129); nitrate nitrogen (r = 0.6540) primary productivity (r = 0.4860) and negative correlation with particulate nitrogen (r = 0.4168). Total nitrogen showed positive correlation with total inorganic nitrogen (r = 0.8279); organic nitrogen (r = 0.2986); nitrate nitrogen (r = 0.4820); nitrite nitrogen (r = 0.5817); primary productivity (r = 0.5483) and negative correlation (r = -0.5706); particulate nitrogen (-0.4168).

Table 26. Correlation matrix of parameters at Stations I to VI

	Temp. 1	pH 2	SAL 3	$DISO_2$ 4	TAL 5	TP 6	TN 7	SIO 8	PRP 9	Cu 10	Zn 11	Fe 12
Temp.	1	* 0.7265	* 0.7017	* 0.6604	* -0.7614	* -0.4275	@ -0.1467	* -0.5711	* -0.2822	@ -0.0416	* -0.7635	* -0.7836
pH		1	* -0.2438	* -0.5635	* -0.4692	* 0.3337	* 0.2960	* 0.5421	* 0.3980	* 0.7152	* 0.7039	@ 0.1660
SAL			1	* 0.4238	* 0.3438	@ -0.0215	@ 0.1029	* -0.3859	@ -0.1021	* -0.8191	* -0.6123	* -0.8298
$DISO_2$				1	* -0.3857	* -0.2561	@ 0.0863	* -0.6564	* -0.3484	* -0.6901	* -0.7267	* -0.2797
TAL					1	@ -0.1515	@ 0.0496	* -0.4464	@ -0.0661	* -0.8165	* -0.5179	* -0.8496
TP						1	* 0.6009	* 0.2621	* 0.2860	@ 0.0873	* 0.5041	* -0.2898
TN							1	@ 0.1815	* 0.4433	@ -0.0290	@ 0.2163	* -0.7940
SIO								1	@ -0.1579	* 0.4528	* -0.2780	@ -0.1860
PRP									1	* 0.3932	@ -0.0518	@ 0.0358
Cu										1	* 0.7357	* 0.8006
Zn											1	* 0.7157
Fe												1

*Significant at 5% level
@Not Significant

1: Temperature; 2: pH; 3: Salinity; 4: Dissolved Oxygen; 5: Total Alkalinity ; 6: Total Phosphorus 7: Total Nitrogen; 8: Silicate; 9: Primary Productivity; 10: Copper in water; 11: Zinc in water 12: Iron in water

Table 27. Correlation matrix of parameters at Stations I to VI

	TP	IP	OP	PP	TN	TIN	ON	NO_3-N	NO_2-N	NH_3-N	PN	PRP
	1	2	3	4	5	6	7	8	9	10	11	12
TP	1	* 0.9284	* 0.4116	* 0.6590	* 0.6009	* 0.5714	* 0.5702	* 0.7129	* 0.6540	@ 0.0209	* -0.4168	* 0.4860
IP		1	* -0.3285	* 0.6134	* 0.5190	* 0.4871	* 0.5300	* 0.6227	* 0.5092	@ -0.1392	* -0.4372	@ 0.2511
OP				@ 0.1109	* 0.3670	* 0.3638	@ 0.2748	* 0.3089	* 0.5690	@ -0.2280	@ -0.2396	@ -0.1132
PP				1	* 0.4630	@ 0.2860	* 0.3790	@ 0.2460	* 0.3840	@ -0.1357	* 0.4167	@ 0.0734
TN					1	* 0.8279	* 0.2986	* 0.4820	* 0.5817	* -0.5706	* -0.4168	* 0.5483
TIN						1	* 0.7834	* 0.6480	* 0.7240	@ 0.2050	@ -0.0882	* 0.3537
ON							1	* 0.7506	* 0.4802	* 0.4532	@ -0.1812	@ 0.2822
NO_3-N								1	* 0.7098	@ 0.0417	@ -0.1034	* 0.4153
NO_2-N									1	@ -0.1665	@ -0.2017	@ 0.2123
NH_3-N										1	@ -0.0529	@ -0.2413
PN											1	@ -0.0474
PRP												1

*Significant at 5% level
@Not significant

1: Total Phosphorus ; 2: Inorganic Phosphorus; 3: Organic Phosphorus; 4: Particulate Phosphorus
5: Total Nitrogen; 6: Total inorganic Nitrogen ; 7: Organic Nitrogen; 8: Nitrate Nitrogen
9: Nitrite Nitrogen; 10: Ammonia Nitrogen; 11: Particulate Nitrogen; 12: Primary Productivity

5. DISCUSSION

An examination of different parameters as described earlier by Sankaranarayanan and Qasim (1969) revealed that during the monsoon period the bottom layers of the backwater suddenly become cold, saline, oxygen - deficient and rich in nutrient. Concurrent with the freshwater discharge from the Cochin Backwater during the monsoon months, there is an incursion of cold saline water from the Arabian Sea into the backwater. This water becomes particularly noticeable at the bottom, and has been recognised by Ramamritham and Jayaraman (1963) as "upwelled water from the Arabian Sea" which finds its way into the backwater through the main channel. George (1958) opined that two factors, namely the connection of the canal with the sea through the backwater area throughout the year and the consequent effects of admixture with large volumes of seawater brought in by the regular tidal action, and the large volumes of freshwater pouring into the backwaters directly and indirectly through the rivers, especially during the monsoon period seem to profoundly influence the salinity.

The Vembanad lake and the adjacent backwaters are more influenced by the monsoons (Pillai et al., 1975). This results in pronounced seasonal variation in the environmental parameters as well as the production at the primary and secondary levels. Changes in the environmental parameters and production are also caused by the freshwater influx, nutrient distribution, incident solar radiation, nature of the medium and species composition of the primary and secondary producers. Rajagopalan et al. (1980) opined that environmental characters showed considerable seasonal fluctuations, especially the salinity which in some of the natural ponds in the mangrove

area varied from freshwater condition to high saline, mainly due to the monsoonal and tidal influxes. Sankaranarayanan et al. (1980) showed that the environment was subjected to seasonal variations due to monsoons.

The annual changes reported in the environmental features of the backwater will not be complete without mentioning, briefly, the changes occurring in the coastal waters around Cochin. Ramamritham and Jayaraman (1960), while discussing the hydrography of the shelf waters off Cochin, have divided the annual periods into four seasons, namely (1) The period of the south west monsoon (June, July and early August). (2) The period of upwelling (end of August, September and early October). (3) The period of sinking (end of October to February). (4) The period of stable conditions (March, April and probably May). While Sankaranarayanan and Qasim (1969), indicated the cycle of events in the estuary is fairly regular, making the year divisible into three distinct seasons, each of four months duration. 1. The stable season, January to April; 2. The monsoon season, May to September; 3. The recovery season, October to December.

During the stable season the upper reaches of the estuary show simple and uniform conditions. The monsoon season is associated with sudden changes from typically marine to brackish water conditions. With the heavy rain, the estuary becomes a focal point of freshwater discharge. During the recovery season there is a general reduction in the freshwater discharge and the marine components of the system begin to develop with the invasion of the seawater from the bottom zone towards surface.

The temperature in the present study showed wide range of variation from 28.00 to 31.90° C in different prawn culture systems. The temperature

was at its maximum during the pre-monsoon months, extending up to May, after which with the onset of monsoon it began to decline. This seems associated with warmer weather and maximum solar radiation during these months. During monsoon and in the early post-monsoon periods the temperature was very low. The changes in temperature clearly indicate that the freshwater discharge and incursion of a large volume of cold water from the sea into the estuary are responsible for the phenomena.

