STUDIES ON ECOPHYSIOLOGY OF *PENAEUS INDICUS* H. MILNE EDWARDS IN THE GROW-OUT SYSTEM

THESIS SUBMITTED
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
OF THE
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

By
SUBHASH CHANDER, M. Sc. (Honours School)

NOVEMBER, 1986

CENTRE OF ADVANCED STUDIES IN MARICULTURE
CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
COCHIN - 682 031

CERTIFICATE

This is to certify that the thesis entitled "STUDIES ON ECOPHYSIOLOGY OF *PENAEUS INDICUS* H. MILNE EDWARDS IN THE GROW-OUT SYSTEM" is the bonafide record of the work carried out by Mr Subhash Chander under my guidance and supervision and that no part thereof has been presented for any other Degree.

Dr A D DIWAN, M.Sc., Ph.D.
Associate Professor and Scientist,
Central Marine Fisheries Research Instit
Cochin - 682 031.

Cochin-682 031,
November 1986.

DECLARATION

I hereby declare that this thesis entitled "STUDIES ON ECOPHYSIOLOGY OF PENAEUS INDICUS H. MILNE EDWARDS IN THE GROW-OUT SYSTEM" has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles of recognition.

Subhash Chander

Cochin-682 031,
November 1986.

SUBHASH CHANDER
Senior Research Fellow

ACKNOWLEDGEMENTS

I wish to express my hearty thanks to Dr A D Diwan, Associate Professor and Scientist, Centre of Advanced Studies in Mariculture (ICAR/FAO/UNDP Project), Central Marine Fisheries Research Institute and my research supervisor, for his incessant inspiration, unstinted supervision and guidance from the genesis of the research work till the work was moulded into the present form.

My sincere thanks are due to Dr E G Silas, D.Sc., Former Director, and Sub-Project Coordinator, C A S in Mariculture, for providing me with an opportunity to carry out research work by extending the best laboratory and the library facilities and also for his invaluable suggestions and constant encouragement throughout the period of my study.

I am grateful to Dr P S B R James, Director C M F R Institute, and Sub-Project Coordinator, C A S in Mariculture, for allowing me to utilise various facilities for completion of my research work.

The help and the general guidance from Dr P V Rao, Senior Scientist, and O I C, Mandapam Regional Centre of C M F R Institute is deeply appreciated.

I am indebted to Dr P V R Nair, Former Joint Director and Shri V Kunjukrishna Pillai, Scientist, of this Institute for their timely and useful help for metal analysis on Atomic Absorption Spectrophotometer. I am thankful to Shri M Srinath, Scientist, for his help in statistical data analysis.

Candidate owes a considerable debt of gratitude to Dr K C George, Senior Scientist who took personal interest to help me in providing Cadalmin boat as and when needed for the period of two years.

The ever-helping and accomodative nature of Shri A Nandkumar, Field Assistant will always be remembered and acknowledged.

The sharp grasp of minor details of the material to be typed as well as the typing accuracy by Miss K G Isha is laudable.

I am deeply obliged to the authorities of ICAR/FAO/UNDP for grant of Senior Research Fellowship to carry out this work at CAS in Mariculture, C M F R Institute, Cochin.

Subhash Chand

Cochin-682 031,
November 1986.

(SUBHASH CHANDER)
Senior Research Fellow

CONTENTS

PREFACE

'Ecophysiology' involves the study of the interactions of ecological characteristics with the physiology of the animal inhabiting a particular niche. In the typical estuarine areas, land run off and heavy precipitation especially during monsoon, bring about a drastic change in the ecosystem and also result in heavy siltation, adsorption/desorption, precipitation/ remobilization phenomena in addition to iron, manganese, humic and fluvial cycles. These phenomena alter the physicochemical nature of the estuarine ecosystem. The estuarine zone serves as a 'sink' of pollutants, metals and organic debris subject to the topography, type of the catchment area, nature of rock formations, and the nature and the extent of industrial activity in the viscinity. The fauna and the flora inhabiting the estuarine ecosystem have to either 'adapt' their physiological mechanisms or 'migrate' to the more conducive habitat or get perished under the changed ecological conditions. The study of interactions of various physicochemical characteristics of the ecosystem with the animals adaptive physiological mechanisms in situ provides a more authentic, direct and realistic approach to the cause-effect relationship.

The Cochin backwaters and the coastal inshore sea off Cochin, the area investigated during the present study, are generally under heavy rainfall during southwest monsoon period and to a lesser extent during northeast monsoon. The Cochin backwater receives water from many rivers which originate from western ghats. This estuarine area has permanent connections with the Arabian sea through Cochin and Azhikode barmouths. 'Siltation' in the estuarine and, to some extent, in the nearshore area occurs in the pre- and post-monsoon periods whereas 'flushing' of the riverine material takes place mainly during the monsoon period. The sediments of the area are riverine as well as marine in origin.

Presence of a major port, Udyogmandal Industrial complex, shipping activities, rare-earth mining complex and ship traffic and their activities along with domestic pollution in the viscinity of this estuarine complex serve as a significant pathway for the entry of industrial effluents containing polychlorinated hydrocarbons, heavy metals and other chemicals. Fertilizer application in the paddy fields, retting of coconut husk, dredging, other human activities, weathering of rocks and erosion also contribute to affect this ecosystem quite often. All these factors have pronounced effect during active monsoon and to a lesser extent during post-monsoon when freshwater and seawater churning and dynamics alter the estuarine ecosystem significantly, through sorption/desorption, flocculation/deflocculation and related phenomena. Associated with these are the 'upwelling' and the 'sinking' phenomena in the nearshore sea. Keeping in view all these factors, it is presumed that the physicochemical imbalance occurs in the ecosystem of the Cochin backwater during monsoon and post-monsoon season. The nearshore marine area too is presumed to depict seasonal physicochemical variations though to a relatively lesser extent. The drastically altered estuarine ecosystem may stress physiological mechanisms of the harbouring fauna which has to either 'adapt' or 'escape' to the favourable niche.

Most penaeid prawns including P. indicus, which is the target species of present investigations, show protracted breeding season often extending throughout the year. The P. indicus breeds and spawns in the sea in relatively deeper waters upto 50-60 m depth zone of the inshore continental shelf. Thereupon, post-larve enter the estuaries and backwater areas in large numbers and grow rapidly. These areas serve as natural nurseries for the juveniles. The euryhaline nature of these prawns enable them to colonise the estuaries and backwaters. The animal then again 'migrate' to sea for maturation and spawning. The reason(s) for such migratory behaviour in their life cycle, which may be of ecophysiological nature, is not known at present.

A perusal of the literature shows that most of the crustacean research work has been on general physiological aspects. The works of Travis, Dall, Greenaway, Huner, Graf, Croghan, Gross, Panikkar, Parry and Robertson need a special mention. Though the crustacean research work related to the effects of various physicochemical parameters has also been adequately known, but most of it has been carried out in the laboratory where simulation of natural physicochemical dynamics becomes a limiting factor in obtaining the true picture of the ecophysiological interactions occurring in nature.

The indepth study of the existing literature reveals that most of the work relates to physiology or ecology and that too, of fragmented isolated thrusts to unravel the basic principles governing the physiology of animals. For better success of the aquaculture in any ecosystem, understanding of the scientific knowledge pertaining to the manipulation of ecological conditions, and the integrated factors affecting on the physiological systems of the inhabiting fauna of a particular niche is a primary requisite. There is a considerable lack of concerted and integrated ecophysiological approach to visualise the in situ dynamics in the ecosystems. It becomes more pertinant in view of the priority being accorded to the intensive aquaculture. The ever-increasing demand of finfish and shellfish has to be satisfied through intensive aquaculture as the marine capture fishery is stagnating between 1.4 to 1.6 million MT for the last six years. Though India has developed aquaculture technology for various species groups in the seventies, yet their exist biotechnical and economic obstacles to production efficiency upgrading. Optimal balanced nutrition for various larval stages, disease and disease control, reproductive endocrinology, moulting physiology, and ecophysiological interactions are some of the major areas of biotechnical ignorance.

"Studies on ecophysiology of P. indicus H. Milne Edwards in the grow-out system " - a research project investigated by the candidate, the results of which are embodied in the present thesis, is a part of the well coordinated strategy of the CAS in Mariculture to develop manipulative mastery over physiology and biology of the animal. This assignment was prompted as relatively meagre availability of maturing and mature P. indicus in estuarine territory coupled with declined fishing activity during monsoon in the coastal shelf areas serve as a major constraint for the sound aquaculture industry to sustain itself, as mature P. *indicus* is a pre-requisite for the controlled spawning and hatchery production of prawn seeds throughout the year.

In the present study, the main emphasis was to find out if seasonal and ecosystem specific variations of calcium, magnesium, phosphorus, copper and zinc in the water and the sediment has any role to play in altering the concentration of these elements in different tissues of intermoult P. *indicus* as evidenced by the seasonal studies in the grow-out and the marine ecosystems.

The candidate, after passing M.Sc.(Honours school) Zoology (Entomology and Cytogenetics) from Panjab University, Chandigarh in April, 1981, joined CAS in Mariculture at CMFR Institute as a Senior Research Fellow in October 1981. During the first semester, the candidate underwent an intensive course work in mariculture comprising of the following aspects: Biology and culture of fishes, crustaceans, molluscs, seaweeds and live-food organisms, biochemistry, statistics, research methodologies, farm-engineering and aquaculture management. The special subject i.e. "Ecophysiology of Crustacea" was studied in detail during the second semester. In the mean time, relevant scientific literature collection and standardization of research methodology was carried out. At the end of the second semester, the candidate passed the Ph.D. qualifying examination conducted by the Cochin University of Science and Technology. The field and the analytical work related to the topic of research was carried out from November 1982 to October 1984.

The entire thesis comprises of only one Chapter having an introduction, material and methods, results, discussion, summary, and references..

'Introduction' describes sequentially, the importance of aquaculture, traditional aquaculture practices, penaeid life cycle, and geological nature and description of the ecosystems. Thereafter, meteorology and seasonal water dynamics of the area, resultant seasonal changes in physico-chemical characteristics of the water and the sediment, and description of the literature relevant to each ecosystem is presented. Subsequently, relevance and scope of the present investigations, review of the closely related ecophysiological works and their drawbacks, and the description of the work carried out during present investigation are presented.

'Material and Methods' describes the general description of the work carried out including sampling frequency; description of each ecosystem and sampling stations; meteorology parameters, sampling strategy, sampling and preservation of water, sediment and prawns in the grow-out and the marine ecosystems. Sampling of prawns include the haemolymph and the tissue collection as well. Thereafter, analytical methods of various physicochemical parameters of the water and the sediment are separately described. Subsequently, methods of analysis of calcium, magnesium, copper and zinc in water, sediment, haemolymph and tissues are presented. Methods for analysis of phosphorus in the haemolymph and the other tissues is given at the end.

"Physicochemical and biological parameters in the grow-out ecosystem" - the first sub-heading under 'Results' - includes physicochemical parameters of water, physicochemical parameters of sediment, bioelements in various tissues of male P. indicus and bioelements in various tissues of female P. indicus in a sequential manner. Subsequently, similar pattern is followed for the description of results obtained in the marine ecosystem.

In 'Discussion', the 'Results' of the present investigations are discussed in the light of the available relevant literature, and bioelement interactions between the ecosystem and the animal are explained. The sex-specific and the ecosystem specific differences are discussed wherever they occurred.

The 'Summary', of the contents of the research work presented hitherto, has been reported after 'Discussion'. The 'References' forms the last part of the thesis.

Southwest monsoon exerts a profound influence on the hydrology of the estuarine ecosystem, followed by north-east monsoon, the influence of which is relatively very less. The marine ecosystem, though presumably influenced by the monsoon in the surface layer, remains more or less stable near bottom as evidenced by the results. With the advent of summer season, almost marine conditions prevail in the estuarine Cochin backwater harbouring grow-out ecosystem. The ecophysiological interactions and tissue metal concentrations depicted very little ecosystem-specific differences during non-monsoon period but significant ecosystem-specific differences were noted during monsoon and post-monsoon period. Sex-specific differences within each of the ecosystems were insignificant, in general, though exceptions were there.

The relatively stable tissue bio-element concentrations in the marine ecosystem as compared to the grow-out ecosystem during monsoon and post-monsoon period seems to justify animal's preference for the marine ecosystem as it can keep off stress and strain and thereby avoid wasteful expenditure on active ion- and osmo-regulation and rather, utilize and concentrate all energies at its disposal for gonad development.

The results of the investigations have enhanced our knowledge on the physicochemical characteristics of the ecosystems studied during present investigation, and the interactions of various metals in the environment with those in the different tissues of P. indicus.

LIST OF FIGURES

LIST OF DATA TABLES*

TABLE NUMBER	CONTENT
I A_1 to I G_1	Monthly mean and standard deviation values of physicochemical and biological parameters studied during IST YEAR at STATION I in the grow-out ecosystem
I A_2 to I G_2	Monthly mean and standard deviation values of physicochemical and biological parameters studied during 2ND YEAR at STATION I in the grow-out ecosystem
I A_1 to I G_1	Monthly mean and standard deviation values of physicochemical and biological parameters studied during IST YEAR at STATION II in the grow-out ecosystem
II A_2 to II G_2	Monthly mean and standard deviation values of physicochemical and biological parameters studied during 2ND YEAR at STATION II in the grow-out ecosystem
III A_1 to III G_1	Monthly mean and standard deviation values of physicochemical and biological parameters studied during IST YEAR at STATION III in the grow-out ecosystem
III A_2 to III G_2	Monthly mean and standard deviation values of physicochemical and biological parameters studied during 2ND YEAR at STATION III in the growout ecosystem
IV A_1 to IV G_1	Monthly mean and standard deviation values of physicochemical and biological parameters studied during 1ST YEAR at STATION IV in the marine ecosystem

---

*The number 1 or 2 at the base of a particular table number refers to FIRST (from November '82 to October '83) or SECOND (from November '83 to October '84) YEAR respectively.

LIST OF CORRELATION TABLES*

TABLE NUMBER	CONTENT
VII A, VII B & VII C	Correlation values of physico-chemical and biological parameters at STATION I
VIII A, VIII B & VIII C	Correlation values of physico-chemical and biological parameters at STATION II
IX A, IX B & IX C	Correlation values of physico-chemical and biological parameters at STATION III
XAA, X B & X C	Correlation values of physico-chemical and biological parameters at STATION IV
XI A, XI B & XI C	Correlation values of physico-chemical and biological parameters at STATION V
XII A, XII B & XII C	Correlation values of physico-chemical and biological parameters at STATION VI

---

* The correlation values of different tissues of female *P. indicus* are presented in the tables without brackets; and those of male *P. indicus* are given within brackets.

INTRODUCTION

Aquaculture was in vogue for several thousand years (>500 BC) and the first ever thesis on this subject was published in 47 BC by Fan Li (Dill , 1967). The basic factors for revival of aquaculture industry are rapid population growth, food shortage, stagnating fisheries production, insufficient agriculturel production to cope with the high rate of human population growth, and awareness and demand for materials that make life better. Aquaculture will not be a panacea for human nutritional problems but it can and must contribute to ward off the spectre of hunger.

Japan, Taiwan, Philippines and China are the pioneers to give fresh impetus to modern scientific intensive aquaculture leading to a lucrative business. Several Western nations have also shown keen interest and curiosity of late. Traditional aquaculture has been practised since long in the coastal low-lying estuarine regions within India (Muthu, 1978). India has developed aquaculture technology for various species groups in the seventies, but there exists biotechnical and economic obstacles to production efficiency upgrading. Substantial improvements at various levels of intensity are needed to have control over reproductive biology to produce off-spring during any season. Optimal balanced nutrition for various larval stages, disease and disease control, reproductive endocrinology, moulting physiology, and ecoshysiological interactions are some of the major areas of biotechnical ignorance.

Most of the commercial penaeid prawns including P. indicus show protracted breeding season, often extending throughout the year. The Indian white prawn, P. indicus breed and spawn in the sea in relatively deeper waters upto 50-60 m depth zone, of the inshore ground (deeper in relation to the area of normal existance). Thereupon, post larvae enter the estuaries and backwater areas in large numbers and grow rapidly. These areas serve as natural nurseries for the juveniles. The euryhaline nature of these prawns enables them to colonize the estuaries and backwaters. In the traditional culture operations, these naturally occurring post-larvae and juveniles are trapped in the brackishwater impoundments and allowed to grow for short periods before they are caught. The ponds are constructed in suitable coastal brackishwater areas where there is a good tidal range and an abundant supply of prawn seed. This type of prawn culture is practised in the brackishwater 'bheries' in West Bengal, and in the 'paddy fields' and 'perennial prawn culture fields' adjoining the Vembanad Lake in Kerala. The fields are connected by canals to the Vembanad

Lake and are subjected to the tidal influence. The largest and the relatively deeper impoundment at Edvanakadu, Vypeen Island (Fig. A) was selected as the grow-out ecosystem because the probability of getting maturing or mature P. *indicus* throughout the year, at the site, was more.

The ecosystems dealt with during present investigation comprise of a grow-out ecosystem (Fig.A) at Vypeen Island connected only to the Cochin backwaters through canals and a marine ecosystem (Fig. B) consisting of the inshore area off Cochin corresponding to about 30 m depth isoline.

Cochin backwaters which includes Vembanad Lake (Fig. 4) is a typical tropical estuary lying at 76°10' to 76°30' latitude and 9°30' to 10°10' longitude and extends into the central part of Kerala state. It runs almost parallel to the mainland with a depth range of 1.5 to 12 m (Shynamma and Balakrishnan, 1973) and comprises of total area of 300 square kilometers extending from Alleppey in the south to Azhikode in the north. The Cochin backwaters is well connected with the rivers originating from the Western Ghats in the east and flowing towards the west, such as Pamba and Muvattupuzha joining Vembanad Lake in the southern half and Periyar river with its tributaries on the northern half. These rivers traverse through the Precambrian formations in their upper reaches and recent alluvium in the lower reaches supplying the dissolved and solid material to the backwaters especially during the monsoon months (Murthy and Veerayya, 1981). Silting in the estuarine portion occurs during pre- and post-monsoon while flushing of the river material takes place during the monsoon period (Gopinathan and Qasim, 1971). Bottom sediments of the estuarine region comprise of the sediment load brought from the rivers as well as materials transported from the sea into the estuary during pre- and post-monsoon through tidal currents. The fact that materials from inshore region find their way into the estuary is also confirmed by the radioactive tracer studies (Gole and Tarapore, 1966). The clay mineral assemblage of Pamba river from source to mouth consists of predominantly kaolinite group of minerals with subordinate amounts of montmorillonite and illite. Gross mineralogy of other contributing rivers is considered to be the same as the mineralogy of Pamba river sediments except for minor differences (Aswathanarayana, 1964). Additionally, Kerala is a zone of intense weathering. The role of rivers in transporting material from continents to oceans is paramount (Goldberg, 1976). They carry metal in solution, absorbed in inorganic solids, as metallic coating on solids, in organic solids and in detrital crystalline material (Gibbs, 1973). Human activities, weathering of rocks and other natural phenomena also constitute an important pathway for the entry of metals into the aquatic environment.

Cochin backwaters has two permanent connections to the sea: the 450 m wide and 12 m deep main entrance to the Cochin Harbour; and the Azhikode bar-mouth further north. It forms an extensive and an important nursery ground for the penaeid prawns (Shynamma and Balakrishnan, 1973) and is the site of traditional and extensive aquaculture.

Historically, there are evidences to believe that in the past, the area presently covered by the backwater and the land-strip in between backwater and the sea was submerged under the sea. Later on, due to some natural causes, huge masses of sediment might have got deposited in between the present backwaters and the sea. This has been proved by the boring experiments (Bristow, 1938). Murty et al. (1984) hypothesize that the entire area between the foot of hills of Western Ghats and at about 75 m depth off the coast was a deep basin, which got subsequently filled up with mud and sand, over which a sandy crust was formed in some places.

According to Sankaranarayanan and Qasim (1969), the average maximum atmospheric temperature ranges from

28 to 34°C and minimum from 20 to 25°C at Cochin backwaters. The daily temperature has a maximum in April/May and minimum in July/August. Annual rainfall is about 3200 mm of which 75% occurs during southwest monsoon period. The prevailing winds are southwesterly during monsoon and northeasterly during late October and November, for the rest of the year wind direction keeps changing. Maximum solar radiation reaches the surface from December to March; and minimum from June to September. Underwater illumination is least during monsoon months because of turbidity. Tides are of mixed type, predominantly diurnal whose maximum range is about 1 m (Sankaranarayanan and Qasim, 1969).

The Cochin backwaters and the coastal inshore waters off Cochin are susceptible to the influence of the two monsoons (Rao et al., 1968). As a result of freshwater run off from rivers, the local precipitation and incursion of cool seawater towards the estuary during the monsoon period, a tongue of less dense, less saline, oxygenated warm water of about 10 m thickness extends over more dense, highly saline, poorly oxygenated and cool continental shelf waters (Rao et al., 1968). According to Ramamirtham and Jayaraman (1960), the main circulation in the Arabian Sea results in the establishment of a surface current along the West coast which reverses itself in the course of the year. This stream is southerly when the circulation in the open part of the Arabian Sea is clockwise and northerly when the circulation is counter clockwise. Associated with these drifts are 'upwelling' and 'sinking' phenomena. The existence of these phenomena has been pointed out earlier by Sastry and Myrland (1960). 'Upwelling' occurs along the coast during peak southwest monsoon period. The drastic decrease in temperature (6-7°C), combined with oxygen poor, upwelled waters could be probably the result of upwelling phenomenon (Ramamirtham, 1967). The intense upwelling brings up nutrients from the deeper layers resulting in high productivity (Subrahmanyan et al., 1959). These above mentioned phenomena of seasonal rainfall and upwelling in both the ecosystems results in the seasonal variation of physicochemical and consequently, biological characteristics in the estuary and the adjoining inshore waters.

The Cochin backwaters and the adjoining inshore areas are lashed by heavy rainfall from June to August (southwest monsoon) and with mild, less frequent rainfall from November to January (northeast monsoon). Consequently, there is a tremendous rate of water outflow in the rivers which pour into the Vembanad estuary during the monsoon and thereby, brings alongwith industrial effluents containing polychlorinated hydrocarbons, heavy metals and other materials from Udyogamandal Industrial Complex, in addition to silt, clay, municipal discharges and atmospheric contribution. Retting of coconut husk, shipyard activities, regular ship traffic, port activities, chipping off and painting activities on ships, and dredging activities contribute to alter the ecosystem of the area (Venugopal *et al.*, 1982; Rajendran and Kurian, 1986). Dredging in estuaries particularly disturbs sediments with their contained metals and produce a change in the chemical properties of the metals and the potential change in its biological availability (Morton, 1977). Seasonal changes in run-off (Sankaranarayanan *et al.*, 1978) also affects the total level of metals in the marine environment. The Vembanad estuary is the place of mixing of freshwater and seawater and this may result in various phenomena such as siltation, flocculation/deflocculation, desorption/adsorption depending upon the regulating factors (Bourg, 1981). These phenomena may significantly alter the ecosystem indirectly via change in various physicochemical characteristics of the water and the sediment.

Physicochemical characteristics have been worked out in the estuarine complex of Cochin backwaters by many workers.

Ramamirtham and Jayaraman (1963) examined temperature, salinity, and dissolved oxygen in the water of Cochin backwaters around Willingdon Island and observed that tidal exchanges across the channel are fairly high, as also the influx of freshwater. The diurnal variations of some physicochemical factors of the water in the Cochin backwaters during southwest monsoon were reported by Shynamma and Balakrishnan (1973). Salinity, temperature and dissolved oxygen in the Cochin backwaters were studied by Haridas et al. (1973) during pre-monsoon, monsoon and post-monsoon period. Ansari (1974) noted that, in general, bottom temperature was high in the pre-monsoon months in the Vembanad Lake and reported high seasonal variation of salinity.

Nutrients of Cochin backwaters in relation to environmental characteristics were examined by Sankaranarayanan and Qasim (1969) who noted low nutrient values during pre-monsoon period and high values during monsoon and post-monsoon periods. Manikoth and Salih (1974) reported the distribution characteristics of nutrients in water of the estuarine complex of Cochin. Nair et al. (1975) studied primary production in the waters of the Vembanad Lake.

Regeneration of phosphates in the muds of Cochin backwaters has been examined by Reddy and Sankaranarayanan (1972). Ansari and Rajagopal (1974) noted wide variations of mud phosphate which revealed a decreasing trend from marine to estuarine zone, and its concentration was high during monsoon and low in the pre- and post-monsoon periods. Sankaranarayanan and Panampunnayil (1979) studied organic carbon, nitrogen and phosphorus in the sediments of Cochin backwaters.

Manikoth (1975) studied the distribution of calcium in water of Cochin backwaters. Rao *et al.* (1982) investigated the seasonal variations of calcium in water, sediment and different tissues of *Penaeus indicus* collected from a perennial brackish water prawn culture pond near Cochin.

Particulate copper and zinc in the waters of Cochin backwaters were examined by Sankaranayayanan and Stephen (1978) who reported significant concentrations of copper at the river mouth. Rajendran and Kurian (1986) described copper and zinc in water and sediment of Cochin backwaters while surveying these metals in the environment and the oyster, *Crassostrea madrasensis*. Copper content in the inshore and estuarine waters along the central west coast of India was reported by Sankaranarayanan and Reddy (1973a).

Distribution of copper in the sediments of Vembanad lake was reported by Murty and Veerayya (1981) who observed that river sands contain very low concentrations of copper. Venugopal *et al.* (1982) noted prevailing physicochemical conditions and 'backland' influence to govern seasonal variations of trace metals in the sediments of Cochin backwaters and reported that the bar-mouth region showed an increase in metal content of sediments in the post-monsoon season.

Considerable amount of literature is available with regard to physicochemical parameters of water and sediment in the coastal, especially inshore, areas.

Ramamirtham and Jayaraman (1960) observed that the influence of southwest monsoon on coastal waters is very profound while that of the northeast monsoon is at best indirect and also mentioned upwelling and sinking processes along the continental shelf waters off Cochin coast. Ramamirtham and Nair (1964) noted that the stability in the immediate surface layers of Arabian Sea off Cochin is high, but the bottom waters over the shelf are unstable. Vertical turbulence during monsoon and early post-monsoon and restoration of stable conditions by the onset of winter are indicated in the coastal Arabian sea, and high stability values during winter and summer seasons are stated to be sufficient to immobilize the bottom nutrients(Ramamirtham and Nair, 1964). Temperature, salinity, dissolved oxygen and water-mass characteristics of the inshore waters of the west coast were described by Ramamirtham and Patil (1965) during pre-monsoon season. Upwelling phenomenon and winter conditions were noted by Ramamirtham (1967) along the west coast during monsoon and post-monsoon period. Rao *et al.* (1968) examined temperature and salinity of surface waters along the west coast of India. Seasonal variations in the hydrographic features along the southwest coast of India were noted by Rao and Ramamirtham (1976).

Primary production in the seas around India was reviewed by Nair (1974). Primary productivity in the southeast as well as the northeast Arabian Sea was described by Bhargava *et al.* (1978) and Radhakrishna *et al.* (1978) respectively.

Total phosphorus content in the waters of the Arabian Sea along the west coast of India was given by Sankaranarayanan and Reddy (1970). Distribution of inorganic phosphate in the upper 10 m column in different regions of northern Indian Ocean was studied by Anand and Jayaraman (1972) who reported that the concentration of inorganic phosphate increased in almost all the regions during the southwest monsoon period and this rising trend was maintained during months immediately following it.

Distribution pattern of phosphate in the sediments of the western continental shelf of India in relation to the hydrographic features of the overlying waters was discussed by Rao *et al.* (1978) who mentioned that phosphate content exhibits an increasing trend away from the coast. Marchig (1973) described the distribution of calcium and magnesium in the western continental shelf of India.

Copper content in the inshore and estuarine waters along the central west coast of India was studied by Sankaranarayanan and Reddy (1973a). The processes leading to the incorporation of copper in the sediments of the western continental shelf of India were reported by Rao *et al.* (1974). Trace elements in the marine environment of the west coast of India were described by Sreekumaran *et al.* (1966). Murty *et al.* (1980) considered removal of copper in association with hydroxide of ferric and manganese as the most effective process in the near-shore regions for the incorporation of trace elements in non-lithogenous fraction of sediments of western continental shelf of India.

It becomes quite clear, from the literature cited hitherto, that the sufficient but fragmented work on various aspects of physicochemical characteristics has already been carried out and that these characteristics exhibit marked seasonal variation subject to land run-off, local precipitation and other factors.

The relatively dry summer spell upto May is followed by a short period of heavy monsoon which contributes about three fourths of the annual rainfall (av. 3200 mm). The resultant heavy run off and local precipitation compounded with other physicochemical phenomena alter the marine phase of the estuarine growout ecosystem into an almost freshwater phase. The marine ecosystem undergoes relatively mild alteration as vertical mixing of less saline surface waters with the deeper saline water is restricted.

The sudden and drastic alteration of the ecosystem stresses various physiological phenomena of the inhabiting flora and fauna. The stressed fauna either 'adapts' to the changed ecosystem or 'migrates' to more conducive ecological niche. The penaeid prawn, P. indicus, a commercially important species comprising about 6% of the prawn catch in India is extensively cultured in the brackishwater fields of Kerala (Silas, 1983). The penaeid catch from Kerala constitutes 46.9% (52633 MT) of the total penaeid production of 1.12 lakh tonnes in India. (MFIS-35, 1982). Scarcity of maturing and mature P. indicus in estuarine waters and its relatively easy availability in 25-30 m depth on the continental shelf of the Arabian sea lead us to presume that the 'migratory' behaviour of the animal sets in at the initiation of its reproductive development. This is supported by Rao's (1968) observation that P. indicus migrate back to the sea from their nursery grounds in the estuaries as they approach adult hood. George (1962) studied breeding of penaeids in the Cochin backwaters and opined that spawning activity is closely related to the changes in salinity, whereas Rao (1968) opined that there seems to be no clear relationship between salinity and spawning. Imai (1977) stated that the beginning of the immature stage is said to be during the period when the penaeid prawns shift their growing places from the coastal regions to regions in the open seas. He (Imai, 1977) further said that the penaeid gonads are either immature or have just started to mature in the bays or estuaries but spawning does not take place there. Correlation between water temperature and spawning has been reported by a number of workers (Lindner and Anderson, 1956; Eldred _et al._, 1961; Cummings, 1961; and Idyll _et al._, 1963). It has been shown that the intensive spawning activity is generally related to rise in water temperature. Rao (1968) opined that spawning seems to be not influenced by the temperature since temperature variation in the tropical waters is not significant. But Imai (1977) stated that there is no definite explanation of the factors contributing to the movement of prawns from nursery to open sea and vice-versa.

Non-availability of maturing and mature _P. indicus_ in estuarine waters compounded by the decline in fishing activity in the coastal shelf areas during the monsoon season is a major constraint for the sound aquaculture industry to sustain itself as availability of mature P. *indicus* is a pre-requisite for controlled spawning and hatchery production of prawn seeds throughout the year.

The fact that maturing and mature P. *indicus* are available primarily in the 25-30 m depth-zone off Cochin lead us to presume that some physicochemical parameters of the estuarine ecosystem or their synergistic effect seems to alter, directly or indirectly, the ecosystem and thereby inhibit the normal maturation process in the estuarine zone.

The present work was undertaken to understand the crustacean ecological niche of P. *indicus* and its interactions with the animal's physiology. Most of the crustacean research work has either been on general physiological aspects such as moulting and osmo-regulation or ecological aspects. Though there is sufficient literature, most of the work has been carried out in the laboratory where simulation of *in situ* natural physicochemical dynamics becomes a limiting factor in obtaining a true picture of the ecophysiological interactions occurring in the ecosystem. Lewis and Cave (1982) suggested that the amount of the metal taken from the water into the biological material is also a function of the nature of the environment and the physiological requirements of the organism. Seasonal changes in environmental factors are known to affect the rate of metal intake by the organisms (Wolfe and Rice, 1972). The interactions of the organism with the environment and the sediment becomes important in understanding the uptake of trace metals (Pellenbarg, 1978).

In the present study, the main emphasis was to find out if seasonal variations of calcium, magnesium, phosphorus, copper and zinc in the water and the sediment have any important role to play in altering the concentration of these elements in different tissues of the prawn P. indicus as evidenced by the seasonal studies in the grow-out as well as the marine ecosystem.

There are basically three reservoirs for metals in the marine environment: water, sediment, and biota. Metal levels in these reservoirs are determined by a complex equilibrium governed by various physical, chemical and biological factors (Murrey and Murrey, 1973). Seasonal variation in metal concentration in the environment and in the organism may be related to the seasonal changes in land drainage and thus metal import into estuarine systems (Bryan, 1973).

Very few attempts have been made to study the effect of environmental metal concentrations on the animal tissue concentrations.

The only directly related work is of Rao *et al.* (1982) who studied seasonal variations of calcium levels in the exoskeleton, muscle and haemolymph of *Penaeus indicus* in relation to the variations of water temperature, salinity, pH and calcium in the water and pH and calcium in the sediment of a perennial prawn culture field near Cochin and observed that calcium content of the pond water and the haemolymph show a direct relationship with salinity. Dall (1965b) studied calcium metabolism of *Metapenaeus* species and observed that calcium was lost rapidly in calcium low artificial seawater and most of the loss was made good within twenty four hours. Greenaway (1972) examined calcium regulation in the freshwater crayfish *Austropotamobius pallipes* and observed that calcium turnover was very low and the normal balance was negative for much of the winter intermoult stage. Calcium and magnesium in the environment and the exoskeleton of decapod crustaceans was reported by Gibbs and Bryan (1972). Colvocorresses *et al.* (1974) reported that cyclic seasonal variation in mean calcium and magnesium of the blue crab, *Callinectes sapidus* didn't exhibit any obvious seasonal trends and no clear relationship with salinity was found. Reduction in relative calcification was described as an adaptation to the concentration of calcium existing in the environment inhabited by Crayfish (Mills and Lake, 1976; Mills et al., 1976). Chichibu(1979) reported calcium concentration changes in the aesthetic hairs of crayfish caused by the environmental salinity shifts. Regulation of blood ions in Carcinus maenas in normal and dilute seawater was reported by Zanders(1980). Greenaway (1985) reviewed the calcium balance and moulting in crustacea. Uptake and turnover of radio-active calcium in the crayfish was reported by Miyazaki and Jazuka (1964).

In relation to copper and zinc, most of the work is on purely physiological aspects and, that too, mainly on toxicity.

Lewis and Cave (1982) reviewed the literature in relation to copper in the marine environment. Colvocorresses and Lynch (1975) noted variations of copper and zinc in serum of the blue crab, Callinectes sapidus and observed no significant correlation with environmental salinity. Bryan (1964) studied the zinc regulation in Homarus vulgaris and explained that increase in sea water zinc concentration did not appreciably affect zinc concentration of the blood, abdominal muscle and gonad.

Matkar et al. (1981) studied the distribution of copper and zinc in water, sediment and crustaceans in the Bombay Harbour Bay. White and Rainbow (1982) noted the ability of Palaemon elegans to regulate the internal concentration of trace metal over a wide range of external trace metal concentrations. White and Rainbow (1984) studied the effects of temperature and zinc concentration on the regulation of zinc concentration in Palaemon elegans. Rajan et al. (1986) noted the effects of season, weight, sex and reproductive cycle on zinc concentration in the soft tissues of a mussel Meretrix casta. Shiber (1979) suggested the occurrence of higher levels of metals in organisms at certain times of the year. Petkevich and Stepanyuk (1970) showed that the seasonal variation of some trace metals in shrimp is very pronounced especially during the breeding season.

It becomes quite apparent from the available literature that the ecophysiological approach to ecosystem dynamics was rarely followed and, therefore, the present attempt has been made.

The present investigation was carried out in two different ecosystems inhabited by Penaeus indicus during its life i.e. a grow-out ecosystem comprising of 176 hectare estuarine impoundment located at Edavanakadu on Vypeen Island and connected to the estuarine complex of Cochin backwaters which remains marine dominated from November to May, and a marine ecosystem located at about 30 m depth in the inshore area off Cochin where maturation and spawning usually occur, more or less, during most part of the year.

Therefore, the stress in the present investigations was on the study of seasonal dynamics of physicochemical characteristics and metals in water and sediment in each ecosystem. Subsequently, the effect of seasonal variation of each metal in water and sediment, on the seasonal metal dynamics in male and female prawn P. *indicus* was worked out in the respective ecosystems.

MATERIAL AND METHODS

Regular fortnightly samples of water, sediment and prawns of male (Fig.C) and female (Fig. D) *Penaeus indicus* of maturing or mature size were collected in the grow-out (Estuarine) as well as the marine ecosystems for the period of two years (from November 1982 to October 1984) to study the interactions of various physicochemical parameters and some of the trace metals with the bioelements of the animal. As prawns are benthic organisms, it was considered more appropriate to collect water samples from just 30 cm above the base of the water-column in both the ecosystems. The water samples were analysed for temperature, dissolved oxygen, pH, Eh, salinity, net primary productivity, nitrate, nitrite, ammonia, calcium, magnesium, total phosphorus, copper and zinc. Sediment samples were analysed for temperature, pH, Eh, calcium, magnesium, total phosphorus, copper and zinc. Simultaneously, different tissues(exoskeleton, muscle, hepatopancreas and ovary/testis) and haemolymph of the prawn samples were subjected to analytical methods to find out their calcium, magnesium, phosphorus, copper and zinc content.

The grow-out ecosystem is an estuarine impoundment of about 176 hectares located at Edavanakadu in Vypeen Island near Cochin (Fig. A). This is connected to the Vembanad

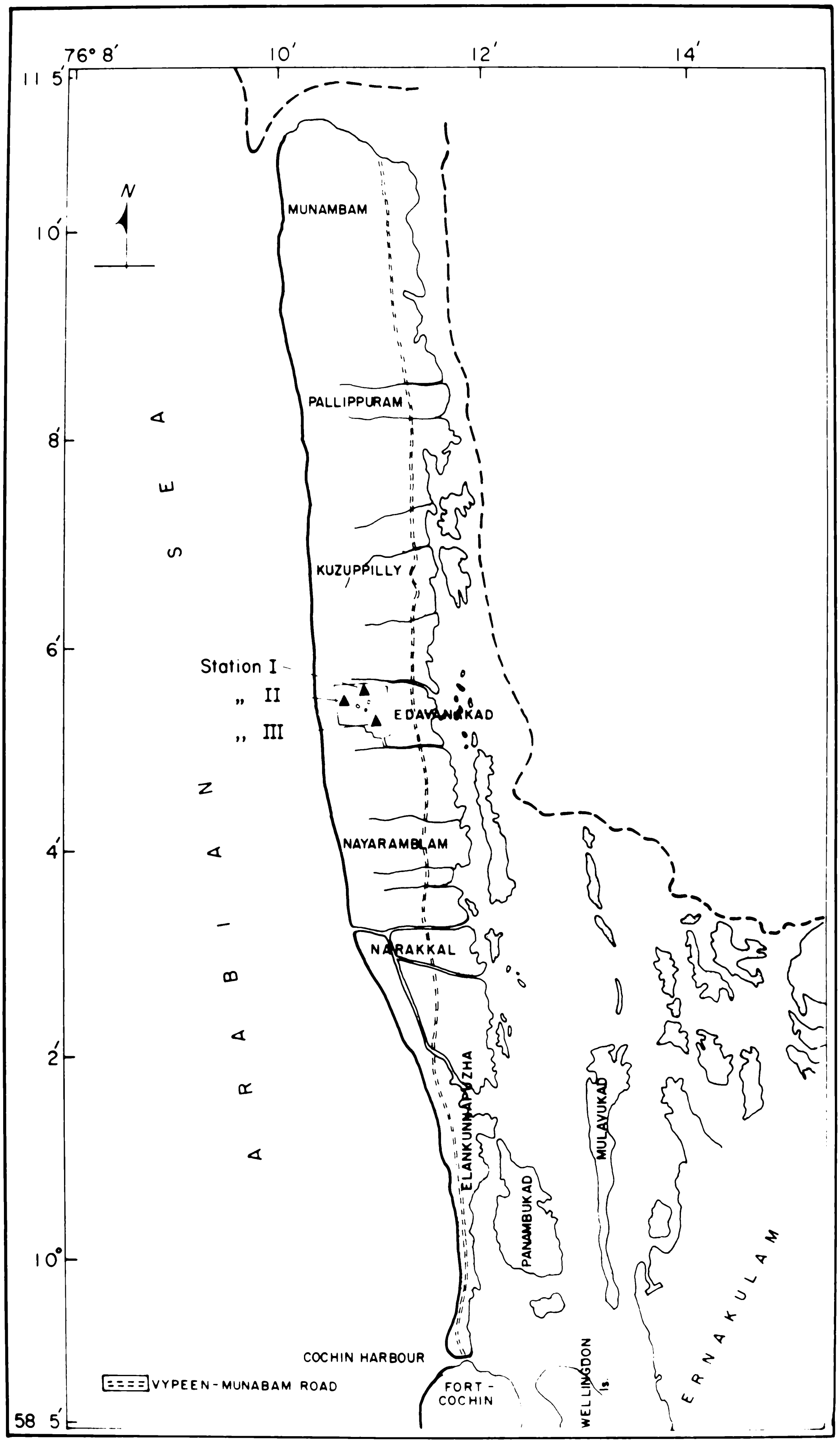


FIG. A- MAP SHOWING THE GROWOUT ECOSYSTEM

Fig. C : Male *Penaeus indicus*

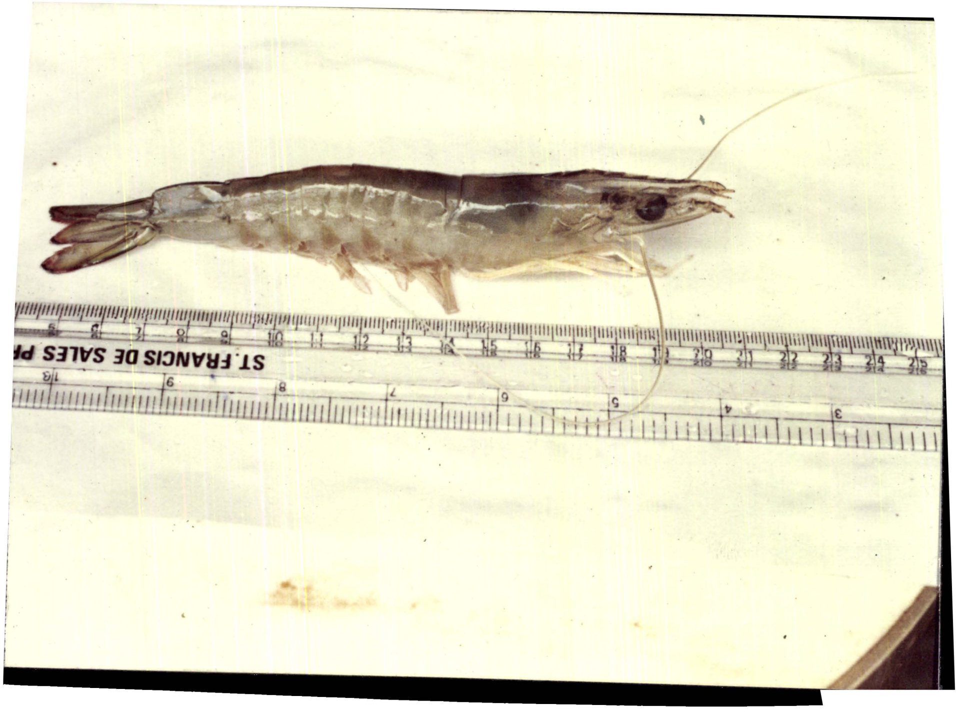


Fig. D : Female *P. indicus*

estuary through a net work of a few canals (Fig. A2). The average depth of the estuarine impoundment is about 1.5 m and the tidal amplitude is about 0.5 m. Three research stations representing the approximate total area of the grow-out impoundment were selected, keeping in view various factors, to carry out the seasonal variation studies. These were station I, station II and station III, (Fig. A).

The marine ecosystem (Fig. B) lies at about 30 m depth-zone on the continental shelf of Arabian Sea off Cochin. Three stations i.e. station IV, station V and station VI(Fig.B) were identified for regular sampling of water, sediment and male and female P. indicus in the marine ecosystem. This area is considered to represent the optimum grounds for maturation and spawning of prawns though the outer limit extends upto 50-60m depth-zone as reported by Rao (1978).

METEOROLOGICAL PARAMETERS

The monthly data relating to maximum and minimum aerial temperature, humidity and rainfall was regularly collected, to have the general seasonal picture of the local climate, from the Meteorology Department, Government of India's local data recording centre at Cochin Air-Port.

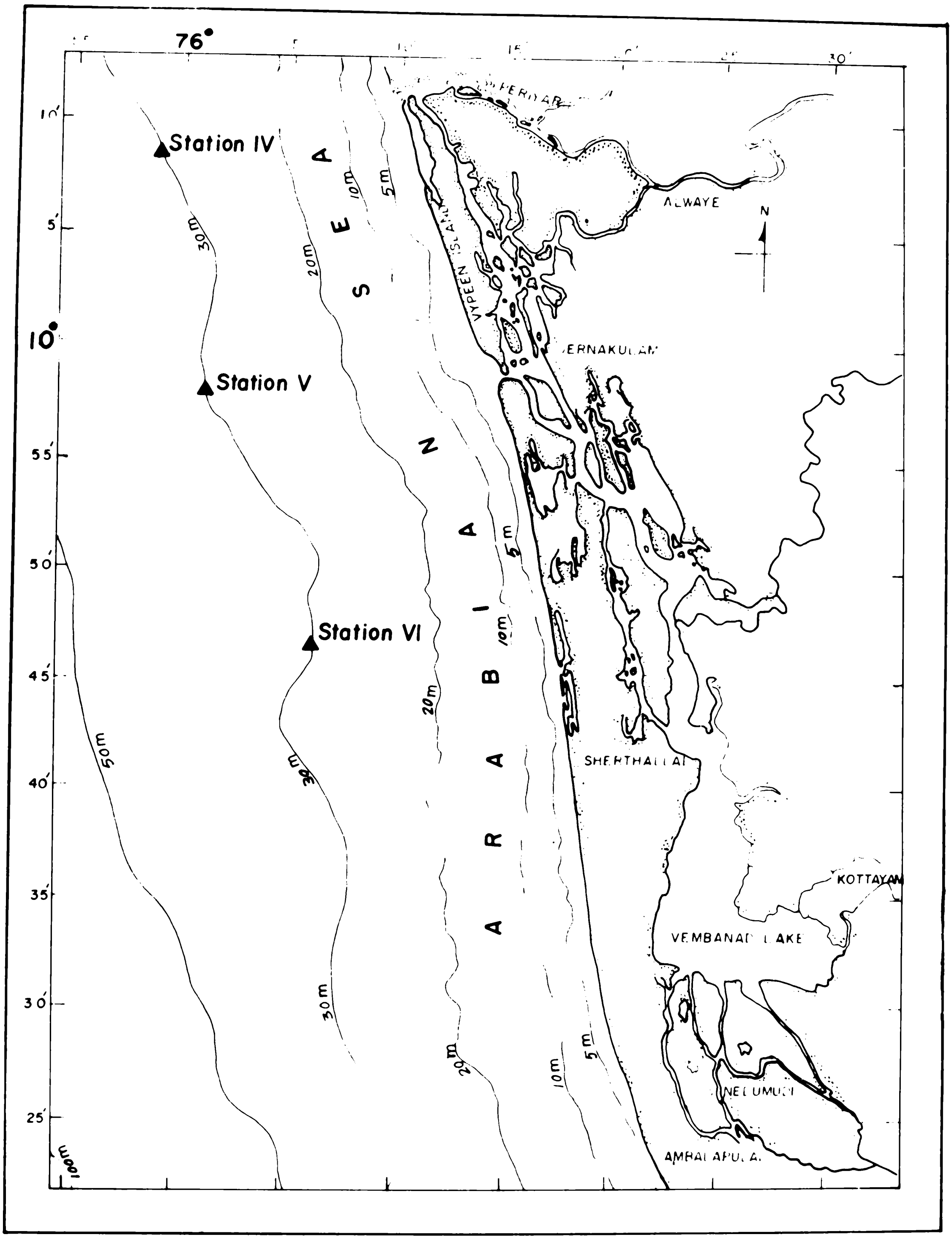


FIG. B - MAP SHOWING THE MARINE ECOSYSTEM, COCHIN BACKWATERS & CATCHMENT AREA

Fig. A-1 : Perennial prawn-culture pond(grow-out ecosystem)

Fig. A-2 : Canal connected to the grow-out ecosystem

SAMPLING STRATEGY

Samples of water, sediment, and male and female *P. indicus* (intermoult stage) of maturing or mature size were collected sequentially, every fortnight, from each ecosystem during high tide period only, as copper concentration is known to vary on a tidal basis (Young *et al.*, 1977; Zirino *et al.*, 1978). Sampling was usually carried out onboard a dug-out Canoe (Fig. E) and research vessel R.V. Cadalmin (Fig. F) at the grow-out and the marine ecosystems respectively.

SAMPLING IN THE GROW-OUT ECOSYSTEM

SAMPLING OF WATER

For oxygen analysis, 125 ml 'Corning' reagent bottle with a BOD stopper was used. The bottles were washed twice with the 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 chloride) and 1 ml of Winkler B (4.1 g NaOH + 75 g KI in 100 cc water) were added using the automatic pipette 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

Fig. E : Dug-out Canoe used in the grow-out ecosystem

Fig. F : Research Vessel - R.V. Cadalmin used in the marine ecosystem by shaking. The fixed samples were kept in a covered rack to prevent evaporation.

Water samples for net primary productivity studies were collected in the same way as for the dissolved oxygen but for the addition of Winkler A & B using 'Light and Dark' bottle method (Strickland and Parsons, 1968). Only 'light' bottles were used in the present investigation as emphasis was to know the rate of net primary production only. The bottles were stoppered inside the water-column without trapping any air-bubble. Reagent bottles of 125 ml capacity were used as 'Light' bottles.

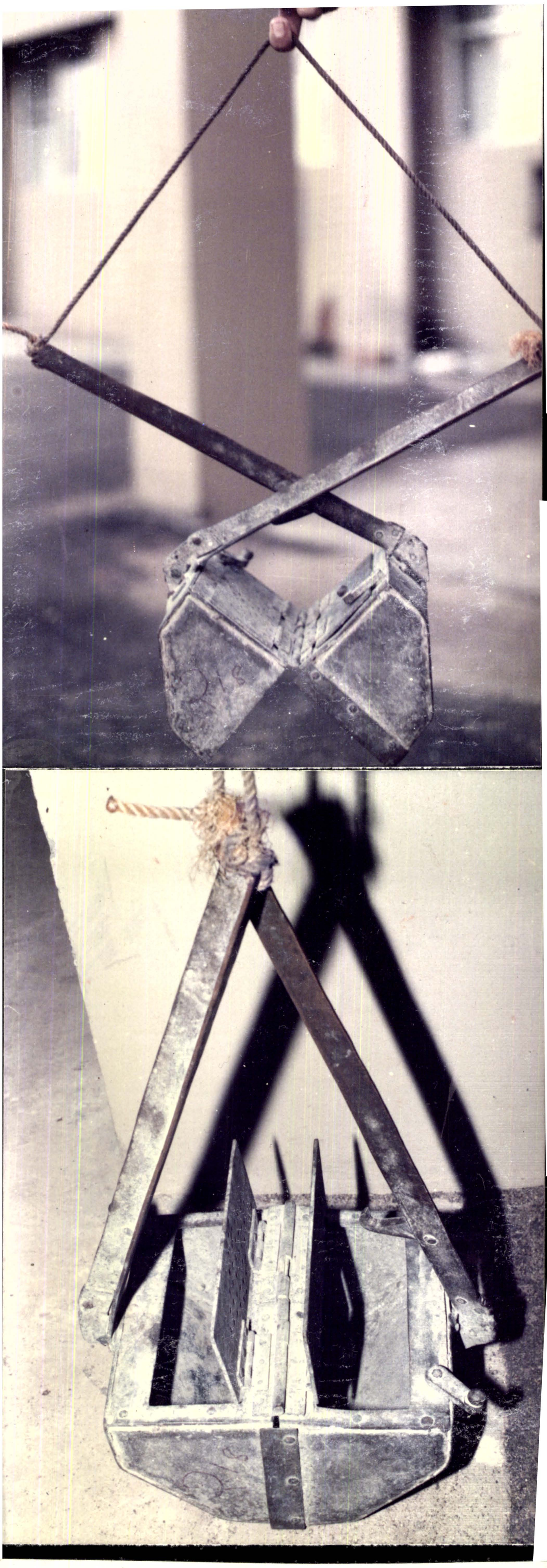
Water samples for temperature, salinity, pH, Eh, nitrate, nitrite and ammonia were collected in 2 l narrow-mouth polypropylene (FAO, 1975) bottles precleaned twice with the ambient water. The bottle was dipped to just 30 cm above the bottom in a closed condition and then, it was opened to let the water in under undisturbed conditions. Once filled, it was taken out, capped and stored in a wooden-box after recording the water temperature. Water samples for calcium, magnesium, total phosphorus, copper and zinc were also collected similarly except that these samples were acidified to about pH 4, capped and stored in a wooden-box.

Water samples were analysed for pH and Eh immediately after reaching the laboratory. Thereafter, water samples were either preserved or analysed as early as possible for various parameters. Light bottles for net primary productivity studies were kept in the shade near window for 24 hours before analysis.

SAMPLING OF SEDIMENT

Sediment samples for temperature, pH, Eh, calcium magnesium, total phosphorus, copper and zinc were collected with the help of a Van Veen grab (Fig. G) lowered from the dug-out canoe using polypropylene rope. The grab was hauled up once it penetrates the bottom. Thereupon, sediment sample was collected at random from inside the grab and pooled up in 200 ml capacity wide-mouth polypropylene bottle, capped air-tight after noting the temperature and stored in a wooden-box.

Sediment samples were analysed for pH and Eh immediately after reaching the laboratory. Subsequently, these were dried in hot-air oven at 100°C for 24 hour. Thereupon, sediment samples were cooled to room temperature, powdered with agate mortar, put into small polythene bags along with date, station and sample number information, sealed and stored in a desiccator for metal analysis.



Open

Close

Fig. G : Van Veen grab (Open and close condition)

SAMPLING OF PRAWNS

The Indian white prawn, P. *indicus* of intermoult stage and maturing or mature size were collected with the help of stake net, every fortnight preferably on full-moon and new-moon days, immediately after the water and the sediment sampling. The moult staging was done by referring to the methods described by Scheer (1960). It involved hand-touch feeling of the carapace and the rostrum, and hand-lens examination of the setae of the uropod.

The maturing or mature prawns were collected based on the taxonomical characteristics of P. *indicus* described by Rao (1978). The female prawns (Fig. D) belonged to 140 to 200 mm size range and had light yellow to dark green colour of ovary along the mid-dorsal line; and male prawns (Fig. C) belonged to 110 to 160 mm size range and had white terminal ampoule of vas deferens one on each side of the thoracic region.

HAEMOLYMPH COLLECTION

Each prawn was washed with the ambient medium before taking out haemolymph so as to clear off any extraneous material sticking to the arthrodial membrane or the carapace. A 1 ml glass syringe with No 22 hypodermic needle was used after washing with an anticoagulant (3% aquous Tri-Sodium citrate) for haemolymph collection from each prawn. The haemolymph was taken out either after piercing the posterior wall of the heart along the mid-dorsal line by inserting the hypodermic needle through the arthrodial membrane connecting the carapace and the first tergite or by piercing the dorsolateral wall of the carapace. The haemolymph was transferred to 2 ml screw-capped vial precleaned with an anti-coagulant. The vial was numbered and stored in chilled condition in an ice-box. Thereafter, the numbered prawns were wrapped in aluminium foil and put into a polythene bag, which was, in turn, put into another polythene bag. A label containing the relevant information was placed in the outer bag which was tightly tied with a rubber band and stored in an iced ice-box. All haemolymph samples collected were preserved in the freezer after reaching the laboratory.

TISSUE COLLECTION

The prawn samples were dissected immediately after reaching the laboratory for different tissues (Viz. exoskeleton, muscle, hepatopancreas and ovary/testis). The haemolymph and the tissue portions of the various animals were pooled up for analysis. The tissue samples were kept on tin foil pieces and dried overnight in an hot-air oven at 80°C. Subsequently, dried tissues were cooled to room temperature, powdered in agate-mortar and put in small polythene bags containing relevant scientific information. Thereafter, these bags were sealed and stored in a desiccator for further metal analysis.

