STUDIES ON THE EFFECT OF HYDROGEN SULPHIDE ON THE PENAEID PRAWNS OF KAYAMKULAM LAKE, SOUTH WEST COAST OF INDIA

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UNDER FACULTY OF MARINE SCIENCES

BY

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Marine Products Export Development Authority

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Shri Gopakumar. G, under my scientific supervision and guidance in the School of Marine Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the degree of Doctor of Philosophy of the Cochin University of Science and Technology and no part thereof has been presented before for the award of any other degree, diploma or associateship in any University.

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DECLARATION

*I, **GOPAKUMAR. G**, do hereby declare that this thesis, entitled **"STUDIES ON THE EFFECT OF HYDROGEN SULPHIDE ON THE PENAEID PRAWNS OF KAYAMKULAM LAKE, SOUTHWEST COAST OF INDIA"** is a genuine record of the research work done by me under the scientific supervision of **Dr. V.J. KUTTYAMMA**, Reader, Division of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, and has not previously formed the basis of the award of any degree diploma or associateship in any University.*

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GOPAKUMAR. G

It is apparent that the ever increasing human population, technological development and anthropogenic activities are causing serious stress on the inshore marine environment with a resulting decrease on its effective use. Shallow waters of bays and estuaries are areas frequently used for cultivation of several important fishes and shell fishes and are prone to both industrial and domestic pollution. Such pollution, both man made and natural fosters conditions that may diminish the harvest of these marine resources.

Estuaries form the nursery ground for several fishes and shellfishes. Further, estuaries are the main source of water for coastal aquaculture. Thus the quality of estuarine water can have profound influence on the growth and survival of the species cultured in these impoundments. Moreover, the information on the baseline levels of various pollutants commonly present in water must be taken into consideration while suggesting suitable guidelines for management practices to maintain the quality of water.

Prawn culture in brackish water earthen ponds is becoming increasingly popular in recent years. Prawn culturists have consistantly met with several serious problems while developing reliable techniques for pond management with a view to increase production.

Hydrogen sulphide which is commonly present in the water and soil of estuaries have received little attention from among pollution researchers. It is known that hydrogen sulphide can cause oxygen depletion

and thus result in mass mortality of economically important prawns and fishes. Moreover, information available on the cause and effects of hydrogen sulphide on estuarine ecology are rather scarse. This was the main guiding principle for the initiation of the present study which centred around delineation of the effect of hydrogen sulphide on penaeid prawns.

CONTENTS

1

ACUTE TOXICITY

INTRODUCTION

Hydrogen sulphide (H_2S) is exceedingly important in the aquatic environment. Its presence and reactions rank with photosynthesis, algal respiration and the iron cycle. Although hydrogen sulphide is an ubiqutous component of the soil its importance in polluted and natural waters has been underestimated in the evaluation of suitable water quality for aquatic organism. The rapid oxidation of hydrogen sulphide by the dissolved oxygen present in the water and the depletion of dissolved oxygen due to its high chemical oxygen demand, the highly toxic nature of un-ionised hydrogen sulphide are matters of great significance.

Eventhough the presence of hydrogen sulphide and other sulphides in aquatic environment causes mortality to aquatic organisms, many people assumed that hydrogen sulphide had no direct toxic effect, but that it caused oxygen depletion and the resulting anoxic condition was the real cause of mortality. It is true that the presence of hydrogen sulphide causes oxygen depletion because of its high oxygen demand. But the direct toxic effect of hydrogen sulphide on aquatic organisms cannot be ignored.

Un-ionised hydrogen sulphide is more toxic to aquatic organisms. The percentage of un-ionised hydrogen sulphide varies with pH, at pH 5,99% is in un-ionised form and at pH 9 only 1% is in un-ionised form (Smith & Oseid. 1974; Boyd, 1989).

Toxicity is a biological response, which when quantified in terms of concentration of the toxicant can constitute the basis of bioassay procedure. Bioassay (toxicity) tests are defined as the estimation of the amount of biologically active substances by the level of their effect on test organisms (Chapman and Long, 1983).

The effect of H_2S has been determined on certain fish and aquatic organisms (Longwell and Pentelow, 1935; Schaut, 1939; Cole, 1941; Jones, 1948). Shelford (1917) noted that H_2S was more toxic when accompanied by low oxygen.

Issatchenko (1924) has reported the seasonal production of H_2S in the sea of Azov in sufficient intensity to destroy large numbers of fish and other aquatic animals.

Van Horn et al (1949) determined that the minimum lethal dose of H_2S for lake emerald shiners for 120h was 1ppm.

Haydu et al (1952) found that the amount of H_2S tolerated without harm by Chinook Salmon (9-12cm), Coho Salmon (7.5-11cm) and cutthroat trout (9.5-12cm) to be 0.3, 0.7 and 0.5ppm respectively. However, Smith (1952) found cyprinodont fishes live in water containing 12mg H_2S/l. Blazka (1958) could keep carps healthy in sulphide rich waters while the presence of sulphide in the muscle tissue was demonstrable.

Mckee and Wolf (1963) studied the effect of H_2S on channel cat fish. Ictalurus punctatus. They also reported that H_2S dissociates primarily according to pH and temperature, other factors playing a minor role. Sinise (1965)

mentioned that H_2S gas, produced by aerobic bacteria, is harmful to catfish, but gives no tolerance limits. Bonn and Follis (1967) reported that the poor production of channel catfish in many acid lakes in North-East Texas is due to natural production of sulphides. They determined the TLm of un-ionised H_2S for channel catfish at different pH. They also estimated the TLm values for different sizes of channel catfish. They found that the TLm value increases with size.

Colby and Smith (1967) studied the TLm values of dissolved sulphide for walleye eggs for 48h and 144h. The TLm for walleye sac fry for 24h and 96h was also determined.

Adelman and Smith (1970) conducted a series of bioassays to study the effect of H_2S at two concentrations of oxygen on northern pike (Esox lucins.L.) eggs and sac fry.

Smith and Oseid (1970) studied the toxic effects of H_2S to eggs of Walleye (Stizostedion vitreum), rainbow trout (Salmo gairdnerii) and white sucker (Castostomus commersoni). They also determined the TLm for periods from 72h to 19 days at different levels of H_2S and dissolved oxygen.

Adelman and Smith (1972) conducted bioassays to test the effect of temperature and oxygen on H_2S toxicity to gold fish (Carassius auratus.L.) and to investigate some factors that influence the bioassay results. Smith and Oseid (1972) reported 96 h TL_{50} values for eggs and sac fry of various fish species. Oseid and Smith (1972) found that the swimming endurance of blue gill sunfish was reduced after chronic exposure to low levels (0.4 g/l) of H_2S.

Barid et al (1973) reported that Breqmacerons nectabanus can tolerate H_2S for a short period.

Smith and Oseid (1974) studied the effect of H_2S on development and survival of 8 species of freshwater fishes.

Boyd (1982) suggested a safe level of H_2S for fresh water fish.

Smith and Oseid (1975) demonstrated the toxic effect of the very low concentrations of H_2S frequently found over natural organic bottom. They studied the chronic effect on four species of fish, brook trout, blue gill, fat head minnow and gold fish and an amphipod, Gammarus pseudolinnaeus.

Smith et al (1976) determined 96h and threshold LC_{50} concentrations of H_2S. They also studied the effect of sub-lethal concentration on various life history stages of the blue gill.

Smith et al (1979) published a review of the literature concerning toxic effects of sulphide, particularly to mammals and fishes.

Patel and Spencer (1963) reported that Arenicola marina was remarkably tolerant to sulphide and survived upto 24h in sea water bubbled with H_2S and protected from air. Colby and Smith (1967) reported increased sensitivity of Gammarus pseudolimnaeus to dissolved sulphides with decreased oxygen concentration. Theede et al (1969) investigated the resistance of some gastropods, polychactes, crustaceans and echinoderms to oxygen deficiency and presence of H_2S.

Oseid and Smith (1974) studied the factors influencing acute toxicity

estimates of H_2S to fresh water invertebrates like isopod Asselus militaris, two amphipods. Crangomyx richmondensis and Gammarus pseudolimnaeus and three Ephemeroptera, Bactis vagans, Ephemerera simulans and Hexagenia limibata.

Shick (1976) reported that the LT_{50} values for the star fish Ctenodiscus crispatus when exposed to hypoxia reduced in the presence of H_2S.

Groenendaal (1980) determined the tolerance of different height classes of Arenicola marina to sulphide solutions.

Shummay et al (1983) studied the tolerance of mactrid clam Mulinia lateralis to anoxia in the presence and absence of H_2S.

Chen (1985) recommended a safe level of H_2S for Penaeus monodon culture.

Law (1988) reported that hydrogen sulphide is highly toxic to organisms such as prawns which disturb the sediment. He recommended a safe level of H_2S for P. monodon culture.

Since very little work is carried out on the direct toxic effect of H_2S on the cultivable species of penaeid prawns, the present study was undertaken to get information on the toxicity of hydrogen sulphide to different size groups of the Indian white prawn Penaeus indicus H. Milne Edwards, a candidate species for culture and Metapenaeus dobsoni (Meirs), prime species in the coastal brackishwater extensive farming ponds in Kerala

MATERIAL AND METHODS

Test Organisms

Penaeus indicus and Metapenaeus dobsoni of different size ranges were used for the assays. P. indicus of size ranges 20-25mm, 35-40mm and 85-90mm were used for the 96 h LC_{50} experiments in sea water of pH 8.1-8.3. M. dobsoni of size ranges 20-25mm and 35-40mm were also used for the same experiments. M. dobsoni longer than 35-40mm were not used for the study. To study the effect of pH on Hydrogen sulphide toxicity P. indicus and M. dobsoni of size group 20-25mm and 35-40mm were used.

Test animals were collected from the estuary and different size groups of both the species were seggregated and maintained in separate acclimatisation tanks for more than 7 days. The animals were well fed in the acclimatisation tank and maximum care was exercised to avoid injury to the animals. Only healthy animals were selected. All prawns used for the experiments were in the intermoult stage

Test Apparatus (Flow-through system)

The experiments were conducted in a flow-through apparatus (Fig. 1:1). The flow-through apparatus used was similar to the one described by Adelman and Smith (1970) with some modifications. It has three main units, made of plexiglass: the test chamber, reservoir for H_2S stock solution and sea water reservoir.

The test chamber measures 30x15x12 cms (5 litre capacity) with an inlet at one end and an outlet at the other. Three baffles (2 incomplete

and 1 complete) were provided at the inlet end for proper mixing of the water. The third baffle (complete one) has perforations at the top to allow free flow of water and to prevent the entry of animals into the baffle chamber. The animal chamber is provided with a wide circular opening at the top for introducing and removing the animals. The opening is closed with an air-tight lid.

The reservoir for H_2S stock solution is a cylindrical vessel of about 2 litre capacity hung from a stand. The upper end is open and the convex bottom has an outlet.

The sea water reservoir is an open rectangular tank with a capacity of 25 litres and is placed at a height of about 50cms above the test chamber. The outlets from the seawater and H_2S reservoir are connected to a 'Y' tube by plastic tubings which have plastic regulators in the middle. The tail of the 'Y' tube is connected to the test chamber by a plastic tube. Sea water and the H_2S stock solution from the respective reservoirs, after mixing in the 'Y' tube enter the test chamber where the baffles ensure thorough mixing of the sea water with the H_2S solution. The regulator on the H_2S line could be adjusted to allow the water to flow through the animal chamber continuously at a rate of 120 ml/minute.

Test Solution

The H_2S stock solution was prepared by dissolving a known quantity of analar grade Na_2S, $9H_2O$ in 1 litre of oxygen free distilled water and was siphoned into the reservoir where some liquid paraffin was kept. The paraffin formed a layer on top of the H_2S solution, preventing diffusion of

air which would oxidise the stock solution. The concentration of H_2S in the water flowing out of the test chamber was monitered every hour and the desired H_2S level was maintained by adjusting the flow of the stock solution through the regulator. By this procedure the H_2S concentration did not deviate from the desired level by more than 5%.

Test Water

Sea water filtered through a 50 micron mesh filter cloth was stored in a plastic pool and pumped to the sea water reservoir as and when necessary. During the course of the experiments, the sea water in the reservoir had a salinity of 32-33ppt, pH of 8.1-8.3 and temperature 28.0-28.5°C. The water in the reservoir was aerated vigourously to maintain dissolved oxygen level of not less than 4 ml/l. H_2S concentration and pH of the sea water flowing out of the animal chamber was determined hourly and the dissolved oxygen was estimated thrice a day. The out flowing water had reduced oxygen content ranging from 1.5 to 2 ml/l, the pH ranged from 8.1 to 8.3.

Lethal Toxicity Bioassays

96 h LC_{50} experiments: To find out the 96 h median lethal concentration (LC_{50}) different size groups of Penaeus indicus and Metapenaeus dobsoni were exposed to various concentrations of hydrogen sulphide. Three size ranges of P. indicus 20-25mm, 35-40mm and 85-90mm were used to have a better understanding on the size related effect of hydrogen sulphide, whereas for M. dobsoni only two size groups (20-25mm and 35-40mm) were used.

Experiments with each H_2S concentration was repeated twice for every size group. Every experimental run was accompanied by a control run in which the same number of prawns of the same size were kept through which H_2S - free sea water from the same reservoir was made to flow through at the same flow rate of 120 ml/mt by adjusting the regulators connected to the inlet and outlet tubes leading to and from the test apparatus. Both the experimental and control animals were not fed during the 96 h period of the experiment.

The behaviour of the prawns in the animal chamber was closely observed throughout the experimental period (96 h). Animals that lay on the side and showed no movement of the appendages were considered dead. Dead animals were removed from the chamber and examined for any discolouration or damage to gills etc.

From the mortality percentage observed in each H_2S level at the 12h, 24h, 36h, 48h, 60h, 72h, 84h & 96h the LC_{50} value was calculated by weighted probit analysis.

Effect of pH on H_2S Toxicity

As pH of the medium is known to affect toxicity of H_2S to animals, using the same equipment and procedures described above, the 96h LC_{50} values for 20-25mm & 35 to 40mm prawns of P. indicus and M. dobsoni were determined at three different pH levels, viz. 6.0 - 6.3, 7.0 - 7.3 and 8.1 - 8.3 at temperature 28°-28.5°C. For lower pH ranges aged sea water was used. For each run, controls were also kept in identical pH ranges. No mortality

was observed in the control chamber for the 96 h duration of the experiments. The concentrations of H_2S for different pH ranges experiments is given in (Table 1:1) the LC_{50} values for 96h at 12h intervals were calculated for each pH range.

Chemical Analyses

pH of the water was measured using CENTURY 'CP 901' digital pH meter.

Salinity was estimated by using Mohr titration (Strickland and Parsons, 1968).

Dissolved oxygen was estimated by Winkler method (Strickland and Parsons, 1968).

Hydrogen sulphide in the water was estimated colorimetrically (FAO, 1975) using a ECIL Jr. spectrophotometer. At higher concentrations of sulphides the samples were diluted with oxygen free distilled water before measuring optical density. The Hydrogen sulphide concentrations are expressed in parts per billion (ppb). Three species of hydrogen sulphide exist in sea water, depending on the pH (Goldhaber and Kaplan, 1975) but for the purposes of these experiments no distinction was made between the species.

Computation and Presentation of Data

The median lethal concentration (LC_{50}) levels and their 95% confidence limits were computed using the Computer Software developed by the Institute

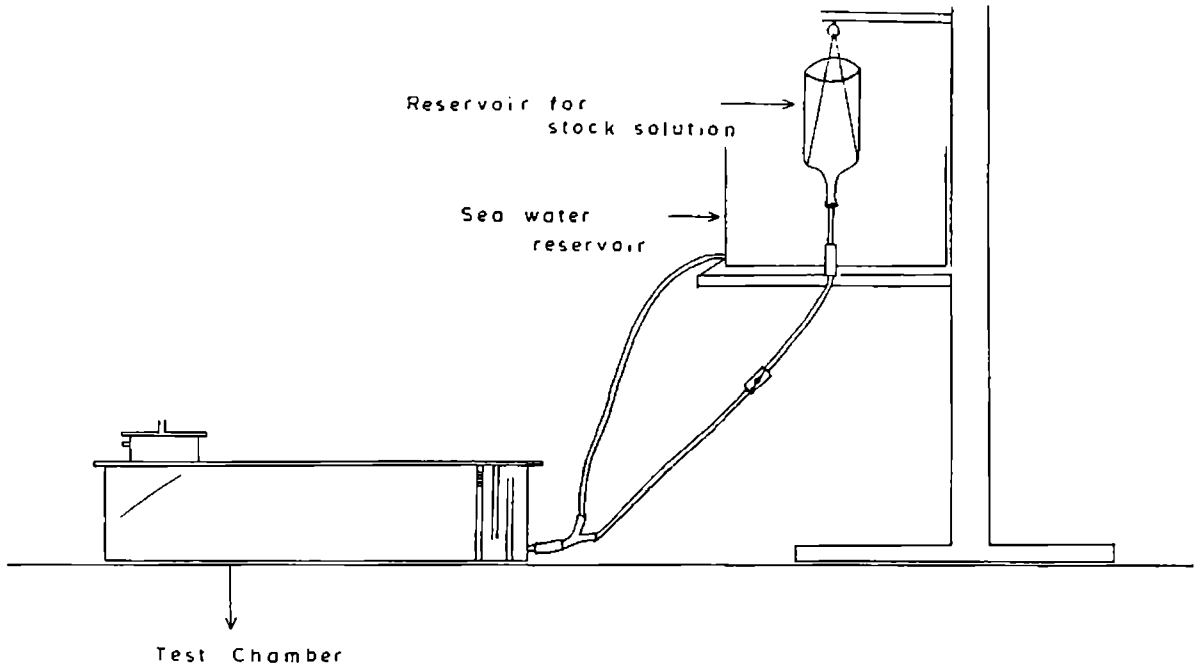


Fig. 1:1 FLOW - THROUGH SYSTEM

of Inland Water Management and Waste Water Treatment, Netherlands, based on probit analysis (Finney, 1971). Experiments with each hydrogen sulphide concentration was repeated twice for every size group, the mean percentage mortality was calculated and used for computation of the LC_{50} value. The LC_{50} levels, ET_{50} values and toxicity curves were represented graphically to demonstrate the lethal effects of the test compound (Sprague, 1973).

All the computations involved in the work were carried out by a personal computer (HCL Model Busybee PC/XT).

RESULTS

96 h LC_{50} Experiments

Results obtained from experiments conducted on three different size groups (85-90mm, 35-40mm and 20-25mm) of Peneaus indicus and two size groups (35-40mm and 20-25mm) of Metapenaeus dobsoni exposed to various concentrations of hydrogen sulphide in normal sea water having pH of 8.1-8.3 are presented here. The percentage mortality of different size groups of P. indicus and M. dobsoni exposed to different concentrations are given Table 1:1 to 1:5. In general it was observed that smaller size groups are more resistent to hydrogen sulphide than larger size groups in both the species (Table 1:11 and Fig. 1:2).

P. indicus (85-90mm) in sea water

The LC_{50} value for 96 h, 72 h and 48 h with 95% confidence limit was calculated and presented in Table 1:6. The values were 144.73 ppb,

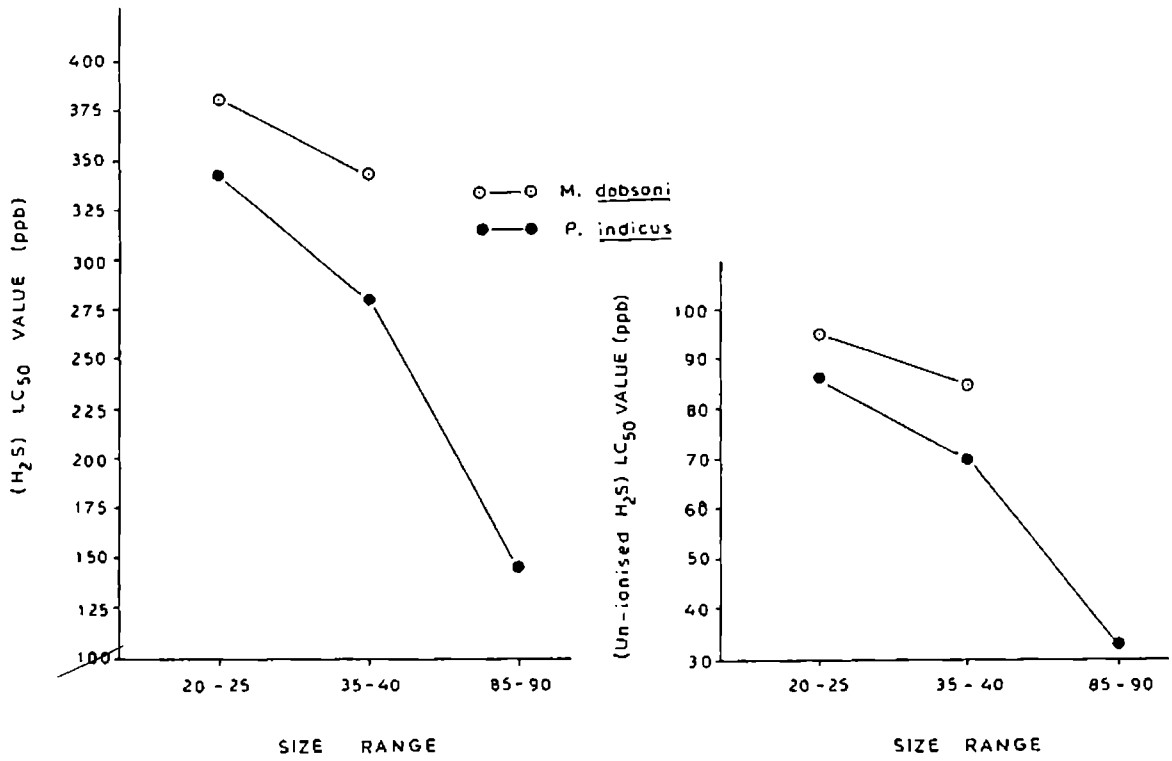


Fig. 1:2 Variation of LC_{50} with size of the animal.

176.03 ppb and 229.78 ppb for 96 h, 72 h and 48 h respectively. The effective time for 50% mortality of the test animals in various concentration is given in Fig. 1:3. At 140 ppb the effective time for 50% mortality was around 72 h whereas at 240 ppb it was 41 h. The ET_{50} values show that with the increase in period of exposure the lethal concentration of H_2S decreases. Further it was proved that concentration less than 120 ppb of H_2S is not lethal for this size group of P. indicus. Results presented in Fig. 1:3c and d.

P. indicus 35-40mm in sea water

Calculated LC_{50} values for 48h, 72h and 96h with 95% confidence limit is given in Table - 1:7. The values were 417.95 ppb, 322.14 and 281.81 ppb respectively. The ET_{50} of the test animals under various concentrations of H_2S is presented in Fig. 1:4. At 360 ppb, 400 ppb and 440 ppb the ET_{50} was 60 h, 48 h and 36 h respectively. The nature of Hydrogen sulphide toxicity is evident from Fig. 1:4c and d. With increase in exposure time the LC_{50} showed a decreasing trend. The ET_{50} also showed a decreasing trend with increase in concentration of H_2S.

P. indicus 20-25mm in sea water

The LC_{50} for 48h, 72h and 96h with 95% confidence limit is given in Table 1:8. The LC_{50} for the above mentioned time were 522.02 ppb, 409.96 ppb and 342.41 ppb respectively. The effective time taken for 50% mortality of the test animals in H_2S concentrations of 400 ppb, 440 ppb and 480 ppb were 84 h, 60 h and 46 h respectively. The ET_{50} value also declined with increase in H_2S concentration. None of the animal died at

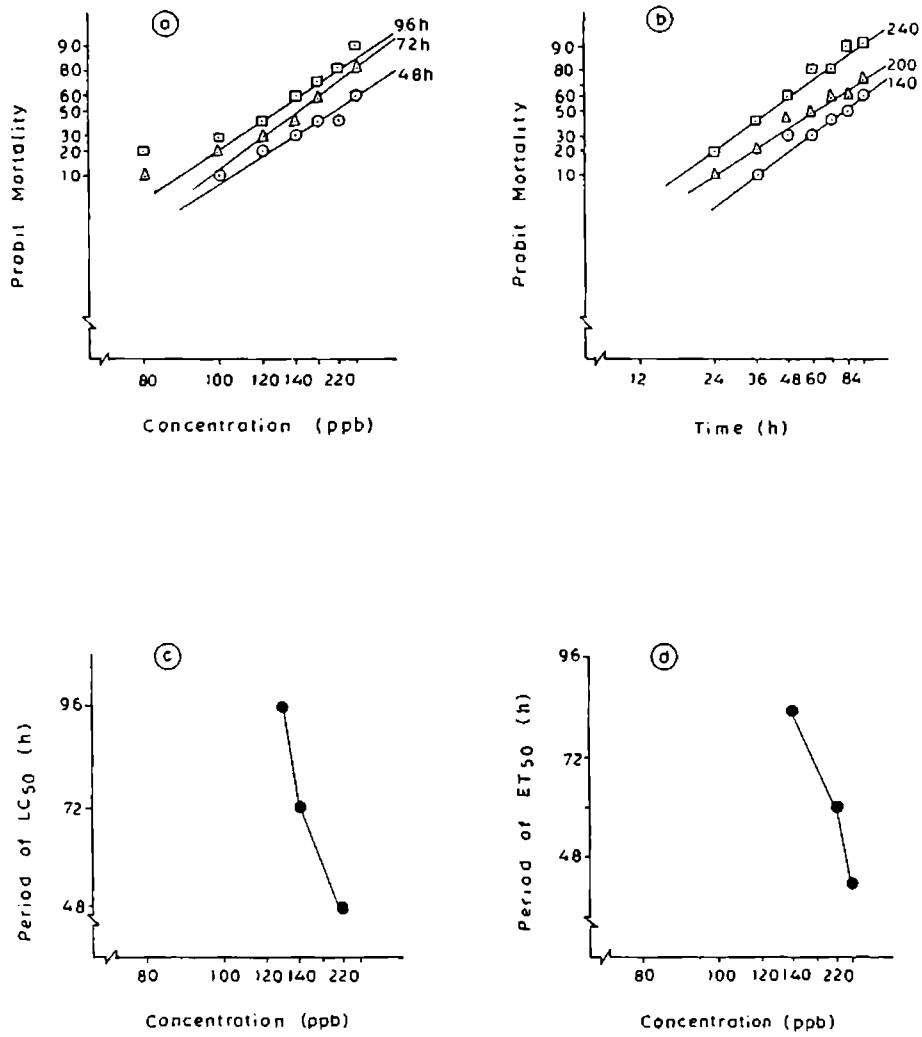


Fig. 1:3 Lethal effect of H_2S on P. indicus
(Size 85-90mm, pH 8.1-8.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

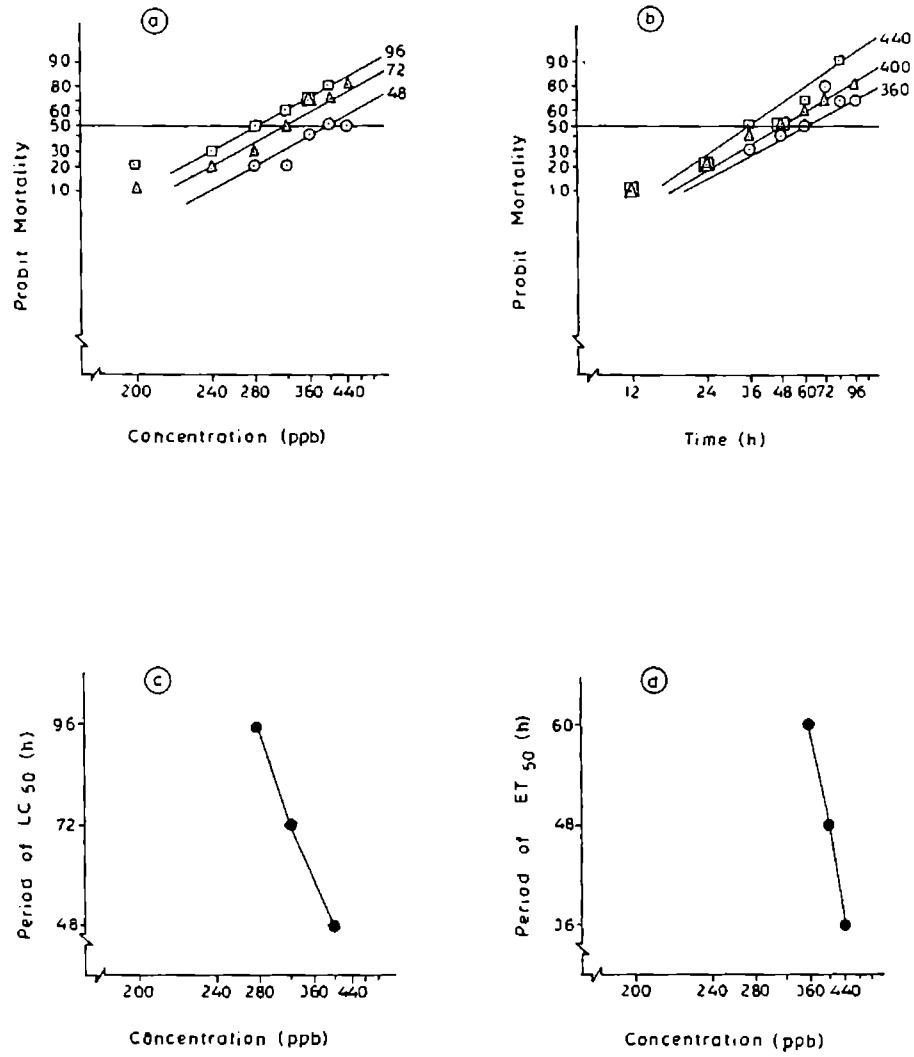


Fig. 1:4 Lethal effect of H_2S on P. indicus
(Size 35-40mm, pH 8.1-8.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

concentrations < 320 ppb (Fig. 1:5). The progress of mortality of test animals is clear from Fig. 1:5c and d.

M. dobsoni 35-40mm in sea water

LC_{50} values with 95% confidence limit for 96h, 72h and 48h is given in Table 1:9 and the values were 340.59 ppb, 377.20 ppb and 482.75 ppb respectively. The effective time taken for 50% mortality of the test organism in different concentration of H_2S is given in Fig. 1:6. The ET_{50} values at 400 ppb, 440 ppb and 480 ppb were 72h, 48h and 36h respectively. The nature of H_2S toxicity to the test animals is evident from Fig. 1:6c and d. With increase in exposure time the LC_{50} values declined. The ET_{50} values increased with decrease in exposure time of the test organism to various concentration of H_2S. Below 320 ppb H_2S was not lethal for M. dobsoni of size 35-40mm.

M. dobsoni 20-25mm in sea water

The calculated LC_{50} values for 48h, 72h and 96h with 95% confidence limit for M. dobsoni of size 20-25mm were 567.24 ppb, 468.42 ppb and 378.53 ppb respectively. Details given in Table 1:10. The ET_{50} value for the test animals at 460 ppb, 500 ppb and 540 ppb were 84 h, 54 h and 39 h respectively. This is presented in Fig. 1:7. The LC_{50} value was found to increase with decrease in exposure period. The ET_{50} also showed a similar trend. Less than 370 ppb H_2S was not be lethal for this size group of M. dobsoni.

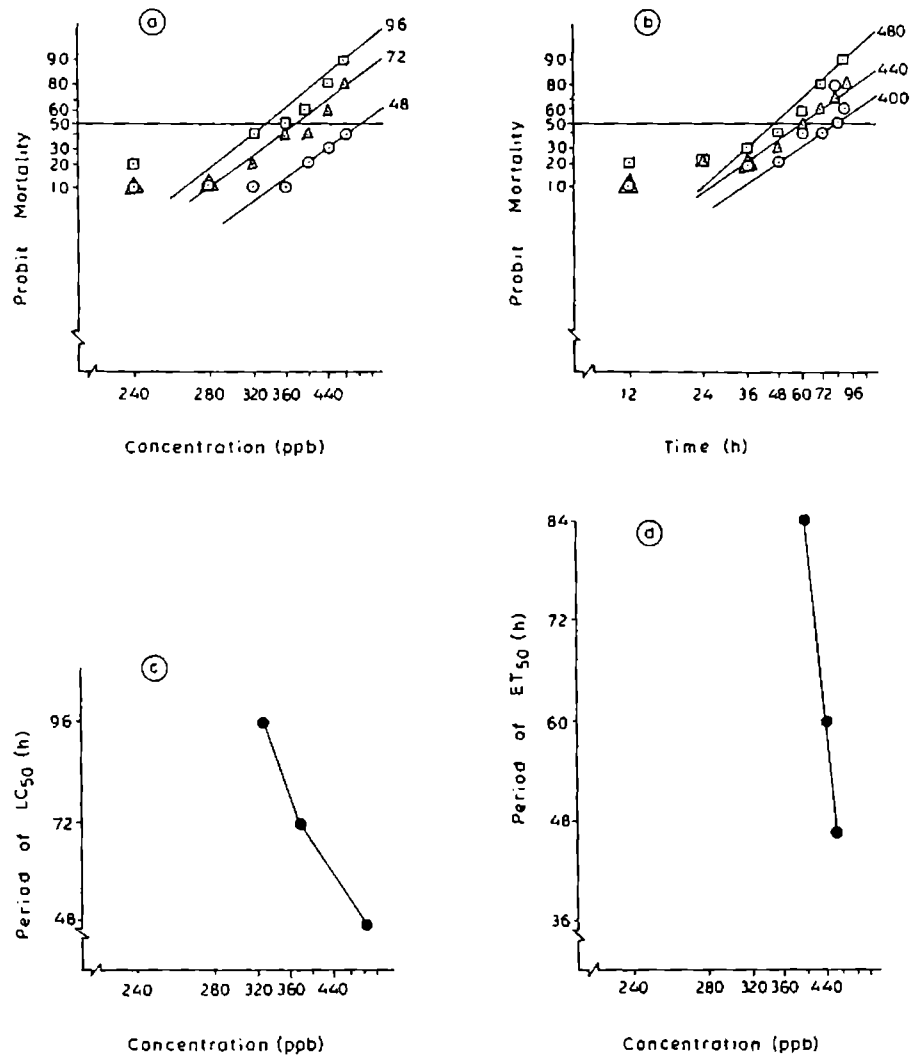


Fig. 1:5 Lethal effect of H_2S on P. indicus
(Size 20-25mm, pH 8.1-8.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

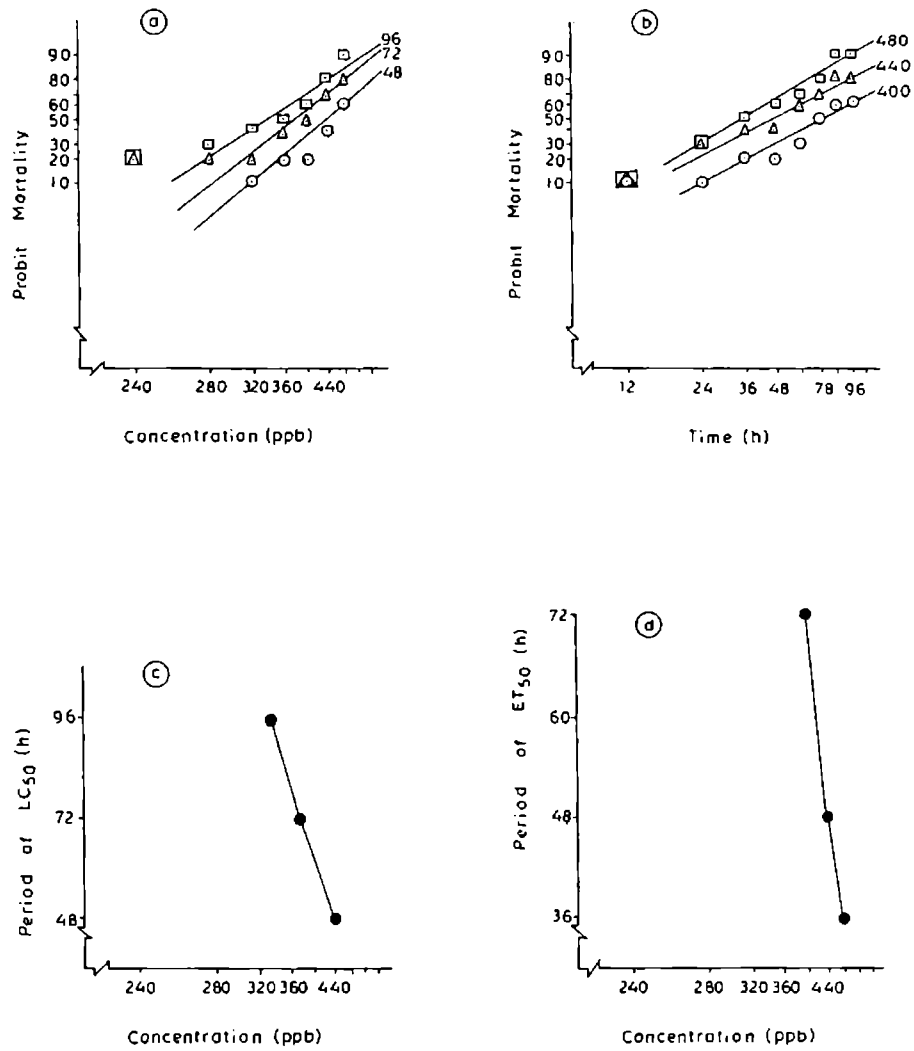


Fig. 1:6 Lethal effect of H_2S on M. dobsoni
(Size 35-40mm, pH 8.1-8.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

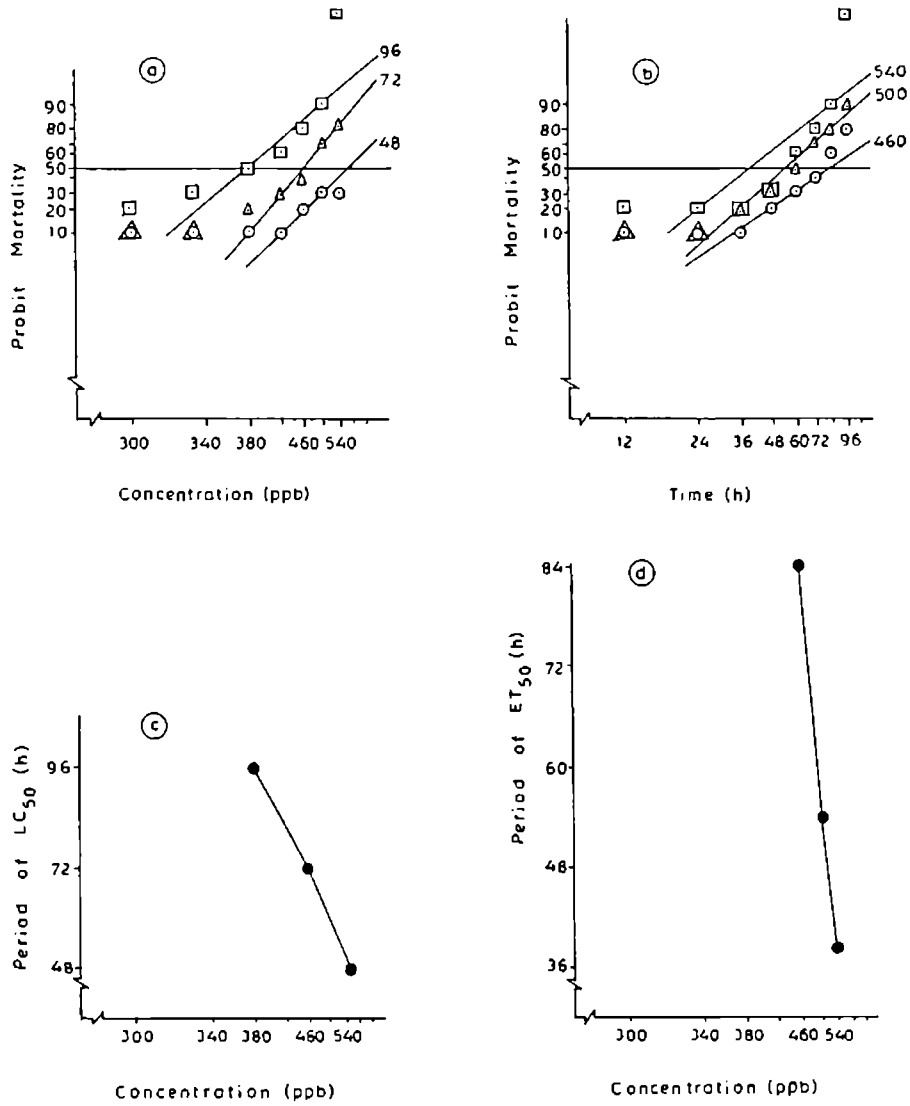


Fig. 1:7 Lethal effect of H_2S on M. dobsoni
(Size 20-25mm, pH 8.1-8.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

Effect of pH on H_2S toxicity

The percentage mortality of the two different size groups (20-25mm and 35-40mm) of P. indicus and M. dobsoni exposed to various concentrations of H_2S at three pH ranges (6.0 6.3, 7.0 - 7.3 and 8.1 - 8.3) are given in Table 1:1 to 1:5 and 1:12 to 1:19. The calculated 96 h LC_{50} values for P. indicus and M. dobsoni are given in Table 1:6 to 1:10 and 1:22 to 1:27. It is evident that the LC_{50} values decline with decrease in pH, indicating that H_2S becomes more toxic to both P. indicus and M. dobsoni at lower pH levels (Fig. 1:8 and Table 1:28). In different pH also the sensitivity of P. indicus to H_2S is more compared to M. dobsoni. In other words M. dobsoni could withstand a higher level of H_2S concentration in the medium than P. indicus. The smaller size groups of P. indicus and M. dobsoni were more resistant to H_2S than larger size groups.