The pH in the present study, showed a wide range of variation of 7.40 to 9.10 in different prawn culture fields. The pH was at its minimum during the pre-monsoon months, extending up to May, after which it began to increase. This may be due to the freshwater discharge to the system. Salinity value, in the present study, varied between 1.08 to 33.80 $\%_{o}$ in the prawn culture systems. During the pre-monsoon season, especially during March-April, the salinity at all stations exhibited considerable increase, while during monsoon, its values showed decrease. This may be due to extension of the adjoining seawater to the prawn culture systems. With the commencement of monsoon the surface water is considerably diluted with brackishwater or freshwater.

The oxygen values in the present investigation showed fluctuation from 2.50 to 6.80 ml/l. Dissolved oxygen showed a distinct pattern of seasonal fluctuation in the prawn culture fields. Local production, diffusion and advection, exchange of oxygen across the surface and biochemical utilization have been found to control dissolved oxygen in many areas and this has been early demonstrated by Richards (1957). In the present investigation the total alkalinity values of the water showed fluctuation from 0.07 to 2.72 m eq/l in different prawn culture fields. The values were found to

be high during the pre-monsoon and monsoon months and low during post monsoon months.

Panickar and Jayaraman (1956) opined that distinct seasonal cycle of phosphates have been observed in the inshore waters of the Arabian sea. The phosphate values were very high during the period of the south-west monsoon, May to September. The nitrates are also high during the same period. During the south-west monsoon, the surface water off the west coast are replenished with nutrient salts to a considerable extent. Sankaranarayanan and Qasim (1969) and Gopinathan et al. (1978) suggested that during the period when the backwater system remains predominantly marine, the nutrient concentrations are low and remain homogenous througnout the water column, but during the period of fresh water discharge, high concentrations of nutrients occur with gradient zones within the system. Dharmaraj et al. (1980) observed that the inorganic nutrients such as reactive phosphate, silicate, nitrite and nitrate exhibited high values during the north east monsoon period or by the diminishing stage of the south west monsoon.

A noticeable influence of freshwater has been discovered only in regard to silicate concentrations in the uppermost layer of the seawater and, in some place, enrichment in nitrogen and phosphorus quite close to estuaries (Propp, 1977). A comparison of monthly changes of the total stock of nitrogen and phosphorus in the water, reflecting the differences between sedimentation and excretion by the bottom communities, shows that these are values of the same order of magnitude. Consequentially the observed changes in the total stock may be fully accounted for by phytoplankton growth, sedimentation and bottom regeneration, through it is more probable that the exchange of water between the bay and sea is of some

importance too. Wangresky (1977) opined that absolute amount of nitrogen and phosphorus in the system will determine the maximum standing crop of phytoplankton, while the temperature of the water will determine the maximum rate of bacterial metabolism.

Rutgers Vander Loeff (1981) opined that estuarine mixing plots show that there was a net release of silica in the Dollard during late summer. The origin of this silica was probably dissolution of suspended material in the water phase. During the emersion the inorganic nitrogen, nutrients can become nearly depleted at the sediment and may limit diatom growth. The places in which the nutrient cycles will be interrupted should differ due to different kinds of nutrient limitation. The organics dumped under nitrogen limitation should be different from those dumped under phosphorus limitation. The uptake of nutrients should be very fast. This has been postulated earlier by Goldman and Gilbert (1982), and recent work of Shoglund and Jensen (1976) suggests that measured uptake rates are really rates of molecular diffusion of the nutrient across the stagnant layer of water surrounding the organisms.

The interchange of phosphorus between the bottom and the overlying water may be another feature to be considered. According to Moore, (1930) the phosphorus content of estuarine mud is fifty times greater than that of the water above and, therefore, any stirring up of the sediment would greatly influence the concentration of phosphorus in the bottom layers. In estuaries, the release of phosphorus "from silt occurs at low oxygen concentration"(Rochford, 1951) and at an increased pH (Carrit and Goodgal, 1954). Depending on the degree of organic matter degradation each winter, different amounts of humic substances can be expected to accumulate, which are

considered important in chemical removal of phosphate (Smith and Longmore, 1980). The release or accumulation of phosphate by the sediment is strongly dependent on exchange equilibrium with the particulate inorganic phosphate fraction, which equilibria are influenced by redox potential,pH and temperature (Rutgers Vander Loeff, 1981).

Qasim et al. (1969), stated that while there is a close correlation between the cycle of phosphorus and organic production in the Cochin Backwater, the nitrogen cycle is completely unconnected with productivity rhythm, for most of the year there is little or no nitrate - N in the water. Sankaranarayanan and Qasim (1969) showed variation in the values of organic phosphorus except for the monsoon period, when the two forms of phosphorus were in almost equal proportions. This suggests that probably, the freshwater run off brings in both organic and inorganic phosphorus. It is stated that the inorganic phosphorus increases during the post and pre-monsoon period. Nair (1972) observed that phosphate values were relatively low in the Gulf of Mannar and did not show much seasonal variation. The monthly average values varied from 0.08 to 0.29 /ug at/l.

Individual phosphorus measurements in winter can be further influenced by the extent of vertical mixing as the resultant resuspension of sediment particles increase oxic sites of dissolved solid phase interaction. Bodungen (1986) opined that an increase of phosphate concentration superimposed over considerable interannual variability. While discussing the comparatively lower level of phosphate in the Gulf of Mannar combined with the absence of marked seasonal cycles, Jayaraman (1954) had speculated whether this could be indicative of a low level of organic production in these waters. Delsman (1939) stated that probably the rapid metabolism

in the tropical seas would check such an accumulation of nutrients as usually occurs in most northern waters during the winter.

The maximum phosphorus value observed by Sankaranarayanan and Qasim (1969) has been around 2 to 2.5 /ug at/l, while values exceeding 15 /ug at/l have been observed by Pillai et al. (1975). In the near shore waters of Port Novo, Krishnamurthy (1966) observed phosphate values to range between 0.25 and 1.45 /ug at/l,in the surface and 0.25 and 1.33 /ug at/l in the bottom; and total phosphorus varied between 1.00 and 8.35 /ug at/l in the surface and 0.50 - 9.25 /ug at/l in the bottom. Krishnamurthy (1967) recorded inorganic phosphate in the surface water between 0.04 and 1.45 and in the bottom water from 0.02 to 1.42 /ug at/l.

In the present study, the range of variation of total phosphorus (TP) varied from, 1.06 to 13.76 /ug at/l. The values were at their maximum during the monsoon months, extending up to September after which they began to decline, during the pre-monsoon and post-monsoon months, when the T P was very low. The maximum value observed here may be due to the transport of phosphate by bubbles rising to the surface, decomposition of particulate organic matter, rapid regeneration with microbial precipitation, the excretion by plankton, horizontal and vertical transport of water and advection. Release of the sediment could have contributed to higher values phosphate.

It was also observed in the present study that the concentration of different fractions of phosphate showed fluctuation between 0.16 and 8.80 of inorganic phosphorus (IP); 0.40 and 3.68 of organic phosphorus (OP); 0.13 and 1.16 /ug at/l of particulate phosphorus (PP). In general, higher values were recorded during monsoon period, the lowest during the pre-monsoon season.