SAMPLING IN THE MARINE ECOSYSTEM

SAMPLING OF WATER

Water samples for temperature, salinity, dissolved oxygen, pH, Eh, net primary productivity, nitrate, nitrite and ammonia were taken with the help of a Nansen bottle (Fig. H). [Nansen bottle is a reversing bottle fitted with two plug valves on each end of the Nansen cylinder. The valves are operated synchronously by means of a connecting (metallic) rod fastened to the clamp that secures the bottle to the wire-rope. When the bottle is lowered, this clamp is at the lower end and the valves are in the open position (Fig. H-1) so that the water can pass through the bottle. The water sampler is held in this position by the release mechanism which passes around the wire-rope]. Nansen bottle was lowered after fixing it to the metallic winch-wire in such a way that sample is collected from about 30 cm above bottom of the water column. A messenger was then forced through the water column. The messenger strikes the release, the water sampler fall over and turns through 180°C (Fig. H-1), shuts the valves which are then held closed by

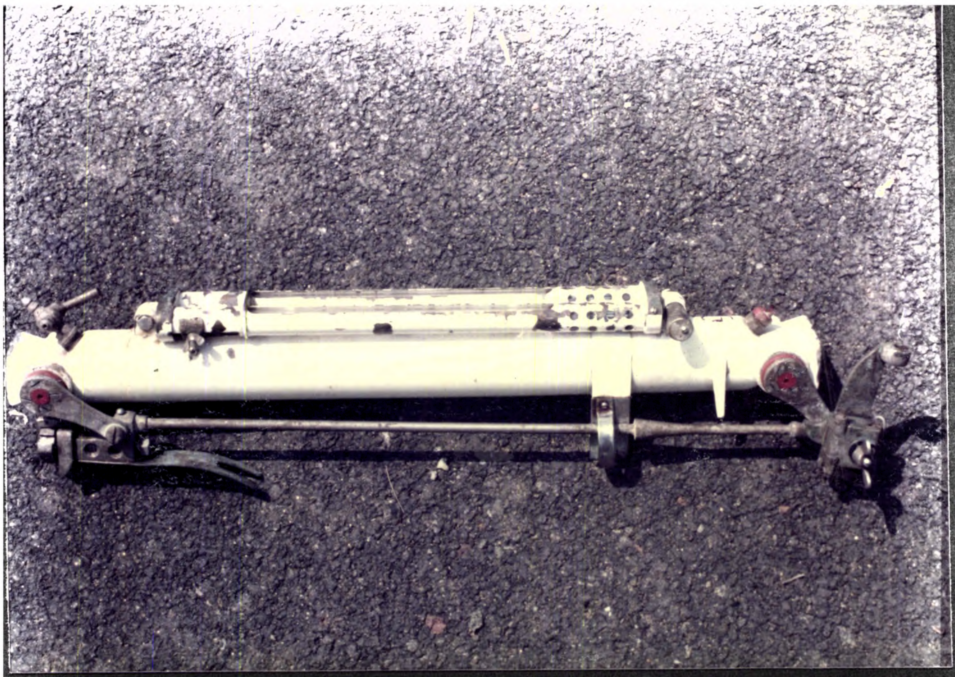


Fig. H : Nansen water-bottle

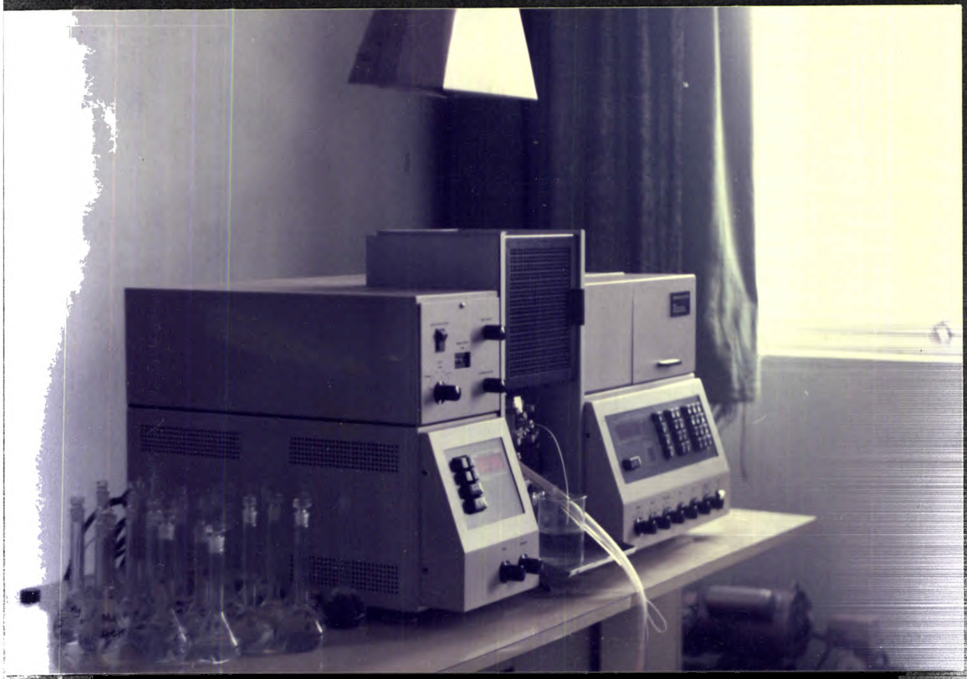


Fig. K : Atomic Absorption spectrophotometer

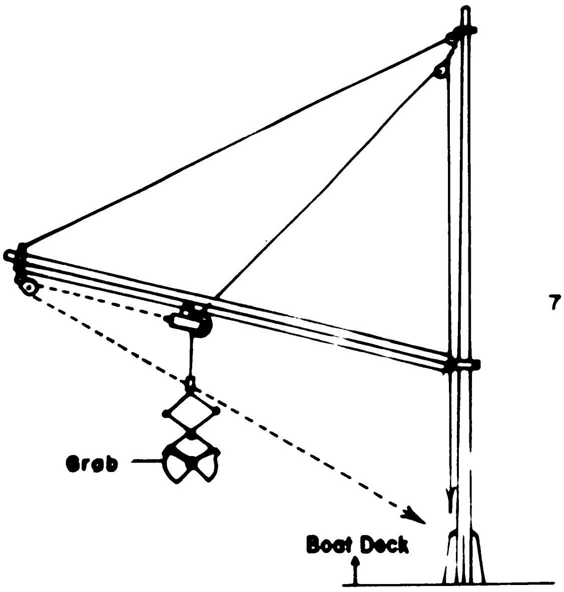


*FIG. F-1: System for hauling grab using jockey pulley

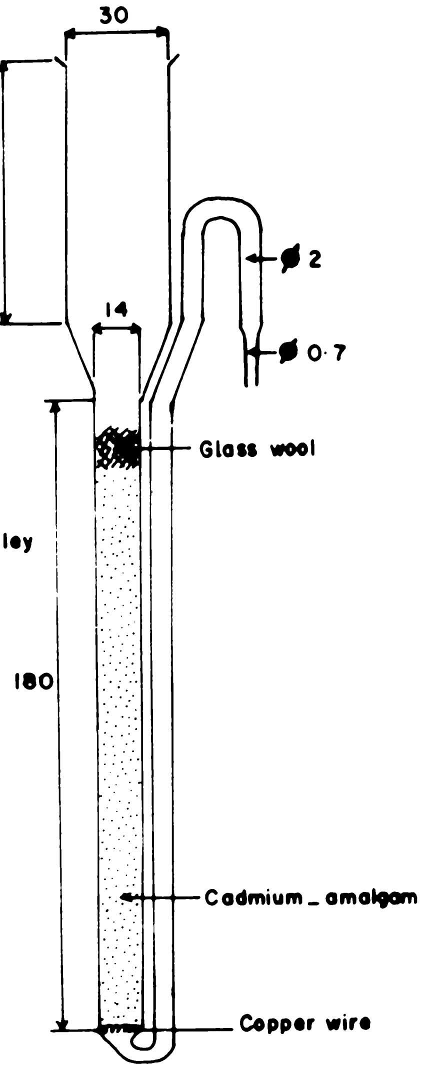


FIG. J: Cadmium Reduction Column
(all measures given in
millimetres)

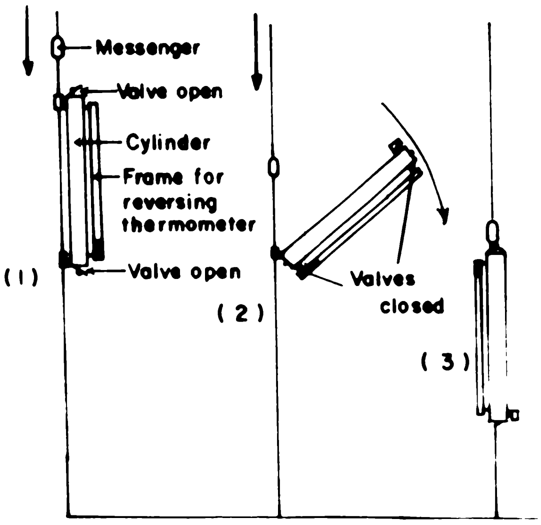


*FIG. H-1: Diagram of the action of a Nansen water_bottle

*Not to scale

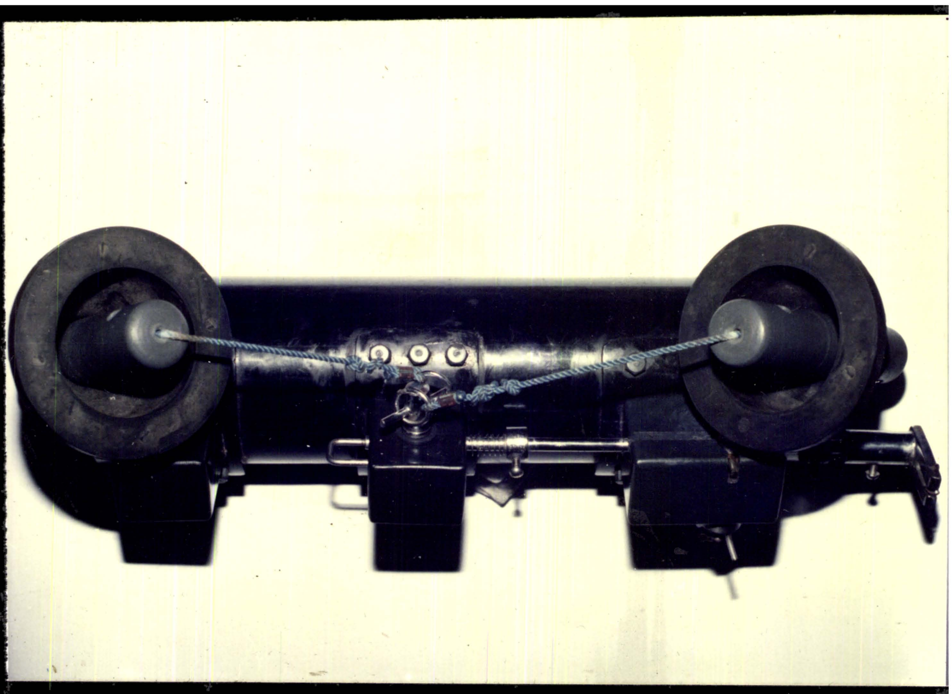
a locking device, and reversed the attached reversing thermometer too. Nansen bottle was winched up onboard and the sample aliquots were taken.

Water samples, thus collected from the Nansen bottle, were used for determination of all physicochemical parameters but for metals. The methodology employed for preserving the samples till analysis was the same as the methods used in the grow-out ecosystem.

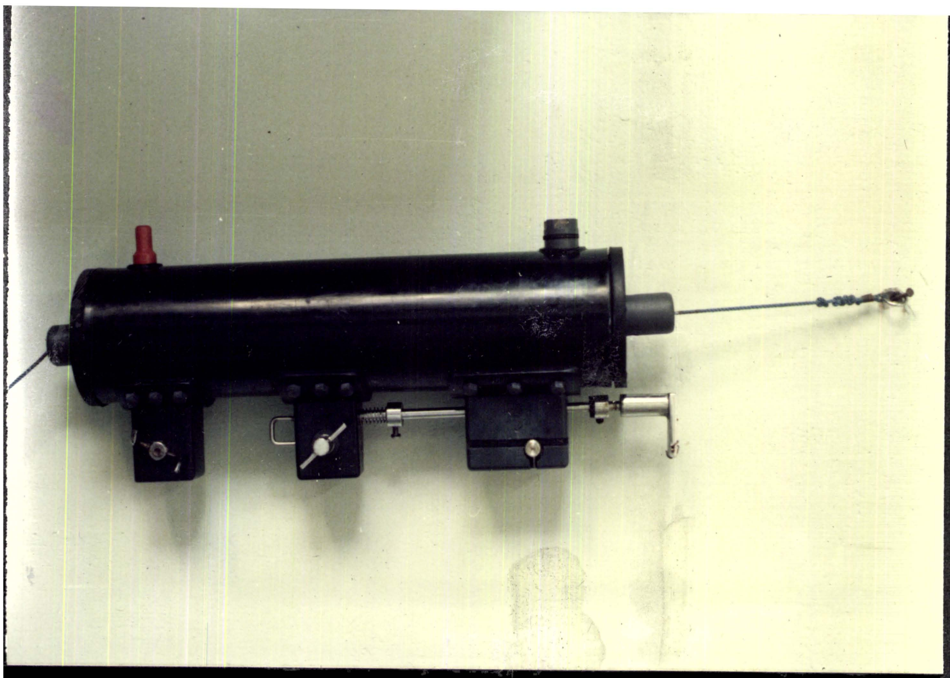
Water samples for calcium, magnesium, total phosphorus, copper and zinc analysis were collected with the help of 'Van-Dorn' polypropylene water sampler (Fig. I) having least metallic parts. It was lowered down from the research vessel Cadalmin alongside a polypropylene rope in open condition. After lowering it to just 30 cm above sea floor, a messenger was forced through the water column. It striked, resulting in unlocking of the spring which in turn closed the sampler tightly. Thereafter, it was hauled up onboard and the water was transferred to 2 l narrow mouth polypropylene bottle, acidified to pH 4.0, capped and stored in a wooden-box. Further laboratory treatment was similar to the grow-out ecosystem.

SAMPLING OF SEDIMENT

Sediment samples were collected and stored in a similar way, after recording sediment temperature, pH and



Open



Close

Fig. I : Van Dorn water sampler
(Open and close condition)

Eh, as carried out in the grow-out ecosystem. In this case the Van Veen grab was lowered from the research vessel Cadalmin using jockey pulley (Fig. F-1). As soon as the sea bottom was reached, the winch brake was applied. The hauling up of the grab was commenced immediately as any delay on the bottom will increase the wire angle, causing the grab to be pulled out obliquely.

SAMPLING OF PRAWNS

The prawns of intermoult stage and of maturing or mature size were collected with the help of a trawl-net operated from R.V. Cadalmin at each of the research stations. Trawling time per unit haul never exceeded twenty minutes. The prawns were sorted out immediately after hauling. The further treatment for collection of haemolymph and tissue samples and their preservation was the same as described earlier in the grow-out ecosystem.

ANALYSIS OF PHYSICOCHEMICAL PARAMETERS OF WATER

TEMPERATURE

A 0-50°C high precision thermometer was dipped into water (unacidified) contained in 2 l narrow-mouth polypropylene bottle immediately after its sampling at the grow-out ecosystem and the temperature was recorded. At the marine ecosystem, water temperature was noted on the reversing thermometer attached to the Nansen bottle immediately after it is hauled up onboard after water sampling.

SALINITY

Water sample collected in 2 l polypropylene bottles (unacidified) were used for salinity estimation. It was determined by the classical Mohr's titration method (Strickland and Parsons, 1968). 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 standardization 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:

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

Where,

V_1 = Volume of silver nitrate for 10 cc standard seawater.

V_2 = Volume of silver nitrate for 10 cc sample.

S = Salinity of standard seawater.

HYDROGEN ION CONCENTRATION (pH)

Water samples collected in 2 l polypropylene bottles (unacidified) were used for electrometric pH determination utilizing Elico pH-meter model LI-10T having a glass electrode and a calomel electrode. The instrument was calibrated with the help of pH buffers. After taking the pH-meter reading, the *in-situ* pH was calculated using the formula (Gieskes, 1969):

$$pH_{in-situ} = pH_{measured} + 0.0118\ (t_2 - t_1)$$

Where,

t_1 = temperature *in situ*

t_2 = measurement temperature.

REDOX POTENTIAL (Eh)

Water samples collected in 2 l polypropylene bottles (unacidified) were used for electrometric Eh determination utilizing Elico pH meter model LI-10T having a platinum electrode and a calomel electrode. Eh readings were taken after calibration.

DISSOLVED OXYGEN

125 ml 'corning' reagent bottles having precipitated water sample were used for oxygen analysis. Traditional Winkler method with azide modification was used to determine

the dissolved oxygen content. The outline of the method (FAO, 1975) is as follows:

The precipitate was dissolved in the laboratory using 1 ml of 1+1 sulphuric acid. The solution 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:

$$\text{Oxygen (ml/l)} = \frac{a.N.\ 22393}{4.\ (V-2)}$$

Where,

a = Volume of sodium thiosulphate consumed in ml.

N = Normality of sodium thiosulphate solution.

V = Volume of Winkler bottle in ml.

NITRATE

Water samples collected in 2 l polypropylene bottles (unacidified) were used. Nitrate was estimated using cadmium reduction column (Solyom and Carlberg, 1975). Nitrate is reduced to nitrite almost quantitatively by amalgamated cadmium column (Fig. J). The nitrate is then determined according to the classical Griess's reaction. The outline of the method followed (FAO, 1975) is presented below:

75 ml of the water sample was run through the amalgamated cadmium column. First 10 ml of the sample flowing through the column was discarded and the next 10 ml was used to wash the Erlenmeyer flask. Then 50 ml was collected in two flasks of 25 ml each. To 25 ml of the reduced sample and the blank sample, 0.5 ml sulphanilamide reagent (prepared by dissolving 8 g of sulphanilamide in a mixture of 80 ml concentrated hydrochloric acid and 420 ml of water) was added. After not less than 3 minutes and not longer than 8 minutes, 0.5 ml of N-(1-Naphthyl)-ethylene diamine solution (prepared by dissolving 0.8 g NNED 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.

NITRITE

Water samples collected in 2 l polypropylene bottles (unacidified) were used. Nitrite was determined by the Azo-dye method (Bendschneider and Robinson, 1952). The determination of nitrite is based on the classical Griess's reaction in which the nitrification at pH 1.5-2.0 is diazotized with sulphanilamide, resulting in a diazo compound, which in turn is coupled with N-(1-napthyl)-ethylene diamine to form a highly coloured azo-dye with an absorption maxima at 545 nm that is measured spectrophotometrically.

The methodology used was the same as for the determination of nitrate after reducing the sample through the amalgamated cadmium reduction column (FAO, 1975).

AMMONIA

Water samples collected in 2 l polypropylene bottles (unacidified) were used. Ammonia was determined following the phenol-hypochlorite method (Solorzano, 1969). The following methodology was employed in the analysis:

To 50 ml of the sample and the blank (having distilled water), added successively, 2 ml of phenol solution (prepared by dissolving 10 g of phenol in 100 ml of 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 5 g 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 865 D at 640 nm.

NET PRIMARY PRODUCTION

Net primary production was estimated by 'Light and Dark bottle' technique (Strickland and Parsons, 1968). The dissolved oxygen values were taken for the Initial bottle (IB).

After keeping in laboratory for 24 hours the water samples collected in the 'Light and the 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:

$$\text{Net Primary Production (mgC/m}^2\text{/d)} = 605\, f\, \frac{[V_{(LB)} - V_{IB)}]}{PQ}$$

Where,

f = "f" factor determined through sodium thiosulphate standardization.

$V_{(LB)}$ and $V_{(IB)}$ = Sodium thiosulphate titre values obtained from the titrations of 'Light' and 'Initial' bottles respectively.

PQ = Photosynthetic Quotient (here taken as 1.2).

TOTAL PHOSPHORUS

Water samples collected in 2 l polypropylene bottles (acidified) were used. The modified method of Murphy and Riley (1962) was followed for the estimation of 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 peroxydisulphate was added, and boiled gently in a electric heating mantle until the volume is 5-7 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 anti-monyltartarate 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 865 D at 882 nm after five minutes.

ANALYSIS OF PHYSICOCHEMICAL PARAMETERS OF SEDIMENT

TEMPERATURE

A 0-50°C high precision thermometer was inserted in the sediment sample contained in the Van Veen grab immediately after it was hauled up onboard and the temperature was noted.

HYDROGEN ION CONCENTRATION (pH)

Sediment samples collected in air-tight 200 ml wide mouth polypropylene bottle were used. The pH of the sediment was determined using Elico pH meter model LI-10T and the method followed was similar to water pH analysis.

REDOX-POTENTIAL (Eh)

Sediment samples collected in air-tight 200 ml wide-mouth polypropylene bottle were used. The Eh of the sediment was estimated using the same Elico pH meter but with a platinum electrode following water Eh methodology.

TOTAL PHOSPHORUS

Total phosphorus was determined by prolonged nitric-perchloric acid hot digestion of dry finely powdered sediment sample of known weight taken from sealed polypropylene bag in a desiccator. This brings all phosphorus into solution except that held in resistant silicate lattice structural sites. The outline of the method (FAO, 1975) is as follows:

0.5 g dried finely powdered sediment sample was taken in a 100 ml Kjeldhal flask; and three small acid-washed glass-beads, 2 ml concentrated nitric acid and 2 ml of concentrated perchloric acid were added. The sediment sample was then heated to dry. After cooling, dilute sulphuric acid (prepared by diluting 50 ml concentrated sulphuric acid to 1000 ml) was added to the sediment. It was then boiled slowly for 10 minutes. After cooling, the solution was filtered using moistened Whatman 42 filter paper into a 250 ml volumetric flask and diluted to 250 ml. To 5 ml of this solution, 25 ml of water, 5 drops of 0.4 M ascorbic acid and 1 ml of sulphuric acid-ammonium molybdate solution (prepared as for the total phosphorus estimation of water) were added. After 5 minutes, the absorbance was measured on ECIL Senior Spectrophotometer model GS865D at 882 nm against distilled water as blank. The results were calculated from the equation:

$$X = \frac{a.1}{b}$$

Where,

X - total concentration of phosphorus in ug/g

a - values obtained from the curve, in ug/0.5 g

b - sample weight in g

ANALYSIS OF CALCIUM, MAGNESIUM, COPPER AND ZINC IN WATER SEDIMENT AND VARIOUS TISSUES OF P. INDICUS

Perkin-Elmer 2380 Atomic Absorption Spectrophotometer (Fig.K) incorporated with automatic curve correction microprocessor technology was utilized for metal analysis. The light source used was an intesitron 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.

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 the matrix interference, standards were matched, as closely as possible, to the samples. Always used deionized double glass distilled water. Used proper number (usually two) of calibration standards, and also check standards (falling in the middle of the range being covered by calibration) to make sure that the analysis will be accurate. The blank was a representative of the sample matrix. Whenever sample was digested, the blank contained all the reagents used in the sample preparation. The burner and the burner head assembly was cleaned regularly.

PREPARATION OF STOCK STANDARD SOLUTIONS

CALCIUM (500 mg/l)

To 1.249 g of $CaCO_3$, added 50 ml of deionised water, and then added to it drop wise a minimum volume of Hcl to effect complete solution of the calcium carbonate and diluted to 1 litre with deionized water.

MAGNESIUM (1000 mg/l)

Dissolved 1 g of magnesium ribbon in a minimum volume of (1+1) Hcl and diluted to 1 litre with 1%(V/V)

Hcl having 0.1% Lanthanum as chloride.

COPPER (1000 mg/l)

Dissolved 1 g of copper metal in a minimum volume of (1+1) HNO_3 and diluted to 1 litre with 1% (V/V) HNO_3.

ZINC (500 mg/l)

Dissolved 0.5 g zinc metal in a minimum volume of (1+1) Hcl and diluted to 1 litre with 1% (V/V) Hcl.

PREPARATION OF DILUTE WORKING STANDARD SOLUTIONS

Prepared suitable dilute standards from the stock solutions described under the standard conditions for each element, adjusting the pH of standards to pH 4.0 with hydrochloric acid. Added incremental amounts of these dilute standards to the distilled water (containing 1% lanthanum in case of calcium) to prepared working standards containing 0, 2, 5 and 10 ug/l of the elements of interest.

In case of copper and zinc, the incremental amounts of their dilute standards are added to the extracted sea-water to prepare the working standards containing 0, 2, 5 and 10 ug/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 pyrrolidine dithiocarbamate (APDC) solution, and equilibrated for 30 minutes on a mechanical shaker. Separated the organic layer in polypropylene bottle 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.

METAL ANALYSIS OF WATER SAMPLES

CALCIUM:

Acidified seawater sample (pH 4.0) was diluted with distilled water (having 1% lanthanum) so as to place the element concentration within a suitable analytical range. The calibration standards as well as the samples were aspirated under standard conditions (422.7 nm wave length; 0.7 nm slit width) as described in Perkin-Elmer manuel. The slight ionization in the flame was controlled by the addition of an alkali salt (0.1% potassium as chloride). The concentrations were then calculated as follows:

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

Where,

d.f. = dilution factor, if used

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

MAGNESIUM

Acidified seawater sample (pH 4.0) was diluted with distilled water so as to place the elemental concentration with in a suitable analytical range. The procedure followed was similar to that of calcium except that the wave length of 285.2 nm was used and lanthanum addition was not carried out.

COPPER AND ZINC

Acidified water samples (pH 4.0) contained in 2 l narrow mouth polypropylene bottles were used. Took 750 ml aliquot into 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 phases to separate and retained the aquous phase) and equilibrated for 30 minutes on a mechanical shaker. Separated the organic layer in a polypropylene bottle. It was aspirated and analysed preferably within 3 hour of extraction and the aquous layer was saved for the preparation of standard solutions. The slit width was 0.7 nm for copper and zinc. The operating wavelengths for copper and zinc analysis were 324.8 nm and 213.9 nm respectively. The calculation of metal concentrations were carried out as for calcium.

METAL ANALYSIS OF SEDIMENT SAMPLES

Ignited 1 g of the dried and finely powdered sediment sample in silica crucible at 700°C for 24 hour. Thereafter, sediment sample was cooled to room temperature and transferred to a 100 ml beaker. Added to it, 10 ml

(1+1) Hcl and heated at 60-80°C for one hour. Decanted the supernatent into a 250 ml volumetric flask and retained. Added to the residue, 10 ml aqua-regia and evaporated to dryness in a fume-hood. Repeated the addition of aqua regia and evaporation to dryness. Dissolved the residue in a minimum amount of Hcl and transferred to a 100 ml beaker alongwith the 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. For the determination of calcium the final dilution contained 1% lanthanum to prevent potential anionic interferences. For copper and zinc, APDC-MIBK extraction was carried out. The procedure followed for analysis of calcium, magnesium, copper and zinc was same as described for metal analysis of water.

THE HAEMOLYMPH AND THE TISSUE ANALYSIS

Known weight (usually 1 g) of dried and finely powdered tissue or known volume (0.5 ml) of haemolymph was taken in a silica crucible covered with silica lids and transferred to a cool muffle furnace and slowly raised the temperature to 450-500°C. Ashed overnight, removed samples to let it cool to room temperature. Then added cautiously 2 ml HNO_3 and swirled. Evaporated carefully just to dryness on warm hotplate. Transferred to cool furnace, slowly raised the temperature to 450-500°C and held at this temperature for 1 hour. Again removed the crucible and cooled it. Repeated HNO_3 treatment, as and when necessary, to obtain clean, practically carbon free ash. Added 10 ml 1 N Hcl and dissolved the ash by heating cautiously on a hot plate. Transferred to 25 ml volumetric flask and added Hcl as necessary. Cooled and diluted to volume (AOAC, 1980). Metal analysis was carried out after further suitable dilution/extraction of the digested sample and procedure followed was same as for metal analysis of water. The results were expressed in dry weight or volume basis.

PHOSPHORUS ANALYSIS IN HAEMOLYMPH AND OTHER TISSUES

Phosphorus in haemolymph and various tissues was estimated by Lowery *et al.*'s (1954) method using phosphomolybdate and ascorbic acid.

To the weighed dry tissue sample or haemolymph of known volume, added ashing mixture (containing 70% perchloric acid and 20 N sulphuric acid). Heated the mixture in an hot-air oven at 95°C for 2 hour, followed by heating to 165°C for another two hour. The mixture was cooled to room temperature, and to the cooled, wet ashed sample, added mixture of ammonium molybdate and ascorbic acid. Immediately mixed thoroughly and placed the tubes at 37°C for two hour. The optical density was recorded when the samples were cool on ECIL Senior Spectrophotometer at 882 nm. The phosphorus was expressed on dry weight basis or volume basis (in case of blood) and values were the mean of triplicate analysis.

STATISTICAL ANALYSIS

All the statistical analysis were carried out according to Snedecor and Cochran (1967). Monthly mean and standard deviations were calculated for all the parameters. Correlations between all the physicochemical and biological parameters were computed at Regional Computer Centre, Government of India, Chandigarh.

RESULTS

Seasonal variations of different physicochemical parameters in the grow-out as well as the marine ecosystems are governed by seasonal rainfall during monsoon and therefore, for convenience, season-wise description was adhered to. An year has been classified arbitrarily as follows:

1. Monsoon period (June, July and early August)
2. Post-monsoon period (Late August, September and October)
3. Non-monsoon period (November to May)

Seasonal variations of meteorological parameters such as maximum and minimum aerial temperature, rainfall and humidity, as reported by the local office of Meteorology Department from November 1982 to October 1984, are given in figure 1.1 to 1.4 to have an idea of the seasonal climate at Cochin.

The results obtained at the grow-out as well as the marine ecosystem depict very minor inter-station differences within the each ecosystem. Therefore, to avoid repeatative description and for the sake of convenience & brevity, seasonal trends of various physicochemical and biological parameters have not been

METERIOLOGICAL PARAMETERS (COCHIN)

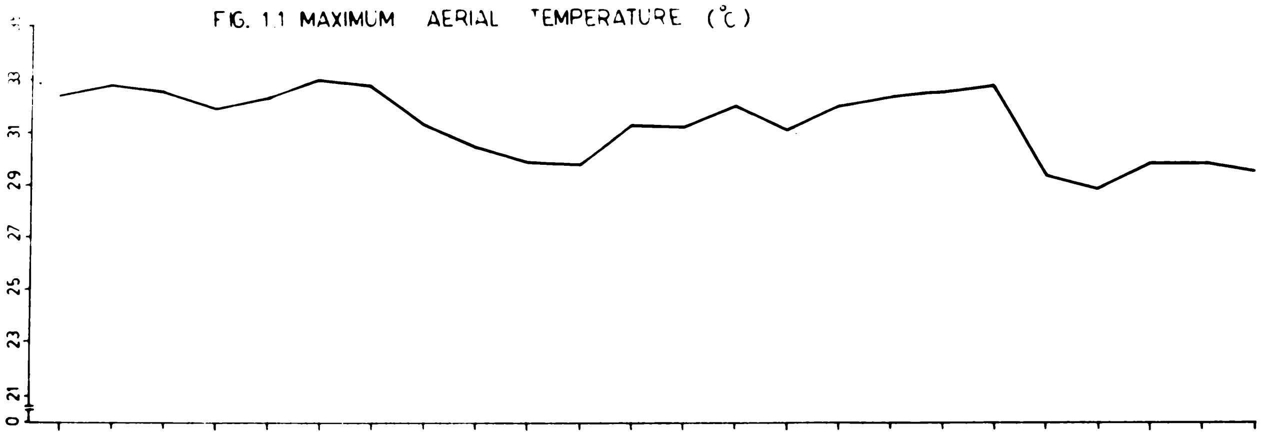


FIG. 1.1 MAXIMUM AERIAL TEMPERATURE (°C)

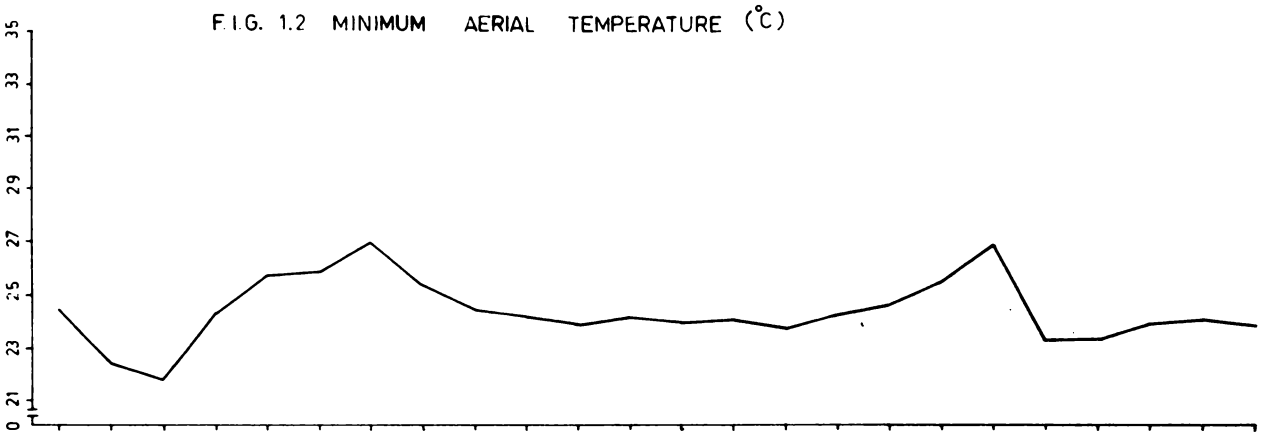


FIG. 1.2 MINIMUM AERIAL TEMPERATURE (°C)

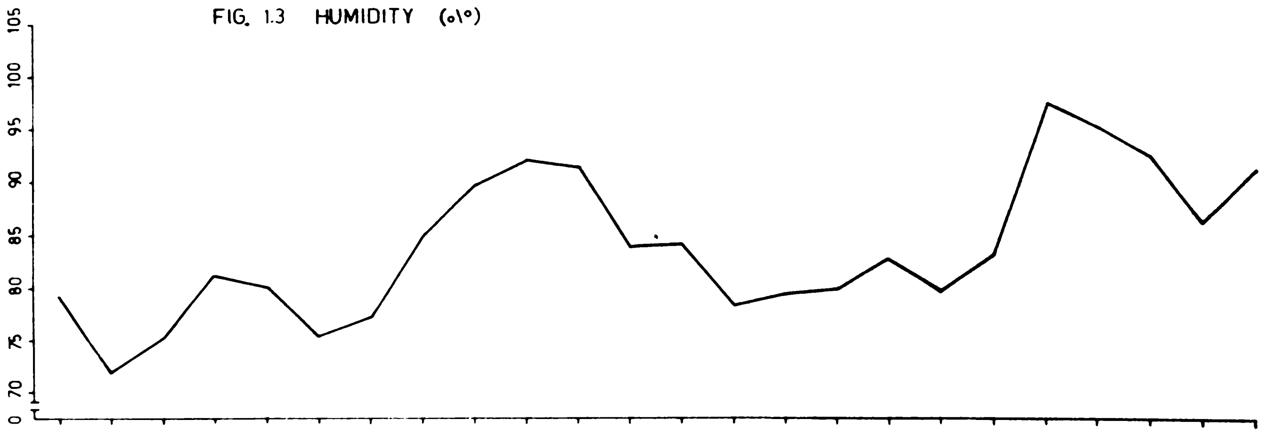


FIG. 1.3 HUMIDITY (%)

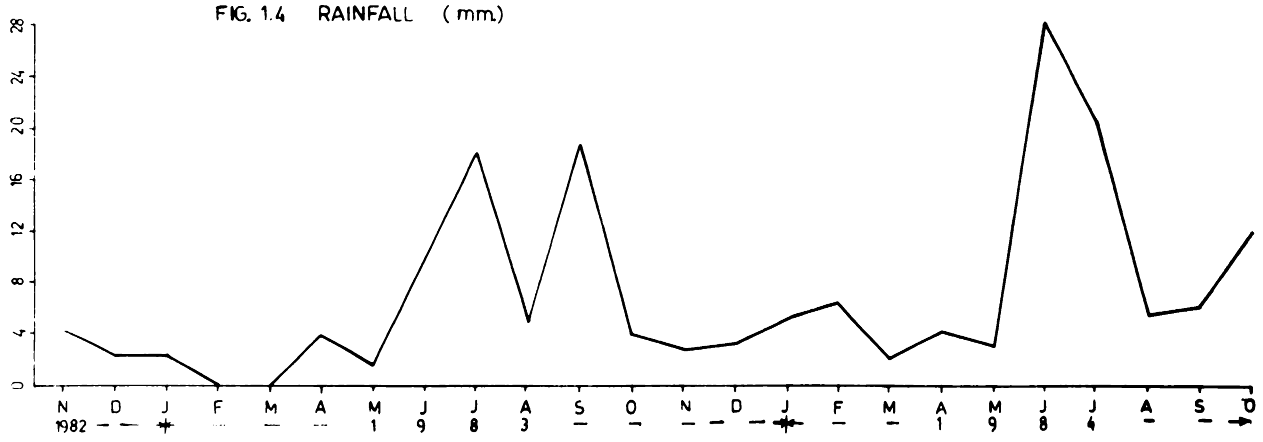


FIG. 1.4 RAINFALL (mm)

described at each station of a particular ecosystem. The values mentioned in the text, though almost similar at all stations, refer to Station I(representing the grow-out ecosystem) and station IV (representing the marine ecosystem). The monthly mean and standard deviation values of all the physicochemical and biological parameters at each station studied during present investigations are given in Table I A_1 to VI G_2. The research data of seasonal variation study was statistically analysed at Regional Computer Centre, Chandigarh to see if any significant correlations* exist amongst various parameters. The correlations with 'r' value equal to or more than 0.28 were found to be significant. The 'significant' correlations mentioned in the text should be taken as significant at all the three research stations of the particular ecosystem. The correlation values of various physicochemical parameters of the grow-out ecosystem are given in Table VII A, VII B & VII C (station I); VIII A, VIII B and VIII C(Station II); and IX A, IX B and IX C(station III). The correlation values of the various physicochemical parameters of the marine ecosystem are given in the table X A, X B and X C (station IV); XI A, XI B and XI C (station V); and XII A, XII B and XII C (station VI).

---

* Positive correlations means that the rate of increase/ decrease of two parameters is directly proportional to each other.

* Negative correlation means that the rate of increase/ decrease of two parameters is inversely proportional to each other.

PHYSICOCHEMICAL AND BIOLOGICAL PARAMETERS IN THE GROW-OUT ECOSYSTEM (Edavanakadu, Vypeen Island).

PHYSICOCHEMICAL PARAMETERS OF WATER*

The results of the data on temperature, pH, Eh and dissolved oxygen are given in Figures 2.1, 2.4 and 2.7

TEMPERATURE

Temperature values of water were high from November '82 to May 1983 (30.05 to 31.50°C) and subsequently, low values were recorded upto October '83(27.00 to 28.80°C). In the subsequent year too, values were low from July '84 to September '84 and minima were noticed in June '83 (27.00°C) and September '84 (28.25°C). Temperature showed significant positive correlation with salinity, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment. It depicted significant negative correlation with rainfall, pH, net primary productivity, nitrite, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

DISSOLVED OXYGEN

Dissolved oxygen concentration was relatively low from early monsoon to late monsoon period (May to October) but for the month of July in both 1983(2.99 to 3.47 ml/l)

---

*For correlation values see table VII A(station I), VIII A(station II) and IX A(station III).

PHYSICOCHEMICAL PARAMETERS (WATER)
STATION I

FIG. 2.1

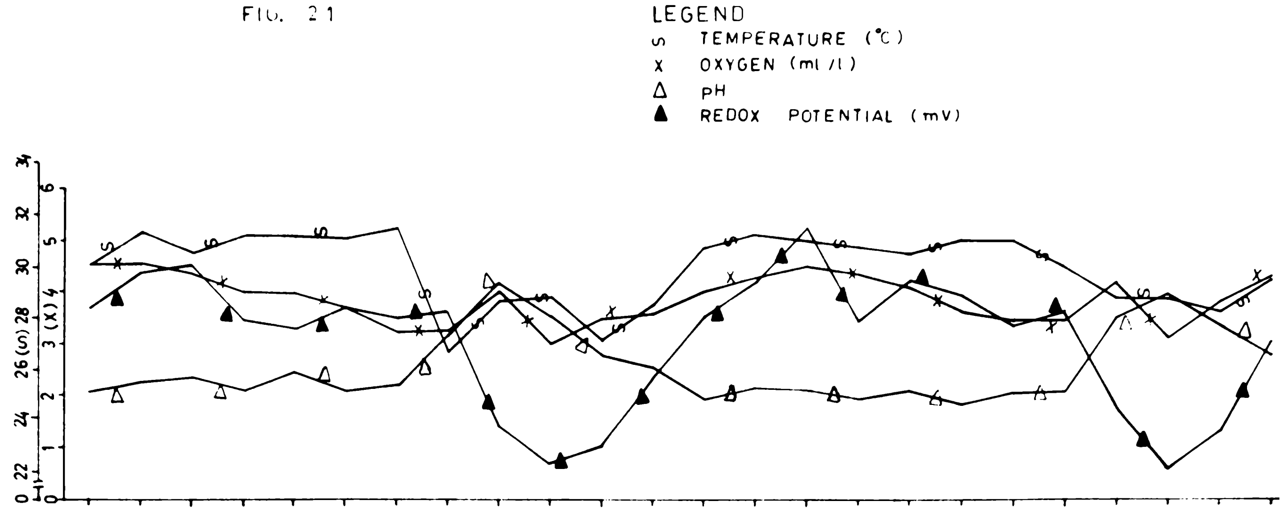


FIG. 2.2

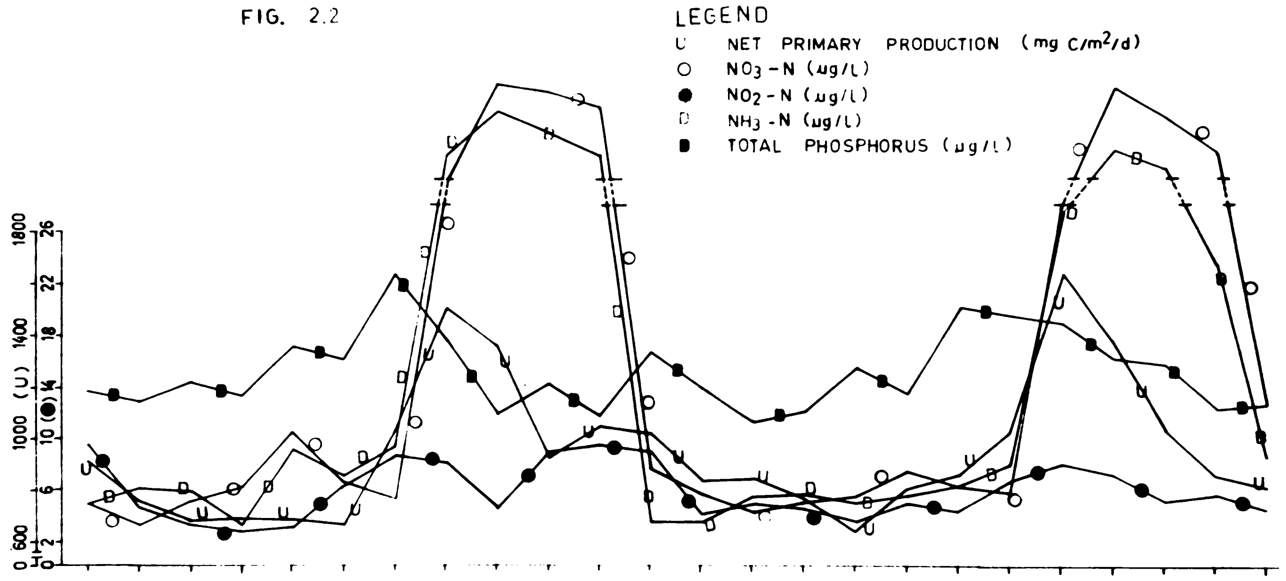
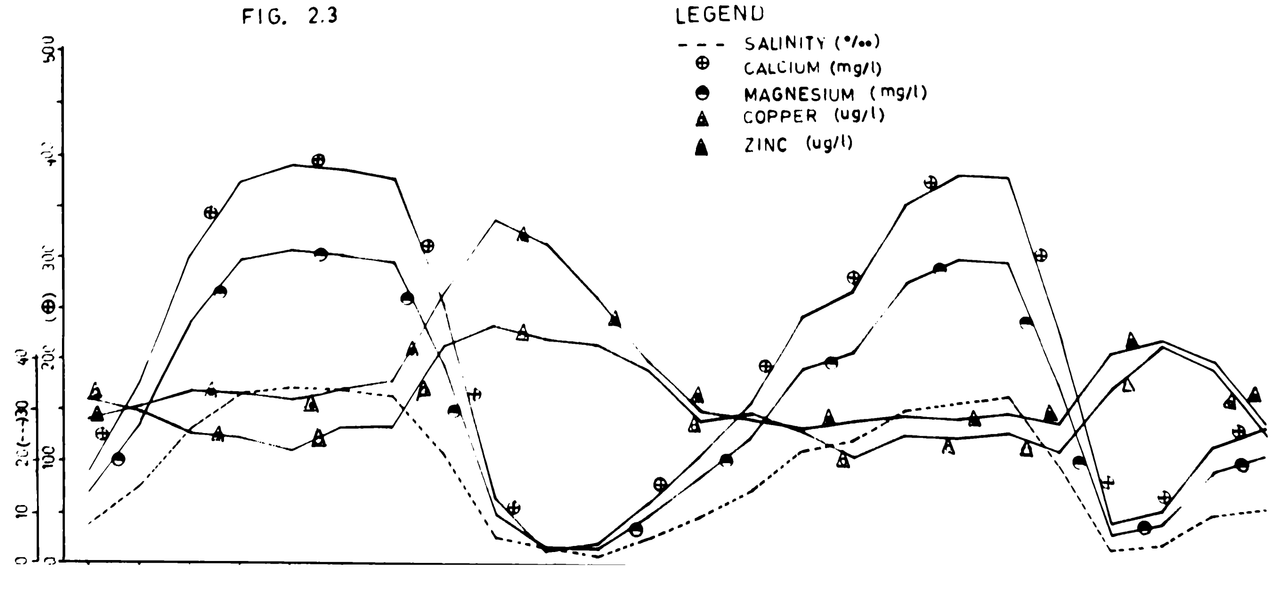


FIG. 2.3



PHYSICOCHEMICAL PARAMETERS (WATER)
STATION II

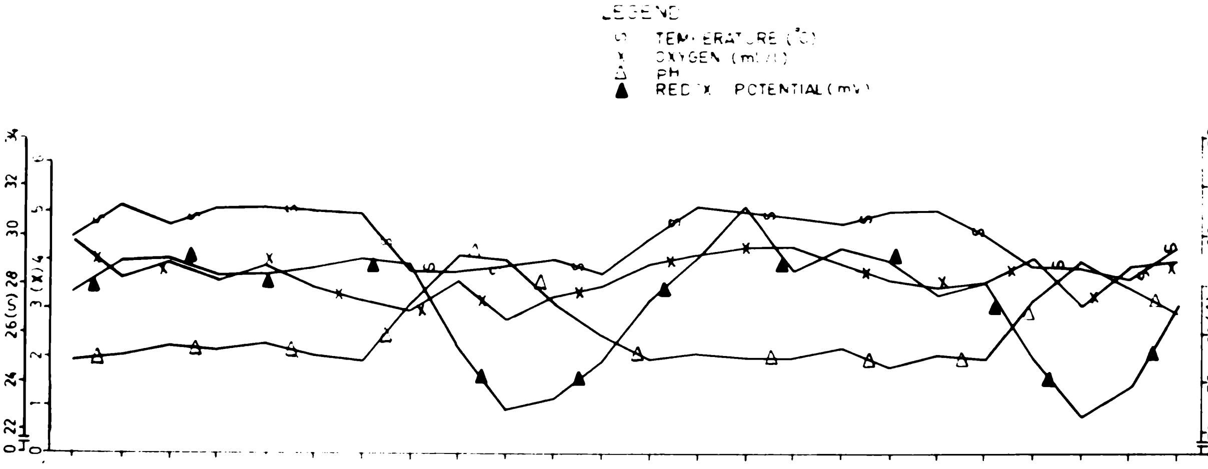


FIG. 2.5

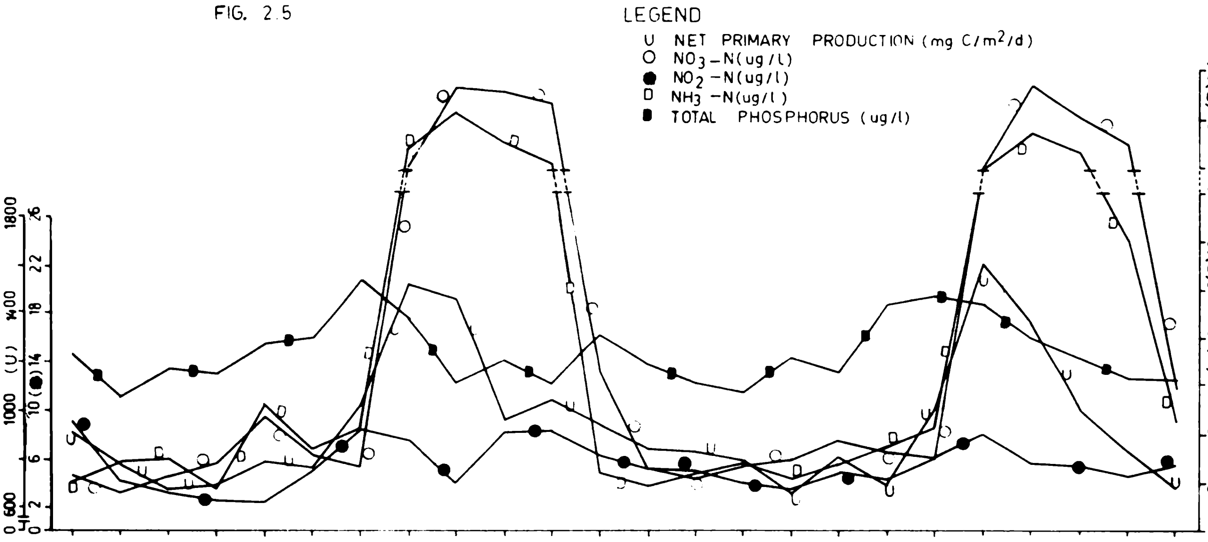
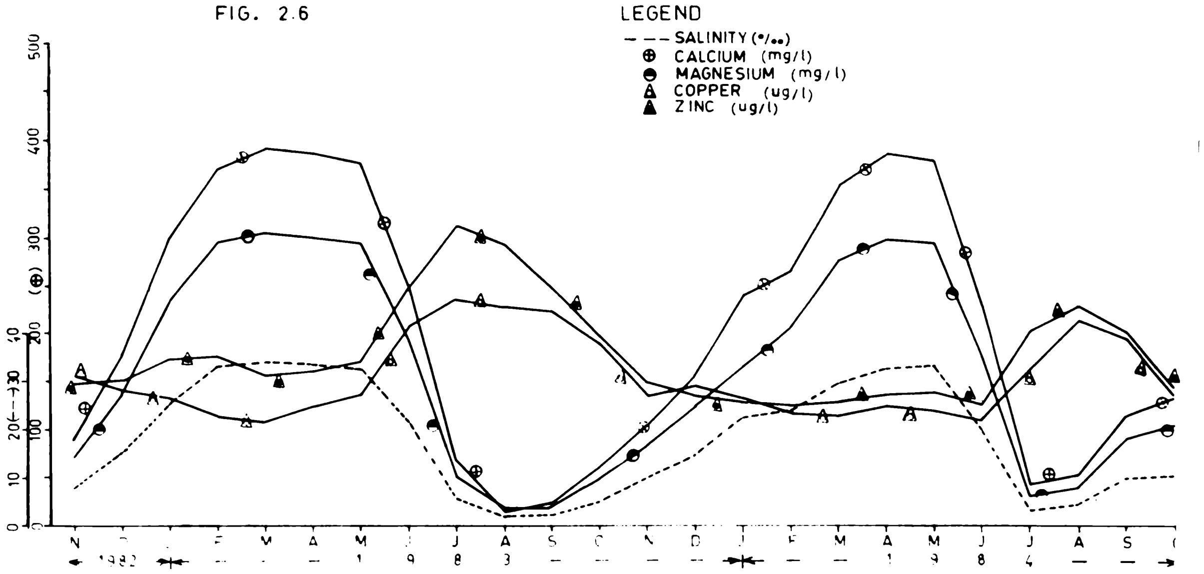


FIG. 2.6



PHYSICOCHEMICAL PARAMETERS (WATER)
STATION III

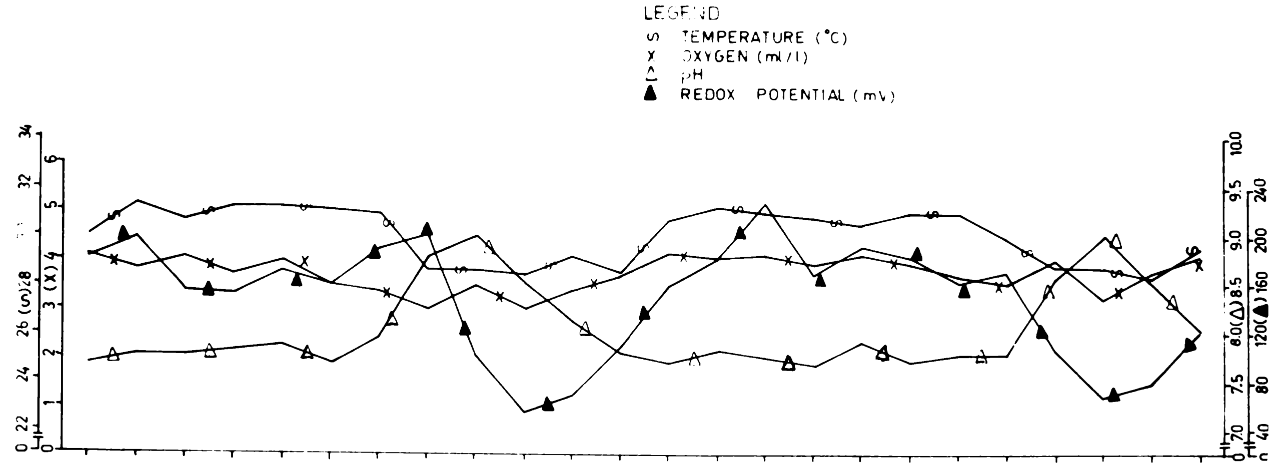


FIG. 2.8

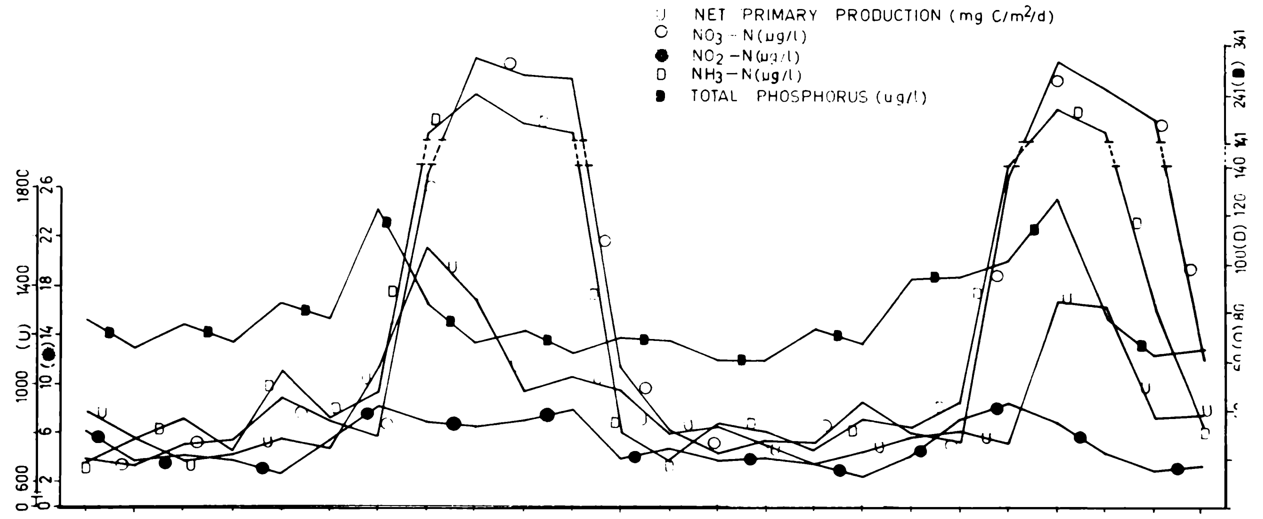
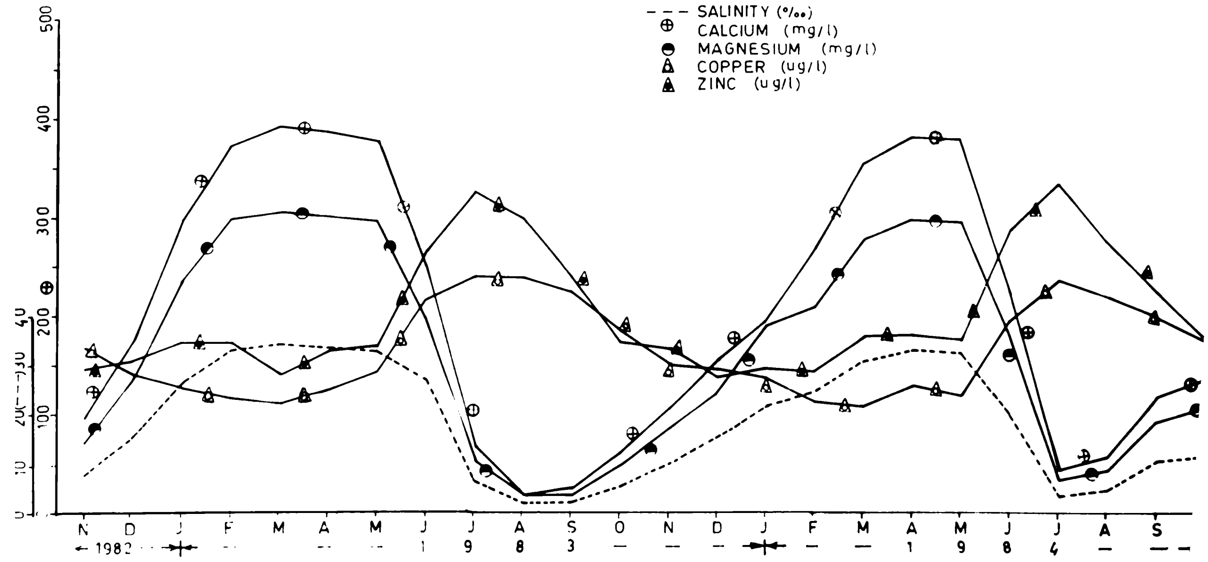


FIG. 2.9



and 1984 (3.11 to 3.80 ml/l). Values ranged between 3.65 to 4.53 ml/l during rest of the study period. It exhibited significant positive correlation with net primary productivity, nitrite, ammonia, total phosphorus, copper and zinc of water; and with phosphorus of sediment.

HYDROGEN ION CONCENTRATION (pH)

pH remained less than 7.97 from November '82 to May '83, and from November '83 to June '84 but higher values were recorded during monsoon and post-monsoon period [i.e. from June to October '83 (8.02 to 8.82) and from July to October '84 (8.12 to 8.71)]. The maxima were noticed in July '83 (8.82) and August '84 (8.72). pH has significant positive correlation with rainfall, net primary productivity, nitrate, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment. It showed significant negative correlation with temperature, salinity, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

REDOX-POTENTIAL (Eh)

Eh values were less than 90 mV during monsoon period (i.e. from July to September) and minima of 47 and 42 mV was observed in August month each of 1983 and 1984 respectively. The values ranged between 142 to 230 mV except October '83 (115 mV) in rest of the study period.

Redox-potential observed significant positive correlation with temperature, salinity, dissolved oxygen, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment. The values showed significant negative correlation with rainfall, pH, net primary productivity, nitrate, ammonia, copper and zinc of water; and with total phosphorus, copper and zinc of sediment.

The results of the data on net primary productivity, nitrate, nitrite, ammonia and total phosphorus are presented in Figures 2.2, 2.5 and 2.8

NET PRIMARY PRODUCTIVITY

Net primary productivity values were more than 1350 $mgC/m^2/d$ during monsoon period (i.e. June and July) in both the years and maxima of 1497 and 1625 $mgC/m^2/d$ were recorded in June month each of 1983 and 1984 respectively. Values for all other months fluctuated between 628 to 1040 $mgC/m^2/d$. It showed significant positive correlation with rainfall, pH, nitrate, nitrite, ammonia, copper and zinc of water; and with pH and total phosphorus of sediment. The values depicted significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature and Eh of sediment.

NITRATE

Nitrate concentration was more during monsoon and post-monsoon period (i.e. June to September) in both the years, and maxima of 323 and 317 µg/l were noticed in July '83 and July '84 respectively. Nitrate values fluctuated between 21 to 62 µg/l for all other months of the study period. It showed significant positive correlation with rainfall, pH, net primary productivity, nitrate, ammonia, copper and zinc of water. It has significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

NITRITE

Nitrite content showed minor variation and fluctuated between 2.9 to 9.5 µg/l from November '82 to October '84 and no seasonal trend was observed. It exhibited significant positive correlation with rainfall, net primary productivity, nitrate and copper of water. It depicted significant negative correlation with temperature, salinity, dissolved oxygen, calcium and magnesium of water; and with temperature of sediment.

AMMONIA

Ammonia values were high ($>$ 116 µg/l) during monsoon period (i.e. June to September) in both the years and maxima of 268 and 195 µg/l were noticed in July month each of 1983 and 1984 respectively. The values recorded for other months varied between 16 to 46 µg/l. Ammonia depicted significant positive correlation with rainfall, pH, net primary productivity, nitrate, copper and zinc of water; and with pH, total phosphorus and copper of sediment. It showed significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature of sediment.

TOTAL PHOSPHORUS

Total phosphorus showed fluctuating values but relatively higher values were recorded in May (113 µg/l) and June (87 µg/l) of 1983, and in April (99 µg/l), May (96 µg/l) and June (93 µg/l) of 1984. The values in rest of the period ranged between 55 to 85 µg/l. It depicted significant positive correlation with salinity, calcium and magnesium of water; and with calcium and magnesium of sediment. It showed significant negative correlation with dissolved oxygen of water; and with copper and zinc of sediment.