P. indicus 35-40mm at pH 6.0 - 6.3

The calculated LC_{50} values with 95% confidence limit is given in Table 1:16 and 48h, 72h and 96h LC_{50} values were 120 ppb, 85.31 ppb and 63.44 ppb respectively. The ET_{50} under various H_2S concentrations is given in Fig. 1:9. It is evident that when the ET_{50} decreases there is a sharp increase in the concentrations. The nature of toxicity is evident from the Fig. 1:9c and d. Below 60 ppb H_2S was not lethal at the pH 6.0 6.3.

P. indicus 20-25mm pH 6.0 - 6.3

LC_{50} for 48h, 72h and 96h with 95% confidence limit is calculated and given in Table 1:17. 96 h LC_{50} was 117.69 whereas the 72 h and 48h

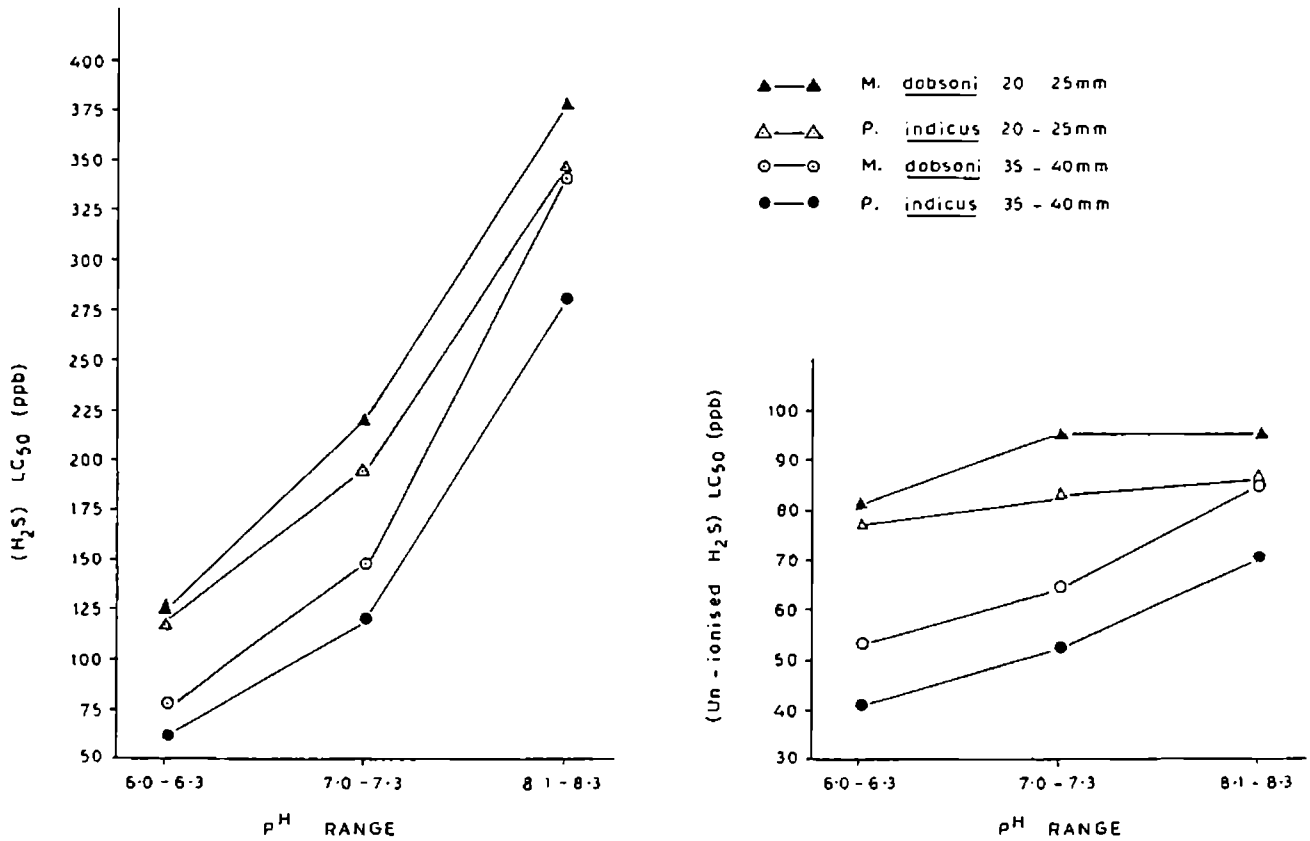


Fig. 1:8 Variation of LC_{50} with pH of the medium.

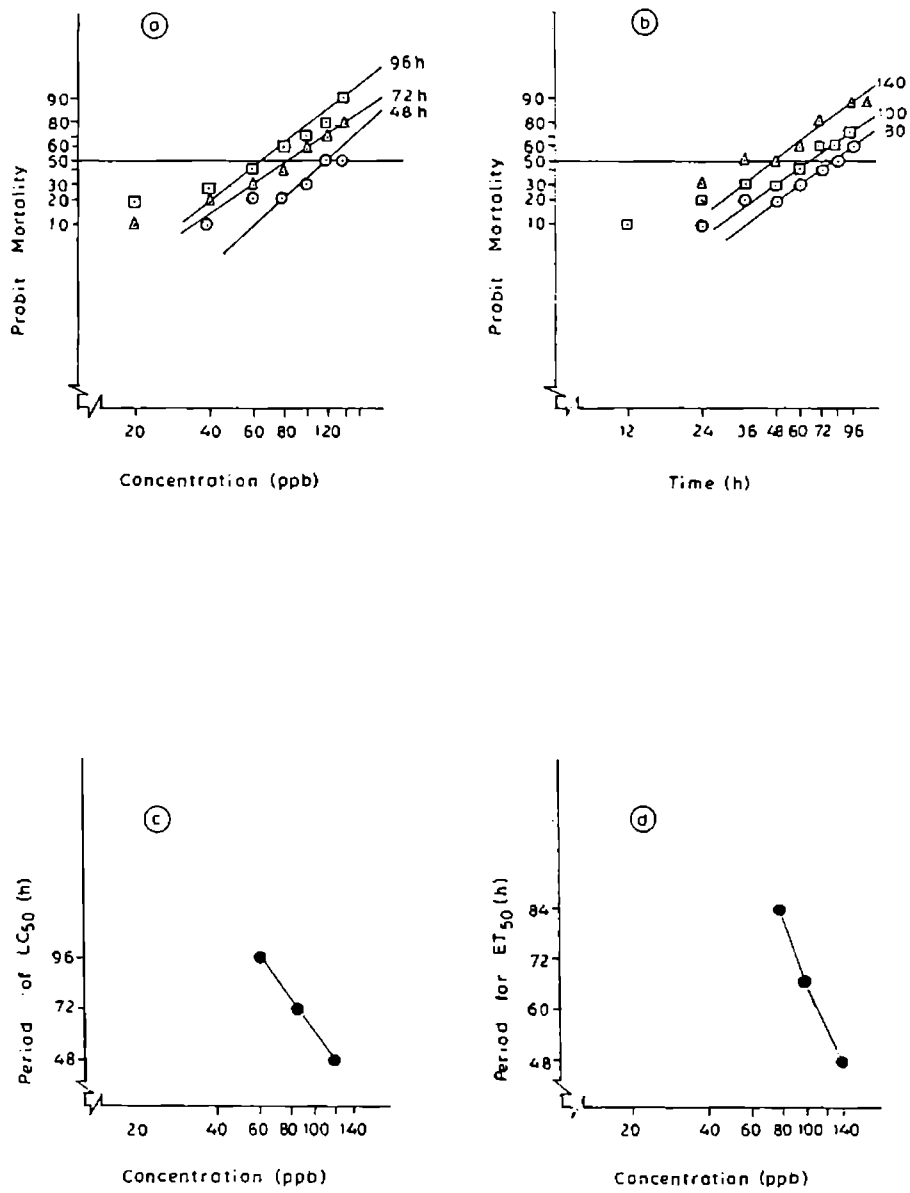


Fig. 1:9 Lethal effect of H_2S on P. indicus
(Size 35-40mm, pH 6.0-6.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

LC_{50} were 146.71 ppb and 167.14 ppb respectively. The ET_{50} of the test animals under various concentrations of H_2S is given in Fig. 1:10. At 140 ppb the period of ET_{50} was between 66 h to 72 h and at 180 ppb it was 36 h. Fig. 1:10c and d depicts the nature of toxicity.

M. dobsoni 35-40mm pH 6.0 - 6.3

Calculated LC_{50} values for 48h, 72h and 96h is given in Table 1:18. The LC_{50} decreases with increase of time. At 48 h the LC_{50} was 121.57 ppb and at 72h it was 97.52 ppb, at 96h it was 47.32 ppb. The ET_{50} of the test animals under various concentrations of H_2S is given in Fig. 1:11. The nature of toxicity is also evident from Fig. 1:11c and d.

M. dobsoni 20-25mm pH 6.0 - 6.3

Calculated LC_{50} values for 48h, 72h and 96h is given in Table 1:19. The LC_{50} were 175.85 ppb, 147.48 ppb and 125.07 ppb respectively. The values were higher when compared to the previous value of M. dobsoni 35 - 40mm exposed to different H_2S concentrations. This shows that smaller size groups are more resistance to H_2S than larger size. The ET_{50} of the test animals under various concentrations of H_2S is given in Fig. 1:12. With decrease in period of ET_{50} the toxicity of H_2S concentration shows an increasing trend. The nature of toxicity is evident from the Fig. 1:12c and d.

P. indicus 35-40mm pH 7.0 - 7.3

LC_{50} for 48h, 72h and 96h is given in Table 1:12. As in previous cases the sensitivity of the test animal decreases with increase in the exposure

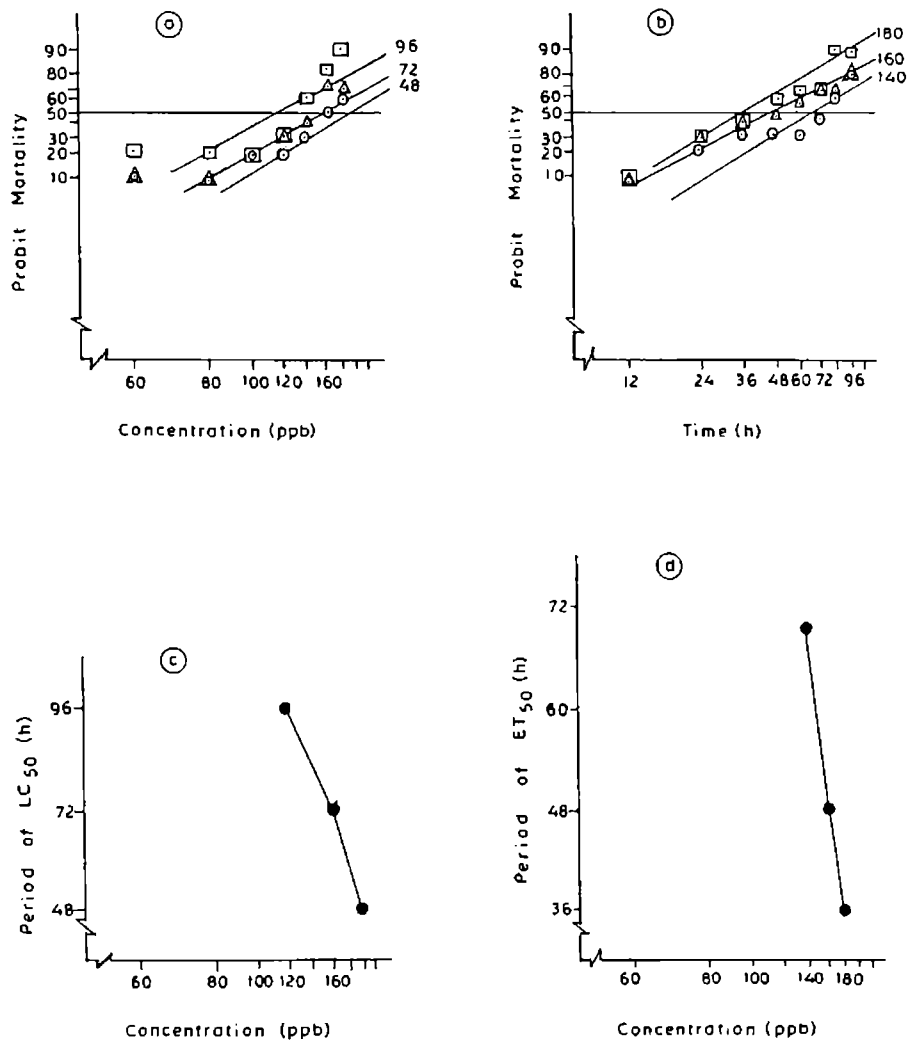


Fig. 1:10 Lethal effect of H_2S on P. indicus
(Size 20-25mm, pH 6.0-6.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

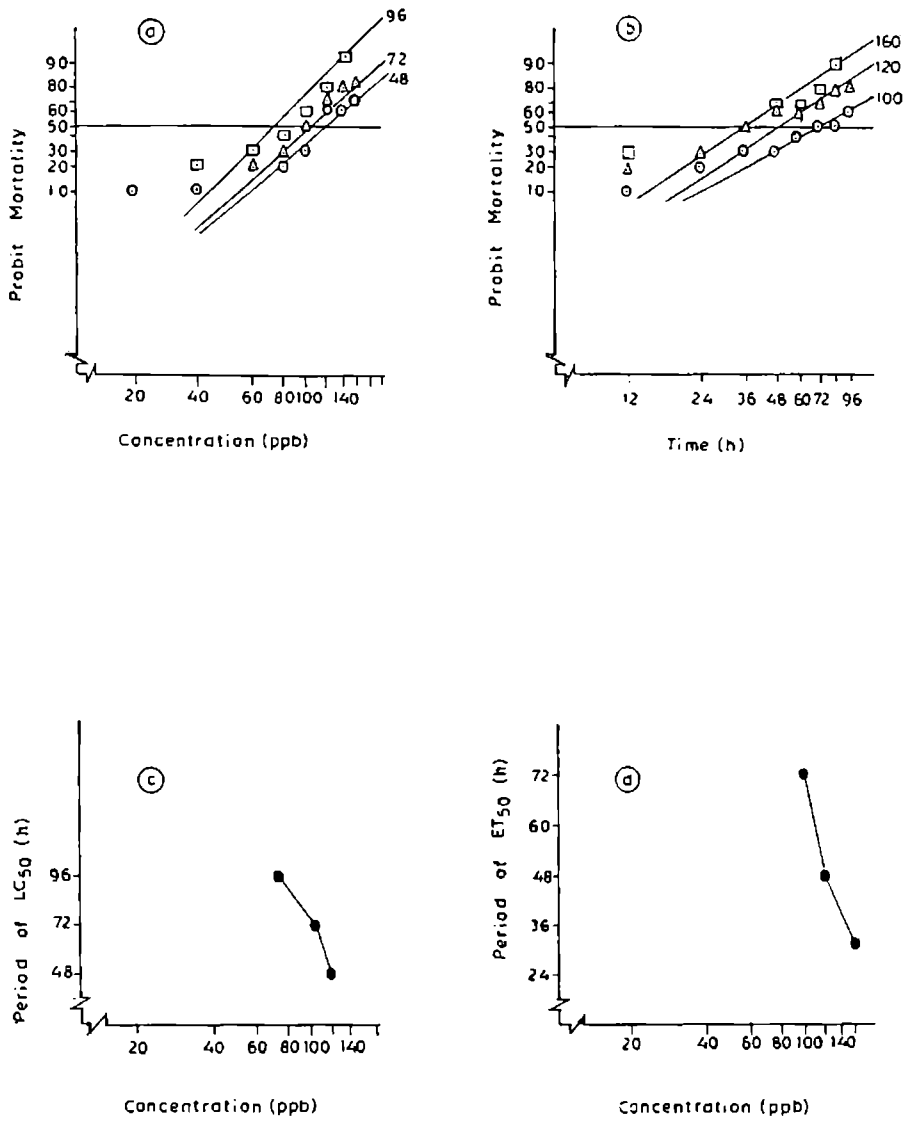


Fig. 1:11 Lethal effect of H_2S on M. dobsoni
(Size 35-40mm, pH 6.0-6.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

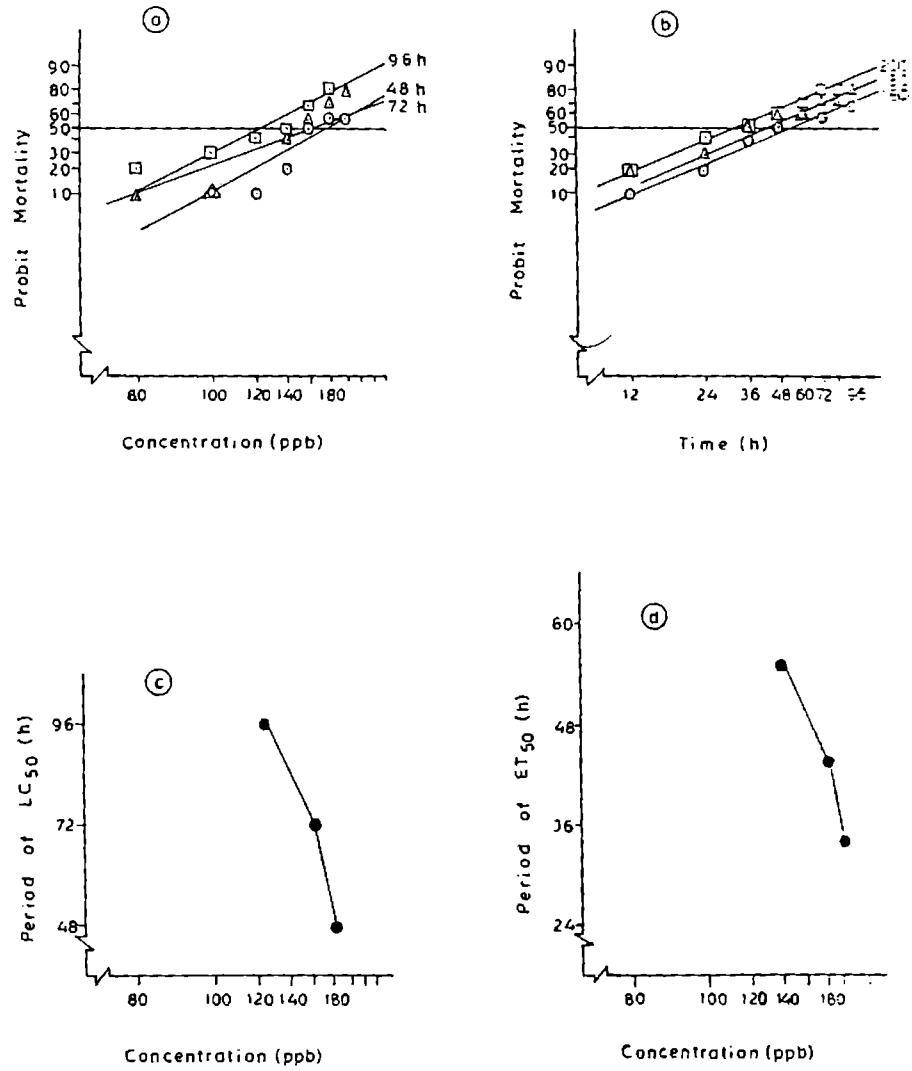


Fig. 1:12 Lethal effect of H_2S on M. dobsoni
(Size 20-25mm, pH 6.0-6.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

time. At 48h the LC_{50} were 140.91 ppb and 119.06 ppb respectively. The effective time to kill 50% of the test animals under different concentrations of H_2S is given in Fig. 1:13. With the increase in concentration of H_2S the ET_{50} showed decreasing trend. The nature of toxicity is evident from Fig. 1:13c and d.

P. indicus 20-25mm pH 7.0 - 7.3

48h, 72h and 96h LC_{50} were calculated and given in Table 1:13. The values were 360.55 ppb, 281.69 ppb and 189.12 ppb respectively. The values were higher when compared with that of the size group 35-40mm of P. indicus. It is clear that the larger animals are more sensitive to H_2S toxicity than smaller ones. The effective time to kill 50% of the test animals under different concentrations of H_2S is given in Fig. 1:14. At 180 ppb the ET_{50} was 96h and at 360 ppb it was around 40h. The nature of toxicity is evident from Fig. 1:14c and d.

M. dobsoni 35-40mm pH 7.0 - 7.3

LC_{50} for 48h, 72h and 96h are given in Table 1:14. The LC_{50} decreases with increase in exposure time. The values were 199.45 ppb, 169.73 ppb and 147.76 ppb at 48h, 72h and 96h respectively. The ET_{50} of the test animals under different concentrations of H_2S is given in Fig. 1:15. Fig. 1:15c and d shows the nature of toxicity to the test organism in the above mentioned conditions.

M. dobsoni 20-25mm pH 7.0 - 7.3

The 48h, 72h and 96h LC_{50} were 445.02 ppb, 306.47 ppb and 219.8

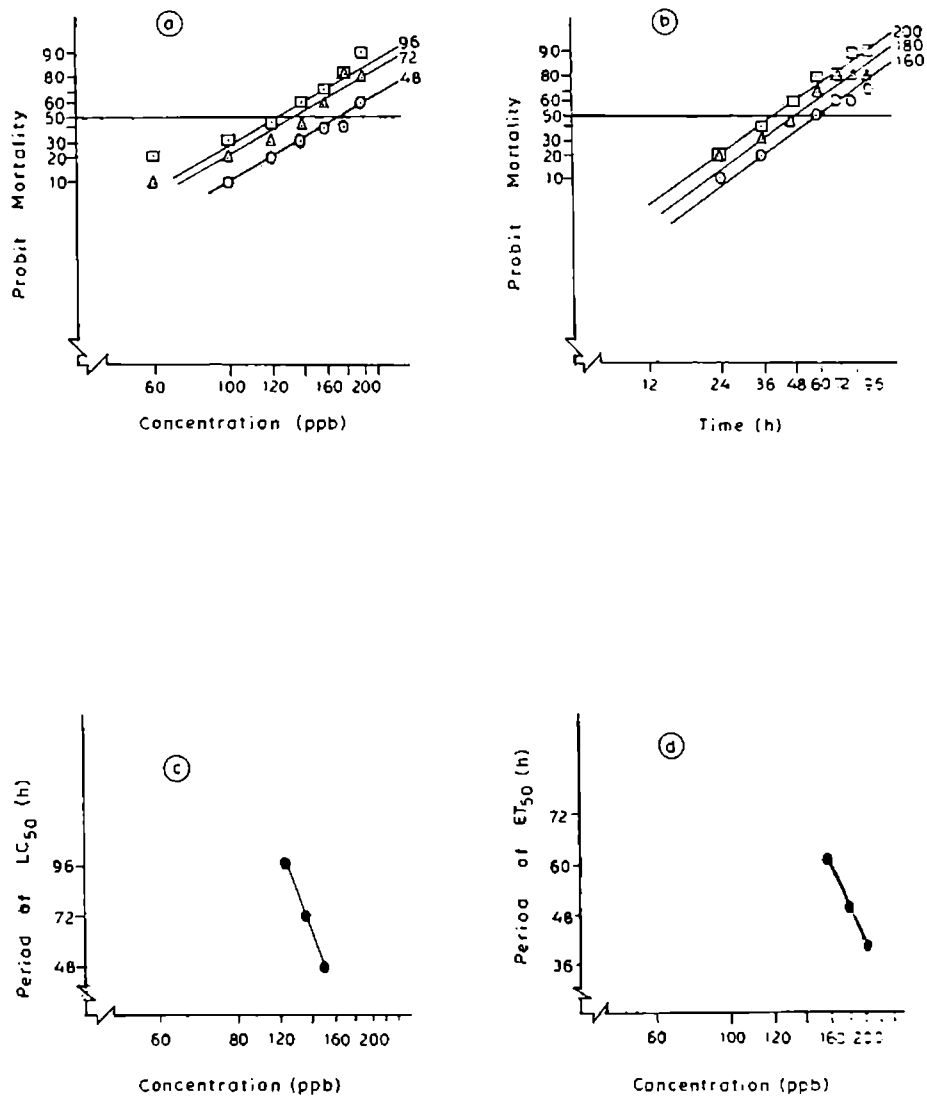


Fig. 1:13 Lethal effect of H_2S on *P. indicus*
(Size 35-40mm, pH 7.0-7.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

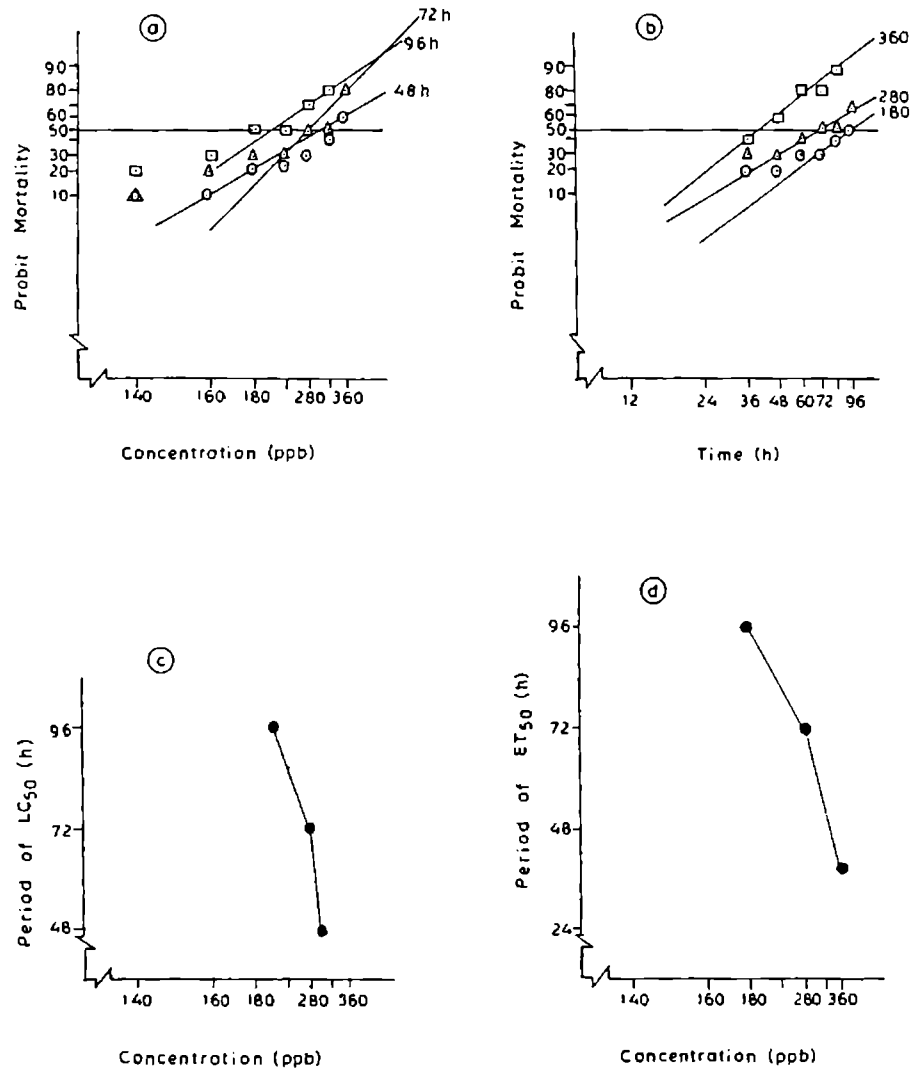


Fig. 1:14 Lethal effect of H_2S on P. indicus
(Size 20-25mm, pH 7.0-7.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

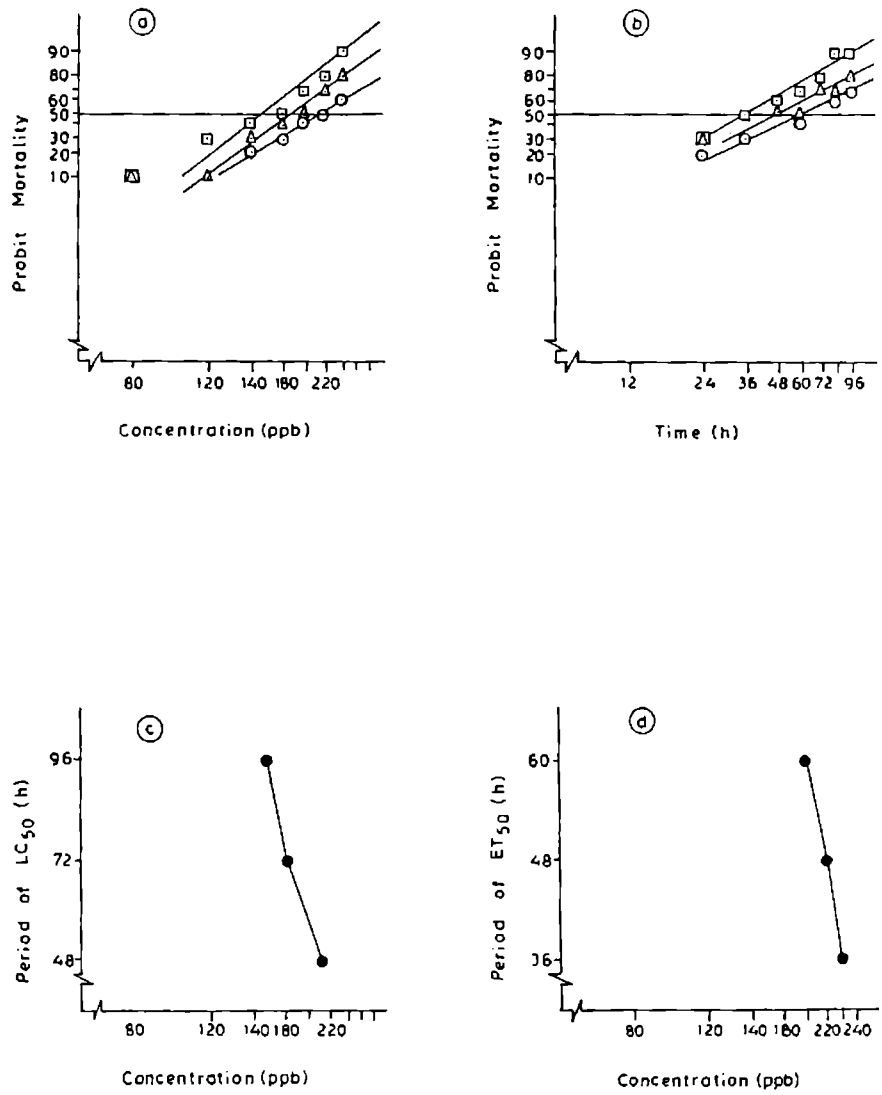


Fig. 1:15 Lethal effect of H_2S on M. dobsoni
(Size 35-40mm, pH 7.0-7.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

ppb respectively (Table 1:15). The ET_{50} of the test animals under different concentrations of H_2S is given in Fig. 1:16. The effective time to kill 50% of the test animals at 300 ppb and 340 ppb was 78h and 60h respectively. The nature of toxicity of H_2S is evident from the Fig. 1:16c and d. In this series of experiments also 20-25mm size M. dobsoni showed more resistance than 35-40mm of the same species.

P. indicus 35-40mm pH 8.1 - 8.3

Table 1:7 gives the LC_{50} for 48h, 72h and 96h with 95% confidence limit. The LC_{50} were 417.95 ppb, 322.14 ppb and 281.81 ppb respectively. The ET_{50} of the test animals under different concentrations of H_2S is given in Fig. 1:4. The effective time to kill 50% of the test animals at 360 ppb and 400 ppb was 60h and 48h respectively. The nature of the toxicity of H_2S is evident from the Fig. 1:4c and d. H_2S concentration below 280 ppb was not lethal.

P. indicus 20-25mm pH 8.1 - 8.3

LC_{50} for 48h, 72h and 96h is given in Table 1:8 with 95% confidence limit. The LC_{50} were 522.02 ppb, 409.96 ppb and 342.41 ppb respectively. The ET_{50} of the test animals is also given in Fig. 1:5. With the increase in exposure time the LC_{50} value was found to decrease. Toxicity nature is presented in Fig. 1:5 c and d.

In this experiment with 20-25mm and 35-40mm and 85-90mm P. indicus at pH 8.1 8.3 the smaller size group are found more resistant to H_2S toxicity than higher size (Fig. 1:2). The results also showed that with the increase in pH the LC_{50} also increased. At pH 6.0 6.3 the LC_{50} was lowest and

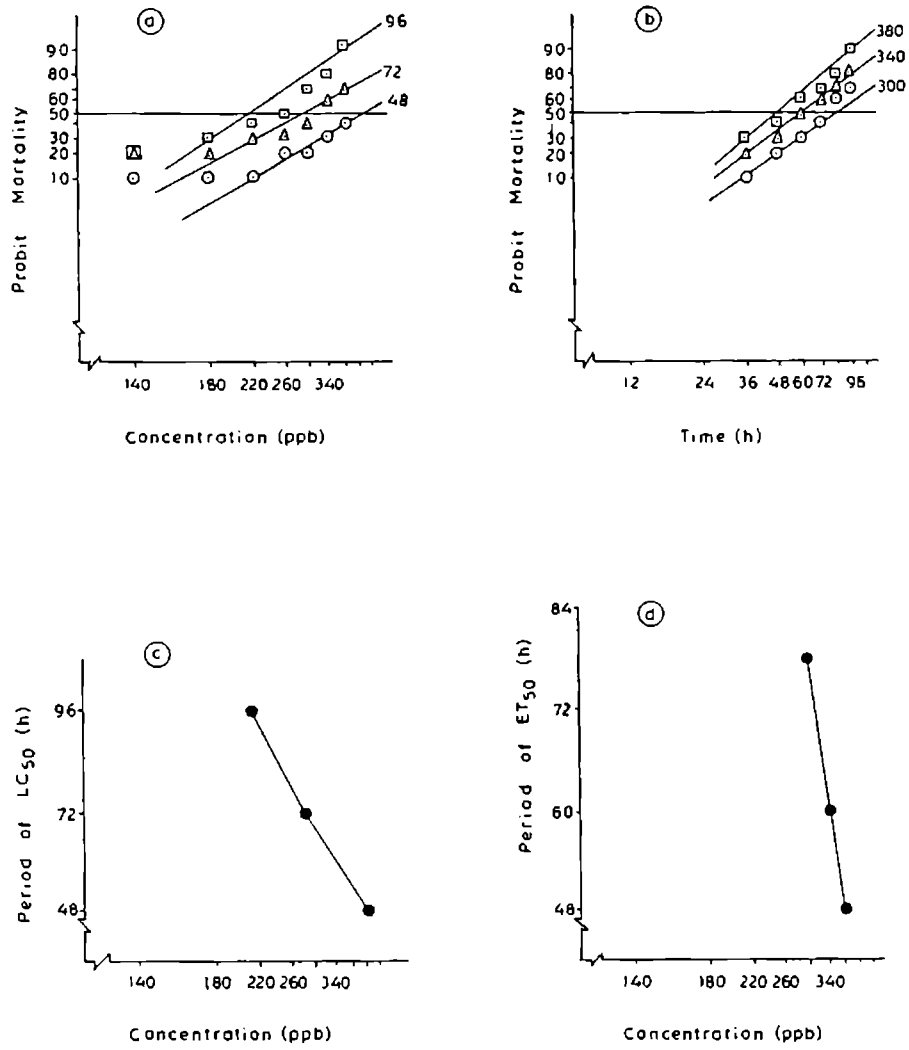


Fig. 1:16 Lethal effect of H_2S on M. dobsoni
(Size 20-25mm, pH 7.0-7.3)

a. Progress of mortality against time

b. Progress of mortality against concentration

c&d. Toxicity curves

it increased gradually with increase in pH (Fig. 1:8).

M. dobsoni 35-40mm pH 8.1 - 8.3

The calculated LC_{50} for 48h, 72h and 96h are given in Table - 1:9. The LC_{50} were 482.75 ppb, 377.20 ppb and 340.59 ppb respectively.

The ET_{50} of the test animals is also given in Fig. 1:6. The effective time to kill 50% of the test animal was 72h at 400 ppb and 36h for 480 ppb. Fig. 1:6c and d shows the toxicity nature to the test organisms under the above mentioned experimental condition.

M. dobsoni 20-25mm pH 8.1 - 8.3

Calculated LC_{50} for 48h, 72h and 96h are given in Table 1:10. With 95% confidence limit. The LC_{50} were 567.24 ppb, 468.42 ppb and 378.53 ppb for 48h, 72h and 96h respectively. The effective time to kill 50% of the test organism under different concentrations of H_2S is given in Fig. 1:7. The ET_{50} increases with decrease in concentration of H_2S. The LC_{50} showed an increasing trend with decrease in exposure time. The nature of toxicity is clearly shown in Fig. 1:7c and d.