There are several explanations for the enrichment of inorganic phosphorus in the top sediment layers which occurred in all cores and which could be traced back to be contained in the oxalate fraction, ie, primarily the inorganic p-bound to labile compounds. A similar decrease with the depth of inorganic phosphorus reported by Balzer (1986) with in the top layers of Long Island Sound sediments was ascribed by Krom and Berner (1981) to the liberation of phosphorus from adsorption sites on ferric oxyhydroxide particles during anoxic reduction. They opined that a respective amount of IP is present in addition to the phosphate arising from the degradation of organic matter. For Kieler Bucht sediments, however, observed release rates could be traced back to organic matter degradation and there was no need to invoke an additional inorganic source.

After the decomposition of IP in association with iron in a redox-stratified sediment column there might be an upward migration of IP from low to the top oxidised sediment layers. The most common way to explain surface enrichment of various components in the sediment column is by increasing the annual input to the sediment due to the influence of human beings. During the investigation of forms and accumulation rates of phosphorus in lake Erie sediment, Williams et al. (1976) found that 'Pre-colonial' sediments contained mainly apatite phosphorus which has derived from erosion of surrounding shore line bluffs. Moreover, the rates of accumulation of this excess phosphorus in the top layers consisting of non-apatite - P and organic phosphorus agreed well with the rates of net annual - P load to Lake Erie (Williams et al., 1976; Kemp et al., 1976).

Generally, the amount of nitrite (NO_2-N) in the sea is relatively less as compared to that of nitrate (NO_3-N) and ammonia (NH_3-N) although

in temperate waters it shows a slight increase in winter (Cooper, 1933). In the backwater, both these forms of nitrogen appears at the bottom presumably as a result of decomposition of organic nitrogen (ON) within the sediment. The available source of inorganic nitrogen in an aquatic environment are nitrite, nitrate and ammonia. These are formed as part of the nitrogen cycle, either by oxidation of ammonia or by reduction of nitrate to nitrite and ammonia. The latter process has been found to occur both in the water column and in the sediment at lower concentration (Vaccaro, 1965).

Sankaranarayanan and Qasim (1969) in their study of the Cochin Backwater have observed a trimodal cycle with a peak occurring during a period when the system remains freshwater dominated. They observed that nitrate-nitrogen occurs in a very high concentration during the monsoon period especially in the surface waters. Pillai et al. (1975), have suggested that the nitrite-nitrogen may be formed as a result of decomposition of organic nitrogen and as it is a transitory stage in the nitrogen cycle and its progressive decrease from the surface to the bottom suggests its possible conversion into nitrate-nitrogen.

Sankaranarayanan and Qasim (1969) reported the nitrate concentration was ranging between 0.31 and 39.97 µg at/l in the Cochin backwaters. In Port-Novo waters, Krishnamurthy (1967) reported nitrate values between 0.35 and 14.25 µg at/l. Sounararaj and Krishnamurthy (1973) reported nitrate values from nil to 20.30 µg at/l. In the present study, the total nitrogen(TN) of the water in all the prawn culture fields varied from 15.83 to 94.54 µg at/l. The concentration of different fractions of nitrogen showed a range of 3.63 and 32.90 in the total inorganic nitrogen (TIN); 8.94 to 52.64 in dissolved organic nitrogen (DON); 1.14 to 25.40 in nitrate-nitrogen (NO_3-N);

0.10 to 4.20 in nitrite nitrogen (NO_2-N); 0.45 to 13.50 in ammonia-nitrogen (NH_4-N); 1.60 to 12.04 µg at/l in particulate nitrogen (PN) in the prawn culture systems.

Nitrite production was observed to be high which may be due to the biological processes like excretion of nitrogenous compounds by plankton and decay of vegetation. It may be noted that nitrite is recycled here relatively repeated number of times than other compounds. Nitrite is an intermediate product in the regeneration of nitrogen compounds by bacterial action. Changes in concentration of nitrate are the net effect of nitrification, nitrate reduction and assimilation. For their supply of nitrogen algae prefer ammonia, as long as its concentration exceeds 1 to 5 per mol l^{-1} (Eppley, et al., 1969; Strickland et al., 1969). In Dollard estuary Rutgers Vander Loeff (1981) reported nitrification and denitrification may also proceed simultaneously at the same depth horizon. In the sediment, nitrification and denitrification act together, nitrogen may be lost as N_2 or N_2O without any apparent consumption of nitrite or nitrate. The release of dissolved organic compounds by autotrophic and heterotrophic organisms adds to the autochthonous nitrogen supply in the euphotic zone. Inorganically polluted and inshore ecosystems, allochthonous nitrogen supply in the form of nitrate, ammonia and urea might also be of significance (Wassmann, 1986).

Nitrogen is considered as a limiting nutrient for marine primary production, and the re-cycling of nitrogen is, therefore, an important factor in the regulation of primary production (Blackburn, 1986). Benthic fauna can influence all the process of N-cycling in marine sediments. There is an increase in the rate of organic-N mineralisation, at least as long as fresh organic detritus is available (Henriksen et al., 1980; Blackburn and Henriksen, 1983). Integrated over a long time period, however, it seems unlikely that

there is a greater total mineralisation of organic-N due to animal action. This is because of the general situations such as organic material is in limiting supply, and bacteria would eventually mineralise all degradable material, even in the absence of animals. Due to their burrowing and ventilation activity, animals have a very marked effect on process that involve oxidation/ reduction, i.e. nitrification and denitrification due to the introduction of oxygenated water into the deeper sediment layers. The simultaneous presence of ammonium and oxygen provide optimal conditions for nitrification. Burrow walls have a high potential for nitrification and probably account for 40% of total sediment nitrification (Henriksen et al., 1983; Kristensen et al., 1985).

In general,even if there is not a net flux of nitrate from the overlying water, it is probable that denitrification is increased due to bioturbation. The present result also agrees with the concept of bioturbation thus decreases the amount of mineralised nitrogen that is potentially transferred from the sediment of the water column and make them available to primary producers. This is in contrast to the effect of bioturbation in initially speeding up the rate of organic-N mineralisation, and thus increasing the availability of nutrients to the overlying water. About 30-70% of the nitrogen requirement of the primary producers are met by flux of inorganic nitrogen from inshore marine sediments (Blackburn and Henriksen, 1983).

In the present study, during the monsoon season, especially during June-July the total nitrogen (TN) in all the stations exhibited considerable increase, while during pre- and post-monsoon season values showed decreasing trend. Total inorganic nitrogen (TIN) values were found to be high during the monsoon months and low during pre- and post-monsoon poeriods. The

dissolved organic nitrogen (DON) were at its maximum during monsoon months, extending upto July, after which it began to decline. The higher values of nitrate-nitrogen, nitrite-nitrogen and particulate-nitrogen were recorded during monsoon period and low values were noted during pre- and post-monsoon periods. Ammonia-nitrogen did not show a distinct pattern of seasonal fluctuations during the pre- and post-monsoon season.