The results of the data on salinity, calcium, magnesium, copper and zinc are presented in Figures 2.3, 2.6 and 2.9

SALINITY

Salinity increased from November '82 (7.5‰) to February '83 (33‰) and thenceforth, remained steady upto May

(32.5‰) followed by a uniform sharp decrease during monsoon period (5.5‰ in July). Subsequently, it showed a minor decrease upto September and thereafter, increased gradually to a maximum value of 32.5‰ in May '84 followed by a sharp uniform decrease to 3.5‰ by July (monsoon period). Thereupon, it increased gradually to 11.5‰ by October '84. Salinity exhibited significant positive correlation with temperature, Eh, total phosphorus, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment. It depicted significant negative correlation with rainfall, pH, net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

CALCIUM

Calcium concentration increased from November '82 (90 mg/l) to February '83 (372 mg/l) and after that, varied a little upto May (375 mg/l). Subsequently, it decreased during monsoon to a minimum value in August (15 mg/l). In the subsequent year too, calcium values were high from February to May. Thereafter, it sharply decreased during monsoon to 42 mg/l (July) followed by a gradual increase to 135 mg/l by October. Calcium showed significant positive correlation with temperature, salinity, Eh, total phosphorus and magnesium of water; and with magnesium of sediment. It exhibited significant negative correlation with rainfall, pH, net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

MAGNESIUM

Magnesium increased from November '82 (280 mg/l) to February '83 (1190 mg/l) and thereafter, the level varied a little upto May (1178 mg/l). Subsequently, it decreased during monsoon to a minimum value of 72 mg/l in August. In the subsequent year too, low magnesium values were recorded during monsoon period (130 mg/l in July '84) followed by a gradual increase to 423 mg/l by October. Magnesium showed significant positive correlation with temperature, salinity, Eh, total phosphorus and calcium of water; and with temperature, calcium and magnesium of sediment. It depicted significant negative correlation with rainfall, pH, net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

COPPER

Copper values were high during monsoon and post-monsoon period [i.e. from June to October (7.50 to 9.30 µg/l) in 1983, and from July to September (6.93 to 8.62 µg/l) in 1984] and maxima occurred in July '83 (9.30 µg/l) and

August '84 (8.62 µg/l). Values of copper varied between 4.18 to 5.98 µg/l except November (6.36 µg/l) in rest of the study period. Copper showed significant positive correlation with pH, net primary productivity, nitrate, nitrite, ammonia and zinc of water; and with pH, total phosphorus, copper and zinc of sediment. It depicted significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

ZINC

Zinc depicted increased values during monsoon and post-monsoon period [i.e. from June to October (7.92 to 13.35 µg/l) in 1983, and from July to September (7.97 to 8.84 µg/l) in 1984] and maximum values of 13.35 and 8.84 µg/l were recorded in July '83 and August '84 respectively. It varied between 5.30 to 7.10 µg/l during all other months of study. Zinc has shown significant positive correlation with pH, net primary productivity, nitrate, ammonia and copper of water; and with pH, total phosphorus, copper and zinc of sediment. It depicted significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

PHYSICOCHEMICAL PARAMETERS OF SEDIMENT*

The results of the data on temperature, pH and Eh are given in Figures 3.1, 3.3 and 3.5

TEMPERATURE

Temperature recorded during monsoon and post monsoon period was low and varied a little from June (29.20°C) to October '83 (29.05°C), and from July to October '84. It was relatively high and depicted minor fluctuations in rest of the period (30.82 to 31.90°C). Temperature has shown significant positive correlation with salinity, Eh, calcium and magnesium of water; and with calcium and magnesium of sediment. It depicted significant negative correlation with rainfall, pH, net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

HYDROGEN ION CONCENTRATION (pH)

pH values remained low alkaline from November to May but high alkaline values were recorded during monsoon in both the years [i.e. during June (7.82), July (8.10) and August (7.82) in 1983; and during July (7.87), August (8.02) and September (7.90) in 1984]. The values fluctuated between 7.32 to 7.77 in rest of the period. pH showed

---

*For correlation values see table VII A(station I), VIII A (station II) and IX A(station III)

PHYSICOCHEMICAL PARAMETERS (SEDIMENT)

STATION I

FIG. 3.1

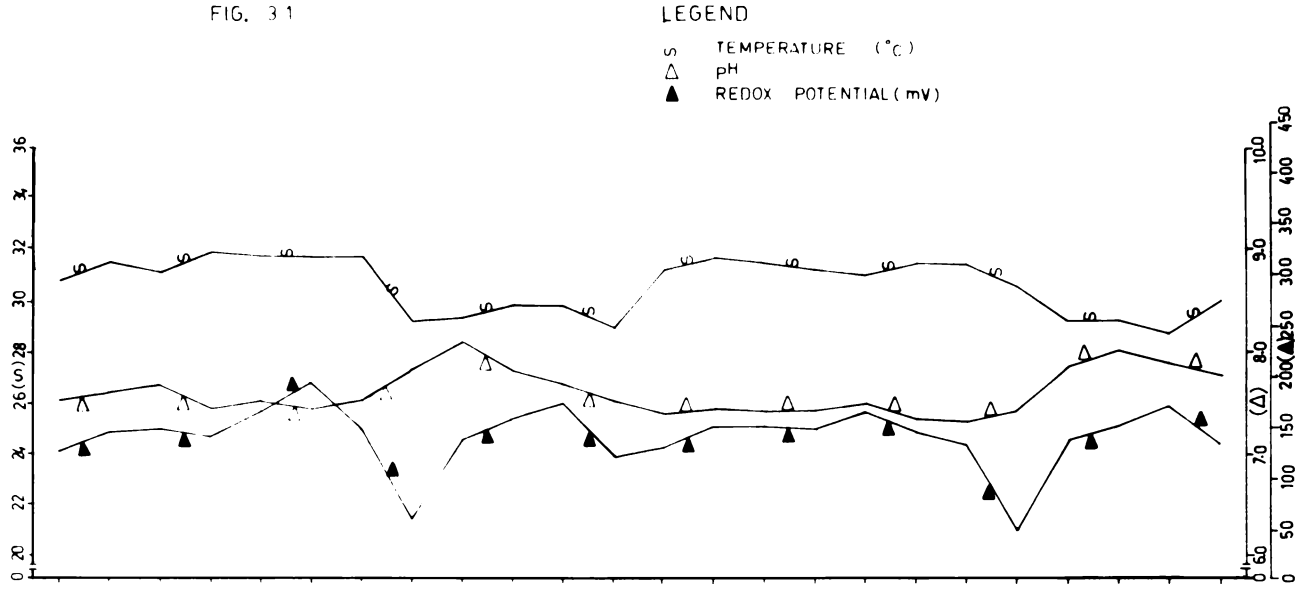
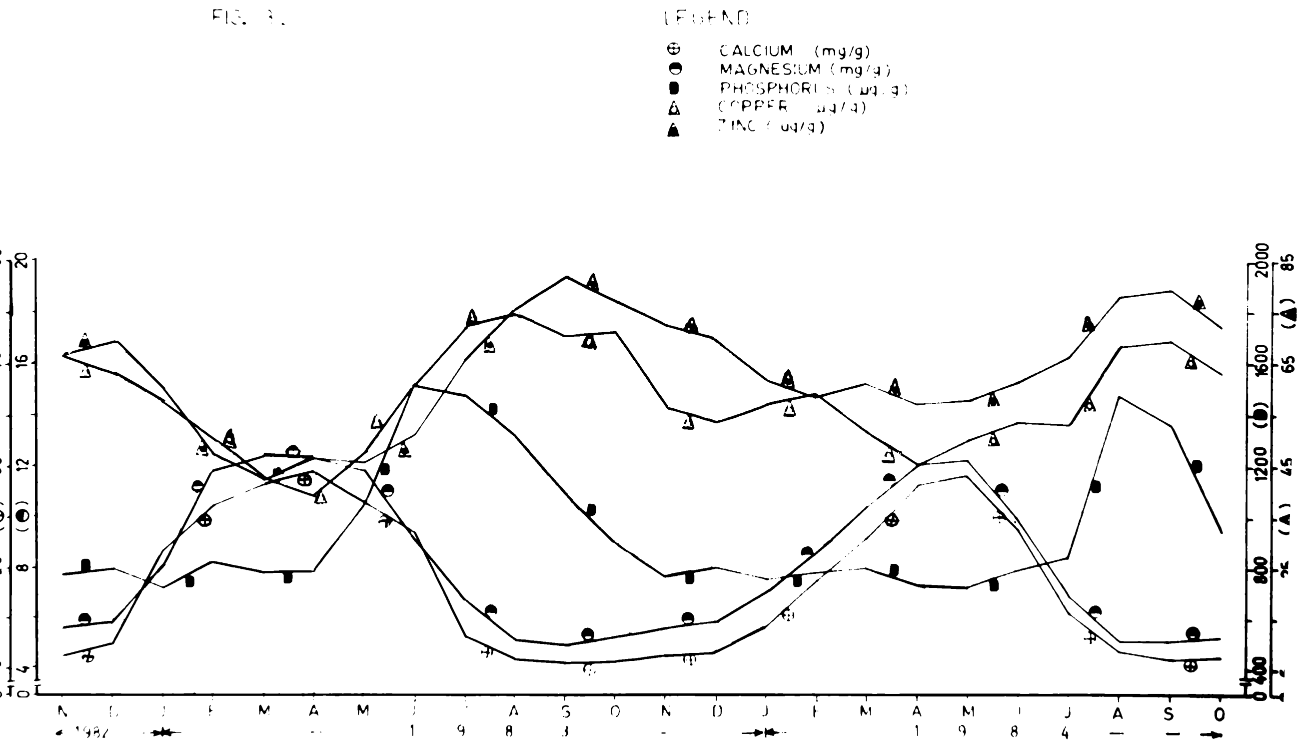


FIG. 3.2



PHYSICOCHEMICAL PARAMETERS (SEDIMENT)
STATION II

FIG. 3.3

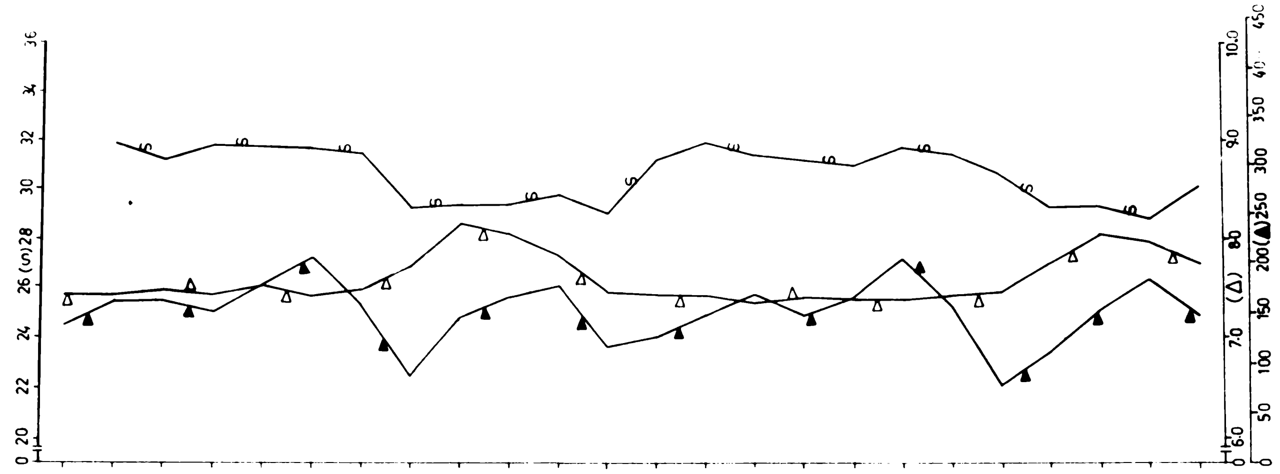
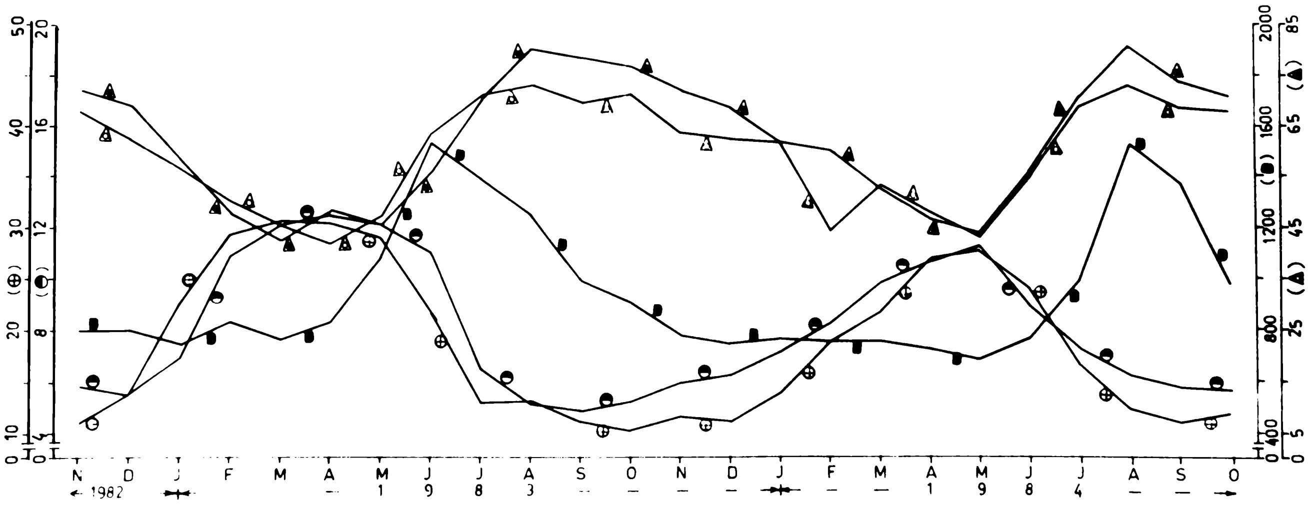


FIG. 3.4



PHYSICOCHEMICAL PARAMETERS (SEDIMENT)
STATION III

FIG. 3.5

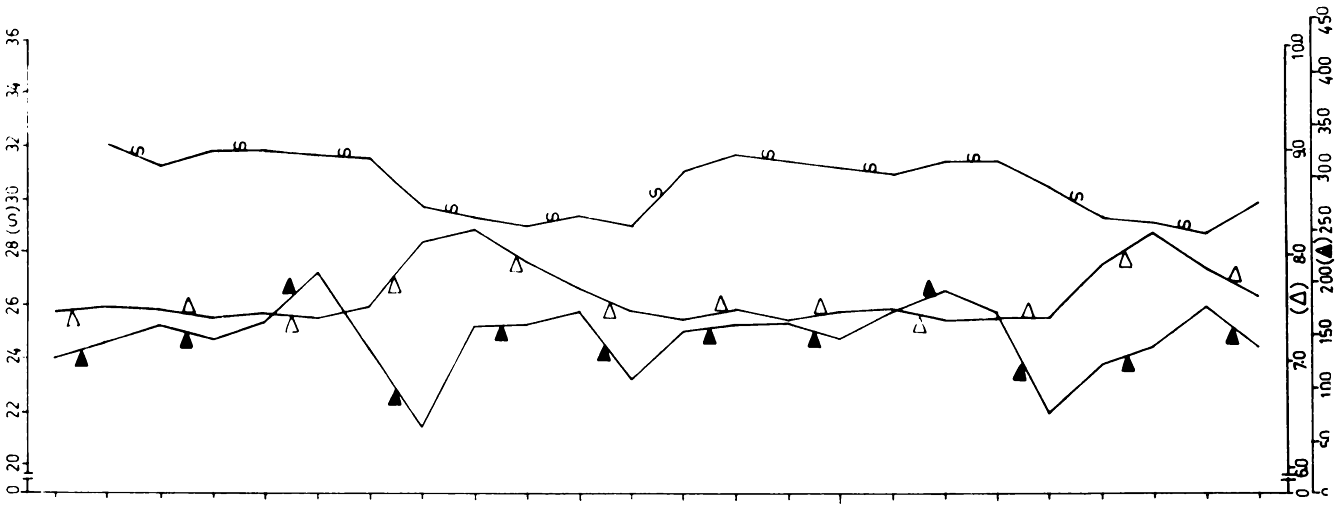
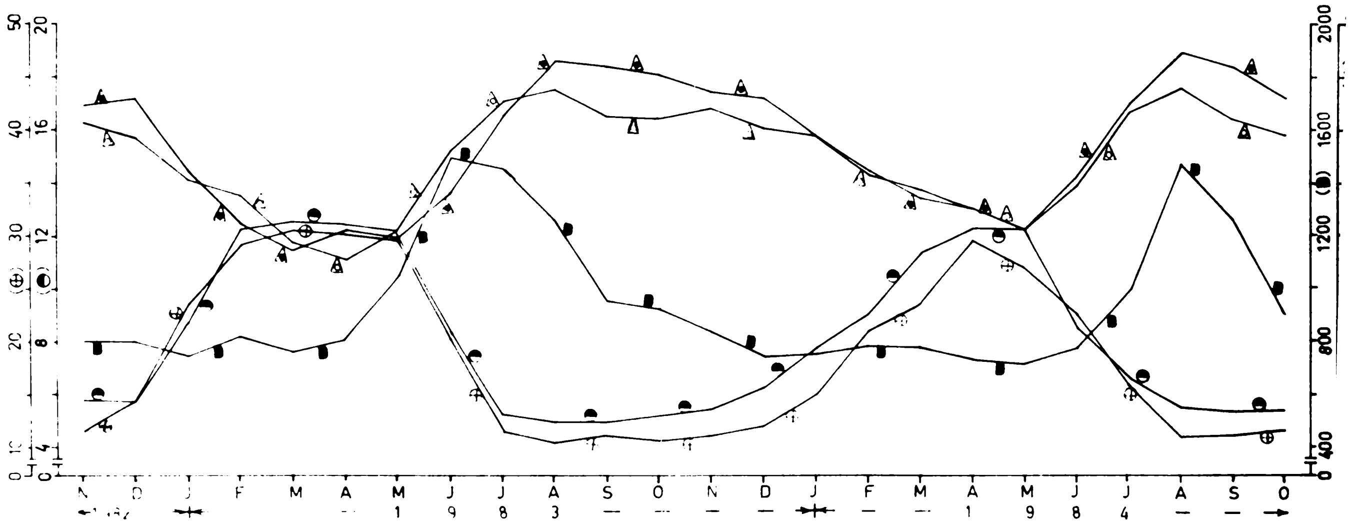


FIG. 3.6



significant positive correlation with rainfall, pH, net primary productivity, nitrate, ammonia, copper and zinc of water; and with total phosphorus, copper and zinc of sediment. It depicted significant negative correlation with temperature, salinity, Eh, calcium and magnesium of water; and with calcium and magnesium of sediment.

REDOX POTENTIAL (Eh)

Eh values fluctuated between -122 to -172 mV during both the years except for a high value in April '83 (-195 mV) and low values of -60 and -50 mV during early monsoon (June) of 1983 and 1984 respectively. It exhibited significant negative correlation with rainfall and net primary productivity of water.

The results of the data on calcium, magnesium, total phosphorus, copper and zinc are presented in Figures 3.2, 3.4 and 3.6

CALCIUM

Calcium concentration showed continuous increase from 11.25 (November '82) to 29.50 mg/g (April '83) and subsequently, decreased to 11.80 mg/g by August. Thereafter, it varied little upto December (11.50 mg/g). In the next year too, higher values recorded in April (28.00 mg/g) and

May (29.00 mg/g) decreased subsequently to 11.75 mg/g in August followed by little variation upto October (11.25 mg/g). Calcium depicted significant positive correlation with temperature, salinity, redox-potential, total phosphorus, calcium and magnesium of water and with temperature and magnesium of sediment. It showed significant negative correlation with nitrate and copper of water; and with pH, total phosphorus, copper and zinc of sediment.

MAGNESIUM

The values of magnesium increased from 5.60(November '82) to 12.40 mg/g in March '83 which varied little upto May (11.90 mg/g). Subsequently, it uniformly decreased during monsoon months (5.15 mg/g in August) and remained low upto December. In the subsequent year too, high values were recorded in April (12.10 mg/g) and May (12.20 mg/g). Magnesium showed significant positive correlation with temperature, salinity, Eh, total phosphorus, calcium and magnesium of water; and with temperature and calcium of sediment. It depicted significant negative correlation with pH, nitrate, copper and zinc of water; and with pH, total phosphorus, copper and zinc of sediment.

TOTAL PHOSPHORUS

High values of total phosphorus were recorded from May to October '892 to 1515 µg/g) in 1983 and from July to

October (840 to 1474 µg/g) in 1984. Values were low and fluctuated between 717 to 801 µg/g except February '83 (821 µg/g) in rest of the study period. Total phosphorus showed significant positive correlation with pH, net primary productivity, nitrite, ammonia, copper and zinc of water; and with pH, copper and zinc of sediment. It exhibited significant negative correlation with temperature, salinity, dissolved oxygen, Eh, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

COPPER

High values of copper were noticed in November '82 (66.63 µg/g), December '82 (63.31 µg/g), from June to October (60.79 to 74.72 µg/g) in 1983, and from August to October (62.51 to 69.50 µg/g) in 1984. The maximum level was seen in August 1983 (74.72 µg/g) and September '84 (69.50 µg/g). The values fluctuated between 39.42 to 59.04 µg/g in rest of the study period. Copper depicted significant positive correlation with pH, nitrate, ammonia, copper and zinc of water; and with pH, nitrate, ammonia, copper and zinc of water; and with pH, total phosphorus and zinc of sediment. It exhibited significant negative correlation with temperature, salinity, Eh, total phosphorus, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

ZINC

Zinc concentrations observed were in low profile from January to June (42.54 to 61.72 µg/g) in both the years of study; but relatively higher values were recorded during November '82 (86.70 µg/g), December '82 (69.55 µg/g), from July to December (65.42 to 81.52 µg/g) in 1983, and from July to October (65.97 to 79.29 µg/g) in 1984. Zinc has exhibited significant positive correlation with nitrate, copper and zinc of water; and with pH, total phosphorus and copper of sediment. It has shown significant negative correlation with temperature, salinity, pH, Eh, total phosphorus, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment.

BIOELEMENTS IN VARIOUS TISSUES OF MALE P. INDICUS*

CALCIUM

The results of the data on calcium in haemolymph, exoskeleton, muscle, hepatopancreas and testis are presented in Figures 4.1, 4.2 and 4.3

HAEMOLYMPH

Calcium concentration of haemolymph increased from 0.405 mg/ml (November 1982) to 0.755 mg/ml in March 1983

---

* For correlation values see table VII B, VII C (station I); VIII B, VIII C(station II); IX B, IX C (station III).

followed by a little decrease upto May. Subsequently, it sharply decreased to 0.395 mg/ml in September and thereafter, little variation occurred upto December. In the subsequent year too, low values were recorded during monsoon period. Haemolymph calcium depicted significant positive correlation with salinity of water; and calcium of water, sediment, muscle, hepatopancreas and testis.

EXOSKELETON

Calcium concentration of exoskeleton remained high and varied between 106 to 119 mg/g from November 1982 to May 1983 but for March 1983 (99 mg/g). Subsequently, relatively decreased values were found during June (94 mg/g), July (91 mg/g) and August (102 mg/g) only. In the subsequent year too, decreased values were recorded during monsoon period. Exoskeletal calcium depicted significant positive correlation with salinity and calcium of water.

MUSCLE

Calcium concentration of muscle increased gradually from 3.129 (November 1982) to 4.389 mg/g in May 1983 except for a decreased value in March 1983. Thereupon, it decreased to 3.098 mg/g by September followed by little variation upto December. In the next year too, calcium values decreased during monsoon and late monsoon period only. It exhibited

LEGEND

FROM FIG. 4·1 TO 4·3

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

CALCIUM IN ♂ PENAEUS INDICUS

FIG. 4.1 STATION I

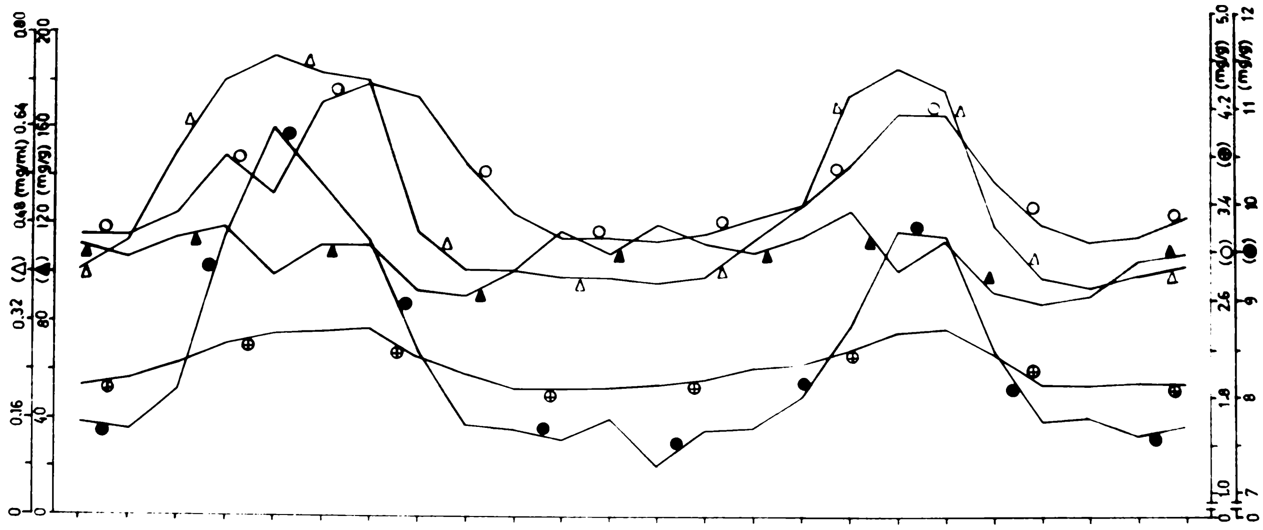


FIG. 4.2 STATION II

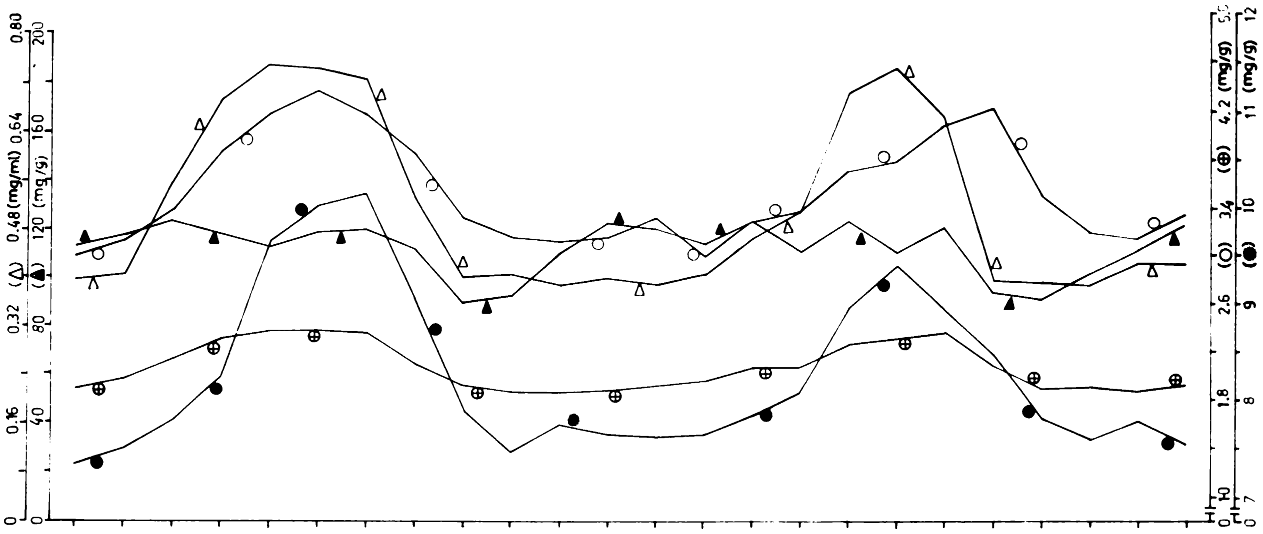
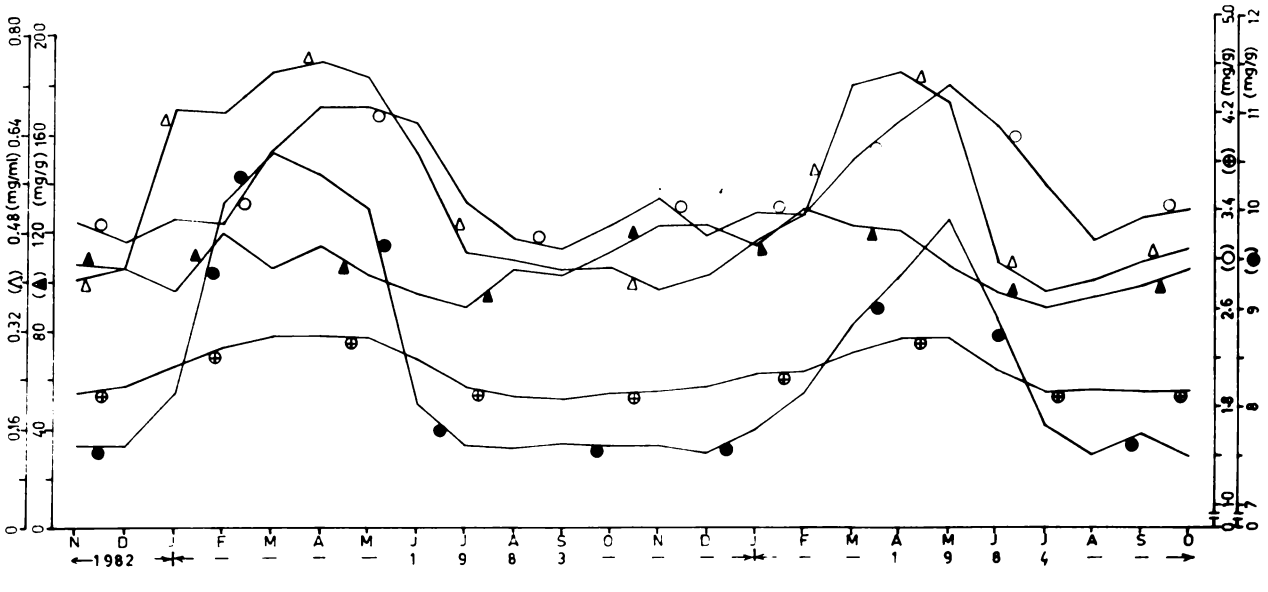


FIG. 4.3 STATION III



significant positive correlation with salinity of water; and calcium of water, sediment, haemolymph, hepatopancreas and testis.

HEPATOPANCREAS

Calcium values of hepatopancreas remained relatively low(8.484 to 9.556 mg/g) except from February to May '83 when high values (9.633 to 10.774 mg/g) were recorded. In the subsequent year too, high values of calcium were recorded from February to June. Hepatopancreatic calcium depicted significant positive correlation with salinity of water; and calcium of water, sediment, haemolymph, muscle and testis.

TESTIS

Calcium concentration increased gradually from 1.872 (November '82) to 2.355 mg/g in May '83 followed by a uniform decrease to 1.861 mg/g by August. Subsequently, it slightly increased to 1.946 mg/g by December. In the subsequent year too, calcium content decreased during monsoon period. Testicular calcium showed significant positive correlation with salinity of water; and calcium of water, sediment, haemolymph, muscle and hepatopancreas.

MAGNESIUM

The results of the data on magnesium in haemolymph, exoskeleton, muscle, hepatopancreas and testis are given in Figures 5.1, 5.2 and 5.3

HAEMOLYMPH

Magnesium concentration increased gradually from 74 (November 1982) to 133 µg/ml in March 1983 followed by minor variation upto May (132 µg/ml). Subsequently, it decreased to 76 µg/ml by August followed by little variation upto October. In the subsequent year too, low values were recorded during monsoon period. Haemolymph magnesium depicted significant positive correlation with salinity of water; and magnesium of water, sediment, exoskeleton, muscle, hepatopancreas and testis.

EXOSKELETON

The concentration of magnesium in exoskeleton remained high and fluctuated between 7325 to 8173 µg/g except for July (6670 µg/g) during the first year of study. In the subsequent year too, exoskeletal magnesium decreased during July(6796 µg/g) and August (6845 µg/g). It exhibited significant positive correlation with salinity of water; and magnesium of water, haemolymph and testis.

LEGEND

FROM FIG. 5·1 TO 5·3

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

MAGNESIUM IN ♂ PENAEUS INDICUS

FIG. 5.1 STATION I

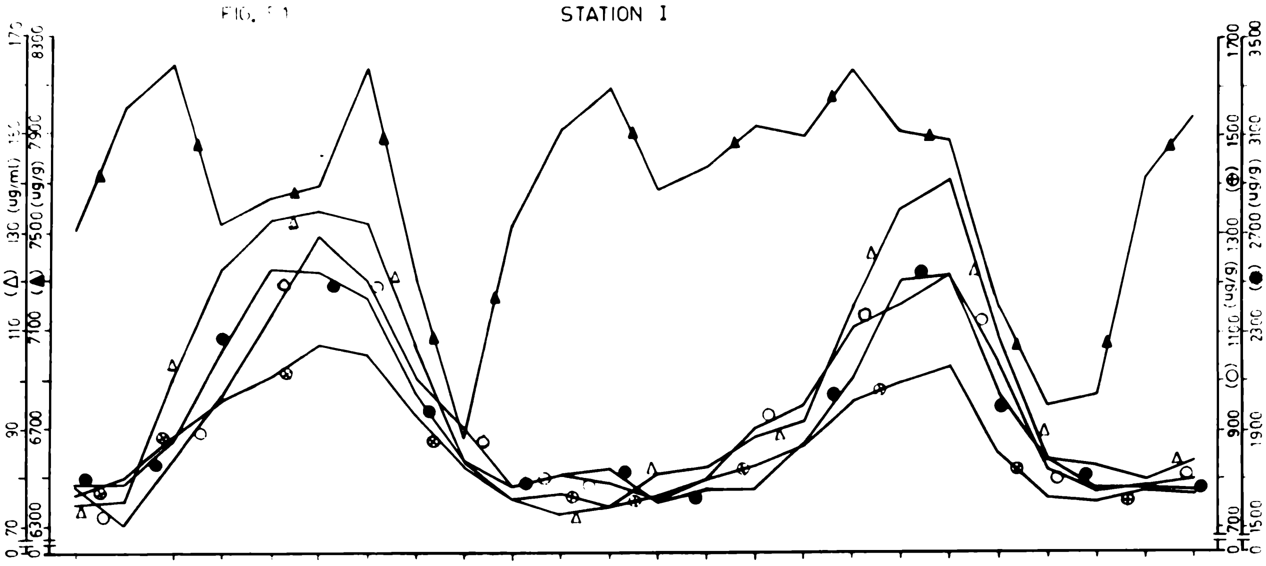


FIG. 5.2 STATION II

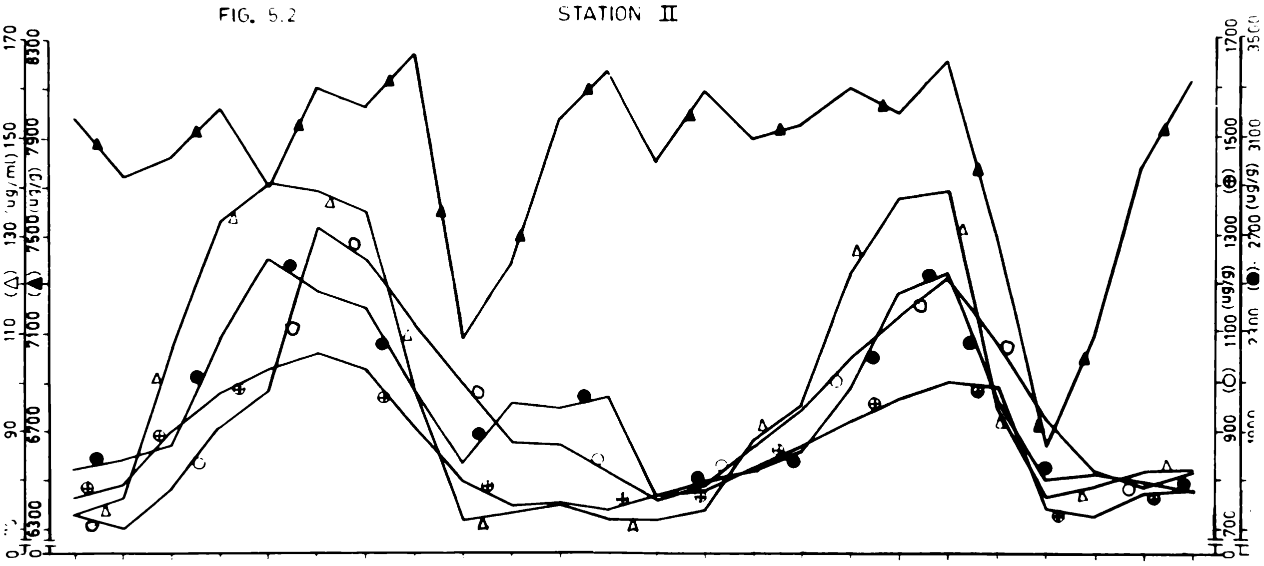
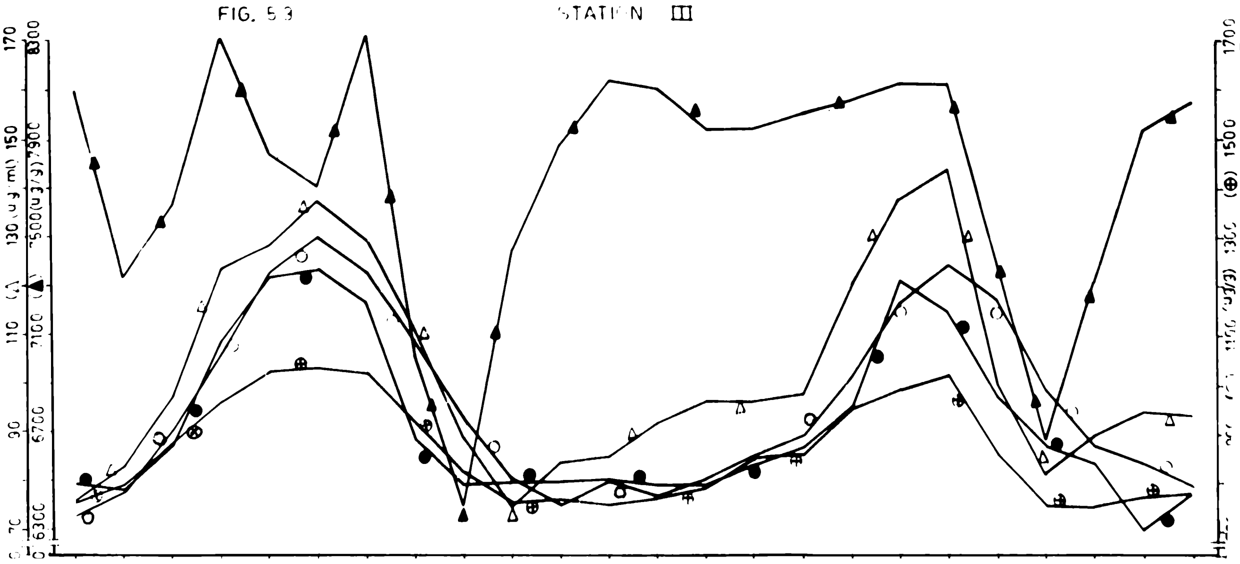


FIG. 5.3 STATION III



MUSCLE

Magnesium level was found to be decreased from 781 µg/g in November '82 to 705 µg/g in December '82 and thereafter, it uniformly increased for rest of the period showing maximum value of 1299 µg/g in April '83 followed by a decrease to 787 µg/g in August. Thereafter, it varied a little upto October (795 µg/g). In the subsequent year too, values decreased during monsoon period. Muscle magnesium showed significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, hepatopancreas and testis.

HEPATOPANCREAS

Magnesium of hepatopancreas varied little during November and December '82 (1663 µg/g) afterwhich, it increased to 2557 µg/g in March '83 followed by a decrease to 2444 µg/g in May. Subsequently, it decreased to 1674 µg/g by August followed by minor variation upto December (1671 µg/g). In the subsequent year too, values decreased during monsoon period. Hepatopancreatic magnesium showed significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, muscle and testis.

TESTIS

Magnesium level of testis increased from 764 µg/g in November '82 to 1074 µg/g in April '83 followed by little variation till May (1056 µg/g). Subsequently, it decreased to 760µg/g by August. Thenceforth, a little variation occurred upto November 1983 (767µg/g). In the following year too, decreased values were noticed during monsoon period. It depicted significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, exoskeleton, muscle and hepatopancreas.

PHOSPHORUS

The results of the data on phosphorus in haemolymph, exoskeleton, muscle, hepatopancreas and testis are given in Figures 6.1, 6.2 and 6.3

HAEMOLYMPH

Haemolymph phosphorus showed low and fluctuating values (39 to 53µg/ml) but for the high concentrations recorded in June 1983 (63µg/ml) and June 1984 (64µg/ml) during the study period.

EXOSKELETON

Exoskeletal phosphorus depicted low values in July 1983 (12004µg/g), July 1984 (11799µg/g) and August 1984 (12142µg/g) but fluctuated from 13789 to 16726µg/g in rest of the study period. It depicted significant positive correlation with salinity of water and phosphorus of testis; and showed significant negative correlation with phosphorus of sediment.

LEGEND

FROM FIG. 6·1 TO 6·3

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

PHOSPHORUS IN ♂ PENAEUS INDICUS

FIG. 6.1

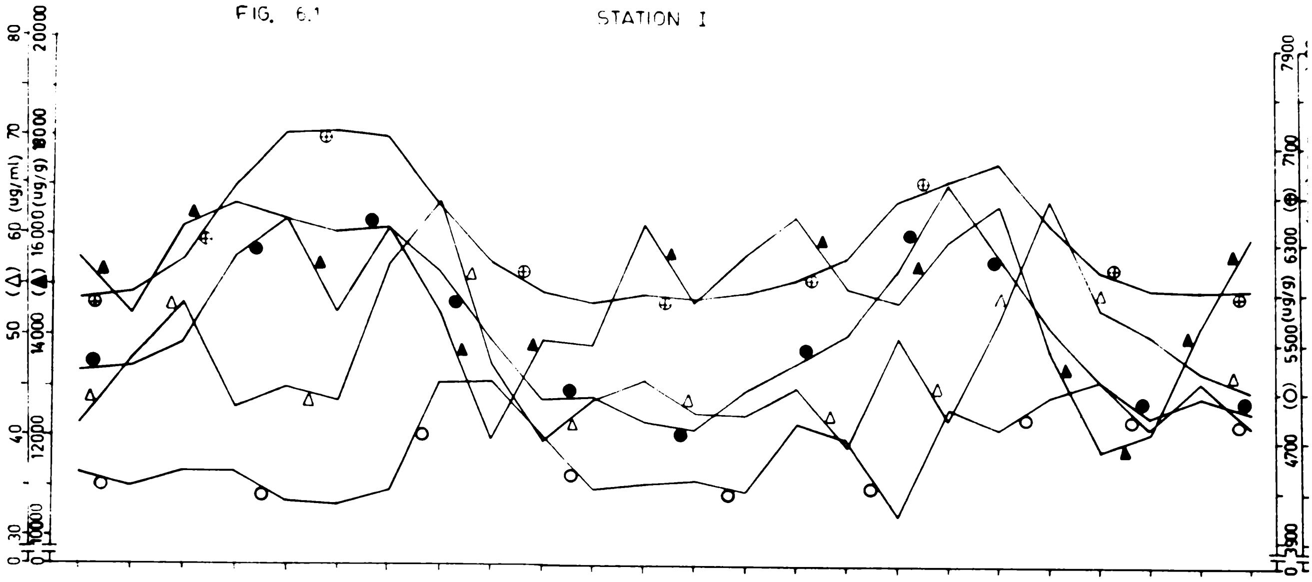

STATION I

FIG. 6.2

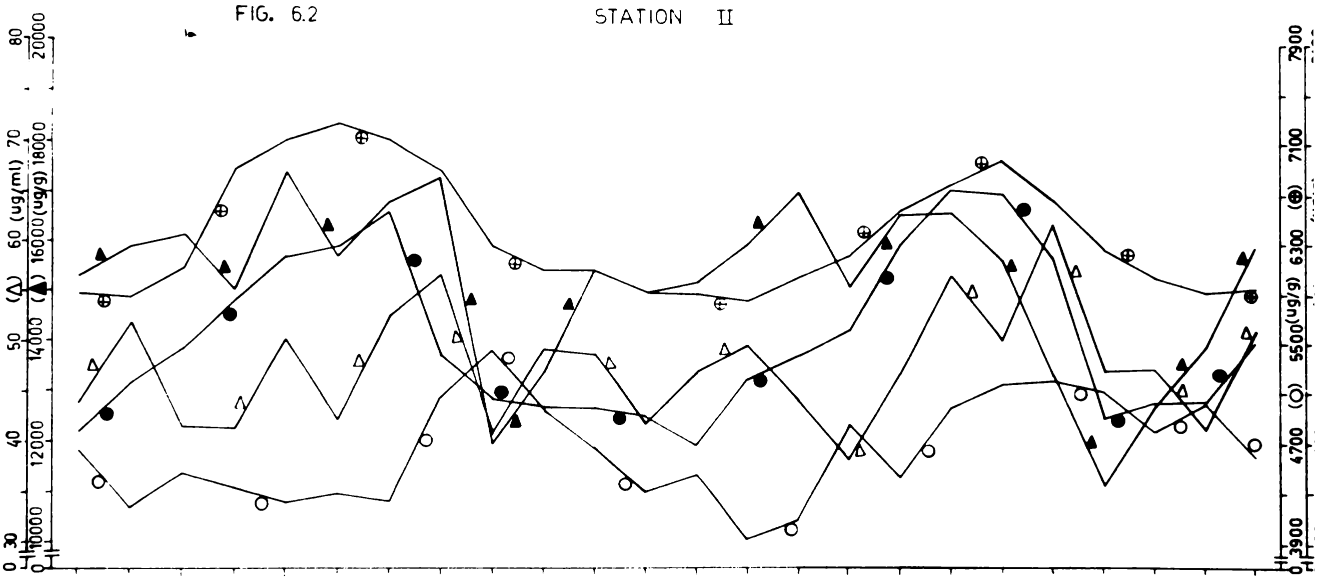
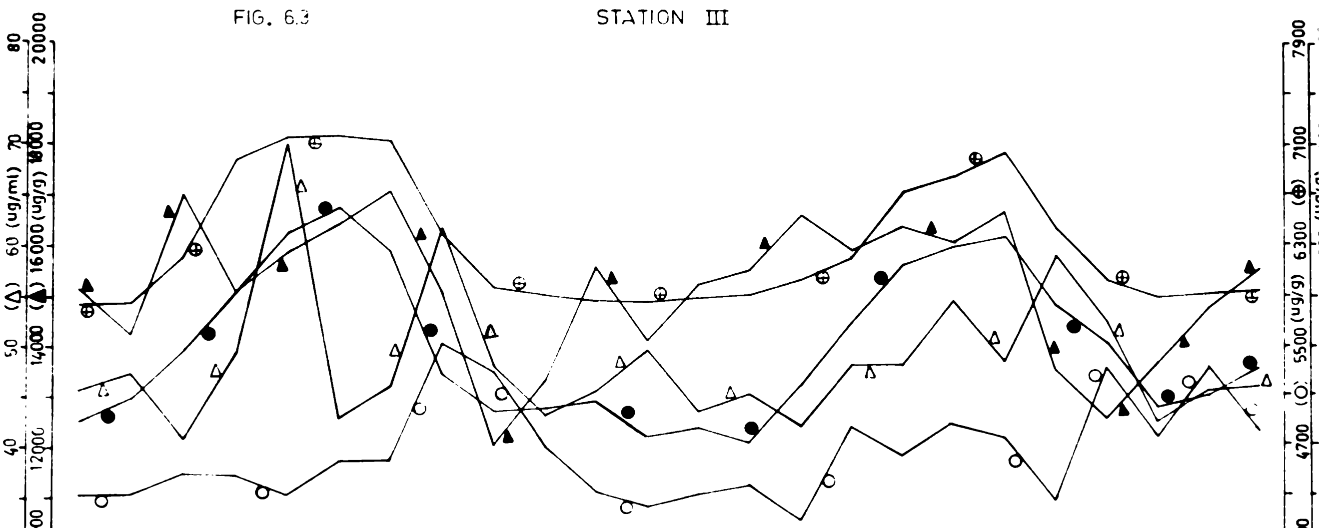

STATION II

FIG. 6.3


STATION III

MUSCLE

High phosphorus values were recorded during June (5154 µg/g) and July (5170 µg/g) in 1983; and during June, July and September in 1984. In rest of the study period, fluctuating and low values were observed. Muscle phosphorus exhibited significant positive correlation with phosphorus of sediment; and significant negative correlation with phosphorus of testis.

HEPATOPANCREAS

Phosphorus values increased from 1278 µg/g in November '82 to 2033 µg/g in March '83 followed by a little decrease upto May (2019 µg/g). Subsequently, it decreased to 1678 µg/g by August followed by minor variation upto December (1699 µg/g). In the subsequent year too, values decreased during monsoon period. Hepatopancreatic phosphorus depicted significant positive correlation with salinity of water; and phosphorus of water, exoskeleton and testis; and showed significant negative correlation with phosphorus of sediment.

TESTIS

Phosphorus of testis increased gradually from 5792 µg/g in November '82 to 7166 ug/g in April '83 and a minor decrease occurred in May (6772 µg/g) followed by a decrease to 5793 µg/g by September '83. Subsequently, it increased to 5874 µg/g by December. In the following year too, values decreased during monsoon period. Phosphorus exhibited significant positive correlation with salinity of water; and phosphorus of water, exoskeleton and hepatopancreas.

COPPER

The results of the data on copper in haemolymph, exoskeleton, muscle, hepatopancreas and testis are given in figures 7.1, 7.2 and 7.3

HAEMOLYMPH

Copper concentrations of haemolymph fluctuated in the range of 106.0 to 115.0 µg/ml from November 1982 to June 1983 and thereafter, increased to 128.4 µg/ml in July followed by a decrease to 112.2 µg/ml by September. In the subsequent year too, high values were recorded in June (120.1 µg/ml), July (128.8 µg/ml) and August (120.7 µg/ml) only. Haemolymph copper showed no significant correlation.

EXOSKELETON

There was a gradual increase in exoskeletal copper concentrations from 15.7 µg/g in November 1982 to 23.2 µg/g in May 1983 followed by a decrease to 14.6 µg/g by July. It increased to 16.9 µg/g in August and thereafter, varied a little upto October. In the subsequent year too, it decreased during monsoon period. Exoskeletal copper depicted significant positive correlation with salinity of water.

LEGEND

FROM FIG. 7·1 TO 7·3

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

COPPER IN ♂ PENAEUS INDICUS

FIG. 7.1 STATION I

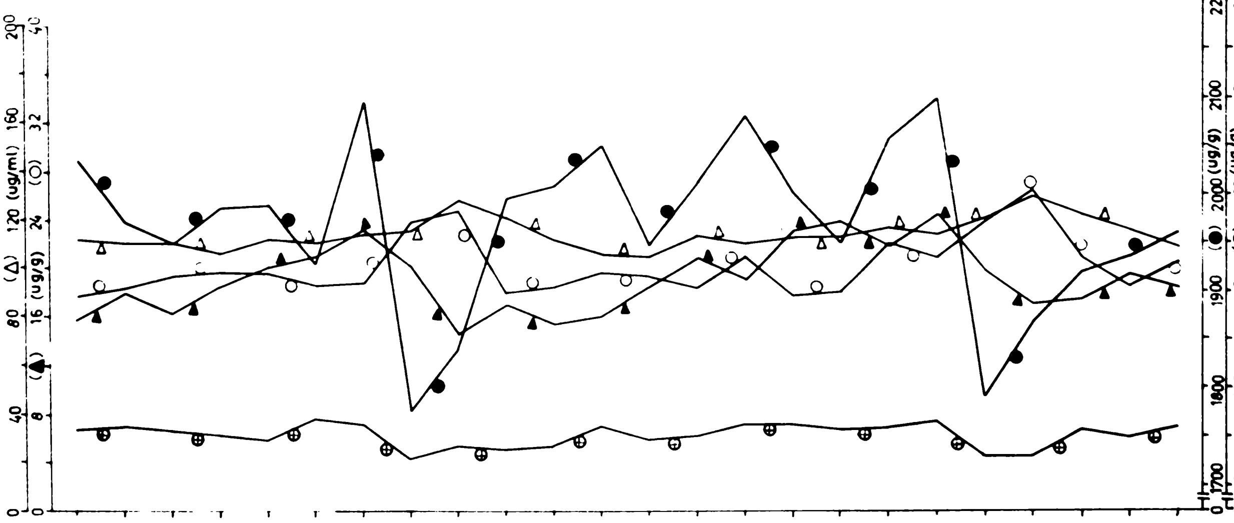


FIG. 7.2 STATION II

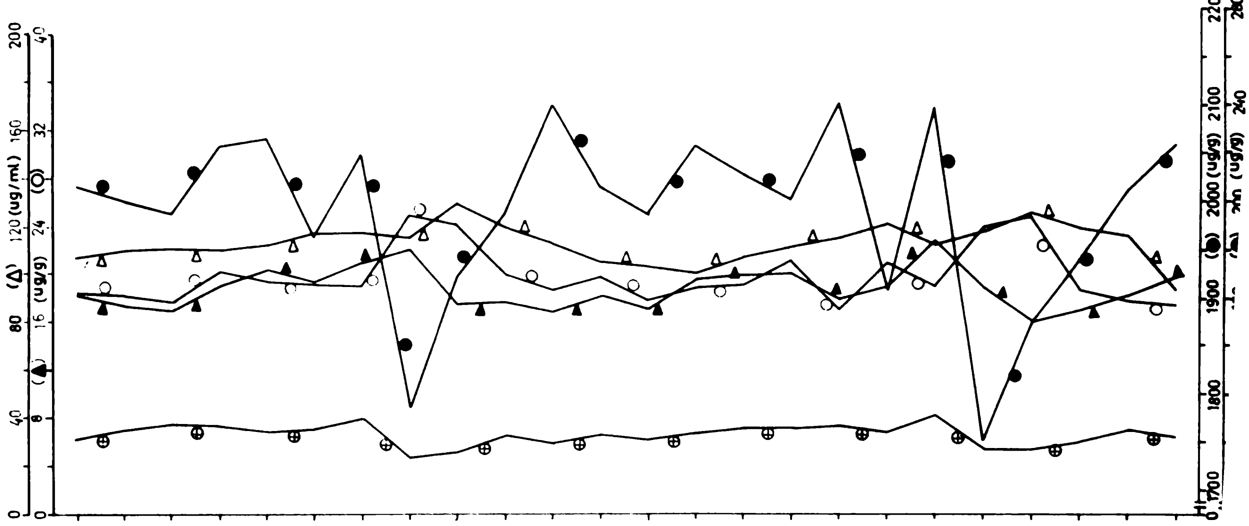
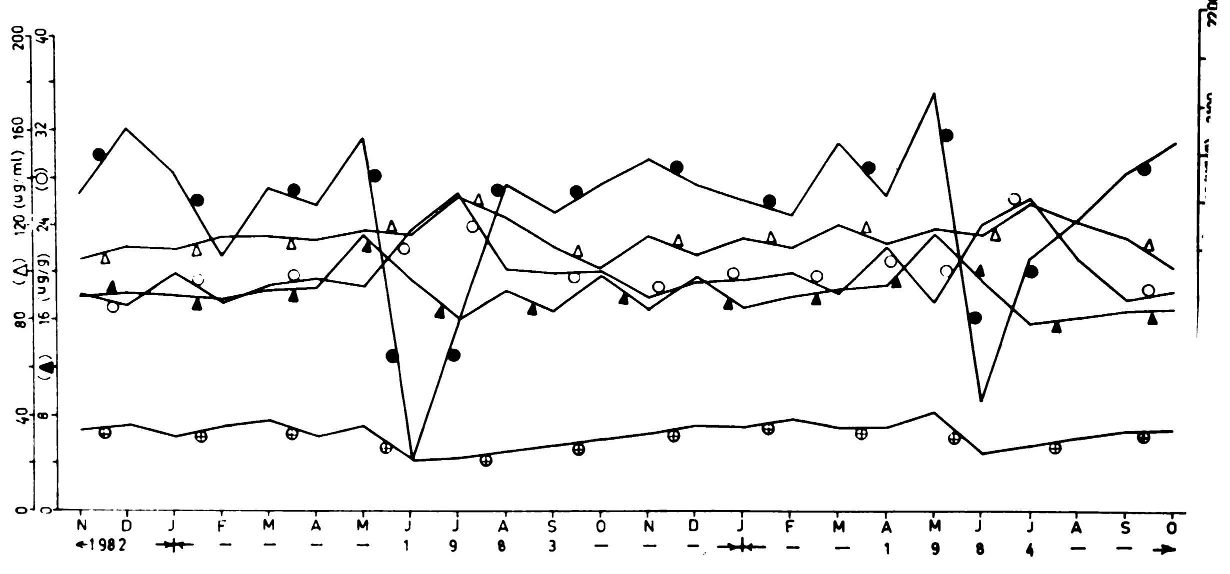


FIG. 7.3 STATION III



MUSCLE

Copper concentration of muscle showed minor fluctuations (17.1 to 19.5 µg/g) from November '82 to October '83 but for increased values in June (23.9 µg/g) and July (24.7 µg/g). In the following year too, high values were recorded during monsoon period. It showed significant negative correlation with copper of hepatopancreas and testis.

HEPATOPANCREAS

Hepatopancreatic copper remained relatively high and fluctuated between 1929 to 2102 µg/g from November '82 to October '83 but for decreased values in June (1779 µg/g) and July (1843 µg/g). In the subsequent year too, decreased copper concentrations were recorded during monsoon period. It showed significant positive correlation with copper of testis.

TESTIS

Copper varied a little (99.5 to 105.9 µg/g) from November '82 to May 1983 followed by a decreased value in June (91.9 µg/g) which increased to 104.7 µg/g by October. In the subsequent year too, values decreased during June and July only. It showed significant positive correlation with salinity of water and copper of hepatopancreas; and depicted significant negative correlation with copper of water and muscle.

ZINC

The results of the data on zinc in haemolymph, exoskeleton, muscle hepatopancreas and testis are given in Figures 8.1, 8.2 and 8.3

HAEMOLYMPH

Zinc concentrations of haemolymph remained low from November 1982 to October 1983 but for increased values in July (17.3 µg/ml) August (17.2 µg/ml) and September (16.4 µg/ml). In the subsequent year too, copper concentration increased during monsoon period only. Haemolymph zinc showed significant positive correlation with zinc of water, sediment and muscle.

EXOSKELETON

Exoskeletal zinc content fluctuated in the range of 40.7 to 48.9 µg/g from November 1982 to March 1983 and hi values were recorded during April and May (56.3 µg/g) followed by a decrease to 43.2 µg/g in July. Subsequently, it increased to 48.3 µg/g by October. In the subsequent year too, it decreased during monsoon. It showed significant negative correlation with zinc of haemolymph.

MUSCLE

Zinc concentration depicted fluctuating trend (40.0 to 46.7 µg/g) from November 1982 to October 1983 but for

LEGEND

FROM FIG. 8·1 TO 8·3

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

ZINC IN ♂ PENAEUS INDICUS

FIG. 8.1

STATION I

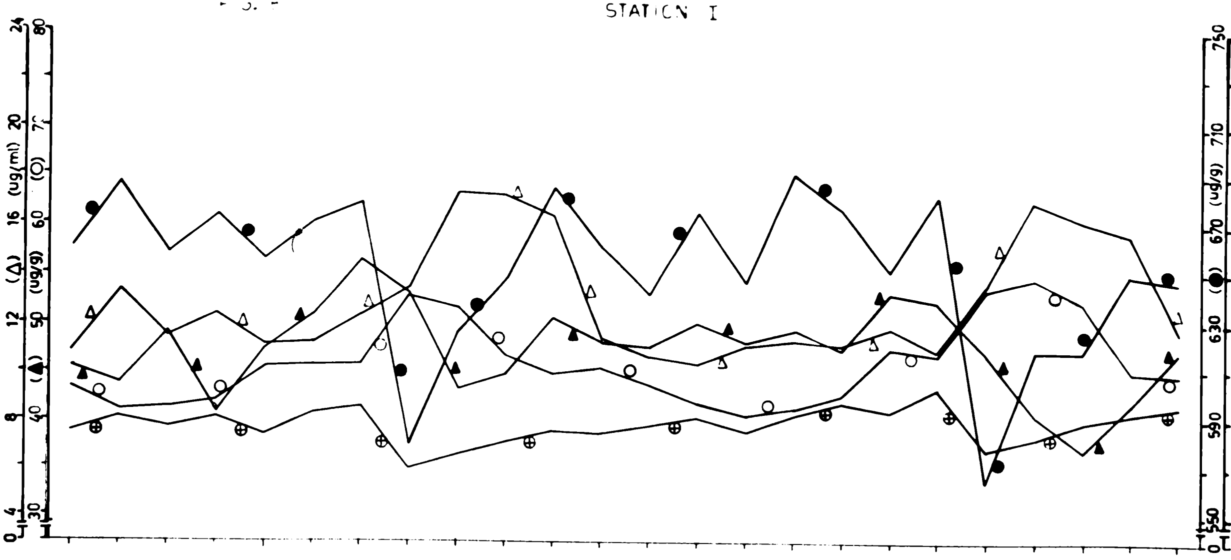


FIG. 8.2

STATION II

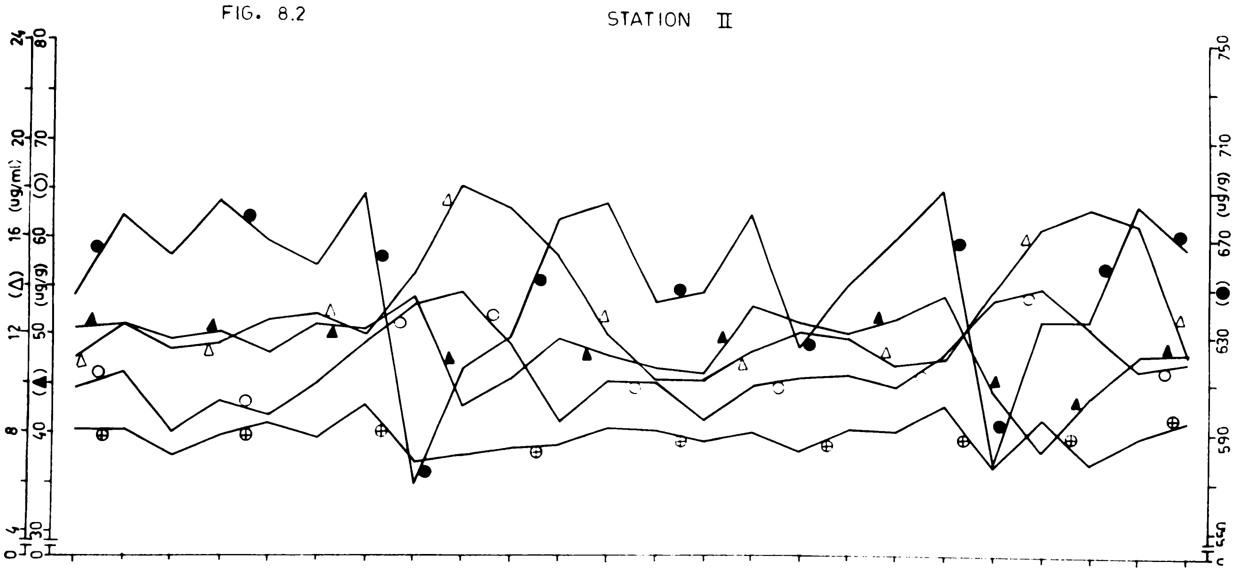
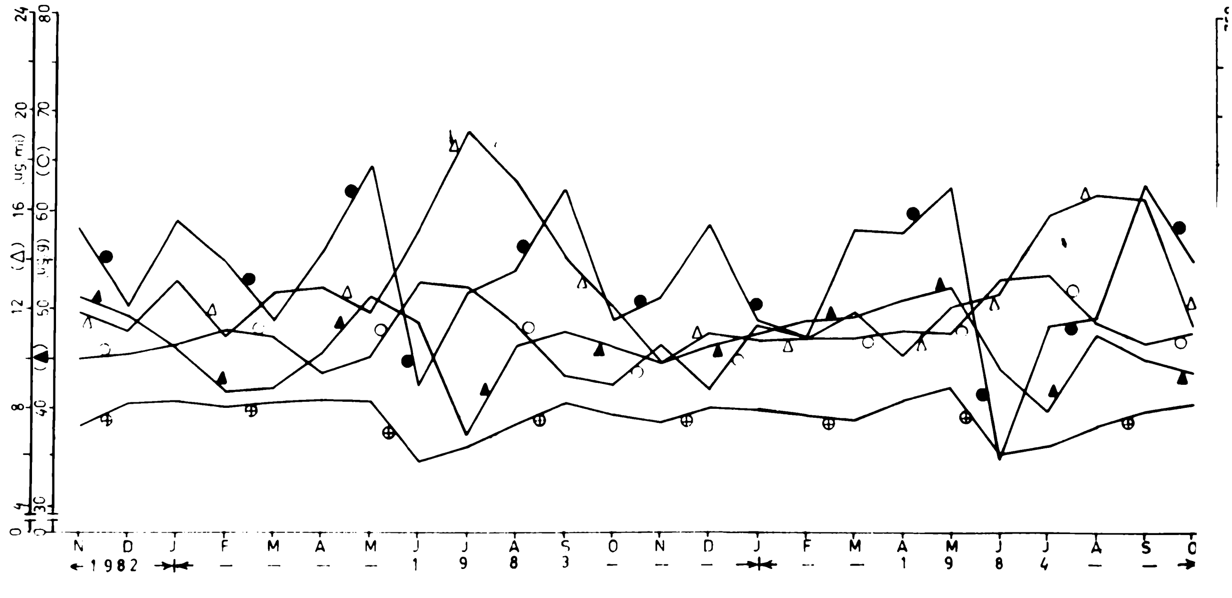


FIG. 8.3

STATION III



high values in June (52.8 µg/g) and July(51.7 µg/g). In the subsequent year too, high values were observed during monsoon period only. Zinc of muscle showed significant positive correlation with zinc of water and haemolymph, and significant negative correlation with zinc of hepatopancreas.