The results of the experiment with two different size group (20-25mm and 35-40mm) of M. dobsoni showed that smaller size groups are more resistant to H_2S toxicity. However, M. dobsoni is highly resistant to H_2S toxicity than P. indicus.

At lower pH the toxic effect of H_2S on prawns is high whereas at higher pH value it is less. This is obviously due to the fact that at lower

pH values a greater proportion of H_2S is present in the un-ionised form which is more toxic to animals than the ionised form (HS^-). No mortality was observed in the controls in lower pH ranges during 96h experiment period.

General Observations

During the course of this experiment some general observations were made on the appearance and behaviour of prawns subjected to different concentrations of H_2S. In almost all concentrations both P. indicus and M. dobsoni were active for first 20-30h and then the activity of some prawns became less. They became sluggish and showed restricted movement. Later some prawns performed occasional shooting movements similar to those of a sea horse. Some swam on the back with the appendages directed upwards. The moment they touched the bottom of the tank they showed circular movement in the lying down position. All the individuals exposed to H_2S concentrations above 300 ppb showed blackening of gills. The entire gill was black and could be easily seen through the carapace. The intensity of the black colour on the gills varied with the concentration of H_2S and duration of exposure. Blackening was apparent on animals exposed to H_2S for more than 48h.

Another observation was that prawns subjected to various H_2S concentration showed intensification of colour. The body chromatophores were found fully dispersed and entire body was dark in colour. This was more obvious in P. indicus of size 35-40mm. For M. dobsoni also the body colour of animal exposed to H_2S was dark when compared to that of the control. The same phenomenon was noted for smaller size group of both the species.

TABLE - 1:1

Cumulative percentage mortality of 85-90mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 8.1 8.3 (sea water).

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
80	0	0	0	0	10	10	10	20
100	0	0	10	10	10	20	30	30
120	0	0	10	20	30	30	40	40
140	0	0	10	20	30	40	50	60
200	0	10	20	40	50	60	60	70
220	0	20	30	40	70	80	80	80
240	0	20	40	60	80	80	90	90

TABLE - 1:2

Cumulative percentage mortality of 35-40mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 8.1 8.3 (sea water).

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
200	0	0	0	0	10	10	20	20
240	0	0	0	0	10	20	20	30
280	0	0	10	20	30	30	40	50
320	0	10	20	20	30	50	60	60
360	10	29	30	40	50	70	70	70
400	10	20	40	50	60	70	70	80
440	10	20	50	50	70	80	90	100

TABLE - 1:3

Cumulative percentage mortality of 20-25mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 8.1 8.3 (sea water).

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
240	0	0	0	10	10	10	10	20
280	0	0	0	10	10	10	20	30
320	10	10	10	10	10	20	20	40
360	10	10	10	10	30	40	40	50
400	10	20	20	30	40	40	50	60
440	10	20	20	30	50	60	70	80
480	20	20	30	40	60	80	80	90

TABLE - 1:4

Cumulative percentage mortality of 35-40mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 8.1 8.3 (sea water).

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
240	0	0	0	0	10	20	20	20
280	0	0	0	0	10	20	20	30
320	0	0	10	10	10	20	30	40
360	0	10	10	20	40	40	50	50
400	10	10	20	20	30	50	60	60
440	10	30	40	40	60	70	80	80
480	10	30	50	60	70	80	90	90

TABLE - 1:5

Cumulative percentage mortality of 20-25mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 8.1 8.3 (sea water).

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
300	0	0	0	10	10	10	10	20
340	0	0	0	10	10	10	20	30
380	0	0	10	10	10	20	30	50
420	10	10	10	10	20	30	50	60
460	10	10	10	20	30	40	60	80
500	10	10	20	30	50	70	80	90
540	20	20	20	30	60	80	90	100

TABLE - 1:6

LC_{50} and 95% confidence limit in ppb of 85-90mm P. indicus exposed to different concentrations of H_2S as a function of time, at pH 8.1 - 8.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	240.00	
24.0	316.68	248.36 - 403.81
36.0	260.27	224.30 - 302.02
48.0	229.78	204.52 258.17
60.0	189.86	171.49 - 210.20
72.0	176.03	158.64 195.33
84.0	146.84	130.66 - 165.03
96.0	144.73	128.52 - 163.00

TABLE - 1:7

LC_{50} and 95% confidence limit in ppb of 35 - 40mm P. indicus exposed to different concentrations of H_2S as a function of time at pH 8.1 8.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	689.20	473.08
24.0	558.02	427.15 - 728.98
36.0	445.48	373.02 - 532.03
48.0	417.95	356.34 - 490.21
60.0	361.67	320.84 - 407.68
72.0	322.14	287.78 - 360.61
84.0	301.51	267.85 - 339.40
96.0	281.81	248.10 - 320.10

TABLE - 1:8

LC_{50} and 95% confidence limit in ppb of 20-25mm P. indicus exposed to different concentrations of H_2S as a function of time at pH 8.1 8.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	645.00	480.38 - 866.04
24.0	597.37	462.47 - 771.62
36.0	578.44	455.11 - 735.19
48.0	522.02	433.45 - 628.68
60.0	447.17	394.55 - 506.79
72.0	409.96	366.11 - 459.06
84.0	389.66	349.02 - 435.03
96.0	342.41	305.74 - 383.49

TABLE - 1:9

LC_{50} and 95% confidence limit in ppb of 35-40mm M. dobsoni exposed to different concentrations of H_2S as a function of time at pH 8.1 8.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	714.92	506.35 -
24.0	573.47	457.39 719.00
36.0	503.76	424.65 597.61
48.0	482.75	413.18 564.02
60.0	418.68	373.23 469.67
72.0	377.20	340.42 - 417.96
84.0	350.77	316.28 389.01
96.0	340.59	306.35 378.67

TABLE - 1:10

LC_{50} and 95% confidence limit in ppb of 20-25mm M. dobsoni exposed to different concentrations of H_2S as a function of time at pH 8.1 8.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	663.28	542.61 810.77
24.0	663.28	542.61 - 810.77
36.0	625.79	528.21 741.40
48.0	567.24	497.43 646.85
60.0	513.05	462.15 569.56
72.0	468.42	428.97 511.50
84.0	424.14	391.03 460.05
96.0	378.53	346.87 - 413.09

TABLE - 1:11

96 h LC_{50} values (ppb) for different size groups of P. indicus and M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 8.1 - 8.3 (sea water) and the un-ionised Hydrogen sulphide for the respective LC_{50} concentrations.

Size Range (mm)	P. indicus LC_{50} (ppb)	un-ionised H_2S (ppb)	M. dobsoni LC_{50} (ppb)	un-ionised H_2S (ppb)
85 - 90	144.73	32.56		-
35 40	281.81	70.45	340.54	85.13
20 25	342.41	85.50	378.53	94.63

TABLE - 1:12

Cumulative percentage mortality of 35-40mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 7.0 7.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
60	0	0	0	0	10	10	10	20
100	0	0	10	10	10	20	30	30
120	0	0	10	20	30	30	40	40
140	0	0	10	30	30	40	50	60
160	0	10	20	40	50	60	60	70
180	0	20	30	40	70	80	80	80
200	0	20	40	60	80	80	90	90

TABLE - 1:13

Cumulative percentage mortality of 20-25mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 7.0 - 7.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
140	0	0	0	10	10	10	10	20
160	0	0	0	10	20	20	20	30
180	0	0	20	20	30	30	40	50
240	0	0	20	20	30	30	40	50
280	0	0	30	30	40	50	50	70
320	0	0	30	40	50	50	70	80
360	0	0	40	60	80	80	90	100

TABLE - 1:14

Cumulative percentage mortality of 35-40mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 7.0 - 7.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
80	0	0	0	0	0	10	10	10
120	0	0	0	0	10	10	20	30
140	0	0	0	20	20	30	30	40
180	0	0	20	30	30	40	50	50
200	0	20	30	40	40	50	60	70
220	0	30	30	50	50	70	70	80
240	0	30	50	60	70	80	90	90

TABLE - 1:15

Cumulative percentage mortality of 35-40mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 7.0 - 7.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
140	0	0	0	10	10	20	20	20
180	0	0	0	10	10	20	30	30
220	0	0	0	10	20	30	30	40
260	0	0	10	20	30	30	40	50
300	0	0	10	20	30	40	60	70
340	0	0	20	30	50	60	70	80
380	0	0	30	40	60	70	80	90

TABLE - 1:16

Cumulative percentage mortality of 35-40mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 6.0 - 6.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
20	0	0	0	0	10	10	20	20
40	0	0	10	10	10	20	30	30
60	0	10	10	20	20	30	30	40
80	0	10	20	20	30	40	50	60
100	10	20	30	30	40	60	60	70
120	10	30	30	50	60	70	80	80
140	10	30	50	50	60	80	90	90

TABLE - 1:17

Cumulative percentage mortality of 20-25mm P. indicus exposed to different concentrations of Hydrogen sulphide at pH 6.0 - 6.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
60	0	0	0	10	10	10	20	20
80	0	0	0	10	10	10	20	20
100	0	10	20	20	20	20	30	30
120	10	20	20	20	30	30	40	40
140	10	20	30	30	30	40	60	60
160	10	30	40	50	60	70	70	80
180	10	30	40	60	70	70	90	90

TABLE - 1:18

Cumulative percentage mortality of 35-40mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 6.0 6.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
20	0	0	0	10	10	10	10	10
40	0	0	0	10	10	10	20	20
60	0	0	10	10	10	20	20	30
80	0	10	20	20	30	30	30	40
100	10	20	30	30	40	50	50	60
120	20	30	50	60	60	70	80	80
140	20	30	40	60	80	80	90	90
160	30	30	50	70	70	80	90	100

TABLE - 1:19

Cumulative percentage mortality of 20-25mm M. dobsoni exposed to different concentrations of Hydrogen sulphide at pH 6.0 - 6.3.

Concentration (ppb) \ Time (h)	12	24	36	48	60	72	84	96
Control	0	0	0	0	0	0	0	0
80	0	0	0	0	10	10	20	20
100	0	0	0	10	10	20	20	30
120	0	10	10	10	20	20	30	40
140	10	10	10	20	20	40	40	50
160	10	20	40	50	60	60	70	70
180	20	30	50	60	60	70	70	80
200	20	40	50	60	70	80	80	100

TABLE - 1:20

LC_{50} and 95% confidence limit in ppb of 35-40mm P. indicus exposed to different concentrations of H_2S as a function of time, at pH 7.0 - 7.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	200.00	
24.0	335.38	208.11 - 540.48
36.0	239.49	175.90 - 326.06
48.0	189.55	154.51 232.52
60.0	155.31	130.89 184.29
72.0	140.91	119.23 166.54
84.0	127.91	107.95 151.56
96.0	119.06	99.70 - 142.19

TABLE - 1:21

LC_{50} and 95% confidence limit in ppb of 20-25mm P. indicus exposed to different concentrations of H_2S as a function of time, at pH 7.0 - 7.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	360.00	-
24.0	360.00	-
36.0	432.95	316.09 593.00
48.0	360.55	291.08 - 446.59
60.0	290.14	250.84 - 335.61
72.0	281.69	243.04 - 326.49
84.0	242.38	200.80 292.57
96.0	189.12	152.15 235.08

TABLE - 1:22

LC_{50} and 95% confidence limit in ppb of 35-40mm M. dobsoni exposed to different concentrations of H_2S as a function of time at pH 7.0 - 7.3.

Time (h)	LC_{50}(ppb)	95% confidence	
12.0	220.00		
24.0	269.04	209.62	- 345.31
36.0	232.12	192.06	280.55
48.0	199.45	172.55	230.56
60.0	192.09	167.49	230.30
72.0	169.73	150.29	191.67
84.0	158.43	140.27	178.93
96.0	147.76	130.05	167.88

TABLE - 1:23

LC_{50} and 95% confidence limit in ppb of 20-25mm M. dobsoni exposed to different concentrations of H_2S as a function at time at pH 7.0 - 7.3.

Time (h)	LC_{50}(ppb)	95% confidence	
12.0	380.00		
24.0	380.00		
36.0	613.14	366.45	-
48.0	445.02	325.61	608.22
60.0	359.13	283.79	454.47
72.0	306.47	251.35	373.66
84.0	256.60	213.26	308.75
96.0	219.81	179.72	268.83

TABLE - 1:24

LC_{50} and 95% confidence limit in ppb of 35-40mm P. indicus exposed to different concentrations of H_2S as a function of time at pH 6.0 6.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	217.26	150.20 - 314.25
24.0	165.85	131.10 209.81
36.0	140.00	116.89 167.68
48.0	120.00	102.52 140.46
60.0	109.54	94.69 126.72
72.0	85.31	74.77 97.34
84.0	72.54	63.48 - 82.90
96.0	63.44	54.56 73.75

TABLE - 1:25

LC_{50} and 95% confidence limit in ppb of 20-25mm P. indicus exposed to different concentrations of H_2S as a function of time at pH 6.0 - 6.3.

Time (h)	LC_{50}(ppb)	95% confidence
12.0	328.67	192.18 562.12
24.0	222.71	165.12 - 300.37
36.0	193.83	155.20 - 242.07
48.0	167.14	141.43 - 197.53
60.0	154.29	132.23 180.05
72.0	146.71	126.10 170.68
84.0	120.50	102.21 142.07
96.0	117.69	99.36 139.39

TABLE - 1:26

LC_{50} and 95% confidence limit in ppb of 35-40mm M. dobsoni exposed to different concentrations of H_2S as a function of time at pH 6.0 6.3.

Time (h)	LC_{50}(ppb)	95% confidence	
12.0	224.28	151.33	332.39
24.0	186.88	137.46	254.05
36.0	143.79	115.16	179.54
48.0	121.57	99.86	148.00
60.0	108.89	89.64	132.28
72.0	97.52	80.74	117.78
84.0	87.07	72.09	105.17
96.0	77.32	63.18	94.62

TABLE - 1:27

LC_{50} and 95% confidence limit in ppb of 20-25mm M. dobsoni exposed to different concentrations of H_2S as a function of time at pH 6.0 - 6.3.

Time (h)	LC_{50}(ppb)	95% confidence	
12.0	272.90	198.09	375.97
24.0	226.39	178.96	286.40
36.0	197.42	164.31 -	237.20
48.0	175.85	151.34 -	204.34
60.0	162.12	141.69 -	185.48
72.0	147.48	129.86	167.48
84.0	139.65	123.02	158.52
96.0	125.07	109.12	143.35

TABLE - 1:28

96h LC_{50} value (ppb) for different size ranges (35-40mm & 20-25mm) of P. indicus and M. dobsoni exposed to different concentrations of Hydrogen sulphide at three pH ranges viz. 8.1 8.3, 7.0 - 7.3 and 6.0 6.3 and the un-ionised Hydrogen sulphide for the respective LC_{50} concentrations.

pH Range	P. indicus LC_{50} value (ppb)		un-ionised H_2S (ppb)		M. dobsoni LC_{50} value (ppb)		un-ionised H_2S (ppb)	
	35-40mm	20-25mm	35-40mm	20-25mm	35-40mm	20-25mm	35-40mm	20-25mm
8.1 - 8.3	281.81	342.41	70.45	85.50	340.54	378.53	85.13	94.63
7.0 7.3	119.06	189.12	51.79	82.27	147.76	219.81	64.27	94.50
6.0 - 6.3	63.44	117.69	41.24	76.50	77.32	125.07	50.26	81.30

It was also noticed that the experimental P. indicus of 35-40mm size taken from the flow through chamber after 96h exposure to different concentrations of H_2S felt flabby to touch (soft) in contrast to the healthy turgid "feel" of the control prawns of the same size. However, M. dobsoni exposed to different concentrations of H_2S was not soft like P. indicus. This flabbiness was observed in some prawns which succumbed to H_2S toxicity and also those survived beyond 96h in concentrations above 240 ppb.

DISCUSSION

Hydrogen sulphide may occur naturally in many lakes during summer (Hutchenson, 1957; Bonn and Folis, 1967) and at the sediment-water interphases in the marshes (Adelman, 1969). In nature it is produced by anaerobic decomposition of organic materials like animal and plant remains in the sediments. Hydrogen sulphide is also produced by the decomposition of organic effluents from city sewage and many industries particularly wood fibre sludge from pulp mill (Colby and Smith, 1967; Ziebell et al., 1970; Van Horn et al., 1949) oil refineries (Dorris et al., 1960); and from chemical manufactures (Ellis, 1937).

The importance of H_2S in polluted and natural waters has been overlooked in the evaluation of water quality for the culture of aquatic organisms. H_2S often occurs near the sediment-water interface where organic material is undergoing decomposition and where the early life stages are spent by many shellfish and other related aquatic animals. Because of the short half life of H_2S in the presence of oxygen it has not been detected in many environmental situations. However, the direct toxic effect of H_2S on aquatic

organisms cannot be ignored.

While the effect of H_2S has been determined on certain fishes and invertebrates no much work has been done especially on prawns which is a benthic form. Shigueno (1972) has briefed that Penaeus japonicus lost equilibrium when exposed to H_2S at 0.1 2.0 ppm. Chen (1985) recommended a safe level of 0.33 mg/l H_2S for Penaeus monodon culture whereas Law (1988) suggested 0.005 mg/l H_2S as the safe level of the same species.

In the present investigation the acute toxicity of H_2S to P. indicus and M. dobsoni have been studied. The results obtained are discussed below with the available results of fishes and other invertebrates.

The H_2S toxicity bioassays conducted with different size groups of P. indicus and M. dobsoni in sea water have shown that the 96h LC_{50} declined with increase in size of the prawns. The LC_{50} of P. indicus exposed to various concentrations of H_2S in sea water having pH 8.1 - 8.3 showed significant variation between different size groups. 85-90mm size group was highly sensitive followed by 35-40mm size group and 20-25mm size group. The LC_{50} were 144.73 ppb, 281.81 ppb and 342.41 ppb respectively. Similarly for M. dobsoni the LC_{50} between 35-40mm and 20-25mm also showed variation. The former size group was more sensitive to H_2S than the latter. For 35-40mm size the LC_{50} was 340.54 ppb and 378.53 ppb for 20-25mm size. A comparison of the 96h LC_{50} values show that the larger sized animals (85-90mm) were more sensitive than the smaller size groups and the sensitivity could be as high as four fold. This indicates that though there is considerable difference between the LC_{50} of the post larvae and

juveniles, it was not so high between post larvae and adult prawns.

The sensitivity of H_2S also varies with species. P. indicus is more sensitive to H_2S than M. dobsoni. It is also evident that smaller size groups of prawns are more tolerant to H_2S toxicity than larger groups. In this context the work of Shigueno (1972) is worth mentioning. He reported that adult Penaeus japonicus lost equilibrium when exposed to hydrogen sulphide at 0.1-2.0 ppm and instantly succumbed to a concentration of 4.0 ppm, which seems to indicate that the adult penaeids are in fact more sensitive to H_2S than their juveniles and post larvae as observed in the present study.

It is interesting to note that Groenendal (1980) worked on the polychaete, Arenicola marina and Bonn and Follis (1967) on the channel catfish. Ictalurus punctatus found that in those two animals which live in the sulphide rich environment, tolerance to H_2S increased with increase in size. The present study on prawns also showed similar tolerance to H_2S.

The LC_{50} given includes both ionised and un-ionised/un-dissociated H_2S. It is important to note that the toxicity of H_2S is highly influenced by the pH of the medium. The lower the pH the higher the toxicity. This is because of the presence of greater proportion of un-ionised H_2S at low pH.

The marked reduction in LC_{50} at lower pH levels recorded during the present experiments is in agreement with the results obtained by earlier workers (Longwell and Pentelow, 1935; Jacques 1936; Jones 1948; Bonn and Follis 1967; Colby and Smith 1967; Groenendal, 1981) who attributed the greater toxicity of sulphides at lower pH to the fact that total hydrogen sulphide (dissolved sulphides) at low pH levels exist mainly as un-ionised H_2S

which is more toxic to animals than the ionised forms; HS^- and S^{--}. These ionised forms can penetrate cell membranes only with diffculty because of their electric charge while, un-ionised H_2S can move freely across the membranes (Jacques, 1936). At pH 9 only 1% exists as un-ionised H_2S while at pH 5, 99% are present as un-ionised H_2S (Smith and Oseid, 1974). However, the rate of entry to the tissue so as to result in enhanced toxicity could be expected only if the internal pH of the tissues involved in the uptake of H_2S is congineal for H_2S entry. This is a factor so far not studied by any researchers.

In the present study the sea water used for the experiment was having a pH of 8.1 - 8.3, at which almost 25% H_2S was in the un-ionised form. Thus the 96h LC_{50} determined during the present study for the 20-25mm, 35-40mm and 85-90mm size groups of P. indicus if expressed in terms of un-ionised H_2S will be approximately 85.50 ppb, 70.5 ppb and 32.6 ppb. Similarly for 20-25mm and 35-40mm size groups of M. dobsoni the concentration of un-ionised H_2S will be 94.6 and 85.0 ppb.

Similarly in the experiment at pH 6.0 6.3 about 65% H_2S was in the un-ionised form. Thus 96h LC_{50} for post larvae (20-25mm) and juveniles (35-40mm) of P. indicus, if expressed in terms of un-ionised H_2S will be approximately 76.5 ppb and 41.2 ppb whereas for the same size group of M. dobsoni the un-ionised H_2S will be 81.3 ppb (20-25mm post larvae) and 77.3 ppb (35-40mm juveniles).

It is clear that there are comparabilities between the overall lethal toxicity of different size groups with respect to un-ionised H_2S. It is also clear that the low pH increases the toxicity of H_2S to prawns. But even

at low pH the smaller size groups are more resistant than the bigger size groups. There is also prominent variation in the tolerance levels between the two species of penaeid prawns. At all pH levels tried in the present experiments, P. indicus was found to be more sensitive to H_2S than M. dobsoni. Shelford (1917), Colby and Smith (1967) and Adelman and Smith (1970) found that the toxicity of sulphide increased in fishes (Salmon) with the lowering of oxygen levels from 6 ppm to 2 ppm. In the present study for all the experiments the dissolved oxygen level in the test water was maintained at 1.5 to 2 ml/l. P. indicus and M. dobsoni being oxyconformers the dissolved oxygen level is not reported lethal (Kripa, 1984; Kuttyamma, 1980). So in the present study the influence of low dissolved oxygen on the toxicity cannot be considered, as the amount of dissolved oxygen present was within the safe level.

Oseid and Smith (1974), estimated 96h LC_{50} of hydrogen sulphide for Gammarus pseudolimnaeus as 0.059 mg/l. This value is much lower than the LC_{50} observed for prawns in the present study. On the other hand the LC_{50} for peaneid prawns were lower than that of the LC_{50} for isopod Assellus militaris. The LC_{50} for Assellus militaris was 1.07 mg/l (Oseid and Smith, 1974). They also determined the 96h LC_{50} of amphipod Crangony richmondensis laurentianus to H_2S (0.84 mg/l) which showed a higher value than that of the prawns. Some species of Ephemeroptera, Ephemera simulans and Hexagenia limbata, showed H_2S toxicity as similar to that of prawns.

From these observations it is evident that the benthic groups are more tolerant to hydrogen sulphide toxicity than other non-benthic forms. Among the benthic groups like polychaetes, isopods, amphipods and decapods, the

prawns are less resistant or in otherwords less tolerant to H_2S. It may be noted that species of polychaetes, isopods and amphipods which are highly resistant to H_2S usually live in habitats with higher sulphide concentrations.

Though the 96h LC_{50} and influence of pH on the toxicity of H_2S agrees with the findings of earlier workers, there are some major points where more information is still required. As there is only limited references available regarding the toxicity studies of hydrogen sulphide on various invertebrates the results cannot be properly compared and discussed. In prawns, this is a pioneering work on the toxicity of H_2S. Much more work in this line has to be carried out to have more understanding of aspects like bio-accumulation, enzyme activity, physiological disorders etc. The present study offers a better understanding of the significance of hydrogen sulphide in prawn culture.

2

INFLUENCE OF HYDROGEN SULPHIDE ON THE ECOLOGY OF ESTUARY

INTRODUCTION

Sulphur is the tenth most abundant element in the universe and 8th and 14th most abundant element in the solar atmosphere and the earth's crust, respectively (Kaplan, 1972). It is a major element essential to all life on the earth's surface. This element occurs in the biosphere, lithosphere, atmosphere, hydrosphere and pedosphere.

Sulphur is essential for the growth of plants and is utilized partly as sulphide by most of them. Animals obtain their requirement largely from plants, other animals or bacteria. Sulphur is liberated from the remains of animals and plants by bacteria, almost exclusively as H_2S. All bacteria are not able to liberate hydrogen sulphide from sulphur containing organic matter. However, those which are endowed with this ability are wide spread in the aquatic environment.

Hydrogen sulphide often occurs near the sediment water interface where organic material is undergoing decomposition and where early life stages of many fish, shell fish and other aquatic animals are passed. Under anaerobic conditions, certain heterotrophic bacteria can use sulphate and other oxidised sulphur compounds as terminal electron acceptors in metabolism and excrete sulphide (Boyd, 1982). Sulphide is an ionization product of hydrogen sulphide and precipitates.

With the increase in population, the human intrerference is increasing which in turn increase the pollution problems, such as industrial, domestic, urban and other chemical pollution which leads to the production and liberation of hydrogen sulphide and other toxic compounds. These pollutants deplete the quality of water and leave this area unsuitable for the aquatic animals to grow.

As a developing country India is still depending mainly on natural source of water. So the pond fertility depends on the fertility of the estuarine surroundings. Moreover it has been established that estuaries form the nursery ground of several economically important species of penaeid prawns (Kuttuhn, 1966; Mohammed and Rao, 1971; George, 1973; Wicken, 1976).

Kerala is famous for its long stretches of backwaters spread along the coast line. The total brackish water area is estimated to be around 2,42,000 ha (Anon, 1990).

Kayamkulam lake one among the largest estuarine system in the west coast of India provide the nursery grounds for several marine prawns (Kuttyamma, 1980a; Gopakumar, 1987).

Domestic sewage, agriculture run off, the effluents from the retting grounds and some industries are the main source of pollutants in this area. Apart from the natural production of hydrogen sulphide by anaerobic decomposition, the effluents from retting ground form the major source of hydrogen sulphide.

Only few studies have been carried out on the hydrography and sedimentology of Kayamkulam lake. Mary John (1958) conducted a priliminary

survey of the estuary. Sivankutty Nair (1971) studied the hydrography of the estuary. Kuttyamma (1980a) and Gopakumar (1987) studied the distribution of prawn larvae and hydrography of the Kayamkulam lake. Apart from the above said work no further work has been done to study the nutrient cycle, sedimentology and other parameters in the estuary.

The hydrography and biology of many of the estuaries of the west coast of India have been the subject of studies for many years, Rao and George (1959), Ramamirtham and Jayaraman (1963), Qasim and Reddy (1967), Sankaranarayanan and Qasim (1969), Murthy and Veerayya (1972), Rajan (1972), Kurian (1974), Manikoth and Salih (1974), Kurian et al (1975), Silas and Pillai (1975), Balakrishnan and Shynamma (1976), Sankaranarayanan and Panampunnayil (1976), Pillai (1977, 1978), Haridas et al (1980), Nair et al (1987), Pillai and Ravindran (1988).

However, investigations on organic pollution and ecology of retting grounds have been carried out in the estuaries of Kerala.

Unnithan et al (1975) studied the organic pollution in Cochin backwaters. Vijayan et al (1976) studied the effect of organic pollution on some hydrographic features. The pollution in Cochin backwaters with reference to indicator bacteria was reported by George et al (1979). Studies on the effect of pollution with special reference to benthos was done by Remani (1979). Remani et al (1983) also studied the indicator organism of pollution for Cochin backwaters.

Though numerous studies on the process of retting were done since 1920 the pioneering work on the ecology of coconut husk retting grounds

of Kerala was done by Azis and Nair (1976, 1978, 1983). Remani et al (1981, 1983) carried out studies on the sediments or retting yard and the indicator species of pollution of the retting zone.

Ajithkumar and Alagarswami (1986) studied the effect of pollution due to coconut husk retting on reproductive potential of green mussel Perna viridis.

Eventhough the marked features associated with retting are the depletion of oxygen and increase in levels of hydrogen sulphide the importance of H_2S is under estimated in many ecological studies.

Hydrogen sulphide may occur naturally in many lakes during the summer (Hutchinson, 1957, Bonn and Follis, 1967), in ice-covered lakes (Seidmore, 1957) and at the sediment water interface in the marshes (Adelman, 1969). In these instances it is produced by anaerobic decomposition of organic material in the sediments. H_2S is also produced by the decomposition of organic effluents from municipal sewage and many industries particularly wood fibre sludge from pulp mill (Colby and Smith, 1967; Ziebell et al, 1970). It may also be released directly in industrial effluents from pulp mills (Van Horn et al., 1949) from oil refineries (Dorris et al, 1960) and from chemical manufactures (Ellis, 1937).

In the bottom deposits from the Clyde sea, Ellis (1932) demonstrated 10,000 to 3,000,000 saprophytes per gram, nine tenths of which liberated hydrogen sulphide from albuminons material. Zobell (1938a) found from 10,000 to 1,000,000 hydrogen sulphide producing bacteria per gram of bottom sediments from the Pacific Ocean off the coast of California.

Although sulphide concentration was used as a sediment parameter in ecological studies (Thamdrup, 1935; Fenchel and Riedl, 1970; Wharfe, 1977), little is known about the distribution of hydrogen sulphide in the marine environment. The hydrogen sulphide concentrations in the marine environment are influenced by complex processes of synthesis, transport, oxidation and precipitation and cannot be easily predicted on theoritical grounds.

Ziebell et al (1970) reported high levels of hydrogen sulphide in a variety of fish habitats. Higher concentrations were reported in polluted areas.

Smith and Oseid (1971, 1972) indicated that concentrations of hydrogen sulphide usually not measured or overlooked as unimportant can be extremely toxic to fish or have more subtle chronic effects which reduce potential production in fish population. Adelman and Smith (1972) indicated that hydrogen sulphide is present in both polluted and natural ecosystems at levels that are detrimental to fish and invertebrates. They also pointed out that even trace amounts of hydrogen sulphide have chronic effects.

Bell et al (1972) have shown higher levels of hydrogen sulphide near the bottom in many fish habitats during the spawning period.

Schindler et al (1972) investigated the seasonal variation of temperature, water transparancy, pH, dissolved oxygen, nutrients, ammonia, hydrogen sulphide methane, primary productivity and phytoplankton in a small eutrophic lake at Minnesota over a period of several years.

Jorgensen and Fenchel (1974) studied the sulphur cycle of a marine

sediment model system and estimated the maximum mean rate as about 80 nMs/cm²/day.

Cammen (1975) analysed the core samples in a salt marsh sediment for organic carbon content.

Aston and Hewitt (1977) determined the total phosphorus and organic carbon contents of the sediments in the polluted coastal environment at Walton backwaters, England. Berner (1977) studied the release of nutrients by microbial activity in the anoxic sediments of Long Island sound and presented stoichiometric models.

Cohen et al (1977) worked on the occurence of sulphur phototrophic bacteria, their distribution in relation to hydrogen sulphide concentration and light intensities and the primary production of the solar lake.

Jogensen and Cohen (1977) observed the sulphur cycle of the benthic cyanobacterial mats in the coastal hypersaline solar lake and found only 1.5% of the sulphide produced was trapped within the sediment in reduced form and the remaining 98.5% diffused to the surface where it was oxidised.

Bagander and Niemisto (1978) evaluated the use of reduction - oxidation measurements for characterising the sediments in the Baltic sea and the Gulf of Bothnia.

Hansen et al (1978) analysed the mechanism of the hydrogen sulphide release from a small, shallow, anoxic, sedimented Aggersund Area in Limfjorden and a small lagoon Kalo Vig in the coastal area of Denmark.

Rashid and Reinson (1979) found a correlation between the nitrogen, organic carbon and the particle size of the estuarine sediments in Miramichi estuary, Canada.

Krom and Berner (1980) worked on the adsorption of phosphate in anoxic marine sediments of Long Island sound.

Rosenberg (1980) reviewed the number of species, their abundance, biomass and macrobenthic faunal composition reactions to the oxygen deficiency due to organic enrichment and/or Geomorphological conditions in ten fjords and estuaries in northern Europe.

Welsh (1980) estimated the velatine magnitudes of nutrient activity and diel cycle of nutrients of the marsh mudflat ecosystems of Branford River Estuary on the north shore of Long Island Sound.

Vander Loeff et al (1981) analysed the sediment water exchange of nitrate, silica, ammonia, phosphate and oxygen on the tidal flats in the Ems Dollard estuary.

Callender and Hammond (1982) investigated on the C N ratio, macro invertebrate population including polychaete worms, molluscs and amphipods, sulphide, organic carbon, nitrogen and phosphorus, N P ratio and the average benthic flux across the sediment water interface in the Potomac river estuary.

Fisher et al (1982) worked on the phosphate, nitrate and ammonium regeneration from the sediment, in three north Carolina estuaries.

Nedwell (1982) experimented on the exchange of nitrate and the products of bacterial nitrate reduction between sea water and sediment in a salt marsh

and found that the rate by removal of nitrate from water column increased with the steady state concentrations of nitrate. Silas (1985) while studying ecology of a salt water lagoon mentioned the importance of hydrogen sulphide.

In this view a study was conducted in the Kayamkulam estuary for a period of two years to understand the hydrography and biology of Kayamkulam estuary as well as to understand the importance of hydrogen sulphide in the ecology of the estuary. The results of the present observation is discussed with the results obtained from the estuaries and water bodies elsewhere.

MATERIAL AND METHODS

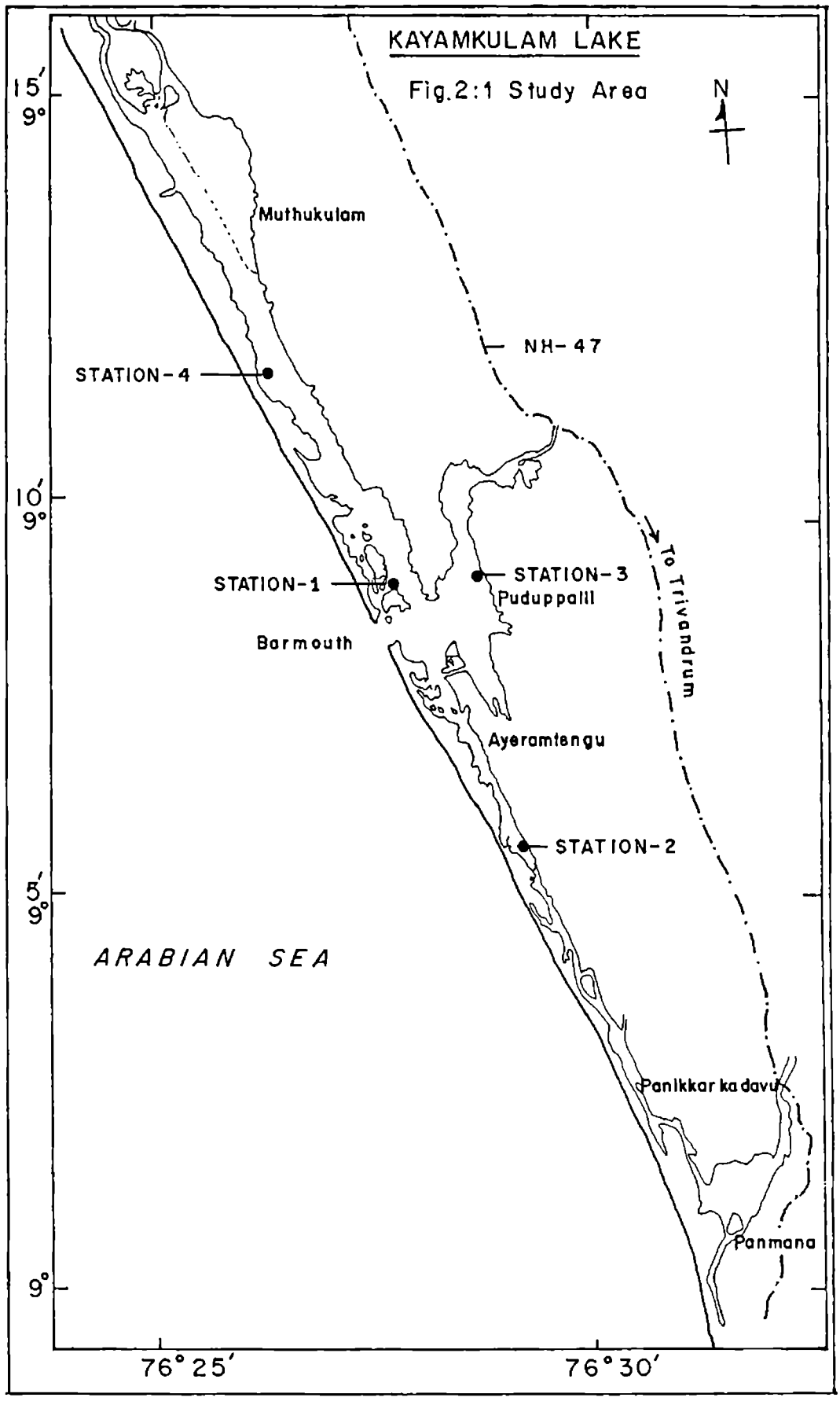
Description of the Study Area

Location

The Kayamkulam lake is a narrow stretch of back water lying between 9°2' and 9°16' latitudes and 76°32'E longitudes. It runs almost parallel to the coast (Fig. 2:1).

Nature of the Estuarine System

The sandy bar of the Kayamkulam estuary is situated almost midway between the northern and southern ends. In front of the barmouth the estuary is about 2.5 Km wide, from the barmouth the width decreases both towards the north and south. The southern half of the estuary is very narrow, the average width not exceeding 0.4 Km. From the region opposite the barmouth an arm of the estuary extends to the Kayamkulam town in the north easterly


KAYAMKULAM LAKE
Fig.2:1 Study Area
N
15'
9°
10'
9°
5'
9°
9°
Muthukulam
NH-47
STATION-4
STATION-1
STATION-3
Puduppalli
Barmouth
To Trivandrum
Ayeramtengu
STATION-2
ARABIAN SEA
Panikkar kadavu
Panmana
76°25'
76°30'

direction. The estuary is connected at the north by three canals, which discharge flood water from the Pampa and Achankoil rivers during the monsoon period. In the south the estuary merges with 'Vattakayal' which forms a sort of reservoir for the flood waters brought down from the adjoining lands and canals during the monsoon. The barmouth closes sometime between March and April and then onwards the water in the estuary is almost stagnant till the middle of June when the flood water accumulates and the bar is cut open to allow the egress of flood water into the sea.

Description of Stations

Four stations were selected in the estuary to conduct the study (Fig. 2:1) trail samples, both water and sediments were collected from different points of the estuary and analysed to know about the presence of hydrogen sulphide. Area where hydrogen sulphide was present and not present were located. Two stations, station I and station II were fixed in hydrogen sulphide free area (clear area) and another two stations, station III and IV in area where hydrogen sulphide was present (polluted area).

Sampling Method and Frequency

Regular fortnightly sampling was carried out from all the four stations for a period of two years (February 1987 to January 1989).