During the increasing phase of the phytoplankton bloom, DIN in the surface layer was observed to be rapidly bound in to organic nitrogen. At the end of the vernal period 99% of the nitrogen was present in the form of organic compounds in the surface layer. Most of the No_3-N which was predominating form of DIN, was exhausted (Leppanen et al., 1986). Both DIN and DON decreased while PN increased. Assuming the system is a closed one except for output through N_2 and N_2O formation and sedimentation, then the changes in the different forms of nitrogen and most probable pathways can be summarised. The initial amount of DIN in the surface layer could support nitrogen assimilation by autotrophs until the end of April. This observation is in agreement with that the observed depletion of No_3-N in the surface layer. The stored DIN was however, used up down to the depth of the halocline (Leppanen et al., 1986).

In the prawn culture systems the differences between the ratios of nitrogen assimilation, recycling and sedimentation may lead to a different response of the marine ecosystems to the increasing monsoon level of DIN. Assuming accepted the fact that DIN is the main limiting factor for primary production during the monsoon period, and if, in the absence of heterotrophs the increase in the initial amount of DIN increases only the peak of the bloom but not the duration of bloom period, then, the sedimentation in deep

localities could remove most of this stored component from the euphotic layer.

Dissolved organic nitrogen is a component which is widely discussed among the Oceanographers. It consists of an unknown mixture of organic compounds, mainly formed by the autolysis of cells, exudation and excretion, and also from the land- based humic substances (Pountanen, 1985). Jackson and Williams (1965) have estimated that the labile fraction is only 5-20% of DON. The formation of DON during the study of Leppanen et al., (1986) about the same order of magnitude as bacterial consumption of DON.

Comparatively little annual differences and no discernible increase in winter Total Inorganic Nitrogen (TIN) levels have been observed (Bodungen, 1986), although processes involved in nitrogen cycling and input from external sources are largely influenced by environmental variables, as indicated by different nitrate concentrations to TIN each winter. Organic matter input in autumn has been shown to be highly variable and this material is only partly remineralised during early winter (Graf et al.,1983; Czytrich et al.,1986) Thus, winter TIN levels are not controlled by year-to-year similarities in organic matter input to sediments and subsequent output of its remineralised products in autumn. Considerable portion of nitrogen from natural sources can be removed by denitrification from shallow coastal ecosystems and only minor portions may be bound due to ammonia adsorption by ion exchange on sediment particles have been discussed earlier (Rosenfield, 1979; Mackin and Aller, 1984). Additional portions are accumulated in sediments (Balzer, 1984) and may be found temporarily in the less labile fractions of the dissolved organic pool.

In Cochin backwater (Qasim et al.,1969) silicate was reported to fluctuate between 5.00 and 59.71 /ug at/l in the surface and 4.79 to 35.73

at 9 m deeper layer. In Porto Novo waters Krishnamurthy (1967) reported silicate values to vary greatly from a minimum of 0.12 to a maximum of 605.20 /ug at/l at the freshwater region of the study. Sundararaj and Krishnamurthy (1973) showed a variation in silicate value of 3.97 to 189.42 /ug at/l. In the present observation in the silicate values showed a wide range of fluctuation from 4.62 to 72.60 /ug at/l. The values were found to be high during the monsoon months and low during the pre- and post-monsoon periods. The silicate content of the water is generally high which is to be expected because of considerable freshwater discharge and land drainage. High silicate values are associated with low salinity of water and vice-versa, indicating that there is an inverse relation between the two (Sankaranarayanan and Qasim, 1969).

The high correlation between silicate and oxygen concentration may mean that the silicate distribution is determined primarily by dissolution in the water column at a rate proportional to the rate of oxygen consumption by organic nitrogen and carbon. Such a high correlation with oxygen consumption could indicate that most silicate regeneration occurs at locations similar to those for nitrate and phosphate. The distribution pattern of silicate in the prawn culture fields supports the findings which indicate that besides biological uptake and dissolution, also non-biological removal of dissolved silicate is involved in controlling concentration of this nutrient. Biogenic particulate silicate dissolution is dependent upon temperature, pH, silicate concentration in solution, organic coating of particulate and particle surface area. These finding have been in accordance with the works of Carlucci, et al. (1970); Kamatani (1971; 1979).

In aquatic systems, the limiting resource are dissolved nutrients such as nitrogen and phosphorus which are converted to particulate form

by plant growth. Transport of the dissolved element can only be effected by movement of the environment itself whereas particles can move selectively through the environment. In aquatic ecosystems, all essential materials can potentially be recycled between primary and secondary producers with in the productive surface layer. Several authors have estimated the amounts of organic material derived from phytoplankton which reach the sediment surface and also the contribution of recycled nutrients to the water column of coastal areas (Ryther and Dunstan, 1971; Davies, 1975; Rowe, et al.,1975; Nixon, 1981). Conclusions in the past indicate, in general, that between 30 and 40% of the annual production settles to the sea floor of the coastal zone and is mineralised and accumulated there (Parson, et al.,1977; Smetacek, 1980; Forskhal, et al., 1982).

Estimates of global nutrient fluxes (Harrisson, 1980) have clearly shown that external nutrient inputs can account for less than 1% of the annual nutrient requirements for marine primary production. Almost all required nutrients come from internal recycling. Internal sources can be further subdivided in to in situ regeneration and allochthonous inputs from deep ocean; reserves by upwelling and eddy diffusion. Eppley and Peterson (1979) suggested that about 20% of the nutrient requirements come from the latter source, leaving 80% from regeneration in situ. Analysis of particulate organic matter in shallow waters has also shown that recycling with in the water column can be important. Yanada and Maita (1978) observed that as an annual basis, 60-80% of particulate C, N and P are mineralised before reaching the sediments in Funka Bay, Japan.

Once the discontinuties become re-established, upward transport of nutrients is necessarily minimal, and in situ regeneration becomes the major

sources of nutrients for primary productivity. Regenerative processes of this sort, where the nutrients are supplied randomly in time and space, no longer conform to strictly deterministic models. Most notably, the concept of competitive exclusion has limited real meaning in an universe where success in gaining and using nutrients depends upon distance from sources of regeneration (Wangresky and Wangresky, 1980; 1981; 1983). At a longer time scales, the entire ocean is a recycling system through which a flux of material from one part of the lithosphere to another usually runs. To what extend the gain and loss of the various elements is in balance is still an open question but there with doubt that organisms have got a profound influence in changing chemistry of the atmosphere and oceans over geological time scales (Holland, et al., 1986).

Redfield (1934), demonstrated that nutrient (NO_3, PO_4) concentrations as well as dissolved oxygen and carbon dioxide, change in fixed relative proportions in seawater. The apparent oxygen utilization concept became important in the later studies of nutrient recycling in sub-surface waters. Ketchum and Corwin (1965), suggested that the nutrient transformation through inorganic-P —— particulate-P —— dissolved organic-P —— inorganic-P, and they were able to evaluate the important mechanism involved in maintaining primary production levels. Menzel (1974), Williams (1975), opined that dissolved organic concentrations are 10 to 20 times higher than particulate concentrations. Phosphorus cycling in estuaries and coastal areas is influenced by river input in both dissolved and particulate form, contribution of sewage and intensive contact of water masses with the underlying sediments. Thus phosphorus concentrtation in shallow sea areas is subject to both biological and physio-chemical controls (Einsele, 1938).

Results indicate that upto 50% of the nutrients incorporated by phytoplankton during photosynthesis could be made available by benthos Ryther and Dunstan, 1971; Davies, 1975; Rowe et al., 1975; Harrison, 1978; Fisher et al., 1982). With in the coastal and oceanic water columns grazing by herbivorous zooplankton has been considered most important mechanism for nutrient recycling from particulate organics (Steel, 1972; Williams, 1975) although direct microbial degradation may also be important. Nutrient cycling between auto-and hetero-trophs can enhance energy flow and can hence be of mutual benefit to those organisms actively involved in retaining essential elements by recycling them within their environment (Smetacek, 1985b).