HEPATOPANCREAS

Zinc values of hepatopancreas exhibited fluctuating trend (642 to 692 µg/g) from November '82 to October '83 but for low concentrations in June (565 µg/g), July (618 µg/g) and August (618 µg/g). In the subsequent year too, values were low during monsoon period. Hepatopancreatic zinc showed significant positive correlation with zinc of testis; and significant negative correlation with zinc of muscle.

TESTIS

Zinc showed minor variations (77.1 to 82.8 µg/g) from November '82 to May '83 but decreased to 69.9 µg/g in June followed by an increase to 77.3 µg/g by October. In the subsequent year too, it decreased during early monsoon period. It depicted significant positive correlation with salinity of water and zinc of hepatopancreas; and significant negative correlation with zinc of water and haemolymph.

BIOELEMENTS IN VARIOUS TISSUES OF FEMALE P. INDICUS*

CALCIUM

The results of the data on calcium in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are given in Figures 4.7, 4.8 and 4.9.

HEAMOLYMPH

Calcium concentration of haemolymph increased from 0.423 mg/ml in November 1982 to 0.801 mg/ml by May 1983 and subsequently, it sharply decreased to 0.393 mg/ml by July 1983 followed by a little variation upto October 1983. In the subsequent year too, the values sharply decreased during June, July and August followed by a little variation upto October. Haemolymph calcium exhibited significant positive correlation with salinity of water; and calcium of water, sediment, muscle, hepatopancreas and ovary.

EXOSKELETON

Calcium showed fluctuating values (87 to 125 mg/g) from November 1982 to October 1984 and no seasonal variation was observed. It showed significant positive correlation with calcium of ovary at station I and II only.

---

* For correlation values see table VII B, VII C(station I); VIII B, VIII C (station II); IX B, IX C (station III).

LEGEND

FROM FIG. 4·7 TO 4·9

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

CALCIUM IN ♀ PENAEUS INDICUS

FIG. 4.7 STATION I

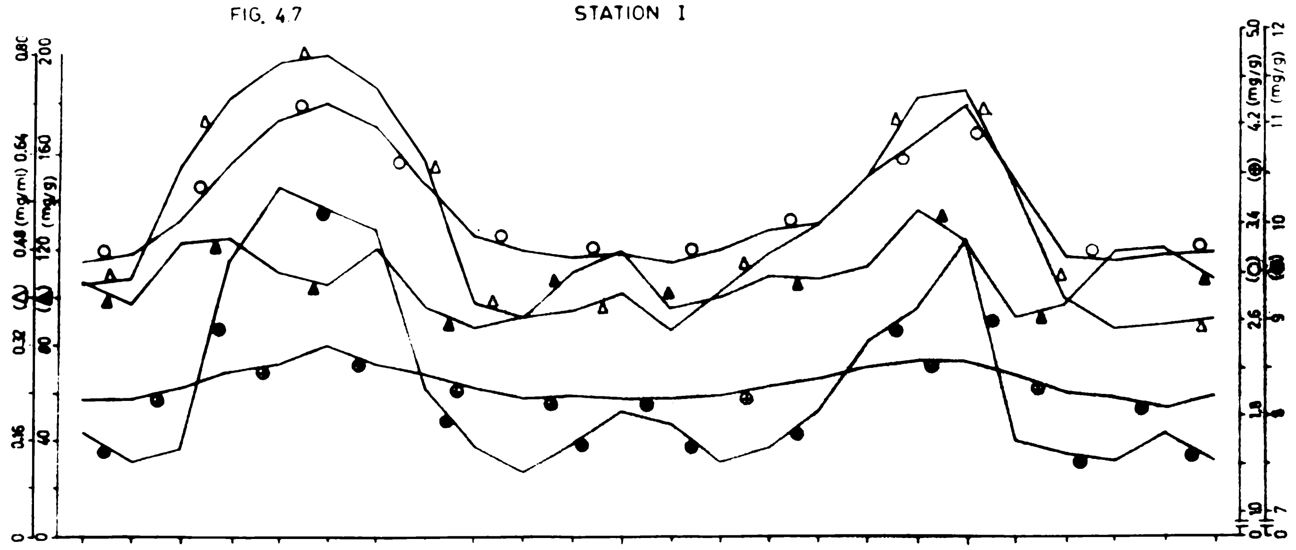


FIG. 48 STATION II

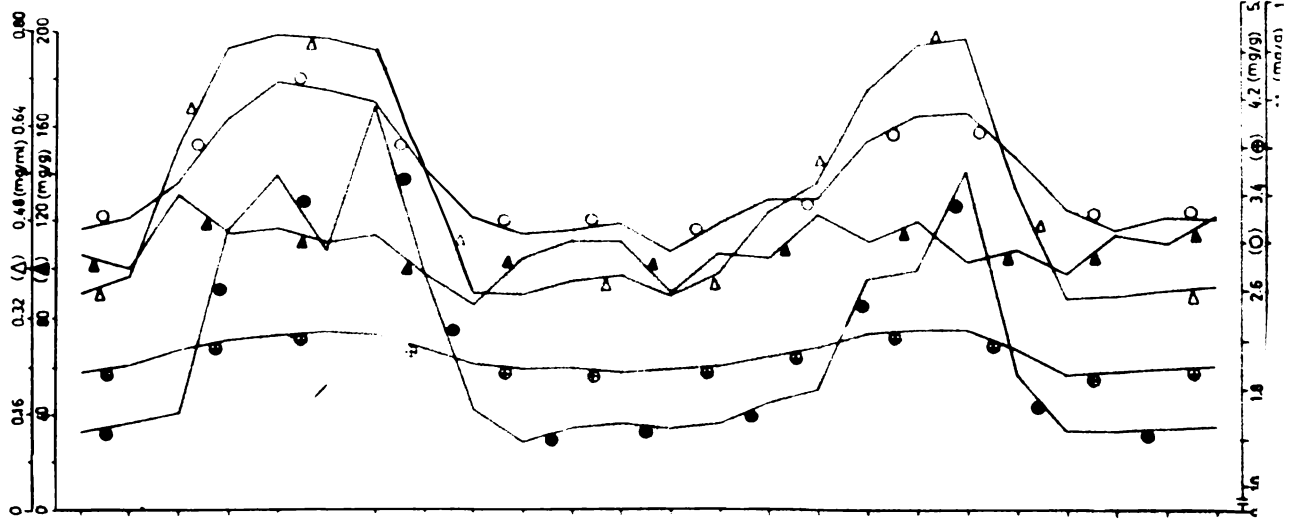
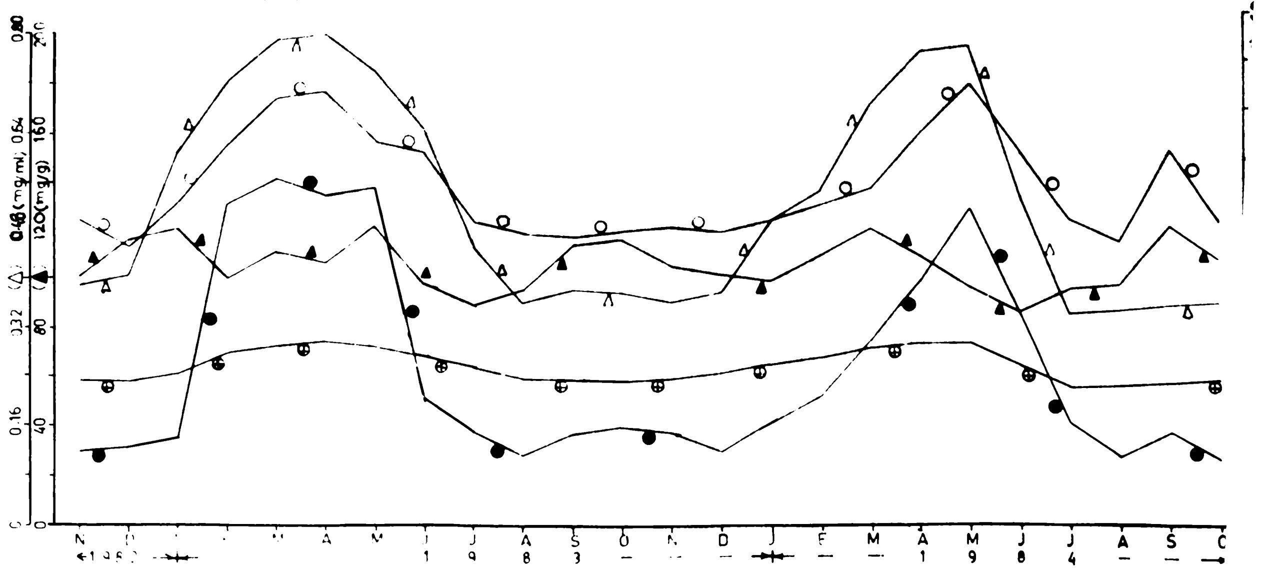


FIG. 4.9 STATION III



MUSCLE

Calcium increased gradually from 3.100 mg/g in November '82 to 4.258 mg/g in March '83 followed by a decrease to 3.145 mg/g during September. In the subsequent year too, calcium values decreased during monsoon period. It depicted significant positive correlation with salinity of water; and calcium of water, sediment, heamolymph, hepatopancreas and ovary.

HEPATOPANCREAS

Calcium values were low and fluctuated between 7.416 to 8.308 mg/g except from February to May during the first year of study when high values (9.655 to 10.393 mg/g) were recorded. In the subsequent year too, high values were observed from February to May. Hepatopancreatic calcium showed significant positive correlation with salinity of water; and calcium of water, sediment, haemolymph, muscle and ovary.

OVARY

Calcium concentration increased gradually from 1.954 mg/g in November '82 to 2.246 mg/g in March '83 and afterwards, varied a little upto May '83 followed by a decrease to 1.970 mg/g by August '83. Subsequently, it varied a little upto December. In the subsequent year too, it decreased during monsoon resulting in 1.954 mg/g by August 1984 followed by little variation upto October. Calcium of ovary depicted significant positive correlation with salinity of water; and calcium of water, sediment, haemolymph, muscle and hepatopancreas.

MAGNESIUM

The results of the data on magnesium in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are given in figures 5.7, 5.8 and 5.9

HAEMOLYMPH

Magnesium concentration of haemolymph increased gradually from 72 µg/ml in November 1982 to 158 µg/ml in March 1983 followed by a little decrease upto May 1983 (146 µg/ml) and further significant decrease to 76 µg/ml by July. Thereafter, it varied little upto October. In the following year too, magnesium values decreased during monsoon period. Haemolymph magnesium showed significant positive correlation with salinity of water; magnesium of water, sediment, exoskeleton, muscle, hepatopancreas and ovary.

EXOSKELETON

Exoskeletal magnesium content remained high and fluctuated between 7334 to 8176 µg/g from November 1982 to

LEGEND

FROM FIG. 5·7 TO 5·9

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

MAGNESIUM IN ♀ PENAEUS INDICUS

Fi .

STATION I

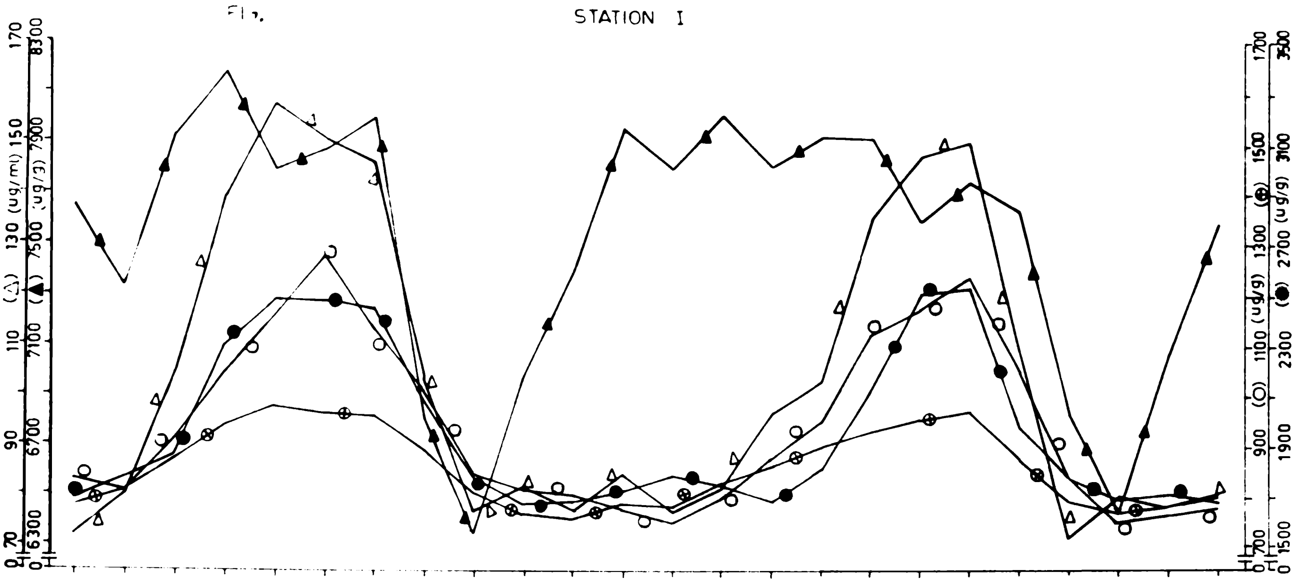


FIG. 5

STATION II

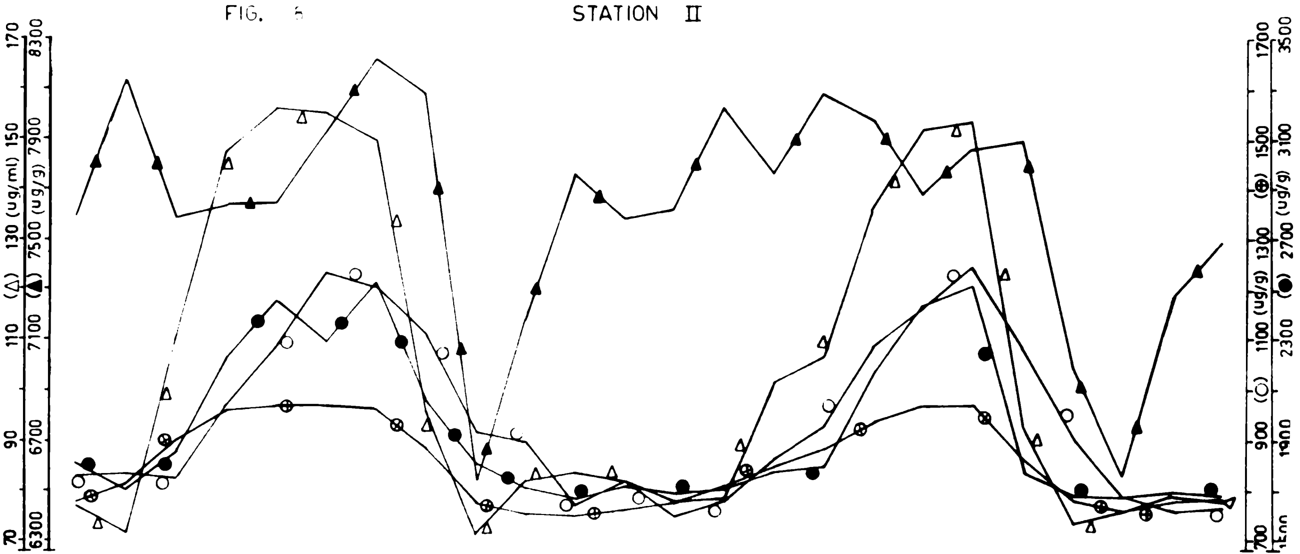
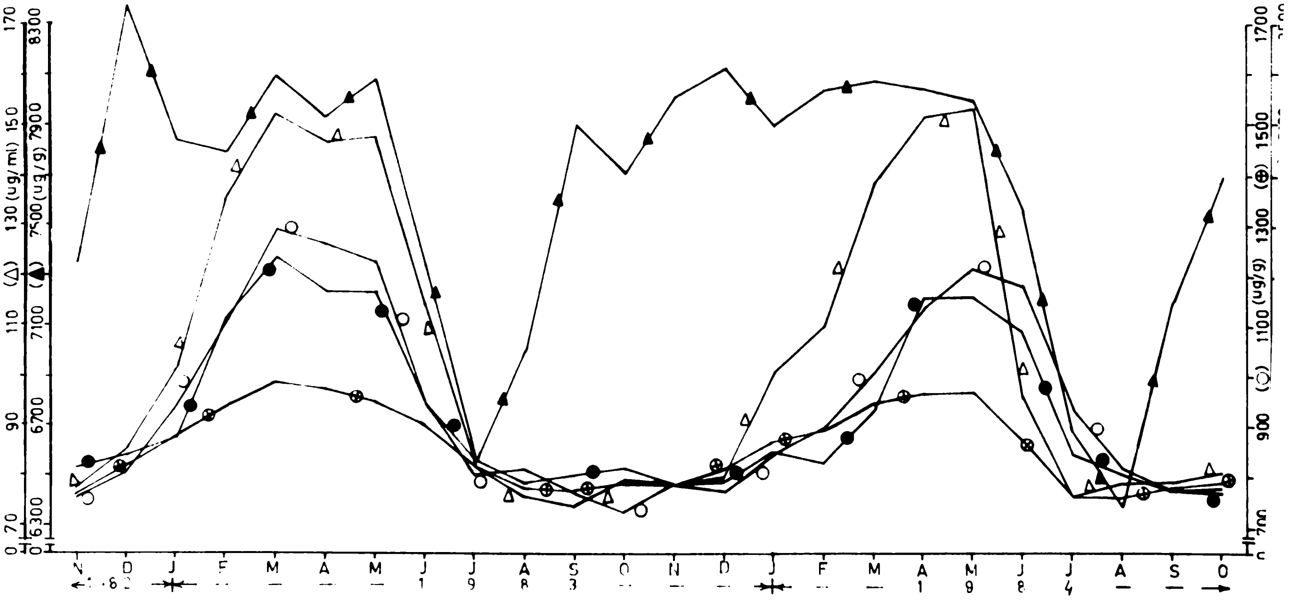


FIG. 5.9

STATION III



October '83 except from June to August when decreased values (6343 to 6981 µg/g) were noticed. In the subsequent year, decreased values were observed during July (6837 µg/g) and August (6438 µg/g). It depicted significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, muscle, hepatopancreas and ovary.

MUSCLE

Magnesium concentration of muscle was low during November (829 µg/g) and December '82 (811 µg/g), followed by a uniform increase to 1282 ug/g by April '83. Subsequently, it decreased again to 842 ug/g by July '83. Thereafter, it showed a minor decrease upto December '83 (794 µg/g). In 1984 too, low values were recorded during June, July and August, followed by a little variation upto October. It showed significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, exoskeleton, hepatopancreas and ovary.

HEPATOPANCREAS

Magnesium content increased gradually from 1687 µg/g in November '82 to 2479 µg/g by March '83. Subsequently, it varied a little upto May '83 (2452 µg/g), followed by a decrease to 1657 µg/g by August '83. Thenceforth, it slightly increased upto October. In the following year too, high values were recorded in April and May (2527 µg/g) which thereafter decreased to 1692 µg/g by August 1984. Magnesium of hepatopancreas showed significant positive correlation with salinity of water; and magnesium of water, sediment, haemolymph, exoskeleton, muscle and ovary.

OVARY

Magnesium increased uniformly from 781 µg/g in November 1982 to 941 µg/g in March 1983. Thereafter, it remained almost steady upto May followed by a decrease to 757 µg/g by August. Subsequently, it varied a little upto October. In the following year too, values decreased during June and July. Magnesium of ovary showed significant positive correlation with salinity of water; magnesium of water, sediment, haemolymph, exoskeleton, muscle and hepatopancreas.

PHOSPHORUS

The results of the data on phosphorus in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are presented in Figures 6.7, 6.8 and 6.9

HAEMOLYMPH

Phosphorus values depicted fluctuations from November 1982 to October 1984 but no seasonal trend was noticed except that the values were maximum in June 1983 (57 µg/ml) and June 1984 (60 µg/ml). Phosphorus levels varied between 41 to 52 µg/ml in rest of the study period. It showed no significant correlation.

LEGEND

FROM FIG. 6·7 TO 6·9

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

PHOSPHORUS IN ♀ PENAEUS INDICUS

FIG. 6.7 STATION I

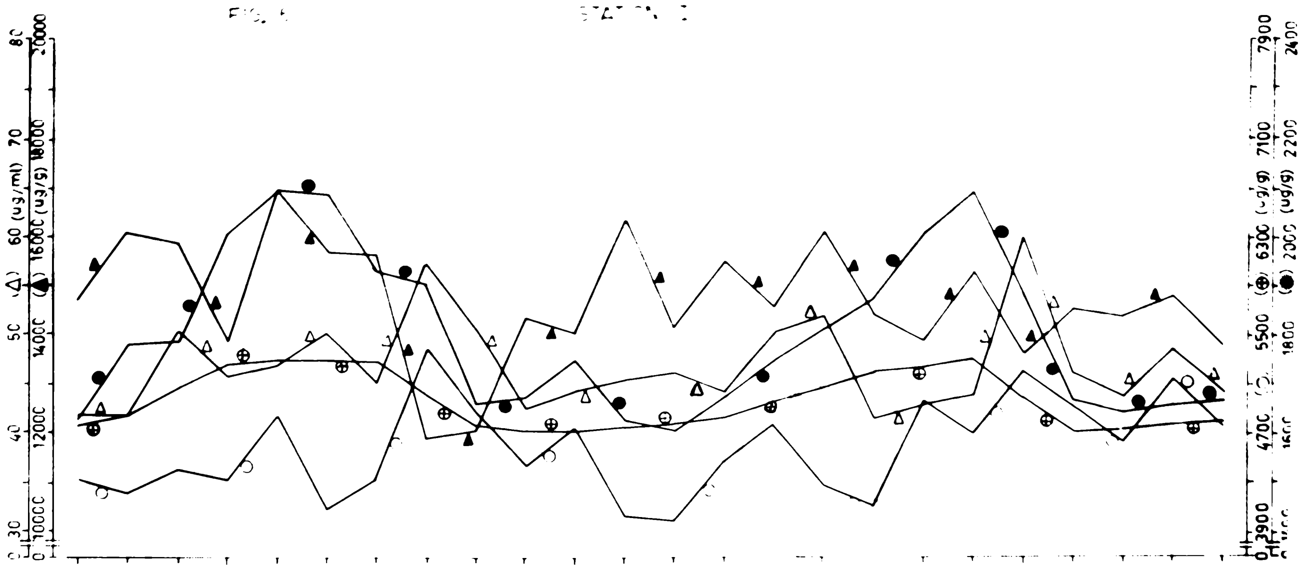


FIG. 6.8 STATION II

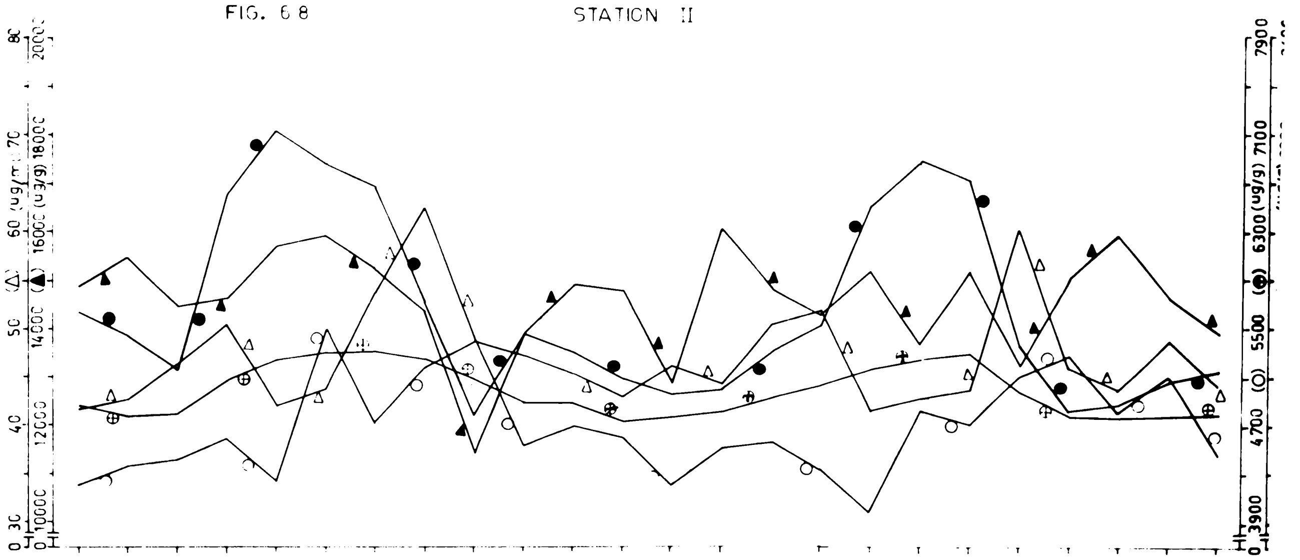
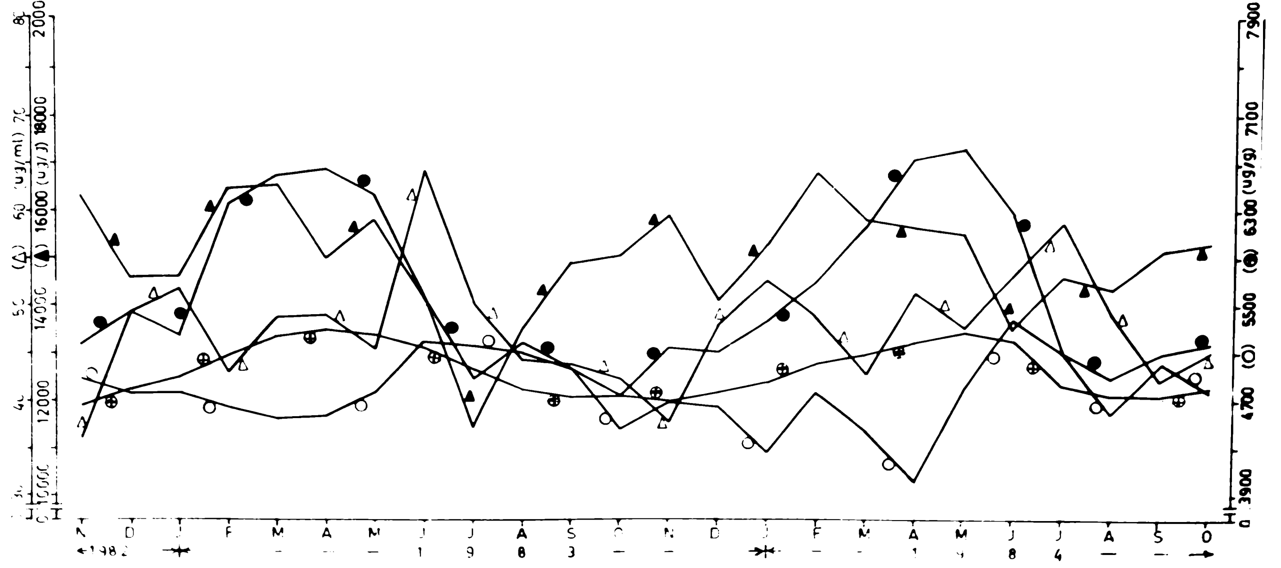


FIG. 6.9 STATION III



EXOSKELETON

Exoskeletal phosphorus depicted fluctuating values from November '82 to October '84 but no seasonal trend was observed except that values decreased during monsoon of 1983 [i.e. June (11913 µg/g) and July (12054 µg/g)]. All values during other months varied from 13719 to 16954 µg/g. It depicted no significant correlation.

MUSCLE

Phosphorus in muscle showed fluctuations from November '82 to October '84 but no seasonal trend was noticed except that relatively higher values were recorded during monsoon period of 1983 [June (5380 µg/g), July (4880 µg/g)] and 1984 [June (5220 µg/g), July (4820 µg/g)]. Phosphorus values ranged between 4000 to 5140 µg/g in rest of the study period. It showed significant positive correlation with phosphorus of sediment.

HEPATOPANCREAS

Phosphorus of hepatopancreas increased from 1637 µg/g in November '82 to 2096 µg/g in March '83. It varied a little in April '83 followed by a decrease to 1661 µg/g by July. Subsequently, it remained steady upto December (1677 µg/g). In the subsequent year too, it decreased during June and July followed by almost steady values upto October '84. Hepatopancreatic phosphorus showed significant positive correlation with salinity of water, and phosphorus of ovary.

OVARY

Phosphorus of ovary increased from 4760 µg/g in November 1982 to 5260 µg/g in February 1983 and thereafter, varied little upto May (5280 µg/g) followed by a uniform decrease to 4760 µg/g by July. It remained almost steady upto November 1983 (4780 µg/g). In the following year too, values decreased during monsoon period and subsequently, varied a little upto October. Phosphorus of ovary depicted significant positive correlation with salinity of water, and phosphorus of water and hepatopancreas.

COPPER

The results of the data on copper in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are presented in Figures 7.7, 7.8 and 7.9

HAEMOLYMPH

Copper content of haemolymph increased gradually from 100.5 (November 1982) to 124.2 µg/ ml in June 1983 but a subsequent, sharper increase to a maximum value of 137.6 µg/ml was noticed by August followed by a sharp decrease to a minimum value of 99.4 µg/ml by November 1983. In the following year too, it increased sharply during July and August resulting in a maximum value of 135.9 µg/ml

LEGEND

FROM FIG. 7·7 TO 7·9

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

COPPER IN ♀ PENAEUS INDICUS

FIG. 7.7 STATION I

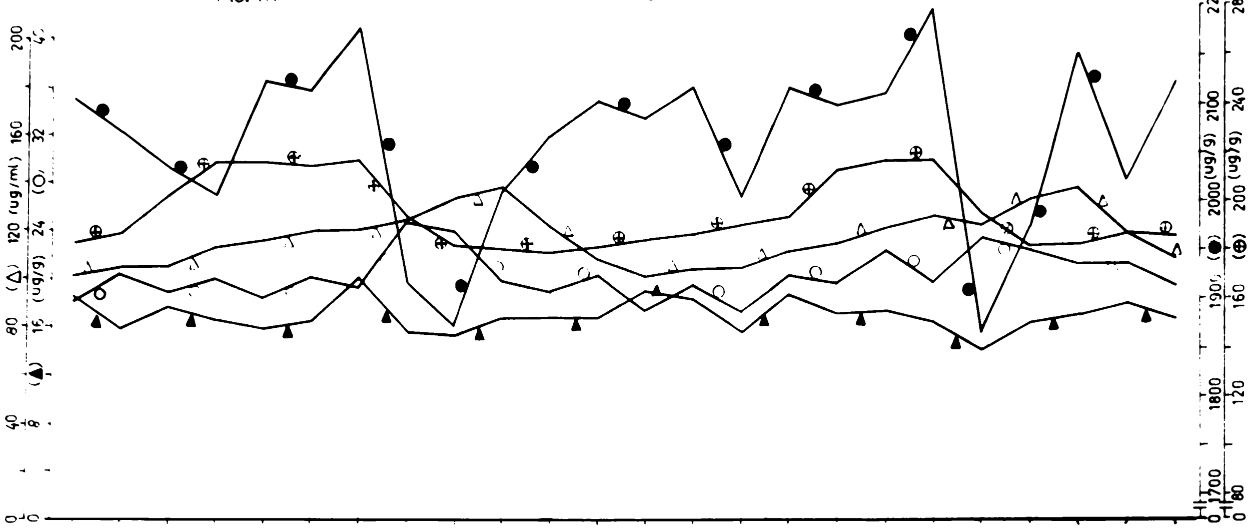


FIG. 7.8 STATION II

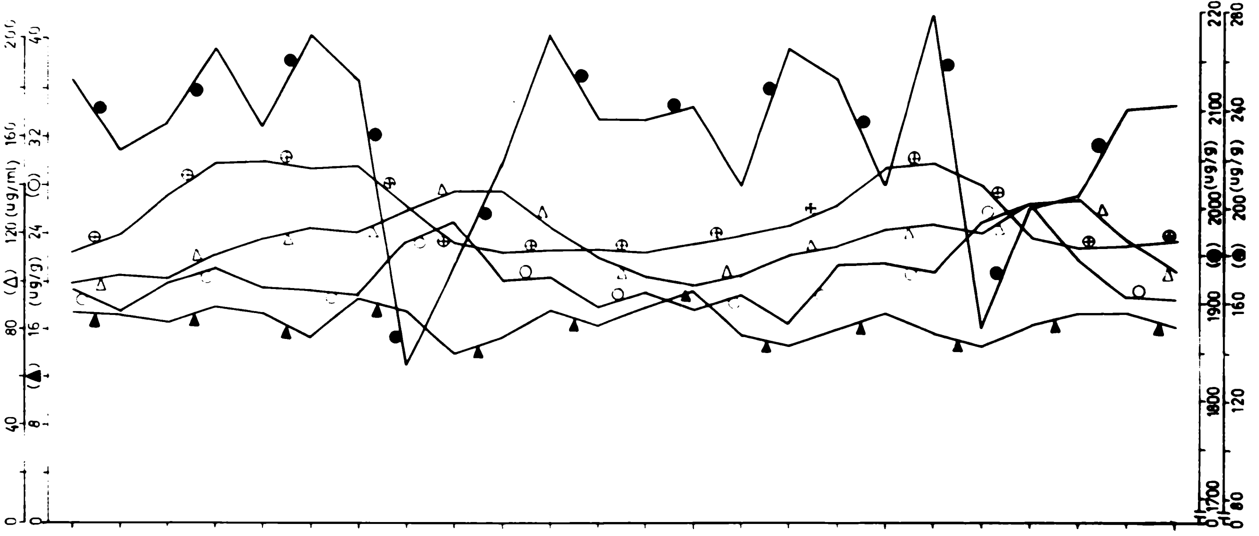
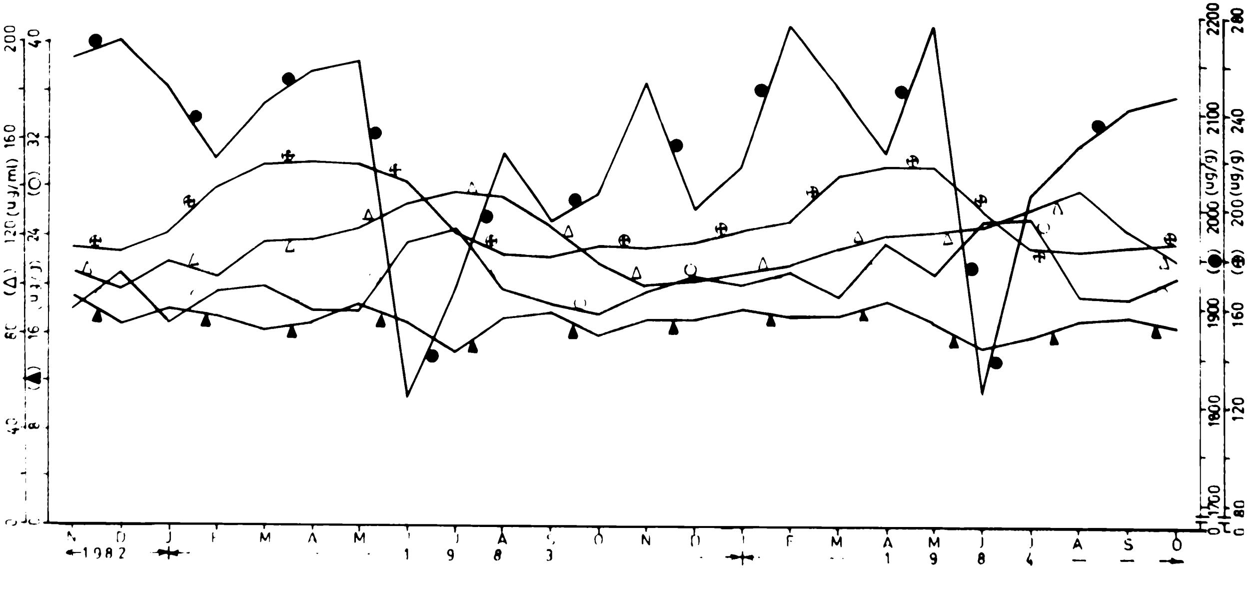


FIG. 7.9 STATION III



in August which thereafter, decreased by October(105.8 μg/ml). Copper of haemolymph showed significant positive correlation with copper of water and muscle; and significant negative correpation with copper of hepatopancreas.

EXOSKELETON

Exoskeletal copper content depicted fluctuating values (13.8 to 20.1 μg/g) from November '82 to October '84 and no seasonal trend was observed. It showed no significant correlation.

MUSCLE

Copper values remained low (17.9 to 20.4 μg/g) except during monsoon period (i.e. June and July) when high values (23.6 to 24.6 μg/g) were recorded during the first year of study. In the subsequent year too, high values were observed during June (23.1 μg/g) and July (26.5 μg/g) only. Muscle copper depicted significant positive correlation with copper of water and haemolymph; and significant negative correlation with copper of hepatopancreas.

HEPATOPANCREAS

Copper content showed fluctuating values (2011 to 2187 μg/g) from November '82 to May '83 and subsequently, decreased during monsoon period to a minimum value (1875 μg/g) in July followed by an increase to 2109 μg/g by October. In the following year too, it decreased during monsoon period (i.e. June and July). Hepatopancreatic copper showed significant negative correlation with copper of haemolymph and muscle.

OVARY

Copper concentration of ovary increased gradually from 183.9 µg/g in November 1982 to 217.7 µg/g in May 1983 and subsequently, it decreased to 183.0 µg/g by July followed by a little variation upto October (182.8 µg/g). In the next year too, decreased values occurred from June to October. Copper of ovary showed significant positive correlation with salinity of water.

ZINC

The results of the data on zinc in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are given in Figures 8.7, 8.8 and 8.9

HAEMOLYMPH

Zinc values remained low (11.1 to 13.3 µg/ml) from November 1982 to May 1983 and high values (16.4 to 18.7 µg/ml) were recorded from June to September 1983. The maximum value was recorded in July 1983 (18.7 µg/ml). In the subsequent year too, high values were recorded from July to September

LEGEND

FROM FIG. 8·7 TO 8·9

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

ZINC IN ♀ PENAEUS INDICUS

FIG. 8.7 STATION I

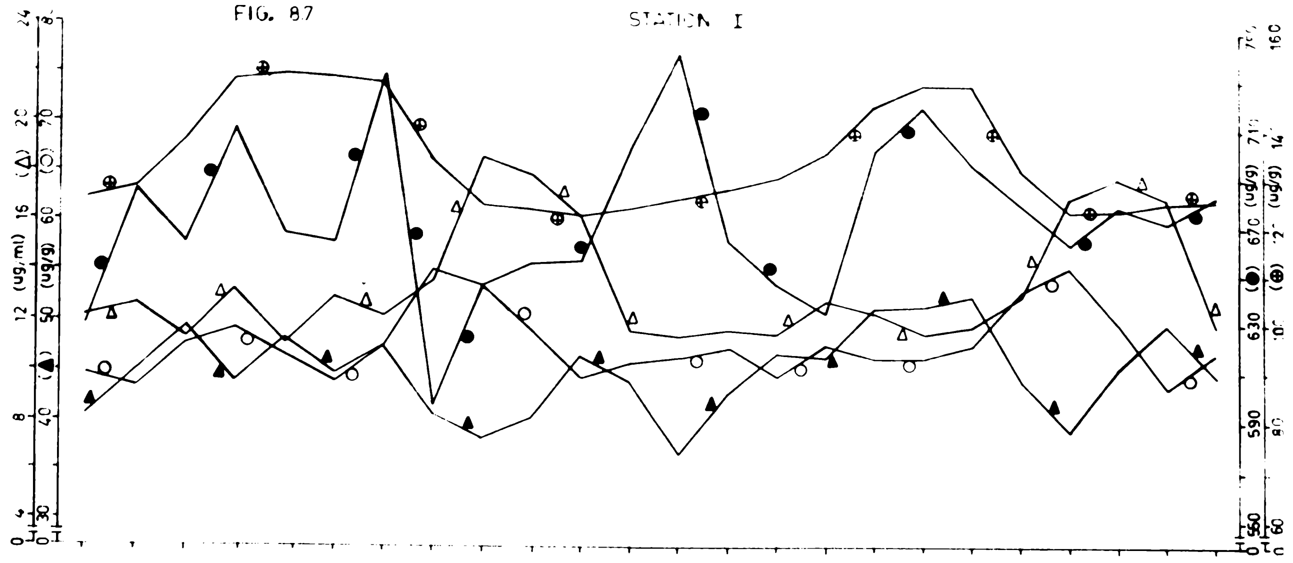


FIG. 8.8 STATION II

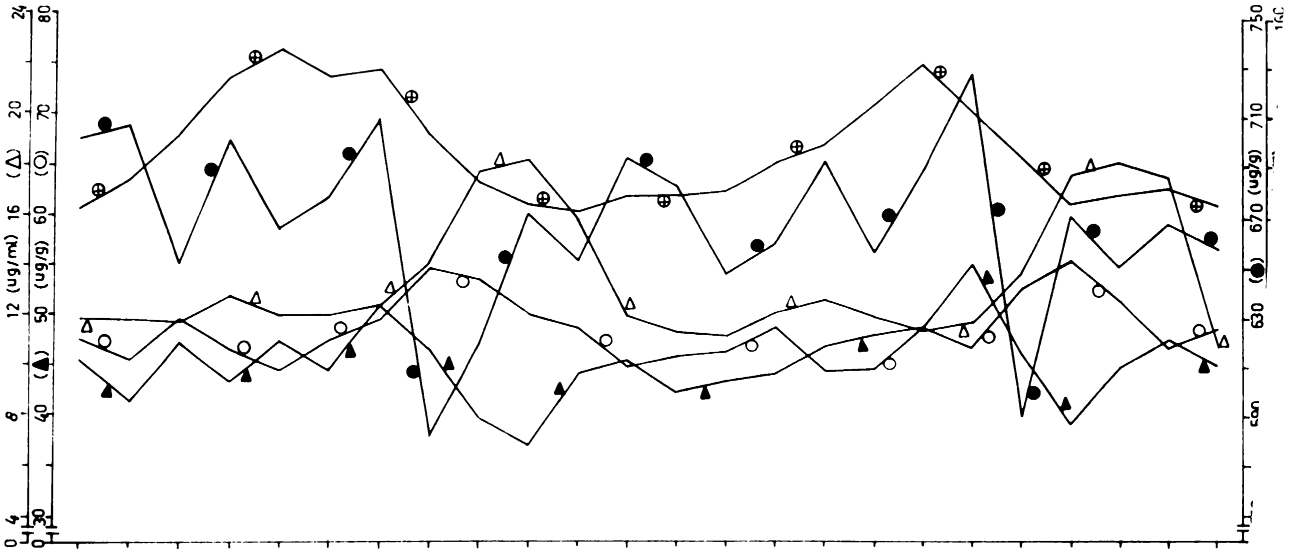
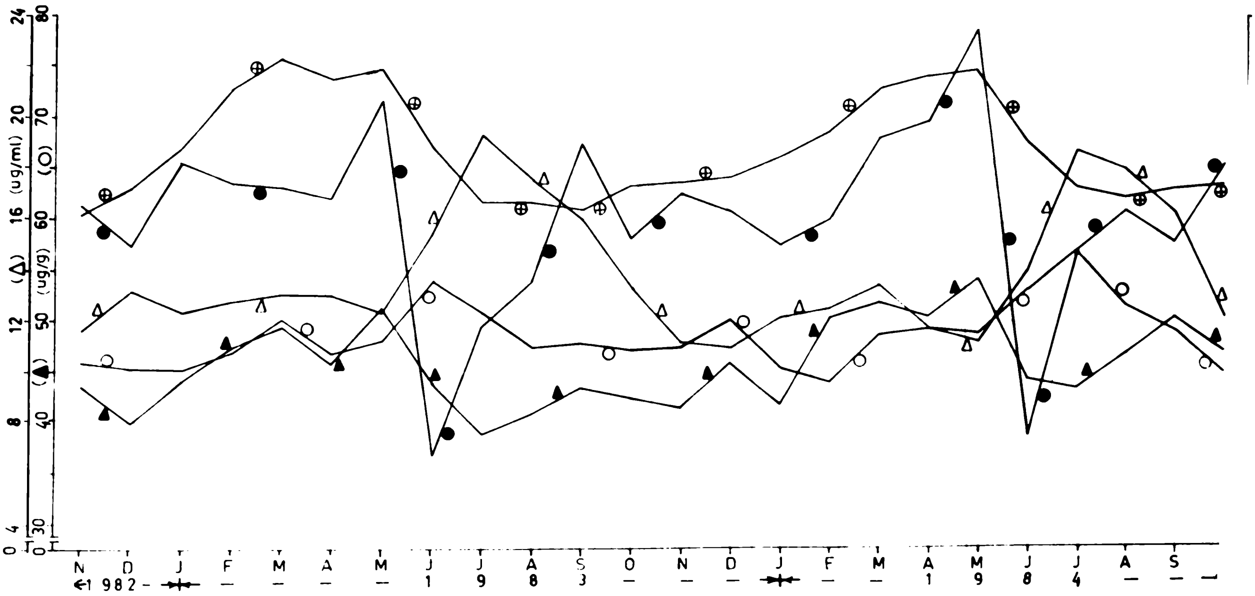


FIG. 8.9 STATION III



(17.1 to 18.1 µg/ml) and the maximum value occurred in August (18.1 µg/ml). Haemolymph zinc showed significant positive correlation with zinc of water, sediment and muscle; and significant negative correlation with salinity of water, and zinc of ovary.

EXOSKELETON

Zinc concentration of exoskeleton showed fluctuating values (36.8 to 52.8 µg/g) from November '82 to October '84 and no seasonal trend was observed. Exoskeletal zinc showed significant positive correlation with salinity of water, and zinc of ovary; and significant negative correlation with zinc of haemolymph.

MUSCLE

Zinc values were relatively low from November '82 to May '83 and from August to October '83. Increased values were recorded during June (55.45 µg/g) and July (53.50 µg/g). In the subsequent year too, high values were recorded during June (55.30 µg/g) and July (55.80 µg/g). Zinc of muscle depicted significant positive correlation with zinc of water and haemolymph.

HEPATOPANCREAS

Zinc values were found to be high and fluctuated (654 to 731 µg/g) from November '82 to October '83 except for the months of June (596 µg/g) and July '83 (645 µg/g) in the first year of study when the concentrations were relatively low. In the second year too, decreased values were recorded during June and July only. Hepatopancreatic zinc showed no significant correlation.

OVARY

Zinc increased from 124.3 µg/g in November '82 to 149.0 µg/g in February '83 followed by a little variation upto May (149.7 µg/g). Subsequently, it decreased to 124.2 µg/g by July. Thereafter, it remained almost steady upto October. In the next year too, values decreased during June and July and thereafter, remained steady. Zinc of ovary depicted significant positive correlation with salinity of water, and zinc of exoskeleton; and significant negative correlation with zinc of water, sediment and haemolymph.

PHYSICOCHEMICAL AND BIOLOGICAL PARAMETERS IN THE MARINE ECOSYSTEM (at 30 m depth off Cochin)

PHYSICOCHEMICAL PARAMETERS OF WATER*

The results of the data on temperature, pH, Eh and dissolved oxygen are presented in Figures 2.10, 2.13 and 2.16

TEMPERATURE

Relatively decreased values of temperature were recorded from June to October (23.50 to 25.25°C) during both the years of study and minimum values of 23.75 and 23.50°C were observed in August of 1983 and 1984 respectively. Temperature values were high and fluctuated between 26.25 to 28.75°C during all other months. It exhibited significant positive correlation with oxygen, pH and Eh of water; and with temperature, pH and magnesium of sediment. It showed significant negative correlation with rainfall, primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment.

DISSOLVED OXYGEN

Dissolved oxygen level remained low (<1.69 ml/l) during monsoon and early post-monsoon (i.e. July to September) in both the years of study and minima of 0.58 and 1.37 ml/l were recorded in August of 1983 and 1984 respectively. It increased and fluctuated between 2.32 to 4.40 ml/l in rest

---

* For correlation values see table X A (Station IV), XI A (Station V) and XII A(station VI)

PHYSICOCHEMICAL PARAMETERS (WATER)
STATION IV

FIG. 2 10

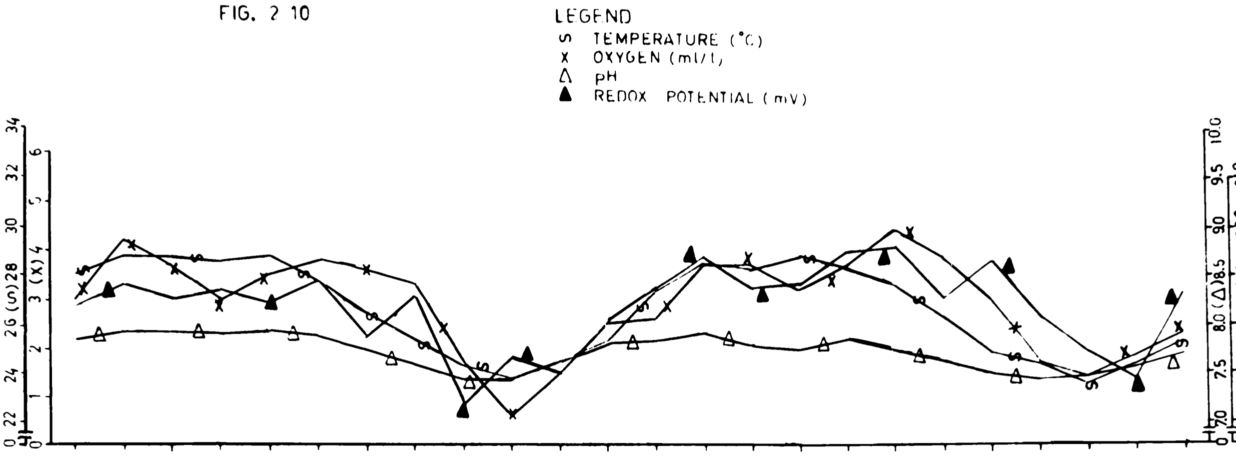


FIG. 2.11

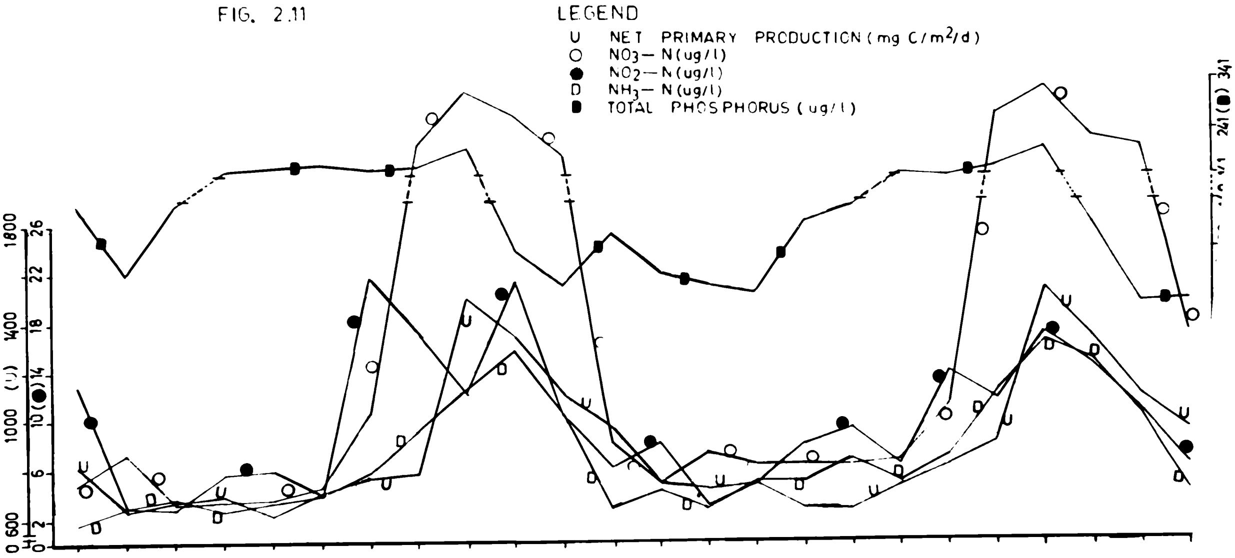
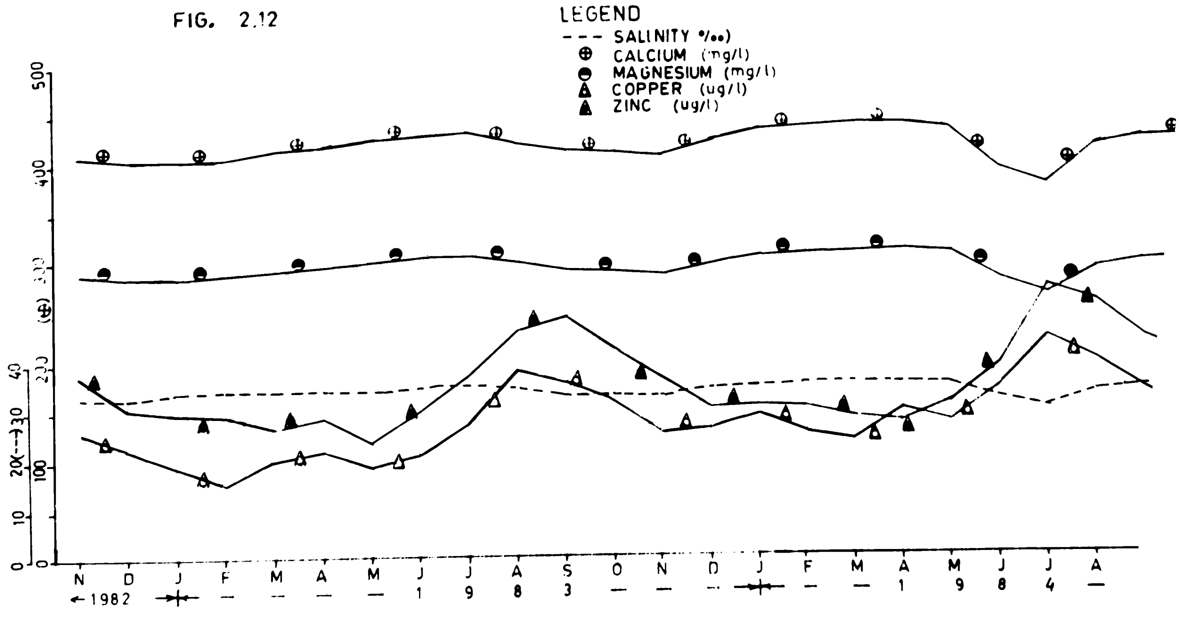


FIG. 2.12



PHYSICOCHEMICAL PARAMETERS (WATER)

STATION V

FIG. 2.13

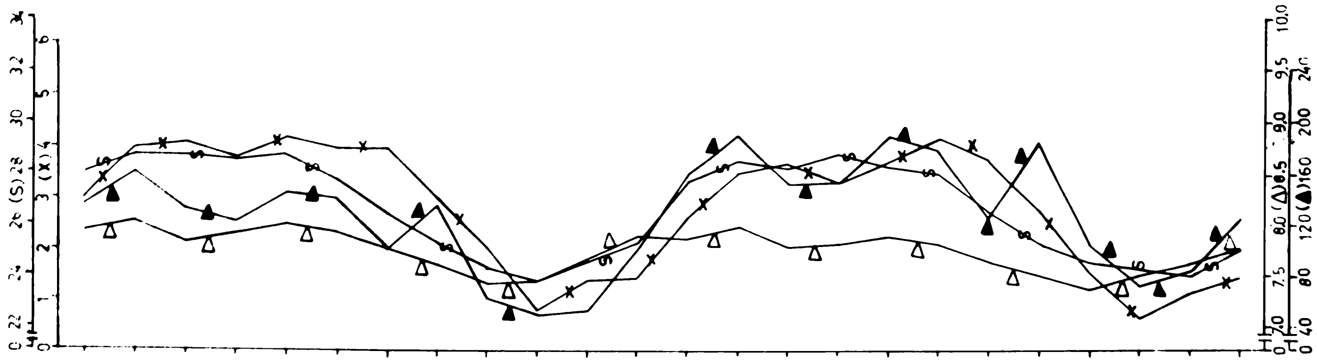


FIG. 2.14

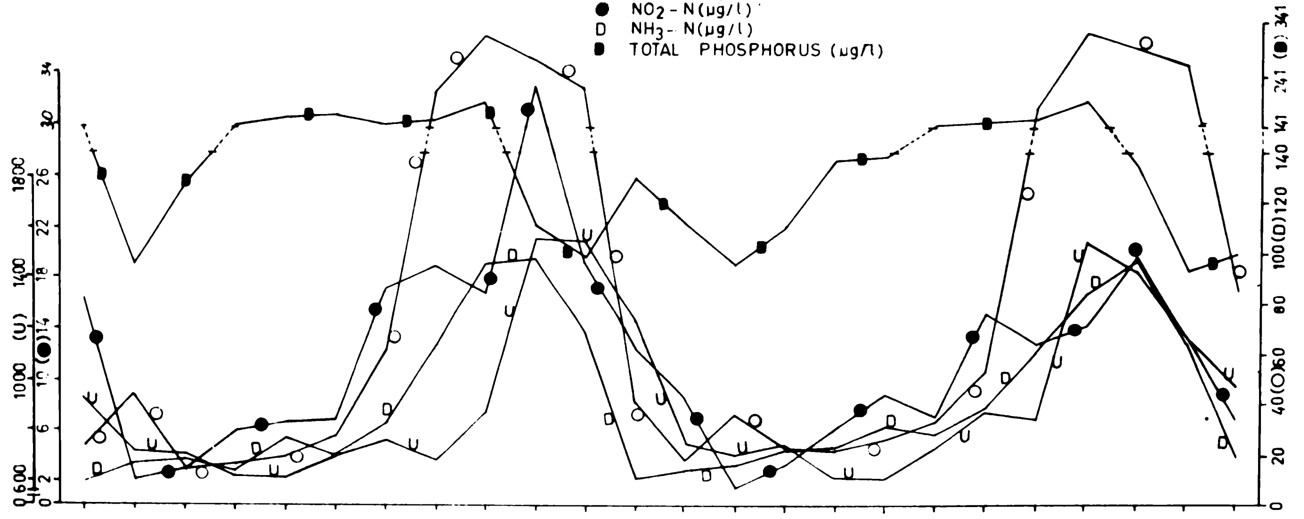
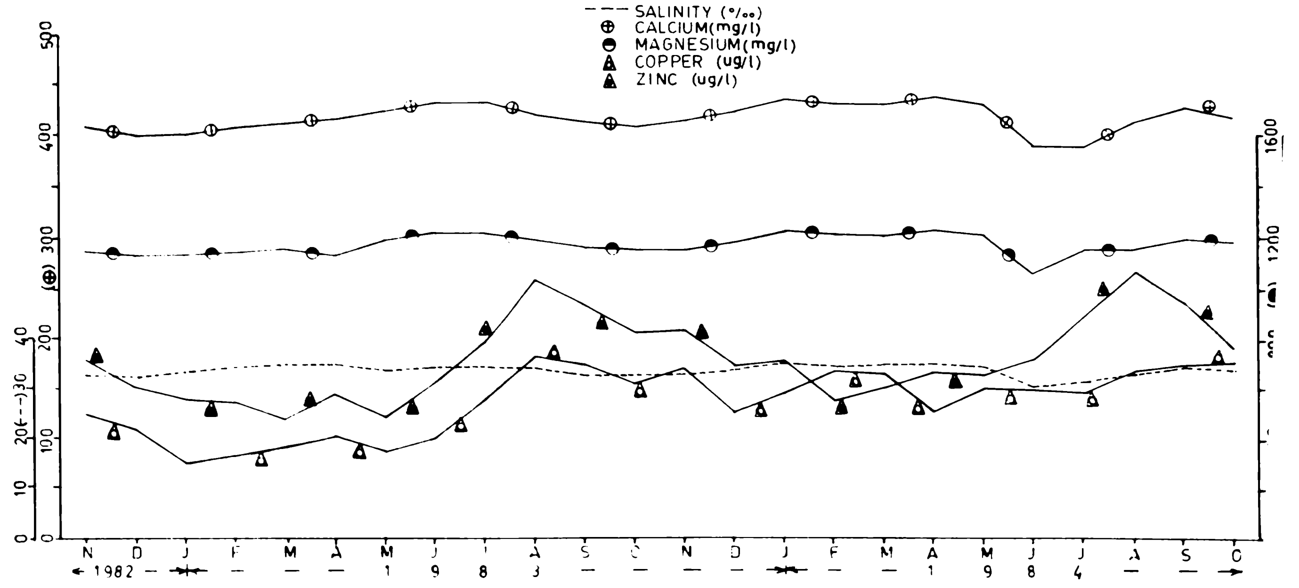


FIG. 2.15



PHYSICOCHEMICAL PARAMETERS (WATER)
STATION VI

FIG. 2.16

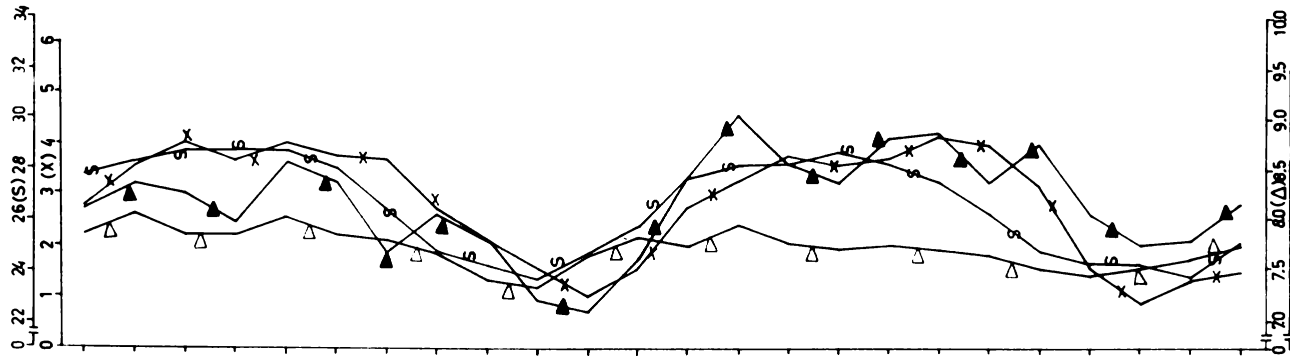


FIG. 2.17

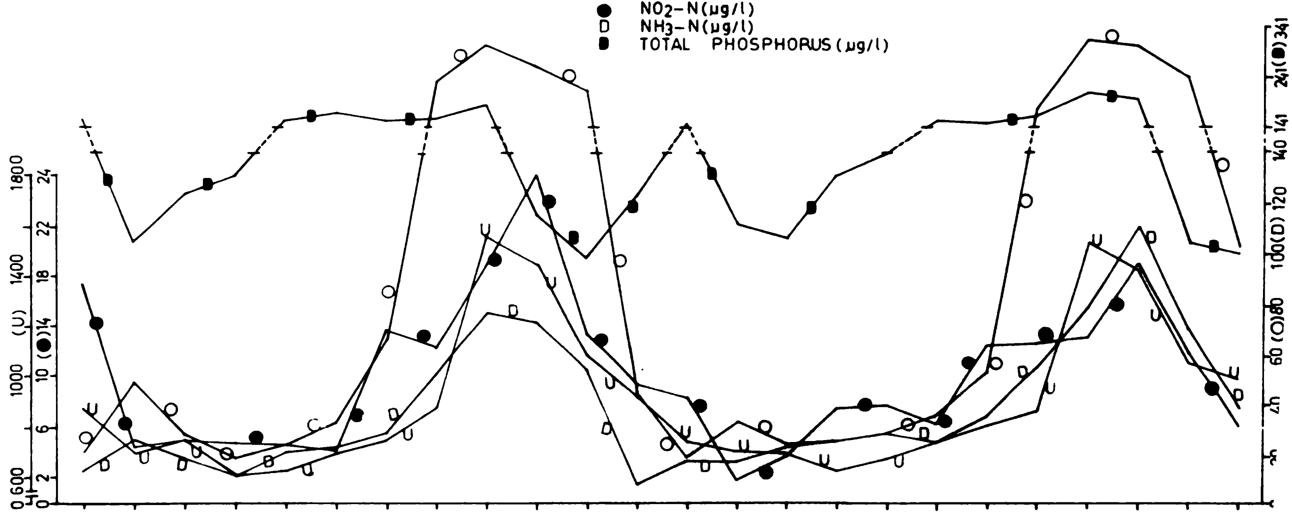
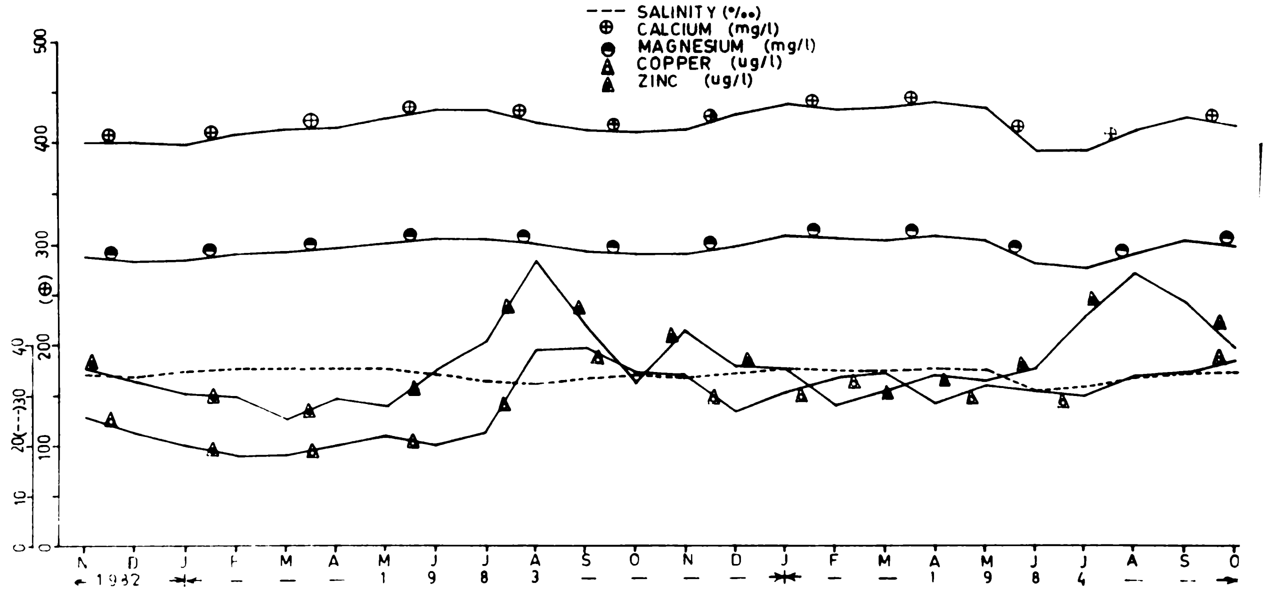


FIG. 2.18



of the study period. Dissolved oxygen of water showed significant positive correlation with temperature, pH and Eh of water; and with temperature, pH and calcium of sediment. It depicted significant negative correlation with rainfall, primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment.