Water Samples

Surface water sampling was done using a 1000 ml plastic bottle. Before sampling, the bottles were throughly washed using the ambient water. Sampling was done by carefully dipping the bottle in the water and taking

caution to avoid the entry of air bubbles. Sub-samples were siphoned into 100 ml bottles from the main sample and kept intact in an ice box till the analyses were carried out.

Bottom water sampling was done slowly by wadeing into the water and the 500 ml plastic bottle was carefully dipped into the water. The water samples were collected from just above the soil surface by gently opening the lid of the bottle after keeping it just above the soil surface. When the bottle was full, it was stoppered there itself and taken out. Immediately after taking out from the water the temperature was noted.

For the estimation of hydrogen sulphide and dissolved oxygen separate sampling was done by giving more care to avoid any air bubbles getting trapped in the bottle. As soon as the sampling was over Winkler A and B solutions were added for estimation of dissolved oxygen and N - I - N dimethyl ethelene diamine hydrochloride and ferric chloride for hydrogen sulphide estimation.

Soil Sampling

Soil samples were collected using a Van Veen grab of 225 cm^2 gape. As soon as the grab sediment was taken out of the water column sediment sample was filled in 100 ml wide mouth plastic bottles with minimum aeration and closed air tight. At the same time temperature of the sediment also was noted. For estimation of total sulphide the sediment was transferred into 100 ml wide mouth plastic bottle and 1 ml of 2 N zinc acetate solution was added as quickly as possible. The bottle was shaken well after closing and the samples were carefully kept in ice box. Sample for grain size

analysis was taken in a polythene bag and tightly closed by using a rubber band. These samples were collected regularly from the second year of study (February 1988 to January 1989) and stored. The dried samples collected during February, March, and May were mixed together and the soil texture was analysed. The results are given for season ie Pre-monsoon, Monsoon and Post-monsoon.

The following parameters were observed during the study.

1) Water temperature (surface and bottom)

2) Sediment temperature

3) Water pH (surface and bottom)

4) Sediment pH

5) Water salinity (surface and bottom)

6) Dissolved oxygen content in water (surface and bottom)

7) Nitrite nitrogen in water (surface and bottom)

8) Nitrate nitrogen in water (surface and bottom)

9) Reactive phosphorus in water (surface and bottom)

10) Hydrogen sulphide in water (surface and bottom)

11) Available phosphorus in sediment

12) Available nitrate in sediment

13) Eh (Redox potential) in sediment

14) Organic carbon in sediment

15) Total sulphide in sediment.

Analyses of Hydrographical Parameters

Temperature

Temperature was measured with ordinary thermometer of range 0 50°C each division being 0.1°C.

pH

pH was measured using digital 'Century' pH meter. The pH meter was standardised with pH 4 and pH 9 buffer solution during every set of analysis.

Salinity

Salinity was estimated by Mohr's titration method (Strickland and Parsons 1968).

Dissolved Oxygen

Traditional Winkler method was used to determine the dissolved oxygen content (FAO, 1975).

Nitrite-Nitrogen

Nitrite Nitrogen was estimated by Shinh method modified by Bendsneider and Robinson (Strickland and Parsons, 1968). The reagents used were acidic sulphanilamide and NNED. The absorbance was measured in a colorimeter at 530 nm.

Nitrate-Nitrogen

Nitrate Nitrogen was determined by Morris and Reley method (Strickland

and Parsons, 1968). Water samples after keeping for reduction using copper sulphate and hydrazine sulphate for 20 hours in darkness, was treated with the sulphanilamide and NNED and the absorbance was measured at 530 nm using photoelectric colorimeter.

Reactive Phosphorus

For estimating Reactive phosphorus Murphy and Reley method (Strickland and Parsons, 1968) was used. Water was allowed to react with ammonium molybdate and potassium antimony tartrate in an acid medium (Sulphuric acid and Ascorbic acid). A blue complex was formed. The absorbance was measured in a colorimeter using red filter of 620 nm, using photoelectric colorimeter.

Hydrogen Sulphide

The method by which hydrogen sulphide was determined, is based on the following principle: the acidified sample is allowed to react with dimethyl P - Phenylene diamine dihydrochloride, with ferric - ions as catalyst. A complex oxidation and substitution takes place resulting in the quantitative incorporation of any sulphide - sulphur present, into a heterocyclic dye called Methylene blue. The absorption of light by the sample is measured against the blank at 670 nm (Carlberg, 1975).

The outline of the method followed (FAO, 1975) is given below. Immediately after sampling, using long tipped pippettes, 1 ml. of N - I N dimethyl P - Phenylene diamine dihydrochloride prepared by dissolving 1 g in about 6 N hydrochloric acid to 500 ml, and 1 ml of ferric chloride prepared by dissolving 8 g in about 6 N hydrochloric acid to 500 ml, were added to

the sample and the bottle was stoppered avoiding air bubbles getting in. The sample was shaken well and the blue colour that developed was read in the laboratory against the blank. The colour intensity was constant for atleast 24 h.

Analyses of Sedimentological Parameters

Temperature

As soon as the grab was removed from the water surface, a thermometer of 0 50°C precision was inserted immediately in the sediment and the reading was recorded.

pH

pH was measured using 'Century' pH meter. The pH meter was standardised with pH 4 and pH 9 buffer solution during every set of analysis.

Eh (Redox Potential)

Eh of the sediment was estimated using the same pH meter but with a platinum electrode.

Organic Carbon

The method of Walkley and Black (1934) was used to determine the organic carbon content of the sediment. In this method, hot chromic acid was used to oxidise any organic carbon present and the excess acid not reduced by the organic matter was determined volumetrically with ferrous salt.

Available Nitrate in Sediment

Available nitrate was estimated from the extract of sediment prepared with distilled water. The extract was evaporated and treated with phenol disulphonic acid and ammonium hydroxide (Mackereth, 1957). The yellow colour developed was measured as absorbance using 420 nm in photo electric colorimeter.

Available Phosphorus in Sediment

Available phosphorus in air dried soil was extracted using sodium bicarbonate of 8.5 pH. This extract was treated with acidic ammonium molybdate, potassium antimony tartrate and freshly weighed ascorbic acid (Olsen; 1954). The blue colour developed between 30 and 40 minutes was measured using red filter of 620 nm in photoelectric colorimeter.

Total Sulphide

The sulphide estimation was done following the standard method (American Public Health Association, 1960). The principle of the method being sulphides are stripped off from the acidified sample with an inert gas and collected in zinc acetate solution. Excess iodine solution was added to the zinc sulphide suspension which react with sulphide under acidic conditions. Thiosulphate was used to measure unreacted iodine to indicate the quantity of iodine consumed by sulphide.

Grain Size Analysis

The representative samples of air dried soil was taken and analysed

for grain size by the seive and pippette method of Krumbein and Pettijohn (1938). The soil type was named according to Shepard (1954).

Benthic Macrofauna

A hand operated grab of 225 cm^2 gape was used to collect the mud samples. At each station, for each sampling the grab was operated five times thereby covering an area of 0.1125 m^2. The sediment sample was brought to the shore where it was sieved through 0.5 mm sieve. Sieved samples were preserved in 5% buffered formalin to which 1 g of rose bengal per litre was added. In the laboratory, the animals were sorted out by hand picking, and identified the important taxonomical groups (Fauvel, 1953). The results are presented as nos/0.1 m^2.

Distribution of Prawn Post Larvae/Seed

Distribution of penaeid prawn post larvae in the four stations was noted by collecting fortnightly post larval samples using drag net. 2 m x 1 m size velon screen was used as drag net. The net was operated in shallow waters in all the stations. Two persons operated the net by holding on two sides and draging in water for a period of 5 mts. Five such trail samplings were done and the average number/haul was calculated. The samples were preserved in 10% formalin. In the laboratory, the post larvae were sorted out and identified (Mohammed et al, 1963). The results were presented as number/haul.

Statistical Analysis

All the statistical analyses were carried out according to Snedecor

and Cochran (1967). Monthly mean and standard deviations were calculated for all the parameters. Correlation between all the hydrographical and sedimentological parameters were computed and the correlation matrices for all the stations are given in the tables and discussed. Occurance of benthic organisms and prawn larvae in different stations were statistically tested (ANOVA) to find any significant difference in the distribution.

RESULTS

The data on different hydrographical and sedimentological parameters were collected from four stations in the study area for a period of two years. The period of observation extended from February 1987 to January 1989. In order to present the data, the period from February 1987 to Janaury 1988 has been considered as the "first year" and February 1988 to January 1989 as the "second year".

Graphs were drawn with monthly mean values. The monthly mean and standard deviation values of all the hydrographical and sedimentological parameters at each station studied during the present investigations are given in Table 2:1 to 2:23. In order to evaluate the nature of relationship between different parameters studied, the data were analysed for estimating the correlation coefficient (r) values.

Rainfall

Monthly total rainfall as reported by the Meterological Department of CPCRI Kayamkulam from Feb. 1987 to Jan. 1989 is plotted in Fig. 2:2 to

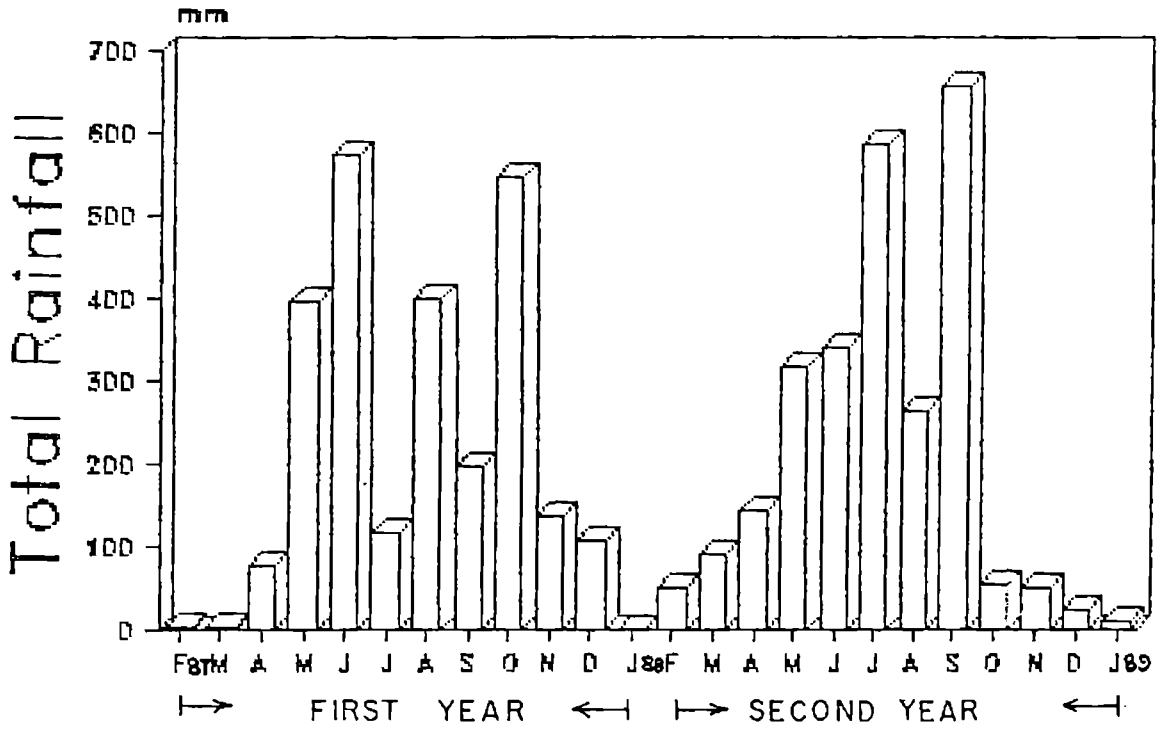


Fig.2: 2 Total Rainfall

have an idea of the total rainfall received in Kayamkulam area during the study period. The rain water from Kayamkulam town and other nearby places flow into the estuary and this influences the salinity of the estuary to a considerable extent. There was no significant difference between the monsoons of 1987 and 1988. In 1987 there was rain throughout the year. In 1988 January no rain was recorded. Except January there was moderate rain throughout. In the first year of observation maximum rainfall was recorded on June 1987 (575.5 mm) followed by 546.8 mm in October 1987. Where as in the second year maximum rainfall was recorded in September 1988 (658.6) followed by 588.2 mm in July 1988 (Table 2:28).

In the first year, bar mouth was closed during the third week of April 1987 and opened on June 1987. In the second year, bar mouth was closed on the second week of April 1988 and opened on the second week of July 1988.

Station I

Hydrography

Temperature

Both surface and bottom water temperature showed a similar trend. The bottom water temperature was lower than surface water temperature. In the first year (1987-88) maximum surface water temperature was recorded during April-May (30.5°C). Lowest temperature (28.0°C) was observed in August and December. Highest bottom water temperature was observed in March and May (29.5°C) and the lowest value was noted in December (27.3°C) (Fig. 2:3).

Water temperature in the second year (1988-89) also showed a similar pattern as the previous year. Highest and lowest surface water temperature were recorded during April (31.0°C) and September (28.0°C) respectively. Highest bottom water temperature was recorded in April '88 and May (29.5°C). Lowest values 27.5°C was noted in August, September and December.

Salinity

Both surface water and bottom water salinities were recorded for two years (Fig. 2:7). In almost all the months bottom water salinity was more than the surface water salinity. In the first year highest surface water salinity was recorded in April (34.0 ppt). Lowest value was noted in July (10.25 ppt). Similarly highest bottom water salinity was recorded in April (34.5 ppt) and lowest in July (14.5 ppt). The trend was almost same during the second year's observation also. Highest surface water salinity was observed in April (33.00 ppt) and lowest in July (10.00 ppt). In the case of bottom water the highest value was recorded in March (34.05 ppt). Both the surface and bottom water salinity showed a sharp and study decrease from June onwards.

Dissolved Oxygen

Surface water and bottom water dissolved oxygen were recorded for two years and plotted in Fig. 2:11. Bottom water dissolved oxygen values were lower than surface water dissolved oxygen values. During the first year observations highest value of surface water dissolved oxygen was recorded in July (4.60 ml/l), the lowest value was recorded in the month of May (3.10 ml/l). Bottom water dissolved oxygen was high in December (3.98 ml/l)

lowest value of 2.74 ml/l was in May.

In the second year of study highest surface water dissolved oxygen was observed in the month of July (5.04 ml/l) and the lowest value in the month of May (3.12 ml/l). For bottom water the maximum dissolved oxygen was recorded in August (4.04 ml/l) and the minimum was observed in May (2.77 ml/l).

pH

Surface and bottom water pH were observed during the study period of two years. The trend was almost same for both the years. Surface water pH were higher compared to bottom water pH in almost all the stations. Surface water pH was more or less constant within the range of 8.0 to 8.4. In the first year maximum surface water pH value was recorded December (8.36) and the minimum was in May (7.9). In the case of bottom water pH the highest value was in October (8.24) and the lowest value in May (7.78). In the second year also the trend is similar as in the first year. High surface water pH value was recorded in the month of August (8.40) and low value in May (8.10) where as in bottom water pH value was high in September (7 30) and low in April (7.87) (Fig. 2:15). In general though there is no much fluctuation in the pH values lower values were observed during the pre-monsoon period when compared to monsoon and post-monsoon.

Nitrate - Nitrogen

Nitrate-Nitrogen in surface and bottom water was observed for two years (Fig. 2:19). In the first year nitrate content was in its peak in the

surface water in July (39.07 µg - at NO_3 N/l) and low in May (3.85 µg - at NO_3 - N/l). A sharp increase in the nitrate value was observed from June onwards similarly the nitrate value strated decreasing from December onwards.

Bottom water nitrate value also showed a similar trend as surface water nitrate. The nitrate value was lowest in May (3.32 µg at NO_3 - N/l). After May the value sharply increased and a highest value of 42.53 µg at - NO_3 N/l was recorded in July. From July onwards the values showed a decreasing trend.

In the second year of observation surface water nitrate content was maximum in July (39-72 µg at NO_3 - N/l) and lowest in May (3.44 µg at NO_3 N/l). With the onset of monsoon the nitrate value started showing increased value, and after the monsoon it showed a decreasing trend. In bottom water also the trend was same. High nitrate value was noted in July (39.72 µg at NO_3 N/l) and low in May (3.62 µg - at NO_3 - N/l).

Nitrite - Nitrogen

Surface water and bottom water nitrite was recorded for a period of two years from February 87 to January 89 and is given in Fig. 2:23. In the first year nitrite values showed a peak of occurance in July (5.88 µg - at NO_2 - N/l) in the surface water and in bottom water also the peak period was same with a concentration of 6.72 µg at NO_2 - N/l. The lowest value was observed in April in surface and bottom water. The concentration was 0.25 µg at NO_2 - N/l and 0.34 µg at NO_2 - N/l respectively.

The nitrite values of surface and bottom water showed a similar trend.

From May onwards the values started showing a sharp increase and the peak was in July. After that a same trend of decrease in value was observed.

In the second year of observation also the trend was more or less same. Values were high during monsoon. Lowest nitrite values was observed for both surface and bottom water in the month of April. The values were 0.43 µg - at NO_2 - N/l and 0.47 µg at NO_2 N/l respectively.

Reactive Phosphorus

Reactive phosphorus in surface and bottom water were estimated and ploted in Fig. 2:27. There was pronounced difference in the concentrations of PO_4 P during pre-monsoon, monsoon and post-monsoon. High values were observed during the monsoon period and lowest values were observed during pre-monsoon. In the first year for both surface and bottom water peak of occurance was in August (16.2 µg at PO_4 - P/l surface water and 2.72 µg - at PO_4 - P/l in bottom water).

In the second year also the trend of phosphate was similar to that of the first year. Phosphate values showed high variation between seasons. Highest value for both surface and bottom water was recorded in August (15.86 µg at PO_4 - P/l in surface water and 15.92 µg at PO_4 - P/l in bottom water). Lowest values were recorded in April (2.84 µg - at PO_4 - P/l in both surface and bottom water).

Hydrogen Sulphide

Hydrogen sulphide was not present in the surface and bottom waters during the period of the study.

Sedimentology

Temperature

During both the years the much variation was not recorded in the temperature of the sediment. In the first year maximum temperature was recorded in April (29.5°C) and the minimum was in August (27.15°C) where as in the second year of study highest temperature was noted in May (29.5°C) and lowest in September, November, December (27.5°C) (Fig. 2:3).

pH

pH of the soil showed more or less constant trend. Though there was slight fluctuation the range varied from 7.5 to 7.8. In the first year maximum pH of 7.79 was observed in the month of November and minimum 7.50 in the month of May. During the second year highest pH (7.77) was recorded in the month of November the lowest pH 7.50 was again recorded in the month of May (Fig. 2:15).

Eh

Eh of the soil showed fluctuation. Highly reduced values were observed during pre-monsoon period and the condition slightly improved by post-monsoon. In the first year highly reduced value of Eh (-86 mv) was recorded in the month of April and the minimum reduced value -30 mv was recorded in July. During the second years observation maximum reduced value -82 mv was recorded in the month of May and the minimum reduced value in July (-26 mv) (Fig. 2:32).

Organic Carbon

There was slight fluctuation in the organic carbon of the soil in different seasons. Low values were observed in monsoon season in both the years. High values were recorded in pre-monsoon season. In the first year high organic carbon (3.04%) was observed in May and the lowest 2.10% was noted in July. In the second year also the trend was same highest 3.12% in May and lowest 2.02% in July (Fig. 2:33).

Available Phosphorus

Phosphate distribution was more or less constant. In the first year highest value of 1.60 µg at PO_4 P/g was observed in July and lowest in January (0.92 µg at PO_4 - P/g). During the second year the highest value was observed in June (1.56 µg - at PO_4 - P/g) and lowest in September (0.95 µg at PO_4 - P/g) (Fig. 2:27). In general phosphate values were higher during monsoon period and slightly decreased towards post-monsoon period.

Available Nitrate

Nitrate in the sediment showed fluctuation. In the first year maximum nitrate value was observed in June (2.40 µg - at NO_3 - N/g) and minimum in August (0.81 µg - at NO_3 - N/g). During the second year maximum nitrate value was observed in June (2.43 µg at - NO_3 - N/g) and minimum 0.74 µg at NO_3 - N/g was observed in January (Fig. 2:19).

Total Sulphide

Total sulphide in the soil was estimated for both years. In most of the time during monsoon and post-monsoon total sulphide was not present

in the soil. Sulphide was mainly present in the soil during pre-monsson period. In both the years high sulphide was observed in April (0.92 µg at H_2S - S/g, 1.06 µg at H_2S - S/g) (Fig. 2:37).

Station II

Hydrography

Temperature

Both surface and bottom temperature showed a similar trend. Maximum temperature was recorded in May in both the years (31.5°C, 30.0°C) and minimum surface temperature was observed in December (28.25°C) in the first year. In the second year minimum temperature were recorded in July and December (28.5°C) (Fig. 2:4).

In the first year high bottom water temperature of 29.5°C was observed in March, April, May and low in July, September (28.0°C). A similar trend was observed in the second year also. Highest temperature was observed in May (29.75°C) and lowest (27.75°C) in December in the second year.

Salinity

Salinity in the estuary showed wide fluctuation from almost fresh water condition to high saline water. The trend was same for both surface and bottom water salinity (Fig. 2:8). During the pre-monsoon period the salinity was high almost nearing sea water salinity. With the onset of monsoon there was a steep drop in salinity. In the first year of the study maximum surface water salinity was recorded in March, April (30.0 ppt) and the minimum in

November (4.25 ppt) whereas in the second year maximum salinity of the surface water was recorded in April (29.5 ppt) minimum in September (2.15 ppt). Salinity of the bottom water also showed a same trend as surface water. In almost all months bottom salinity was more than surface water salinity. In the first year maximum bottom water salinity was recorded in March-April (30 ppt) and minimum was observed in August (5.5 ppt). During the second year highest salinity of bottom water was observed in the month of April (30.0 ppt) and lowest in September (4.3 ppt).

Dissolved Oxygen

Wide fluctuation in dissolved oxygen was observed in the surface water and bottom water. With the onset of monsoon the dissolved oxygen values showed a gradual increase (Fig. 2:12). In surface water low values of dissolved oxygen was recorded in the month of May 1987 (3.94 ml/l) and 4.0 ml/l in May 1988. From June onwards in both the year the dissolved oxygen values strated increasing and the highest dissolved oxygen value was recorded in the month of August 1987 (5.14 ml/l) and 5.18 ml/l in November 1988. In bottom water the dissolved oxygen values were comparatively lower than the surface water values but the trend was same as that of the surface water. During both the years high dissolved oxygen values were reported in post-monsoon period (August 87, 5.01 ml/l, November 88, 4.96 ml/l).

pH

pH of the surface water and bottom water showed less fluctuation. The values were more or less constant with very slight fluctuation. In the first year high pH value was recorded in July (8.45) and the lowest 8.0 in

September. In the second year's observation highest pH value was recorded in November (8.34) and lowest in May (8.19).

Bottom water pH also showed the same trend as surface water. In the first year high value of 8.38 was recorded in July and lowest in May (7.93) (Fig. 2:16).

In the second year study period maximum pH value was recorded in the month of August and September (8.24) and minimum in July (7.96).

Nitrate - Nitrogen

In the first year high nitrate value was observed in the month of August (29.96 µg at NO_3 - N/l) in the surface water and low in May (3.25 µg at NO_3 N/l). In the same period the nitrate content in the bottom water also showed its maximum in the month of August (30.75 µg at NO_3 - N/l) and minimum in May (3.53 µg at NO_3 N/l) (Fig. 2:20). During the second year also the nitrate value showed a similar trend as in the first year. In the second year highest nitrate value in surface and bottom water was recorded in the month of August (32.76 µg at NO_3 - N/l) and (33.1 µg at NO_3 - N/l) and lowest in May (3.32 µg at NO_3 - N/l).

In general the nitrate content in the water was high during the monsoon period and low during the pre-monsoon period. The lowest value was recorded in the month of May, after that the nitrate value sharply increased and the trend continuous upto July, August. After August there was a sudden drop in the value and it was still lower in the subsequent months.

Nitrite - Nitrogen

Nitrite content also showed drastic fluctuation. High values were shown in the monsoon period. The values were low in March, April during both the years of study. After May the values showed a sudden increase and from September onwards the values strated decreasing. In the first year high values were found in July in surface water (32.44 µg - at NO_2 - N/l) and in bottom water the maximum nitrite value recorded in July (32.44 µg at NO_2 N/l) and low value observed in March (4.21 µg at NO_2 - N/l). During the second year study period high nitrite values in surface water was observed in July (30.24 µg at NO_2 - N/l) low in January (2.32 µg at NO_2 - N/l) whereas in bottom water the high nitrite value was recorded in July (30.44 µg at NO_2 - N/l) and low in January (2.46 µg at NO_2 - N/l) (Fig. 2:24).

Reactive Phosphorus

In the second year the reactive phosphorus in the surface water was lowest during March 2.60 µg at PO_4 - P/l and highest during July 13.36 µg at PO_4/l for bottom water also the lowest value recorded was during March 2.6 µg - at PO_4- P/l and highest in July 13.52 µg - at PO_4 - P/l. In general it was observed that phosphate availability in the water was very low during pre-monsoon. It increased gradually and reached a peak in monsoon followed by reduced values in post-monsson (Fig. 2:28).

Hydrogen Sulphide

Hydrogen sulphide was not present in the bottom and surface water during the period of study.

Sedimentology

Temperature

Not much variation was observed in the temperature of the sediment. During the first and second years the minimum temperature recorded was in December, 27.5°C and 27.0°C respectively. High values of the range 29.0°C 29.5°C was observed during the pre-monsoon period during the both the years (Fig. 2:4).

pH

Variation in the pH values were not pronounced during period of study. The minimum values were observed in April during both the years, 7.42 and 7.43 respectively.

In first year the highest value (7.82 was noted in September whereas in second year, the maximum value 7.83 was observed in November (Fig. 2:8).

Eh

Marked variation in the Eh value was noted throughout year. Highly reduced values were recorded in April during both the years, -115 mv and -105 mv respectively. The minimum reduced values, -40 mv in the first year and -42 mv in the second year was recorded in July. In general it was observed that the Eh values were low during premonsoon and high during monsoon (Fig. 2:32).

Organic Carbon

The organic carbon content was highest (3.20%) during January and

lowest (2.55%) in December in 1987-88. However, during the second year, (1988-89) maximum (3.04%) organic content was observed during June - July and minimum (2.04%) in December. There was not much variation in the organic carbon content of the soil during the entire period of study (Fig. 2:34)

Available Phosphorus

Phosphate in the sediment was highest 1.12 µg at PO_4 - P/g during October in the first year and 1.21 µg at PO_4 P/g during March in the second year. The lowest values recorded were 0.86 µg at PO_4 - P/g in December 1987 and 0.76 µg at PO_4 P/g in November 1988. However the variation in phosphate values was almost negligible (Fig. 2:28).

Available Nitrate

The nitrate values fluctuated between 0.90 µg at NO_3 N/g (January) to 1.7 µg at NO_3 N/g (July) during first year. In the second year the lowest value recorded was the same as that of the previous year. The maximum value recorded 1.94 µg at NO_3 N/g was in July for the second year also (Fig. 2:20).

Total Sulphide

Total sulphide was noted throughout the pre-monsoon period, in the beginning of monsoon (June only) and in the end of (in January only) post-monsoon during both the years (Fig. 2:37). Maximum value recorded was 6.2 µg at H_2S - S/g and 5.4 ug at H_2S - S/g in April during the first and second years respectively. The minimum values were 1.9 ug at H_2S - S/g in June and 2.2 µg at H_2S S/g in January respectively for the first and

second years. In both the years no total sulphide was detected in the soil during the period July - December.

Station III

Hydrography

Temperature

The temperature of the bottom water ranged from 27.0°C (January) to 29.5 (April May) during the first year and between 27.75°C (December) and 29.75°C (April - May) during the second year (Fig. 2:5). The highest temperature recorded for the surface water was 30.5°C in April and lowest, 28.25°C in August during the first year. In the second year the maximum temperature (30.25°C) of the surface water was recorded in April and the minimum, 28.0°C in January.

Salinity

The bottom water salinity was maximum, 31.0 ppt and 30.5 ppt in April 1987 and '88 respectively. The minimum values were 9.5 ppt (November) and 9.65 ppt (August) for during the first and second years respectively. The surface water temperature was highest (31.0 ppt) in April and lowest (9.5 ppt) in November 1987. During the second year the maximum salinity 30 ppt was recorded in February as well as April and the minimum 8.0 ppt in August (Fig. 2:9).

Dissolved Oxygen

There was not much fluctuation in the dissolved oxygen content of

bottom and surface water (Fig. 2:13). The minimum value observed in bottom water was 2.42 ml/l and 2.21 ml/l in April of the first and second years. For surface water also the lowest value was recorded in April (2.94 ml/l) and 2.82 ml/l respectively during 1987 and 1988. The maximum value noted for the bottom water was 3.17 ml/l (1987) and 3.14 ml/l (1988) respectively in the month August. The dissolved oxygen content of the surface was highest (3.52 ml/l and 3.38 ml/l) in August for both the years.

pH

The bottom water pH was highest 7.34 and 7.30 during November 1987 and 1988 respectively. The lowest values in pH were 6.90 and 6.94 in April of the first and second years respectively. The variation in surface water pH was negligible. It showed a minimum 7.14 (March) and 7.11 (April) in the first and second years respectively. The maximum values recorded were 7.52 (November 1987) and 7.54 (October - November 1988) (Fig. 2:17).

Nitrate - Nitrogen

The variation in the nitrate nitrogen of both the bottom and surface water was pro-nounced. In both the years the lowest amount 2.95 µg at NO_3 N/l and 3.17 µg at NO_3 - N/l was recorded in the surface water during May. The maximum nitrate nitrogen was 42.77 µg at NO_3 N/l and 44.82 µg at NO_3 N/l in July during the first and second years respectively. The minimum nitrate value recorded in the bottom water was 4.51 µg at NO_3 - N/l during November and July 1987 respectively. For the second year also the same trend was noticed. The lowest 5.10 µg at NO_3 N/l and the highest 45.96 µg at NO_3 N/l was observed in November and July respectively.

In general the nitrate nitrogen was high during monsoon and remarkably low during pre-monsoon (Fig. 2:21).

Nitrite - Nitrogen

For both, surface and bottom water the nitrite values were low during pre-monsoon and high during monsoon. The lowest nitrite value recorded in the bottom water was 0.72 µg at NO_2 N/l in November 1987 and 0.82 µg at NO_2 - N/l in March 1988. The highest values were 6.24 and 5.30 µg at NO_2 - N/l during July 1987 and 1988 respectively. The minimum nitrite values recorded in the surface water were 0.82 µg at NO_2 N/l in March 1987 and 0.86 µg at NO_2 N/l November 1988. The maximum values were 6.3 and 5.24 µg at NO_2 - N/l during the first and second years respectively (Fig. 2:25).

Reactive Phosphorus

The phosphate availability was recorded and it was noted that the maximum phosphate availability was during pre-monsoon. The bottom water the highest value recorded were 9.45 and 8.72 µg at PO_4 P/l during April 1987 and 1988 respectively. In the surface water also it was in April (i.e. pre-monsoon) that the peak values were noted. A maximum of 8.96 and 8.42 µg at PO_4 - P/l was noted in April and a minimum of 0.96 and 0.98 µg at PO_4 - P/l during August of the first and second years respectively (Fig. 2:29).

Hydrogen Sulphide

Hydrogen sulphide was observed in the surface water only during the

period March - May. It was highest 4.0 µg at H_2S - S/l and 3.6 µg at H_2S - S/l during April 1987 and 1988 respectively. The minimum value recorded were 2.8 µg at H_2S S/l (March) 1987 and 2.4 µg at H_2S - S/l (March) 1988. However, H_2S was detected in the bottom water in all the seasons except in the month of July and August. The highest value recorded was 44.0 and 38.0 µg at H_2S - S/l in April 1987 and 1988 respectively. It was observed that the H_2S content of the bottom water was notably high during the pre-monsoon (Fig. 2:31a).

Sedimentology

Temperature

The sediment temperature varied from 27.5°C (January) to 29.5°C (April-May) in the first year and from 27°C (Jan, Nov-Dec) to 29.0°C (April/May) in the second year. The variation in temperature was not very pronounced (Fig. 2:5).

pH

During the first year the pH of the sediment ranged from 6.38 (April) to 6.83 in August. In the second year slightly higher pH was noted 7.04 was the maximum and 6.40 the minimum pH recorded during the second year of study. The fluctuation in pH is not worth mentioning (Fig. 2:17).

Eh

The Eh of the sediment showed a maximum reduced value 295 -mv in April and a minimum reduced value of 136 -mv in November in the first year. During the second year the highly reduced value, 282 -mv was noted

in April and the less reduced value, 144 -mv in August. The Eh values were low during the pre-monsoon period and increased with the onset of monsoon (Fig. 2:32).

Organic Carbon

The variation in organic content of the soil was not well marked. The maximum 3.54% and 3.77% were recorded during September 1987 and November 1988 respectively (Fig. 2:35). The minimum values recorded are 2.73% and 2.76% in April 1987 and 1988. The organic content of the soil was found to increase with the onset of monsoon.

Available Phosphorus

The phosphate available in the soil was recorded for both the years and it was observed that the availability of phosphate was high during pre-monsoon than in the other seasons. The maximum values observed were 2.76 and 3.32 µg at PO_4 P/g during April 1987 and 1988 respectively. The minimum values noted were 0.81 and 0.82 µg at PO_4 - P/g during August 1987 and November 1988 respectively (Fig. 2:29).

Available Nitrate

Nitrate in the sediment showed slight fluctuation. During the first year the peak value observed was 1.16 µg at NO_3 - N/g in September and the lowest 0.57 µg at NO_3 N/g in April. In the second year the maximum observed value was 1.42 µg at NO_3 N/g in July and the minimum 0.59 µg at NO_3 - N/g in April (Fig. 2:21).

Total Sulphide

Total sulphide was detected in the sediment from January July in the first year and throughout the year during the second year study. In the first year maximum value recorded was 3128.9 µg at H_2S S/g (April). The following year, the peak value was again noticed in April, 3238.6 µg at H_2S S/g. Thereafter it started declining with the onset of monsoon and reached the lowest 116.2 µg at H_2S S/g in October (Fig. 2:37).

Station IV

Hydrography

Temperature

For both the surface and bottom water the temperature was comparatively high during the pre-monsoon period. The maximum values recorded for the surface water were 30.5°C and 30.0°C during April - May 1987 and March - May 1988 respectively. For surface water minimum temperature recorded was 28.5°C during October - December 1987 and in December 1988. The maximum bottom water temperature 30.5°C and 30.0°C was recorded in May 1987 and March - May 1988 respectively. The minimum temperature recorded for bottom water was 28.5°C, during October - December 1987 and in December 1988 (Fig. 2:6).

Salinity

For both bottom and surface water the salinity was high during pre-monsoon period and low during monsoon (Fig. 2:10). In the first year the minimum salinity recorded for bottom water was 6.3 ppt in August and for

surface water 5.5 ppt during the same month. In the second year the minimum salinity recorded was 4.5 ppt for August for both surface and bottom water. The maximum salinity recorded for bottom water was 30.0 ppt and 29.0 ppt during April 1987 and 1988 respectively. For surface water also the salinity was at its peak in April in both the years, 29.5 ppt and 28.5 ppt respectively.

Dissolved Oxygen

The dissolved oxygen content of the surface water was minimum 1.76 ml/l and 1.68 ml/l in May during both the years. The maximum values recorded were 3.99 ml/l (November) and 3.72 ml/l (December) for the first and second years respectively. Comparatively the dissolved oxygen content of the bottom was low (Fig. 2:14). It was minimum 1.02 ml/l and 1.03 ml/l during May 1987 and 1988. Maximum values recorded were 2.24 ml/l and 2.18 ml/l in August during both the years.

pH

pH of the surface water varied form a minimum of 6.72 (April) to a maximum of 7.54 (August) in 1987 and from 6.73 (May) to 7.50 (October) during 1988. The bottom water pH showed very little fluctuation. The minimum values of 6.50 (April 87) and 6.51 (April 88) and maximum values of 6.81 (September 87) and 6.92 (September 88) were recorded (Fig. 2:18).

Nitrate - Nitrogen

During the pre-monsoon very low values of nitrate were in the bottom water. Minimum of 0.76 µg at NO_3 - N/l and 0.82 µg at NO_3 N/l was observed during April 1987 and 1988 respectively. The maximum values

recorded for nitrate in bottom water were 20.6 µg at NO_3 N/l and 27.75 µg at NO_3 - N/l during July of the first and second years. In the surface water the lowest value recorded in 1-12 µg at NO_3 - N/l during April in both the years. The maximum nitrate value in surface water was 29.7 and 27.75 µg at NO_3 - N/l in July for the first and second years of the study. In general it can be seen that the nitrate values were low during pre-monsoon and high during monsoon (Fig. 2:22).

Nitrite - Nitrogen

The minimum nitrite content in the surface water recorded was 0.75 µg at NO_2 N/l during April for both the first and second years of the study. The maximum values recorded were 4.32 µg at NO_2 N/l and 3.87 µg at NO_2 - N/l during July 1987 and August 1988 respectively. For bottom water a minimum of 0.68 and 0.76 µg at NO_2 - N/l was observed during April 1987 and '88 and a maximum of 5.64 and 3.89 µg at NO_2 - N/l during July and August of the first and second years were recorded. The fluctuation followed a general pattern of low values during pre-monsoon followed by high nitrite values in monsoon (Fig. 2:26).

Reactive Phosphorus

The reactive phosphorus in the surface water was highest, 16.00 and 16.72 µg at PO_4 - P/l during April 1987 and 1988 and lowest, 1.03 and August 1988 respectively. In the bottom water the highest values for reactive phosphorus was noted in monsoon, 17.73 and 18.00 µg at PO_4 - P/l during April 1987 and 1988 respectively. With the onset of monsoon the phosphate content started declining and a minimum of 1.12 and 1.75 µg at PO_4 P/l

was noted in September 1987 and August 1988 (Fig. 2:30).

Hydrogen Sulphide

Hydrogen sulphide was observed in the bottom water throughout the year (Fig. 2:31b). The maximum values were 150.14 and 161.2 µg at H_2S S/l during April of both the years and the minimum content of H_2S in the bottom water 4.86 µg at H_2S S/l and 3.44 µg at H_2S - S/l in the month of August for the first and second year. H_2S was not present in the surface water during the period July - December of both the years. The peak values, 42.0 and 46.0 µg at H_2S S/l and minimum values, 6.7 and 12.82 µg at H_2S S/l was noted in April and June of 1987 and 1988 respectively.

Sedimentology

Temperature

The temperature recorded a maximum 29.5°C (April - May) and minimum 27.5°C (December) in 1987. In the second year the maximum value recorded was the same (29.5°C) as in the previous year, but the minimum was 27.0 (December). However the fluctuation in temperature is not very prominent (Fig. 2:6).

pH

The variation in sediment pH was not pronounced. During the entire period of study the lowest value, 6.22 was recorded in April 1987 and the highest 6.58 in November 1987 and December 1988 (Fig. 2:18).

Eh

The maximum reduced values 340 -mv and 345 -mv were recorded in April 1987 and 1988 respectively. The minimum reduced values180 -mv and 197 -mv were observed in November of the first and second year respectively. Very highly reduced values were observed during pre-monsoon during the period of study (Fig. 2:32).