In the present study it was observed that the total phosphorus (TP) was at its maximum during the monsoon months, extending up to September after which it's values began to decline. During the pre-monsoon and post-monsoon months the TP was very low. Inorganic phosphorus (IP) during the monsoon season especially during June-July months at all the stations studied exhibited considerable increase, while during pre- and post-monsoon periods values showed decreasing trend. Organic phosphorus (OP) was high during monsoon period and recorded the lowest during pre-monsoon season. In the case of particulate phosphorus (PP) at its maximum during the monsoon months, extending upto August, after which it began to decline. During pre- and post-monsoon season the particulate phosphorus value was very low.

The present result is comparable with the seasonal phase of nutrient cycling in Kiel Bight (Noji et al., 1986) which evinced considerable differences in their temporal occurrence and duration, particularly at the start and end of the growth phase. This principally reflects the year-to-year variability of the physical environment, in which the impact of horizontal advection

is more important for the regulation of the physical structure of the water column than for the import of or export of nutrients. During spring and autumn, when primary production is fuelled by accumulated nutrients, remarkably constant biomass accumulation has been reported by Peinert et al. (1982), Graf et al. (1982; 1983). Thus, the winter period appears to be most suited for differentiation of annual variability from quantitative changes in nutrient cycling due to external nutrient input to the system.

Nutrients remineralised (Smetacek et al.,1984), from phytoplankton bloom material are not directly returned to the primary production cycle. They are cut off from the euphotic zone by stratification in summer whereas in winter photosynthetic uptake is impeded by low light levels. The dominant sources of nutrients in these longer cycle are the deeper sediments areas and thus the production may be termed 'new production'. Here the term made does not meet Dugdale and Goering's (1967) the definition as nitrate is not the only by nitrogen source. The differentiation in 'new' and 'regenerated' production was originally propounded for marine ecosystem with a different time scale of water circulation being in the range of many years. But their application to a shallow coastal system like Kiel Bight seems still very useful as two different temporal states of bentho-pelagic interaction in the production cycles can be distinguished. The results of the nutrients in the present study closely agrees with the above concept of 'new' and 'regenerated' production.

The 'regenerated' production in the present study in monsoon period which displays a close interaction between the euphotic zone and the shallow sediments and combines low concentrations of organic matter fast turnover times in both sediment and water agrees with the findings of Pollenhe (1986). The 'new' bloom production during spring and

autumn which is based on the interaction with the deeper areas of Kiel Bight when both organic matter in the sediment and water show high concentrations and slow turnover rates are comparable with the dynamics of the prawn culture systems of the present study.

If regeneration were complete, it is excepted to find an equilibrium level of productivity, with new production balanced by regeneration. On each turn of the regenerative cycle some proportions of the photosynthetically fixed material drops out of the euphotic zone and is not available for regeneration. The productivity of a regenerative system is continuously declining, and is dependent on episodes of renewal to re-establish the store of nutrients. In a system behaving in this manner, the productivity measured will depend upon the time since the last renewable statements of a single measurement, made with estimate of the point reached in the cycle, tells us little about the state or the potential of the system (Wangresky, 1983).

The present study indicates that the phytoplankton have the potential to bring about fundamental change in nutrient concentrations of the estuarine ecosystem at much shorter time scales. Walsh (1983), suggested that diatom bloom sinking over the continental shelves annually transfer a significant portion of the anthropogenically produced, hence 'excess' nitrogen to the sediments. Smetacek (1985b), suggests that species-specific differences in seeding strategies of bloom diatoms will affect the rapidity and hence affectivity of sinking and also the depths to which the bulk of the bloom is eventually transported. Nair (1972), suggested that the water masses are without stratification throughout the year and are in constant contact with the bottom, the regeneration of phosphate taking place at the bottom is constantly utilized by the phytoplankton at almost the same rate. The speed of regeneration from the shallow bottom seems to be high enough

to maintain the phosphate almost at a constant level.

Wangresky (1974; 1976; 1977), opined that there are two major modes of phytoplankton population control in the oceans. The one involves the supply of nutrients to the surface waters by the actual addition to these waters of new nutrient-rich water. The nutrients in this new water have been regenerated usually at depth. Because of the supply of nutrients to the surface waters is dependent upon the supply of new water, this system of regulation is prevalent of productivity the 'renewal' system. It is typical of upwelling areas everywhere, and of the temperate and boreal oceans in the period before the spring bloom, when deeper water is brought to the surface by mixing due to the break down of summer thermal structure in the water column and to winter storms. The positive correlation between the productivity and chlorophyll values with nutrients as observed in the present study agrees with the Wangresky's view's of renewal system. In such renewal systems the inorganic nutrients are characteristically all high, at least at the start of the growing season or upwelling incident, and the characteristic phytoplankton organisms are diatoms. Since the nutrients are supplied from 'new' water high productivity this can occur with little regeneration, and with a rather low particle content at the start. Obviously, continued high productivity will lead to high particle content as both dissolved and particulate materials are added to the surface layers. In the case of the spring blooms, the inorganic nutrients are consumed in a relatively short period, and the system shifts from a renewable › a regenerative mode.

Nutrients released through benthic community metabolism have been considered as an important source for primary producers in coastal waters (Davies, 1975; Rowe et al., 1975; hartwig, 1976; Zeitzshel, 1980).

Harris (1959) and Ketchum (1962) concluded that zooplankton alone could satisfy over 70% of the nutrient requirements for primary production. Macrozooplankton excretion can account for 40-60% of the phytoplankton nitrogen requirements and over 100% of the phosphorus requirements (Eppley,et al., 1973). Biggs (1977), has recently suggested that gelatinous zooplankton may be an important component of the macrozooplankton of oligotrophic waters in nutrient regeneration.

The microheterotrophs account for the bulk of planktonic respiration, phytoplankton grazing and nutrient regeneration have been supported in more recent studies (Harrison, 1978; Caperon et al., 1979; King et al., 1978). Jackson (1980), argued that microzooplankton account for as much as 85% of the phytoplankton mortality in oligotrophic waters and could presumably contribute a comparable proportion to nutrient regeneration. Sorokin (1980) has suggested that protozoan abundance is significantly under-estimated by using conventional collection methods and may contribute even more to grazing and nutrient recycling. Schell (1974), has shown that natural phytoplankton populations excrete as much as 10% (dissolved organic nitrogen) of the organic nitrogen they assimilate within a population doubling time. Phytoplankton have been shown to excrete significant quantities of dissolved organic phosphorus (Johannes, 1965). This can in turn be rapidly mineralised by intra or extra-cellular phosphatases (Johannes, 1965; Fogg, 1966; Kobori et al., 1979). In general, phytoplankton appears to have a relatively minor direct role in nutrient cycling in the marine ecosystem.

The population growth is dependent upon regeneration of nutrients, for the main part either by bacteria or by zooplankton. This regeneration occurs in discrete micropatches, and is picked up by the phytoplankton before

any effective diffusion can take place. To the phytoplankters the ocean is not a region of homogenous nutrient distribution, but rather a very uncertain environment, where bundles of food appear randomly in time and space (Wangresky and Wangresky 1980; 1981). The positive correlation got between primary productivity and phosphorus, nitrogen and silicon in the present study proves to effects the nutrient regime up on the dynamics of population growth and phytosynthetic process in the ecosystem. Once the nutrient has been absorbed, it should be fed into the photosynthetic cycle. The cycle would then proceed until it is blocked by a shortage of some necessary ingredients.