HYDROGEN ION CONCENTRATION (pH)

pH values were relative low (7.42 to 7.47) during monsoon period i.e. during July and August in 1983 and from June to August in 1984. It fluctuated in the range of 7.52 to 7.92 during rest of the study period. pH of water showed significant positive correlation with temperature, dissolved oxygen and Eh of water; and with temperature, pH and magnesium of sediment. It exhibited significant negative correlation with rainfall, primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment.

REDOX-POTENTIAL (Eh)

Eh values were less during monsoon period in 1983 [July (55 mV), August (92 mV) and September (80 mV)] and 1984 [August (95 mV) and September (75 mV)]. It remained high and fluctuated between 122 to 182 mV in rest of the study period except May '83 (110 mV). Eh of water exhibited significant positive correlation with temperature, dissolved oxygen and pH of water; and with temperature and pH of sediment. It showed significant negative correlation with net primary productivity, nitrate, nitrite, ammonia and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment.

The results of the data on net primary productivity, nitrate, nitrite, ammonia and total phosphorus are given in Figures 2.11, 2.14 and 2.17

NET PRIMARY PRODUCTIVITY

Net primary productivity of water showed fluctuating values from November '82 (810 mgC/m^2/d) to June '83(784 mgC/m^2/d). Thereafter, it sharply increased to a maximum value of 1499 mgC/m^2/d in July and decreased gradually to 966 mgC/m^2/d by October. In the subsequent year too, high values were recorded during monsoon and post-monsoon period [i.e. during July (1499 mgC/m^2/d), August (1346 mgC/m^2/d),September(1346 mgC/m^2/d) and October (965 mgC/m^2/d)]. It showed significant positive correlation with rainfall, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment. It depicted significant negative correlation with temperature, salinity, dissolved oxygen, pH and Eh of water; and with temperature and pH of sediment.

NITRATE

Nitrate values were observed to be relatively less (<55 µg/l) from November to May and higher values with maxima in July '83 (322 µg/l) and July '84 (311 µg/l) were recorded from June to September during both the years of study. Nitrate depicted significant positive correlation with rainfall, net primary productivity, nitrite, total phosphorus, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment. It exhibited significant negative correlation with temperature, salinity, dissolved oxygen, pH and Eh of water; and with temperature, pH, calcium and magnesium of sediment.

NITRITE

Nitrite values were high from May to September in both the years of study except January '83 (12.8 µg/l) and maxima of 21.4 and 17.2 µg/l were recorded in August '83 and July '84 respectively. In rest of the study period, values were relatively low and ranged between 2.7 to 9.4 µg/l. Nitrite showed significant positive correlation with rainfall, net primary productivity, nitrate, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment. It exhibited significant negative correlation with temperature, dissolved oxygen, pH and Eh of water; and with magnesium of sediment.

AMMONIA

Ammonia values remained high from June to September in both the years of study and maxima were observed in August '83 (78 µg/l) and July '84 (83 µg/l). In rest of the period, values showed variations from 8 to 34 µg/l. Ammonia exhibited significant positive correlation with rainfall, net primary productivity, nitrate, nitrite, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment. It showed significant negative correlation with temperature, pH and Eh of water; and with temperature, pH and magnesium of sediment.

TOTAL PHOSPHORUS

Total phosphorus maxima of 195 and 194 µg/l in July month each of 1983 and 1984 respectively, decreased to minima of 105 and 98 µg/l in September month of the respective year. It fluctuated between 103 to 158 µg/l in rest of the period. Total phosphorus depicted significant positive correlation with rainfall and nitrite of water. It depicted significant negative correlation with total phosphorus and copper of sediment.

The results of the data on salinity, calcium, magnesium, copper and zinc are presented in Figures 2.12, 2.15 and 2.18

SALINITY

Salinity was a little low from September (32.93‰) to November (32.79‰) in 1983 and from June (31.77‰) to August (33.14‰) in 1984. It remained high (33.79 to 35.11‰) and showed little variation in rest of the study period but for November and December '82. Salinity exhibited significant positive correlation with dissolved oxygen, calcium and magnesium of water; and with temperature, calcium and magnesium of sediment. It showed significant negative correlation with rainfall, net primary productivity, nitrate, copper and zinc of water; and with Eh and zinc of sediment.

CALCIUM

Calcium levels were observed to be high except for the monsoon months of June (394 mg/l) and July '84 (374 mg/l) and the values fluctuated between 404 to 438 mg/l in the rest of the study period. Calcium depicted significant positive correlation with salinity of water; and calcium of water and sediment. It depicted significant negative correlation with rainfall and zinc of water.

MAGNESIUM

Magnesium levels recorded were high except for the monsoon months of June (1115 mg/l) and July '84 (1059 mg/l), and the values fluctuated between 1137 to 1234 mg/l in rest of the study period. Magnesium exhibited significant positive correlation with salinity of water; and calcium of water and sediment. It depicted significant negative correlation with rainfall.

COPPER

Copper showed minor variation from November '82 to July '83 (5.2 to 5.4 µg/l) and higher values were recorded in August (7.6 µg/l), September (7.1 µg/l) and October (6.3 µg/l). Subsequently, low values occurred from November '83 to May '84 (5.0 to 5.4 µg/l). Thereafter, higher values were recorded from June (6.8 µg/l) to September (6.7 µg/l) with a maximum in July (8.8 µg/l). It, again, decreased to 5.6 µg/l in October. Copper depicted significant positive correlation with rainfall, net primary productivity, nitrite, ammonia and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment. It showed significant negative correlation with temperature, salinity, dissolved oxygen, Eh and pH of water; and with temperature, pH and calcium of sediment.

ZINC

Zinc was 7.5 µg/l in November '82 and subsequently, remained low (4.7 to 6.1 µg/l) upto June '83 followed by higher values (7.4 to 9.7 µg/l) upto November '83. In the subsequent year too, values were low up to May '84 and higher values (7.7 to 10.9 µg/l) occurred from June to October '84. The maximum values were recorded in September '83 (9.7 µg/l) and July '84 (10.9 µg/l). Zinc showed significant positive correlation with rainfall, net primary productivity, nitrate, nitrite, ammonia and copper of water; and with Eh, total phosphorus, copper and zinc of sediment. It depicted significant negative correlation with temperature, salinity, dissolved oxygen, pH and Eh of water; and with temperature, pH, calcium and magnesium of sediment.

PHYSICOCHEMICAL PARAMETERS OF SEDIMENT*

The results of the data on temperature, pH and Eh are presented in Figures 3.7, 3.9 and 3.11

TEMPERATURE

Temperature showed minor variations from November '82 (28.2°C) to April '83 (28.50°C) but decreased, subsequently, to a minimum value of 25.00°C by August followed by a gradual increase to 29.00°C by December. Thereafter, values varied

---

* For correlation values see table X A(station IV), XI A (station V) and XII A(station VI).

a little upto April '84 (28.00°C). Subsequently, it decreased gradually to a minimum value in August (24.20°C) followed by a gradual increase to 25.70°C by October. Sediment temperature exhibited significant positive correlation with temperature, salinity, dissolved oxygen, pH and Eh of water; and with pH, and magnesium of sediment. It depicted significant negative correlation with rainfall, net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh, total phosphorus, copper and zinc of sediment.

HYDROGEN ION CONCENTRATION (pH)

pH of sediment fluctuated between 7.00 to 8.00from November '82 to October '84 but no seasonal trend was observed. It showed significant positive correlation with temperature, dissolved oxygen, pH and Eh of water; and with temperature of sediment. It depicted significant negative correlation with net primary productivity, nitrate, nitrite, ammonia, copper and zinc of water; and with Eh and copper of sediment.

REDOX-POTENTIAL (Eh)

Eh values were relatively high (-277 to -320 mV) during monsoon period (i.e. July and August) each in 1983 and 1984. It remained low and showed fluctuating values

PHYSICOCHEMICAL PARAMETERS (SEDIMENT)
STATION IV

FIG. 3.7

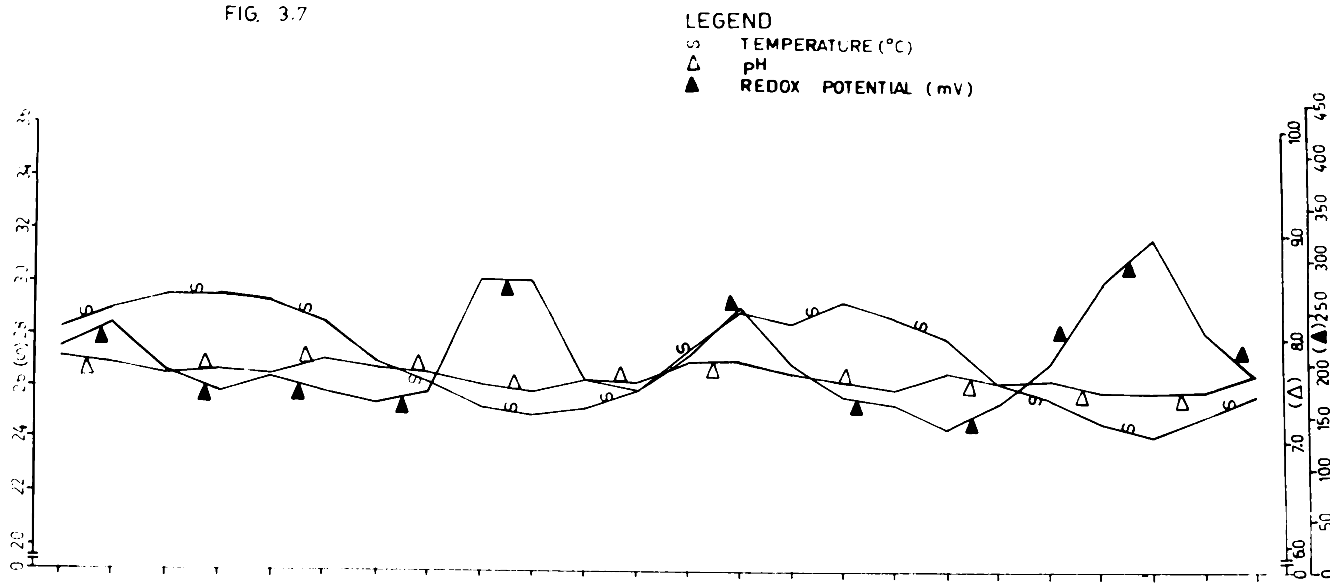
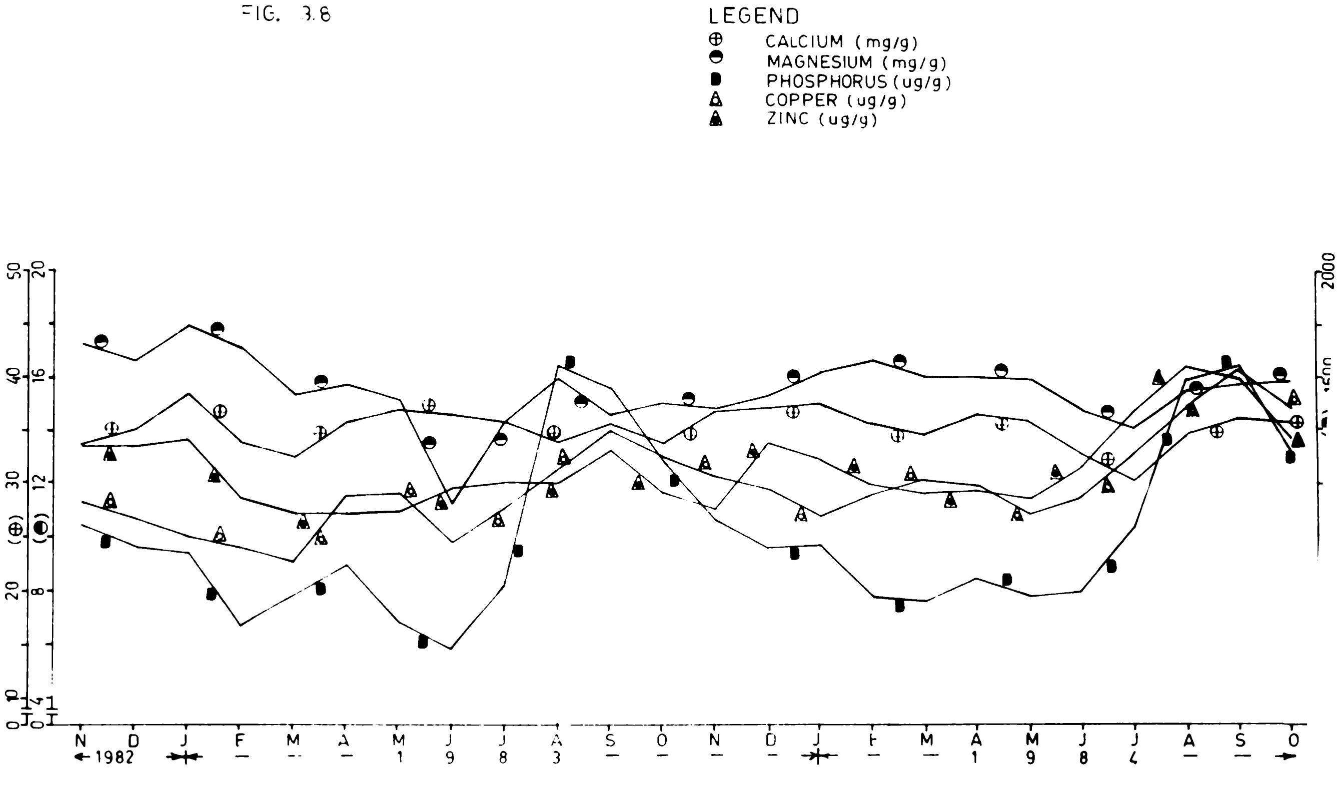


FIG. 3.8



PHYSICOCHEMICAL PARAMETERS (SEDIMENT)
STATION V

FIG. 3.9

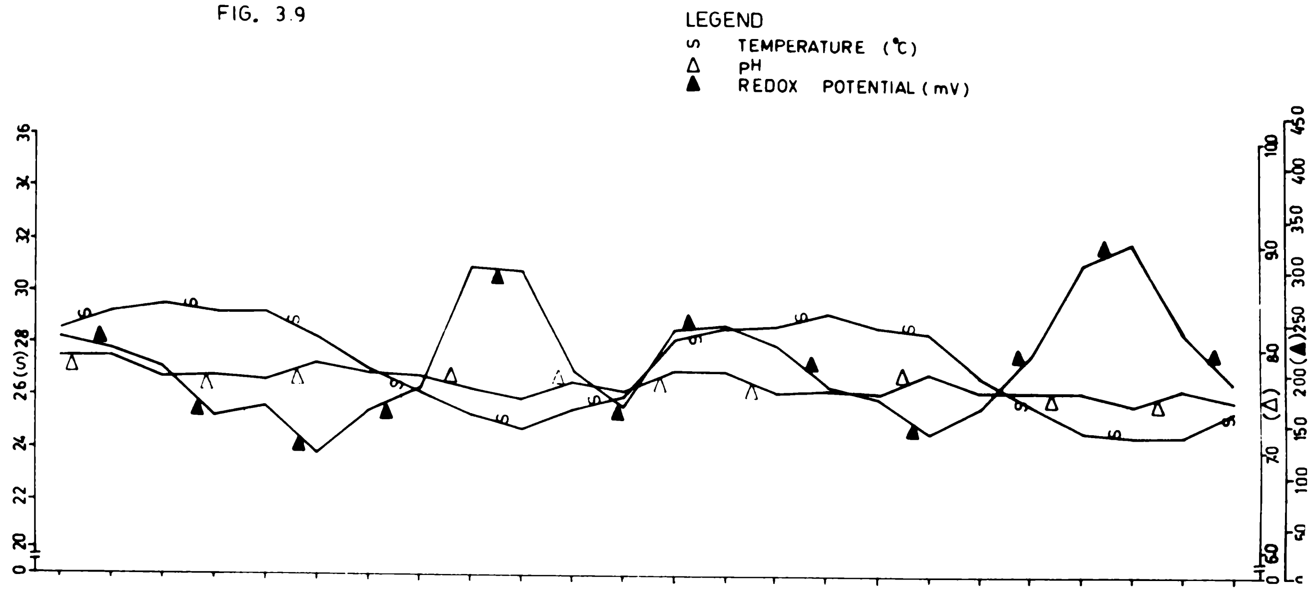
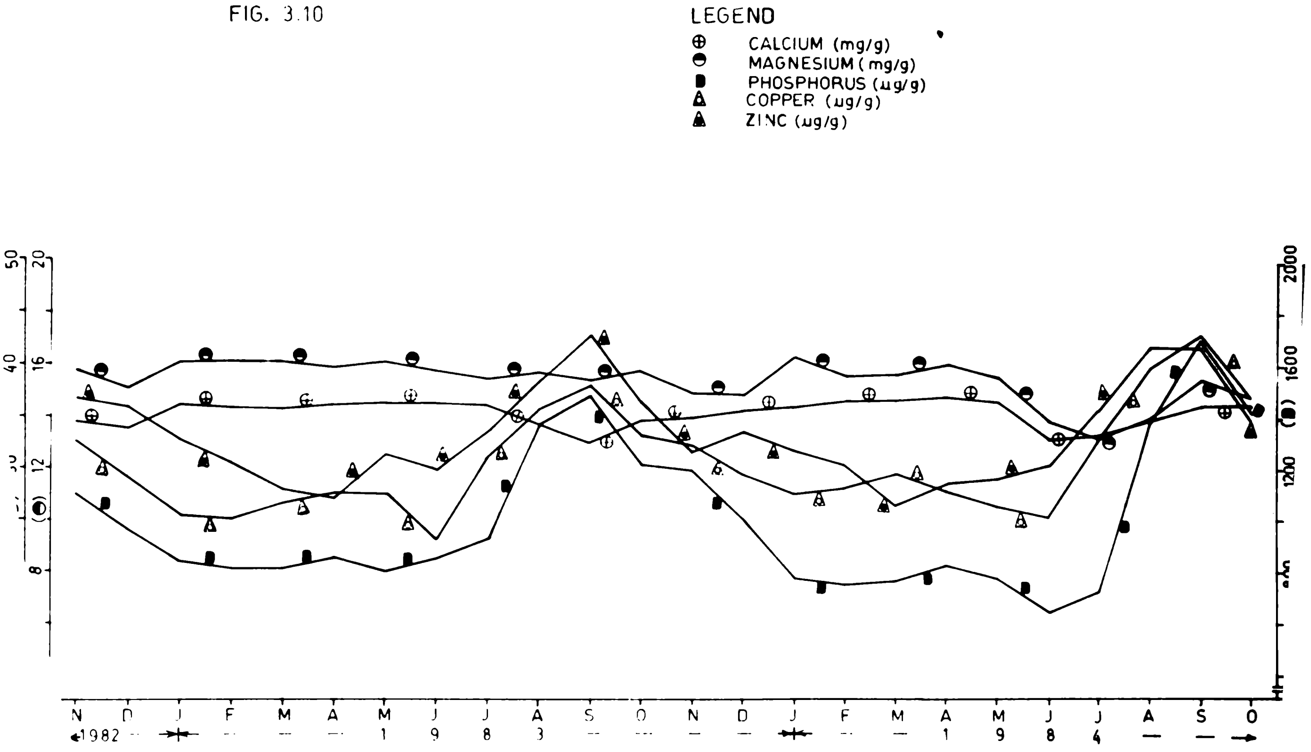


FIG. 3.10



PHYSICOCHEMICAL PARAMETERS (SEDIMENT)

STATION VI

FIG. 3.11

LEGEND

S TEMPERATURE (°C)
Δ pH
▲ REDOX POTENTIAL (mV)

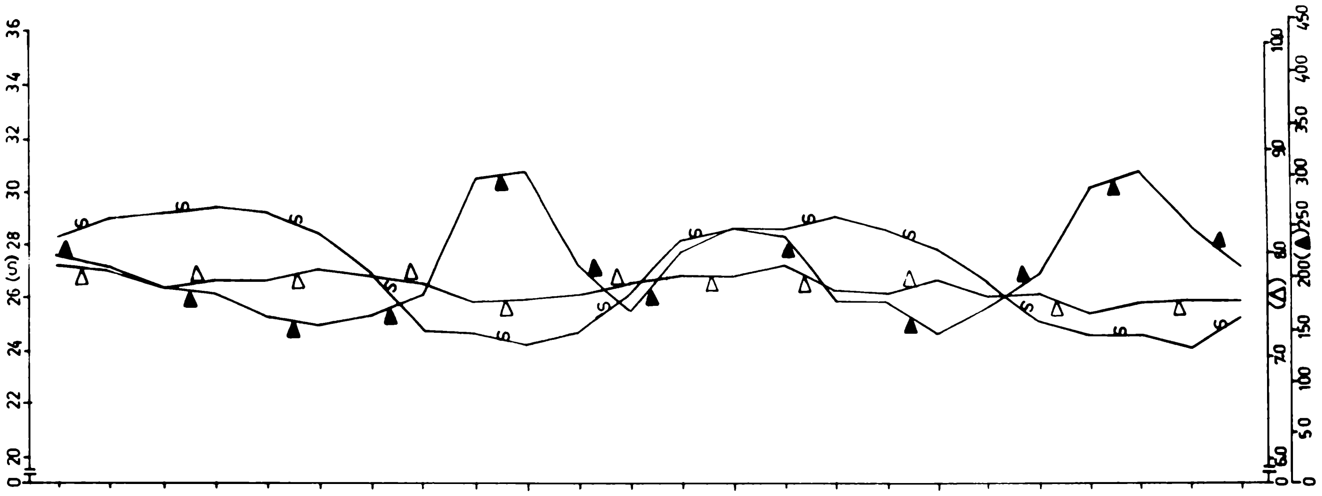
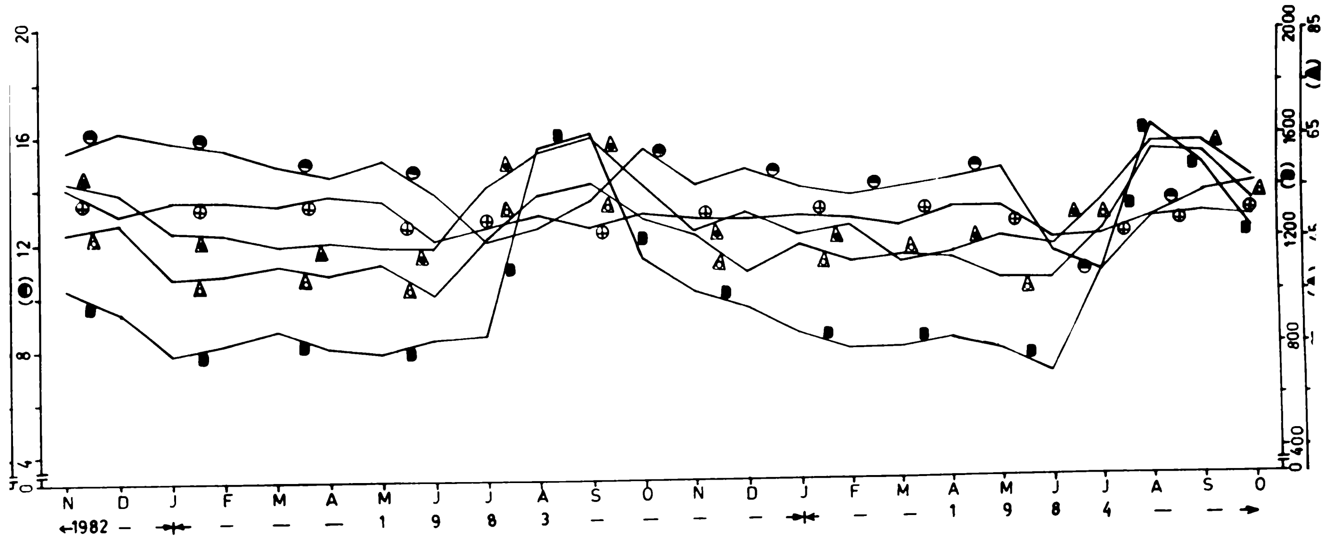


FIG. 3.12

LEGEND

⊕ CALCIUM (mg/g)
● MAGNESIUM (mg/g)
▮ PHOSPHORUS (ug/g)
Δ COPPER (ug/g)
▲ ZINC (ug/g)



(-137 to -235 mV) but for December '83 (-255 mV) in rest of the study period. Eh showed significant positive correlation with rainfall, net primary productivity, nitrate, ammonia, copper and zinc of water; and with total phosphorus, copper and zinc of sediment. It exhibited significant negative correlation with temperature, salinity, dissolved oxygen, pH and Eh of water; and with temperature and pH of sediment.

The results of the data on calcium, magnesium, total phosphorus, copper and zinc are presented in Figures 3.8, 3.10 and 3.12

CALCIUM

Calcium showed fluctuating values (32.3 to 37.5 mg/g) except for a slightly low value in July '84 (30.2 mg/g) without any seasonal trend from November '82 to October '84. Sediment calcium depicted significant positive correlation with salinity, dissolved oxygen, calcium and magnesium of water. It showed significant negative correlation with rainfall, copper, zinc, nitrate and net primary productivity of water.

MAGNESIUM

Magnesium concentrations of sediment were observed to be relatively low during June '83 (11.2 mg/g), July '83 (14.3 mg/g) and July '84 (14.1 mg/g). It showed higher values fluctuating between 14.6 to 17.8 mg/g in rest of the study period. It depicted significant positive correlation with temperature and pH of water; and with temperature of sediment. It depicted significant negative correlation with rainfall, nitrate and ammonia of water.

TOTAL PHOSPHORUS

Total phosphorus values were high in November '82 (1038 µg/g), from August to November (1057 to 1646 µg/g) in 1983 and from July to October (1027 to 1635 µg/g) in 1984; and maxima were recorded in August '83 (1646 µg/g) and September '84 (1635 µg/g). The values fluctuated between 583 to 956 µg/g during rest of the months. Total phosphorus of sediment showed significant positive correlation with net primary productiility, nitrate, copper and zinc of water; and with Eh, copper and zinc of sediment. It depicted significant negative correlation with temperature, dissolved oxygen, pH , Eh and total phosphorus of water; and with temperature, pH and magnesium of sediment.

COPPER

Copper values were high from August to October (47.4 to 54.7 µg/g) in 1983, and from July to October (50.5 to 66.5 µg/g) in 1984 with maxima in September '83 (54.7 µg/g) and September '84 (66.5 µg/g). The values were low, and fluctuated in the range of 30.0 to 46.4 µg/g for remaining months. Sediment copper showed significant positive correlation with net primary productivity, nitrate, ammonia, copper and zinc of water; and with Eh, total phosphorus and zinc of sediment. It depicted significant negative correlation with temperature, dissolved oxygen, pH, Eh and total phosphorus of water; and with temperature, pH and magnesium of sediment.

ZINC

Zinc values were high during November and December in 1982 and from July to December each in 1983 and 1984. The maximum values were recorded in September '83 and August '84. The values recorded were low in rest of the study period. Zinc of sediment showed significant positive correlation with net primary productivity, nitrate, ammonia, copper and zinc of water; and with Eh, total phosphorus, and copper of sediment. It depicted significant negative correlation with temperature, salinity, dissolved oxygen and pH of water; and with temperature of sediment.

BIOELEMENTS IN VARIOUS TISSUES OF MALE P. INDICUS*

CALCIUM

The results of the data on calcium in haemolymph exoskeleton, muscle, hepatopancreas and testis are presented in Figures 4.4, 4.5 and 4.6

HAEMOLYMPH

Haemolymph calcium concentrations were high and fluctuated between 0.738 to 0.761 mg/ml during the first year of study except for decreased values (0.713 to 0.718 mg/ml) during November and December in 1982; and September and October in 1983. In the second year too, decreased values occurred from June to August. It exhibited significant positive correlation with salinity of water; calcium of water, sediment, muscle, hepatopancreas and testis.

EXOSKELETON

Calcium values ranged between 113 to 132 mg/g from November '82 to October '84 and no seasonal trend was observed. It exhibited no significant correlation.

MUSCLE

Calcium depicted minor variations (4.096 to 4.360 mg/g) from November '82 to October '84 and no seasonal trend was

---

* For correlation values see table X B, X C (station IV); XI B, XI C (station V); XII B, XII C (station VI).

LEGEND

FROM FIG. 4·4 TO 4·6

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

CALCIUM IN ♂ PENAEUS INDICUS

FIG. 4.4 STATION IV

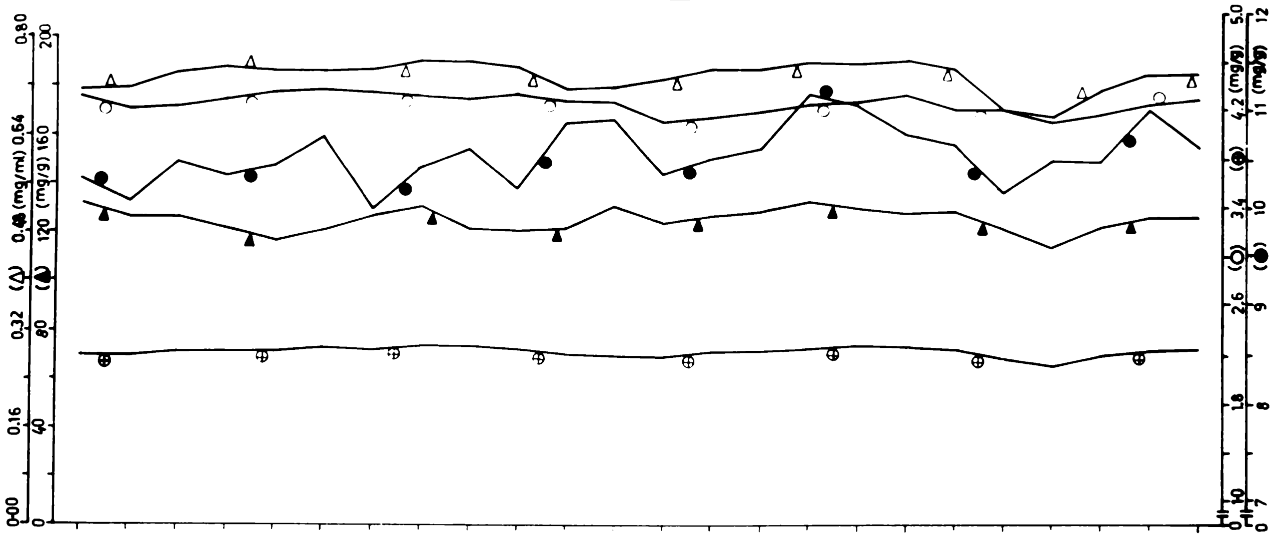


FIG. 4.5 STATION V

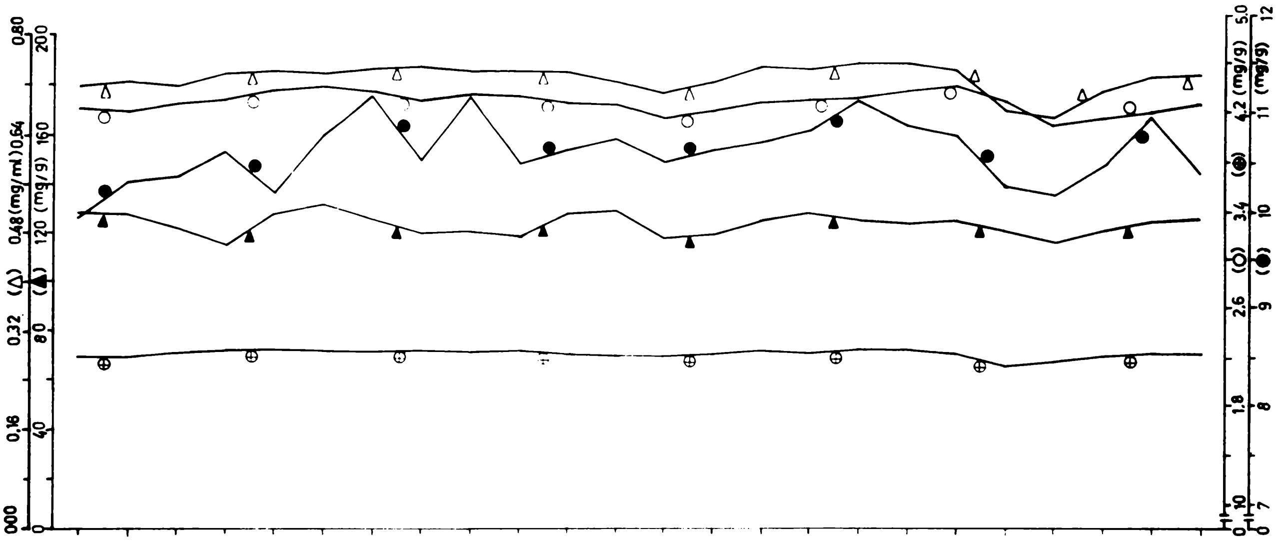
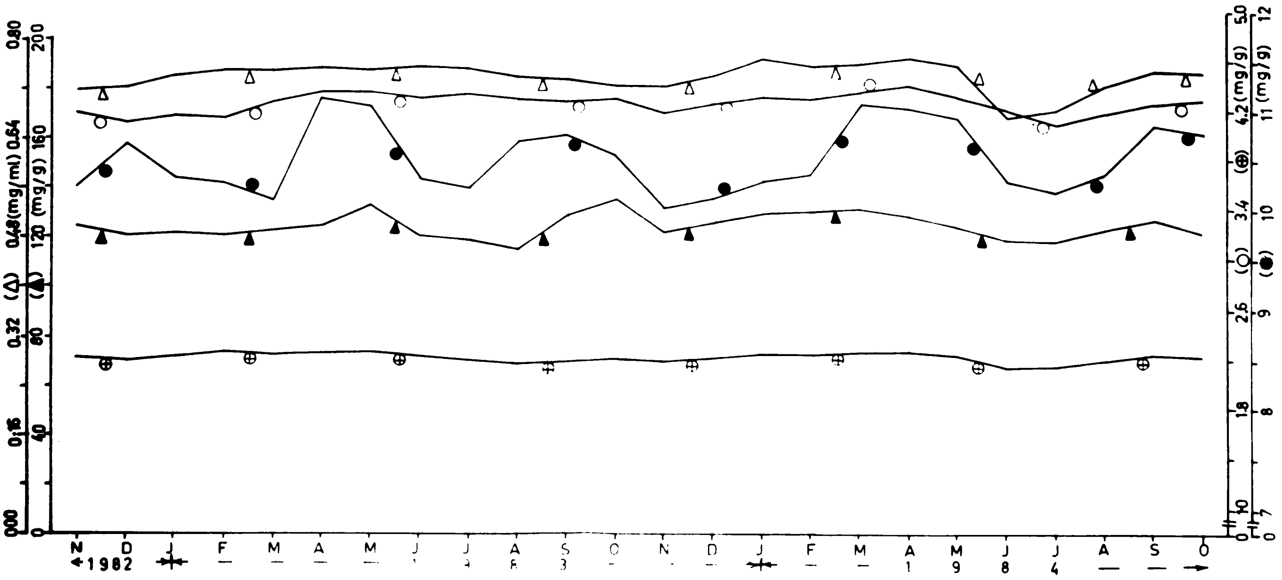


FIG. 4.6 STATION VI



observed. Calcium of muscle depicted significant positive correlation with salinity of water; and calcium of water, haemolymph and testis.

HEPATOPANCREAS

Calcium values fluctuated in the range of 10.083 to 11.154 mg/g from November '82 to October '84 but no seasonal trend was recorded. Hepatopancreatic calcium showed significant positive correlation with calcium of water, haemolymph and testis.

TESTIS

Calcium depicted minor variations (2.104 to 2.270 mg/g) from November '82 to October '84 and no seasonal trend was observed. Calcium of testis showed significant positive correlation with salinity of water; calcium of water, sediment, haemolymph, muscle and hepatopancreas.

MAGNESIUM

The results of the data on magnesium in haemolymph, exoskeleton, muscle, hepatopancreas and testis are presented in Figures 5.4, 5.5 and 5.6.

HAEMOLYMPH

Magnesium values fluctuated in the range of 139 to 160 µg/ml from November '82 to October '84 and no seasonal trend was observed. Haemolymph magnesium showed significant positive correlation with salinity of water; magnesium of water, exoskeleton, hepatopancreas, muscle and testis.

EXOSKELETON

Exoskeletal magnesium values fluctuated in the range of 7118 to 8205 µg/g from November '82 to October '84 and no seasonal trend was recorded. It exhibited significant positive correlation with salinity of water; magnesium of water, haemolymph and testis.

MUSCLE

Magnesium depicted minor variations (1245 to 1364 µg/g) from November '82 to October '84 but for a decreased value in July '84 (1160 µg/g) and no seasonal trend was noticed. Muscle magnesium showed significant positive correlation with salinity of water; magnesium of water, haemolymph, hepatopancreas and testis.

HEMATOPANCREAS

Magnesium showed minor variations (2514 to 2690 µg/g) from November '82 to October '84 but for a decreased value in July (2380 µg/g) and no seasonal trend was recorded. Hepatopancreatic magnesium showed significant positive correlation with salinity of water; magnesium of water, haemolymph, muscle and testis.

LEGEND

FROM FIG. 5·4 TO 5·6

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

TESTIS

Magnesium depicted minor fluctuations (980 to 1091 µg/g) from November '82 to October '84 but for relatively decreased values in December '82 (958 µg/g) and July '84 (994 µg/g) and no seasonal trend was recorded. Magnesium of testis showed significant positive correlation with salinity of water; magnesium of water, sediment, haemolymph, muscle and hepatopancreas.

PHOSPHORUS

The results of the data on phosphorus in haemolymph, exoskeleton, muscle, hepatopancreas and testis are presented in Figures 6.4, 6.5 and 6.6

HAEMOLYMPH

Phosphorus values fluctuated (39 to 51 µg/ml) very often from November '82 to October '84 but no seasonal trend was recorded. Haemolymph phosphorus showed no significant correlation.

EXOSKELETON

Exoskeletal phosphorus concentrations depicted minor variation (15350 to 18050 µg/g) from November '82 to October '84 and no seasonal trend was recorded. It depicted

LEGEND

FROM FIG. 6·4 TO 6·6

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

MAGNESIUM IN ♂ PENAEUS INDICUS

FIG. 5.4

STATION IV

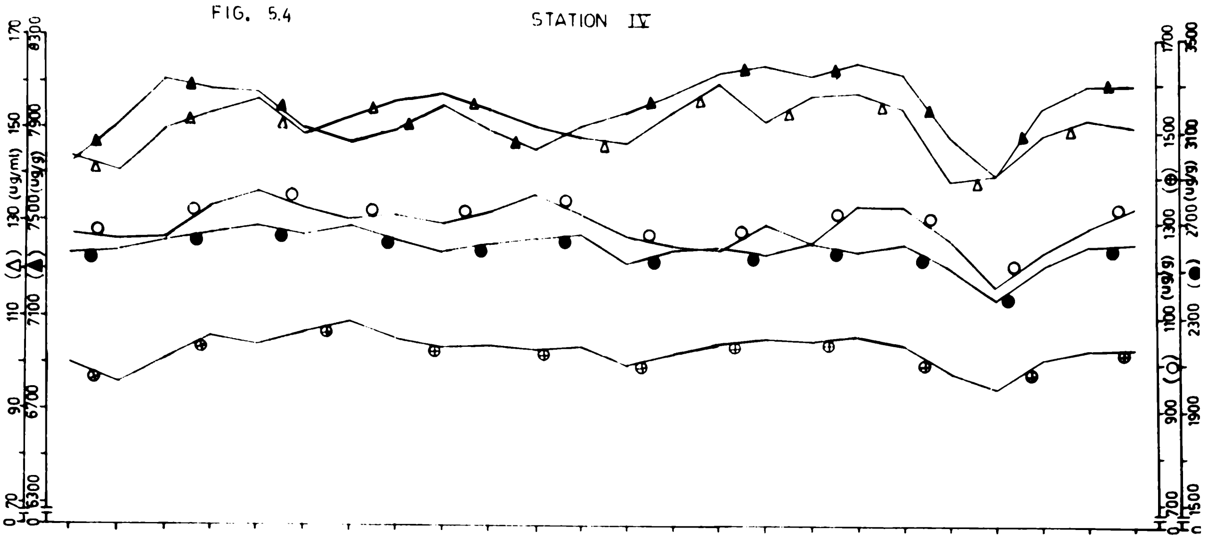


FIG. 5.5

STATION V

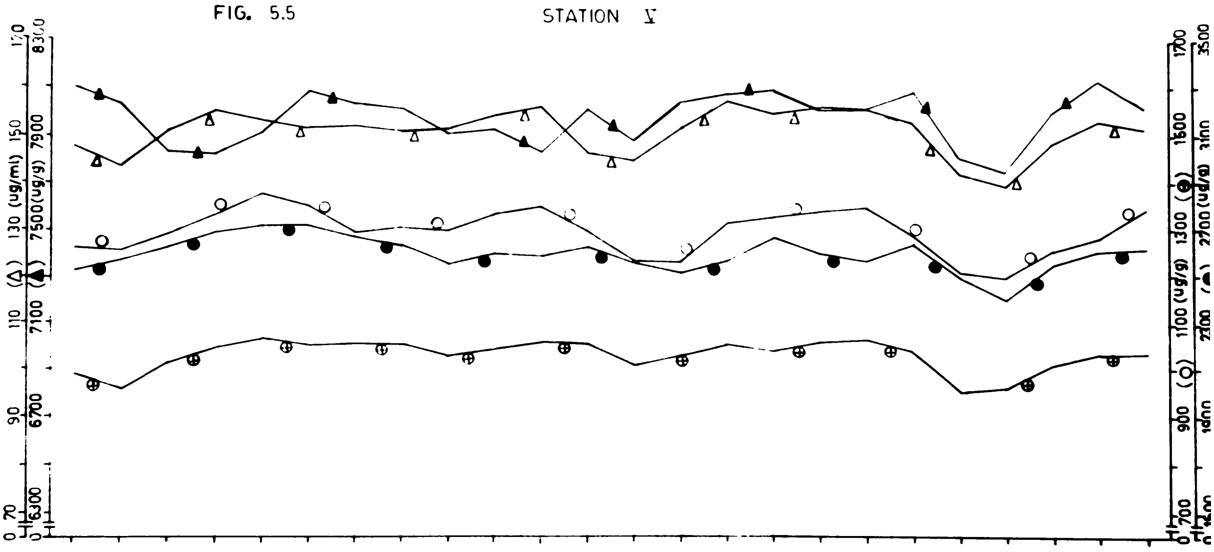
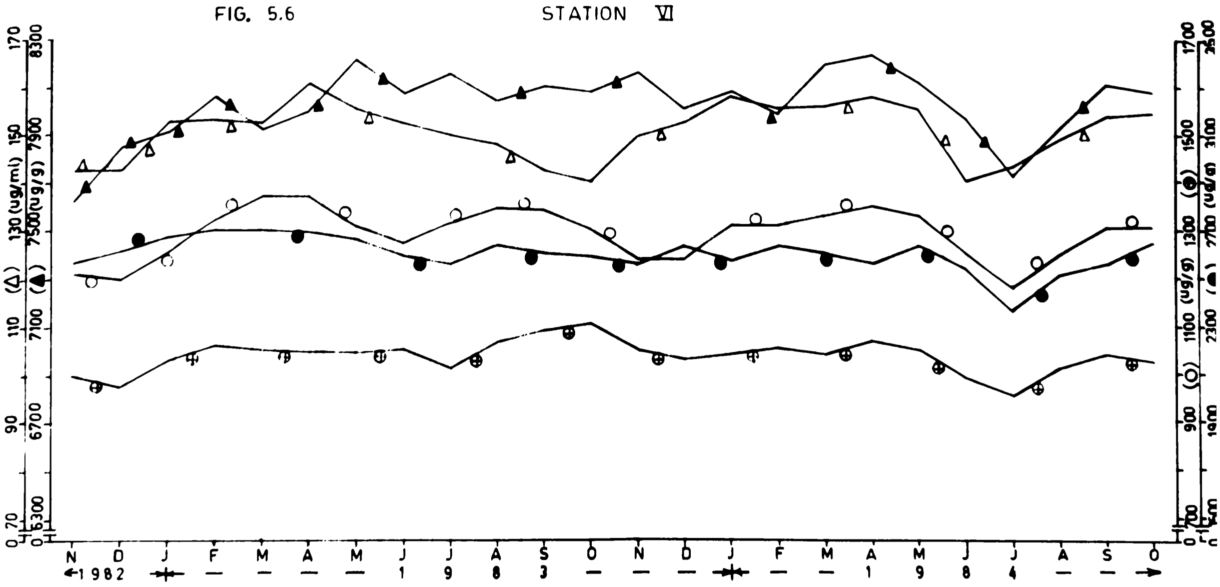


FIG. 5.6

STATION VI



PHOSPHORUS IN ♂ PENAEUS INDICUS

FIG. 6.4 STATION IV

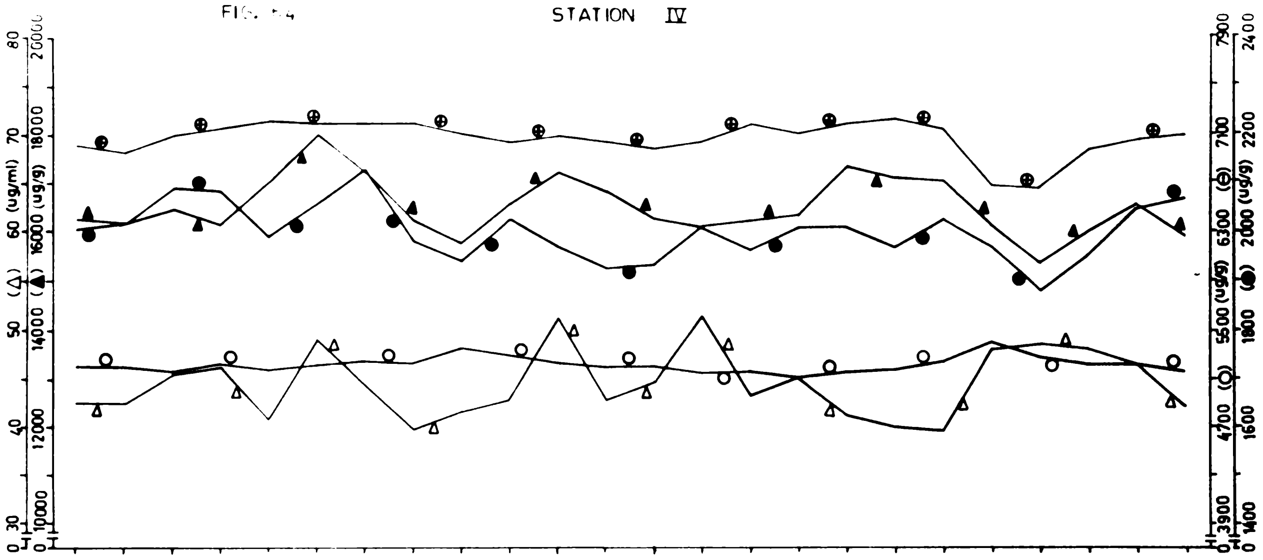


FIG. 6.5 STATION V

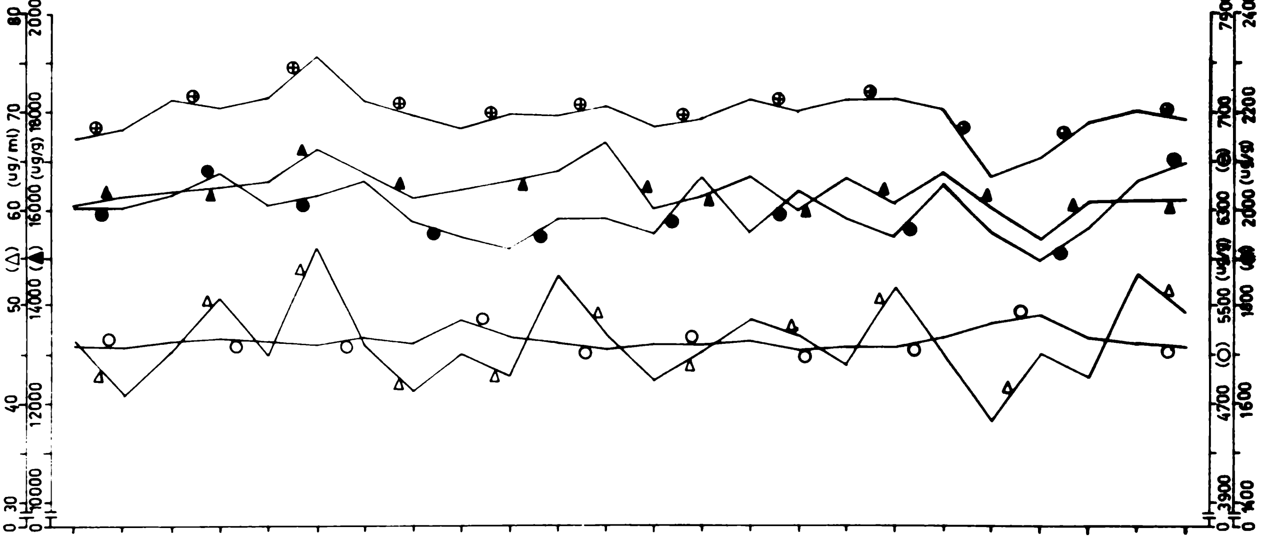
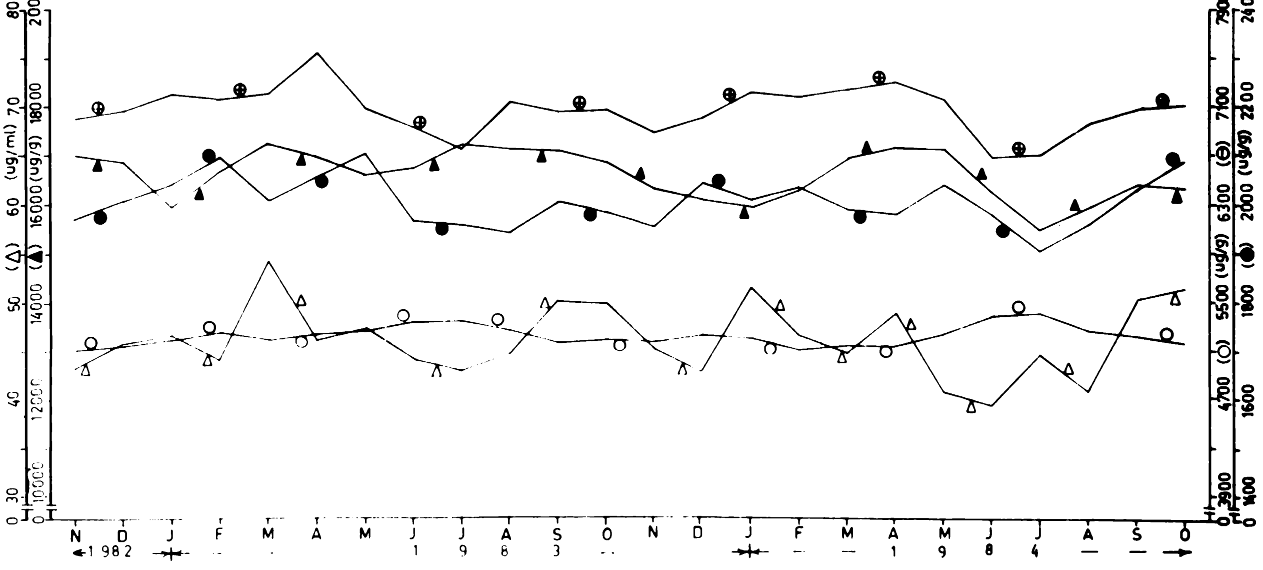


FIG. 6.6 STATATION VI



significant positive correlation with salinity of water; and phosphorus of testis.

MUSCLE

Phosphorus concentrations of muscle remained low and fluctuated between 5120 to 5240 µg/g except for slightly increased values in July '83 (5360 µg/g) and June '84 (5400 µg/g). It exhibited significant positive correlation with phosphorus of water; and significant negative correlation with salinity of water.

HEMATOPANCREAS

Phosphorus fluctuated in the range of 1880 to 2135 µg/g from November '82 to October '84 and no seasonal trend was noticed. Hepatopancreatic phosphorus showed significant positive correlation with salinity of water and magnesium of testis. It depicted no significant correlation.

TESTIS

Phosphorus depicted minor variations from November '82 (7020 µg/g) to May '84 (7160 µg/g), but decreased to 6680 µg/g in June followed by little variation in July (6660 µg/g). Subsequently, it increased to 7075 µg/g by October '84. Phosphorus of testis exhibited significant positive correlation with salinity of water; phosphorus of exoskeleton, hepatopancreas and muscle.

COPPER

The results of the data on copper in haemolymph, exoskeleton, muscle, hepatopancreas and testis are presented in Figures 7.4, 7.5 and 7.6

HAEMOLYMPH

Copper showed minor variations from November '82 (115.3 µg/ml) to June '83 (116 µg/ml) but thereafter, uniformly increased to 138.5 µg/ml by August followed by uniform decrease to 116.4 µg/ml by October.. In the subsequent year too, high values were recorded during July (138.5 µg/ml) and August (136.5 µg/ml). Haemolymph copper showed significant positive correlation with copper of water, sediment and muscle; and significant negative correlation with salinity of water.

EXOSKELETON

Copper showed minor fluctuations (20.8 to 24.2 µg/g) from November '82 to October '84 and no seasonal trend was recorded. Exoskeletal copper depicted no significant correlation.