Organic Carbon

The highest values recorded in the first year of study was during the post monsoon period. A maximum of 4.21% of organic carbon was noted in November and a minimum of 2.52% in May 1987. However in 1988 the peak record of organic content was 4.06% in December and the lowest 2.82% in May. In general the organic content of the soil was found to be low during late pre-monsoon and early post-monsoon (Fig. 2:36).

Available Phosphorus

The phosphate content of the soil was observed to be low during the monsoon season and high during the pre-monsoon period. The maximum values recorded were 3.19 µg at PO_4 - P/g and 3.24 µg at PO_4 - P/g in April during the first and second year of the study. The minimum values were 0.98 and 1.25 µg at PO_4 - P/g in November of the both the years (Fig. 2:30).

Available Nitrate

The fluctuation in the nitrate content of the soil was not very pronounced during the entire period of study (Fig. 2:22). During the first year,

the maximum value recorded was 0.96 µg at NO_3 - N/g (August) and the minimum 0.31 µg at NO_3 N/g (April). However in the following year a slight increase was noted in the maximum value. 1.06 µg at NO_3 - N/g was the peak value and 0.42 µg at NO_3 - N/g was the peak value and 0.42 µg at NO_3 N/g was the lowest value recorded in the second year.

Total Sulphide

Throughout the year total sulphide was detected in the sediment. However a well marked variation in the quantity was noticed between the season. Very high values were recorded during pre-monsoon. During the first year the maximum value recorded was 4244.7 µg at H_2S S/g in April and the minimum 311.5 µg at H_2S - S/g in November. The same trend was observed in the following year also (Fig. 2:37).

The peak value recorded in the second year was 4344.9 µg at H_2S S/g in April and the minimum values, 510.0 µg at H_2S S/g in November.

Correlation

In order to evaluate the nature of relationship between different hydrographical and sedimentological parameters and also to understand the relationship between hydrogen sulphide in the water and total sulphide in the sediment to other ecological parameters, the two years data (1987 to 1989) were ploted and analysed for estimating the correlation coefficient ('r') values. The results obtained at Station I, II, III and IV are presented in Table 2:24 to 2:27. In the ensuing account the 'r' values given within the brackets for the corresponding stations are first is surface water value and second is bottom

water value respectively.

In Station I (St. I) and Station II (St. II) hydrogen sulphide was not found in the surface and bottom water whereas hydrogen sulphide was present in surface water and bottom water of Station III (St. III) and Station IV (St. IV). In the case of sediment, total sulphide was present in all the stations either throughout the year or during some part of the year. In St. I and St. II total sulphide in the sediment was mainly observed during January to June only that too in very less quantity. Total sulphide in the sediment was high and found throughout the year in St. III and St. IV.

Total sulphide of the sediment was positively correlated to temperature of water (St I, r = 0.703, 0.563; St. II, r = 0.804, 0.478, St. III, r = 0.501, 0.797, St. IV, r = 0.570, 0.590), salinity (St. I, r = 0.468, 0.418; St. II r = 0.959, 0.936; St. III, r = 0.509, 0.542; St. IV, r = 0.401, 0.631) available phosphorus of sediment (St. I, r = 0.479, St. II, r = 0.432; St. III, r = 0.763, St. IV, r = 0.612), reactive phosphorus of water (St. III, r = 0.673, 0.786; St. IV, r = 0.830, 0.803).

Total sulphide of sediment showed negative correlation to Nitrate - Nitrogen of water (St. II r = -0.617, -0.509; St. III r = -0.641, -0.699; St. IV r = -0.697, -0.638), nitrite of water (St. II r = -0.539, -598; St. III r = -0.519, -0.430; St. IV r = -0.638, -0.573), reactive phosphorus of water (St. II r = -0.570, -0.534), available nitrate of sediment (St. III r = -0.439; St. IV r -0.529) dissolved oxygen of water (St. I r = -0.521, 0.672; St. II r = -0.919, -0.877; St. III r = -0.515, -0.642; St. IV r = -0.458, -0.861), pH of water (St. I r = -0.76, -0.491; St. II r = -0.618, -0.449; St. III r = -0.524, -0.780;

St. IV r = -0.556, -0.792), Eh of sediment (St. I r = -0.554; St. II 4 -0.671, St. III r = -0.645, St. IV r = -0.765).

H_2S of surface water was positively correlated to temperature of water (St. III r = 0.662, 0.756; St. IV r = 0.810, 0.714), salinity (St. III r = 0.650, 0.658; St. IV r = 0.910, 0.900), reactive phosphorus of water (St. III r = 0.847 0.863; St. IV r = 0.965, 0.961), H_2S of bottom water (St. III r = 0.814; St. IV r = 0.526) temperature of sediment (St. III r = .750; St. IV r = 0.804) available phosphorus of sediment (St. III r = 0.830, St. IV r = 0.875) total sulphide of the sediment (St. III r = 0.803, St. IV r = 0.768), H_2S of surface water was negatively correlated to dissolved oxygen (St. III r = -0.644, -0.736; St. IV r = -0.867, -0.868), pH of water (St. III r = -0.741, -0.0783; St. IV r = -0.847, -0.767) nitrate of water (St. III r = -0.429, -0.438; St. IV r = -0.562, -0.623) nitrite of water (St. III r = -0.437, -0.406; St. IV r = -0.840, -0.781) pH of sediment (St. III r = -0.823, St. IV r = -0.861) Eh of sediment (St. III r = -0.783, St. IV r = -0.823) organic carbon of sediment (St. III r = -0.712; St. IV r = -0.563), available nitrate of sediment (St. III r = -0.640; St. IV r = -0.876).

H_2S of bottom water was positively correlated to temperature of water (St. III r = -0.761, 0.776; St. IV r = 0.687, 0.682) salinity (St. III r = 0.811, 0.796; St. IV r = 0.642, 0.616), reactive phosphorus of water (St. III r = 0.833; St. IV r = 0.498, 0.466) H_2S of surface water (St. III r = 0.814; St. IV r = 0.526) temperature of sediment (St. III r = 0.751, St. IV r = 0.514) available phosphorus of sediment (St. III r = 0.832, St. IV r = 0.594) total sulphide of sediment (St. III r = 0.816; St. IV r = 821). H_2S of bottom water was negatively correlated. Dissolved oxygen (St. III r = -0.761, -0.806; St. IV

r = -0.555, -0.687) pH of water (St. III r -0.650, -0.729; St. IV r -0.475, -0.571), nitrate of water (St. III r = -0.417, -0.430; St. IV r = -0.561, -0.567) nitrite of water (St. III r = -0.510, -0.512; St. IV r = -0.588, -0.582) pH of sediment (St. III r = -0.838; St. IV r = -0.642), Eh of sediment (St. III r = -0.709, St. IV r = -0.805), organic carbon of sediment (St. III r = -0.675, St. IV r = -0.702) available nitrite of sediment (St. III r = -0.785, St. IV r = -0.617).

Temperature of surface water was positively correlated to temperature of bottom water (St. I r = 0.8070; St. II r = 0.468; St. III r = 0.714; St. IV r = 0.808), temperature of sediment (St. I r = 0.855; St. II r = 0.704; St. III r = 0.672; St. IV r = 0.824), salinity (St. I r = 0.804, 0.784; St. II r = 0.747, 0.765; St. III r = 0.641, 0.624; St. IV r = 0.839, 0.848), reactive phosphorus of water (St. III r = 0.662, 0.692; St. IV r = 0.834, 0.843) available phosphorus of sediment (St. III r = 0.618, St. IV r = 0.850), reactive phosphorus of water (St. III r = 0.662, 0.696; St. Iv r = 0.834, 0.843), total sulphide of sediment (St. I r = 0.703; St. II r = 0.864; St. III r = 0.501; St. IV r = 0.570), hydrogen sulphide of water (St. III r = 0.662, 0.761; St. IV r = 0.810, 0.687) and negative correlation was found with dissolved oxygen (St. I r = -0.828, -0.881; St. II r = -0.807, -0.697; St. III r = -0.550, -0.624; St. IV r = -0.901, -0.845), pH of water (St. I r = -0.764, -0.470; St. II r = -0.497, -0.432; St. III r = -0.454, -0.441; St. IV r = -0.766, -0.603), reactive nitrate of water (St. I r = -0.558, -0.577, St. II r = -0.533, -0.503), available nitrite of water (St. I r = -0.426, -0.418; St. II r = -0.478, -0.503), available phosphorus of water (St. I r = -0.671, -0.686; St. II r = -0.548, -0.556), pH of sediment (St. I r = -0.826; St. II r = -0.791; St. III r = -0.734; St. IV r = -0.782), Eh of

sediment (St. I r = -0.793; St. II r = -0.425; St. III r = -0.686; St. IV r = -0.694).

Temperature of bottom water was positively correlated to sediment temperature (St. I r = 0.850; St. II r = 0.541; St. III r = 0.674; St. IV r = 0.792), salinity (St. I r = 0.834, 0.817; St. II r = 0.547, 0.508; St. III r = 0.449, 0.440; St. IV = 0.714, 0.701), total sulphide of the sediment (St. I r = 0.563; St. II r 0.478; St. III r = 0.561; St. IV r = 0.570), hydrogen sulphide of the water (St. III r 0.756, 0.776; St. IV r = 0.702, 0.682), reactive phosphorus of water (St. III r = 0.671, 0.630; St. IV r = 0.702, 0.705), and negative correlation was found with dissolved oxygen (St. I r = -0.840, -0.858; St. II r = -0.574, -0.613; St. III r = -0.485, -0.603; St. IV r = -0.829, -0.757), pH of water (St. I r = -0.628, -0.446; St. II r = -0.694, -0.561; St. III r = -0.521, -0.510; St. IV r = -0.581, -0.448), nitrate of water (St. I r = -0.477, -0.496), pH of sediment (St. I r = -0.689, St. II r = -0.582, St. III r = -0.661, St. IV r = -0.718) Eh of sediment (St. I r = -0.737; St. II r = -0.531; St. III r = -0.613; St. IV r = -0.707) organic carbon of sediment (St. III r = -0.534; St. IV r = -0.620) available nitrate of sediment (St. III r = -0.456; St. IV r = -0.568).

Temperature of sediment was positively correlated to water temperature (St. I r = 0.855, 0.850; St. II r = 0.704, 0.541; St. III r = 0.672, 0.674; St. IV r = 0.824, 0.792), salinity (St. I r = 0.827, 0.830; St. II r = 0.733, 0.735; St. III r = 0.465, 0.458; St. IV r = 0.792, 0.792), total sulphide of sediment (St. I r = 0.583; St. II r = 0.669, St. III r = 0.670; St. IV r = 0.552), hydrogen sulphide of water (St. III r = 0.751; St. IV r = 0.514), reactive phosphorus of water (St. III r = 0.702, 0.698; St. IV r 0.762, 0.755), available phosphorus of sediment (St. III r = 0.618; St. IV r = 0.839) and negatively correlated

to dissolved oxygen (St. I r = -0.850, -0.855; St. II r = -0.620, -0.509; St. III r -0.571; St. IV r = -0.885, -0.858), pH of water St. I r = -0.568, -0.472; St. II r = -0.564, -0.443; St. III r = -0.644, -0.508; St. IV r = -0.709, -0.621), nitrate of water (St. I r = -0.424, -0.440; St. II r = -0.462, -0.439) reactive phosphorus of water (St. I r = -0.424, -0.440; St. II r = -0.462, -0.439) reactive phosphorus of water (St. I r -0.616, -0.624; St. II r = -0.483, -0.472), pH of sediment (St. I r = -0.813; St. II r = -0.536; St. III r = -0.683; St. IV r -0.807), Eh of sediment (St. I r = -0.857; St. II r = -0.482; St. III r -0.724; St. IV r = -0.654), nitrite of sediment (St. III r = -0.452; St. IV r = -0.773), organic carbon (St. III r = -0.738; St. IV r = -0.544).

Salinity of surface water was positively correlated to temperature of water (St. I r = 0.804, 0.834; St. II r = 0.797, 0.542; St. III r = 0.641, 0.449; St. IV r = 0.839, 0.703), temperature of sediment (St. I r = 0.827; St. II r = 0.733; St. III r = 0.465; St. IV r = 0.792), bottom water salinity (St. I r = 0.987; St. II r = 0.986; St. III r = 0.997; St. IV r = 0.991), total sulphide of sediment (St. I r = 0.468; St. II r = 0.959; St. III r = 0.509; St. IV r = 0.401), hydrogen sulphide of water (St. III r = 0.650, 0.811; St. IV r = 0.910, 0.642) and negatively correlated to dissolved oxygen (St. I r = -0.945, -0.945, -0.903; St. II r = -0.917, -0.986; St. III r = -0.869, -0.720; St. IV r = -0.918, -0.959) pH of water (St. I r = -0.549, -0.448; St. II r = -0.472, -0.455; St. III r = -0.691, -0.713; St. IV r = -0.882, -0.781), nitrate of water (St. I r = -0.652, -0.656; St. II r = -0.670, -0.642; St. III r = -0.429, St. IV r = -0.644, -0.743) nitrate of water (St. I r = -0.531, -0.537; St. II r = -0.635, -0.652; St. III r = -0.471, -0.466), pH of sediment (St. I r = -0.805; St. II r = -0.898; St. III r = -0.845; St. IV r = -0.751), Eh of sediment (St. I r = -0.901; St. II r = -0.480; St. III r = -0.809; St. IV r = -0.856).

Salinity of bottom water was positively correlated to temperature of water (St. I r = 0.784, 0.817; St II r = 0.765, 0.508; St. III r = 0.624, 0.440; St. IV r = 0.848, 0.701) temperature of sediment (St. I r = 0.830; St. II r = 0.735; St. III r 0.458; St. IV r = 0.792), surface water salinity (St. I r = 0.987; St. II r = 0.986; St. III r = 0.997; St. IV r = 0.991), total sulphide of sediment (St. I r = 0.418; St. I r = 0.478; St. III r = 0.542; St. Iv r = 0.631), hydrogen sulphide of water (St. III r = 0.658, 0.796; St. IV r = 0.900, 0.616), available phosphorus of sediment (St III r = 0.858; St. IV r = 0.904) and negatively correlated to dissolved oxygen (St. I r = -0.959, -0.882; St. II r = -0.922, -0.850; St. III r = -0.878, -0.730; St. IV r = -0.917, -0.947), pH of water (St. I r = -0.520, -0.495; St. II r = -0.436, -0.413; St. III r = -0.727, -0.736; St. IV r = -0.727, -0.757), nitrate of water (St. I r -0.677, -0.677; St. II r = -0.643, -0.645; St. IV r = -0.611, -0.711) nitrate of water (St. I r = -0.566, -0.564; St. II r = -0.650, -0.671; St. III r = -0.437, -0.427; St. IV r = -0.874, -0.799) pH of sediment (St. I r = -0.793; St. II r = -0.866; St. III r = -0.836; St. IV r = -0.748), Eh of sediment (St. I r = -0.893; St. II r = -0.519; St. III r = -0.696; St. IV r = -0.603), organic carbon of sediment (St. III r = -0.685; St. IV r = -0.518). Salinity showed positive correlation to reactive phospherous of water in (St. III r = 0.827, 0.863 and St. IV r = 0.965, 0.905) and negative correlation in St. I (r = -0.760, -0.741); St. II (r = -0.607, -0.560).

Dissolved oxygen of surface water was positively correlated to pH of water (St. I r = 0.642, 0.532; St. II r = 0.476, 0.470; St. III r = 0.648, 0.667; St. IV r = 0.843, 0.724), nitrate of water (St. I r = 0.574, 0.574; St. II r = 0.595, 0.566; St. III r = 0.446; St. IV r = 0.363, 0.512) nitrate of water (St. I r = 0.435, 0.424; St. II r = 0.483, 0.509; St. III r = 0.493, 0.499; St. IV r = 0.718, 0.662), bottom dissolved oxygen (St. I r = 0.937; St. II r = 0.947;

St. III r = 0.829; St. IV r = 0.957), pH of sediment (St. I r = 0.854; St. II r = 0.924; St. III r = 0.746; St. IV r = 0.815), Eh of sediment (St. I r = 0.877; St. II r = 0.406; St. III r = 0.716; St. IV r = 0.746). Dissolved oxygen showed negative correlation to temperature of water (St. I r = -0.828, -0.840; St. Ii r = -0.807, -0.468; St. III r = -0.550, St. IV r = -0.901, -0.581), temperature of sediment (St. I r = -0.850; St. II r = -620; St. IV r = -0.815), salinity (St. I r = -0.945, -0.959; St. II r = -0.917, -0.912; St. III r = -0.867, -0.878; St. IV r = -0.918, -0.917), total sulphide of sediment (St. I r = -0.521; St. Ii r = -0.919; St. III r = -0.815; St. IV r = -0.858), hydrogen sulphide of water (St. III r = -0.664, -0.761; St. IV r = -0.867, -0.555), available phosphorus sediment (St. III r = -0.568; St. IV r = -0.969).

Dissolved oxygen of bottom water hear positively correlated to surface water dissolved oxygen (St. I r = 0.723; St. II r = 0.947; St. III r = 0.829; St. IV r = 0.957), pH of water St. I r = 0.723, 0.458; St. II r = 0.665; St. III r = 0.753, 0.682; St. IV r = 0.882, 0.767), nitrate of water (St. I r = 0.447, 0.445; St. II r = 0.587, 0.566; St. IV r = 0.564, 0.767), nitrate of water (St. II r = 0.456, 0.476; St. IV r = 0.806, 0.749) pH of sediment (St. I r = 0.858; St. II r = 0.879; St. III r = 0.778; St. IV r = 0.754), Eh of sediment (St. I r = 0.844; St. II r = 0.698; St. III r = 0.868; St. IV r = 0.803) and negative correlation was observed with hydrogen sulphide of water (St. III r = -0.763, -0.806; St. IV r = -0.868), water temperature (St. I r = -0.881, -0.858; St. II r = -0.699, -0.613; St. III r = -0.441, -0.510; St. IV r = -0.845, -0.757), salinity (St. I r = -0.903, -0.882; St. II r = -856, -0.850; St. III r = -0.720, -0.720, -0.730; St. IV r = -0.959, -0.947), available phosphorus of sediment (St. I r = -0.442; St. III r = -0.869; St. IV r = -0.939), total sulphide

of sediment (St. I r = -0.677; St. II r = -0.877; St. III r -0.842; St. IV r = -0.861).

pH of surface water was positively correlated to pH of bottom water (St. I r = 0.664; St. II r = 0.663; St. III r = 0.756; St. IV r = 0.882), dissolved oxygen (St. I r = 0.642, 0.723; St. II r = 0.476, 0.665; St. III r = 0.648, 0.753; St. IV r = -0.843, -0.882), pH of sediment (St. I r = 0.702; St. II r = 0.629; St. III r = 0.789; St. IV r = 0.709), Eh of sediment (St. I r = 0.644; St. II r = 0.472; St. III r = 0.634; St. IV r = 0.671) and negatively correlated to hydrogen sulphide of water (St. III r = -0.741, -0.650; St. IV r = -0.847, -0.475), salinity (St. I r = -0.549, -0.520; St. II r = -0.472, -0.436; St. III r = -0.691, -0.727; St. IV r = -0.882, -0.877), available phosphorus of sediment (St. I r = -0.481; St. II r = -0.557; St. III r = -0.853; St. IV r = -0.880), total sulphide of sediment (St. I r = -0.706; St. II r = -0.618; St. III r = -0.524; St. IV r = -0.556).

pH of bottom water was positively correlated to surface water pH (St. I r = 0.664; St. II r = 0.663; St. III r = 0.756; St. IV r = 0.820), Eh of the sediment (St. I r = 0.409; St. III r = 0.536; St. III r = 0.629; St. Iv r = 0.702), pH of sediment (St. I r = 0.435; St. II r = 0.473; St. III r = 0.763; St. IV r = 0.562), available nitrate of sediment (St. II r = 0.478; St. III r = 0.649; St. IV r = 0.838), dissolved oxygen (St. I r = 0.532, 0.458; St. II r = 0.470, 0.477; St. III r = 0.667, 0.682; St. IV r = 0.724, 0.767) and negatively correlated to temperature of sediment (St. I r = -0.472; St. II r = -0.443; St. III r = -0.508; St. IV r = -0.621), salinity (St. I r = -0.448, -495; St. II r = -0.445, -0.561; St. III r = -0.719, -0.736; St. IV r = -0.744), total sulphide of sediment (St. I r = -0.491; St. II r = -0.499; St. III r = -0.780; St. IV r

= -0.792), hydrogen sulphide of water (St. III r = -0.767, -0.571; St. IV r = -0.510, -0.729).

Nitrate of surface water was positively correlated to dissolved oxygen (St. I r = 0.574, 0.447; St. II r = 0.595, 0.587; St. III r = 0.467, St. IV r = -- 0.564), pH of water (St. I r = 0.401, --; St. II r = 0.803, 0.728; St. III r = 0.836, 0.661; St. IV r = 0.816, 0.785), bottom water nitrate (St. I r = 0.986; St. II r = 0.781; St. III r 0.872; St. IV r = 0.785) pH of sediment (St. I r = 0.467; St. II r = 0.567), reactive phosphorus of water (St. I r = 0.809, 0.761; St. II r = 0.802, 0.800), Eh of sediment (St. I r = 0.639; St. II r = 0.488) and negatively correlated to temperature of water (St. I r = -0.558, -0.477; St. II r = -0.533), temperature of sediment (St. I r = -0.424; St. II r = -0.462), salinity (St. I r = -0.652, -677; St. II r = -0.670, -0.643; St. III r = -0.429, -0.392; St. Iv r = -0.644, -0.611), hydrogen sulphide of water (St. III r = -0.429, -0.417; St. IV r = -0.552, -0.522, -0.561), total sulphide of sediment (St. II r = -0.617; St. III r = -0.641; St. IV r = -0.697).

Nitrate of bottom water was positively correlated to dissolved oxygen (St. I r = 0.574, 0.445; St. II r = 0.566, 0.566; St. Iv r = 0.512, 0.674), surface water nitrate (St. I r = 0.986; St. Ii r = 0.998; St. III r = 0.661; St. IV r = 0.900), nitrate of water (St. I r = 0.916, 0.912; St. II r = 0.781, 0.701; St. III r = 0.410, 0.503; St. IV r = 0.791, 0.766), pH of sediment (St. I r = 0.491; St. II r = 0.546), Eh of sediment (St. I r = 0.632; St. II r = 0.471) and negatively correlated to temperature of sediment (St. I r = -0.440; St. II r = -0.513; St. IV r = -0.471), temperature of water (St. I r = -0.577, -0.496; St. II r = --; -0.439), salinity (St. I r = -0.656, -0.677; St. II r = -0.642, -0.615; St. IV r = -0.743, -0.716), hydrogen sulphide of water (St. III

r -0.438, -0.430; St. IV r = -0.623, -0.567), total sulphide of sediment (St. II r = -590; St. III r = -0.649; St. IV r = -0.608).

Nitrite of surface water was positively correlated to dissolved oxygen (St. I r = 0.435, --; St. II r = 0.480, 0.456; St. III r = 0.493, --; St. IV r = 0.718, 0.806), nitrate of water (St. I r = 0.915, 0.994; St. II r = 0.803, 0.781; St. III r = 0.836, 0.496; St. IV r = 0.816, 0.791), reactive phosphorus of water (St. I r = 0.750, 0.709; St. II r = 0.933, 0.982), nitrite of bottom water (St. I r = 0.994; St. II r = 0.982; St. III r = 0.988; St. IV r = 0.962), Eh of sediment (St. I r = 0.609; St. II r = 0.445), available nitrate of sediment (St. II r = 0.511, St. III r = 0.541, St. IV r = 0.763) and negative correlation was shown with temperature of water (St. I r = -0.426, --; St. II r = -0.478; St. Iv r = -0.690, -0.570), Eh of sediment (St. III r = -0.597; St. IV r = -0.670), salinity (St. I r = -0.531, -0.566; St. II r = -0.635, -0.650; St. III r = -0.471, -0.434; St. IV r = -0.883, -0.874), available phosphorus of sediment (St II r = -0.411; St. IV r = -0.708), hydrogen sulphide of water (St. III r = -0.437, -0.510; St. IV r = -0.840, -0.588), total sulphide of sediment (St. II r = -0.539, St. III r = -0.519, St. Iv r = -0.638).

Nitrite of bottom water was positively correlated to dissolved oxygen (St. I r = 0.424, --; St. II r = 0.509, 0.476; St. III r = 0.499, --; St. IV r = 0.662, 0.749), nitrate of water (St. I r = 0.915, 0.912; St. II r = 0.728, 0.701; St. III r = 0.872, 0.503; St. IV r = 0.785, 0.766), nitrite of surface water (St. I r = 0.994; St. II r = 0.982; St. III r = 0.988; St. Iv r = 0.962), reactive phosphorus of water (St. I r = 0.722, 0.679; St. II r = 0.901, 0.865), Eh of sediment (St. I r = 0.612; St. II r = 0.453) and negatively correlated to temperature of water (St. I r = -0.418, --; St. II r = -0.642, -0.615; St. III

r = -0.466, -0.422; St. IV r = -0.814, -0.729), temperature of sediment (St. II r = -0.461; St. IV r = -0.543), total sulphide of sediment (St. II r = -0.548; St. III r = -0.430; St. IV r = -0.573), available phosphorus of sediment (St. II r = -0.431; St. IV r = -0.674), hydrogen sulphide of water (St. III r = -0.437, -0.510; St. IV r = -0.840, -0.588).

Reactive Phosphorus of surface water was positively correlated to hydrogen sulphide of water (St. III r = 0.841, 0.671; St. IV r = 0.965, 0.498), total sulphide of sediment (St. III r = 0.673; St. IV r = 0.830). In stations where hydrogen sulphide was negligible or absent the reactive phosphorus of surface water showed positive correlation with dissolved oxygen (St. I r = 0.706, 0.674; St. II r = 0.574, 0.473), pH of water (St. I r = 0.476, St. II r = 0.442, --;), nitrate of water (St. I r = 0.809, 0.810, St. II r = 0.802, 0.782), Eh of sediment (St. I r = 0.690; St. II r = 0.593) and stations where hydrogen sulphide was high phosphorus of surface water exhibited negative correlation with dissolved oxygen (St. III r = -0.794, -0.853; St. IV r = -0.869, -0.858), pH of water (St. III r = -0.854, -0.797; St. IV r = -0.895, -0.779), nitrate of water (St. IV r = -0.510, -0.651), Eh of sediment (St. III r = -0.840; St. IV r = -0.813).

Reactive Phosphorus of bottom water was positively correlated with hydrogen sulphide of water (St. III r = 0.814, 0.841; St. IV r = 0.526, 0.466), total sulphide of sediment (St. III r = 0.786; St. IV r = 0.673), temperature of water (St. III r = 0.696, 0.630; St. IV r = 0.843, 0.705), temperature of sediment (St. III r 0.693; St. IV r = 0.755), salinity (St. III r = 0.859, 0.863; St. IV r = 0.910, 0.905). In stations where presence of hydrogen sulphide was very less or absent the type of correlation was also different. Available

phosphorus of bottom water showed negative correlation to temperature of water in stations I and II, where hydrogen sulphide in the water was absent. Similarly negative correlation to temperature of sediment (St. I r = -0.624; St. II r = -0.472), salinity (St. I r = -0.725, -0.793; St. II r = -0.573, -0.560).

pH of sediment was positively correlated to dissolved oxygen (St. I r 0.854, 0.858; St. II r = 0.924, 0.824; St. III r = 0.746, 0.778; St. IV r = 0.815, 0.754), pH of water (St. I r= 0.702, 0.435; St. II r = 0.629, 0.473; St. III r = 0.789, 0.763; St. IV r = 0.709, 0.562), reactive phosphorus of water (St. I r = 0.664, 0.665; St. II r = 0.458, 0.416), organic carbon of sediment (St. III r 0.823; St. IV r = 0.580), Eh of sediment (St. I r = 0.820, St. II r = 0.401; St. III r = 0.753; St. IV r = 0.708) and negatively correlated to hydrogen sulphide of water (St. III r = -0.823, -0.838; St. IV r = -0.861, -0.642), available phosphorus of sediment (St. III r = -0.900; St. IV r = -0.762) temperature of sediment (St. I r = -0.813; St. II r = -0.536; St. III r = -0.683; St. IV r = -0.807), total sulphide of sediment (St. I r = -0.561; St. II r = -0.677; St. III r = -0.678; St. IV r = -0.696).

Organic carbon of sediment was positively correlated to Eh of sediment (St. I r = 0.464; St. II r = 0.473; St. III r = 0.675; St. IV r = 0.721), pH of water (St. III r = 0.882, 0.682; St. IV r = 0.636, 0.501) and negatively correlated to pH of water (St. I r = -0.502, -0.434; St. II r = -0.480, -0.446), total sulphide of sediment (St. I r = -0.554; St. II r = -0.671; St. III r = -0.645; St. IV r = -0.765), hydrogen sulphide of water (St. III r = -0.712, -0.675; St. IV r = -0.563, -0.702), reactive phosphorus of water (St. III r = -0.860, -0.871; St. IV r = -0.621, -0.656).

Available Phosphorus of sediment was positively correlated to temperature of sediment (St. III r = 0.618; St. IV r = 0.839), hydrogen sulphide of water (St. III r = 0.959, 0.947; St. IV r = 0.895, 0.886), temperature of water (St. III r = 0.618, 0.645; St. IV r = 0.850, 0.762), total sulphide of sediment (St. I r 0.479; St. II r = 0.432; St. III r = 0.763; St. IV r = 0.612) and negatively correlated to pH of water (St. I r = -0.481, -0.404; St. II r -0.557, -0.418; St. III r = -0.853, -0.826; St. IV r = -0.880, -0.763), Eh of sediment (St. II r = -0.485; St. III r = -0.488; St. IV r = -0.425), pH of sediment (St. III r = -0.900; St. IV r = -0.762), available nitrate of sediment (St. III r = -0.800; St. IV r = -0.894).

Available nitrate sediment was positive correlated to organic carbon of sediment (St. III r = 0.606, St. IV r = 0.474), Eh of sediment (St. III r = 0.544; St. IV r = 0.687), pH of sediment (St. III r = 0.776; St. IV r = 0.679), nitrate of water (St. III r = 0.508, 0.536; St. IV r = 0.590, 0.732), nitrate of water (ST. II r = 0.511, 0.495; St. III r = 0.541, 0.546; St. IV r = 0.763, 0.694) and negative correlation to temperature of water (St. III r = -0.532, -0.450; St. IV r = -0.743, -0.568), reactive phosphorus of water (St. III r -0.764, -0.807; St. IV r = -0.895, -0.879), hydrogen sulphide of water (St. III r = -0.640, -0.785; St. IV r = -0.876, -0.617), total sulphide of sediment (St. III r = -0.439, St. IV r = -0.529), available phosphorus of sediment (St. III r = -0.735; St. IV r = -0.894).

Distribution of Benthic macrofauna

Benthic macrofauna distribution in the four selected stations were observed during the study period February 1987 to January 1989. The results

of the observation, number per 0.1 m^2 is given in Table 2:29 to 2:32.

The major groups of macro benthic animals collected during the period of investigation includes Polychaetes, Tanaids, Amphipods, Isopods, Bivalves, Gastropods and Nematods. Among the different groups of macro benthic animals polychaetes was the most abundant group in all the stations. In Station I and II the number of macro benthic groups were much higher than that of Station III and Station IV. In Station I and II seven groups were found whereas in Station III only two groups and in Station IV only one group was observed during the study period.

Station I

Polychaetes, Tanaids, Amphipods, Gastropods and Nematods were observed in Station I.

Polychaetes were the most dominant group. The maximum number of Polychaetes 114 nos/0.1 m^2 was observed during March 1987 (First year) and 186 nos/0.1 m^2 in April 88 (Second year). Similarly the minimum number 34 nos/0.1 m^2 and 44 nos/0.1 m^2 was recorded in August of both first and second year (Fig. 2:38).

Tanaids was the second prominant group in this station (Fig. 2:39). Maximum number 42 nos/0.1 m^2 was recorded in the month of December 87 (First year) and 62 nos/0.1 m^2 in January 89 (Second year) minimum number 20 nos/0.1 m^2 was observed during May 87 (First year) and 12 nos/0.1 m^2 in the same month during the second year's observation. In other words maximum number was found during post-monsoon period.

Amphipods were found throughout the period of study (Fig. 2:40). Highest number 43 nos/0.1 m^2 was observed in the month of December 87 (First year) and 40 nos/0.1 m^2 in November 88 (Second year). Similarly the lowest number 5 nos/0.1 m^2 and 4 nos/0.1 m^2 were recorded in the month of April during the first year and second year respectively. Amphipods also were found in less numbers during the pre-monsoon period and more during post-monsoon period.

Isopods were not found throughout the period of study (Fig. 2:41). During the first year observation isopods were completely absent in the collection during April, August and October. In the second year it was not present in the samples during March, May and August. Maximum availability was recorded (10 nos/0.1 m^2) in July and December 87 (First year). During second years observation highest availability 12 nos/0.1 m^2 was observed in December 88.

Bivalves were found in the collections during most of the months except September in the first year and August to October in the second year (Fig. 2:42). Maximum number 12 nos/0.1 m^2 was observed in January 88 (First year) and 14 nos/0.1 m^2 in January 89 (Second year).

Gastropods were absent in the collections during most of the months (Fig. 2:43). 6 nos/0.1 m^2 was the maximum which was recorded in the month of January 88 (First year). In the second year 7 nos/0.1 m^2 (highest) was observed during December 88. Gastropods were present in the collections only during first year and February, December, January during second year.

Nematods were also found in the benthic collections during February

to July and December, January (First year) and in the second year it was observed during February to May and October, December. Maximum number 14 nos/0.1 m^2 was recorded in March 87 (First year) and 11 nos/0.1 m^2 in April 88 (Second year) (Fig. 2:44).

Station II

The distribution of benthic macro fauna was almost same as observed in Station I. In Station II also polychaetes was the prominant group. Other groups like Tanaids, Amphipods, Isopods, Bivalves, Gastropods and Nematopods were also present in this station.

Polychaetes maximum number 114 nos/0.1 m^2 and 126 nos/0.1 m^2 was observed during May in the first and second year respectively. Minimum number 24 nos/0.1 m^2 was recorded during September, October (Second year) and 19 nos/0.1 m^2 was observed in September in the first year (Fig. 2:38).

Tanaids were also found throughout the period of observation. The numbers (6 nos/0.1 m^2) present in May 87 (First year) was the lowest from May 87 onwards the number started increasing and the highest 45 nos/0.1 m^2 was recorded in the month of October 87 (First year). The number of Tanaids slowly decreased in the collection from November 87 onwards (Fig. 2:39). In the second year the lowest 10 nos/0.1 m^2 was recorded during March, April and May 88 and the from June onwards the number slowly increased and the highest 40 nos/0.1 m^2 was observed in October.

Amphipods were found in the collection throughout the period of observation. Maximum number 21 nos/0.1 m^2 was recorded in the month

of November 87 (First year) and 29 nos/0.1 m^2 in October 88 (Second year). The minimum number 10 nos/0.1 m^2 was observed during March 87, June 87 (First year) and 9 nos/0.1 m^2 was found in April 88 (Second year) (Fig. 2:40).

Isopods were observed in all the collection in the first year and in the second year it was absent in February 88 and November 88 (Fig. 2:41). Maximum number 8 nos/0.1 m^2 was observed in July 87 (First year) and 12 nos/0.1 m^2 in the same month (Second year).

Bivalves were present in the collection throughout the year except June to September 87 in the first year and June to August 88 in the second year (Fig. 2:42). Peak occurance 9 nos/0.1 m^2 was recorded in the month of March 87 (First year) and 3 nos/0.1 m^2 in February and December 88 (Second year).

Gastropods were found in the collections only during February, March, December, January in the first year's observation and February, March, November, December, January in the second year. Maximum occurance 8 nos/0.1 m^2 during first year was in January and in the second year the maximum 15 nos/0.1 m^2 was recorded in December (Fig. 2:43).

Nematods were mainly observed during March, April, May, June months in both year's collection (Fig. 2:44). It was also found in October, December in the first year and in January in the second year. Maximum occurance 8 nos/0.1 m^2 was found in March (First year) and 11 nos/0.1 m^2 in May second year.

Station III

In this station only two groups were present, Polychaetes and Tanaids, Polychaetes were found in more numbers than Tanaids.

Polychaetes were found throughout the period of observation (Fig. 2:38). The number per unit area was considerably less than that of Station I and Station II. Statistical analysis showed that there was significant difference in the occurrance of polychaetes in this station, compared to station I and II (Table 2:33). Peak occurance 15 nos/0.1 m^2 was recorded in the month of February '87 (First year) and 19 nos/0.1 m^2 in December 88 (Second year). The minimum number 3 nos/0.1 m^2 was recorded in August during first year's observation and 3 nos/0.1 m^2 in October 88 in second year.

Tanaids were present in the first year's collection only during December, January. In the second year it was found only in December 88 (Fig. 2:39).

Station IV

In this station only a single group, Polychaetes was observed throughout the period of observation. During April in the first year and October in the second year benthic macro fauna was totally absent.

Polychaetes ranged from 0-13 nos/0.1 m^2 in the first year and in the second year it was from 0-15 nos/0.1 m^2. Peak occurance 13 nos/0.1 m^2 was found during December 87 (First year) and 12 nos/0.1 m^2 in January 89 (Second year) (Fig. 2:38).

The number of polychaetes observed in this station was significantly lower than what was observed in the other stations (Table 2:33).

Distribution of Penaeid Prawn Post Larvae/Seed

Two years data on penaeid prawn seed distribution is given in Table 2:34.

Penaeus indicus, Metapenaeus dobsoni, Metapenaeus monocerous were the important species present in the Kayamkulam estuary. P. indicus was the dominant species followed by M. dobsoni and M. monocerous in Station I and II whereas in station III and IV M. dobsoni was the major species. Among the four stations the availability of prawn seeds was more in station I followed by station II whereas in station III and station IV the degree of abundance was considerably low. In station III and station IV, where hydrogen sulphide in the water and total sulphide in sediment was comparitively higher, the abundance of prawn larvae was very less. In station III and IV P. indicus was almost absent throughout the year. M. dobsoni and M. monocerous were present only during certain months of the years.

Penaeus indicus

Station I

P. indicus was found more in this station than in other stations. There was significant difference in the abundance of prawn seed between stations (Table 2:35). Peak occurance of P. indicus was in March during both the years. The maximum number/haul was 40 nos/haul in March 1987 (First year) and 51 nos/haul in March 1988 (Second year).

Station II

In station II maximum abundance 20 nos/haul was noticed in April 1987

(First year). In the second year the peak was recorded in February 1988 (34 nos/haul). In both the years from April onwards the number/haul slowly reduced.

Station III

P. indicus was present during July, October, November, and December in both first and second years observations. Apart from these P. indicus was not present in the collection.

Station IV

In station IV during the first year's observation P. indicus was not found throughout the year. In the second year it was present only during August and November.

Statistical analysis (ANOVA) showed that there was no significant difference in the occurance of P. indicus seeds between station I and II where hydrogen sulphide was not present. On the other hand significant difference in the occurance of P. indicus seeds between station I, II and station III, IV, where hydrogen sulphide was present. On the other hand significant difference in the occurance was noticed between stations I, II and station III, IV where hydrogen sulphide was present.