In the euphotic zone of open shelf waters phytoplankton growth is largely based on allochthonous nitrogen from the aphotic zone in the form of nitrate and on autochthonous nitrogen from heterotrophic organism in the form of ammonia and urea (Dugdale and Goering, 1967). The release of dissolved organic compounds by autotrophic and heterotrophic organisms adds to the autochthonous nitrogen supply in the euphotic zone. Inorganically polluted and inshore ecosystems allochthonous nitrogen supply in the form of nitrate, ammonia and urea might also be of significance (Wassmann, 1986). This allochthonous ammonia and urea may originate from land (mainly sewage and agricultural runoff from microbial processes in the sediment and stagnant deep basins. In such areas allochthonous and autochthonous nitrogen cannot be distinguished chemically. Wassmann (1986) suggested a differentiation of total primary production in to new production (based on allochthonous supply) and regenerated production (based on autochthonous supply).

Smetacek (1985) opined that depletion of nutrients can cause sinking out of phytoplankton is supported by two lines of argument. Diatom blooms

are frequently terminated by nutrient depletion in the warming of the stabilizing surface layer. Such an environment precludes further growth of the population and hence it is advantageous to sink out of the surface layer as it must be replaced with nutrient-rich water in any case before a new diatom bloom can start. In Narrangasett Bay increase in phosphate in summer, when inorganic nitrogen is still virtually zero, is more marked than in the Laholm Bay (Kremer and Nixon, 1978). This suggests that nitrogen, not phosphorus limits phytoplankton growth. In the Laholm Bay an increase in the external phosphorus load may lead to a situation similar to the one in Narrangasett Bay, an increasing excess of phosphate in summer, although immediately outside river mouth primary production may increase. If nitrogen loading is increased primary production most likely would also increase (Graneli et al., 1986). The calculated phytoplankton biomass indicate that the benthic nutrient efflux could be of considerable importance to phytoplankton production. Phytoplankton biomass resulting from potential benthic nutrient release was limited by nitrogen in Lindaspollene and Vagsbopollen, but by phosphorus in Nordasvannet and Kviturdvik Pollen of Norwegian Coast (Wassmann, 1986).

In the present investigation the primary productivity values of the water showed fluctuation from 642.00 to 1246.00 in the perennial field; 636.00 to 1283.75 in the coconut grove canal field and 587.50 to 1403.75 mg $C/m^3/day$ in the pokkali field. In general, the prawn culture fields showed higher productivity near to the coastal zones. Many factors contribute to this increase; irregularities in the bottom topography induce turbulence and upwelling, bringing regenerated nutrients into the photic zone; winds can also produce upwelling by moving the surface waters away from the coast; the relative shallowness permits mixings all the way to the bottom,

again bringing nutrient-rich deeper wqter up in to the surface; these same may cause re-suspension of sediments. The net result is a higher primary productivity and a faster cycling time for the organic material produced. A high rate of photosynthesis in the water all through the year requires a considerable amount of nutrients. As stated by Ketchum (1947), it is the replenishment and not the instantaneous concentration which determines the fertility of an aquatic environment.

The observations of Qasim et al., (1969), based on the primary production values, and those of Gopinathan et al. (1974); Joseph and Pillai (1975), based on the total cell counts, indicated that fluctuations of the standing crop of phytoplankton in the Cochin Backwaters varied year to year, depending on the shifting of climatic conditions, chiefly the monsoon, and the resulting environmental parameters. Vijayalakshmi (1980) observed a seasonal cycle of gross and net photosynthesis presented a bimodal type of variation with minimum in November and maximum in April. In the present study maximum production was recorded during the month of May-June and minimum recorded in the month of December-January. In general, high primary productivity values were recorded during the monsoon and the post-monsoon periods, and the low rate observed during pre-monsoon season. The bimodal seasonal cycle in gross and net production with markedly higher values in warmer months may ascribed to rapid regeneration of nutrients from bottom waters due to increased bacterial metabolism at higher temperature.

The present results have been supported by the studies of Smetacek (1984), at Kiel Bight Bay. The over all pattern of the production in both spring and autumn is superficially similar when contrasted with the summer

situation. In both former cases a large phytoplankton biomass is built up within a few weeks and is subsequently deposited on the sea-bed following bloom culmination. Metazooplankton grazing pressure is low whereas the protozooplankton is high in comparison to the summer period. The superficial similarities between spring and autumn blooms, are however, surprising as the respective growth environments differ in many respects; temperature is much higher but irradiation lower and both decrease significantly during autumn blooms. Nurtrient distribution are high in both seasons but ammonia rather than nitrate is the dominant nitrogen source in autumn. Autumn bloom culmination and subsequent sedimentation are not triggered by nutrient depletion as is the case is spring (Smetacek, 1985a). Further, because the autumn bloom signal the end rather than the start of the growth season, the pelagic system in a complex statge of development and fairly large stocks of species representing various groups are present in summer water immediately prior to nutrient input and build up of autumn bloom.

The concept of new and regenerated production, first introduced by Dugdale and Goering (1967) have now become popular as they provide a first order frame work for differentiating marine systems on a budgetary basis (Eppley and Peterson, 1979; Smetacek, 1984). Regenerating communities are those in which the bulk of primary production is based on short-term recycling within the surface layers. The organisms comprising regenerating systems will differ fundamentally in their modes of adaptation, both to the environment and to each other from those of a new systems. New systems can only arise where environmental transport energy provides new nutrients for plant growth, regenerating systems are dependent only on radiant energy for this maintanance. Sakshaug and Holm Hansen (1984) stated that the

regenerating system will be much more wide spread in their occurrance, both the spatially and temporarily, than the new systems.

Gopinathan et al. (1978) reported that the chlorophyll 'a' values showed a distinct seasonal and spatial variation, chlorophyll 'a' values showed single maximum during monsoon, indicating an inverse relationship with production. Chlorophyll 'b' showed a primary maximum during monsoon and a secondary one during September. Chlorophyll 'c' gave exceptionally high values during pre-monsoon and monsoon. The result obtained in the present study shows that chlorophyll 'a' concentration of the water varied between 0.36 and 9.69; chlorophyll 'b' varied between 0.01 and 4.95; chlorophyll 'c' varied between 0.06 and 6.98 mg/m^3. During the monsoon season especially during July-August, the chlorophyll at all stations showed considerable increase, while during post-monsoon values showed their decreasing tendency.

The chlorophyll carrying capacity of the water column will be determined by the availability of the limiting nutrient. It is necessary to stress here that nutrient limitation does not mean that the organisms are suffering physiologically merely because they are unable to grow. As shown by Margalef (1978a) regenerating systems emerge after departure of a new system, the transition being concomitant with loss due to sinking of particles. In the regenerating systems, the bulk of the primary producers are in the very small size classes and cyanophytes are important members of the phytoplankton; further, active flagellates are more abundant than passive diatoms. As a considerable portion of the total organic pool is in the form of detritus rather than living organisms, the microbial loop will play an important role in total system of respiratory processes. Symbiotic forms are common;

between cyano-bacteria and diatoms, bacteria and dinoflagellates, various algae and protozoans. Many copepod species are present and it is difficult to ascribe dominance to just a few gelatinous forms, particularly coelenterates are abundant (Parson, 1979).