MUSCLE

Copper showed minor fluctuations (21.9 and 23.0 µg/g) from November to June but increased values were recorded in

LEGEND

FROM FIG. 7·4 TO 7·6

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

COPPER IN ♂ PENAEUS INDICUS

FIG. 7.4 STATION IV

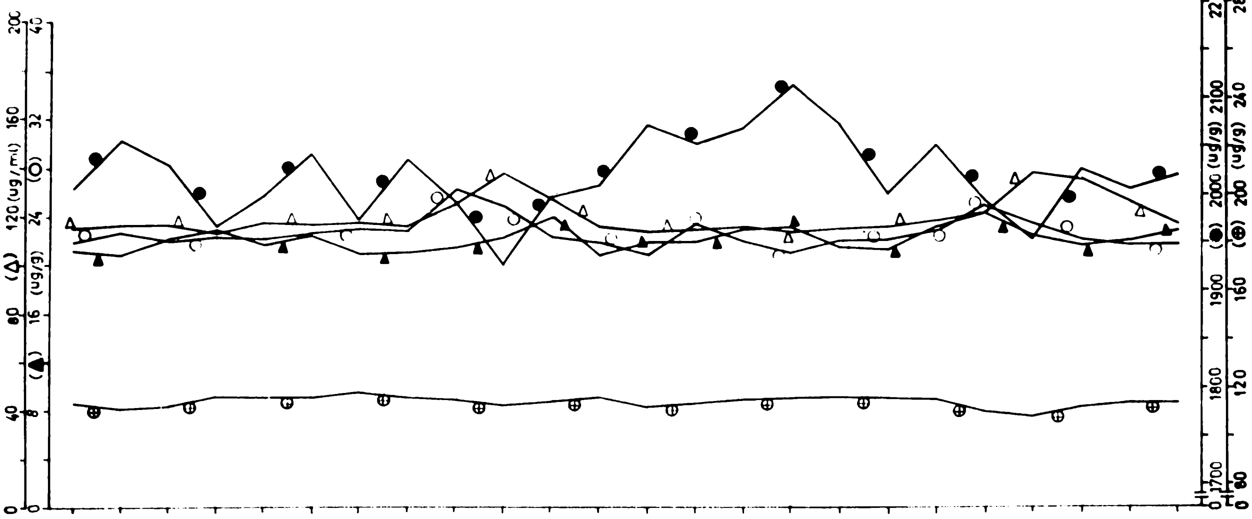


FIG. 7.5 STATION V

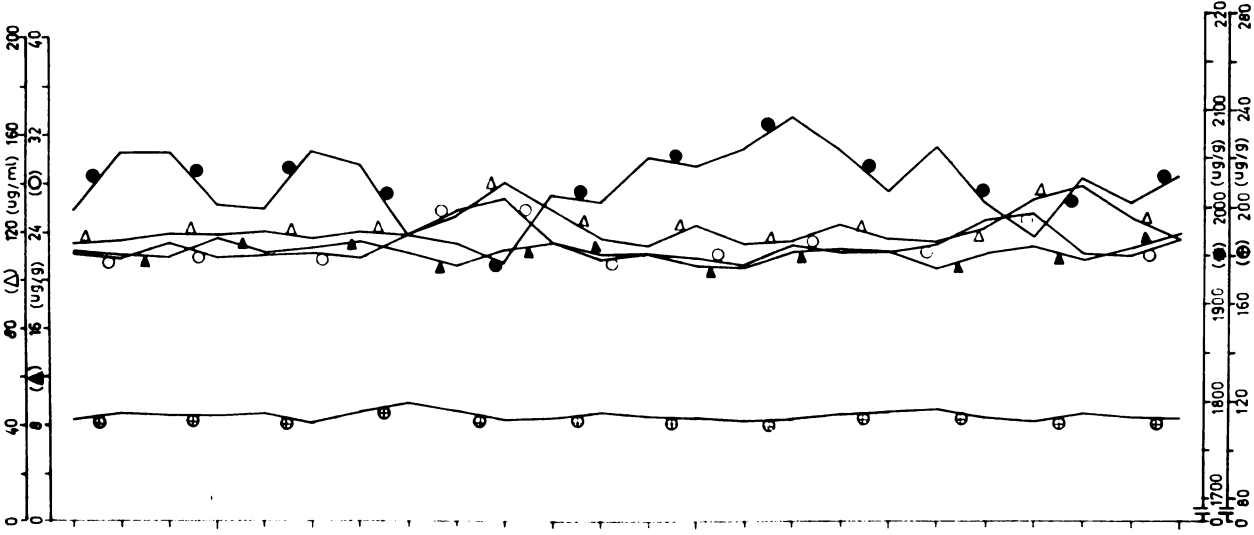
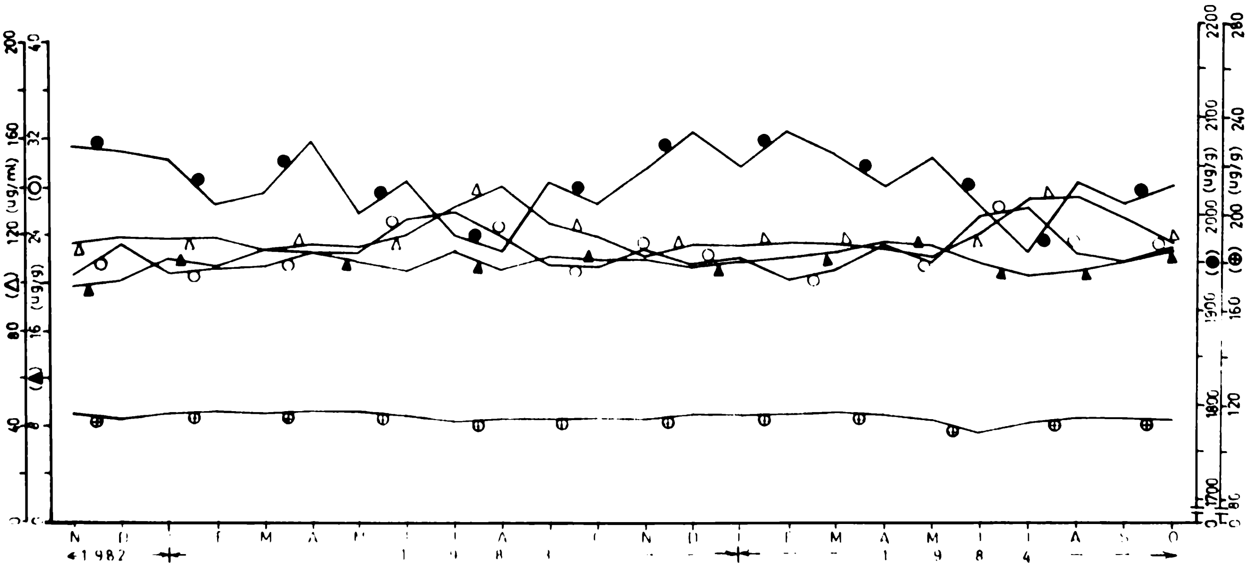


FIG. 7.6 STATION VI



July (26.4 µg/g) and August (24.9 µg/g) followed by decreased values. Thereupon, increased values were noticed during June and July months of the subsequent year. Muscle copper showed significant positive correlation with copper of haemolymph.

HEPATOPANCREAS

Hepatopancreatic copper concentrations remained high and fluctuated in the range of 1973 to 2129 µg/g except for the relatively decreased values in August '83 (1927 µg/g) and July '84 (1954 µg/g). It showed no significant correlation.

TESTIS

Copper showed minor variations (110.1 to 118.1 µg/g) from November '82 to October '84 and no seasonal trend was observed. It showed no significant correlation.

ZINC

The results of the data on zinc in haemolymph exoskeleton, muscle, hepatopancreas and testis are presented in Figures 8.4, 8.5 and 8.6

HAEMOLYMPH

Zinc depicted minor variations from November '82 (11.6 µg/ml) to June '83 (12.8 µg/ml) and subsequently, increased to 18.1 µg/ml by August followed by a decrease to 13.8 µg/ml in September. In the following year too, increased values were observed during monsoon period. Haemolymph zinc exhibited significant positive correlation with zinc of water, sediment and muscle.

EXOSKELETON

Zinc values fluctuated in the range of 53.1 to 57.4 µg/g from November '82 to October '84 and no seasonal trend was recorded. Exoskeletal zinc depicted no significant correlation.

MUSCLE

Muscle concentrations of zinc remained relatively low and depicted minor fluctuations (50.1 to 52.1 µg/g) from November '82 to October '83 except for slightly increased values in July (53.6 µg/g) and August (56.0 µg/g). In the subsequent year, increased zinc values were recorded during July. Muscle zinc showed significant positive correlation with zinc of water and haemolymph; and significant negative correlation with zinc of hepatopancreas.

HEPATOPANCREAS

Zinc showed minor variations from November '82 to May '83 (679 to 712 ug/g) but low levels were noticed during June (640 µg/g), July (642 µg/g) and August(653 µg/g)

LEGEND

FROM FIG. 8·4 TO 8·6

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	TESTIS

ZINC IN ♂ PENAEUS INDICUS

FIG. 8.4 STATION IV

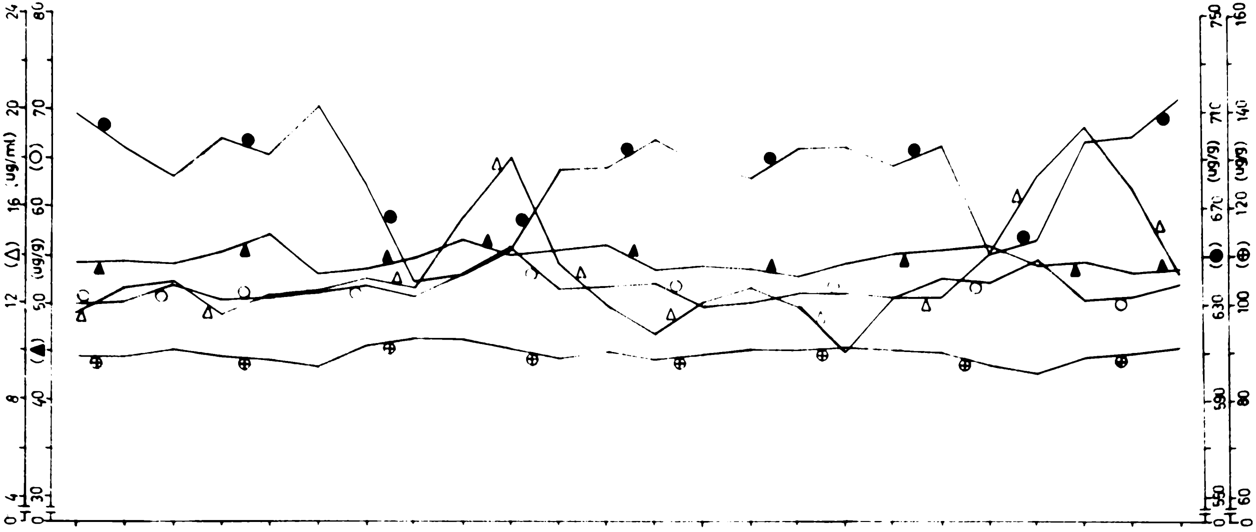


FIG. 8.5 STATION V

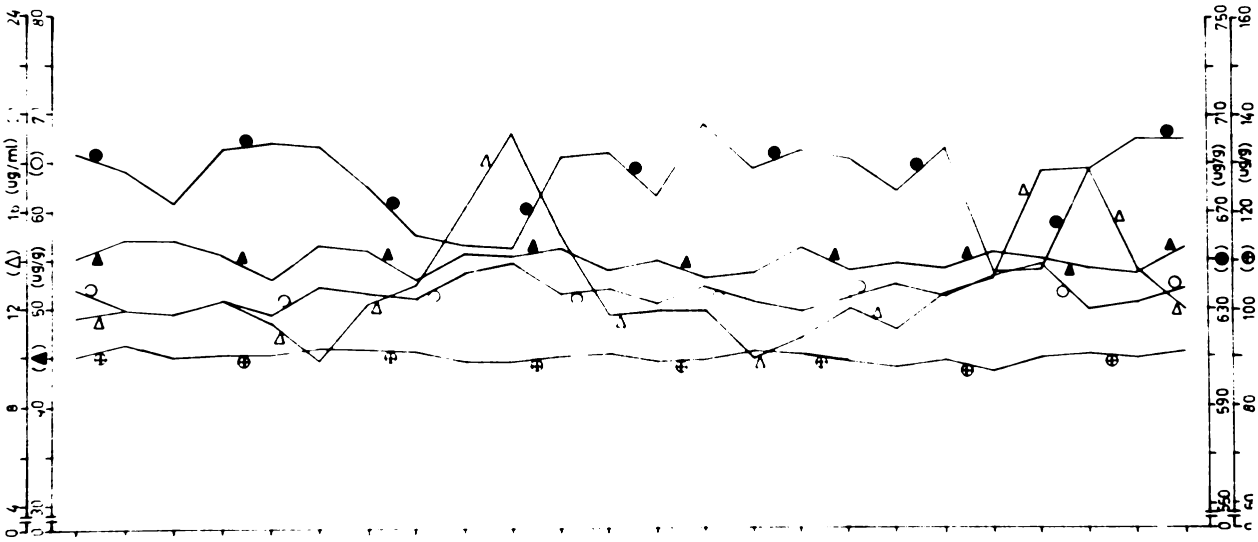
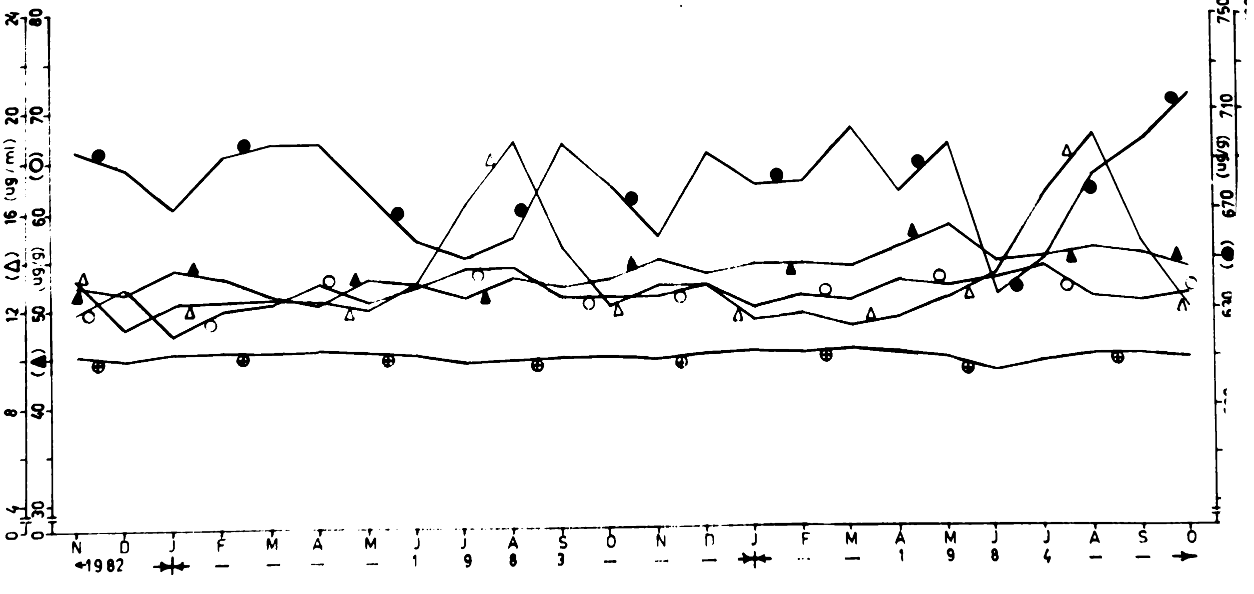


FIG. 8.6 STATION VI



and thereafter, high values were recorded upto October (687 µg/g). In the subsequent year too, low values were recorded during monsoon period. Hepatopancreatic zinc showed significant positive correlation with zinc of haemolymph; and significant negative correlation with zinc of muscle.

TESTIS

Zinc depicted minor variations (86.0 to 93.0 µg/g) from November '82 to October '84 and no seasonal trend was observed. Zinc of testis showed no significant correlation.

BIOELEMENTS IN VARIOUS TISSUES OF FEMALE P. INDICUS*

CALCIUM

The results of the data on calcium in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are given in Figures 4.10, 4.11 and 4.12

HAEMOLYMPH

In the first year, calcium concentrations increased gradually from 0.710 mg/ml in November to 0.748 mg/ml in February and subsequently, remained high and varied a little upto August (0.748 mg/ml). Decreased levels of calcium

---

* For correlation values (r) see Table X B, X C (station IV); XI B, XI C (station V); and XII B & XII C (station VI).

LEGEND

FROM FIG. 4·10 TO 4·12

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

CALCIUM IN ♀ PENAEUS INDICUS

FIG. 4.10 STATION IV

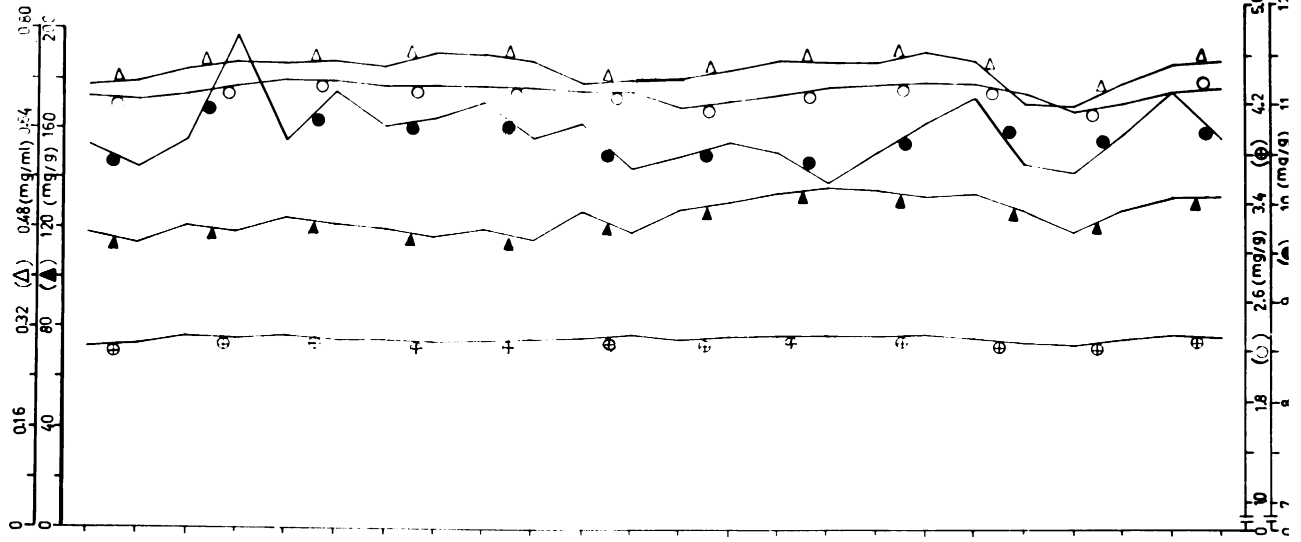


FIG 4.11 STATION V

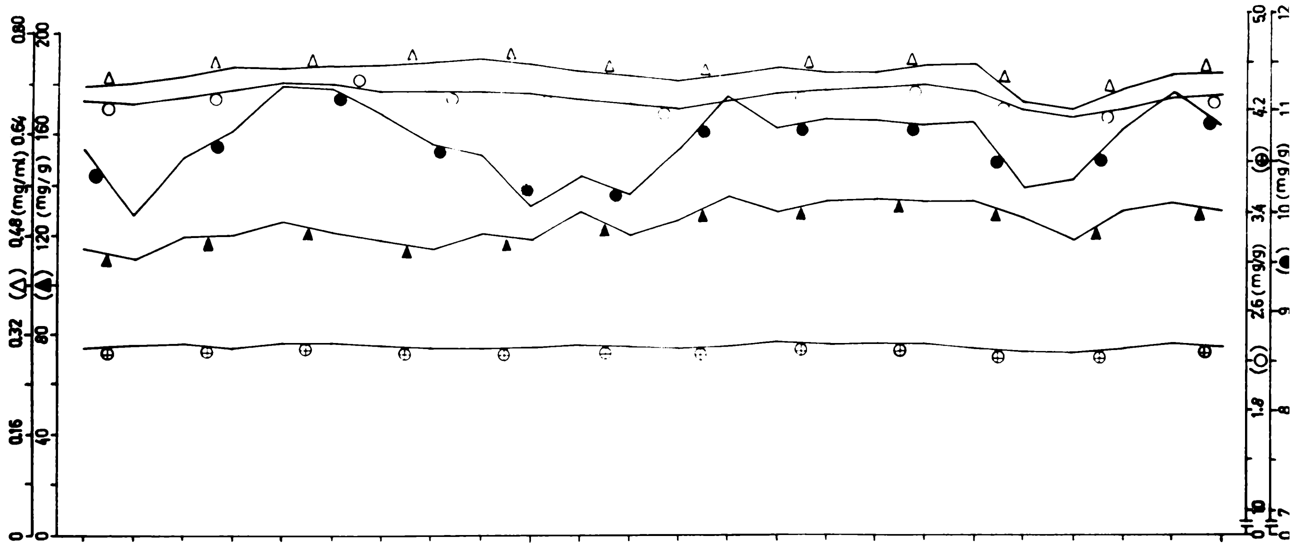
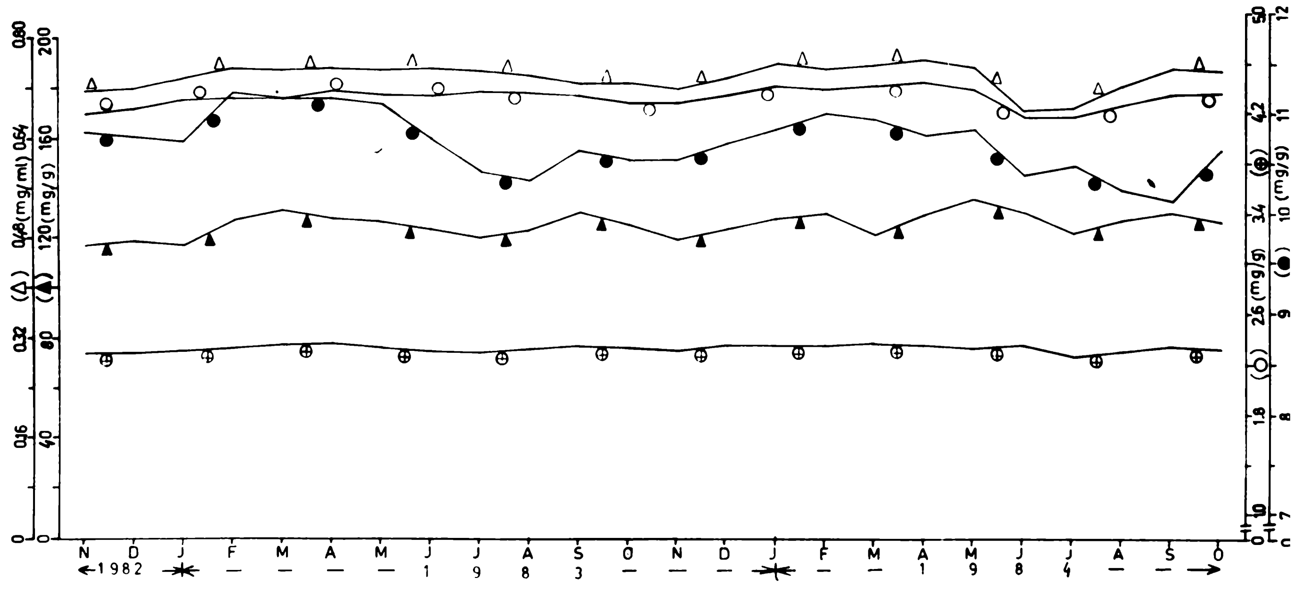


FIG 4.12 STATION VI



were noticed in September (0.714 mg/ml), October (0.721 mg/ml) and November (0.722 mg/ml). In the second year, decreased values were recorded in June (0.682 mg/ml), July (0.674 mg/ml) and August (0.713 mg/ml). Haemolymph calcium exhibited significant positive correlation with salinity of water; calcium of water, sediment, muscle, hepatopancreas and ovary.

EXOSKELETON

Calcium concentrations showed fluctuating levels (114 to 136 mg/g) from November '82 to October '84 and no seasonal trend was observed. Exoskeletal calcium showed significant positive correlation with calcium of ovary.

MUSCLE

Calcium showed fluctuating values (4.141 to 4.390 mg/g) from November '82 to October '84 and no seasonal trend was recorded. Muscle calcium depicted significant positive correlation with salinity of water; and calcium of water, haemolymph, hepatopancreas and ovary.

HEPATOPANCREAS

Low values of calcium were recorded from August to October (10.041 to 10.223 mg/g) in 1983, and also during June (10.234 mg/g) and July (10.296 mg/g) in 1984. Calcium concentration remained relatively high (10.546 to 11.223 mg/g) in rest of the months. Hepatopancreatic calcium showed significant positive correlation with salinity of water; and calcium of haemolymph and muscle.

OVARY

Calcium remained almost steady from November '82 to October '84 (2.231 to 2.324 µg/g) and showed little seasonal variations. Calcium of ovary showed significant positive correlation with salinity of water; and calcium of water, haemolymph, exoskeleton and muscle.

MAGNESIUM

The results of the data on magnesium in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are presented in Figures 5.10, 5.11, and 5.12

HAEMOLYMPH

Relatively low values of magnesium were recorded in November (148 µg/ml) and December (146 µg/ml) in 1982, September to November (142 to 149 µg/ml) in 1983, and during June (143 µg/ml) and July (144 µg/ml) in 1984. Magnesium levels were high and ranged between 152 to 158 µg/ml in rest of the study period. Haemolymph magnesium

LEGEND

FROM FIG. 5·10 TO 5·12

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

MAGNESIUM IN ♀ PENAEUS INDICUS

FIG. 5.10 STATION IV

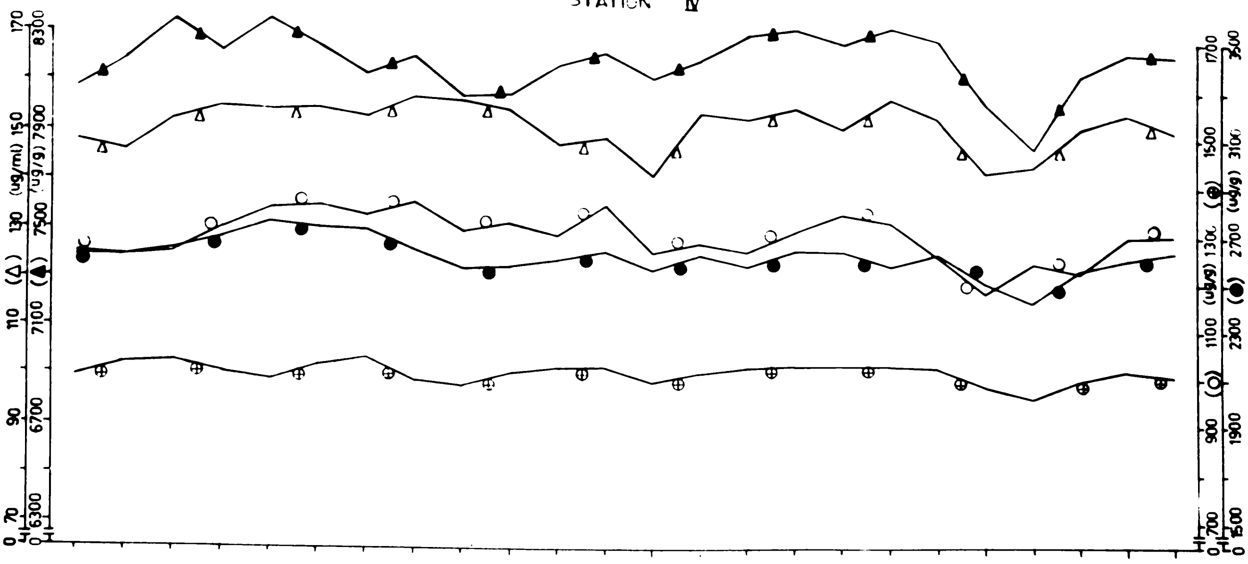


FIG. 5.11 STATION V

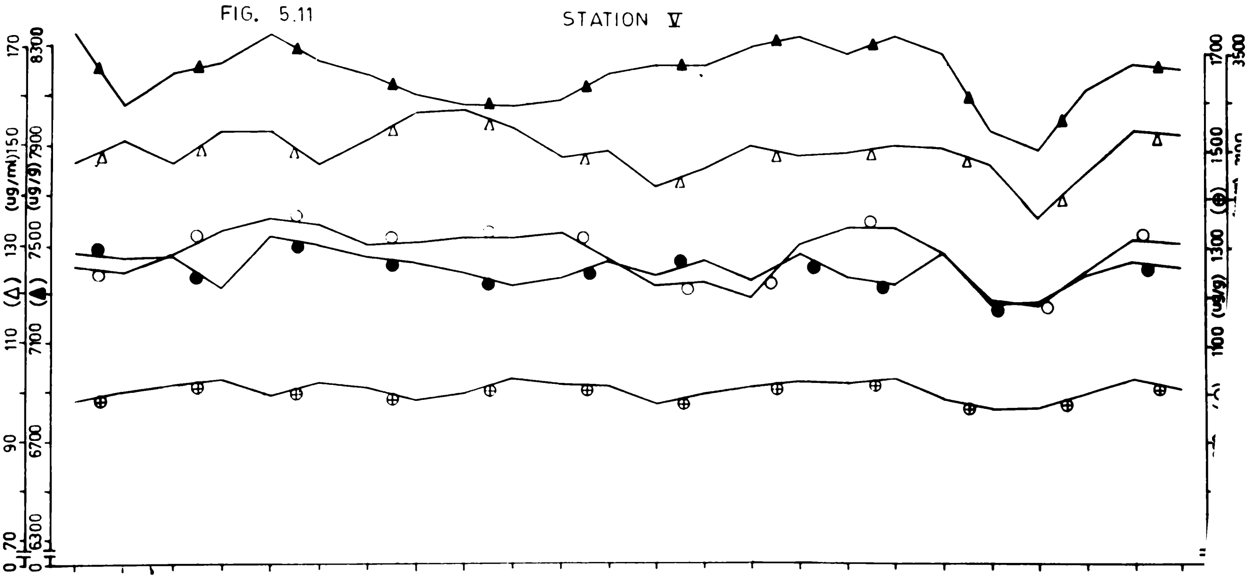
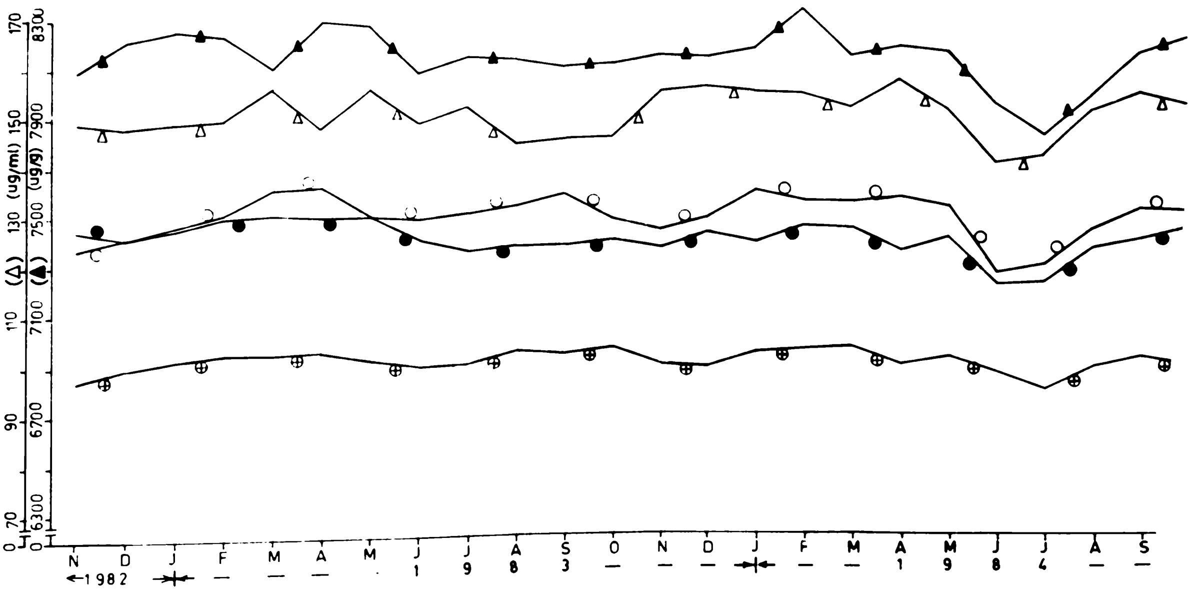


FIG. 5.12 STATION VI



showed significantly positive correlation with salinity of water; magnesium of water, sediment, muscle, hepatopancreas and ovary.

EXOSKELETON

Magnesium values were relatively low during November '82 (8074 µg/g), July (8060 µg/g) and August (8071 µg/g) in 1983 and during June (8039 µg/g) and July (7863 µg/g) in 1984. Magnesium levels were slightly high and varied between 8137 to 8354 µg/g in rest of the period. Exoskeletal magnesium exhibited significant positive correlation with salinity of water; magnesium of water, sediment, muscle, hepatopancreas and ovary.

MUSCLE

Magnesium concentrations remained high and fluctuated between 1221 to 1357 µg/g except for the low value of 1179 µg/g in June '84, and no seasonal variation was observed. Magnesium of muscle depicted significant positive correlation with salinity of water; and magnesium of water, haemolymph, exoskeleton, hepatopancreas and ovary.

HEPATOPANCREAS

Magnesium values were low during November and December (2591 µg/g) in 1982; July (2552 µg/g) and August (2556 µg/g) and August (2556 µg/g) in 1983; and in June (2500 µg/g), July

(2419 μg/g) and August (2550 μg/g) in 1984. It was high for the rest of the period and ranged between 2594 to 2728 μg/g. Hepatopancreatic magnesium showed significant positive correlation with salinity of water; and magnesium of haemolymph, exoskeleton and muscle.

OVARY

Magnesium showed minor variations ranging between 980 to 1035 μg/g and no seasonal trend was recorded. Magnesium of ovary showed significant positive correlation with salinity of water; and magnesium of water, haemolymph, exoskeleton and muscle.

PHOSPHORUS

The results of the data on phosphorus in haemolymph, exoskeleton, muscle, hepatopancreas and ovary one given in Figures 6.10, 6.11 and 6.12

HAEMOLYMPH

Phosphorus depicted erratic values from November '82 to October '84 and no seasonal trend was noticed except that a low value of 33 μg/ml was recorded in May '83. The values ranged between 39 to 60 μg/ml in rest of the period. Haemolymph phosphorus showed no significant correlation.

LEGEND

FROM FIG. 6·10 TO 6·12

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

PHOSPHORUS IN ♀ PENAEUS INDICUS

FIG. 6.10 STATION IV

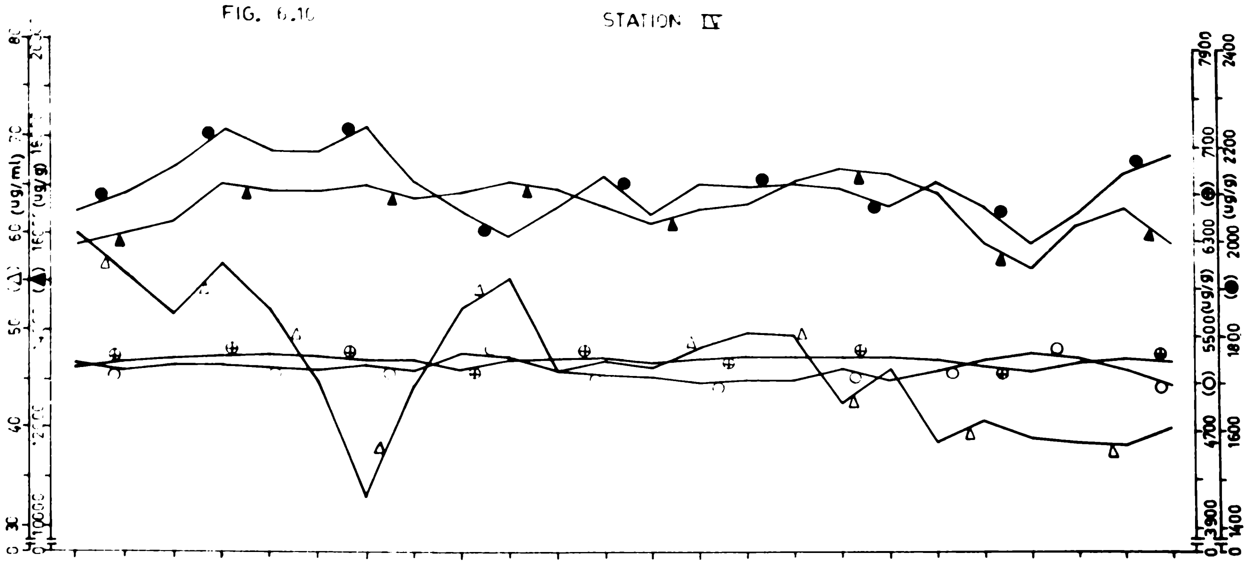


FIG. 6.11 STATION V

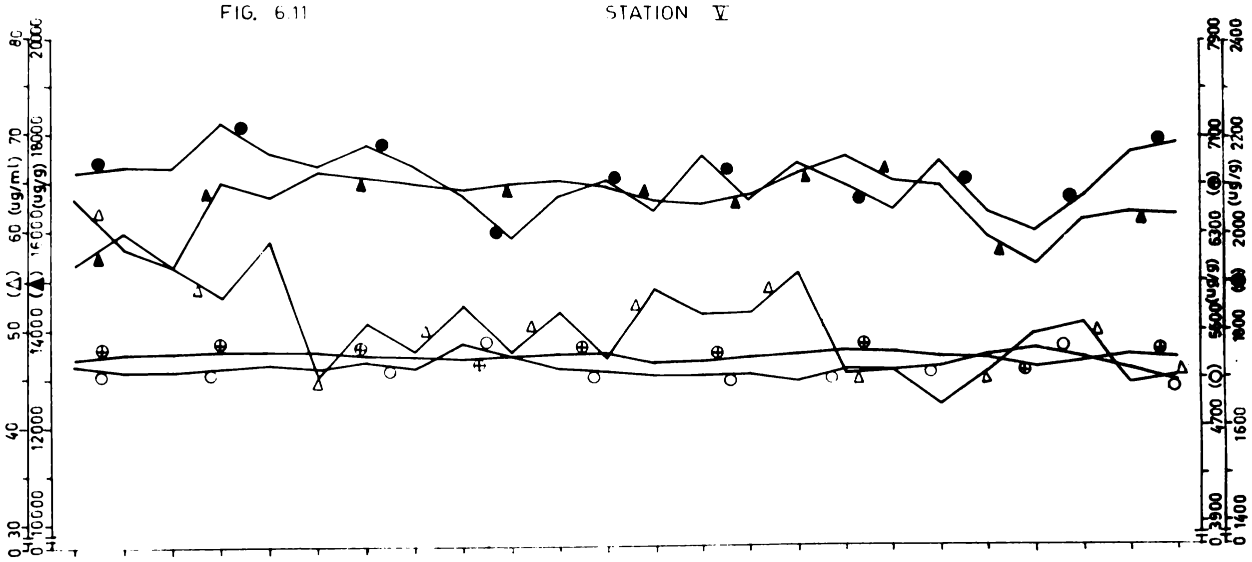
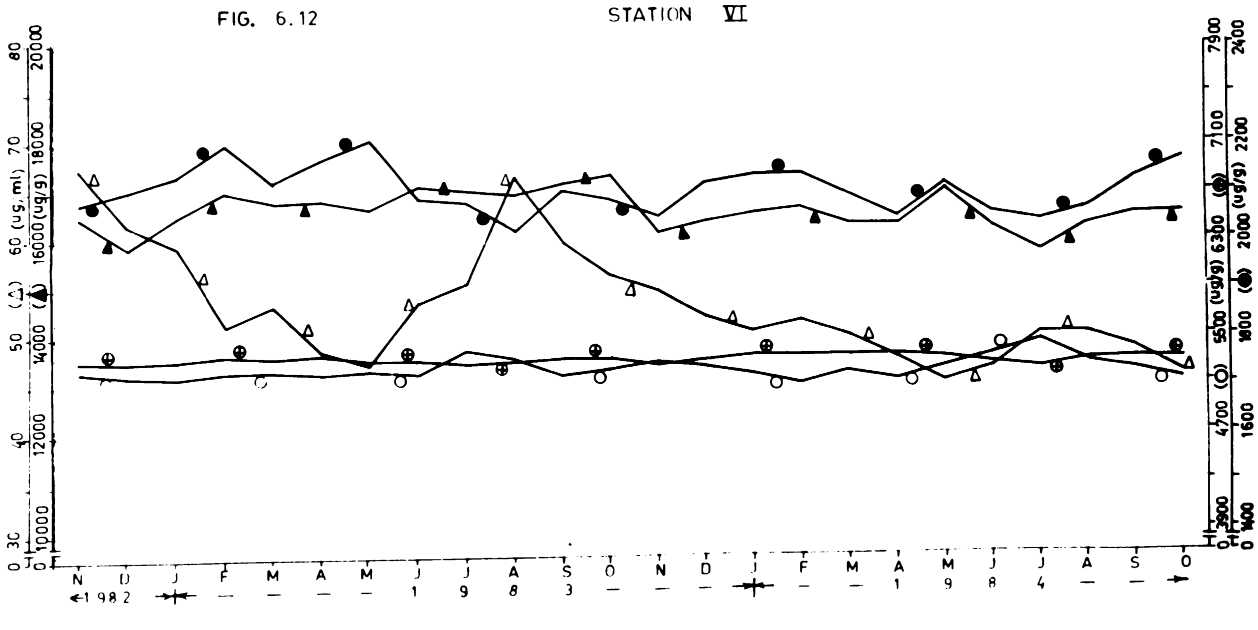


FIG. 6.12 STATION VI



EXOSKELETON

Phosphorus concentration showed fluctuating values from November '82 to October '84 and no seasonal trend was noticed except that decreased values were recorded in monsoon of 1984 [June 15095 µg/g, July 15042 µg/g]. Values ranged between 15080 to 17052 µg/g in remaining months of the study period. Exoskeletal phosphorus depicted significant positive correlation with salinity of water; and phosphorus of ovary.

MUSCLE

Phosphorus showed minor fluctuations from November '82 to October '84 and no seasonal trend was observed except that values were slightly high during monsoon of 1983 [July (5340 µg/g), August (5300 µg/g)] and 1984 [(5300 µg/g), July (5360 µg/g), August (5320 µg/g)]. The values ranged between 5090 to 5240 µg/g in rest of the study period. Muscle phosphorus showed significant negative correlation with salinity of water; phosphorus of hepatopancreas and ovary.

HEPATOPANCREAS

Phosphorus increased gradually from 2050 µg/g in November '82 to 2320 µg/g in May '83 and thereafter, decreased to 2005 µg/g by August. Subsequently, it increased to 2130 µg/g by October. In the subsequent year too, low values occurred during monsoon period (1995 µg/g in July). Hepatopancreatic phosphorus depicted significant positive correlation with salinity of water; and significant negative correlation with phosphorus of muscle.

OVARY

Phosphorus varied a little from November '82 to October '84 and no seasonal trend was recorded except that values slightly decreased during monsoon period of 1983 (July 5200 µg/g) and 1984 (June 5240 µg/g, July 5200 µg/g). Values ranged between 5260 to 5320 µg/g in rest of the study period. Phosphorus of ovary exhibited significant positive correlation with salinity of water; phosphorus of exoskeleton and hepatopancreas. It showed significant negative correlation with phosphorus of muscle.

COPPER

The results of the data on copper in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are presented in Figures 7.10, 7.11 and 7.12

HAEMOLYMPH

Copper values were high during August (141.1 µg/ml) and September (136.9 µg/ml) in 1983 and during July

LEGEND

FROM FIG. 7·10 TO 7·12

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

(134.4 µg/ml), August (140.8 µg/ml) and September (128.9 µg/ml) in 1984. It remained low and fluctuated between 113.5 to 123.2 µg/ml in rest of the period of observation. Haemolymph copper depicted significant positive correlation with copper of water, sediment and muscle; and significant negative correlation with copper of hepatopancreas.

EXOSKELETON

Copper showed minor variation from November '82 to October '84 and all values fluctuated between 17.8 to 22.9 µg/g. It depicted no seasonal trend and showed no significant correlation.

MUSCLE

Copper values were high during monsoon of 1983 [i.e. July (23.2 µg/g), August (24.5 µg/g)] and 1984 [i.e. June (23.7 µg/g), July (25.9 µg/g), August (22.7 µg/g)]. Copper values remained low (18.4 to 21.2 µg/g) in rest of the months. Muscle copper depicted significant positive correlation with copper of water and haemolymph. It showed significant negative correlation with salinity of water; copper of hepatopancreas and ovary.

HEPATOPANCREAS

Copper values were low during July (2075 µg/g) and August (2070 µg/g) of 1983, and during July (2067 µg/g) and September (2077 µg/g) of 1984. For the rest of the period, high values between the range of 2101 to 2167 µg/g have been recorded. Hepatopancreatic copper exhibited significant positive correlation with salinity of water; and significant negative correlation with copper of sediment, haemolymph and muscle.

OVARY

Copper showed minor variations (212.4 to 221.5 µg/g) from November '82 to October '84 and no seasonal trend was recorded. Copper of ovary showed significant positive correlation with salinity of water; and copper of muscle.

ZINC

The results of the data on zinc in haemolymph, exoskeleton, muscle, hepatopancreas and ovary are presented in Figures 8.10, 8.11 and 8.12

HAEMOLYMPH

Zinc concentrations of haemolymph were high from July to September each in 1983 (15.3 to 19.8 µg/ml) and 1984 (14.6 to 19.0 µg/ml). Values were low, fluctuating between 12.4 to 13.7 µg/ml in rest of the study period. Haemolymph zinc showed significant positive correlation with zinc of water, sediment and muscle.

LEGEND

FROM FIG. 8·10 TO 8·12

△	HAEMOLYMPH
▲	EXOSKELETON
○	MUSCLE
●	HEPATOPANCREAS
⊕	OVARY

ZINC IN ♀ PENAEUS INDICUS

FIG. 8.10

STATION IV

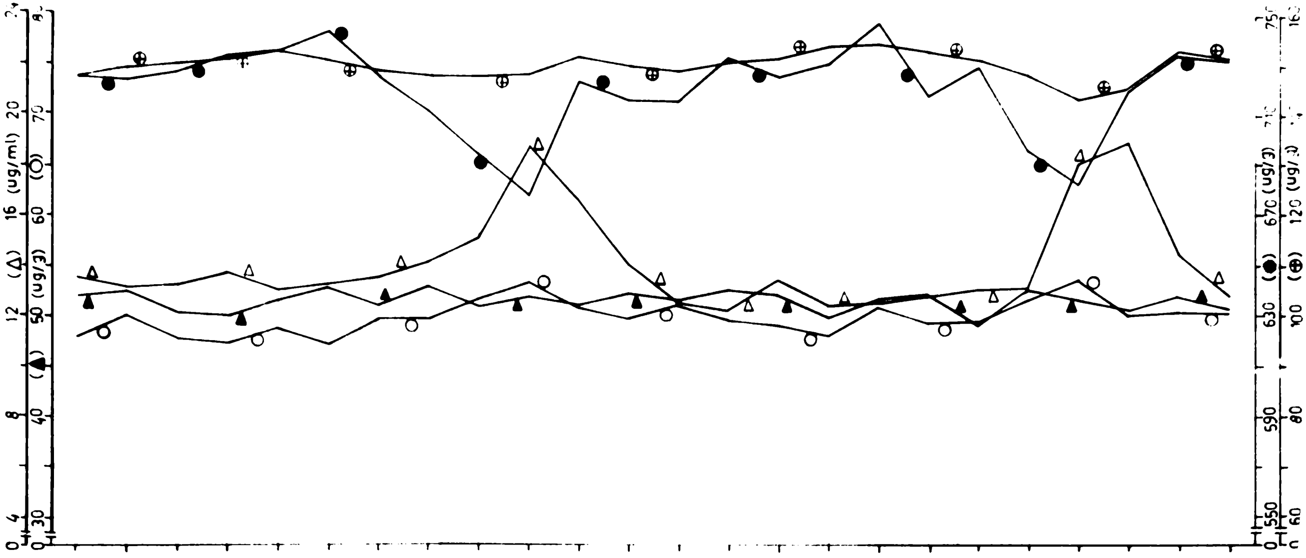


FIG. 8.11

STATION V

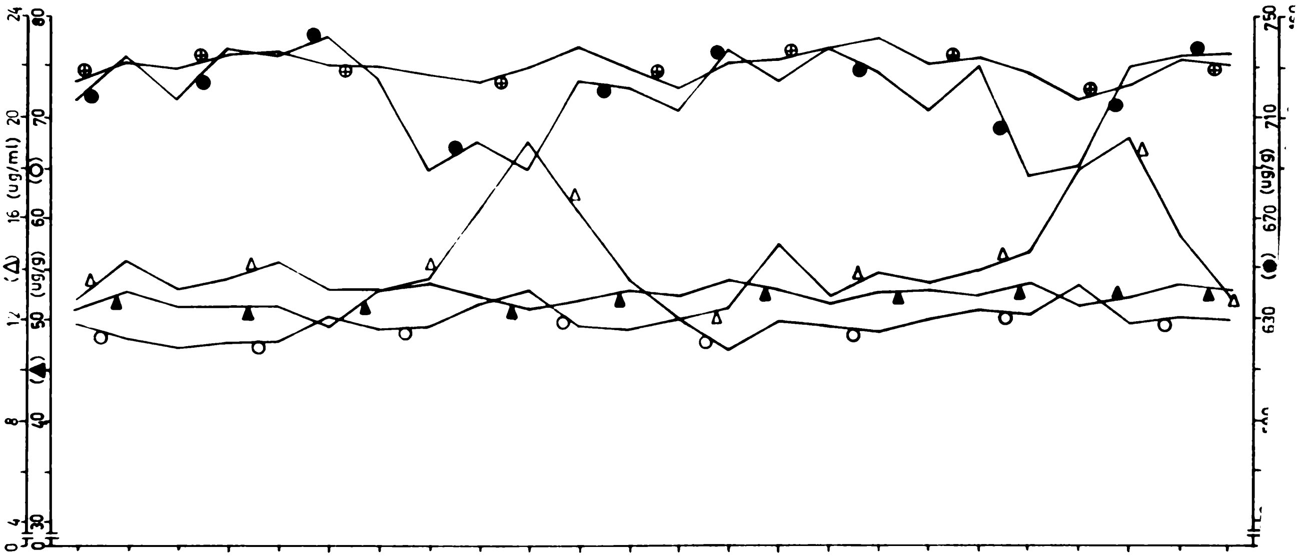
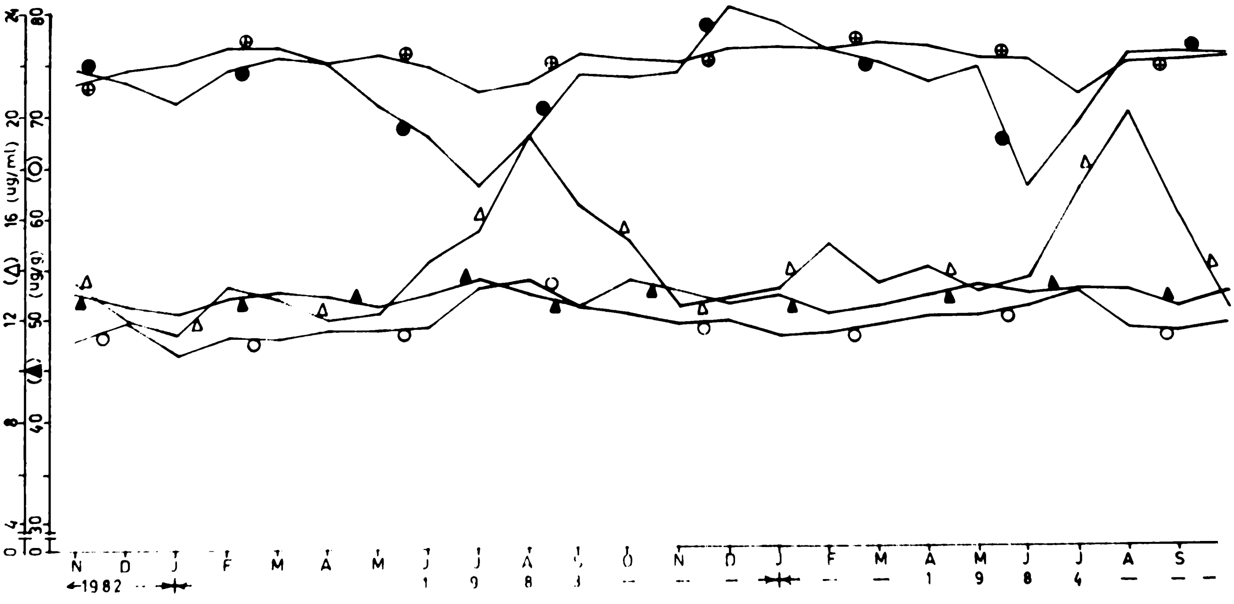


FIG. 8.12

STATION VI



EXOSKELETON

Zinc depicted very minor variations (49.5 to 53.3 µg/g) from November '82 to October '84 and no seasonal trend was recorded. It showed no significant correlation.

MUSCLE

Zinc values increased slightly during July (52.0 µg/g) and August (54.6 µg/g) in 1983, and during July (54.9 µg/g) in 1984. The values remained low and fluctuated between 47.4 to 51.5 µg/g in rest of the study period. Muscle zinc exhibited significant positive correlation with zinc of water and haemolymph; and significant negative correlation with zinc of hepatopancreas and ovary.

HEPATOPANCREAS

Zinc showed minor fluctuations from November '82 (724 µg/g) to May '83 (725 µg/g) and subsequently, it decreased to 679 µg/g by August '83. It increased to 724 µg/g in September. In the next year, decreased values were recorded in June (677 µg/g) and July (684 µg/g) only. Hepatopancreatic zinc showed significant positive correlation with salinity of water, and zinc of ovary; and significant negative correlation with zinc of muscle.

OVARY

Zinc showed slightly low levels during July (144.3 $\mu g/g$) and August (146.2 $\mu g/g$) in 1983; and during July (144.0 $\mu g/g$) in 1984. In rest of the study period, values fluctuated between 149.7 to 153.3 $\mu g/g$. Zinc of ovary exhibited significant positive correlation with salinity of water and zinc of hepatopancreas. It showed significant negative correlation with zinc of water, sediment and muscle.

DISCUSSION

Physicochemical parameters are governed by seasonal rainfall during monsoon and post-monsoon in both the ecosystems and therefore, as already mentioned in the 'Results', in the discussion part too, season-wise description is adhered to.

In the grow-out ecosystem, temperature, salinity and dissolved oxygen of water and temperature of sediment decreased during monsoon and post-monsoon period in the present study. Freshwater run-off from rivers and local precipitation bring about decrease in temperature and salinity. The low dissolved oxygen encountered during monsoon and post-monsoon period is due to the increased decomposition of higher levels of organic debris at bottom. The higher amount of organic debris is formed as a result of high productivity rate and subsequent death and decay(Rochford, 1951). The increased content of silt-load in the river water and respiration of increased biomass during monsoon and post-monsoon are the additional causes for dissolved oxygen depletion (Shynamma and Balakrishnan, 1973). Ramamirtham and Jayaraman (1963) described temperature, salinity and dissolved oxygen of the Cochin backwaters and observed that apart from the influence of monsoon rains and the considerable amount of evaporation during hot months, the influence of various type of phenomena in the Arabian Sea such as 'upwelling', 'sinking', 'coastal piling' etc. are considerably affecting the characteristic variations in the hydrographical and associated conditions in this area. Sankaranarayanan and Qasim (1969), while studying the nutrients of Cochin backwaters in relation to environmental characteristics, noted that changes in water temperature, salinity and dissolved oxygen were small during the pre-monsoon period and large during monsoon period. Shynamma and Balakrishnan (1973) also observed that dissolved oxygen values remained low during monsoon period while investigating diurnal variations of some physicochemical factors of Cochin backwaters. Ansari (1974) recorded high water temperatures and salinity concentrations of water in the Vembanad lake during pre-monsoon period similar to those recorded during present investigation. While describing the seasonal distribution of water temperature, salinity and dissolved oxygen in the inshore waters of Karwar Bay, Annigeri(1968) also recorded lowest temperature and salinity during southwest monsoon. Nagarajaiah and Gupta (1983) has reported that the monsoon and the freshwater discharge are the main factors which regulate different physicochemical parameters of an estuary while studying the physicochemical characteristics of brackishwater ponds along Nethravati estuary, Mangalore.

The marine ecosystem, in the present study, too showed low water temperature and dissolved oxygen during monsoon and post-monsoon period but salinity level was not affected much. The incursion of cool, poorly oxygenated waters into the continental shelf during monsoon and post-monsoon period as reported by Ramamirtham and Jayaraman (1960) may account for the present observation. High salinity bottom waters were also observed by Sankaranarayanan and Qasim (1969) in the inshore waters of Cochin area during monsoon and post-monsoon period. Gopinathan and Joseph (1980) have reported low temperature and dissolved oxygen, and high salinity during monsoon and post-monsoon period in the inshore waters off-Karwar coast. While investigating physicochemical parameters in the inshore region of Karwar, Annigeri (1972) reported higher range of dissolved oxygen than those observed in the present investigation. This disparity may be related to the nature of the sediment and the prevalence of more reducing conditions near bottom off Cochin.

The higher decrease in water temperature and dissolved oxygen in the marine ecosystem when compared to the grow-out ecosystem during monsoon and post-monsoon may be related to the relative shallowness, and the regular mixing of water (due to the tidal influence) in the grow-out ecosystem and incursion of offshore waters and monsoonal stratification (Ramamirtham & Nair, 1964) in the marine ecosystem.

The prevalence of highly saline stable inshore waters brought in by the offshore incursion (Ramamirtham and Jayaraman, 1960) and restricted vertical mixing of stratified waters (Ramamirtham and Nair, 1964) account for almost normal salinity of seawater in the marine ecosystem, whereas in the growout system, encountering of almost freshwater conditions during monsoon and post-monsoon period are related to heavy precipitation and local riverine run-off, (Ramamirtham and Jayaraman, 1963). The relatively low dissolved oxygen values recorded in the marine ecosystem when compared to the grow-out ecosystem during non-monsoon period are presumed to be related to the reduction of increased content of dead and decaying matter which got accumulated due to increased rate of its 'sinking' to sea-floor which, in turn, is due to the presence of enormous amount of overlying waters in the marine ecosystem. The vertical water-mass is relatively very less in the grow-out ecosystem of the present study. The 'sinking' phenomenon compounded with the incursion of poorly oxygenated offshore waters as reported by Ramamirtham and Jayaraman (1960) explain the acute oxygen depletion in the marine ecosystem during monsoon and post-monsoon period.

Prasad (1982), Sreenivasan (1982) and Suganan (1983), while investigating ecology of brackishwater culture ponds near Cochin, have reported water and sediment to be of more alkaline nature during monsoon and post-monsoon period. In the present study, increased hydrogen-ion concentration of water and sediment recorded in the grow-out ecosystem during monsoon and post-monsoon period may be related to the removal of carbondioxide which is assimilated due to increased photosynthetic activity of the system during that time (Sreenivasan, 1982). In the present case the hydrogen ion-concentration did not behave conservatively as observed in Gironde and Charante estuaries in France by Martin <u>et al.</u> (1978).

In the marine ecosystem, relatively low hydrogen-ion concentration noted in the water and the sediment during monsoon may be due to the increased sedimentation and subsequent reduction of organic debris resulting in relatively more reducing conditions near bottom. Such characteristics were also reported by Ramamurthy (1963) while studying hydrology of the inshore waters of Karwar. Annigeri (1972) described seasonal hydrological variations in the inshore region of Karwar during non-monsoon period and reported pH range similar to the present findings. Sankaranarayanan and Qasim (1969) have also reported decreased pH values in the inshore area of Cochin during monsoon and post-monsoon period. Radhakrishnan (1978) carried out hydrological studies in the inshore waters of Mangalore with an emphasis on the effects of the southwest monsoon and reported decreased pH values during southwest monsoon period.

The difference in seasonal behaviour of pH between both the ecosystems during monsoon and post-monsoon period may be due to the prevalence of freshwater conditions in the backwaters and incursion of poorly oxygenated offshore waters in the marine area.

The low redox-potential values of the water and the sediment recorded in the present investigation during monsoon period in both the ecosystems seems consistent with the occurrence of relatively reduced conditions due to the increased rate of death and decay of organic debris during that period as already discussed. While studying ecology of prawn-culture brackishwater ponds around Cochin, Paulinose et al. (1981), Sreenivasan (1982) and Suguman (1983) have reported seasonal redox-potential trend similar to present findings in the grow-out ecosystem. Unfortunately, there is little record of redox-potential analysis related to the marine ecosystem in the literature.

The extent of increase of nitrate, ammonia and net primary production was considerable, whereas nitrite and total phosphorus showed fluctuating but mildly increased values during monsoon and post-monsoon period in both the ecosystems. These parameters show non-conservative behaviour. Incursion of nutrient rich offshore waters into inshore area as well as the freshwater discharge and land run-off from the catchment area in the vicinity are the main causes for higher concentration of nutrients and net primary production during monsoon and post-monsoon period in both the ecosystems. But the explanation of various authors (Ewins and Spencer, 1967; Sankaranarayanan and Qasim, 1969; Nair et al., 1975) that such an increase of nutrients is entirely due to freshwater discharge and land run-off, based on the fact that minimal values occurred during marine conditions period in estuarine area and thereby, implying little marine contribution is not consistent with the present finding of recording similar seasonal behaviour of nutrients and net primary production in both the ecosystems. This suggests that both the ecosystems may have similar contributory sources. This is supported by the observation of

Ramamirtham and Jayaraman (1963) who, while studying hydrology of the Cochin backwaters during monsoon and post-monsoon period, reported that the bottom water of the estuary is the same as the upwelled water of the Arabian Sea which has spread over the continental shelf. Nair et al. (1975), described nutrients and primary productivity in the Vembanad Lake and emphasised that the distribution of nutrients is largely dependant on the marine influence and the freshwater discharge.