Metapenaeus dobsoni

M. dobsoni was the second prominant species after P. indicus. It was present throughout the year in station I and II.

Station I

Maximum number 41 nos/haul was found during November 87 (First year) and 34 nos/haul during February 1988 (Second year).

Station II

First year's peak occurance was in March 87, 14 nos/haul. In the second year highest collection 15 nos/haul was recorded during March 88.

Station III

In this station occurance of M. dobsoni in the collection was from March to December 87 in the first year and from March 88 to August 88 and October 88 to January 89, in the second year. M. dobsoni was observed more than the other species.

Station IV

M. dobsoni the dominant species in this station was observed in the collection during June 87 to January 88 (First year) and from June 88 to December 88 in the second year. During rest of the months M. dobsoni was not present in the collection. Maximum number 5 nos/haul was recorded in the month of December 87 (First year) and 6 nos/haul in September 88 (Second year).

There was significant difference in the occurance of M. dobsoni between stations (Table 2:36).

Metapenaeus monoceros

Station I

Maximum number 7 nos/haul was recorded during February 87 and June 87 (First year) and 12 nos/haul in the month of February 88 (Second year). In the first year M. monoceros was absent in the August collection and in the second year it was not observed in the September collection.

Station II

In this station also the number of M. monoceros was very less compared to P. indicus and M. dobsoni. Peak period of occurance was in April (4 nos/haul) in the first year and 5 nos/haul in March (Second year).

Station III

M. monoceros was observed from March 87 to January 88 in the first year and during rest of the months it was absent in the collection. In the second year M. monoceros was found in the collection during June, July and from October 88 to January 89.

Station IV

In the first year M. monoceros was found in the collection during June, July and from October to December whereas in the second year it was found in June and from August to December.

There was significant difference in the occurance of M. monoceros species between stations (Table 2:37).

Grain Size

The details of the texture of the sediments in the four stations are given in table 2:38.

Soil samples for grain size analyses were collected only during the second year of investigation from February 1988 to January 1989. The results are given season wise ie. Pre-monsoon (February to May), Monsoon (June to September) and Post-monsoon (October to January). The composition of the sediment of the estuary was found to vary from station to station.

Station I

The soil was sandy during all the seasons percentage composition of sand, silt and clay varied slightly with season. Sand percentage was less during post-monsoon period (78.3%) and high during monsoon (90.56%). Similarly silt and clay percentage was high during post-monsoon (13% and 8.7%) and low in monsoon 5.44% and 4.00%.

Station II

The soil composition of station II was more as less similar to that of station I. The type of soil was sandy. Percentage of sand varied from 71.6% to 87.0%. Highest sand percentage was found during monsoon period (87.0%) and lowest in post-monsoon (71.0%). High silt and clay percentage were recorded during post-monsoon.

Station III

Soil type was different from that of station I and II. The soil was

TABLE - 2:1

Monthly mean values of surface water temperature (°C) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	29.5 (0.05)	29.5 (0.51)	29.0 (0.25)	29.5 (0.31)	29.5 (0.37)	30.0 (0.23)	29.0 (0.30)	29.75 (0.51)
Mar	30.0 (0.56)	30.0 (0.47)	30.0 (0.20)	30.5 (0.33)	30.5 (0.41)	30.5 (0.35)	30.0 (0.27)	30.0 (0.52)
Apr	30.5 (0.37)	30.0 (0.34)	30.5 (0.27)	30.0 (0.41)	31.0 (0.34)	30.0 (0.22)	29.6 (0.24)	30.0 (0.23)
May	30.5 (0.42)	31.5 (0.43)	31.0 (0.18)	30.5 (0.20)	30.5 (0.36)	30.0 (0.28)	31.0 (0.26)	30.5 (0.32)
Jun	29.5 (0.35)	29.0 (0.37)	29.5 (0.24)	29.5 (0.34)	29.5 (0.29)	29.5 (0.31)	28.75 (0.31)	29.5 (0.34)
July	28.25 (0.37)	28.5 (0.26)	28.5 (0.31)	29.0 (0.26)	28.75 (0.36)	28.5 (0.22)	28.50 (0.37)	29.5 (0.29)
Aug	28.0 (0.29)	29.0 (0.14)	28.25 (0.21)	28.75 (0.19)	28.5 (0.21)	29.5 (0.24)	28.5 (0.38)	29.0 (0.31)
Sep	28.25 (0.36)	28.5 (0.30)	29.0 (0.17)	29.0 (0.23)	28.0 (0.24)	29.0 (0.27)	28.5 (0.32)	29.0 (0.33)
Oct	28.5 (0.20)	29.0 (0.32)	29.5 (0.26)	28.5 (0.24)	29.0 (0.30)	29.5 (0.25)	29.5 (0.29)	29.5 (0.37)
Nov	29.0 (0.41)	29.0 (0.51)	28.5 (0.17)	28.5 (0.26)	29.0 (0.31)	29.0 (0.30)	29.0 (0.22)	29.0 (0.29)
Dec	28.0 (0.32)	28.25 (0.06)	28.5 (0.20)	28.5 (0.31)	28.5 (0.27)	28.5 (0.33)	29.0 (0.27)	28.5 (0.26)
Jan	29.25 (0.24)	29.5 (0.31)	28.5 (0.37)	29.5 (0.32)	29.5 (0.17)	30.0 (0.41)	28.0 (0.30)	29.5 (0.23)

TABLE - 2:2

Monthly mean values of bottom water temperature (°C) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	29.0 (0.26)	29.0 (0.15)	28.0 (0.25)	29.0 (0.20)	29.25 (0.10)	29.0 (0.15)	28.25 (0.30)	29.20 (0.27)
Mar	29.5 (0.10)	29.5 (0.10)	29.0 (0.33)	29.5 (0.12)	29.00 (0.20)	29.5 (0.20)	29.0 (0.15)	29.0 (0.35)
Apr	29.0 (0.10)	29.5 (0.13)	29.5 (0.42)	29.0 (0.35)	29.5 (0.27)	29.00 (0.18)	29.00 (0.18)	29.00 (0.25)
May	29.5 (0.24)	29.5 (0.05)	29.5 (0.50)	29.5 (0.30)	29.5 (0.30)	29.75 (0.34)	29.75 (0.20)	30.0 (0.51)
Jun	29.0 (0.26)	28.25 (0.12)	29.0 (0.15)	28.75 (0.33)	29.0 (0.35)	28.5 (0.45)	28.5 (0.35)	29.0 (0.35)
July	28.0 (0.26)	28.0 (0.25)	28.0 (0.28)	28.5 (0.30)	28.5 (0.25)	28.25 (0.31)	28.0 (0.32)	28.5 (0.42)
Aug	27.5 (0.05)	28.5 (0.20)	28.0 (0.20)	28.72 (0.15)	27.5 (0.23)	29.0 (0.23)	28.0 (0.28)	28.5 (0.30)
Sep	27.75 (0.35)	28.0 (0.17)	28.25 (0.15)	28.5 (0.26)	27.5 (0.20)	28.5 (0.25)	28.2 (0.15)	28.5 (0.15)
Oct	28.25 (0.25)	28.5 (0.05)	28.75 (0.20)	28.25 (0.35)	28.5 (0.17)	29.0 (0.15)	29.0 (0.10)	28.70 (0.20)
Nov	28.50 (0.26)	28.5 (0.25)	27.5 (0.15)	27.75 (0.23)	28.5 (0.30)	28.5 (0.15)	28.5 (0.10)	28.5 (0.27)
Dec	27.30 (0.05)	27.5 (0.15)	27.5 (0.17)	27.0 (0.20)	27.5 (0.15)	27.75 (0.05)	28.5 (0.18)	28.0 (0.18)
Jan	29.0 (0.35)	29.0 (0.17)	27.0 (0.25)	29.0 (0.15)	29.0 (0.05)	29.5 (0.20)	27.5 (0.27)	29.0 (0.15)

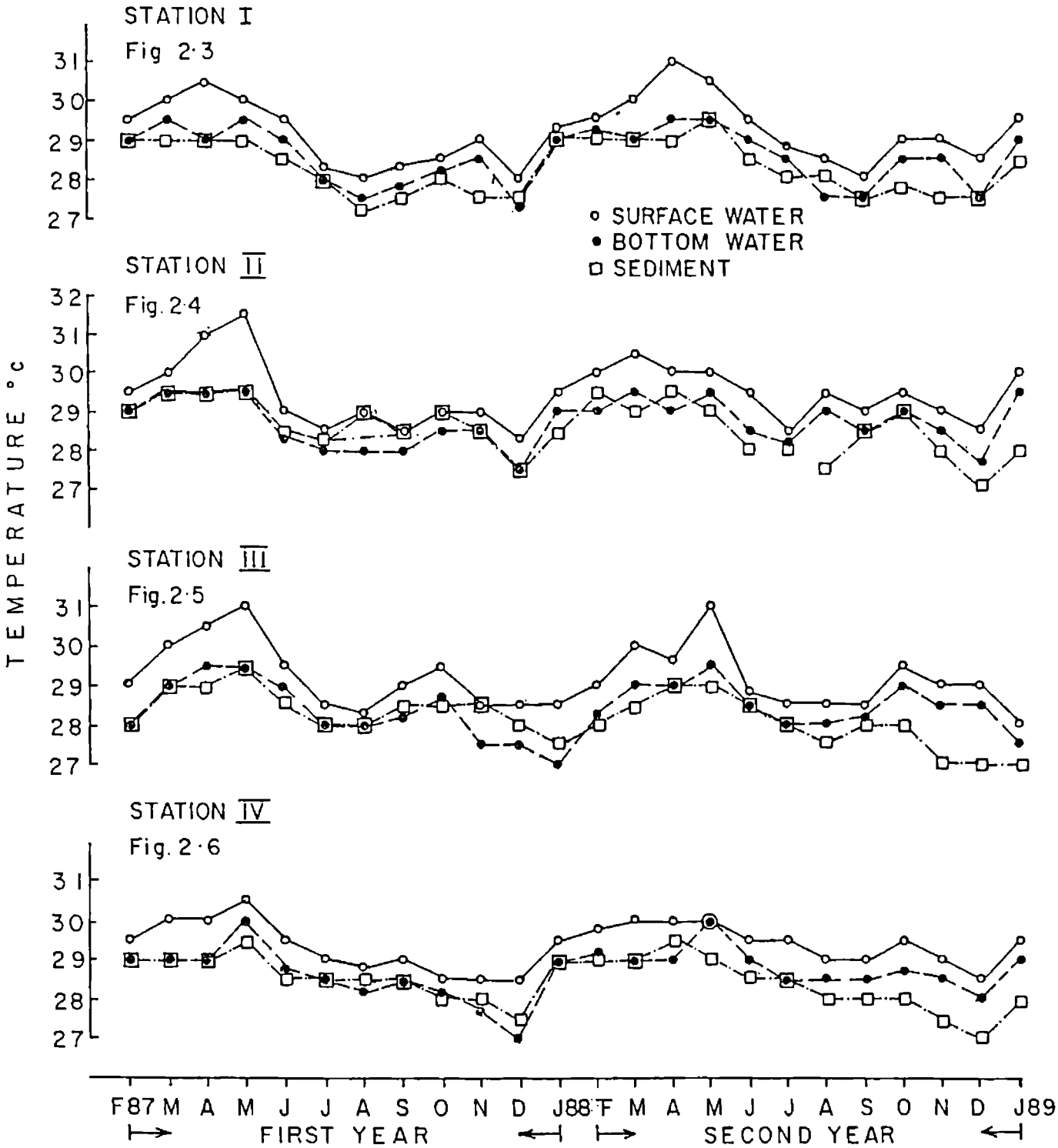


Fig 2.3 to 2.6 Temperature variation in different stations

TABLE - 2:3

Monthly mean values of surface water salinity (ppt) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	32.05 (0.49)	24.25 (0.51)	30.0 (2.36)	25.0 (0.92)	30.5 (0.52)	22.5 (0.32)	30.50 (1.44)	24.5 (1.27)
Mar	33.25 (0.52)	30.0 (0.61)	30.0 (1.01)	29.0 (1.03)	32.5 (0.81)	28.5 (6.06)	28.00 (1.22)	27.0 (6.07)
Apr	34.0 (0.6)	30.0 (0.72)	31.0 (2.13)	29.5 (0.74)	33.00 (0.22)	29.5 (0.98)	30.00 (1.25)	28.5 (1.22)
May	29.0 (0.87)	25.5 (2.16)	30.5 (0.82)	28.0 (2.31)	29.0 (0.94)	24.5 (1.66)	29.00 (2.71)	28.0 (6.47)
Jun	26.0 (0.92)	16.5 (4.32)	23.25 (3.14)	17.5 (3.82)	26.5 (2.34)	17.42 (3.46)	20.45 (3.77)	16.5 (3.02)
Jul	10.25 (3.12)	8.4 (2.5)	12.0 (4.35)	9.7 (3.14)	10.00 (3.12)	4.30 (2.96)	10.15 (3.82)	8.5 (3.94)
Aug	14.55 (4.25)	3.36 (0.83)	10.5 (5.33)	5.5 (2.13)	12.00 (1.85)	5.0 (0.74)	8.0 (3.64)	4.5 (1.87)
Sep	17.55 (5.4)	10.82 (2.41)	16.4 (2.34)	6.4 (1.36)	18.00 (2.23)	2.15 (0.67)	12.45 (2.82)	8.4 (2.53)
Oct	17.0 (1.53)	11.34 (2.70)	16.5 (2.20)	10.6 (2.39)	19.00 (1.71)	7.43 (2.31)	16.70 (2.44)	12.4 (2.42)
Nov	14.0 (1.92)	4.25 (1.14)	9.5 (3.17)	7.5 (3.17)	16.5 (1.03)	5.0 (2.42)	10.15 (3.06)	5.2 (2.86)
Dec	13.75 (2.24)	6.82 (1.77)	20.5 (1.82)	10.6 (2.82)	13.5 (2.12)	6.0 (0.88)	20.50 (2.86)	12.6 (1.23)
Jan	28.5 (2.44)	22.5 (4.81)	25.5 (3.84)	14.0 (3.81)	28.0 (3.71)	20.0 (1.42)	25.75 (2.06)	22.5 (2.34)

TABLE - 2:4

Monthly mean values of bottom water salinity (ppt) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	33.5 (0.43)	28.5 (0.52)	30.0 (0.42)	25.25 (0.57)	32.55 (0.33)	28.0 (0.45)	30.25 (0.37)	24.0 (0.36)
Mar	34.0 (0.33)	30.0 (0.31)	30.5 (0.35)	29.50 (0.44)	34.05 (0.42)	29.5 (0.32)	29.65 (0.24)	27.5 (0.37)
Apr	34.5 (0.25)	30.0 (0.25)	31.0 (0.36)	30.00 (0.23)	34.00 (0.21)	30.0 (0.27)	30.50 (0.37)	29.0 (0.34)
May	29.5 (0.32)	26.0 (0.72)	30.5 (0.39)	29.0 (0.97)	29.75 (0.66)	26.5 (0.92)	29.85 (0.25)	28.0 (0.22)
June	26.25 (0.72)	20.0 (1.27)	23.25 (1.37)	19.5 (2.14)	27.00 (0.71)	19.5 (2.34)	21.05 (0.82)	17.0 (2.71)
July	14.5 (2.16)	9.0 (4.32)	14.0 (3.76)	10.25 (2.58)	12.00 (5.76)	8.5 (4.15)	12.36 (3.77)	9.75 (3.23)
Aug	17.0 (0.96)	5.5 (2.14)	11.5 (0.84)	6.3 (4.53)	15.55 (2.31)	7.25 (3.43)	9.65 (3.54)	4.5 (3.74)
Sep	21.0 (1.57)	11.5 (1.85)	17.0 (2.31)	9.4 (3.36)	18.75 (3.15)	4.3 (2.17)	14.50 (2.92)	8.0 (2.84)
Oct	20.5 (0.76)	12.5 (0.76)	16.8 (0.43)	11.7 (4.05)	19.00 (2.71)	10.0 (1.78)	16.70 (3.02)	13.0 (2.71)
Nov	19.75 (0.82)	5.5 (1.32)	9.5 (2.14)	3.4 (2.76)	17.85 (2.06)	5.0 (2.03)	10.75 (3.76)	5.5 (2.67)
Dec	18.75 (0.46)	10.25 (2.35)	21.00 (1.72)	12.5 (2.09)	16.50 (1.89)	6.85 (1.72)	20.35 (2.17)	13.0 (2.14)
Jan	29.0 (1.23)	25.5 (0.77)	26.5 (2.54)	24.0 (2.84)	29.5 (1.76)	25.0 (2.44)	26.85 (2.82)	22.0 (2.56)

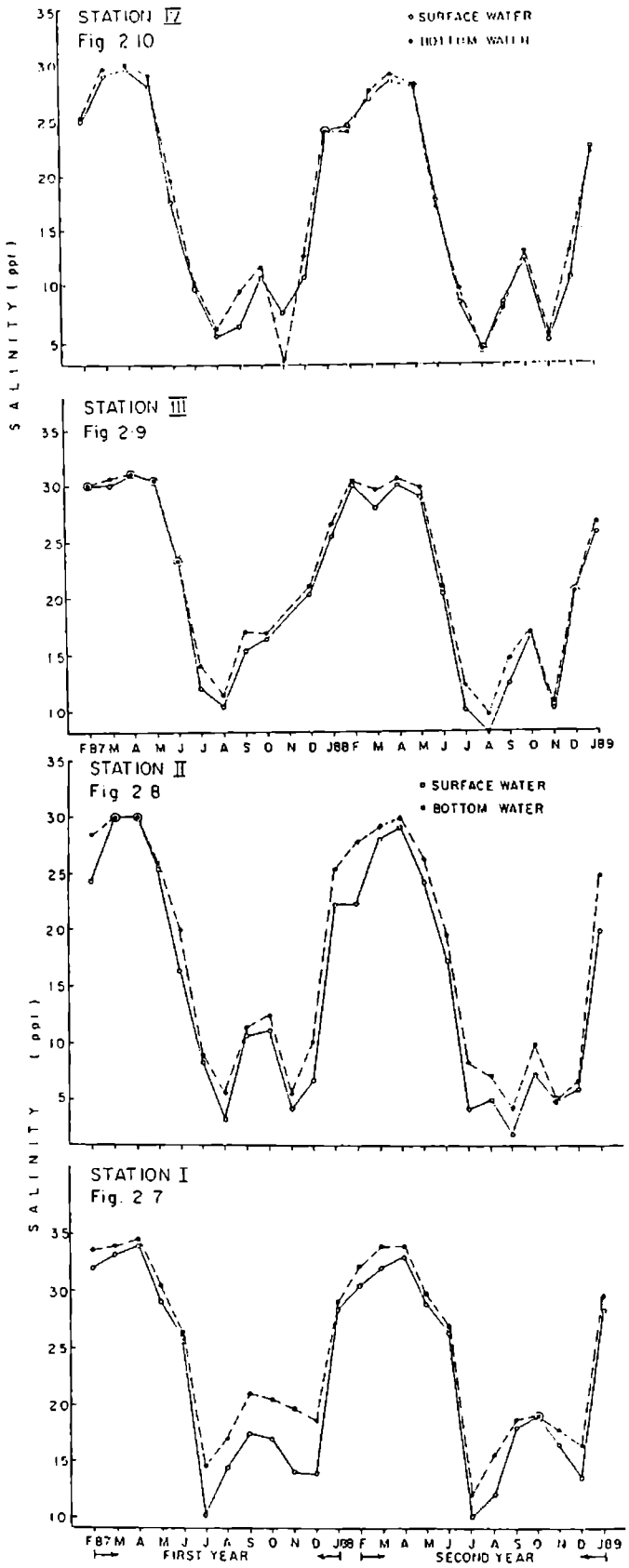


Fig 2.7 to 2.10 Salinity variation in different stations.

TABLE - 2:5

Monthly mean values of surface water dissolved oxygen (ml/l) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	3.40 (0.15)	4.55 (0.22)	2.98 (0.19)	2.22 (0.24)	3.36 (0.23)	4.45 (0.31)	2.92 (0.22)	2.2 (0.37)
Mar	3.25 (0.29)	4.2 (0.18)	3.0 (0.22)	1.98 (0.17)	3.23 (0.27)	4.18 (0.27)	2.87 (0.18)	1.92 (0.42)
Apr	3.20 (0.32)	4.03 (0.26)	2.94 (0.31)	2.06 (0.13)	3.18 (0.26)	4.0 (0.31)	2.82 (0.17)	2.0 (0.33)
May	3.10 (0.41)	3.94 (0.24)	3.02 (0.32)	1.76 (0.08)	3.12 (0.14)	4.10 (0.22)	2.96 (0.22)	1.68 (0.36)
Jun	3.75 (0.32)	4.43 (0.31)	3.25 (0.46)	2.82 (0.12)	3.52 (0.36)	4.23 (0.18)	3.15 (0.31)	2.78 (0.28)
Jul	4.60 (0.26)	4.82 (0.31)	3.48 (0.54)	2.92 (0.20)	5.04 (0.27)	4.90 (0.19)	3.26 (0.26)	2.94 (0.45)
Aug	4.45 (0.44)	5.14 (0.36)	3.52 (0.50)	3.44 (0.27)	4.88 (0.33)	5.03 (0.22)	3.38 (0.29)	3.35 (0.52)
Sep	4.35 (0.35)	5.06 (0.26)	3.36 (0.39)	3.62 (0.23)	4.76 (0.42)	4.93 (0.17)	3.30 (0.21)	3.55 (0.59)
Oct	4.32 (0.26)	4.64 (0.21)	3.30 (0.28)	3.70 (0.21)	4.70 (0.39)	4.88 (0.31)	3.24 (0.34)	3.62 (0.37)
Nov	4.40 (0.27)	5.08 (0.38)	3.42 (0.26)	3.99 (0.26)	4.89 (0.23)	5.18 (0.26)	3.16 (0.32)	3.62 (0.32)
Dec	4.48 (0.32)	4.72 (0.41)	3.36 (0.44)	3.82 (0.31)	4.86 (0.17)	5.06 (0.24)	3.21 (0.30)	3.72 (0.28)
Jan	3.45 (0.18)	4.5 (0.24)	3.02 (0.34)	2.34 (0.28)	3.5 (0.33)	4.55 (0.29)	3.06 (0.27)	2.24 (0.47)

TABLE - 2:6

Monthly mean values of bottom water dissolved oxygen (ml/l) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	3.20 (0.17)	4.23 (0.31)	2.68 (0.27)	1.16 (0.10)	3.18 (0.20)	4.2 (0.38)	2.72 (0.15)	1.14 (0.15)
Mar	2.85 (0.32)	3.9 (0.26)	2.50 (0.20)	1.20 (0.13)	3.06 (0.23)	4.06 (0.27)	2.43 (0.16)	1.16 (0.16)
Apr	2.76 (0.41)	3.85 (0.14)	2.42 (0.27)	1.14 (0.18)	2.98 (0.15)	3.92 (0.17)	2.21 (0.27)	1.1 (0.10)
May	2.74 (0.32)	3.76 (0.22)	2.66 (0.31)	1.02 (0.21)	2.77 (0.18)	3.36 (0.31)	2.26 (0.17)	1.03 (0.09)
Jun	2.92 (0.28)	4.02 (0.23)	2.98 (0.54)	1.66 (0.19)	3.04 (0.21)	4.12 (0.32)	2.37 (0.18)	1.52 (0.23)
Jul	3.52 (0.15)	4.73 (0.44)	3.02 (0.47)	1.98 (0.18)	3.95 (0.32)	4.64 (0.41)	2.74 (0.23)	1.94 (0.13)
Aug	3.93 (0.45)	5.01 (0.82)	3.17 (0.39)	2.24 (0.20)	4.04 (0.42)	4.76 (0.27)	3.14 (0.48)	2.18 (0.17)
Sep	3.78 (0.47)	4.91 (0.73)	3.08 (0.62)	2.14 (0.31)	3.86 (0.57)	4.75 (0.31)	3.09 (0.39)	2.13 (0.42)
Oct	3.81 (0.25)	4.53 (0.34)	2.70 (0.18)	2.06 (0.14)	3.70 (0.17)	4.8 (0.33)	2.87 (0.61)	2.08 (0.29)
Nov	3.85 (0.17)	4.86 (0.26)	2.98 (0.27)	2.17 (0.26)	3.88 (0.43)	4.96 (0.26)	2.92 (0.53)	2.12 (0.31)
Dec	3.98 (0.18)	4.42 (0.47)	3.02 (0.30)	2.05 (0.29)	3.95 (0.32)	4.76 (0.39)	2.98 (0.42)	2.25 (0.14)
Jan	3.15 (0.32)	4.4 (0.51)	2.75 (0.50)	1.10 (0.21)	3.25 (0.31)	4.45 (0.42)	2.8 (0.41)	1.12 (0.22)

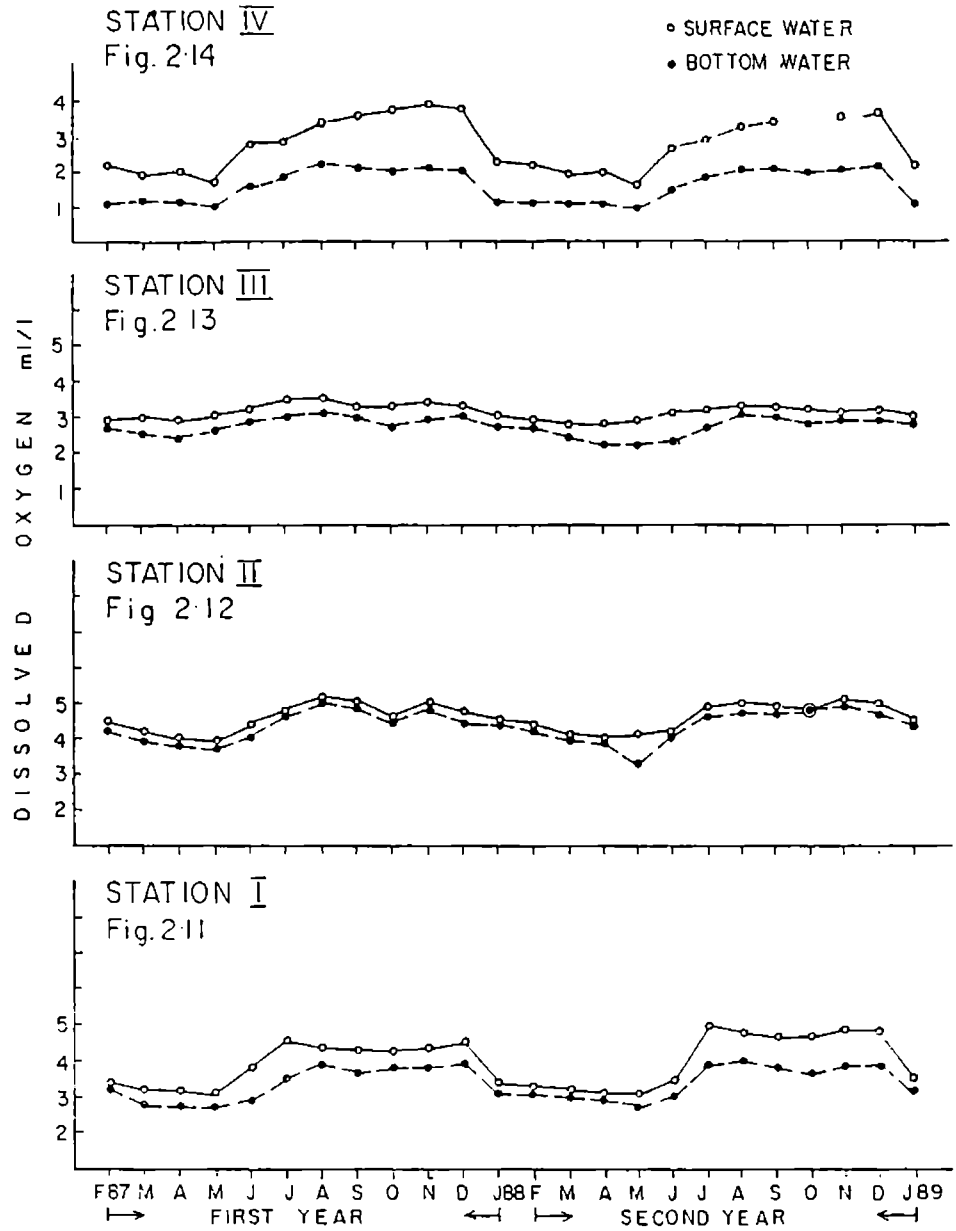


Fig 2.11 to 2.14 Dissolved Oxygen variation in different stations

TABLE - 2:7

Monthly mean values of surface water pH in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	8.31 (0.08)	8.27 (0.13)	7.30 (0.09)	6.92 (0.60)	8.32 (0.12)	8.28 (0.12)	7.32 (0.07)	6.92 (0.11)
Mar	8.26 (0.06)	8.21 (0.09)	7.14 (0.13)	6.84 (0.09)	8.22 (0.09)	8.25 (0.13)	7.12 (0.11)	6.84 (0.09)
Apr	8.12 (0.09)	8.2 (0.11)	7.21 (0.08)	6.72 (0.00)	8.19 (0.07)	8.22 (0.11)	7.11 (0.10)	6.79 (0.08)
May	7.9 (0.16)	8.76 (0.08)	7.20 (0.07)	6.76 (0.12)	8.10 (0.13)	8.19 (0.09)	7.18 (0.09)	6.73 (0.12)
Jun	8.2 (0.09)	8.31 (0.13)	7.26 (0.12)	6.92 (0.10)	8.20 (0.19)	8.21 (0.13)	7.24 (0.08)	6.81 (0.14)
Jul	8.34 (0.11)	8.45 (0.14)	7.31 (0.09)	7.34 (0.12)	8.30 (0.12)	8.24 (0.17)	7.32 (0.12)	7.26 (0.13)
Aug	8.33 (0.03)	8.42 (0.21)	7.36 (0.11)	7.54 (0.04)	8.40 (0.08)	8.32 (0.07)	7.38 (0.15)	7.32 (0.11)
Sep	8.24 (0.12)	8.0 (0.12)	7.45 (0.17)	7.36 (0.07)	8.37 (0.11)	8.34 (0.12)	7.40 (0.09)	7.42 (0.12)
Oct	8.3 (0.08)	8.10 (0.27)	7.38 (0.13)	7.40 (0.12)	8.27 (0.16)	8.25 (0.10)	7.45 (0.13)	7.50 (0.09)
Nov	8.28 (0.15)	8.2 (0.12)	7.52 (0.16)	7.23 (0.13)	8.32 (0.10)	8.42 (0.15)	7.54 (0.14)	7.34 (0.06)
Dec	8.36 (0.12)	8.35 (0.14)	7.42 (0.20)	7.10 (0.10)	8.30 (0.09)	8.36 (0.12)	7.50 (0.10)	7.32 (0.13)
Jan	8.30 (0.10)	8.3 (0.10)	7.32 (0.18)	7.0 (0.17)	8.27 (0.12)	8.32 (0.12)	7.35 (0.11)	7.12 (0.11)

TABLE - 2:8

Monthly mean values of bottom water pH in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-8()			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	8.14 (0.12)	8.18 (0.05)	7.17 (0.20)	5.56 (0.05)	8.17 (0.03)	8.18 (0.05)	7.19 (0.13)	6.59 (0.09)
Mar	7.92 (0.09)	8.1 (0.24)	7.06 (0.18)	6.52 (0.07)	7.92 (0.01)	8.12 (0.07)	7.0 (0.09)	6.53 (0.06)
Apr	7.84 (0.14)	8.10 (0.05)	6.90 (0.16)	6.50 (0.10)	7.87 (0.15)	8.10 (0.03)	6.94 (0.08)	6.51 (0.12)
May	7.78 (0.22)	7.93 (0.21)	7.12 (0.13)	6.62 (0.14)	7.92 (0.12)	8.07 (0.14)	7.08 (0.08)	6.57 (0.21)
Jun	7.96 (0.16)	8.25 (0.17)	7.16 (0.15)	6.61 (0.13)	8.02 (0.13)	8.0 (0.20)	7.17 (0.10)	6.62 (0.13)
Jul	8.2 (0.07)	8.38 (0.18)	7.20 (0.17)	6.66 (0.15)	8.22 (0.10)	7.96 (0.22)	7.24 (0.13)	6.71 (0.17)
Aug	8.15 (0.13)	8.35 (0.12)	7.17 (0.09)	6.75 (0.13)	8.36 (0.17)	8.24 (0.04)	7.20 (0.18)	6.67 (0.15)
Sep	7.91 (0.21)	8.0 (0.20)	7.23 (0.21)	6.81 (0.12)	8.33 (0.13)	8.24 (0.15)	7.26 (0.12)	6.92 (0.18)
Oct	8.24 (0.22)	7.94 (0.18)	7.20 (0.14)	6.77 (0.10)	8.27 (0.19)	8.16 (0.17)	7.22 (0.20)	6.75 (0.18)
Nov	8.06 (0.16)	8.15 (0.21)	7.34 (0.08)	6.62 (0.21)	8.30 (0.19)	8.06 (0.14)	7.30 (0.21)	6.66 (0.10)
Dec	7.85 (0.19)	8.0 (0.17)	7.14 (0.03)	6.66 (0.10)	8.06 (0.17)	8.10 (0.13)	7.2 (0.13)	6.67 (0.21)
Jan	8.10 (0.21)	8.21 (0.10)	7.1 (0.14)	6.55 (0.14)	8.15 (0.16)	8.22 (0.12)	7.15 (0.17)	6.57 (0.07)

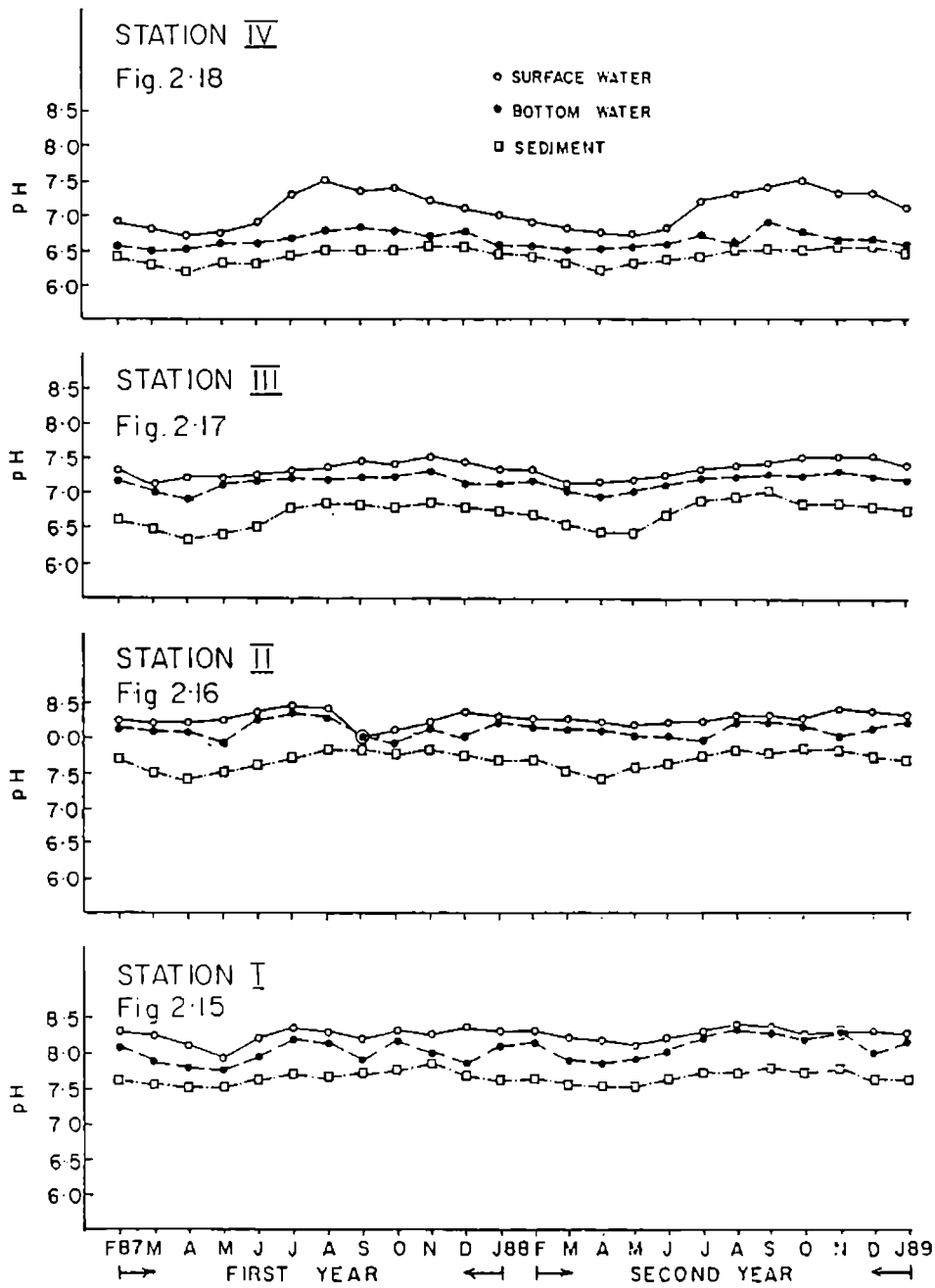


Fig 2.15 to 2.18 pH variation in different stations.