Estimates of the proportion of the primary productivity used by the bacteria range from 10-80%. Few workers in their field would argue with a rough estimate of half of the primary production being recycled directly through the bacteria. Sorokin (1978) has suggested that 75% of the primary organic production (particulate and dissolved) in the marine ecosystem passes through bacteria directly. The bulk of the evidence now suggests that with the possible exception of urea, used as nitrogen source by many diatoms (Carpenter et al., 1972; Mc Carthy, 1972), almost all of the heterotrophic uptake of dissolved organic material is the result of bacterial activities. There is even evidence that some phytoplankters possesses active transport system for some small molecules/Hellebust and Guillard, 1967; Hellebust, 1971; Hellebust and Lewin, 1972; rth and Stephens, 1972).

However, whenever labelled organic substances have been added to natural communities the bacterial reaction has always been much faster than that of the phyloplankton (Munro and Brock, 1968; Wright and Hobbie, 1975; Berman, 1975; Sepens, 1977). Johannes (1965) suggested that bacteria are important in recycling phosphorus only indirectly through their conversion of dissolved organic matter into bacterial biomass for subsequent utilization as a food source by protozoans. Protozoans then excrete inorganic phosphate as a waste product of their metabolic activity. Johannes (1965), showed bacteria may actually compete with phytoplankton for inorganic-P. This has been verified for phosphate and possibly for nitrogen in oligotrophic

marine systems (Faust and Correl, 1976; harrison et al., 1977).

Wright (1974) have an alternative view that bacteria are principal users of only dissolved organic compounds in sea water. It has been argued that since upto 40-50% of the organic matter ingested by consumers at each trophic level is excreted, bacteria must play a more direct role in nutrient mineralisation (Watson, 1978). A complicating factor in previous experiments on comparative nutrient regeneration by bacteria and protozoa has been the difficulty in separating the contribution of each microbial component when bacteria were the sole prey (Johannes, 1965; Barsdate et al., 1974). Goldman et al. (1985), studied phytoplankton and bacteria both were prey, and were able to measure regeneration of nitrogen from grazed phytoplankton in the absence and presence of bacteria. The lack of nitrogen regeneration in the bacterial control cultures and it is clearly confirmed that the microflagellate solely was responsible for the net excretion of nitrogen.

Goldman et al. (1985) opined that regeneration of ammonium was minimal during active bacterial growth, a conclusion consistant with the contemporary view that bacteria are consumers rather than regenerators of nutrients (Williams, 1981; Azam et al., 1983; Hagstrom and Larson, 1984; Goldman et al., 1985) views are in line with the view of Johannes (1965) and Pomeroy (1984), that protozoa rather than bacteria are the main regenerators of nutrients at the microbial level, at least in system in which primary productivity is in reasonable balance with grazing.

The biological maintenance of this ratio is generally accepted, particularly by geologists who consider phosphorus distribution to be primarily controlled by its geochemistry but that of nitrogen geared to phosphorus

by organisms (Smith, 1984). As pointed out by Smith (1984) biologists tends to favour nitrogen over phosphorus as the limiting element controlling plant growth in the sea. The phosphorus load of the water column is geochemically controlled at the sediment/water interface; nitrogen on the other hand, permeats the biosphere in its molecular form and can be converted to reactive nitrogen by certain prokaryotes. However, in confined system the delivery rate of phosphorus determines net ecosystem production because nitrogen fixation will adjust the N/P-ratio to the value needed for full utilization of all available phosphorus.

Stefansson and Richards (1963) suggested that anomalously of low NO_3 : PO_4 ratios near the sea surface implied that N-regeneration and subsequent assimilation were too rapid to be observed in nitrogen concentration changes. Vaccaro (1965), supported this assumption by evincing that the inclusion of the regenerative forms of nitrogen, ammonium, in N : P calculations brought ratios closer to the expected 16 : 1. He also demonstrated that seasonal variations in dissolved and particulate N : P ratios followed a similar pattern. According to him N : P particulate ratio's increased with depth, suggesting more rapid phosphorus regeneration. The Baltic sea is a highly confined ecosystem with a water residence for time of years. Therefore net ecosystem production in the Baltic ought to be limited by the phosphorus supply according to Smith (1984). The Baltic surface water has a low inorganic N/P ratio (6-7.1) during winter and spring although total N/P ratio of the external nutrient supply to the Baltic proper is over 30 (Larsen et al., 1985). This is due to extensive denitrification in the Baltic proper deep water and sediments (Shaffer and Ronner, 1984; Ronner, 1985), which causes a low inorganic-N concentration in the water transported upwards.

Besides benthic denitrification, zooplankton grazing may cause a lowering of the inorganic-N/P supply ratio in surface waters. Bamstedth (1985), found an N/P excretion ratio of 9.2 for zooplankton from the Swedish west coast. In the shallow Laholm Bay benthic filter feeders may be of greater importance. Narrangasett Bay has an areal nitrogen load equal to that in the Laholm Bay, and receives about three times more total phosphorus (Nixon, 1981). Although the inorganic N/P ratio of the external supply to the Bay was 13.6, the mean annual N/P ratio in Narrangasett Bay was only 3 (Nixon, 1981). Nixon attributed this discrepancy to processes occurring during recycling of nutrients, and suggested that benthic denitrification was responsible. Clear cut cases of N-deficiency in marine water are known from coastal areas which are relatively shallow and exposed to significant amounts of sewage (Ryther and Dunstan, 1971; Smadya, 1974; Gargas, 1975; Sakshaug, 1977; Niemei, 1979; Graneli, 1981). Various amounts of household sewage are supplied to all fjords (Wassmann, 1986) and the N/P-ratio of these supplied nutrients may be as low as 3-5 (Sakshaug and Olsen, 1986). Sewage supply will, thus, tend to shift natural system towards N-limination.

Sankaranarayanan and Qasim (1969), showed the range in the N : P ratio by atoms throughout the period of observation. It is clear that anomalously low and high ratios occur in the backwater. During the stable period (pre-monsoon) the ratios are consistantly low, but become considerably high during the monsoon period, and showed no consistancy whatsoever during the post-monsoon period. Ewins and Spencer (1967), have drawn attention to wide variations in the N : P ratio of the Menai straits. Dharmaraj et al. (1980), observed that N/P ratios where always found to be low which indicated

that if any limitation of primary production occurs in the Vihinjam Bay due to the short supply of nutrients, it must be due of nitrogenous nutrients.

In the present study the total N/P ratio of the prawn culture fields showed range from 4.48 to 40.40 throughout the period of study. During the pre-monsoon months ratios were constantly low, but became high during post-monsoon periods. Inorganic N/P ratio of the water in the prawn culture fields showed range from 1.08 to 22.33 throughout the period. Calculated ratio during June-September was 22.33-3.01 in different prawn culture fields. Organic N/P ratio of the prawn culture fields has showed range from 7.96 to 160.21 throughout the period. Particulate N/P ratio of the water in some ecosystem showed range from 3.01 to 28.53 throughout the period. Calculated ratio during January-July was 24.25-5.30 in the different prawn culture fields.