While examining the distribution of primary production and characteristics of nutrients in Cochin area, various authors (Manikoth and Salih, 1974; Nair et al., 1975; Paulinose et al., 1981; and Sreenivasan, 1982) have reported the results similar to those recorded in the grow-out ecosystem during present study.

The fluctuating values of nitrite recorded during present study seems to be related to its transitional nature in the nitrogen cycle (Rakestraw, 1936). The nitrite values recorded by Sreenivasan (1982), while investigating ecology of culture ponds in Vypeen Island, were extremely higher (976 µg/l) than the present observation in the growout ecosystem, though the seasonal trend was similar in both the cases. The relative shallowness (depth 40 cm) of the ponds studied by Sreenivasan (1982) may be the cause of higher values noted by him.

Sankaranarayanan and Qasim (1969) reported fluctuating but relatively higher values of nitrite during monsoon and post-monsoon period in the inshore area off Cochin. Subrahmanyan (1959) and Annigeri (1968, 1972) also reported values similar to the present findings in the inshore areas of Arabian Sea.

The noting of an average of 43 µg/l and 57 µg/l nitrate and ammonia respectively, and recording of significant positive correlation between them by Bhargava *et al.* (1978), while carrying out productivity studies from October to December in the column-waters in Arabian Sea, compare fairly well with the present results in the marine ecosystem.

Frequent oscillations of total phosphorus noted during present study are indicative of the regeneration of phosphate phosphorus from the bottom sediments (Sankaranarayanan and Qasim, 1969). Increase of total phosphorus noted during monsoon and post-monsoon during present study may be due to the greater silt-load in the estuarine ecosystem at that time (Sankaranarayanan and Qasim, 1969). According to Ansari and Rajagopal (1974) large quantity of allochthonous phosphate which finds its way into the estuary may be responsible for high values of phosphorus, even in the inshore waters during the monsoon period. Nagarajaiah and Gupta (1983), while studying physicochemical characteristics of brackishwater ponds along Nehtravati estuary, Mangalore, recorded a nutrient peak during June which is consistant with the present findings in the grow-out ecosystem but their observation of relatively low phosphate phosphorus values during monsoon is not consistant with the present findings.

The range and seasonal variation of phosphorus described by various authors (Ramamurthy, 1963; Anand and Jayaraman, 1972; Annigeri, 1972; Sankaranarayanan and Reddy, 1973b; Bhargava et al., 1978; and Radhakrishnan 1978) in the inshore areas of Arabian Sea along the West coast of India, are in agreement with the present results in the marine ecosystem.

Nair et al. (1975) and Paulinose et al. (1981) noted seasonal variation of primary production in the Cochin backwaters and the prawn culture ponds near Cochin respectively and reported considerably high values during monsoon and post-monsoon period as compared to non-monsoon period and this supports the present similar finding in the grow-out ecosystem. Bhargava et al. (1978) and Radhakrishna et al. (1978) carried out primary productivity studies in the Arabian Sea and reported higher primary productivity values during monsoon and post-monsoon period which support present findings' in the marine ecosystem.

As elucidated by the foregoing discussion, it is clear that when rainfall occurs during monsoon and post-monsoon period, the increased freshwater run-off from the catchment area alters the physicochemical characteristics of the water and the sediment in the grow-out ecosystem and affects to some extent the marine ecosystem too. Incursion of offshore waters into the inshore area during monsoon and post-monsoon period govern the variations of physicochemical parameters in the marine ecosystem though its influence in the backwaters is not ruled out.

While comparing the seasonal variation of physicochemical parameters in the grow-out and the marine ecosystems, it becomes clear that the physicochemical conditions remain similar and little-changed in both the ecosystems during non-monsoon period and that the major noticable variations are encountered only during monsoon and post-monsoon period in both the ecosystems.

As salinity in both the ecosystems depicted significant (negative or positive) correlations with most of the physicochemical parameters discussed hither to, it becomes more appropriate to restrict the discussion of variations of a particular metal in the tissues of *P. indicus* with the variations of salinity of water and with those of the particuler metal in the water and the sediment, father than to discuss variations of each metal in the tissues of *P. indicus* with each of the physicochemical parameters(though correlation values for all the physicochemical and the biological parameters in both the ecosystems are presented in the correlation tables).

Calcium of the water and the sediment in both ecosystems behaved conservatively i.e. positively correlated with salinity (Table VII A To XII A). But quantitatively, the calcium of the water and the sediment behaved quite differently during monsoon and post-monsoon period in both the ecosystems. Calcium decreased in almost direct proportion to the decrease in salinity in the grow-out ecosystem as evidenced by its significant correlation with salinity. (Table VII A to IX A). The sudden and sharp decrease during monsoon is related to the local precipitation and freshwater run-off. Rao *et al.* (1982), described seasonal variation of calcium in water, sediment and tissues of *Penaeus indicus* from a brackishwater pond, and recorded low calcium content in water from August to November when the salinity was also low and noted uniformly increased calcium concentrations from December to May, concommitant with the increased salinity; and also noted a direct relationship between the calcium content and salinity of the pond water. Gupta and Naik (1981) reported that when the rivers get filled with freshwater almost to their mouths during monsoon period, calcium concentration decreases to near zero with decrease in salinity. Manikoth (1975), while investigating variations of calcium concentration in the Cochin backwaters, observed that the calcium decreased in direct proportion to decrease in salinity, which depends upon rainfall and local precipitation. While studying calcium and magnesium concentration in the nearshore waters of Goa, Naik (1978) suggested, on the basis of her findings in the Zuari estuary (Goa), that the contribution of calcium content from the river water is negligible. This supports our findings in the grow-out ecosystem as very low values of calcium are noted during peak monsoon when it is flooded with freshwater.

In the marine ecosystem, the decrease in calcium content of the water during monsoon and post-monsoon period was less though it depicted significant positive correlation with salinity (Tables X A to XII A). The minor decrease during monsoon and post-monsoon period may be related to relatively little vertical mixing of stratified, less saline surface water with the highly saline bottom waters. While studying the variations of calcium and magnesium concentration in the nearshore waters of Goa during the non-monsoon period, Naik (1978) reported constant values in the pre-monsoon period comparable to the oceanic ones but noted variations during the post-monsoon period. Naqvi and Reddy (1979) described the variations of calcium content of the waters around the Laccadives (Arabian Sea) and reported conservative behaviour of calcium at the depth comparable to the present investigation. Gupta et al. (1978) investigated fluoride, calcium and magnesium in the Northern Indian Ocean and reported average calcium concentration of 432.5 mg/l.

Sediment calcium, in the grow-out ecosystem, showed significant positive correlation with water calcium (Tables VII A to IX A) and it constantly increased during stable conditions period and decreased during the transition, monsoon and post-monsoon periods. The dilution effect due to increased water out-flow probably explains decrease of sediment calcium during monsoon and post-monsoon periods. While studying seasonal variations of sediment calcium in a brackishwater prawn-culture field near Cochin, Rao et al. (1982) observed that sediment calcium was varying between 5.1 and 7.1 mg/g DW in most of the months except from January to March when it was relatively low (4.9 and 3.8 mg/g DW).

Though the present results too agree with their (Rao et al., 1982) observation that the total calcium content of the bottom soil of the pond was always higher than in the overlying water, yet the range of values of sediment calcium (10.8 to 29.5 mg/g DW) noted during present investigations are considerably higher than these reported by them. The reason for recording decreased sediment calcium values from January to March even when the salinity as well as the calcium content of the overlying water showed a uniform increase has not been mentioned by them (Rao et al., 1982). While investigating physicochemical features of soils in certain prawn fields around Cochin, Prasad (1982) reported that exchangeable cation, calcium, showed a definite pattern of variation with season in all the estuarine ecosystems. The decline in the exchangeable cation values after the onset of monsoon in June has been explained by him (Prasad, 1982) to be due to the reduction in salinity and the leaching of exchangeable cations as they are water soluble in nature.

Seasonal stability of sediment calcium in the marine ecosystem is due to the presence of highly saline waters near bottom throughout the year. Though there is a complete lack of information regarding seasonal studies, of sediment calcium of inshore areas, yet Rao's (1978) observation, while investigating distribution of calcium carbonate, calcium and magnesium in sediments of the northern half of western continental shelf of India, that the near shore sediments contain 5% calcium content support the present investigations. The range of values reported by Nair *et al.* (1971), while describing calcium/ magnesium ratios in the sediments on the continental shelf off Bombay, agree well with the present findings.

It becomes quite clear that there is little variation of calcium annually both in the water and the sediment in the marine ecosystem but the annual variation of calcium of the water and the sediments in the grow-out ecosystem are governed by water run-off and local precipitation.

The range of haemolymph calcium values (423 to 761 µg/ml) noted during the present investigations in the intermoult male and female *P. indicus* in both the ecosystems are comparable to the observations of various authors (Travis, 1955; Bursey and Lane, 1971; Charmantier, 1972; Greenaway, 1972, 1976; Hagerman, 1973; Wright, 1979, 1980; Sparks and Greenaway; 1984) on haemolymph calcium in the intermoult crustaceans belonging to ten different species. Their reported values range from 452 to 540 µg/ml. The present investigations are supported by the findings of Rao *et al.* (1982), who described the seasonal fluctuation of haemolymph calcium in *Penaeus indicus*. They (Rao *et al*., 1982) found no appreciable difference between the two sexes and that the distribution pattern in different months was also, more or less, similar. The concentration of total calcium in the haemolymph of male and female *P. indicus* in both the ecosystems during the present investigations remained above than that of the surrounding medium throughout the period of study. This probably reflects the contribution of non-ionic calcium to the total blood calcium. It is known that in the crustaceans adapted to normal seawater, about 20% of the blood calcium is bound in an indiffusible form probably to blood proteins (Robertson, 1960b; Greenaway, 1976; Zanders, 1980). It is likely that this bound calcium is a constant value, even in crustaceans adapted to dilute seawater (Greenaway, 1976). The findings of Rao *et al*. (1982), while studying seasonal fluctuations of haemolymph calcium of *P. indicus* in the estuarine pond, that haemolymph calcium remains always at a higher level than the calcium in pond water support the present results. Various authors(Vinogradov, 1953; Prosser, *et al*., 1955; Robertson, 1957; 1960b; Dall 1965a, b; 1974; Dehnel, 1967; Bursey and Lane, 1971; Engelhardt and Dehnel, 1973; Balazas *et al*. 1974; Colvocoresses *et al*. 1974; Kannan, 1982) have recorded haemolymph calcium of intermoult crustaceans to be always above that of the medium. The significant positive correlation of haemolymph calcium of male and female _P. indicus_ with the calcium of water and sediment in both the ecosystems (Table VII B to XII B) during the present investigations show that a unit change of calcium in the ecosystem due to a decrease in salinity brings about a comparable change in the haemolymph calcium. Rao _et al._ (1982) also reported that calcium content of pond water and haemolymph of _P. indicus_ showed a direct relationship with salinity. The change in the total calcium of the haemolymph of _Cancer pagurus_, _C. magister_ and _Panulirus longipes_ with a change in salinity has been reported by various authors (Engelhardt and Dehnel, 1973; Dall, 1974; and Greenaway, 1976).

Though the calcium concentration in haemolymph of both male and female _P. indicus_ depicted significant positive correlation with salinity and calcium of water, calcium of sediment and with calcium of muscle, hepatopancreas and testis/ovary of _P. indicus_ in each ecosystem (Tables VII B to XII C) during present investigation, yet the quantum of variation which occurred only during monsoon and post-monsoon was significantly higher in the grow-out than in the marine ecosystem. This is directly related to the quantum of decrease of salinity and calcium of the water and the sediment in each of the ecosystems. Rao et al. (1982), while studying seasonal fluctuations in calcium levels in the exoskeleton, muscle and haemolymph of P. indicus reported low haemolymph calcium values (280 to 380 µg/ml) during monsoon and post-monsoon period and high haemolymph calcium values (540 to 800 µg/ml) in the non-monsoon period. This supports the higher quantum of variation of haemolymph calcium noted only during monsoon and post-monsoon during the present investigation. The observation of Kannan (1982), on Scylla serrata that though total calcium of haemolymph is always higher, yet the free calcium concentration in the haemolymph is lower than the ambient medium indicating active ion uptake even at normal salinities. Dall (1981), while studying osmoregulatory ability and juvenile habitat preference in some penaeid prawns, also mentioned active regulation of calcium by penaeids in hyposaline conditions. The P. indicus, in the present study, may be resorting to increased active regulation of haemolymph calcium when low salinities are encountered in the ecosystem. Passive ionic equilibria do not, in general, exist between the medium and crustacean body fluids even when these are isotonic (Robertson, 1960a). In the decapods, in general, the regulation of the blood ionic levels is accomplished by active uptake of ions from the medium, chiefly through the gills (Robertson, 1960a; Lockwood, 1962; Smith and

Linton, 1971). All this suggests existence in this species - P. *indicus*, of extremely efficient mechanisms of ionic - and osmotic-regulation capable of maintaining large concentration differences between the haemolymph and the ambient medium even in the most dilute media studied. The rate of active uptake of calcium from the medium into the haemolymph appears to increase with the decrease in calcium concentration of the ambient medium as noted from the seasonal calcium values of the haemolymph and the medium during the present investigations in the grow-out ecosystem. Similar finding of increase in rate of uptake of calcium by *Carcinus maenas* with the decrease in ambient medium calcium concentration was reported by Zanders (1980). This establishes the euryhaline nature of P. *indicus*. It appears that the animal regulates its haemolymph calcium concentration at all the salinities studied during the present investigations. Since the cuticle of the exoskeleton is permeable, it is to be expected that some calcium ions are incorporated directly from the seawater (Digby, 1967). Active regulation of calcium under low salinity conditions was also noted by Greenaway(1976) and Price Sheets and Dendinger(1983) in *Carcinus meanas* and *Callinectes sapidus* respectively. Greenaway (1976) opined that the active regulation appears to get stimulated by a fall in salinity rather than a change in the concentration of calcium of the medium.

It can be inferred that scarcity of mature or maturing P. *indicus* especially during monsoon and post-monsoon period in the estuarine area may be due to the stress of decrease in salinity of the medium (which regulates and controls other physicochemical characteristics) and the concommitant decrease in calcium of water and sediment. P. *indicus* moves to more conducive, less energy spending and, presumably, less stressful marine ecosystem where decrease in salinity or decrease in calcium of water and sediment even during monsoon and post-monsoon is very little. Panikkar (1968), while studying the osmotic behaviour of shrimps and prawns in relation to their biology and culture, has indicated that osmoregulation in dilute media is less-effective in fully developed individuals especially in their reproductive phase and considered this feature as one of the principal factors which forces them to migrate back to sea. Truchot (1975) and Waterman (1960) reported that in portunids, calcium is the critical ion in the haemolymph. In the tropics, salinity is found to play a major role in timing the reproduction of marine invertebrates especially in the nearshore and estuarine animals (Pillay and Nair, 1971). The stable physicochemical characteristics of the sea favour 'homing' of adult and maturing *P. indicus* to the marine ecosystem. It is presumed that the penaeid prawns, in general, tend to spend maximum energy on growth and reproductive activity and try to curb wasteful expenditure of energy by moving towards the sea (Imai, 1977). The present investigations are supported by the finding of Staoles (1980) who has shown that a marked fall in salinity causes emigration of the larger maturing banana prawn *Penaeus merquiensis* to high saline water and that this behaviour is closely associated with seasonal heavy rains. No sex-specific seasonal differences of serum calcium were noted by Colvocoresses *et al.* (1974) and also during the present study.

Though the exoskeletal calcium of male and female *P. indicus* showed relatively lower values in the grow-out ecosystem in the monsoon months during the present investigations, yet, no significant seasonal trend was noted. The seasonal exoskeletal calcium variations of *P. indicus* noted by Rao et al. (1982) fluctuated between 101.3 to 151.2 mg/g DW in males, and between 90.6 to 143.0 mg/g DW in females and this is comparable to the exoskeletal calcium values of male (91 to 119 mg/g

DW) and female (87 to 125 mg/g DW) P. indicus noted during the present investigations; however the range of values is lower in the present studies. There is little sex specific seasonal exoskeletal calcium concentration differences noted by Rao et al. (1982) as well as during present investigations. The low exoskeletal calcium values noted during the monsoon and post-monsoon in the present study may be related to the decrease in calcium of haemolymph as well as water and sediment during the same period. The observation of Mills and Lake (1976), while working on calcium concentration in the crayfish, that exoskeletal calcium is related to the amount of available calcium in the water in which they inhabit, confirms the present findings. The calcium content of the pond water and the sediment and the salinity of water remained high during non-monsoon period in the present study when haemolymph calcium was also high. During monsoon, when there was an appreciable fall in the salinity, calcium of the water and the sediments, and the haemolymph of P. indicus, the calcium of exoskeleton too decreased but not significant (Table VII B to IX C). That the reduction in relative calcification is an adaptation to the low calcium concentrations in the waters inhabited by the crayfish has been reported by Mills and lake (1976) and Mills et al. (1976). It is stated that the initial hardening after ecdysis often results from the utilisation of the stored calcium, but the main calcification of the endocuticle uses calcium and other salts obtained from the external medium (Passano, 1960; Dall, 1965b). This may be the reason for minor insignificant decrease noted during present seasonal studies. Haefner (1964), investigated haemolymph calcium fluctuations of *Callinectes sapidus* and found a direct relationship between post-molt body weight of *Callinectes* and environmental salinity and proposed that crabs in lower salinity seawater possess lighter exoskeleton than their counterparts in the high salinity seawater. Travis and Friberg (1963), while carrying out micro-radiographic studies on the exoskeleton of the crayfish, *Orconectes virilis* also proposed that the amount of calcium accumulated in exo- and endocuticle is dependent on the concentration of calcium in the environment and the number of sites which would serve as nuclei for calcium crystal formation. The purely protective and shaping nature of the exoskeleton might be a compelling reason to bear upon the male or female *P. indicus* to cater fully to its calcium needs even in peak monsoon period. The observation of Dall (1965b), while studying calcium metabolism in *Metapenaeus* sp., that the "bound" calcium in the cuticle serves an important structural role, and is therefore not available for exchange, confirm little seasonal variation in cuticle calcium recorded during the present investigations in the grow-out ecosystem. In the grow-out ecosystem, the animal may be either opting for the prolongation of the inter-moult period to suit the onset of favourable ecological conditions or for active uptake, conservation and storage of calcium prior to ecdysis.

The little seasonal variation in exoskeletal calcium of P. indicus noted during the present investigations in the marine ecosystem is related to little seasonal variation of calcium in the sea water, the sediment, and the haemolymph of P. indicus. There is no need for the animal to conserve or regulate calcium as the physicochemical parameters remain more or less constant in the marine ecosystem. When the values of exoskeletal calcium of P. indicus in the marine ecosystem is compared with those in the grow-out ecosystem during the non-monsoonal period, it becomes clear that the values noted in the marine ecosystem were, in general, always higher even at the same salinity. This may be related to the differential calcium concentration in the respective ecosystem.

Rao *et al.* (1982), described seasonal vatiation of muscle calcium in *Penaeus indicus* and recorded range of values comparable to those noted during present investigation in the grow-out ecosystem. Their (Rao *et al.*,1982) observation that the calcium in the muscle of female prawn was generally lower than in the males, support the present data of little sex-specific seasonal muscle calcium concentration differences. The seasonal trend of variation of calcium in the muscle of male or female prawn in the grow-out ecosystem was similar to that of calcium of the water and the sediment of environment and to the haemolymph of *P. indicus* [as depicted by the significant correlation (Tables VII B to XII C)]. This reflects that the calcium of the muscle cells is partially depleted from its optimum levels found at normal salinity. While studying calcium levels in the exoskeleton, hepatopancreas and abdominal muscle of the grass shrimp, *Palaemonetes pugio*, Brannon and Rao (1979) noted decrease in calcium content of the muscle of control animals kept for 106 days under laboratory conditions having diluted seawater(10%. salinity) containing only one fourth the calcium of oceanic water.

Though muscle calcium showed significant positive correlation with calcium of the water and the sediment in the marine ecosystem (Tables IX B to XII B), yet the comparative quantum of its seasonal variation was little, reflecting, thereby, the seasonal stability of calcium concentration of the water and the sediment, and of the haemolymph of *P. indicus* in the present study. Though there is little direct evidence in support of the present findings, yet the findings of Rao *et al.* (1982) during the marine phase of the estuary (i.e. non-monsoon period) are consistent with the present observations in the marine ecosystem. As compared to the grow-out ecosystem, seasonal variations in muscle calcium values were relatively higher in the marine ecosystem. The conceptual compartmentation of calcium, in the animal and the external medium, into the external seawater, haemolymph, haemolymph bathed organs and the hepatopancreas has been described by Price Sheets and Dendinger (1983), while studying calcium deposition into the cuticle of the blue crab, *Callinectes sapidus* related to external salinity. The noting of calcium values in haemolymph, exoskeleton, muscle and gonad when water and sediment calcium vary during present study confirms the concept of compartmentation described by Price Sheets and Dendinger (1983). The negligible sex-specific seasonal difference of muscle calcium concentration of *P. indicus*, within each ecosystem, underlines the similar needs in both the sexes.

Though there is little work carried out on the lines similar to the present seasonal study, yet the range of hepatopancreatic calcium values reported by Brannon and Rao (1979) (7.50 to 8.64 mg/g DW) in the grass shrimp, *Palaemonetes pugio*, agree well with the present values of hepatopancreatic calcium of *P. indicus* in both the ecosystems (7.40 to 11.22 mg/g DW). Dall (1965 b), while studying calcium metabolism of *Metapenaeus* sp., reported 8.17 mg/g DW) calcium in the digestive gland which is comparable to the present findings.

The little seasonal variation of hepatopancreatic calcium in the marine ecosystem reflects stable seasonal calcium concentrations of the water and the sediment which is confirmed by the significant positive correlation of the hepatopancreatic calcium with calcium of haemolymph, water and sediment (Table X B to XII C). On the other hand, the seasonal variations of hepatopancreatic calcium in the grow-out ecosystem were considerable as compared to the marine ecosystem and it too reflected trends of calcium in haemolymph, water and sediment as confirmed by the significant positive correlations (Table VII B to IX C). No sex-specific hepatopancreatic calcium concentration differences recorded within each ecosystem during present study underlines the similar physiological role of hepatopancreas.

Seasonal variation in calcium levels in the ovary and testis showed little quantitative differences within each ecosystem and their significant positive correlations with calcium of haemolymph, water and sediment (Table VII B to XII C) in both the ecosystems make it amply clear that the calcium has a similar role to play in the gonads of both sexes and that, its concentration depends upon the calcium level in the haemolymph. Though the ecosystem-specific differences of calcium concentrations in the gonads, are not much (1.86 to 2.35 mg/g DW and 2.10 to 2.32 mg/g DW in the grow-out and the marine ecosystem respectively), yet the quantum of seasonal variation is much higher in the grow-out ecosystem. This is related to the higher range of seasonal variation of calcium of haemolymph, water and sediment as compared to the stable marine ecosystem.

While summarizing, it may be said that the variation of tissue calcium contents are a function of the calcium concentrations in the water and the sediment in the particular ecosystem. The variations occur mainly during the period of freshwater discharge and heavy precipitation and the ecosystem-specific differences are considerable during this period. There are little sex-specific calcium concentration differences within each ecosystem.

Magnesium of the water and the sediment in the grow-out as well as the marine ecosystems behaved conservatively but the quantitative seasonal variation in the two ecosystems was quite different during monsoon and post-monsoon period. The sudden decrease in magnesium content of water in direct proportion to the decrease in salinity in the grow-out ecosystem during monsoon is due to the local precipitation and freshwater run-off. There is paucity of literature on seasonal variation of magnesium in the Cochin backwaters. Gupta and Naik (1981) studied the seasonal variations of magnesium content in the Mandovi and Zuari river systems (Goa) and reported that the magnesium appears to take some part in the biogeochemical cycles of the rivers and behave as a conservative parameter. They (Gupta and Naik, 1981) observed least values during monsoon which are comparable the values of present findings. Generally, it is difficult to draw comparisons between different estuaries as distribution of the chemical species are regulated by freshwater run-off, seawater inflow, evaporation, precipitation, and the nature of the catchment area (Perkins, 1976).

Magnesium has also been reported to behave in a conservative way in Chikugegawa river estuary, Japan (Hosokawa, 1970). Sediment magnesium in the grow-out ecosystem behaved seasonally just as magnesium of water and this too is related to the dilution effect caused by increased water inflow during monsoon and post-monsoon period when decreased values were noted. Unfortunately there is no literature on seasonal study of magnesium in sediments.

In the marine ecosystem, the relatively minor decrease in magnesium of water may be due to relatively little mixing of the stratified less saline surface water with the dense, highly saline, nutrient-rich waters which occupy the near bottom space. Observations of Naik (1978), on seasonal variation of magnesium in the nearshore waters of Goa during non-monsoon period, are generally same as observed in the marine ecosystem during the comparable period of the present study. There was a little decrease in mangesium of sediment during monsoon period in the present study which is attributable to little dilution of the overlying waters which showed restricted mixing with less saline surface waters. Seasonal study on the sediment magnesium in the inshore waters of Arabian Sea is wanting. However, Rao (1978), has reported the magnesium to range from 1 to 1.5% in the nearshore sediments of the northern half of western continental shelf of India. This range of value is in general agreement with the range of values (1.46 to 1.78%) noted during present investigation in the marine ecosystem.

From the observations recorded, it is found that there is little seasonal variation of magnesium both in water and sediment in the marine ecosystem whereas annual variation of magnesium of water and sediment in the grow-out ecosystem is profoundly influenced by the freshwater run-off and local precipitation.

Magnesium concentrations of haemolymph, exoskeleton, muscle and hepatopancreas too showed very little, insignificant sex-specific differences within a particular ecosystem just as in the case of calcium. The range of magnesium concentration values of testis (760 to 1074 µg/g DW) and ovary (757 to 941 µg/g DW) in the grow-out ecosystem, as well as of testis (958 to 1091 µg/g DW) and ovary (980 to 1035 µg/g DW) in the marine ecosystem too showed not much quantitative differences within a particular ecosystem. This implies a similar physiological role of magnesium in male and female P. *indicus*. Therefore, further discussion shall be general rather than sex-specific.

Haemolymph magnesium of P. indicus showed wide range of seasonal variation mainly during monsoon and post-monsoon period in the grow-out ecosystem whereas the range of seasonal variation of haemolymph magnesium in the marine ecosystem was, more or less, very little. This can be considered to be the range of normal fluctuations at seawater salinity, and thereby, exhibiting relatively stable milieu of the marine ecosystem. The finding of similar positive correlations (Table VII B to XII C) in both the ecosystems explains that the nature of response to the seasonal variation of physicochemical characteristics by the various tissues of P. indicus is similar in the grow-out and the marine ecosystems. But quantitatively, the wide range of seasonal variation of haemolymph magnesium recorded during monsoon and post-monsoon period in the grow-out ecosystem, in contrast to the stable haemolymph magnesium values in the marine ecosystem, is a function of the quantum of variation of salinity which regulates magnesium of water and sediment. Price-Sheets and Dendinger (1983) investigated magnesium deposition in the cuticle of the blue crab, Callinectes sapidus in relation to the external salinity, and found that haemolymph magnesium exhibit higher concentration in high salinity and lower in low salinity. This supports similar seasonal variation of haemolymph magnesium recorded during present investigation in either of the ecosystems. Colvocoresses *et al.* (1974) described seasonal variation of serum constituents of the blue crab, *Callinectes sapidus* and noted that the serum magnesium was maintained hypoionic to the environment of salinities over 7‰, and hyperionic below that point, which is comparable to present results. The range of haemolymph magnesium values (72 to 160 µg/ml) recorded during present studies in both the ecosystems are comparable to the observation of Zanders (1978) in *Goniopsis cruentata*, (45 to 120 µg/ml) and *Carcinus maenas* (70 to 183 µg/ml). The concentration of haemolymph magnesium of *P. indicus* in both the ecosystems always remained less than that of the surrounding water medium in contrast to the behaviour of calcium, in the present study, which was found to be always higher in haemolymph than in the medium. Zanders (1978) reported that though magnesium is abundant in seawater, it is excreted by most crustaceans resulting in haemolymph levels lower than that of the external medium. *Uca pugettensis* is the only animal that actually has a higher level of magnesium in its haemolymph than in the ambient medium (Waterman, 1960). The known depressent effect of magnesium on nervous and neuromuscular activity and its negative correlation with metabolic rate (Waterman, 1960) may be the reasons for active excretion of magnesium at all the salinities studied during present investigation. At the freshwater concentrations of magnesium in the medium, haemolymph magnesium becomes relatively less hypotonic though it is found to be highly hypotonic at normal salinities, as evidenced by the haemolymph magnesium levels, which is about one-seventh of the magnesium concentration in the medium. But almost halving of the haemolymph magnesium concentration during active monsoon, when magnesium of the ambient water is approaching near zero values in the grow-out ecosystem, bring out the conservative nature of the animal with regard to magnesium. In dilute seawater, the excretion of magnesium in the urine by the antennal gland decreases or ceases completely but it is always maintained below that of the medium as has been reported by Zanders (1978), while investigating ionic regulation in the mangrove crab, <u>Goniopsis cruentata</u> from 100% to 5% seawater. The conservation of magnesium assumes significance as some minimal level of the haemolymph magnesium has to be maintained for the stability of polypeptides of haemolymph (Blair and Van Holde, 1976).

It may be presumed that the significantly decreased divalent cations such as calcium and magnesium in the haemolymph during monsoon and post-monsoon period in the grow-out ecosystem serve as a constraint for proper oxygenation of haemolymph, especially in large size prawns where requirement is more, because these salts are known to raise the oxygen affinity (Waterman, 1960).

The range of seasonal variation of exoskeletal magnesium (6343 to 8176 µg/g DW) was much larger in the grow-out than in the marine ecosystem (7718 to 8354 µg/g DW). Relatively little seasonal variation recorded, due to the relative stability, in the marine ecosystem was in contrast to the range of wide variations recorded in the grow-out ecosystem mainly during monsoon and post-monsoon. But nature of the response to variations in both the ecosystems is similar to that of the haemolymph magnesium as shown by the significant positive correlation values of exoskeletal magnesium with other parameters (Tables VII B to XII C). There is little work to support the present findings but the range of exoskeletal magnesium values recorded during present investigations agree well with those reported by Huner et al. (1976, 1979) in the intermoult Orconectes virilis, Procambarus alleni, P. clarkii and Penaeus californiensis. The decrease in exoskeletal magnesium with the decrease of magnesium in the medium during present study is due to the fact that most of the minerals incorporated in the new exoskeleton after moulting come from the surrounding medium only; and food, resorption from the old exoskeleton and other crustacean stores are considered to be of secondary nature (Graf, 1978). This is also supported by the works of various authors (Kleinholz and Bourquin, 1951; Guyselman, 1953; Robertson, 1960b; Hecht, 1975; and Graf, 1978) who studied exoskeletal calcium in crustaceans and noted surrounding seawater to be the main source for the mineralization of the new exoskeleton.

The muscle, hepatopancreas and gonad of male and female P. indicus showed no sex-specific seasonal differences, just as for haemolymph and exoskeleton, in a particular ecosystem during the present investigation. But the range of seasonal variation of magnesium in the grow-out ecosystem (muscle, 705 to 1299 µg/g DW; hepatopancreas, 1657 to 2557 µg/g DW; ovary, 757 to 941 µg/g DW; testis, 760 to 1074 µg/g DW) were much larger than the same in the marine ecosystem (muscle, 1160 to 1364 µg/g DW; hepatopancreas 2419 to 2728 µg/g DW; ovary, 980 to 1035 µg/g DW; testis, 958 to 1091 µg/g DW). This is presumably, related to the seasonal stability of the marine ecosystem in comparison to the grow-out ecosystem which showed wide range of variations especially during monsoon and post-monsoon period as explained earlier. But nature of the response to variations in both the ecosystems is, in general, similar as proved by the correlation values (Table VII B to XII C). There is scarcity of information on these lines.

The similar trend of magnesium variations in various tissues though quantitatively different, follow the magnesium variations in the haemolymph which, in turn, is influenced by the magnesium in the ambient medium and the sediment.

Total phosphorus, in grow-out system, remained low during non-monsoon period but increased concentrations with a peak value were noted during transition and early monsoon period when the first showers set in. The total phosphorus values after attaining the peak value declined suggesting thereby, that further land run-off from the catchment area does not increase phosphorus concentration in water. Frequent oscillations noted are indicative of regeneration of phosphate phosphorus from the bottom sediments. Decrease during late monsoon and post-monsoon period may be due to greater silt load resulting in removal of phosphorus from solution. Sankaranarayanan and Qasim (1969) described phosphorus dynamics in Cochin backwaters in relation to environmental characteristics and observed low values during non-monsoon period and high peak values during transition or early monsoon period. They (Sankaranarayanan and Qasim, 1969) ruled out freshwater discharge as the source of input but suggested decomposition of organic matter as an input source. While carrying out seasonal study on the primary production in the Vembanad Lake, Nair *et al.* (1975) also reported that high concentration of phosphorus occur either during the monsoon or the post-monsoon period, but their recording of phosphorus values even upto 600 µg/l during monsoon is significantly higher than those recorded in the present investigation. Nagarajaiah and Gupta (1983), have described seasonal variation of physicochemical parameters in the Nethravati estuary, Mangalore and reported range of phosphorus values similar to the present findings but their observation of low values during monsoon is unusual. This may be due to the nature of the hydrobiological features of the overlying waters and the texture and mineralogical composition of sediments. But sediment of the grow-out ecosystem showed high values during transition, monsoon and post-monsoon period in the present study. The phosphorus in the sediments of Cochin backwaters have also been described by Murty and Veerayya (1972) and Ansari and Rajagopal (1974). Ansari and Rajagopal (1974) noted high values during the monsoon and low in the pre- and post-monsoon periods. Their (Ansari and Rajagopal, 1974) observation that release of phosphate from mud takes place during the monsoon period supports the present findings of noting decreasing trend during late monsoon and post-monsoon after reaching a peak value in early monsoon period implying, thereby, that a part of the phosphorus was released to the overlying waters during late monsoon and post-monsoon period. Probably initial flushing of the land run-off from predominantly rice producing Kuttanad area bordering Vembanad Lake, which is famous for utilizing double the amount of fertilizer per unit area normally being utilized in Kerala (Hindu, 1986), and to some extent flushing of allochthonous phosphate from the catchment area of Cochin backwaters (Ansari and Rajagopal, 1974) resulted in a peak value at the time of early showers during monsoon. The subsequent land run-off and local precipitation, which flushes the area at a relatively much faster rate, may account for decline of the peak values of total phosphorus in water. Increased 'siltation' and 'sinking' of organic debris and presence of upwelled water near bottom probably account for increased total phosphorus in sediment during monsoon and post-monsoon period. Rajamanickam and Setty (1973) observed that higher phosphate concentration in sediment during post-monsoon is related to a large supply of terrigenous apatite brought in by the rivers in addition to the other contributing factors such as organic production, upwelling and pollutants.

In the marine ecosystem, increased total phosphorus values in water during monsoon and early post-monsoon is primarily due to the incursion of nutrient-rich off-shore current into inshore area (Ramamirtham and Jayaraman, 1963) of the marine ecosystem and, to some extent, is due to increased flow of silt-loaded organic matter brought in along with water run-off in the surface layers of the water-column. Sankaranarayanan and Reddy (1970) examined total phosphorus content in the waters of Arabian Sea along the west coast of India and observed that it was always more than 80 µg/l in near Cochin shelf-waters. The range of phosphorus reported by Annigeri (1972), while investigating physicochemical parameters of Karwar Bay during non-monsoon period agree well with the present findings of comparable period. The recording of increased phosphorus concentrations during monsoon and post-monsoon by Anand and Jayaraman (1972) in the northern Indian Ocean, also support our findings. The increased total phosphorus of sediment, in the marine ecosystem, noted during late monsoon and post-monsoon in the present study reflects the presence of increased amounts of organic debris at bottom which is the consequence of increase in primary production and its subsequent death & decay and sinking. Unfortunately, there is no record of seasonal study for total phosphorus in sediment of continental shelf waters of west coast of India, but the range of phosphorus in sediments of the western continental shelf of India as reported by Rao *et al.* (1978) agree well with the present results.

Relatively higher values of total phosphorus in water and, to a little extent, in sediment noted in the marine than in the grow-out ecosystem at any time of the year seems to be related to the increased water biomass availability in the marine ecosystem which results in increased death and decay and 'sinking' of organic debris. It results in the higher rate of decomposition of organic debris leading to higher total phosphorus content in the near bottom water in the marine ecosystem. This is supported by the fact that pH in the marine ecosystem always remained lower than that in the grow-out ecosystem and thereby,imply the presence of more reducing conditions in the marine ecosystem. Murty and Veerayya (1972) observed that a comparison of the phosphate values in the Vembanad Lake sediments with those in the shelf sediments indicate that sediments in the estuarine region compare favourably with the sediments in the inneer shelf region.

Phosphorus, though known not to have much physiological importance like other ions studied during present investigation, yet it is of significance being a part of calcite chemistry. Calcite, the structural material of decapod integument, contains more than 99% of its mineral content as calcium carbonate, but also has magnesium carbonate and calcium phosphate as essential minor mineral constituents (Richards, 1951). From the results discussed hitherto, it becomes clear that the seasonal variation of calcium and magnesium is similar, and consequently, therefore, the seasonal variation of phosphorus has to be understood in that context. Sex-specific differences observed were nil. The unpredicable seasonal variation of haemolymph phosphorus recorded during present investigation in both the ecosystems, most possibly, reflects the erratic seasonal variation of phosphorus in the medium. The insignificantly increased haemolymph phosphorus noted during monsoon months may be due to the increase of phosphorus in the medium and the sediment in both the ecosystems.

The relatively lower exoskeletal phosphorus values recorded during monsoon and post-monsoon period in both the ecosystems may be related to relatively lower values of calcium and magnesium in the exoskeleton at that time as noticed during present study, and it is indirectly supported by its significant positive correlation with salinity (Table VII B to XII B). The values noted during present investigation were comparable to those reported by Dall (1965a, b) in *Metapenaeus* sp. (4.95 mg/g DW) and Huner *et al.* (1979) in *Penaeus californiensis* (6.00 to 13.00 mg/g DW).

Though muscle phosphorus showed erratic seasonal variation, yet relatively higher values noted in the monsoon and post-monsoon especially in the grow-out ecosystem may be due to similar behaviour of phosphorus in the medium and the haemolymph. The maintainence of the dynamic chemical equilibrium by the animal with the ecosystem may explain increased values during freshwater run-off.

The relatively low hepatopancreatic phosphorus values recorded during monsoon and post-monsoon period in the grow-out ecosystem may be related to the decrease in calcium and magnesium in the hepatopancreas as noted during present study. The calcium in the hepatopancreas is known to be stored as calcium phosphate granules (Becker *et al.*, 1974) and its variations are anticipated to be emulated by the hepatopancreatic phosphorus too. In the marine ecosystem hepatopancreatic phosphorus showed, more or less, uniform values throughout the study period coinciding with the seasonal stability of the hepatopancreatic calcium as already noted and discussed during present study.

In the grow-out ecosystem, the relatively lower values of testicular phosphorus noted during monsoon and post-monsoon period are contrary to the increase of phosphorus in the medium and the sediment. This shows that the increase in the medium and the sediment does not affect testicular phosphorus. On the other hand, testicular phosphorus variation seems related to the seasonal variation of calcium and magnesium as borne out by the correlation values (Table VII C to IX C). The testicular phosphorus concentration in the marine ecosystem can be said to have remained uniform. It may be related to the seasonal stability of the marine ecosystem. Just as in the grow-out ecosystem, the increase of phosphorus in the medium and the sediment in the marine ecosystem does not seem to affect the testicular phosphorus during monsoon and post-monsoon period.

Ovarian phosphorus though depicting a small decrease (~10% of the non-monsoon values) during monsoon, post-monsoon and even in November, December months in the grow-out ecosystem, yet its significant positive correlation with salinity (Table VII B to IX B), just like testicular calcium in the grow-out ecosystem, relate it to the seasonal variation of calcium and magnesium. The increase of phosphorus in the medium and the sediment does not affect ovarine phosphorus too.

In the marine ecosystem ovarian phosphorus remained uniform, just as the testicular phosphorus, and it may be due to the general seasonal stability of the ecosystem but the increase of phosphorus in the medium and the sediment does not affect the ovarine phosphorus during monsoon and post-monsoon period.

The inexplicable seasonal behaviour of phosphorus in some of the tissues, which is normally anticipated to be a function of phosphorus variation in the ecosystem, is supported by the similar observation of Huner *et al.* (1979) who, whole working on phosphorus in *Penaeus californiensis*, opined that the variations of phosphorus levels are difficult to explain.

In the grow-out ecosystem, copper in the water and the sediment remained low and uniform but for monsoon and post-monsoon period when non-conservative behaviour of copper was quite apparent (i.e. copper concentrations increased with decrease of salinity). The distribution of trace metals in the sediments of Cochin backwaters follow a pattern similar to that in the water, and is controlled by the formation of trace metal enriched clay, silt and organic particles and their subsequent redistribution in the sediment by water movement and bioturbation (Rajendran and Kurian, 1986). The major variations in physicochemical conditions within the estuaries give rise to the possibility of non-conservative behaviour of some of the dissolved substances during the mixing of river and seawaters (Burton, 1978). The presence of flocculated silt-loaded organic matter rich in these biolements in the freshwater run-off, a part of which sinks to the bottom, probably causes increase in copper concentration in the water and the sediment. Presence of Udyogamandal Industrial Complex and other industrial activity in the vicinity discharging their effluents in the rivers flowing into the Cochin backwaters may also partly account for higher copper values during run-off period as effluent rich sediments are deflocculated and flushed out. This is supported by the work of Venugopal et al. (1982) who reported that the main effluent discharge sites at Udyogamandal Industrial Complex contain significant amount of copper during the monsoon season. Estuarine muds are known to serve as 'sink' of riverine metals (Matkar *et al*., 1981). The incursion of nutrient rich offshore waters even in the Cochin backwaters during monsoon and post-monsoon period (Sankaranarayanan and Qasim, 1969) may also contribute to increase of copper concentrations in the water and the sediment though to a limited extent. There is no seasonal study reported on copper in water from this area. Rajendran and Kurian (1986), while studying seasonal metal pollution in Cochin backwaters, reported relatively very low values (0.10 to 1.20 µg/l) but the type of water sample used (filtered/unfiltered) was not specified and concluded that there is little evidence of any overall seasonal pattern. The low values noted by them (Rajendran and Kurian, 1986) may be due to collection of surface water samples which might have been filtered before analysis as compared to unfiltered bottom water samples used for analysis during present investigation. But little seasonal variation recorded during their study (Rajendran and Kurian, 1986) agree well with the uniform values reported during the present study involving the comparable non-monsoon period. The present results fall in the range of copper values (0.9 to 13.7 µg/l) described, by Sankaranarayanan and Stephen (1978), in the waters of Cochin backwater, though their work is not a seasonal study. The results (6.93 to 9.30 µg/l) obtained during freshwater phase of the estuary (monsoon and post-monsoon period) in the present study are in agreement with the Turekian's (1971) finding of 7.00 µg/l copper concentration in the global river water supply. The significant negative correlation between copper concentration and salinity in the estuarine grow-out ecosystem (Tables VII A to IX A) noted during present investigation is confirmed by the recording of similar non-conservative behaviour of copper in estuarine waters by Sundararaj and Krishna murthy (1972). While studying trace metal levels in the sediments of the Cochin backwaters, Venugopal et al. (1982) noted copper to show some degree of seasonal variations and opined that porbably prevailing physicochemical conditions and 'backland' influence govern the variations. He (Venugopal et al., 1982) recorded peak values near Cochin barmouth during monsoon and post-monsoon season with highest value in November and considered upstream sources to contribute considerably and indicated metal sinking in the area of confluence of seawater and freshwater. Rajendran and Kurian (1986) investigated seasonal variation of copper in sediments of Cochin backwaters and opine that although there is a monthly variation in metal concentration, there is little evidence of any overall seasonal pattern in sediment. But their conclusion emanates from the period involving non-monsoon period and June month of the monsoon period only. The range (30-63 µg/g DW) of copper values in sediment of the Vembanad lake reported by Murty and Veerayya (1981), are generally similar to the range of copper values noted during the present investigation. Their (Murty and Veerayya, 1981) observation that copper has a significant correlation with organic matter of the sediments is indirectly confirmed by the higher copper concentrations recorded during present investigation as it, too, coincides with the increase in total phosphorus of sediment during monsoon and post-monsoon period.

In the marine ecosystem, higher values of copper noted during late monsoon and post-monsoon period in the water and sediment may be related to the upwelling of nutrient rich offshore waters, increased primary production and the consequent increased sinking of organic debris. The presence of silt-loaded organic matter, along with freshwater run-off in the surface layer (Venugopal *et al.*, 1982) which becomes less saline during monsoon also contribute to increased levels in bottom-water and sediment as a result of sinking of silt. Release of copper from coastal sediments as suggested by Boyle *et al.* (1981) to explain the observed enrichment of copper in coastal waters during heavy run-off period does not hold good because in the present study copper values in the sediment also showed a concommittant increase during monsoon and post-monsoon period. Knauer and Martin

(1973) observed that copper values are also associated with nearshore upwelling of waters. There is no comparable seasonal variation data of copper in water or sediment of the Indian waters. But the range of copper values in the marine ecosystem recorded during the present investigations are consistent with the findings of Rajendran et al. (1982) who reported that copper in surface water of the inshore areas of western Bay of Bengal varied from 3.50 to 6.62 µg/l. Jegatheesan and Venugopalan (1973) reported 0.50 to 12.00 µg/l copper concentration in Porto Novo waters. Singbal and Sanzgiry (1977) reported 1.70 to 7.90 µg/l copper concentration in Arabian sea waters. The finding of Romanov, et al. (1977), that copper concentrations in the Aegean Sea varied seasonally, with the winter values higher than those of spring and summer, support present results of higher copper values during late monsoon and post-monsoon period in the marine ecosystem. While reviewing copper in the marine environment, Lewis and Cave (1982) reported nearshore seawater copper concentration to range between 0.30-3.80 µg/l and 0-2500 µg/l in the Mediterranean and the adjacent seas respectively. Hoff (1978) described copper in the nearshore waters and observed that concentrations of copper were increased both by St. Lawrence river water and by upwelled subsurface water. Similar phenomenon may be possible in recording of high value of copper in the present study of marine waters. Seasonal fluctuations of copper are known to occur due to fluctuations in run-off, with increased values in the spring and summer at the time of heavy spring run-off (Chow and Thompson, 1954; Thomas and Grill, 1977; Foster and Morris, 1971; Arnac, 1976).

There is paucity of information on seasonal study of copper in sediment in the inshore areas of Indian waters. While studying partition patterns of copper in the sediments of the western continental shelf of India, Rao <u>et al</u>.(1974) reported an average of 193.8 µg/g DW copper in the sediments of the shelf region off Cochin. The copper values recorded during the present investigation are far less than those reported by Rao <u>et al</u>. (1974). While working on copper content in the inshore sediments of Gulf of Kutch, Murty <u>et al</u>. (1978) recorded a range of 18 to 63 µg/g DW which is consistant with the values of copper in sediment recorded in the present study. The observation of Murty <u>et al</u>. (1978) that copper and zinc co-vary with each other in a significant manner in the sediments of Gulf of Kutch support the present result of getting similar significant positive correlation between copper and zinc of sediment (Table X A to XII A) but the range of copper values (175-200 µg/g DW) noted by them were much higher than the values (30-66.5 µg/g DW) recorded here. The higher values noted by them, (Murty <u>et al</u>., 1978) may be related to the discharge of Industrial effluents from the so called Industrial Capital (Bombay) of India. Paropkari *et al.* (1980) also reported similar range (18 to 53 µg/g DW) of copper values in the sediments of Gulf of Kutch. It has been suggested that the innershelf sediments mix regularly with the estuarine sediments (Muller and Forstner, 1975; Salomons and Mook, 1977; Murty and Veerayya, 1981). The slightly higher values of sediment copper noted in the marine than in the grow-out ecosystem in the present study are confirmed by the observation of Murty and Veerayya (1981) who, while studying the distribution of trace metals in the sediments of Vembanad lake, reported that the copper in sediments of estuary showed lower concentration than the copper of adjacent inner shelf sediments.

In the grow-out and the marine ecosystems, the higher haemolymph copper values recorded during monsoon and post-monsoon period in both male and female *P. indicus* in the present study may be due to the higher copper concentrations in the ambient water and bottom sediments. Copper is thought to be absorbed both via the stomach and directly from seawater across the body surface (Bryan, 1968). His (Bryan, 1968) observation that the amount of copper and zinc which can be absorbed directly from seawater across the body surface increases if the concentration of the water is raised, confirms significant positive correlation of copper in the water and the haemolymph (Table VII B to XII B) in the present study. But the quantum of increase of haemolymph copper concentration comparable to the quantum of increase of copper in the ambient medium was less suggesting, thereby, that either the absorption was restricted or that only a fraction of the absorbed copper appears in the haemolymph, or that active excretion of the absorbed metal was resorted to. Bryan (1968) suggested that copper is regulated in all species of decapods and that the removal of excess copper from the body can occur in the faeces, in the urine, or across the body surface. While studying regulation and accumulation of copper in Palaemon elegans, White and Rainbow (1982) observed that the animal can easily regulate body concentrations upto an increase of 100 μg/l copper in the medium. Copper is an essential metal to crustaceans as it is utilized as a prosthetic group in the structure of haemocyanin (Lontie and Vanquickenborne, 1974). The decrease in salinity affects oxygen consumption through osmotic stress (Weiland and Mangum, 1975; Gilles, 1977) and increases copper toxicity (Holm-Jensen, 1948) whereas higher levels of copper in freshwater causes reproductive impairment, decrease in growth, protein content and glutamic oxaloacetate transaminase activity in Daphnia (Biesinger and Chritensen, 1972).

These three above mentioned negative effects in the context of the present findings of almost freshwater conditions and increased copper concentration during monsoon and post-monsoon period in the grow-out ecosystem may explain the supposed triggering of stress mechanism in mature or maturing P. indicus which results in their migration to high salinity i.e. to the less demanding marine environment for further reproductive development. The presence of post-larval and juvenile stages of P. indicus in the estuarine area even during monsoon and post-monsoon period (George, 1962) appears to be related to the more efficient and active regulatory capabilities development by the animal during the post-larval stages, as it is known that the biological effect of copper is different during different parts of the life history of marine organisms (Lewis and Cave, 1982) and that the regulatory capabilities are a function of developmental stage (Lewis and Cave, 1982). Nair and Krishnankutty (1975) described varying effects of salinity on the growth of the juveniles of P. indicus from the Cochin backwaters and suggested that physiological changes as well as a gradual change to stenohalinity may be the reasons for sea-ward migration of this species. The increased concentration of copper in the haemolymph implies the increase in haemocyanin content of haemolymph which may be related to increased metabolic and osmo-regulatory activity (Taylor et al., 1985).

Though there is little work on seasonal studies of haemolymph copper, yet the values reported by Bryan (1968) in *Carcinus maenas*, *Eupagurus bernhardus* and *Cancer pagurus*; (63.7 to 89.0 ug/ml), and Djangmah and Grove (1970) in *Crangon vulgaris* (41 to 159 µg/ml) are comparable to the present findings. Sankaranarayanan, *et al.* (1978) noted seasonal change in the concentration of copper and zinc in a oyster, *Crassostrea madrasensis* from the Cochin backwaters which they related to monsoonal changes in fresh-water run-off from areas receiving industrial and domestic wastes.

The range of seasonal exoskeletal copper values recorded during present investigations in the grow-out (13.8 to 23.2 µg/g DW) and the marine (12.9 to 24.2 µg/g DW) ecosystems and amongst male (14.6 to 24.2 µg/g DW) and female (12.9 to 20.1 µg/g DW) showed little sex-specific or ecosystem-specific differences indicating, thereby, that the effects of copper variations in the ecosystems and in the haemolymph have little to do with the exoskeletal copper concentrations. It is substantiated by the insignificant correlation values (Table VII A to XII C) too. Though there is paucity of directly related works, yet the exoskeletal copper values reported by Bryan (1968) in *Austropotamobius pallipes*, *Corystes cassivelaunus* and *Eupagurus bernhardus* (2.0 to 4.9 µg/g FW), Won (1973) in crabs (4.1 to 9.2

µg/g FW) and Horowitz and Presley (1977) in Rock shrimp (16.3 µg/g DW) confirms the present findings.

The relatively higher muscle copper concentration values of male and female *P. indicus* noted in the grow-out and the marine ecosystems during monsoon period in the present study may be due to the simultaneous increase of haemolymph copper concentrations which is, in turn, a function of copper in the water and the sediment. But the quantum of increase was not more than about 10% of the range of muscle copper values noted in the other seasons. The increased values noted might have been due to the residual effect of haemolymph copper which supplies muscle tissue. Though there is little work to support the present findings, yet the values of muscle copper reported by Bryan (1968) in *Carcinus maenas* (7.5 µg/g FW), *Corystes cassivelaunus* (8.0 µg/g FW); Horowitz and Presley (1977) in Brown shrimp (24.2 µg/g DW) and Rock shrimp (31.3 µg/g DW); Zingde *et al.* (1976) in *Metapenaeus affinis* and *Penaeus monodon* (21.5 & 28.9 µg/g DW) Ishii *et al.* (1978) in *Penaeus japonicus* (14.0 µg/g DW); Stickney *et al.* (1975) in *Penaeus azectus* and *Penaeus setiferus*; (16.0 & 18.0 µg/g DW) and *Lande* (1977) in *Penaeus japonicus* (14.0 µg/g DW) are comparable to the present findings. Bryan (1968), while studying copper in tissues of decapods, mentioned that muscle copper shows the least variable concentrations and that, it is barely affected when excess metal is injected into the haemolymph. He (Bryan, 1968) opined that the muscle, in which the constancy of the concentration of metal seems to be important, may itself be able to regulate against any changes in haemolymph concentration of metal. Bryan (1968) found that muscle exchanges metal with the haemolymph rather slowly, and this presumably helps to protect the tissue from any sudden fluctuations in the haemolymph concentrations. An insignificantly small increase in muscle copper concentration was recorded during heavy freshwater discharge time by Boon (1973), while studying copper concentrations in body meat of the blue crab, Callinectes sapidus. He (Boon, 1973) suggested that the copper concentration of muscle depends to some extent on the season too.

In both the grow-out as well as the marine ecosystems, slightly decreased hepatopancreatic copper values noted during monsoon and post-monsoon period does not deserve much deliberations as the extent of decrease was insignificant (< 5%). It can be best explained to have remained seasonally uniform. The sex-specific differences within an ecosystem were little. The hepatopancreas seems to be not involved in the regulation or storage of copper when increased haemolymph copper levels are encountered during monsoon and post-monsoon period. It is therefore inferred that about 20% increase of copper in haemolymph during monsoon and post-monsoon period, which is a function of increase in ambient copper levels, may be within the 'safe' physiological limits. The copper storage function of hepatopancreas when excess copper is present in the ambient medium (Bryan, 1968) is not noticed in the present study as seasonal variation of hepatopancreatic copper was little. Though, there is little related work, yet the values reported by Bryan (1968) in *Austropotamobius pallipes*, *Crangon vulgaris*, *Galathea squamifera* and *Homarus vulgaris* (335 to 603 µg/g FW) are comparable to the present findings.

The relatively uniform and stable copper concentration values in ovary in the marine ecosystem (212.4 to 221.5 µg/g DW) recorded during present investigations make it clear that water and haemolymph copper variations do not affect those of the ovary. Bryan (1964, 1967) reported that concentration of metal remains fairly constant and, like those of muscle tissues, are not markedly influenced by the haemolymph metal concentration. The relatively lower values noted in the grow-out ecosystem (182.8 to 217.7 µg/g DW) during monsoon and post-monsoon period may be due to the resorption of the ovarian tissue or stagnation of ovarian development as with the onset of monsoon the increase of copper in the haemolymph should have caused concurrent increase of copper in the ovary. But on the contrary, decrease in copper concentration of ovary is noted which can happen only under resorptive conditions. The maturing or mature prawns caught during monsoon and post-monsoon period in the grow-out ecosystem are presumed to be primarily those which could not have set upon "migration to marine waters" due to enclosed nature of the large water body of the grow-out ecosystem. On being confronted with unfavourable ecosystem conditions, these prawns might have stopped or reversed the maturation process to conserve energy. The ovarian tissue may be more judiciously utilised for, presumably, increased metabolic and osmo-regulatory activities during monsoon and post-monsoon period. This is indirectly supported by the findings of Bryan (1968) who, while studying zinc and copper in decapods, noted that ovary itself contained relatively less copper (9 μg/g FW) but if mature eggs are also analysed it is found to be very high (39 μg/g FW). The findings of copper in the sperm motility initiating factor released from the eggs of the horse-shoe crab, *Limulus polyphemus* (Clapper and Brown, 1980) give more significance to the present observation of recording higher copper levels during non-monsoon period in the grow-out ecosystem. The migration of prawns to marine areas for maturation and spawning, as noted in the present study of *P. indicus*, may be tuned to the role of copper to facilitate perfect high efficiency fertilization. The values recorded during present investigations agree well with those of Bryan (1964, 1967, 1968) in Austropotamobius pallipes, Homarus vulgaris, Palinurus vulgaris and Portunus puber (15.0 to 18.0 µg/g FW).

Consistently higher and uniform testicular copper values in the marine than in the grow-out ecosystem of the present study may have a role to play in the testicular development in the estuarine conditions of the grow-out ecosystem. The low copper levels noted during monsoon and post-monsoon period in the grow-out ecosystem, when increase in haemolymph copper is concurrently noticed, may have reasons and constraints similar to ovary development as already discussed. The reported finding of Biesinger and Christensen (1972), that in freshwater conditions higher level of copper causes reproductive impairment and decrease in growth in Daphnia, indirectly support present results. The comparable values in testicular tissues of crustaceans are reported by Bryan (1964, 1967, 1968) in Homarus vulgaris, Portunus puber and Portunus duperator (8.0 to 17.0 µg/g FW).

Relatively higher values of zinc in water recorded during monsoon and post-monsoon in the grow-out ecosystem may be due to heavy run-off resulting in the presence of flocculated silt-loaded organic matter rich in trace elements (Ganapathy et al., 1968; George and Sawker, 1981) a part of which may sink to the bottom, as well as due to the incursion of off-shore waters near bottom even in the estuarine area (Sankaranarayanan and Qasim, 1969). Coinciding with the primary production peak in the grow-out ecosystem, zinc of sediment is also found to be increased during late monsoon, post-monsoon period and even upto November & December months in the present study. The deflocculation and flocculation of muds of the effluent discharge area of Udyogamandal Industrial Complex; other industrial activity in the catchment area of rivers contributing to Cochin backwaters, and sinking of a part of the organic matter rich silt to the estuarine floor probably help in making the zinc non-conservative. The experiments on silt pick-up showed that suspended silt affect the amount of zinc in solution in seawater and that the uptake is dependant on the silt-load (Ganapathy et al., 1968). Flocculation and sedimentation of colloidal and fine material in suspension may cause a net settling of trace elements (Dyer, 1972). Trace elements may undergo net sedimentation in estuaries even if they have undergone initial desorption (Turekian, 1971). Rajendran and Kurian's (1986) suggestion that the distribution of trace metals, including zinc in the sediments follow a similar pattern to those in the water and is controlled by the formation of trace metal enriched clay, silt and organic particles in the Cochin backwaters, support the present findings. The range of zinc values (0.69 to 4.00 µg/l) in water reported by them (Rajendran and Kurian, 1986) were not much different from the range of zinc values (5.30 to 7.10 µg/l) reported during comparable period in the grow-out ecosystem during present investigation. Their (Rajendran and Kurian, 1986) recording of zinc in sediment of Cochin backwaters ranging between 0.50 to 3.21 µg/g DW was extremely low as compared to the values (42 to 81 µg/g DW) noted during present investigation. Their (Rajendran and Kurian, 1986) observation that there is little evidence of any overall seasonal pattern of zinc in sediment agree well with the present finding of noting little variation during comparable non-monsoon period. The period of significant seasonal variation of zinc, i.e. monsoon and post-monsoon period, as borne out by the present study was not covered by them. Venugopal *et al.* (1982) investigated the zinc levels in sediment over an year at four stations on the northern limb of Cochin backwaters and found zinc to vary with seasons and stations. Their (Venugopal *et al.*, 1982) observation of peak zinc values in sediment at Cochin barmouth during monsoon and post-monsoon period confirms present values. The minor differences in values of zinc between different stations in the present study might be due to varying silt-load in different locations (Ganapathy et al., 1968). Though Sankaranarayanan and Stephen's (1978) work was not seasonal, yet the values reported by them (9.4 µg/l) at a station near the grow-out ecosystem of the present study, were not much different from the range of zinc values (5.30 to 7.10 µg/l) encountered during the present study. The present results show that in the freshwater phase of the estuary (monsoon and post-monsoon) zinc concentrations (7.92 to 13.35 µg/l) were consistent with the average riverine zinc concentrations (10 µg/l) reported by Riley and Chester (1971). While studying zinc in water in the Bombay Harbour Bay, Matkar and Pillai (1975) reported higher values (31.35 to 33.92 µg/l) during monsoon period as compared to the non-monsoon period (2.65 to 22.68 µg/l). Though the values noted by them (Matkar and Pillai, 1975) were generally higher than the range of values (5.30 to 13.35 µg/l) noted during present investigation, yet the increased concentrations observed during freshwater run-off period in both the studies support the present findings. The relatively higher zinc values in waters of grow-out (5.30 to 13.35 µg/l) than in the marine ecosystem (4.7 to 10.9 µg/l) are supported by the finding of Braganca and Sanzgiry (1980) who indicated that higher zinc concentrations occurred near the river mouths, and opined that the inflowing river water is richer in zinc. Increased zinc values in sediment noted during freshwater run-off period may also be due to the ability of zinc to be increasingly adsorbed by solid iron particles and its precipitation to the floor (Rajendran and Kurian, 1986). Bourg (1982) observed that the major variations in physicochemical conditions within estuaries give rise to the possibility of non-conservative behaviour of some of the dissolved substances during the mixing of river and seawater. Bourg (1981) also observed that marine waters contain lower concentrations of trace metals than estuarine waters.