TABLE - 2:9

Monthly mean value of Nitrate-Nitrogen (µg at No_3-N/L) in the surface water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	7.70 (1.65)	7.6 (0.98)	7.22 (1.11)	1.30 (0.33)	7.69 (0.53)	6.88 (1.71)	7.32 (0.92)	1.32 (0.62)
Mar	6.75 (1.20)	5.23 (1.32)	6.30 (1.23)	1.20 (0.42)	6.52 (0.97)	4.04 (1.00)	6.72 (1.02)	1.18 (0.51)
Apr	4.05 (1.32)	4.21 (2.12)	5.04 (2.06)	1.12 (0.45)	4.0 (1.06)	3.71 (1.82)	6.05 (0.99)	1.12 (0.04)
May	3.85 (0.98)	3.25 (1.32)	3.95 (0.71)	3.24 (1.03)	3.44 (2.32)	3.32 (1.04)	3.17 (1.12)	3.14 (0.31)
Jun	20.52 (2.43)	14.65 (7.52)	29.3 (3.82)	11.36 (3.07)	25.42 (3.75)	16.75 (2.82)	30.14 (3.21)	11.42 (0.98)
Jul	39.07 (8.92)	23.77 (9.76)	42.77 (7.14)	29.7 (6.14)	39.72 (8.46)	28.33 (5.41)	44.82 (1.32)	27.75 (1.76)
Aug	27.82 (9.31)	29.96 (8.22)	30.86 (10.32)	22.4 (8.70)	25.66 (7.32)	32.76 (7.14)	32.41 (12.54)	22.53 (6.14)
Sep	16.44 ((4.37)	20.0 (3.98)	18.62 (5.71)	12.01 (3.14)	15.32 (3.14)	17.54 (3.20)	17.63 (3.06)	10.72 (2.32)
Oct	12.50 (3.14)	10.28 (3.24)	7.91 (2.82)	6.32 (2.11)	12.50 (1.03)	11.64 (2.17)	7.84 (2.31)	6.11 (0.96)
Nov	9.25 (1.72)	6.5 (1.72)	3.92 (1.92)	4.23 (0.96)	7.36 (0.98)	7.42 (1.44)	4.04 (1.30)	3.72 (1.07)
Dec	10.80 (1.31)	7.6 (2.34)	5.4 (1.34)	4.25 (1.71)	9.44 (1.22)	8.77 (1.21)	5.72 (1.96)	4.32 (1.31)
Jan	8.33 (1.26)	8.31 (3.62)	10.32 (1.98)	1.27 (0.52)	8.38 (2.30)	9.17 (2.54)	9.40 (2.90)	1.25 (0.90)

TABLE - 2:10

Monthly mean values of Nitrate - Nitrogen (µg at No_3-N/l) in the bottom water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	7.02 (1.46)	7.95 (1.54)	7.43 (1.22)	1.0 (0.96)	7.72 (0.71)	6.6 (1.51)	8.52 (0.82)	1.12 (0.99)
Mar	6.49 (0.93)	5.53 (1.71)	6.41 (1.40)	0.94 (0.32)	6.86 (1.32)	5.21 (1.21)	7.83 (0.96)	0.96 (1.03)
Apr	4.06 (0.86)	4.24 (1.03)	5.82 (1.53)	0.76 (0.43)	4.52 (0.94)	4.6 (1.76)	6.24 (1.03)	0.82 (0.72)
May	3.32 (1.23)	3.53 (0.97)	4.91 (1.01)	1.06 (0.52)	3.62 (1.47)	3.36 (0.98)	2.03 (0.97)	1.02 (0.34)
Jun	28.75 (3.42)	15.0 (2.31)	32.2 (3.03)	2.32 (0.64)	26.72 (2.92)	18.23 (1.91)	36.21 (3.06)	2.23 (0.44)
Jul	42.53 (3.57)	22.72 (3.43)	44.77 (4.61)	20.6 (3.41)	39.72 (7.43)	28.0 (4.76)	45.96 (7.56)	27.75 (2.56)
Aug	30.92 (4.03)	30.75 (5.21)	32.01 (4.32)	16.32 (4.05)	27.94 (8.14)	33.1 (7.03)	33.41 (3.54)	22.00 (0.86)
Sep	21.45 (2.71)	20.18 (2.76)	19.41 (3.09)	16.68 (3.91)	16.44 (5.26)	17.62 (4.14)	19.66 (4.07)	10.53 (3.75)
Oct	16.82 (3.80)	10.32 (3.54)	9.34 (2.14)	12.45 (2.76)	12.55 (2.06)	12.52 (2.06)	8.34 (2.30)	6.16 (0.87)
Nov	10.52 (2.05)	5.25 (1.70)	4.51 (1.10)	7.95 (3.41)	9.04 (0.98)	7.46 (1.32)	5.10 (2.14)	4.0 (0.97)
Dec	12.31 (2.14)	7.66 (2.03)	6.43 (1.14)	4.26 (0.93)	9.0 (1.10)	8.03 (1.01)	6.73 (1.24)	4.3 (1.123)
Jan	8.08 (1.86)	8.74 (1.93)	10.32 (1.12)	1.1 (0.76)	8.0 (1.32)	9.21 (1.71)	9.38 (1.86)	1.2 (0.87)

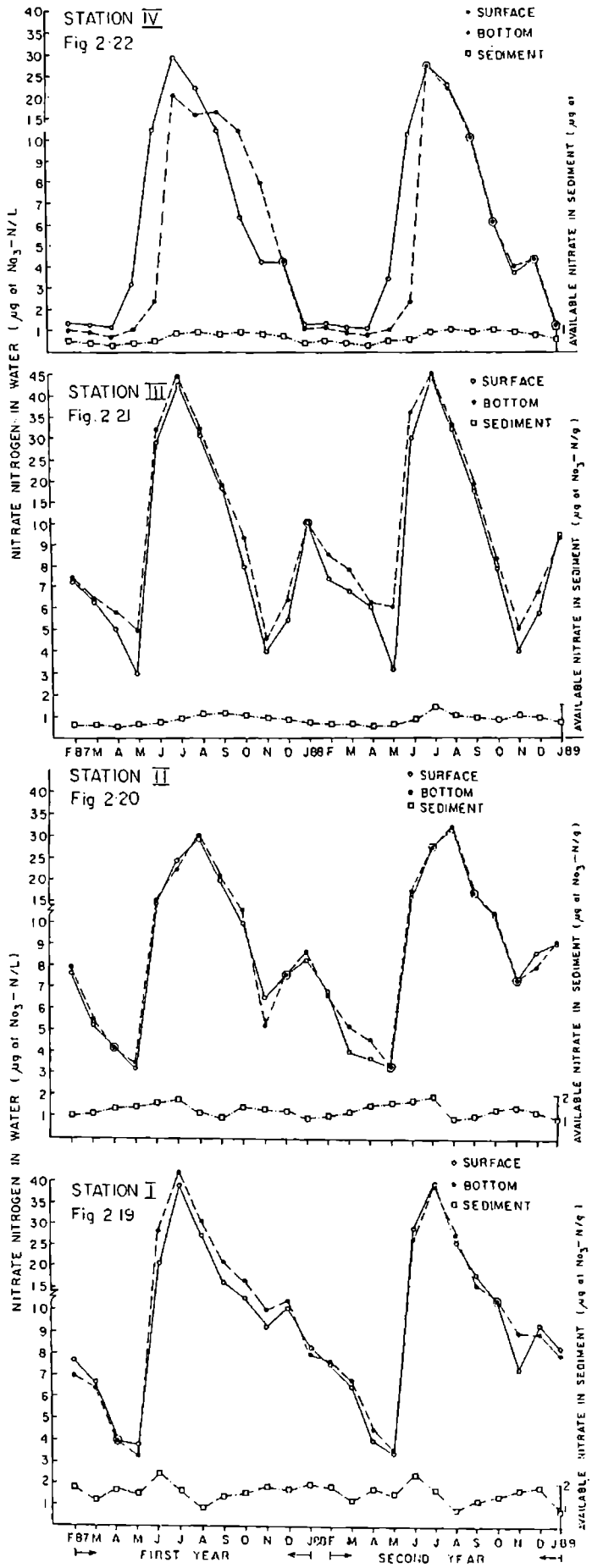


Fig 2.19 to 2.22 Variation of Nitrate-Nitrogen and available Nitrate

TABLE - 2:11

Monthly mean values of Nitrite-Nitrogen (µg at No_2-N/l) in the surface water stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	1.0 (0.03)	3.02 (0.14)	1.00 (0.02)	1.12 (0.31)	1.45 (0.09)	3.04 (0.12)	0.99 (0.12)	1.16 (0.31)
Mar	0.7 (0.02)	4.20 (0.22)	0.82 (0.06)	0.92 (0.07)	0.82 (0.06)	3.86 (0.37)	0.87 (0.17)	0.93 (0.03)
Apr	0.25 (0.00)	5.32 (0.97)	0.90 (0.04)	0.75 (0.12)	0.43 (0.10)	4.77 (0.24)	0.93 (0.01)	0.75 (0.00)
May	1.75 (0.15)	9.45 (1.02)	1.0 (0.03)	1.1 (0.10)	0.82 (0.07)	5.21 (0.92)	1.04 (0.32)	0.96 (0.03)
Jun	4.0 (0.24)	18.50 (0.98)	2.85 (0.32)	3.0 (0.17)	3.22 (0.13)	16.3 (1.98)	2.35 (1.02)	2.16 (0.37)
Jul	5.88 (0.76)	32.44 (6.05)	6.3 (1.04)	4.32 (0.39)	4.75 (0.55)	30.24 (3.14)	5.24 (1.14)	3.12 (0.82)
Aug	4.85 (0.32)	25.66 (2.76)	2.5 (0.15)	3.14 (0.41)	4.20 (0.62)	22.67 (2.03)	2.03 (0.43)	3.87 (0.91)
Sep	2.02 (0.51)	10.36 (0.34)	1.32 (0.14)	3.02 (0.19)	2.06 (0.31)	9.76 (0.72)	1.43 (0.65)	3.16 (0.98)
Oct	0.50 (0.03)	8.21 (0.12)	0.84 (0.22)	2.14 (0.20)	1.02 (0.12)	7.31 (0.31)	0.92 (0.07)	2.21 (0.76)
Nov	1.27 (0.41)	19.50 (0.71)	0.90 (0.31)	2.96 (0.18)	1.86 (0.14)	12.34 (1.00)	0.86 (0.09)	2.57 (10.92)
Dec	0.75 (0.09)	7.0 (0.82)	1.06 (0.41)	2.4 (0.36)	0.82 (0.06)	6.88 (0.97)	1.0 (0.00)	2.13 (0.24)
Jan	1.8 (0.02)	2.51 (0.31)	1.15 (0.21)	2.04 (0.40)	1.6 (0.10)	2.32 (0.93)	1.16 (0.04)	1.84 (0.43)

TABLE - 2:12

Monthly mean values of Nitrite - Nitrogen (µg at No_2-N/l) in the bottom water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	1.06 (0.02)	3.16 (0.17)	0.92 (0.12)	0.82 (0.42)	1.45 (0.12)	3.20 (0.22)	0.86 (0.06)	1.04 (0.21)
Mar	0.76 (0.02)	4.21 (0.21)	0.79 (0.05)	0.75 (0.06)	0.80 (0.14)	3.86 (0.14)	0.82 (0.03)	0.84 (0.26)
Apr	0.34 (0.01)	6.25 (0.32)	0.87 (0.01)	0.68 (0.03)	0.47 (0.14)	4.92 (0.83)	0.91 (0.14)	0.76 (0.18)
May	1.88 (0.17)	10.62 (1.24)	1.24 (0.42)	1.26 (0.20)	0.96 (0.17)	5.36 (0.91)	1.0 (0.61)	0.85 (0.31)
Jun	4.0 (0.20)	20.51 (0.98)	2.95 (1.04)	3.14 (0.13)	3.45 (0.32)	16.85 (1.03)	2.15 (0.32)	2.15 (0.42)
Jul	6.72 (0.54)	32.44 (1.06)	6.24 (1.72)	5.64 (0.29)	4.86 (0.76)	30.44 (0.92)	5.30 (0.97)	3.14 (1.30)
Aug	4.85 (1.32)	26.75 (0.32)	2.60 (0.76)	2.32 (0.47)	4.15 (0.82)	23.04 (0.86)	2.3 (0.93)	3.89 (0.96)
Sep	1.85 (0.57)	11.42 (1.26)	1.35 (0.34)	3.44 (0.56)	2.12 (0.56)	9.82 (1.04)	1.45 (1.08)	3.20 (1.16)
Oct	0.55 (0.34)	7.56 (2.32)	0.96 (0.32)	2.67 (0.32)	1.0 (0.51)	7.44 (0.92)	0.90 (0.76)	2.24 (0.82)
Nov	1.62 (0.98)	28.52 (0.86)	0.72 (0.54)	3.02 (0.14)	1.87 (0.76)	14.81 (0.76)	0.92 (0.85)	2.60 (0.45)
Dec	1.04 (0.06)	8.72 (0.71)	1.34 (0.30)	2.45 (0.39)	0.84 (0.73)	7.2 (0.32)	1.23 (0.32)	2.16 (0.37)
Jan	1.96 (0.32)	2.89 (0.54)	1.26 (0.16)	1.81 (0.82)	1.72 (0.44)	2.46 (0.94)	1.27 (0.47)	1.8 (0.91)

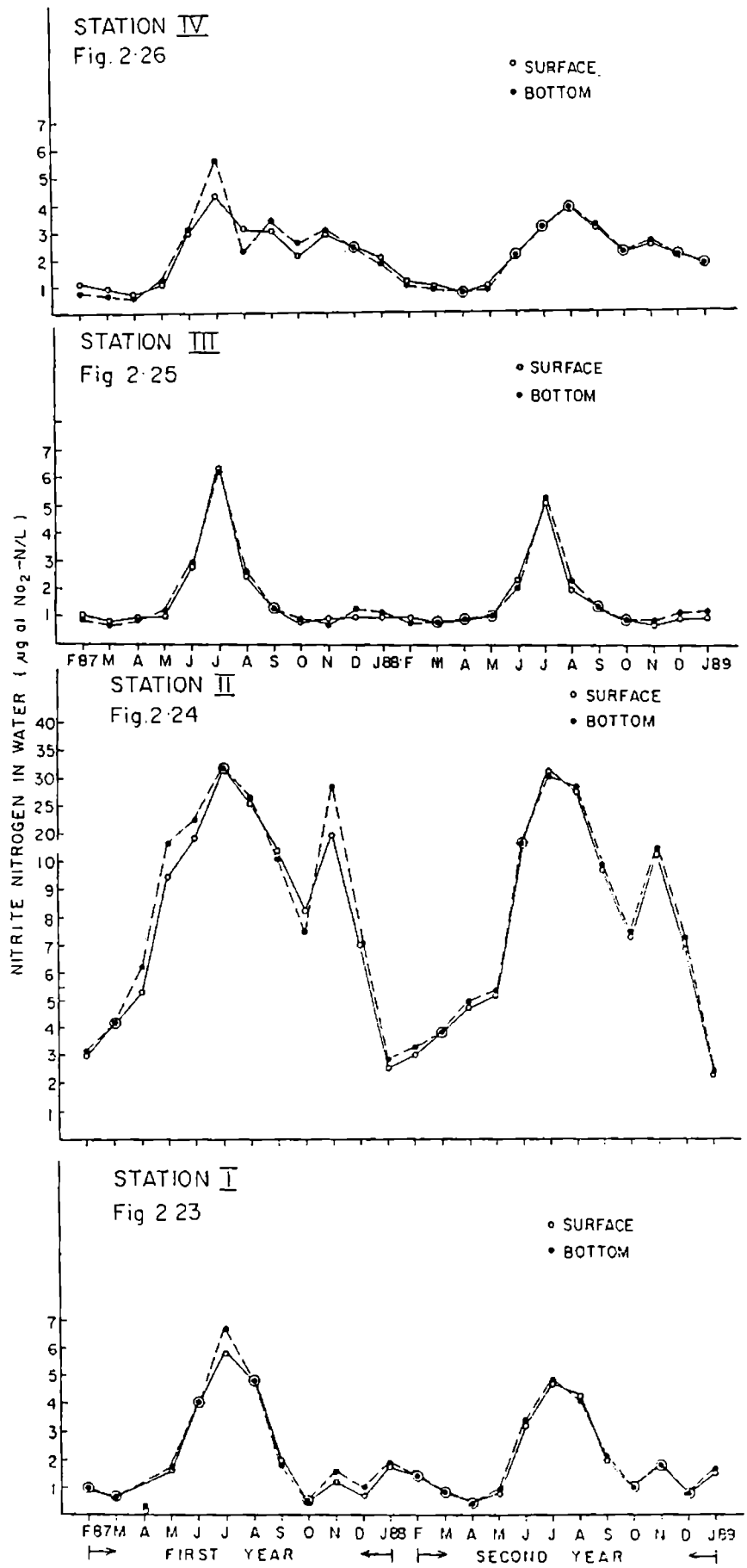


Fig 2.23 to 2.26 Variation of Nitrite-Nitrogen in different stations.

TABLE - 2:13

Monthly mean values of reactive phosphorus (µg at Po_4-P/l in the surface water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	3.65 (0.96)	2.86 (0.81)	4.20 (0.53)	6.6 (1.12)	4.23 (0.63)	2.67 (0.71)	5.24 (1.31)	10.54 (0.06)
Mar	3.40 (0.87)	2.75 (0.94)	5.25 (0.77)	14.64 (2.56)	3.56 (0.72)	2.60 (0.62)	6.36 (1.09)	12.34 (1.11)
Apr	2.24 (0.76)	2.80 (0.76)	8.96 (1.43)	16.00 (1.93)	2.84 (0.51)	2.84 (0.71)	8.42 (1.73)	16.72 (2.31)
May	3.02 (0.92)	3.72 (0.32)	8.04 (0.92)	10.32 (0.94)	3.66 (0.43)	3.04 (0.93)	8.15 (1.07)	12.34 (1.76)
Jun	4.7 (0.66)	7.53 (0.52)	4.24 (0.37)	7.7 (0.76)	8.32 (0.97)	8.62 (0.84)	5.94 (1.21)	9.30 (0.98)
Jul	13.0 (2.03)	12.24 (2.13)	3.02 (0.79)	3.0 (0.44)	13.40 (3.09)	13.36 (2.96)	2.21 (0.34)	2.7 (0.72)
Aug	16.2 (1.72)	7.3 (0.69)	0.96 (0.23)	2.0 (0.17)	15.86 (2.34)	8.2 (1.27)	0.98 (0.72)	1.23 (0.32)
Sep	13.51 (1.63)	6.66 (0.96)	1.24 (0.32)	1.03 (0.62)	10.06 (3.23)	5.82 (0.95)	1.13 (0.04)	1.34 (0.71)
Oct	8.01 (0.82)	4.26 (0.53)	1.12 (0.41)	1.04 (0.32)	9.21 (1.14)	4.33 (1.22)	1.32 (0.14)	1.68 (0.26)
Nov	7.60 (1.34)	7.65 (0.97)	1.02 (0.28)	1.96 (0.21)	6.81 (0.97)	6.21 (1.17)	1.14 (0.15)	2.06 (0.19)
Dec	3.91 (0.77)	3.75 (0.82)	1.75 (0.31)	2.14 (0.34)	4.0 (1.24)	3.24 (0.74)	1.42 (0.09)	4.63 (1.20)
Jan	4.25 (0.87)	4.33 (0.72)	3.14 (0.77)	5.8 (0.42)	4.70 (1.03)	4.0 (0.92)	3.10 (0.31)	7.21 (1.08)

TABLE - 2:14

Monthly mean values of reactive phosphorus (µg at Po_4-P/l) in the bottom water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	3.82 (0.86)	2.92 (0.77)	5.98 (1.06)	6.80 (1.32)	4.27 (0.45)	2.76 (0.61)	5.40 (0.82)	11.55 (0.87)
Mar	3.42 (0.47)	3.0 (0.57)	6.24 (0.93)	15.24 (1.06)	3.90 (0.57)	2.6 (0.72)	6.92 (0.66)	14.56 (0.79)
Apr	2.72 (0.73)	3.40 (0.92)	9.45 (1.26)	17.73 (0.98)	2.84 (0.61)	2.64 (0.62)	8.72 (0.57)	18.00 (0.72)
May	3.52 (0.66)	3.25 (0.78)	8.16 (0.87)	12.64 (2.43)	3.71 (0.53)	3.04 (0.54)	8.50 (0.94)	13.38 (0.44)
Jun	4.74 (0.96)	10.82 (1.03)	4.27 (0.32)	8.74 (1.46)	8.40 (1.23)	9.77 (0.32)	5.04 (1.23)	10.45 (0.93)
Jul	12.32 (1.38)	12.52 (1.32)	3.72 (0.77)	3.02 (1.06)	11.38 (1.29)	13.52 (0.76)	2.04 (0.93)	3.72 (1.32)
Aug	16.55 (1.43)	8.30 (3.53)	1.95 (1.03)	2.25 (1.14)	15.92 (0.74)	8.26 (1.36)	1.10 (0.14)	1.75 (0.93)
Sep	13.71 (1.26)	6.5 (1.72)	2.22 (0.72)	1.12 (0.93)	11.08 (0.86)	5.91 (2.07)	1.23 (0.32)	2.30 (0.76)
Oct	8.72 (2.32)	5.53 (2.04)	2.04 (0.94)	2.15 (1.07)	9.22 (0.82)	4.57 (1.32)	1.42 (0.78)	2.78 (0.82)
Nov	7.24 (1.45)	5.76 (1.33)	2.15 (0.72)	2.06 (0.92)	6.81 (0.71)	6.34 (0.45)	1.77 (0.51)	2.42 (0.51)
Dec	4.32 (1.23)	4.05 (1.07)	3.21 (1.66)	2.42 (1.02)	4.11 (1.36)	3.46 (1.20)	2.86 (1.03)	4.95 (0.32)
Jan	4.24 (1.07)	4.0 (1.22)	4.12 (1.72)	5.92 (1.63)	4.32 (1.44)	4.23 (0.97)	3.09 (1.07)	7.9 (0.93)

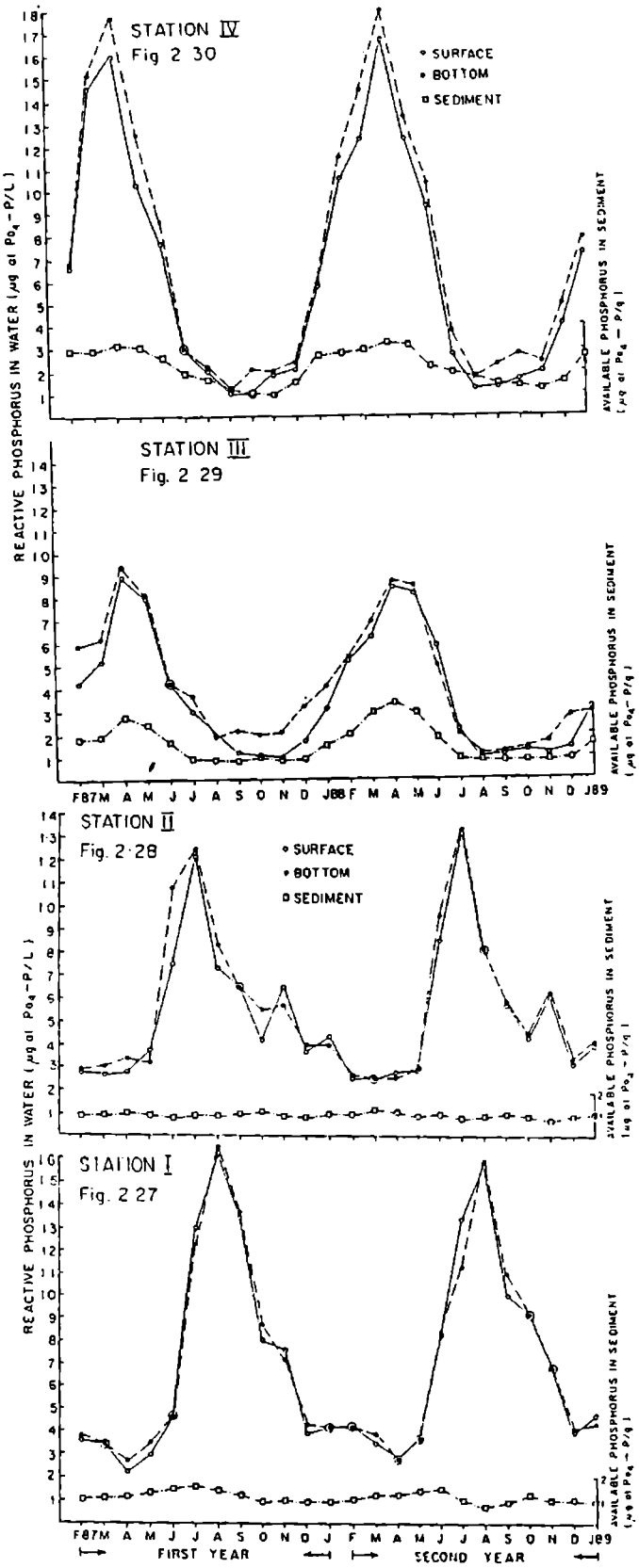


Fig 2.27 to 2.30 Variation of reactive Phosphorus and available Phosphorus in different stations.

TABLE - 2:15

Monthly mean values of hydrogen sulphide (µg at H_2S-S/l) in the surface water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb				16.3 (4.75)			-	18.1 (3.06)
Mar	-		2.8 (0.93)	30.0 (5.32)		-	2.4 (0.74)	33.4 (6.44)
Apr	-	-	4.0 (0.76)	42.0 (3.76)			3.6 (0.34)	46.0 (4.38)
May	-		3.0 (0.33)	22.5 (7.32)		-	2.7 (0.28)	29.65 (3.45)
Jun	-	-	-	6.7 (2.45)	-	-		12.82 (2.26)
Jul			-		-	-		
Aug	-				-	-		-
Sep	-	-	-		-	-	-	-
Oct		-	-				-	-
Nov		-				-	-	
Dec	-			-	-	-	-	
Jan	-		-	14.5 (2.84)	-	-		16.8 (3.71)

TABLE - 2:16

Monthly mean values of hydrogen sulphide (µg at H_2S-S/l) in the bottom water of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb			22.0 (0.07)	92.3 (11.32)			20.4 (0.17)	97.4 (10.32)
Mar			28.0 (0.45)	146.8 (10.76)			24.8 (0.73)	149.21 (14.77)
Apr		-	44.0 (0.97)	150.14 (8.34)			38.0 (1.23)	161.2 (12.32)
May	-	-	32.0 (2.92)	102.5 (7.62)	-		30.6 (3.06)	112.45 (9.32)
Jun	-	-	18.0 (7.23)	22.7 (12.32)	-		16.7 (8.92)	31.75 (9.33)
Jul	-	-	0	10.14 (6.72)	-	-	0	7.32 (2.07)
Aug	-	-	0	4.86 (2.46)			0	3.44 (1.82)
Sep	-	-	10.0 (2.32)	16.0 (3.99)	-		8.7 (2.14)	17.40 (3.46)
Oct	-	-	25.0 (9.72)	18.5 (2.03)	-		21.4	18.25 (2.17)
Nov			5.0 (2.17)	10.6 (2.72)			4.0 (1.03)	14.55 (2.06)
Dec		-	8.0 (2.17)	16.5 (2.72)		-	6.8 (2.42)	18.55 (2.02)
Jan	-	-	10.0 (3.87)	76.0 (8.71)	-	-	9.8 (2.76)	80.20 (5.42)

TABLE - 2:17

Monthly mean values of sediment temperature (°C) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	29.00 (0.15)	29.0 (0.12)	28.0 (0.06)	29.0 (0.18)	29.5 (0.12)	29.5 (0.26)	28.0 (0.15)	29.0 (0.20)
Mar	29.00 (0.05)	29.5 (0.10)	29.0 (0.25)	29.0 (0.22)	29.0 (0.20)	29.0 (0.21)	28.5 (0.20)	29.0 (0.18)
Apr	29.0 (0.10)	29.5 (0.08)	29.0 (0.28)	29.0 (0.18)	29.0 (0.15)	29.5 (0.24)	29.0 (0.18)	29.5 (0.22)
May	29.0 (0.05)	29.5 (0.05)	29.5 (0.15)	29.5 (0.15)	29.5 (0.22)	29.0 (0.18)	29.0 (0.18)	29.0 (0.18)
Jun	28.5 (0.07)	28.5 (0.10)	28.5 (0.15)	28.5 (0.12)	28.5 (0.28)	28.0 (0.17)	28.5 (0.20)	28.5 (0.25)
Jul	28.0 (0.15)	28.2 (0.08)	28.0 (0.18)	28.5 (0.10)	28.0 (0.18)	28.0 (0.15)	28.0 (0.25)	28.5 (0.20)
Aug	27.15 (0.14)	29.0 (0.10)	28.0 (0.27)	28.5 (0.05)	28.0 (0.15)	27.5 (0.05)	27.5 (0.27)	28.0 (0.20)
Sep	27.5 (0.20)	28.5 (0.05)	28.5 (0.20)	28.5 (0.08)	27.5 (0.10)	28.5 (0.31)	28.0 (0.16)	28.0 (0.15)
Oct	28.5 (0.15)	28.0 (0.08)	28.5 (0.18)	28.0 (0.17)	27.75 (0.10)	29.0 (0.30)	28.0 (0.19)	28.0 (0.10)
Nov	27.5 (0.05)	28.5 (0.15)	28.5 (0.26)	28.0 (0.22)	27.5 (0.12)	27.5 (0.15)	28.0 (0.21)	27.5 (0.31)
Dec	27.5 (0.18)	27.5 (0.10)	28.0 (0.22)	27.5 (0.25)	27.5 (0.18)	27.0 (0.05)	27.0 (0.22)	27.0 (0.25)
Jan	28.0 (0.10)	28.5 (0.20)	27.5 (0.15)	28.0 (0.18)	29.5 (0.20)	28.0 (0.25)	27.0 (0.25)	28.5 (0.15)

TABLE - 2:18

Monthly mean values of sediment pH in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	7.61 (0.07)	7.67 (0.03)	6.64 (0.10)	6.41 (0.12)	7.60 (0.14)	7.66 (0.13)	6.66 (0.09)	6.42 (0.06)
Mar	7.58 (0.05)	7.50 (0.04)	6.49 (0.12)	6.35 (0.23)	7.57 (0.06)	7.52 90.14)	6.51 (0.12)	6.36 (0.07)
Apr	7.54 (0.12)	7.42 (0.12)	6.38 (0.13)	6.22 (0.04)	7.53 (0.05)	7.43 (0.07)	6.40 (0.07)	6.24 (0.12)
May	7.50 (0.08)	7.52 (0.17)	6.40 (0.09)	6.30 (0.03)	7.50 (0.12)	7.55 (0.12)	6.43 (0.32)	6.32 (6.32)
Jun	7.62 (0.09)	7.64 (0.09)	6.53 (0.08)	6.34 (0.14)	7.61 (0.13)	7.63 (0.13)	6.66 (0.21)	6.36 (0.09)
Jul	7.73 (0.20)	7.72 (0.13)	6.77 (0.07)	6.42 (0.00)	7.72 (0.14)	7.71 (0.09)	6.87 (0.04)	6.44 (0.12)
Aug	7.69 (0.19)	7.80 (0.16)	6.83 (0.09)	6.51 (0.12)	7.70 (0.06)	7.82 (0.10)	6.92 (0.07)	6.50 (0.13)
Sep	7.74 (0.06)	7.83 (0.15)	6.80 (0.13)	6.52 (0.09)	7.75 (0.17)	7.79 (0.13)	7.04 (0.13)	6.50 (0.13)
Oct	7.75 (0.12)	7.79 (0.12)	6.76 (0.2)	6.54 (0.08)	7.74 (0.13)	7.81 (0.10)	6.84 (0.09)	6.52 (0.14)
Nov	7.79 (0.08)	7.82 (0.08)	6.82 (0.06)	6.58 (0.12)	7.77 (0.12)	7.83 (0.12)	6.80 (0.07)	6.56 (0.12)
Dec	7.68 (0.03)	7.73 (0.03)	6.79 (0.07)	6.56 (0.14)	7.64 (0.07)	7.70 (0.14)	6.77 (0.06)	6.58 (0.13)
Jan	7.64 (0.07)	7.66 (0.12)	6.70 (0.10)	6.45 (0.06)	7.66 (0.09)	7.65 (0.12)	6.72 (0.05)	6.47 (0.17)

TABLE - 2:19

Monthly mean values of sediment Eh (-mv) in the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	72 (4.7)	65 (3.7)	200 (20.3)	300 (26.3)	67 (3.9)	70 (4.5)	204 (21.4)	310 (27.9)
Mar	81 (5.9)	85 (8.6)	240 (18.7)	330 (27.9)	73 (5.7)	85 (5.2)	232 (20.3)	326 (22.3)
Apr	86 (3.7)	115 (7.3)	295 (12.5)	340 (31.2)	80 (4.2)	105 911.3)	282 (21.2)	345 (28.9)
May	76 (2.9)	90 (9.3)	276 (13.2)	328 (40.2)	82 (5.3)	95 (4.9)	265 (18.7)	336 (39.4)
Jun	57 (4.5)	85 (3.7)	270 (21.7)	300 (38.9)	65 (7.9)	87 (7.6)	256 (19.3)	302 (41.4)
Jul	30 (3.2)	40 (5.6)	172 (20.3)	285 (32.4)	26 (8.7)	42 (5.7)	192 (26.7)	290 (30.3)
Aug	41 (5.6)	53 (7.8)	140 (18.7)	252 (31.5)	32 (2.9)	50 (8.3)	144 (27.2)	260 (24.8)
Sep	47 (3.9)	60 (8.3)	170 26.3)	235 (20.8)	43 (5.3)	62 (6.4)	161 (13.9)	242 (21.4)
Oct	66 (4.2)	68 (5.5)	186 (22.4)	215 (29.3)	56 (4.2)	65 (7.3)	183 (17.2)	210 (42.0)
Nov	32 (4.1)	50 (3.2)	136 (18.9)	180 (30.1)	33 (3.5)	53 (8.2)	154 (30.5)	197 (44.5)
Dec	40 (2.7)	55 (7.6)	167 (17.6)	205 (22.9)	43 (3.7)	60 (9.4)	175 (18.3)	200 (29.6)
Jan	50 (3.9)	70 (4.5)	180 (21.3)	282 (31.4)	55 (4.9)	75 (8.6)	174 (26.7)	296 (33.7)

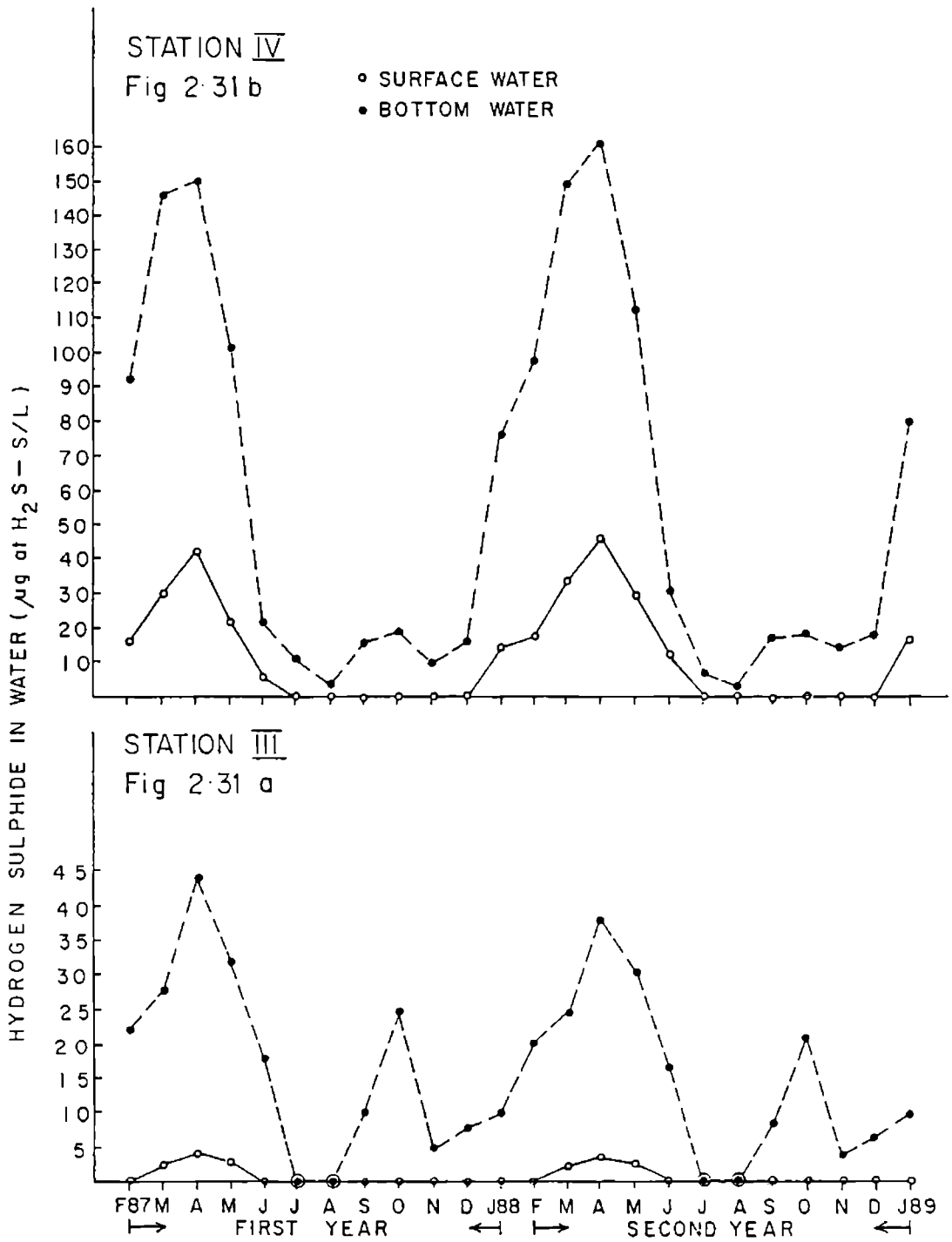


Fig 2.31a and b Variation of Hydrogen Sulphide in Station III and IV.