Forsberg et al. (1978), have suggested that an inorganic - N/P ratio of less than 11 indicates nitrogen limitation of phytoplankton biomass, between 11 and 27 both elements or another factor limit and for N/P above 27, P- is limiting. The above concept can be applied to the present study as it is showed wide range of fluctuation between the N/P ratio. During the pre-monsoon period the ratio was below 11 and hence nitrogen limitation of phytoplankton biomass was observed. Explanation for the apparent shortage of nitrogen in the prawn culture systems during this period may be that the element is lost through denitrification. But during the monsoon period the ratio was above 20 and hence phosphorus is limiting. The phosphorus limitation resulting from the benthic nutrient supply will in ecosystem with an anoxic bottom water with highest hydrogen sulphide concentration.

During the rest of the periods of N/P ratio was constant. This is supported by the observation of Smetacek and Pollenhe (1986), that the phosphorus is mobilized more rapidly from decomposing organic matter than nitrogen. Thus in rapidly sinking particles such as those formed by a crushing diatom bloom, the N : P ratios are not likely to differ much from those of living plankton. However, in organic matter that has undergone some system of break down, such as slowly sinking detritus collecting in the marine ecosystem of a regenerating system, relatively more dissolved phosphorus than nitrogen will be released to the water of the surface layer. This will result on the other hand, in sea with low salinities, the stable halocline promotes stagnation of bottom water and development of anaerobic sediments which release phosphorus at much higher rates than aerobic ones. Further, denitrification processes reduce the reactive nitrogen pool. Thus P - is enriched relative to N in the water column of these systems, providing a niche for nitrogen - fixing organisms to convert 'excess' - P to organic matter and hence restore the 'biological' N : P ratio.

6. EXECUTIVE SUMMARY

1. Six stations were selected in the prawn culture fields to collect water and sediment samples at fort nightly intervals for the period of two years (from January 1986 to December 1987). Variations of temperature, hydrogen ion concentration, salinity, dissolved oxygen, total alkalinity, total phosphorus, inorganic phosphorus, organic phosphorus, particulate phosphorus, total nitrogen, total inorganic nitrogen, nitrate nitrogen, dissolved organic nitrogen, nitrite nitrogen, ammonia nitrogen, particulate nitrogen, primary productivity, chlorophylls, copper, zinc and iron in water, copper, zinc and iron in sediment were studied and reported as monthly mean value.

2. The temperature value of the water showed fluctuations from 28.0 to 31.8°C in different prawn culture systems. The hydrogen ion concentration of the water showed fluctuations between 7.40 and 9.10 in the prawn culture fields. During the pre-monsoon season, especially during the months of March-April, the salinity at all stations exhibited considerable increase, while during monsoon values showed decrease. Dissolved oxygen values were between a minimum of 2.50 ml/l and a maximum of 6.80 ml/l during August and May respectively. The total alkalinity values showed fluctuations from 0.072 to 2.727 meq/l in different prawn culture fields.

3. The range of variation of total phosphorus varied from 1.06 to 13.76 µg at/l. In organic phosphorus of water in all the prawn culture

fields showed fluctuation between 0.19 and 8.80 /ug at/l during the period of study. Organic phosphorus of the water showed fluctuation between 0.40 and 3.88 /ug at/l. The particulate phosphorus was at its maximum during the monsoon months, extending upto August, after which it began to decline. In general, phosphorus values were at their maximum during the monsoon months, extending upto September after which they began to decline during the pre-monsoon and post-monsoon months. The maximum values observed here may be due to the transport of phosphate by bubbles rising to the surface, decomposition of particulate organic matter, rapid regeneration with microbial precipitation, the excretion by phytoplankton, horizontal and vertical transport of water and advection.

4. Total nitrogen of the water in all the prawn culture fields were seen increasing gradually from January to reach a maximum value of 94.54 /ug at/l in July. The range of variation of total nitrogen varied from 15.01 to 94.54 /ug at/l. The concentration of different fractions of nitrogen showed a range of 2.76 and 32.90 in the total inorganic nitrogen (TIN); 6.90 to 52.64 in dissolved organic nitrogen (DON); 1.02 to 22.50 in nitrate nitrogen (NO_3-N); 0.1 to 4.20 in nitrite nitrogen (NO_2-N); 0.55 to 12.75 in ammonia nitrogen (NH_3-N) and 1.60 to 12.04 /ug at/l in particulate nitrogen (PN) in the prawn culture system.

5. Total inorganic nitrogen values were found to be high during the monsoon months, and low during pre- and post-monsoon periods. Dissolved organic nitrogen values were at its maximum during monsoon months, extending upto July after which it began to decline. During pre- and post-monsoon

periods the dissolved organic nitrogen was very low. Nitrate nitrogen and nitrite-nitrogen were at its maximum during the monsoon months and minimum was during pre-monsoon season. During pre- and post-monsoon periods the particulate-nitrogen was very low. Silicate showed a wide range of fluctuations from 5.61 to 72.60 µg at/l.

6. Primary productivity values of the water showed fluctuations from 618.50 to 1403.75 mg C/m^3/day. The range in chlorophyll 'a' concentration of the water showed fluctuations from 0.10 to 11.70, chlorophyll 'b' from 0.01 to 4.95 and chlorophyll 'c' 0.06 to 6.98 mg/m^3. The positive correlation got between primary productivity and phosphorus, nitrogen and silicon in the present study proves to effects the nutrient regime upon the dynamics of population growth and photosynthetic process in the ecosystem. Once nutrients have been absorbed, it should be fed into the phytosynthetic cycle. The cycle would then proceed until it is blocked by a shortage of some necessary ingredients. A high rate of photosynthesis in the water all through the year requires considerable amount of nutrients.

7. Copper concentration of the water showed fluctuation from 3.44 to 12.64 ppb in all the prawn culture fields. Maximum concentration of zinc was recorded during monsoon and post-monsoon months. Iron concentration of the water showed fluctuation from 1.12 to 7.20 ppb Concentrations of zinc showed fluctuation from 32.08 to 92.80 ppb copper from 28.40 to 88.00 and iron from 0.72 to 6.08 ppb in the sediment samples.

8. Total N/P ratio of the prawn culture fields was showed range from 4.48 to 40.40, inorganic N/P ratio from 1.08 to 22.33, organic N/P ratio from 7.96 to 160.21, particulate N/P ratio from 3.01 to 28.53 throughout the period. During the pre-monsoon period the ratio was below 11 and hence nitrogen limitation of phytoplankton biomass was observed. But during the monsoon period the ratio was above 20 and hence phosphorus is limiting.

9. The present result reflects the year to year variability of the physical environment, in which the impact of the horizontal advection is more important for the regulation of the physical structure of the water column than for the import or export of nutrients. Phosphorus cycling in the prawn culture systems is influenced by the river input in both dissolved and particulate form, contribution of sewage and intensive contact of water masses with the underlying sediments. The speed of phosphorus regeneration from the shallow bottom seems to be high enough to maintain the phosphate almost at a constant level. In the regenerating communities the bulk of the primary production is based on short-term recycling within the surface layers. The organisms comprising regenerating system will differ fundamentally in their mode of adaptation, both the environment and to each other from those of new system. New system can only arise where environmental transport of energy provide new nutrients for plant growth, regenerating systems are dependent only on radiant energy for this maintenance. The current state of information on regenerating system indicates them to be much more complexly structured than expected; further, spatial and temporal variability appears to be much greater than initially assumed about the concept of nutrient regeneration.

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