In the marine ecosystem, zinc concentrations remained low (4.7 to 6.1 µg/l) during non-monsoon period but increased values (7.4 to 10.9 µg/l) occurred during monsoon and post-monsoon period. This seasonal phenomenon seems to be related to the incursion of nutrient-rich offshore waters which has been reported by Ramamirtham and Jayaraman, (1963). The consequent increased rate of sedimentation during and after the primary production peak, i.e. sinking, may also be the cause of higher zinc values in sediment during late-monsoon, post-monsoon and even in November December months of the non-monsoon period. The encounter of high sediment zinc values upto November or December month of the non-monsoon period, even though primary production has fizzled out long before, may be due to the residual effect of inshore incursion and 'sinking' phenomenon. Values reported by various authors (Jegatheesan and Venugopalan, 1973; Zingde et al., 1976; Singbal and Sanzgiry, 1977) in the inshore waters of the west coast of India vary from 2.8 to 42.4 µg/l and these are much higher than the range of values (4.7 to 10.9 µg/l) noted in present study of the marine ecosystem. The higher values noted may be due to the difference in processing and analytical methodology. Rajendran et al. (1982) reported soluble zinc in the inshore waters to range between 3.75 to 46.25 µg/l. Danielsson (1980) reported zinc in water of Indian Ocean at 24 m depth to vary from 0.2 to 13 µg/l which is not much different from present findings. The recording of widely differing zinc levels in seawater are not explicable as Brewer (1975) too, while reviewing zinc in seawater, reported zinc levels to range between 15 and 460 µg/l and concluded that although considerable variability exists in the zinc distribution, few coherant explanations have been offered to describe this variability.

In the marine area, though seasonal study on zinc of sediments is lacking, yet some relevant works are available. Zinc in the Arabian sea sediments are reported to range from 16.3 to 51.1 µg/g DW (Sreekumaran et al., 1966). Sarma et al. (1968) reported zinc in the coastal sediments in the Arabian Sea near Tarapore to range from 41.8 to

65.0 µg/g DW. Murty *et al.* (1978) reported sediment zinc to range from 48 to 113 µg/g DW in bulk sample basis in the inshore sediments of Gulf of Kutch. The range of values reported by Paropkari *et al.* (1980) vary from 48 to 114 µg/g DW. The range of values (39.30 to 66.91 µg/g DW) reported during present investigation are in general agreement with the above mentioned works of various authors in the Indian waters.

The seasonal behaviour of haemolymph zinc during the present study was similar to that of haemolymph copper though the levels of haemolymph zinc were only 10-20% of the range of haemolymph copper values. This is related to the importance of copper as a prosthetic group in haemocyanin. The similar seasonal behaviour of both, copper and zinc can be traced to similar seasonal behaviour of these ions in the medium and the sediment. Sex-specific differences of haemolymph zinc during present investigations were little. While studying zinc regulation in the lobster, *Homarus vulgaris*, Bryan (1964) observed that no obvious differences in zinc levels between the sexes exist.

In both the ecosystems, the higher haemolymph zinc values of *P. indicus* recorded during late-monsoon and early post-monsoon period may be related to the higher zinc levels in the ambient water and the bottom sediments. These findings are supported by the correlation values of the present study (Table VII B to XII B) and also by the observation of Bryan (1964, 1966, 1967) who stated that the amount of zinc which can be absorbed directly from seawater across the body surface increases if the concentration of the water is raised. Bryan (1968) observed that animals which feed on worms from sediments may have a considerable intake of zinc. The P. *indicus*, too, is a detrital feeder (Gopalakrishnan, 1952) and exhibit higher concentrations of zinc when there is simultaneous increase in the zinc of water and the sediment. Zinc may be absorbed via the stomach and directly across the body surface (Bryan, 1964). But the quantum of increase of haemolymph zinc (about 20%) comparable to the quantum of increase in zinc in the medium (100%) during heavy freshwater discharge in the present study when compared to non-monsoon values was less suggesting, thereby, that either the absorption was restricted to or that only a fraction of the absorbed zinc is made to appear in the haemolymph or active excretion of the absorbed metal was resorted to. The presence of metallo-proteins, which are not normally saturated, in the haemolymph may help to bind increased zinc levels and the dynamic equibrium with the medium may be attained through active excretion through urinary gland or across body surface (Bryan, 1968). The values noted during present studies (10.8 to 19.8 μg/ml) compare favourably with those reported by Bryan (1968) in *Atelecyclus* *septemdentatus*, *Corystes cassivelaunus*, *Crangon vulgaris*, *Eupagurus bernhardus* and *Piluminus hirtellus*(9.5 to 23.0 µg/g DW).

Exoskeletal zinc values noted in the grow-out ecosystem showed consistently variable values without any seasonal trend but slightly lower values noted during monsoon may be related to the decreased mineralization or demineralization of the exoskeleton during that period as discussed previously in connection with calcium, magnesium and phosphorus levels. Bryan (1968), while studying zinc in the shells of decapods, reported that amounts of zinc in the exoskeleton are variable and this is consistent with the variable seasonal values noted in the present investigation. Bryan's (1964, 1966, 1967) observation that much of the zinc is adsorbed to exoskeleton and as a result, the exoskeletal concentration increases if that of the water is increased, does not apply to present findings as the adsorbed zinc may not be a factor in the results of present investigations as the animals used were washed with tap water prior to dissection.

The general uniform exoskeletal zinc values recorded in the marine ecosystem in the present investigation may be related to poor demineralization of the exoskeleton as in the case of the grow-out ecosystem. But the range of values recorded are comparable to those of Bryan (1968) in *Palinurus vulgaris* and *Pilumhus hirtellus* (16.0 & 17.0 µg/g FW); Lowman *et al.* (1970) in shrimps and prawns (17 to 100 µg/g DW and 15 to 120 µg/g DW respectively); Horowits and Presley, (1977) in brown shrimp (28.3 µg/g DW); and Ray *et al.* (1980) in *Pandalus montagui* (78.0 µg/g DW).

The significant positive correlation of muscle zinc with that of zinc of water and haemolymph in both the ecosystems (Table VII B to XII C) show that variations of zinc in water affect directly the variations of muscle zinc, but quantatively the increase during high discharge time of monsoon and post-monsoon was not appreciable(~10% above the normal non-monsoon levels). The reported observation of Bryan (1964), that when zinc concentration in seawater is increased from 5 to 100 µg/l, the muscle is not appreciably affected, lend credence to the present findings. Zinc in muscle tissue is often associated with the enzyme carbonic anhydrase (Keilin and Mann, 1940). The higher muscle zinc values when compared to that of haemolymph may be related to higher (10-30 times) carbonic anhydrase activity in the muscle tissue (Ferguson *et al.*, 1937) though probably not all of this zinc is associated with carbonic anhydrase. Carbonic anhydrase in the haemolymph may only be associated with cellular elements which are very few (Bryan, 1964). The slightly lower range of muscle zinc values noted in the grow-out ecosystem when compared to the marine ecosystem during non-monsoon period may be related to the presence of higher amounts of detrital material in the marine ecosystem. The range of zinc values similar to present investigation (40.9 to 56.0 µg/g DW) have been reported by Bryan (1968) in *Crangon vulgaris*, *Palaemonetes varians* and *Portunus depurator* (14 to 15 µg/g FW); Lowman *et al.* (1970) in shrimps (44 to 130 µg/g DW); Zingde et al. (1976) in *Penaeus monodon* (21.5 to 70.0 µg/g DW) and *Metapenaeus affinis* (58.3 µg/g DW); Horowitz and Presley (1977) in Rock shrimp and Brown shrimp respectively (47.7 & 56.3 µg/g DW); and Ishii *et al.* (1978) in *Penaeus japonicus* (63.0 µg/g DW).

The recording of relatively lower hepatopancreatic zinc values, similar to the behaviour of hepatopancreatic copper, during monsoon and early post-monsoon period when water medium, sediment, haemolymph and muscle tissues showed increased levels cannot be explained satisfactorily with the present data. The contradictory behaviour of hepatopancreatic zinc is puzzling. The only probable hypothesis may be that, during high freshwater discharge when zinc levels in water and sediment increases to almost double its non-monsoon levels, the animals prevent the absorption of metal ion across the gills or general body surface as a precaution. The zinc taken up along with food may be utilised, via the hepatopancreas, for maintaining relatively higher heamolymph zinc levels in that period. Bryan (1968), while studying zinc in decapods, pointed out that decapods even under normal conditions receive more zinc than they require and, therefore, the process of zinc elimination is probably more important than that of absorption; and also suggested that it seems more likely that the energy utilized for zinc regulation is directed towards removing or preventing of zinc than towards absorption. The range of values noted during present investigation (565 to 731 µg/g DW) are comparable to those reported by Bryan (1968) in *Crangon vulgaris*, *Eupagurus bernhardus*, *Maia squinado*, *Palaemon serratus*; *Palaemonetes varians* and *Palinurus vulgaris* (64.0 - 109.0 µg/g FW).

The testicular zinc remained uniform throughout in both the ecosystems. This suggests that the testis are either almost impermeable to zinc or that zinc regulation is highly efficient. Bryan (1968) described the effects of zinc injections in *Penaeus californiensis* and reported little change in testicular zinc concentration when haemolymph zinc is considerably increased. In the present investigation too, increase in haemolymph zinc had little effect on testicular zinc. The range of testicular zinc values noted during present study (69.9 to 82.8 µg/g DW) are comparable to those reported by Bryan (1968) in *Cancer pagurus*, *Carcinus maenas*, *Corrystes Cassivelaunus*, *Eupagurus bernhardus*, *Homarus vulgaris*, *Maia squinado* and *Portunus puber* (13.0 to 27.0 µg/g FW).

Relatively lower ovarian zinc values recorded in the grow-out ecosystem from July to December during the present investigation is similar to the seasonal behaviour of ovarian copper in the grow-out ecosystem; and it may be related to resorption of the ovarian tissue and reversal of ovary development process as, rather unexpectedly, ovarian zinc decreases at a time when increase in zinc of water, sediment and haemolymph is recorded. This is plausible only under resorptive conditions as discussed earlier in case of ovarian copper.

The relatively uniform ovarian zinc values noted in the marine ecosystem (140 to 153.3 µg/g) imply that ovarian zinc is independant and unaffected by the seasonal variations of zinc in the medium and the sediment. Bryan (1964, 1967), while studying zinc regulation in ovary, observed that concentration of zinc remains fairly constant and is not markedly influenced by the haemolymph zinc.

The ovarian zinc values noted during the present investigation (142.2 to 153.3 µg/g DW) compare well with those of Bryan (1964, 1968) in *Austropotamobius pallipes*, *Eupagurus bernhardus*, *Homarus vulgaris*, *Palinurus vulgaris* & *Portunus puber* (26.0 to 87.0 µg/g FW) and Ray *et al.* (1980) in the eggs of *Pandalus montagui* (100.0 µg/g DW).

SUMMARY

The present study was prompted as availability of maturing and mature P. *indicus* in the estuarine area is meagre as compared to inshore marine area especially during monsoon and post-monsoon period when freshwater run-off and local precipitation, presumably, causes drastic alteration of physicochemical dynamics of the estuarine area. Therefore, in the present investigation, seasonal variation of physicochemical parameters and some of the metals in water and sediment in the marine and the estuarine areas were studied. But the emphasis was to find out if season- and ecosystem-specific variations of calcium, magnesium, phosphorus, copper and zinc in the water and the sediment has any role to play in altering the concentration of these elements in different tissues of P. *indicus* as evidenced by the seasonal studies in the grow-out (representing estuarine area) and the marine (representing marine area) ecosystems.

The grow-out ecosystem, studied, is an estuarine impoundment of 76 hectares, 1.5 m deep in Vypeen Island and connected to the Vembanad estuary through a net-work of a few canals. The marine ecosystem lies at about 30 m

depth-zone on the continental shelf of Arabian Sea off Cochin. Three sampling stations were fixed in each ecosystem. Samples of water, sediment and male and female P. indicus (intermoult) were collected fortnightly. Water samples were collected about 30 cm above the sea- or estuarine-floor in both the ecosystem as penaeids are known to be benthic.

Water was analysed for temperature, dissolved oxygen, pH, Eh, salinity, net primary productivity, nitrate, nitrite, ammonia, calcium, magnesium, total phosphorus, copper and zinc. Sediment samples were analysed for temperature, pH, Eh, calcium, magnesium, total phosphorus, copper and zinc. Different tissues viz. exoskeleton, muscle, hepatopancreas, ovary/testis and the haemolymph of male and female P. indicus were analysed for calcium, magnesium, phosphorus, copper and zinc content.

The results of seasonal variation study of two years(November '82 to October '84) showed that the physicochemical conditions, in general, remained same in both the ecosystems during non-monsoon period but major noticable variations occurred when considerable rainfall poured during monsoon and post-monsoon period. The physicochemical parameters generally recovered to their pre-monsoon level by the end of post-monsoon period.

In the grow-out ecosystem, fresh water run-off from the catchment area and the local precipitation during monsoon and post-monsoon had enormous dilution effect on the pre-monsoonal marine waters of Cochin backwaters resulting in decreased salinity of water; and calcium and magnesium of the water and the sediment. The decreased temperature and Eh of the water and the sediment were noticed during monsoon and post-monsoon period. The considerably increased nutrients, copper and zinc, observed during monsoon and post-monsoon period resulted in increased primary production as a result of which ecosystem became more alkaline as shown by high values of pH during same period. The erratic fluctuations of nitrite were recorded. Total phosphorus showed increased values during transition period and early monsoon. The dissolved oxygen level showed, more or less, uniform values but for a minor decrease during monsoon. The increased primary production caused increase in consequent 'death and decay' and 'sinking'. This resulted in increased level of total phosphorus, copper and zinc in the sediment during monsoon and post-monsoon as recorded in the present study. It is explained that the fresh water discharge brings alongwith suspended silt rich in nutrients and organic matter, to which copper and zinc are, presumably, adsorbed. A part of this silt settles down on estuarine floor. Besides, the presence of a major port, Udyogamandal Industrial Complex, Shipyard and shipping activity, Rare-earth mining complex and other Industrial and geo-chemical activities alongwith domestic pollution, and flushing of these area also contribute to increase the metal and nutrient levels during monsoon and post-monsoon.

In the marine ecosystem, the seasonal variations of salinity, calcium and magnesium of water, and calcium and magnesium of sediment are found to be little. The considerable decrease of water temperature, dissolved oxygen and Eh was noticed during monsoon and post-monsoon period. Relatively low pH was recorded during monsoon and post-monsoon period. The considerably increased nutrients, net primary production, copper and zinc recorded in the marine ecosystem during monsoon and post-monsoon period might be partly due to the 'sedimentation' of organic matter rich silt of riverine origin and 'sinking' of organic debris. It is observed that the incursion of offshore waters are of primary significance and the effect of freshwater discharge and local precipitation is not quite apparent in the marine ecosystem. The marine ecosystem, in comparison to the grow-out ecosystem, provides a relatively stable seasonal picture.

While comparing the seasonal variation in both the ecosystems, the following aspects become clear.

Both the ecosystems showed decrease in temperature of water and sediment during monsoon and post-monsoon but the quantum of decrease was considerably higher in the marine than in the grow-out ecosystem. The pH of water and sediment showed stable values in the marine ecosystem with a little decrease during monsoon period, whereas considerable increase of pH was noticed during monsoon and post-monsoon period in the grow-out ecosystem. The Eh in both the ecosystems behaved in a similar fashion all round the year. The level of dissolved oxygen was considerably higher in the grow-out than in the marine ecosystem and the quantum of seasonal decrease of dissolved oxygen was relatively mild in the grow-out ecosystem. The salinity, calcium and magnesium of the water and the sediment showed considerable decrease to almost freshwater values during monsoon and post-monsoon in the grow-out ecosystem, in contrast to the stable seasonal values recorded in the marine ecosystem. The behaviour of net primary production, nutrients; total phosphorus; copper and zinc of water and sediment was similar in both the ecosystems.

The results of present study showed that the seasonal variations of bio-elements, in different tissues of male and female _P_. _indicus_, were little during non-monsoon period and the variations, whatsoever, recorded, occurred mainly during monsoon and/or post-monsoon period only.

The behaviour of calcium and magnesium in the tissues was similar to that of the same in the water and the sediments of both the ecosystems. During non-monsoon period, calcium and magnesium variation in water, sediment and various tissues was little in both the ecosystems. Considerable decrease of each of these metals was noticed in the water, sediment and haemolymph, muscle, hepatopancreas and gonad of male and female _P_. _indicus_ during monsoon and post-monsoon period in the grow-out ecosystem only. The exoskeletal calcium showed little decrease during monsoon and post-monsoon period. The marine ecosystem showed relatively stable seasonal magnesium values in water, sediment and various tissues of _P_. _indicus_. There were no sex-specific differences in either of the ecosystems. Calcium was found to be always higher in the haemolymph than in the ambient medium but the reverse was true for magnesium.

The haemolymph phosphorus showed erratic seasonal variation in both the ecosystems. The relatively lower values of exoskeletal phosphorus were noted during monsoon and post-monsoon in both the ecosystems. Muscle phosphorus was variable in both the ecosystems, though slightly higher values were noted in the monsoon and post-monsoon especially in the grow-out ecosystem. Phosphorus values of hepatopancreas and testis/ovary were low during monsoon and post-monsoon period in the grow-out ecosystem whereas, in the marine ecosystem there was no much change in the values. There was little effect of seasonal variation of total phosphorus in water and sediment on the variations of the same in animal tissues in either of the ecosystems.

The seasonal behaviour of copper and zinc in various tissues of male and female P. indicus was similar in both the ecosystems. Increased levels of these metals in haemolymph and muscle were noted during monsoon and post-monsoon in both the ecosystems. Exoskeletal copper and zinc levels were recorded to be, more or less, seasonally uniform in both the ecosystems. The hepatopancreatic copper and zinc showed minor decrease during monsoon and post-monsoon period in both the ecosystems. Copper and zinc levels in the ovarian tissue remained seasonally uniform in the marine ecosystem. In the grow-out ecosystem, relatively lower levels of copper and zinc were noted during monsoon and post-monsoon period. The testicular copper and zinc, too, behaved like ovarian tissue. The seasonal variation of copper and zinc in the haemolymph and the muscle are significantly correlated to variations of the same in water and sediment in both the ecosystems.

In general, the uniform seasonal tissue levels of calcium and magnesium noted in the marine ecosystem suggest that the animals were bathed in a stable unaltered milieu involving least stress on osmo-regulatory activity. On the other hand, the drastic alteration of the grow-out ecosystem during heavy fresh water discharge time, make the ecosystem stressful for P. indicus. The animal has to keep on attaining the dynamic chemical equilibrium with the ambient medium.

The findings of present study has its own inborn limitations. However, it may serve as the baseline in vivo information which can be utilized as a springboard to launch more useful in vitro studies to understand the operating physiological principles and to arrive at definite conclusion.

REFERENCES*

Anand, S.P. and R. Jayaraman 1972 Distribution of inorganic phosphate in the upper hundred-meter column in different regions of the northern Indian Ocean. Indian J. mar. Sci., 1: 79-84.

Annigeri, G.G. 1968 Hydrology of the inshore waters of Karwar Bay during 1964-1966. Indian J. Fish., 15:155-165.

Annigeri, G.G. 1972 Hydrological conditions in the inshore region of Karwar during 1965-1967. Indian J. Fish., 19: 156-162.

Ansari, Z.A. 1974 Macrobenthic production in Vembanad Lake. Mahasagar, 7(3 & 4): 197-200.

Ansari, Z.A. and M.D. Rajagopal 1974 Distribution of mud phosphates in the Cochin backwater. Mahasagar, 7 (3 & 4): 151-155.

Arnac, M. 1976 Variations des teneurs en Cd, Pb and Cu dans les eaux de L'eustaire maritime du St. Laurent Durant L'ete 1972. Mar. Chem., 4: 175-187 (In French with English abstract).

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS 1980 Atomic absorption method for fish. In: Willin Horwitz (ed.), Official Methods of Analysis of the Association of official Analytical Chemists 13th Edn.,p.399-400.

Aswathanarayana, U. 1964 "Advancing frontiers in geology and geophysics"pp. 481, Osmania University Press, Hyderabad.

---

* References marked with astrick (*) were not referred to in original.

Balazas, G.H., S.E. Olbrich and M.E. Tumbleson 1974 Serum constituents of the Malayasian prawn (*Macrobrachium rosenbergii*) and pink shrimp (*Penaeus marginatus*). *Aquaculture*, *3*(2): 147-157.

Becker, G.L., C.H. Chen, J.W. Greenawalt and A.L. Lehninger 1975 Calcium phosphate granules in the hepatopancreas of the blue crab *Callinectes sapidus*. *J. Cell Biol.*, *61*: 316-326.

Bendschneider, K. and R.J. Robinson 1952 A new spectrophotometric method for the determination of nitrite in seawater. *J. Mar. Res.*, *11*: 87-96.

Bhargava, R.M.S., P.M.A. Bhattathiri, V.P. Devassy and K. Radhakrishna 1978 Productivity studies in the Southern Arabian Sea. *Indian J. mar. Sci.*, *7*: 267-270.

Biesinger, K.E. and G.M. Christensen 1972 Effects of various metals on survival, growth, reproduction and metabolism of *Daphnia magna*. *J. Fish. Res. Bd. Can.*, *29*(12): 1691-1700.

Blair, D. and K.E. Van Holde 1976 Sedimentation equilibrium studies of a complex association reaction. *Biophys. Chem.*, *5*: 165-170.

Boon, D.D. 1973 Iron, zinc, magnesium, and copper concentrations in body meat of the blue crab, *Callinectes sapidus*. *Chesapeake Sci.*, *14*(2): 143-144.

Bourg, A.C.M. 1981 Critical evaluation of the studies of the chemical behaviour of trace metals in estuaries: Emphasis on surfaces of suspended particulate matter and on water pH. In: *Proc. International Conf. Heavy Metals in the Environment*, p. 355-358.

Bourg, A.C.M. 1982 Role of freshwater/seawater mixing on trace metals adsorption phenomena. In: C.S. Wong *et al.* (ed), *Trace Metals in Seawater*, p. 195-208. Plenum Press, New York.

Boyle, E.D., S.S. Huested and S.P. Jones 1981 On the distribution of copper, nickel and cadmium in the surface waters of the north Atlantic and north Pacific Oceans. *J. Geophys. Res.*, B6, C9, 8040-66.

Braganca, A. and S. Sanzgiry 1980 Concentrations of few trace metals in coastal and offshore regions of the Bay of Bengal. *Indian J. mar. Sci.*, *9*:283-296.

Brannon, A.C. and K.R. Rao 1979 Barium, strontium and calcium levels in the exoskeleton, hepatopancreas and abdominal muscle of the grass shrimp, *Palaemonetes pugio*: Relation to moulting and exposure to barite. *Comp. Biochem. Physiol.*, *63*A: 261-274.

Brewer, P.G. 1975 Minor elements in Seawater. In: J.P. Riley and G. Skirrow (eds.) *Chemical Oceanography*, 2nd edn., Vol *1*; 606 pp., Academic Press, London.

Bristow, R.C. 1938 History of mudbanks. Vols *1* and *2*, 173 pp. and 55 pp. Cochin Government Press, Cochin, India.

Bryan, G.W. 1964 Zinc regulation in the lobster *Homarus vulgaris*. I. Tissue zinc and copper concentrations. *J. mar. biol. Ass. U.K.*, *44*: 549-563.

Bryan, G.W. 1966 The metabolism of Zn and Zn^{65} in crabs, lobsters and freshwater crayfish. *Proc. Symp. Radioecological Concentration Processes*, Stockholm, Sweden, Oxford: Pergamon Press, p. 1005-1016.

Bryan, G.W. 1967 Zinc regulation in the freshwater crayfish (including some comparative copper analysis). J. exp. Biol., 46: 281-296.

Bryan, G.W. 1968 Concentrations of zinc and copper in the tissues of decapod crustaceans. J. mar. biol. Ass. U.K., 48: 303-321.

Bryan, G.W. 1973 The occurrence and seasonal variation of trace metals in the scallops Pecten maximus (L.) and Chlamys opercularies (L.) J. mar. biol. Ass. U.K., 53: 145-166.

Bursey, C.R. and C.E. Lane 1971 Ionic and protein concentration changes during the moult cycle of Penaeus duorarum. Comp. Biochem. Physiol., 40A: 155-162.

Burton, J.D. 1978 Behaviour of some trace chemical constituents in estuarine waters. Pure Appl. Chem., 50: 385-393.

Charmantier, G. 1972 Recherches ecophysiologiques ches Sphaeroma serratum (Fabricius). Bulletin de la Societe Zoologique de France, 97: 35-44 (In French with English abstract).

Chichibu, S. 1979 Calcium concentration changes in the aesthetic hairs caused by the environmental salinity shifts. Proc. Jap. Acad., Ser. B, 54(1):37-42.

Chow, T.J. and T.G. Thompson 1954 Seasonal variation in the concentration of copper in the surface waters of San Juan Channel, Washington. J. mar. Res., 13(3):233-244.

*Clapper, D.L. and G.G. Brown, 1980 *Dev. Biol.*, **76**: 350-357.

Colvocoresses, J.A. and M.P. Lynch 1975 Variation in serum constituents of the blue crab, *Callinectes sapidus*: Copper and Zinc. *Comp. Biochem. Physiol.*, **50**A: 135-139.

Colvocoresses, J.A., M.P. Lynch and K.L. Webb 1974 Variations in serum constituents of the blue crab, *Callinectes sapidus*: Major cations. *Comp. Biochem. Physiol.*, **49**A: 787-803.

Cummings, W.C. 1961 Maturation and spawning of the pink shrimp, *Penaeus duorarum* Burkenroad. *Trans. Am. Fish. Soc.*, **90**(4): 462-468.

Dall, W. 1965a Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea: Decapoda: Penaeidae). III. Composition and structure of the integument. *Aust. J. mar. Freshwat. Res.* **16**: 13-23.

Dall, W. 1965b Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea: Decapoda: Penaeidae). V. Calcium metabolism. *Aust. J. mar. Freshwat. Res.*, **16**: 181-203.

Dall, W. 1974 Osmotic and ionic regulation in the western rock lobster *Panulirus longipes* (Milne-Edwards). *J. exp. mar. biol. Ecology*, **15**: 97-125.

Dall, W. 1981 Osmoregulatory ability and juvenile habitat preference in some penaeid prawns. *J. exp. mar. biol. Ecol.*, **54**: 55-64.

Danielsson, L.G. 1980 Cadmium, cobalt, copper, iron, lead, nickel and zinc in Indian Ocean water. *Mar. Chem.*, **8**: 199-215.

Dehnel, P.A. 1967 Osmotic and ionic regulation in estuarine crabs. In: Lauff, G.H.(Ed.), *Estuaries*, p. 541-547. A.A.A.S., Washington, D.C.

DeRobertis, E.D.P. and E.M.F. De Robertis 1980 *Cell and Molecular Biology*. Saunders College Philadelphia, Holt-Saunders, Japan, Tokyo, pp. 673.

Digby, P.S.B. 1967 Calcification and its mechanism in the shore crab, *Carcinus maenas* (L.). *Proc. Linn. Soc., Lond.*, **178**: 129-146

Dill, W.A. 1967 "FOREWORD" In: Pillay, T.V.R. (ed), FAO Fisheries Report No. **44**(1): 55 pp., FAO of United Nations, Rome.

Djangmah, J.S. and D.J. Grove 1970 Blood and hepatopancreas copper in *Crangon vulgaris* (Fabricius). *Comp. Biochem. Physiol.*, **32**: 733-745.

Dyer, K.R. 1972 Sedimentation in estuaries. In: R.S.K.Barnes and J. Green (eds.). *The estuarine Environment*. Applied Science Publishers, London, 133 pp.

Eldred, B.R., M. Ingle, K.S. Woodburn, R.F. Hutton and H. Jones 1961 Biological observations on the commercial shrimp *Penaeus duorarum* Burkenroad, in Florida waters. *Fla. St. Bd. Conserv., Prof. Ser.*, **3**: 1-39.

Engelhardt, F.R. and P.A. Dehnel 1973 Ionic regulation in the pacific edible crab, *Cancer magister* (Dana). *Canadian J. Zool.*, **51**: 735-743.

Ewins, P.A. and C.P. Spencer 1967 The annual cycle of nutrients in the Menai straits. *J. mar. biol. Ass. U.K.*, **47**: 533-542.

FAO 1975 Manual of methods in aquatic environment research. FAO Fish. Tech. Paper, 137: 1-238.

Ferguson, J.K.W., L. Lewis and J. Smith 1937 The distribution of carbonic anhydrase in certain marine invertebrates. J. Cell. Comp. Physiol., 10: 395-400.

Foster, P. and A.W. Morris 1971 The seasonal variation of dissolved ionic and organically associated copper in the Menai Straits. Deep-Sea Res., 18:231-236.

Ganapathy, S., K.C. Pillai and A.K. Ganguly 1968 Adsorption of trace elements by nearshore seabed sediments. BARC - 376.

George, M.J. 1962 On the breeding of penaeids and the recruitment of their post-larvae into the backwaters of Cochin. Indian J. Fish., 9(1): 110-116.

George, M.D. and K. Sawker 1981 Organically associated copper in Mandovi and Zuari estuaries. Mahasagar, 14(1): 71-73.

Gibbs, R.J. 1973 Mechanisms of trace metal transport in rivers. Science, 1180: 71-73.

Gibbs, P.E. and G.L. Bryan 1972 A study of strontium, magnesium and calcium in the environment and exoskeleton of decapod crustaceans, with special reference to Uca burgersii on Barbuda, West Indies. J. exp. mar. biol. Ecol., 9: 97-110.

Gieskes, J.M. 1969 Effect of temperature on the pH of the seawater. Limnol. Oceanogr., 20: 649-653.

Gilles, R. 1977 Effects of osmotic stresses on the proteins concentration and pattern of Eriocheir sinensis blood. Comp. Biochem. Physiol., 56A: 109-114

Goldberg, E.D. 1976 *The Health of Oceans* 172 pp., Unesco Press, Paris.

Gole, C.V. and Z.S. Tarapore 1966 Radioactive tracer studies at Cochin. *IIOE Newsletter*, *4*: 28pp.

Gopalakrishnan, V. 1952 Food and feeding habits of *Penaeus indicus*. *J. Madras Univ.*, *22*(1B): 69-73.

Gopinathan, C.K. and S.Z. Qasim 1971 Siltation in Navigational channels of the Cochin Harbour Area. *J. mar. biol. Ass. India*, *13*: 14-26.

Gopinathan, C.K. and P.S. Joseph 1980 Physical features of nearshore waters off Karwar. *Indian J. mar. Sci.*, *9*: 166-171.

Graf, F. 1978 Les sources de calcium pour les Crustaces venant de muer. *Arch. Zool. exp. gen.*, *119*(1): 143-161. (In French with English abstract).

Greenaway, P. 1972 Calcium regulation in the freshwater crayfish *Austropotamobius pallipes* (Lereboullet). I. Calcium balance in the intermoult animal. *J. exp. Biol.*, *57*: 471-487.

Greenaway, P. 1976 The regulation of haemolymph calcium concentration of the crab *Carcinus maenas* (L). *64*: 149-157.

Greenaway, P. 1985 Calcium balance and moulting in the crustacea. *Biol. Rev.*, *60*: 425-454.

Gupta, S.R. and S. Naik 1981 Studies on calcium, magnesium and sulphate in the Mandovi and Zuari river systems (Goa). *Indian J. mar. Sci.*, *10*(1): 24-34.

Gupta, S.R., S.S. Naik and S.Y.S. Singbal 1978 A study of fluoride, calcium and magnesium in the northern Indian Ocean. *Mar. Chem.* 6: 125-141.

Guyselman,. J.R. 1953 An analysis of the moulting process in the fiddler crab, *Uca pugilator*. *Biol. Bull.*, **104**: 115-137.

Haefner, P.A. 1964 Haemolymph calcium fluctuations as related to environmental salinity during ecdysis of the blue crab, *Callinectes sapidus* Rathbun. *Physiol. Zool.*, **37**: 247-258.

Hagerman, L. 1973 Ionic regulation in relation to the moult cycle of *Crangon vulgaris* (Fabr.)(Crustacea, Natantia) from brackishwater. *Ophelia*, **12**: 141-149.

Haridas, P., M. Madhu Pratap and T.S.S. Rao 1973 Salinity, temperature, oxygen and zooplankton biomass of the backwaters from Cochin to Alleppey. *Indian. J. mar. Sci.* **2**(2): 94-102.

Hecht, T. 1975 Blood calcium values of *Sesarma catenata* (Ortmann) during the moulting cycle. *South African J. Sci.*, **71**: 281-282.

*Hoff, J. 1978 In: *Proc. Symposium on the Oceanography of the St. Lawrence Estuary*, p. 17, Rimonski, Quebec, Canada, 12-13 Apr. 1978.

Holm-Jensen, I.B. 1948 Osmotic regulation in *Daphnia magna* under physiological conditions and in the presence of heavy metals. *Kgl. Danske Vid. Selsk, Bid. Medd. Kbh.*, **20**: 1-64.

Horowitz, A. and B.J. Presley 1977 Trace metal concentrations and partitioning in zooplankton, neuston, and benthos from the South Texas Outer Continental Shelf. *Arch. Environ. Contamin. Toxicol.*, *5*: 241-255.

Hosokawa, I., F. Ohsima and N. Kondo 1970 On the concentrations of the dissolved chemical elements in the estuary of the Chikugogawa River. *J. Oceanogr., Soc. Jap.*, *26*: 1-5.

Huner, J.V., J.G. Kowalczuk and J.W. Avault Jr. 1976 Calcium and magnesium levels in the intermoult (C_4) carapaces of three species of freshwater crawfish (Cambaridae: Decapoda). *Comp. Biochem. Physiol.*, *55*A: 183-185.

Huner, J.V., L.B. Colvin and B.L. Reid 1979 Postmoult mineralization of the exoskeleton of juvenile california brown shrimp *Penaeus californiensis* (Decapoda: Penaeidae). *Comp. Biochem. Physiol.*, *62*A: 389-393.

Idyll, C.P., A.C. Jones and D. Dimitriou 1963 Production and distribution of pink shrimp larvae and postlarvae. *Circ. U.S. Fish Wildl. Serv.*, *161*: 93-94.

Imai, T. 1977 *Aquaculture in Shallow Seas* - Progress in shallow sea culture, p. 413-474, Translation of: Senkai Kansen Yoshoki (Senkai Yoshoku no shinpo); Amerino Publishing Co., New Delhi.

Ishii, T., M. Suzuki and T. Koyanagi 1978 Determination of trace elements in marine organisms - I. Factors for variation of concentration of trace element. *Bull. Japan. Soc. Sci. Fish.* *44*: 155-162.

Jegatheesan, G. and V.K. Venugopalan 1973 Trace elements in the particulate matter of Porto Novo waters (11° 29' N - 79°49' E) *Indian J. mar. Sci.*, *2*(1):1-5.

Kannan, K. 1982 Studies on haemolymph calcium of *Scylla serrata* Forskal (Crustacea: Decapoda). *Ph.D. thesis*, 283 pp., Madras Univ., India.

Keilin, D. and T. Mann 1940 Carbonic anhydrase. Purification and nature of the enzyme. *J. Biochem.*, *34*: 1163-1176.

Kleinholz, L.H. and E. Bourquin 1951 Moulting and calcium deposition in decapod crustaceans. *J. Cell. Comp. Physiol.*, *18*: 101-107.

Knauer, G.A. and J.H. Martin 1973 Seasonal variations of cadmium, copper, manganese, lead and zinc in water and phytoplankton in Montherey Bay, California. *Limnol. Oceanogr.*, *78*: 597-604.

Lande, E. 1977 Heavy metal pollution in Trondheims fjorden, Norway, and the recorded effects on the fauna and flora. *Environ. Pollut.*, *12*: 187-198.

Lewis, A.G. and W.R. Cave 1982 The biological importance of copper in Oceans and Estuaries. In: Harold Barnes (Founder ed.) and Margaret Barnes (ed.), *Oceanography and Marine Biology - An annual Review*, Vol. *20*: p. 471-695. Aberdeen Univ. Press. Aberdeen.

Lindner, M.J. and W.W. Anderson 1956 Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*. *Fishery Bull. Fish. Wildl. Serv., U.S.*, *56* (106): 555-645.

Lockwood, A.M.P. 1962 The osmoregulation of Crustacea. *Biol. Rev.*, *37*: 257-305.

Lontie, R. and L. Vanquickenborne 1974 The role of copper in haemocyanins. In: Helmut Siegel (ed.), *Metal Ions in Biological Systems*, Vol. *3*: *High Molecular complexes*, p. 183-200, Marcel Dekker Inc., New.York.

Lowman, F.G., J.H. Martin, R.Y. Ting, S.S. Barnes, D.J.P. Swift, G.A. Seiglie, R.G. Pirie, R. Davis, R.J. Santiago, R.M. Escalera, A.G. Gordon, G. Telek, H.L. Besselieure and J.B. McCanless 1970 Bioenvironmental and radiological-safety feasibility studies, Atlantic-Pacific interoceanic canal. *Estuar. and Mar. Ecol.*, Vol. *1*: 1-217, prepared for Battelle Memorial Institute, Columbus, OH, Contract AT (26-1)-17.

Lowry, C.H., N.R. Roberts, K.Y. Leiner, M.L. Wu and A.L.Farr 1954 Inorganic phosphorus determination in biological tissues. *J. Biol. Chem.*, *207*: 1.

Manikoth, S. 1975 A preliminary study of the distribution of calcium in Cochin backwater. *J. mar. biol. Ass. India*, *17*(3): 706-710.

Manikoth, S. and K.Y.M. Salih 1974 Distribution characteristics of nutrients in the estuarine complex of Cochin. *Indian J. mar. Sci.*, *3*(2): 125-130.

Martin, J.M., U. Nijampurkar, F. Salvadori 1978 Uranium and thorium isotope behaviour in estuarine system. In: *Biogeochemistry of estuarine sediments*. Proceedings UNESCO/SCOR workshop, Melreux, Belgium, 111-127.

Matkar, V.M. and K.C. Pillai 1975 Zinc in an estuarine environment *J. mar. biol. Ass. India*, **17**(2): 108-115.

Matkar, V.M., S. Ganapathy and K.C. Pillai 1981 Distribution of Zn, Cu, Mn and Fe in Bombay Harbour Bay. *Indian J. mar. Sci.*, **10**: 35-40.

*Marchig, V. 1973 *Meteor, Forschungsergebnisse.* **11**:104-110

MFIS-35 1982 Synopsis of marine prawn fishery of India-1980. *Mar. Fish. Infor. Serv. T & E Ser.*, **35**: 1-14 CMFRI, Cochin India.

Mills, B.J. and P.S. Lake 1976 The amount and distribution of calcium in the exoskeleton of the intermoult crayfish *Parastacoides tasmanicus* (Erichson) and *Astacopsis fluviatilis* (Gray). *Comp. Biochem. Physiol.*, **53**A: 355-360.

Mills, B.J., P. Suter and P.S. Lake 1976 The amount and distribution of calcium in the exoskeleton of intermoult crayfish of the genera *Engaeus* and *Geocharx*. *Aust. J. mar. Freshwat. Res.*, **27**: 513-523.

Miyazaki, K. and K. Jozuka 1964 Uptake and turnover of ^{45}Ca by the cray-fish *Procambarus clarkii*. *Annu. Rep. Noto. Marine Lab. Japan*, **9**: 111-120.

*Morton, J.W. 1977. *U.S. Fish Widl. Serv.,Tech. Paper* **94**: 33 pp.

Muller, G.and U. Forstner 1975 Heavy metals in sediments of the Rhine and Elbe estuaries: mobilization or mixing effect? *Env. Geol.*, **1**: 33-39.

Murphy, J. and J.P. Riley 1962 A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta.*, *27*: 31-36.

Murrey, C.V. and L. Murrey 1973 Adsorption - desorption equilibria of some radionuclides in sediment freshwater and sediment - seawater systems. *Proc. Symp. on Interaction of radioactive contaminants with the constituents of marine environment*, p. 105-124, International Atomic Energy Commission.

Murty, A.V.S., D.S. Rao, A. Regunathan, C.P. Gopinathan and K.J. Mathew 1984 Hypothesis on mud-banks. In: *Mudbanks of Kerala Coast*. *Bull. Cent. Mar. Fish. Res. Inst.*, *31*: 8-18, CMFRI, Cochin, India.

Murty, P.S.N. and M. Veerayya 1972 Studies on the sediments of Vembanad Lake, Kerala State: Part II - Distribution of phosphorus. *Indian J. mar. Sci.* *1*: 106-115.

Murty, P.S.N. and M. Veerayya 1981 Studies on the sediments of Vembanad Lake, Kerala State: part IV - Distribution of trace elements. *Indian J. mar. Sci.*, *10*: 165-172.

Murty, P.S.N., A.L. Paropakari, C.M. Rao and R.S. Topgi. 1978 Distribution of some elements in sediments of Gulf of Kutch. *Indian J. mar. Sci.*, *7*(1): 44-46.

Murty, P.S.N., C.M. Rao, A.L. Paropkari and R.S. Topgi 1980 Distribution of Al, Mn, Ni, Co and Cu in the non-lithogenous fractions of sediments of the northern half of the western continental shelf of India. *Indian J. mar. Sci.*, *9*(1): 56-61.

Muthu, M.S. 1978 A general review of penaeid prawn culture. Cent. Mar. Fish. Res. Inst. Spl. Publ. No. 3: 25-33. CMFRI, Cochin, India.

Nagarajaiah, C.S. and T.R.C. Gupta 1983 Physicochemical characteristics of brackishwater ponds along Nethravathi estuary, Mangalore. Indian J. mar. Sci., 12: 81-84.

Naik, S.S. 1978 Calcium and magnesium concentration in the nearshore waters of Goa. Mahasagar, 11(3 & 4): 185-189.

Nair, P.V.R. 1974 Studies on the primary production in the Indian Seas. Ph.D. Thesis, 189 pp., Univ. Cochin, India.

Nair, P.V.R., K.J. Joseph, V.K. Balachandran and V.K. Pillai, 1975 A study on the primary production in the Vembanad Lake. Bull. Dept. marine Sci. Univ. Cochin, 7(1): 161-170.

Nair, R.R., R.S. Murali and R.M. Kidwai 1971 Ca^{++}/Mg^{++} ratios in the sediments on the continental shelf off Bombay. Proc. Indian Acad. Sci., 74 (1B): 29-33.

Nair, S.R.S. and M. Krishnankutty 1975 Note on the varying effects of salinity on the growth of the juveniles of Penaeus indicus from the Cochin backwater. Bull. Dept. mar. Sci. Univ. Cochin, 7(1): 181-184.

Naqvi, S.W.A. and C.V.G. Reddy 1979 On the variations in calcium content of the waters of Laccadives (Arabian Sea) Mar. Chem. 8: 1-7.

Panikkar, N.K. 1968 Osmotic behaviour of shrimps and prawns in relation to their biology and culture. FAO Fish. Rep., 57: 2-27.

Paropkari, A.L., R.S. Topgi, C.M. Rao and P.S.N. Murty 1980 Distribution of Fe, Mn, Ni, Co, Cu and Zn in non-Lithogeneous fractions of sediments of Gulf of Kutch. Indian J. mar. Sci., 9(1): 54-56.

Passano, L.M. 1960 Moulting and its control. In: T.H. Waterman (ed.), "The Physiology of crustacea" Vol. I Academic Press Inc., New York.

Paulinose, V.T., T. Balasubramanian, P.N. Aravindakshan, P.Gopala Menon and M. Krishnankutty 1981 Some factors of prawn ecology in Cochin backwaters. Mahasagar, 14(2): 123-133.

Pellenbarg, R.E. 1978 Spaartina alterniflora Litter and the aqeuous surface microlayer in the salt marsh. Estuar. cstl. mar. Sci., 6: 187-196.

Perkins, E.J. 1976 The Biology of estuaries and coastal organisms, 678 pp., Academic Press, London.

*Petkevich, T.A. and Stepanyuk, I.A. 1970 J. Hydrobiol., 6: 80-83.

Pillay, K.K. and N.B. Nair 1971 The annual reproductive cycles of Uca annulipes, Portunus pelagicus and Metapenaeus affinis (Decapoda: Crustacea) from the southwest coast of India. Mar. Biol. 11: 152-166.

Prasad, P.E. 1982 Studies on soils of some brackishwater prawn culture fields around Cochin. M.Sc. Thesis, 80 pp., Cochin Univ. of Sci. & Tech., Cochin, India.

Price Sheets, W.C. and J.E. Dendinger 1983 Calcium deposition into the cuticle of the blue crab, Callinectes sapidus related to external salinity. Comp. Biochem. Physiol., 74A: 903-907.

Prosser, C.L., J.W. Green and J.J. Chow 1955 Ionic and osmotic concentrations in blood and urine of *Pachygrapsus crassipes* acclimated to different salinities. *Biol. Bull.*, *109*: 99-107.

Radhakrishna, K., V.P. Devassy, R.M.S. Bhargava and P.M.A. Bhattathiri 1978 Primary production in the northern Arabian Sea. *Indian J. mar. Sci.*, *7*: 271-275.

Radhakrishnan, N.S. 1978 Hydrological studies in the inshore waters of Mangalore during 1964-1973. *Indian J. Fish.*, *25*(1&2): 222-227.

Rajan, A., B. Shanthi and M. Kalyani 1986 Effect of season, weight, sex and reproductive cycle on the zinc concentration in the soft tissues of *Meretrix casta* collected from Vellar estuary, Porto Novo, South India. In: *Proc. National Seminar Mussel Watch* Vol. *I*: p. 182,13-14 February, 1986, Cochin Univ. of Sci. & Tech., India (Abstract only).

Rajamanickam, G.V. and M.G.A. Padmanabha Setty 1973 Distribution of phosphorus and organic carbon in the nearshore sediments of *Goa*. *Indian J. Mar. Sci.*, *2*: 84-89.

Rajendran, A., S.N. DeSousa and C.V.G. Reddy 1982 Dissolved and particulate trace metals in the western Bay of Bengal. *Indian J. mar. Sci.* *11*: 43-50

Rajendran, N. and C.V. Kurian 1986 *Crassostrea madrasensis* (Preston) - Indicator of metal pollution in Cochin backwaters. In: *Proc. National Sem. Mussel Watch*, Vol. *I*: p. 120-131, 13-14 Feb., 1986 Cochin Univ. of Sci. & Tech., Cochin, India.

Rakestraw, N.W. 1936 The occurrence and significance of nitrite in the sea. Biol. Bull., 71: 133-167.

Ramamirtham, C.P. 1967 Fishery Oceanography C.M.F.R.I. 20th Anniversary Souvenir, p. 94-98.

Ramamirtham, C.P. and R. Jayaraman 1960 Hydrographical features of the continental shelf waters off Cochin during the years 1958 and 1959. J. mar. Biol. Ass. India, 2: 199-207.

Ramamirtham, C.P. and R. Jayaraman 1963 Some aspects of hydrographical conditions of the backwaters around Willington Island (Cochin). J. mar. Biol. Ass. India, 5(2): 170-177.

Ramamirtham, C.P. and C.P.A. Nair 1964 Variation of the vertical stability parameter in the surface layers of the Arabian Sea off Cochin. J. mar. biol. Ass. India 6(2): 202-206.

Ramamirthan, C.P. and M.R. Patil 1965 Hydrography of the West coast of India during the pre-monsoon period of the year 1962. Part 2. In and off-shore waters of the Konkan and Malabar Coasts. J. mar. biol. Ass. India. 7(1): 150-168.

Ramamurthy, S. 1963 Studies on the hydrological factors in the North Kanara Coastal waters. Indian J. Fish 10(1A): 75-93.

Rao, C.M. 1978 Distribution of $CaCO_3$, Ca^{2+} and Mg^{2+} in sediments of the northern half of western continental shelf of India. Indian J. mar. Sci., 7: 151-154.

Rao, C.M., P.S.N. Murty and C.V.G. Reddy 1974 Partition patterns of copper in the sediments of the western continental shelf of India. Indian J. mar. Sci., 3: 12-15

Rao, C.M., G.V. Rajamanickam, A.L. Paropkari and P.S.N. Murty 1978 Distribution of phosphate in sediments of the northern half of the western continental shelf of India. IndianJ. mar. Sci., 7: 146-150.

Rao, D.S. and C.P. Ramamirtham 1976 Seasonal variations in the hydrographic features along the west coast of India. Indian J. Fish., 21(2):514-524.

Rao, D.S., C.P. Ramamirtham and T.S. Krishnan 1968 Oceanographic features and abundance of the pelagic fisheries along the west coast of India. Proc. Symp. on the Living Resources of the Seas around India, p. 400-413, C.M.F.R.I., Cochin, India.

Rao, P.V. 1968 Maturation and spawning of the penaeid prawns of the southwest coast of India. FAO Fish. Rep., 57(2): 285-302.

Rao, P.V. 1978 Maturation and spawning of cultivable marine penaeid prawns. Proc. Summer Institute in Breeding and rearing of marine prawns, CMFRI Spl. Publ. No. 3, C.M.F.R.I., Cochin. IndiaP.57-67.

Rao, P.V., A.D. Diwan and V.S.Kakati 1982 Fluctuation in calcium levels in the exoskeleton, muscle and haemolymph of Penaeus indicus, cultivated in a brackishwater pond. Indian J. Fish., 29(1&2):160-167.

Ray, S., D.W. McLeese, B.A. Waiwood and D. Peezsack 1980 The disposition of cadmium and zinc in *Pandalus montagui*. *Arch. Environ. Contamin. Toxicol.*, *9*: 675-681.

Reddy, C.V.G. and V.N. Sankaranarayanan 1972 Phosphate regenerative activity in the mud of a tropical estuary. *Indian J. mar. Sci.*, *1*: 57-60

Richards, A.G. 1951 The *Integument of Arthropods*. 420 pp., University of Minuesota Press, Munneapolis.

Riley, J.P. and R. Chester 1971 *Introduction to Marine Chemistry*. 647 pp., Academic Press, New York.

Robertson, J.D. 1957 Osmotic and ionic regulation in aquatic invertebrates. In: B.T. Scheer (ed.), *Recent Advances in Invertebrate Physiology*, p. 229-246, University of Oregon Publication, Oregon.

Robertson, J.D. 1960a Osmotic and ionic regulation. In: T.H. Waterman (ed.), *The Physiology of Crustacea Vol. I, Metabolism and growth*, p. 317-339, New York.

Robertson, J.D. 1960b Ionic regulation in the crab *Carcinus maenas* (L.) in relation to the moulting cycle. *Comp. Biochem. Physiol.*, *1*: 183-212.

Rochford, R.J. 1951 Studies in Australian estuarine hydrology 1. Introductory and comparative features. *Aust. J. mar. Freshwat. Res.*, *2*: 1-116.

*Romanov, A.S., A.I. Ryabinin, E.A., Lazareva and L.B. Zhidkova 1977 *Oceanology*, *17*: 160-162.

Salomons, W. and W.G. Mook 1977 Trace metal concentrations in estuarine sediments: mobilization, mixing or precipitation. *Netherlands. J. Sea Res.*, **11**(2) 119-129.

Sankaranarayanan, V.N. and C.V.G. Reddy 1970 Total phosphorus content in the waters of the Arabian Sea along the West coast of India. *Proc. Indian Natn. Sci. Acad.* **36**(B2): 71-79.

Sankaranarayanan, V.N. and S.Z. Qasim 1969 Nutrients of the Cochin backwater in relation to environmental characteristics. *Mar. Biol.*, **2**: 236-247.

Sankaranarayanan, V.N. and C.V.G. Reddy 1973a Copper content in the inshore and estuarine waters along the central west coast of India. *Curr. Sci.*, **42**(7): 223-224.

Sankaranarayanan, V.N. and C.V.G. Reddy 1973b Total phosphorus content in the waters of the Arabian Sea along the west coast of India. *Proc. Indian Natn. Sci. Acad.* **36**(B2): 71-79.

Sankaranarayanan, V.N. and R. Stephen 1978 Particulate iron, manganese, copper and zinc in waters of the Cochin backwaters. *Indian J. mar. Sci.* **7**: 201-203.

Sankaranarayanan, V.N., K.S. Purushan and T.S.S. Rao 1978 Concentration of some of the heavy metals in the oyster *Crassostrea madrasensis* (Preston) from the Cochin region. *Indian J. mar. Sci.*, **7**: 17-22.

Sankaranarayanan, V.N. and S.U. Panampunnayil 1979 Studies on organic carbon, nitrogen, and phosphorus in sediments of the Cochin backwaters. *Indian J. mar. Sci.*, **8**(1): 27-30.

Sarma, T.P., G.R. Doshi, S.S. Gogate, T.M. Krishnamoorthy, V.R., Neralla, M.R. Rao, S.R. Rao, V.N. Sastry, S.M. Shah and C.K. Unni 1968 Geochemical investigations off Tarapur coast. *Bull. Natn. Inst. Sci. India* *38*(1) (*Physical and Chemical Oceanography*): 309-318.

Sastry, A.A.R. and P. Myrland 1960 Distribution of temperature, salinity and density in the Arabian Sea along the south Kerala coast (South India) during the post-monsoon season. *Indian J. Fish.*, *6*: 223-255.

Scheer, B.T. 1960 Aspects of intermoult cycle in natantians. *Comp. Biochem. Physiol.*, *1*: 3-18.

*Shiber, J.G. 1979 *J. Environ. Sci. Hlth., Part B* *14*: 73-96.

Shynamma, C.S. and K.P. Balakrishnan 1973 Diurnal variation of some physicochemical factors in Cochin backwaters during south-west monsoon *J. mar. biol. Ass. India*, *15*(1): 391-398.

Silas, E.G. 1983 Prawn culture and its importance in national development. In: *Proc. Summer Inst. on Hatchery Production of Prawn seeds and Culture of Marine Prawns*, p. 1-8, 18th April-17th May 1983, CMFRI, Cochin, India.

Singbal, S.Y.S. and S. Sanzgiry 1977 A study of heavy metals in dissolved and particulate forms. *Health of the Arabian Sea, NIO Tech. Rep.* 02/77, NIO, Goa, India.

Smith, D.S. and J.R. Linton 1971 Potentiometric evidence for the active transport of sodium and chloride across the excised gill of *Callinectes sapidus*. *Comp. Biochem. Physiol.*, *38*: 367-378.

Snedecor, G.W. and W.C. Cochran, 1967 *Satistical Methods* (VI Edn.) 593 pp., Iowa State Univ. Press, Iowa.

Solorzano, L. 1969 Determination of ammonia in natural waters by the phenol - hypochlorite method. *Limnol. Oceanogr.*, *14*: 799-801.

Solyom, P. and S. Carlberg 1975 Determination of nitrite. *FAO Fish. Tech. Paper*, *137*: 156-160.

Sparkes, S. and P. Greenaway 1984 The haemolymph as a storage site for cuticular ions during premoult in the freshwater/land crab, *Holthuisana transversa*. *J. exp. Biol.* *113*: 43-54.

Sreekumaran C., Y.M. Bhatt, J.R. Naidu, T.M.Krishnamoorthy, S.S. Gagote, M. Rama Rao, G.R. Doshi, V.N. Sastry, S.M. Shah, C.K. Unni and R. Vishwanathan 1966 Minor and trace elements in the marine environment of the west coast of India, AEET/HP/PM-5.

Sreenivasan, R. 1982 Studies on the abundance and distribution of benthos and hydrological parameters in prawn culture systems. *M.Sc. thesis*, 96 pp., Cochin Univ. of Sci. & Tech., Cochin, India.

Staples, D.J. 1980 Ecology of juvenile and adolescent banana prawn *Penaeus merguiensis* in a mangrove estuary and adjacent offshore waters of the Gulf of Carpentaria. II. Emigration and settlement of post larvae. *Aust. J. mar. Freshwat. Res.* *31*: 653-665.

Stickney, R.R., H.L. Windom, D.B. White and F.E. Taylor 1975 Heavy metal concentrations in selected Georgia estuarine organisms with comparative food habit data. In: Howell, F.G., J.B. Gentry, and M.H. Smith (eds.), *Mineral Cycling in Southeastern Ecosystems*. p. 257-267, CONF-740513 from NTIS, U.S. Dept. Comm., Soring field, Va 22161.

Strickland, J.D.H. and T.R. Parsons 1968 A practical handbook of seawater analysis. *Bull. Fish. Res. Bd. Canada*, 310 pp.

Subrahmanyan, R. 1959 Studies on the phytoplankton of the west coast of India Part II. *Proc. Ind. Acad. Sci.*, *50*: 189-252.

Sugunan, V.S. 1983 Ecology of meiobenthos in selected culture fields around Cochin. *M.Sc. Thesis*, 88 pp. Cochin Univ. of Sci. and Tech., Cochin, India.

Sundararaj, V. and K. Krishnamurthy 1972 The distribution of copper in Porto Novo waters. *Curr. Sci.*, *41*: 315-317

Taylor, A.C., S. Morris and C.R. Bridges 1985 Modulation of haemocyanin oxygen affinity in the prawn, *Palaemon elegans* (Rathke) under environmental salinity stress, *J. exp. mar. biol. Ecol.* *94*: 167-180

Thomas, D.J. and E.V. Grill 1977 The effect of exchange reactions between Fraser River sediment and Seawater on dissolved copper and zinc concentrations in the strait of Georgia. *Estuar. cstl. mar. Sci.* *5*: 421-427.

Travis, D.F. 1955 The moulting cycle of the spiny lobster Panulirus argus Latreille. II. Physiological changes which occur in the blood and urine during the moulting cycle. Biol. Bull., 109: 484-503.

Travis, D.F. and V. Friberg 1963 The deposition of skeletal structures in the Crustacea. VI. Microradiographic studies of the exoskeleton of the crayfish Orconectes virilis Hagen. J. Ultrastr. Res., 9: 285-301.

Truchot, J.P. 1975 Factors controlling the in vitro and in vivo oxygen affinity of the haemocyanin in the crab Carcinus maenas (L.). Respir. Physiol., 24: 173-189.

Turekian, K.K. 1971 Rivers, Tributeries, and Estuaries. In: D.W. Hood (ed.), Impingement of Man on the Oceans p.9-74, Wiley Interscience, New York.

Venugopal, P., K.S. Devi, K.N. Remani and R.V. Unnithan 1982 Trace metal levels in the sediments of the Cochin backwaters. Mahasagar, 15(4): 205-214.

Vinogradov, A.P. 1953 Elementary chemical composition of marine organisms. Memoirs Sears Foundn. Mar. Res., 2: 1-647.

Waterman, T.H. (ed.) 1960 The Physiology of Crustacea Vol. I. 670 pp. Metabolism and Growth. Academic Press Inc., New York.

Weiland, A.L. and C.P. Mangum. 1975 The influence of environmental salinity in haemocyanin function in the blue crab, Callinectes sapidus. J. exp. Zool., 193: 265-273.

White, S.L. and P.S. Rainbow 1982 Regulation and accumulation of copper, zinc and cadmium by the shrimp Palaemon elegans. Mar. Ecol. Prog. Ser., 8: 95-101.

White, S.L. and P.S. Rainbow 1984 Regulation of zinc concentration by Palaemon elegans (Crustacea: Decapoda). Zinc flux and effects of temperature, zinc concentration and moulting. Mar. Ecol. Prog. Ser., 16: 135-147.

Wolfe, D.A. and T.R. Rice 1972 Cycling of nutrients in estuaries. Fish. Bull. NOAA, 70: 959-972.

Won, J.H. 1973 The concentrations of mercury, cadmium, lead, and copper in fish and shellfish of Korea. Bull. Korean Fish Soc. 6(1, 2): 1-19.

Wright, D.A. 1979 Calcium regulation in intermoult Gammarus pulex. J. exp. Biol. 83: 131-144.

Wright, D.A. 1980 Calcium balance in pre-moult and post-moult Gammarus pulex (Amphipoda). Freshwat. Biol., 10: 571-579.

Young, D.R., T.K. Jan and M.D. Moore 1977 Metals in Power Plant Cooling Water Discharges, 8th Calif. Coastal water Res. Proc. An. Rept., 25-31.

Zanders, I.P. 1978 Ionic regulation in the mangrove crab Goniopsis cruentata. Comp. Biochem. Physiol., 60: 293-302.

Zanders, I.P. 1980 Regulation of blood ions in Carcinus maenas (L.). Comp. Biochem. Physiol., 65A: 97-108.

Zingde, M.D., S.Y.S. Singbal, C.F. Moraes and C.V.G. Reddy 1976 Areesenic, copper, zinc and manganese in the marine flora and fauna of coastal and estuarine waters around Goa. Indian J. mar. Sci. 5: 212-217.

Zirino, A.H., S.H. Lieberman and C. Clavell 1978 Measurement of Cu and Zn in San Diego Bay by automated anodic stripping voltammetry. Environ. Sci. Tech., 12: 73-79.