TABLE - 2:20

Monthly mean values of organic carbon (%) in the sediment of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	2.56 (0.72)	3.14 (0.62)	2.92 (0.42)	3.72 (0.32)	2.11 (0.68)	2.54 (0.57)	3.12 (0.57)	3.76 (0.48)
Mar	2.77 (0.86)	3.07 (0.66)	2.82 (0.57)	3.52 (0.28)	1.98 (0.92)	2.67 (0.48)	2.97 (0.32)	3.24 (0.32)
Apr	2.97 (0.92)	2.92 (0.73)	2.73 (0.63)	2.86 (0.46)	2.88 (0.14)	2.72 (0.92)	2.76 (0.91)	2.76 (0.28)
May	3.04 (0.87)	3.09 (0.81)	2.88 (0.69)	2.52 (0.51)	3.12 (0.32)	2.97 (0.37)	2.89 (0.82)	2.82 (0.93)
Jun	2.92 (0.78)	3.06 (0.57)	2.96 (0.82)	2.57 (0.32)	2.96 (0.17)	3.04 (0.48)	2.98 (0.37)	2.93 (0.00)
Jul	2.10 (0.86)	2.87 (0.67)	3.08 (0.57)	3.77 (0.42)	2.02 (0.78)	3.04 (0.53)	3.13 (0.91)	3.13 (0.81)
Aug	2.75 (0.92)	2.92 (().32)	3.36 (0.39)	3.83 (0.49)	2.72 (0.82)	2.71 (0.62)	3.42 (0.72)	3.26 (0.80)
Sep	2.79 (0.76)	2.76 (0.39)	3.54 (0.46)	3.88 (0.31)	2.98 (0.81)	2.86 (0.51)	3.59 (0.88)	3.52 (0.73)
Oct	2.60 (0.66)	2.66 (0.47)	3.43 (0.35)	3.94 (0.62)	2.62 (0.93)	2.53 (0.38)	3.62 (0.69)	3.78 (0.84)
Nov	2.32 (0.54)	2.62 (0.67)	3.42 (0.53)	4.21 (0.73)	2.42 (0.77)	2.10 (0.68)	3.77 (0.70)	3.87 (0.67)
Dec	2.38 (0.89)	2.55 (0.82)	3.36 (0.52)	4.06 (0.81)	2.31 (0.76)	2.04 (0.91)	3.44 (0.42)	3.94 (0.52)
Jan	2.44 (0.14)	3.20 (0.37)	3.30 (0.47)	3.86 (0.92)	2.44 (0.68)	2.32 (0.73)	3.64 (0.68)	4.06 (0.55)

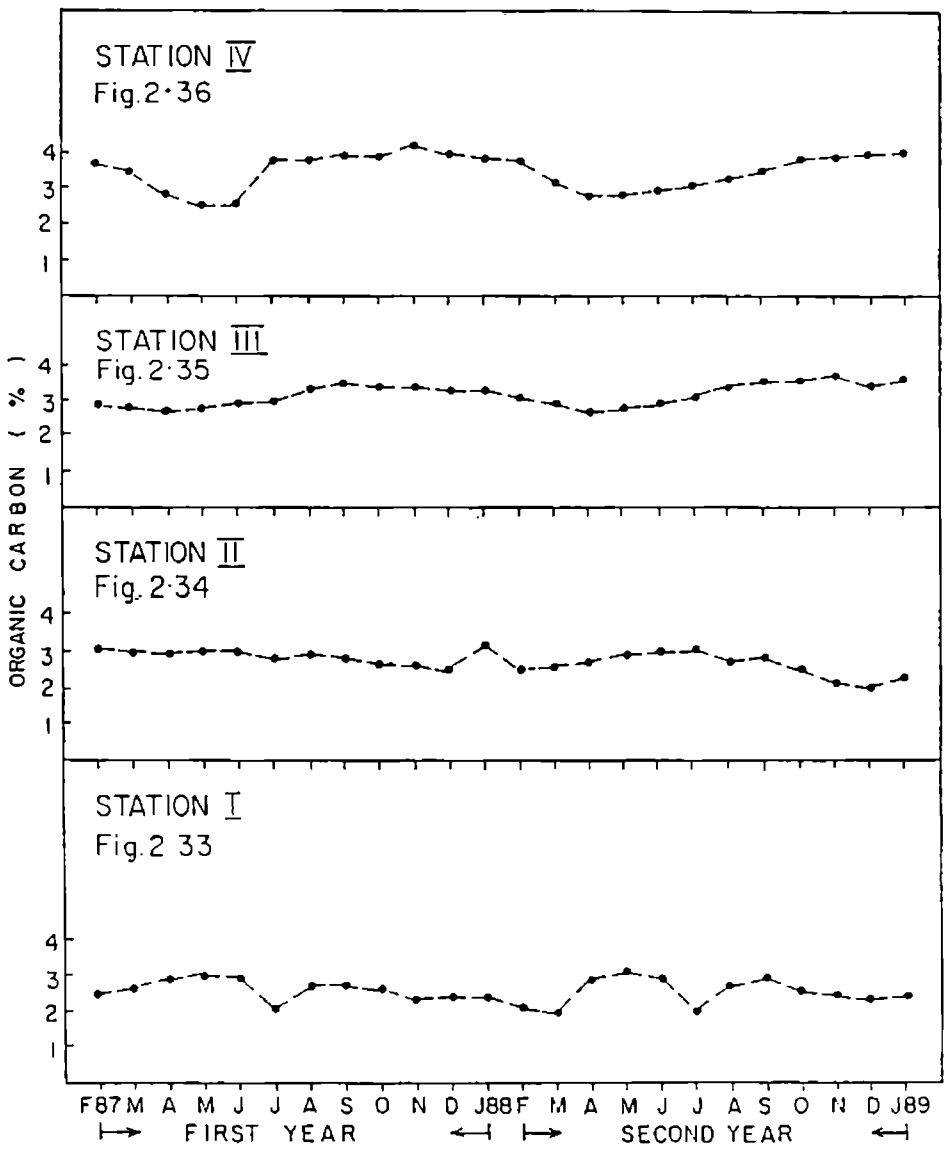


Fig 2.33 to 2.36 Variation of organic Carbon in the sediments of different stations.

TABLE - 2:21

Monthly mean values of available phosphorus (µg at Po_4-P/g) in the sediment of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	1.00 (0.03)	0.98 (0.21)	1.89 (0.18)	2.91 (0.34)	1.02 (0.31)	1.04 (0.38)	2.06 (0.33)	2.82 (1.03)
Mar	1.12 (0.14)	0.91 (0.26)	1.93 (0.14)	2.96 (0.21)	1.22 (0.21)	1.21 (0.41)	2.90 (0.67)	2.94 (0.37)
Apr	1.14 (0.00)	1.06 (0.31)	2.76 (0.22)	3.19 (0.18)	1.24 (0.23)	1.10 (0.37)	3.32 (1.13)	3.24 (1.03)
May	1.34 (0.13)	0.90 (0.12)	2.44 (0.36)	3.01 (0.43)	1.44 (0.32)	0.90 (0.42)	2.96 (0.98)	3.19 (0.98)
Jun	1.52 (0.22)	0.85 (0.21)	1.76 (0.43)	2.65 (0.64)	1.56 (0.28)	1.0 (0.14)	1.88 (0.92)	2.27 (0.93)
Jul	1.60 (0.31)	0.92 (0.31)	0.92 (0.51)	1.92 (0.57)	1.02 (0.34)	0.86 (0.21)	0.96 (0.43)	1.94 (0.67)
Aug	1.41 (0.22)	0.98 (0.42)	0.81 (0.60)	1.62 (0.81)	0.77 (0.16)	0.92 (0.15)	0.85 (0.18)	1.77 (0.32)
Sep	1.20 (0.26)	1.05 (0.03)	0.85 (0.20)	1.24 (0.28)	0.95 (0.32)	1.03 (0.31)	0.87 (0.16)	1.49 (0.34)
Oct	0.98 (0.34)	1.12 (0.41)	0.90 (0.31)	1.01 (0.42)	1.20 (0.29)	0.94 (0.28)	0.89 (0.21)	1.32 (0.52)
Nov	1.06 (0.71)	0.97 (0.37)	0.86 (0.17)	0.98 (0.39)	1.04 (0.51)	0.76 (0.17)	0.82 (0.31)	1.25 (0.76)
Dec	0.96 (0.38)	0.86 (0.46)	0.92 (0.37)	1.52 (0.71)	1.0 (0.00)	0.97 (0.21)	0.91 (0.14)	1.59 (0.32)
Jan	0.92 (0.46)	1.0 (0.63)	1.54 (0.62)	2.72 (0.31)	0.96 (0.21)	1.08 (0.44)	1.64 (0.42)	2.75 (0.65)

TABLE - 2:22

Monthly mean values of available nitrate (µg at No_3-N/g) in the sediment of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb	1.84 (0.13)	1.02 (0.17)	0.60 (0.17)	0.55 (0.15)	1.82 (0.21)	1.02 (0.24)	0.62 (0.13)	0.54 (0.19)
Mar	1.26 (0.17)	1.14 (0.10)	0.62 (0.21)	0.40 (0.14)	1.24 (0.20)	1.24 (0.28)	0.65 (0.14)	0.42 (0.11)
Apr	1.70 (0.12)	1.35 (0.09)	0.57 (0.18)	0.31 (0.20)	1.72 (0.13)	1.54 (0.13)	0.59 (0.09)	0.39 (0.07)
May	1.53 (0.12)	1.45 (0.12)	0.61 (0.07)	0.47 (0.14)	1.55 (0.13)	1.62 (0.29)	0.63 (0.07)	0.53 (0.03)
Jun	2.40 (0.25)	1.66 (0.21)	0.79 (0.09)	0.53 (0.08)	2.43 (0.22)	1.73 (0.47)	0.88 (0.02)	0.62 (0.07)
Jul	1.67 (0.32)	1.73 (0.26)	0.98 (0.12)	0.81 (0.12)	1.77 (0.47)	1.94 (0.21)	1.42 (0.34)	0.98 (0.04)
Aug	0.81 (0.45)	1.17 (0.37)	1.12 (0.34)	0.96 (0.10)	0.87 (0.31)	0.97 (0.12)	1.02 (0.12)	1.04 (0.37)
Sep	1.14 (0.47)	0.92 (0.07)	1.16 (0.21)	0.82 (0.09)	1.24 (0.41)	1.01 (0.32)	0.98 (0.14)	0.96 (0.14)
Oct	1.52 (0.51)	1.43 (0.17)	1.03 (0.13)	0.94 (0.07)	1.45 (0.34)	1.32 (0.43)	0.82 (0.28)	1.06 (0.34)
Nov	1.81 (0.32)	1.36 (0.13)	0.94 (0.46)	0.87 (0.03)	1.72 (0.27)	1.45 (0.25)	1.07 (0.42)	0.92 (0.09)
Dec	1.79 (0.49)	1.24 (0.04)	0.87 (0.59)	6.72 (0.04)	1.83 (0.38)	1.27 (0.32)	0.95 (0.21)	0.88 (0.13)
Jan	1.96 (0.37)	0.90 (0.10)	0.76 (0.32)	0.44 (0.10)	0.74 (0.48)	0.90 (0.21)	0.79 (0.16)	0.60 (0.19)

TABLE - 2:23

Monthly mean values of total sulphide (μg at H_2S-S/g) in the sediment of the four stations, standard deviation is given in parentheses.

	FIRST YEAR (87-88)				SECOND YEAR (88-89)			
	STATIONS				STATIONS			
Month	I	II	III	IV	I	II	III	IV
Feb		3.6 (0.98)	1414.2 (12.3)	2316.2 (28.4)		3.4 (1.22)	1320.6 (14.8)	2330.2 (32.4)
Mar	0.81 (0.42)	4.9 (1.23)	2619.0 (14.5)	4137.4 (32.5)	0.91 (0.51)	4.7 (0.98)	2725.6 (41.3)	3236.8 (30.2)
Apr	0.92 (0.17)	6.2 (1.42)	3128.9 (20.3)	4244.7 (36.8)	1.06 (0.32)	5.4 (1.42)	3238.6 (52.7)	4344.9 (45.6)
May	0.87 (0.32)	4.4 (0.84)	3027.4 (15.7)	4141.8 (44.5)	0.93 (0.21)	4.2 (1.23)	3127.5 (42.3)	4140.7 (40.5)
Jun	0.72 (0.41)	1.9 (0.44)	2910.1 (17.8)	3929.5 (47.3)	0.77 (0.14)	2.8 (0.87)	2812.3 (27.1)	4030.4 (35.7)
Jul			837.3 (41.2)	2165.5 (92.4)	-	-	918.0 (43.3)	2418.4 (41.4)
Aug		-		1111.7 (21.3)	-	-	215.0 (13.7)	1212.5 (22.3)
Sep	-	-		670.6 (18.2)			171.3 (12.1)	712.0 (10.6)
Oct	-			422.4 (13.4)	-	-	116.2 (16.8)	611.3 (11.4)
Nov	-			311.5 (17.2)		-	169.7 (11.1)	510.0 (13.5)
Dec				512.3 (25.5)	-		296.2 (12.3)	711.4 (9.4)
Jan	-	2.0 (0.50)	912.7 (13.3)	1292.3 (24.9)	-	2.2	870.3 (10.5)	1228.0 (30.5)

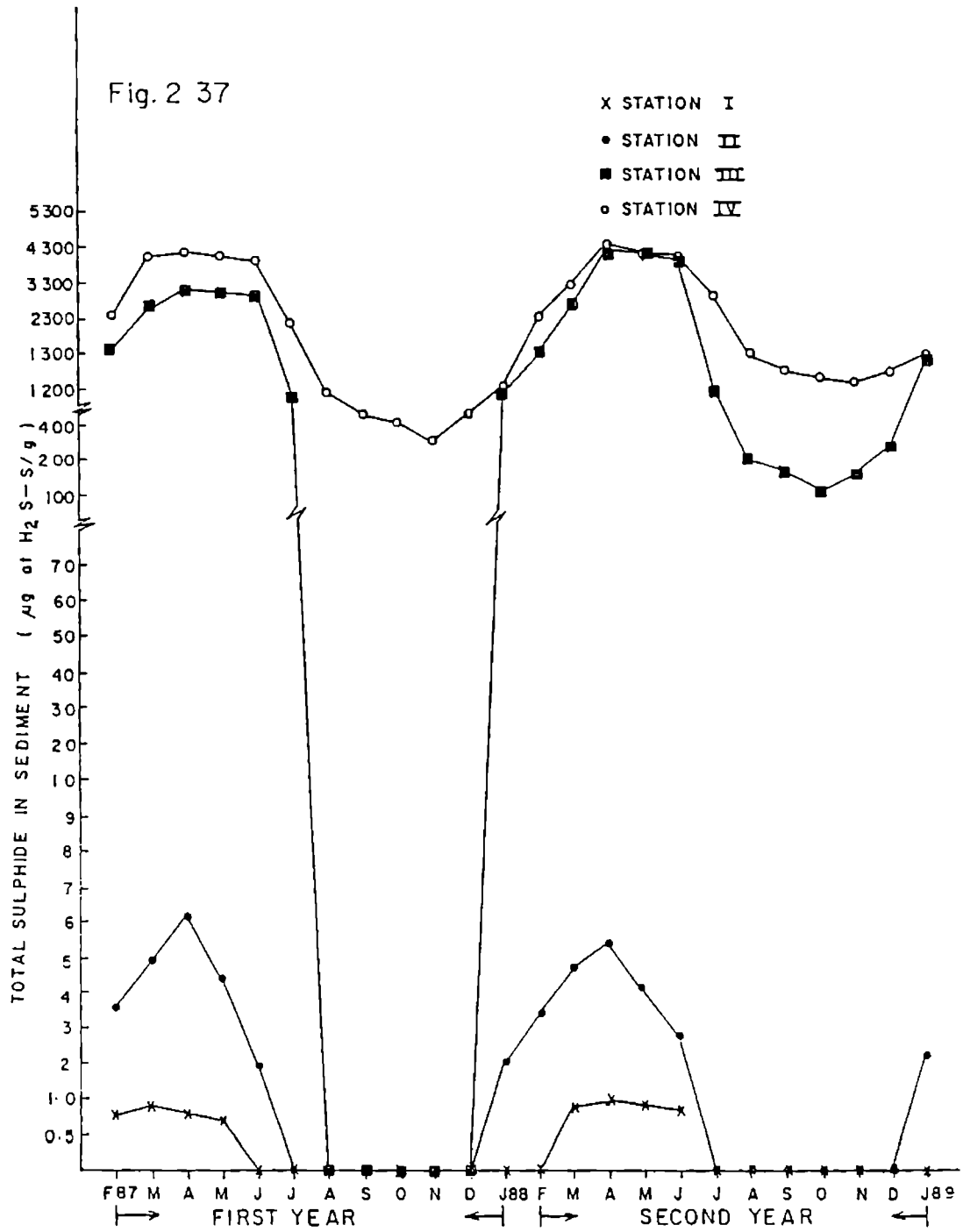


Fig 2.37 Total Sulphide variation in different stations.

TABLE - 2:24

Correlation matrix of hydrographical and sedimentological parameters in Station I

S. Temp	B. Temp	Soil Temp	S.S%	S.DO	S.pH	S.No_3	S.No_2	S.Po_4	B.S%	B.DO	B.pH	B.No_3	B.No_2	B.Po_4	Soil pH	Soil Eh	Soil OC	Soil Po_4	Soil No_3	Soil TS	
1.00	.870	.855	.804	-.828	-.764	-.558	-.426	-.671	.784	-.881	-.470	-.577	-.418	-.686	-.826	-.793	.351	.295	.241	.703	Surface Water Temperature
	1.00	.850	.834	-.840	-.628	-.477	-.358	-.667	.817	-.858	-.446	-.496	-.347	-.699	-.689	-.737	.166	.253	.452	.563	Bottom Water Temperature
		1.00	.827	-.850	-.568	-.424	-.366	-.616	.830	-.855	-.472	-.440	-.356	-.624	-.813	-.857	.234	.208	.215	.583	Soil Temperature
			1.00	-.945	-.549	-.652	-.531	-.744	.987	-.903	-.448	-.656	-.537	-.725	-.805	-.901	.329	.145	.236	.468	Surface Water Salinity
				1.00	.642	.574	.435	.706	-.959	.937	-.532	.574	.424	.694	.854	.877	-.322	-.279	-.257	-.521	Surface Water Oxygen
					1.00	.401	.271	.476	-.520	.723	.664	.393	.266	.471	.702	.644	-.502	-.481	-.174	-.706	Surface Water pH
						1.00	.915	.809	-.677	.447	.143	.986	.915	.761	.467	.639	-.245	.271	-.061	-.078	Surface Water Nitrate
							1.00	.750	-.566	.294	.163	.916	.994	.709	.337	.609	-.144	.364	-.063	-.052	Surface Water Nitrite
								1.00	-.760	.674	.120	.810	.722	.992	.661	.690	-.094	.043	.494	-.330	Surface Water Reactive Phosphorus
									1.00	-.882	-.495	-.677	-.564	-.741	-.793	-.893	.271	.113	.226	.418	Bottom Water Salinity
										1.00	.548	.445	.279	.645	.858	.844	-.388	-.442	-.344	-.672	Bottom Water Oxygen
											1.00	.205	.192	.140	.435	.409	-.434	-.404	-.022	-.491	Bottom Water pH
												1.00	.912	.771	.491	.632	-.192	.313	-.053	-.089	Bottom Water Nitrate
													1.00	.679	.336	.612	-.162	.388	-.026	-.050	Bottom Water Nitrite
														1.00	.655	.655	-.029	.038	.542	-.359	Bottom Water Reactive Phosphorus
															1.00	.820	-.371	-.310	-.170	-.677	Soil pH
																1.00	.464	-.233	.103	-.561	Soil Eh
																	1.00	.797	-.079	-.554	Soil Organic Carbon
																		1.00	.206	.479	Soil Available phosphorus
																			1.00	.286	Soil Available Nitrate
																				1.00	Soil Total Sulphide

r values above .4 are significant at 5% level.

TABLE - 2:25

Correlation matrix of hydrographical and sedimentological parameters in Station II

S. Temp	S.S%	S.DO	S.pH	S. No_3	S. No_2	S. Po_4	B. Temp	B.S%	B.DO	B.pH	B. No_3	B. No_2	B. Po_4	Soil Temp	Soil pH	Soil Eh	Soil OC	Soil Po_4	Soil No_3	Soil TS	
1.00	.797	-.807	-.697	-.533	-.478	-.548	.468	.765	-.699	-.432	-.503	-.480	-.556	.704	-.791	-.425	.216	.371	-.038	.864	Surface Water Temperature
	1.00	-.917	-.472	-.670	-.635	-.614	.547	.986	-.856	-.455	-.642	-.652	-.573	.733	-.898	-.580	.381	.397	-.080	.959	Surface Water Salinity
		1.00	.476	.595	.483	.480	-.574	-.902	.947	.470	.566	.509	.420	-.620	.924	.406	.454	-.296	-.181	-.919	Surface Water Oxygen
			1.00	.276	.320	.442	.694	-.436	.665	.663	.265	2.94	.461	-.564	.629	.472	-.480	-.557	-.005	-.618	Surface Water pH
				1.00	.803	.802	-.098	-.643	.587	.354	.998	.728	.800	-.462	.567	.488	.154	-.202	.081	-.617	Surface Water Nitrate
					1.00	.933	-.238	-.650	.456	.276	.781	.982	.910	-.462	.429	.445	.168	-.411	.511	-.539	Surface Water Nitrite
						1.00	-.132	-.607	.473	.182	.782	.901	.968	-.483	.458	.593	.190	-.389	.498	-.570	Surface Water Reactive Phosphorus
							1.00	.508	-.613	.561	-.100	-.242	-.130	.541	-.582	-.531	-.284	.238	-.293	.478	Bottom Water Temperature
								1.00	-.850	-.413	-.615	-.671	-.560	.735	-.866	-.219	.397	.401	-.120	.936	Bottom Water Salinity
									1.00	.477	.566	.476	.406	-.509	.879	.298	-.453	-.117	-.223	-.877	Bottom Water Oxygen
										1.00	.347	.261	.202	.443	.473	.536	-.446	-.418	-.278	-.449	Bottom Water pH
											1.00	.701	.787	-.439	.546	.471	.172	-.181	.073	-.590	Bottom Water Nitrate
												1.00	.865	-.461	.455	.453	.129	-.431	.495	-.548	Bottom Water Nitrite
													1.00	-.472	.416	.527	.218	-.391	.537	-.537	Bottom Water Reactive Phosphorus
														1.00	-.536	-.482	.433	.413	-.205	.669	Soil Temperature
															1.00	.401	-.348	-.272	-.181	-.940	Soil pH
																1.00	.473	-.485	.120	-.677	Soil Eh
																	1.00	-.023	.152	-.671	Soil Organic Carbon
																		1.00	-.340	.432	Soil Available Phosphorus
																			1.00	.010	Soil Available Nitrate
																				1.00	Soil Total Sulphide

r values above .4 are significant at 5% level.

TABLE - 2:26

Correlation matrix of hydrographical and sedimentological parameters in Station III

S. Temp	S.S%	S.DO	S.pH	S. No_3	S. No_2	S. Po_4	S. H_2S	B. Temp	B.S%	B.DO	B.pH	B. No_3	B. No_2	B. Po_4	B. H_2S	Soil Temp	Soil pH	Soil Eh	Soil OC	Soil Po_4	Soil No_3	Soil TS	
1.00	.641	-.550	-.454	-.298	-.337	.662	.662	.714	.624	-.624	-.441	-.185	-.317	.696	.761	.672	-.734	-.686	-.526	.618	-.532	.501	Surface Water Temperature
	1.00	-.869	-.691	-.429	-.471	.817	.650	.449	.997	-.720	-.719	-.351	-.466	.859	.811	.465	-.845	-.899	-.674	.844	-.885	.509	Surface Water Salinity
		1.00	.648	.467	.493	-.794	-.664	-.485	-.878	.829	.667	.446	.499	-.795	-.761	-.323	.746	.716	.568	-.868	.776	-.815	Surface Water Oxygen
			1.00	-.132	-.011	-.854	-.741	-.521	-.727	.753	.756	.067	-.025	-.829	-.650	-.644	.789	+.634	.882	-.853	.593	-.524	Surface Water pH
				1.00	.836	-.091	-.429	-.088	-.392	.245	.193	.661	.872	-.202	-.417	.019	.214	-.781	-.127	-.223	.508	-.641	Surface Water Nitrate
					1.00	-.211	-.437	-.270	-.434	.306	.227	.490	.988	-.278	-.510	-.145	.295	-.597	-.073	-.338	.541	-.519	Surface Water Nitrite
						1.00	.847	.671	.827	-.853	-.797	-.193	-.197	.975	.833	.702	-.917	-.840	-.860	.959	-.764	.673	Surface Water Reactive Phospho
							1.00	.756	.658	-.736	-.783	-.438	-.406	.863	.814	.750	-.823	-.783	-.712	.830	-.640	.803	Surface Water H_2S
								1.00	.440	-.603	-.510	-.093	-.238	.630	.776	.674	-.661	-.613	-.534	.645	-.450	.797	Bottom Water Temperature
									1.00	-.730	-.736	-.334	-.427	.863	.796	.458	-.836	-.696	-.685	.858	-.874	.542	Bottom Water Salinity
										1.00	.682	.320	.301	-.827	-.806	-.571	.778	+.868	.714	-.869	.625	-.842	Bottom Water Oxygen
											1.00	.234	.209	-.814	-.729	-.508	.763	+.629	.682	-.826	.649	-.780	Bottom Water pH
												1.00	.503	-.246	-.430	.087	.229	-.571	.083	-.277	.536	-.699	Bottom Water Nitrate
													1.00	-.262	-.512	-.144	.277	-.542	-.076	-.324	.546	-.430	Bottom Water Nitrite
														1.00	.841	.698	-.939	-.718	-.871	.947	-.807	.786	Bottom Water Reactive Phospho
															1.00	.751	-.838	-.709	-.675	.832	-.785	.816	Bottom Water H_2S
																1.00	-.683	-.724	-.738	.618	-.452	.670	Soil Temperature
																	1.00	+.753	+.823	-.900	.776	-.808	Soil pH
																		1.00	+.675	-.448	+.544	-.678	Soil Eh
																			1.00	-.795	.606	-.645	Soil Organic Carbon
																				1.00	-.800	.763	Soil Available Phosphorus
																					1.00	-.439	Soil Available Nitrate
																						1.00	Soil Total Sulphide

r values above .4 are significant at 5% level.

TABLE - 2:27

Correlation matrix of hydrographical and sedimentological parameters in Station IV

S. Temp	S.S‰	S.DO	S.pH	S. No_3	S. No_2	S. Po_4	S. H_2S	B. Temp	B.S‰	B.DO	B.pH	B. No_3	B. No_2	B. Po_4	B. H_2S	Soil Temp	Soil pH	Soil Eh	Soil OC	Soil Po_4	Soil No_3	Soil TS	
1.00	.839	-.901	-.766	-.345	-.690	.834	.810	.808	.848	-.845	-.603	-.471	-.641	.843	.687	.824	-.782	-.694	-.675	.850	-.743	.570	Surface Water Temperature
	1.00	-.918	-.882	-.644	-.883	.912	.910	.703	.991	-.959	-.761	-.743	-.814	.910	.642	.792	-.751	-.856	-.484	.922	-.922	.401	Surface Water Salinity
		1.00	.843	.363	.718	-.869	-.867	-.829	-.917	.957	.724	.512	.662	-.866	-.555	-.885	.815	.746	.595	-.969	.852	-.858	Surface Water Oxygen
			1.00	.527	.757	-.895	-.847	-.581	-.877	.882	.820	.682	.692	-.889	-.475	-.709	.709	.671	.636	-.880	.924	-.556	Surface Water pH
				1.00	.816	-.510	-.552	-.233	-.611	.564	.490	.900	.785	-.509	-.561	-.240	.235	.818	-.031	-.384	.590	-.697	Surface Water Nitrate
					1.00	-.814	-.840	-.570	-.874	.806	.642	.791	.962	-.822	-.588	-.588	.658	.670	.321	-.708	.763	-.638	Surface Water Nitrite
						1.00	.965	.702	.905	-.858	-.779	-.651	-.753	.996	.498	.762	-.816	-.813	-.621	.895	-.895	.830	Surface Water Reactive Ph[illegible]
							1.00	.714	.900	-.868	-.767	-.623	-.781	.961	.526	.804	-.861	-.823	-.563	.875	-.876	.768	Surface Water H_2S
								1.00	.701	-.757	-.448	-.370	-.546	.705	.682	.792	-.718	-.707	-.620	.762	-.568	.590	Bottom Water Temperature
									1.00	-.947	-.744	-.716	-.799	.905	.616	.792	-.748	-.603	-.518	.923	-.923	.631	Bottom Water Salinity
										1.00	.767	.674	.749	-.851	-.687	-.858	.754	.803	.480	-.939	.907	-.861	Bottom Water Oxygen
											1.00	.583	.589	-.746	-.571	-.621	.562	.702	.501	-.763	.838	-.792	Bottom Water pH
												1.00	.766	-.646	-.567	-.337	.316	-.589	.179	-.569	.732	-.608	Bottom Water Nitrate
													1.00	-.757	-.582	-.543	.581	-.649	.285	-.674	.694	-.573	Bottom Water Nitrite
														1.00	.466	.755	-.819	-.837	-.656	.886	-.879	.803	Bottom Water Reactive Ph[illegible]
															1.00	.514	-.642	-.805	-.702	.594	-.617	.821	Bottom Water H_2S
																1.00	-.807	-.654	-.544	.839	-.773	.552	Soil Temperature
																	1.00	.708	.580	-.762	.679	-.878	Soil pH
																		1.00	+.721	-.725	.687	-.696	Soil Eh
																			1.00	-.623	.474	-.765	Soil Organic Carbon
																				1.00	-.894	.812	Soil Available Phosphorus
																					1.00	-.529	Soil Available Nitrate
																						1.00	Soil Total Sulphide

r values above .4 are significant at 5% level.

TABLE - 2:28

Monthly total rainfall (mm) during February 87 to January 89 at Kayamkulam

Month	FIRST YEAR (87-88)	SECOND YEAR (88-89)
	TOTAL RAINFALL (mm)	TOTAL RAINFALL (mm)
Feb.	3.0	48.6
Mar	4.2	89.0
Apr	78.2	144.6
May	398.6	317.6
June	575.5	339.2
July	115.4	588.2
Aug	399.3	263.9
Sep	198.1	658.6
Oct	546.8	54.0
Nov	136.8	48.9
Dec	108.0	23.2
Jan	Nil	11.0

TABLE - 2:29

DISTRIBUTION OF MACROBENTHIC FAUNA IN STATION I (Nos/0.1 m^2

Month / Group		F	M	A	M	J	J	A	S	O	N	D	J
Polychaetes	1987 - 88 First Year	86	114	120	121	68	36	34	48	34	42	70	78
	1988 - 89 Second Year	102	144	186	130	90	56	44	60	65	94	66	98
Tanaids	First Year	40	28	26	20	21	22	25	28	39	41	42	38
	Second Year	50	18	19	12	14	20	31	29	37	36	51	62
Amphipods	First Year	12	10	5	11	13	11	18	26	32	37	43	21
	Second Year	12	7	4	8	11	10	21	29	30	40	38	18
Isopods	First Year	2	3	0	5	8	10	0	4	0	9	10	9
	Second Year	3	0	1	0	2	4	1	9	0	5	12	7
Bivalves	First Year	6	9	8	3	7	9	1	0	1	3	8	12
	Second Year	5	7	4	3	2	7	0	0	0	2	4	14
Gastropods	First Year	5	1	0	0	0	0	0	0	0	0	4	6
	Second Year	4	0	0	0	0	0	0	0	0	0	7	2
Nematods	First Year	10	14	12	10	5	0	0	0	0	0	4	3
	Second Year	8	7	11	9	0	0	0	0	2	0	1	0

TABLE - 2:30

DISTRIBUTION OF MACROBENTHIC FAUNA IN STATION II (Nos/0.1 m^2)

Month / Group		F	M	A	M	J	J	A	S	O	N	D	J
Polychaetes	1987 88 First year	92	86	103	114	85	52	30	19	26	37	42	63
	1988 - 89 Second year	104	100	114	126	103	75	50	24	24	54	48	60
Tanaids	First Year	24	15	9	6	11	10	12	32	45	18	21	11
	Second Year	26	10	10	10	14	18	14	34	40	19	26	19
Amphipods	First Year	13	10	11	12	10	15	16	12	14	21	12	15
	Second Year	12	11	9	10	11	12	17	21	29	20	14	17
Isopods	First Year	3	2	5	4	3	8	3	4	1	2	3	3
	Second Year	0	2	8	9	5	12	8	4	6	0	1	2
Bivalves	First Year	6	9	6	3	0	0	0	0	2	3	5	4
	Second Year	3	2	2	1	0	0	0	1	1	2	3	2
Gastropods	First Year	3	3	0	0	0	0	0	0	0	0	6	8
	Second Year	2	1	0	0	0	0	0	0	0	2	15	10
Nematods	First Year	8	4	7	4	0	0	0	0	3	0	1	0
	Second Year	6	7	11	2	0	0	0	0	0	0	0	2

TABLE - 2:31

DISTRIBUTION OF MACROBENTHIC FAUNA IN STATION III (Nos/0.1 m^2)

Month / Group		F	M	A	M	J	J	A	S	O	N	D	J
Polychaetes	First year	15	8	6	5	6	10	3	5	4	5	18	14
	Second year	6	10	9	8	11	6	4	4	3	12	19	17
Tanaids	First Year	0	0	0	0	0	0	0	0	0	6	9	0
	Second Year	0	0	0	0	0	0	0	0	0	4	0	0

TABLE - 2:32

DISTRIBUTION OF MACROBENTHIC FAUNA IN STATION IV (Nos/0.1 m^2)

Month / Group		F	M	A	M	J	J	A	S	O	N	D	J
Polychaetes	First year	11	6	0	4	9	6	5	4	3	4	13	11
	Second year	10	9	5	3	8	4	7	5	0	7	11	12

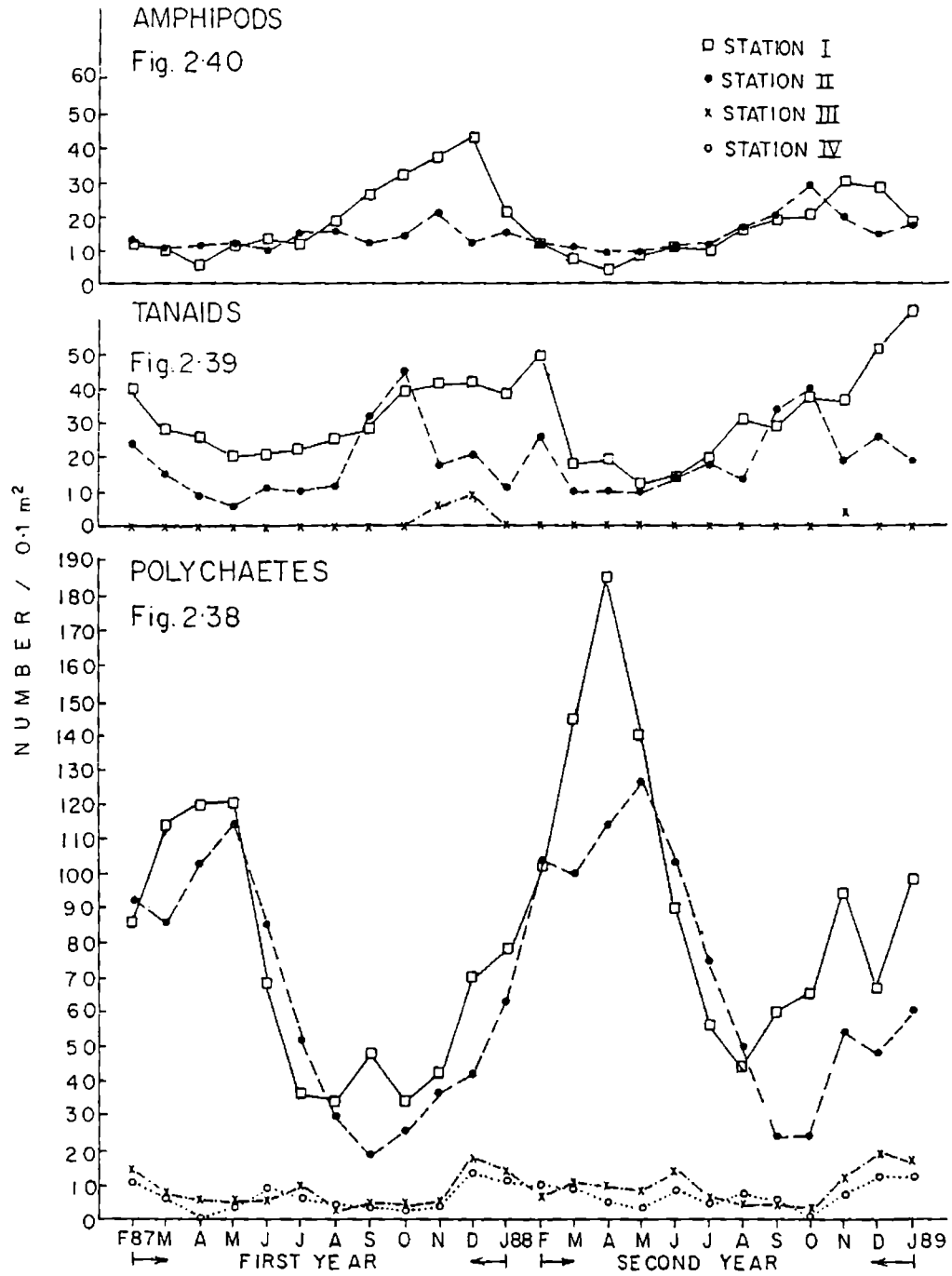


Fig 2.38 to 2.40 Distribution of macro benthic fauna in different stations.

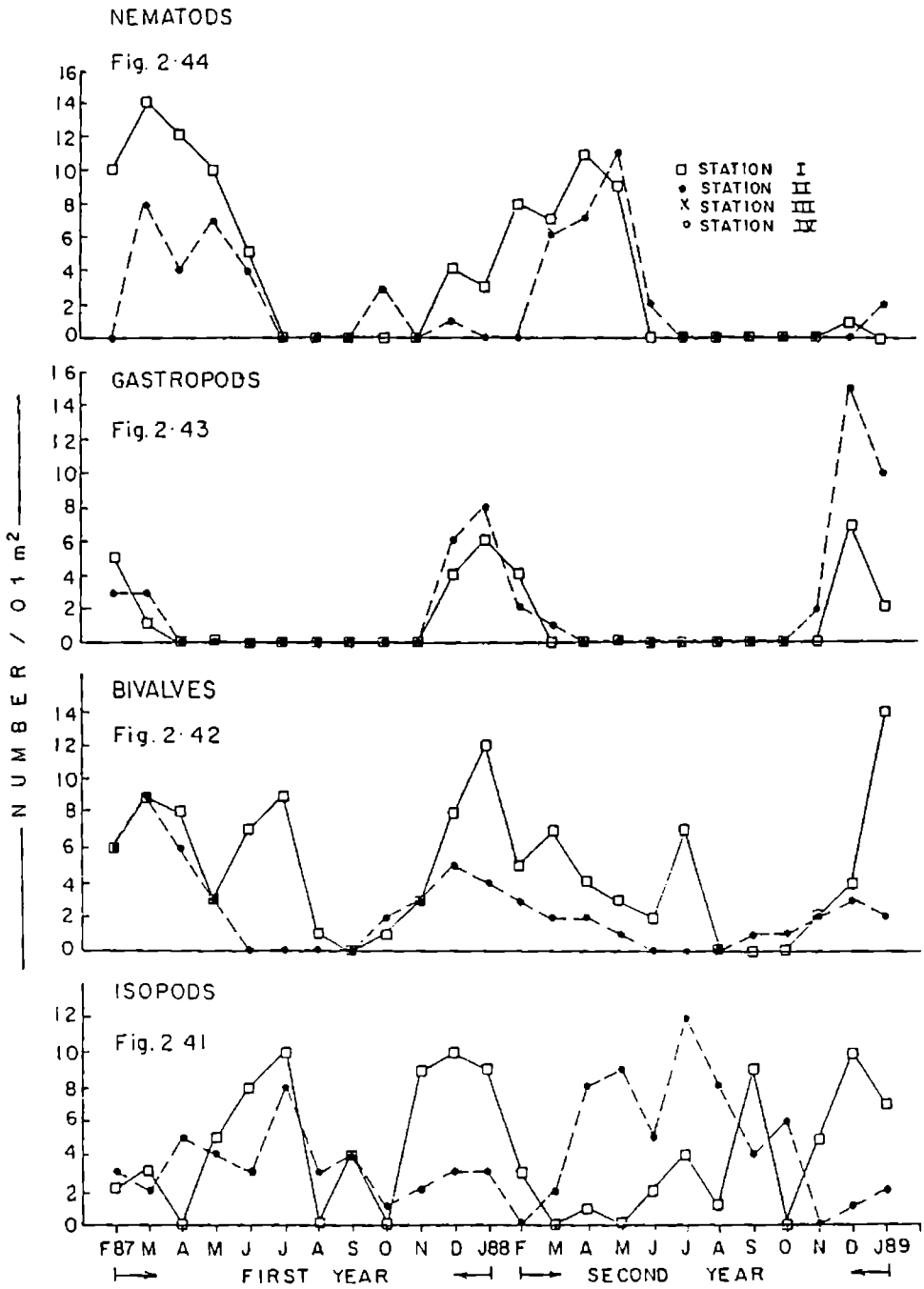


Fig 2.41 to 2.44 Distribution of macro benthic fauna in different stations.

TABLE - 2:33

ANOVA

SOURCE	DF	SS	MSS	F	REMARKS
TREAT	3	137684.800	45894.920	41.10	(HI SIG 1%)
ERROR	92	102727.300	1116.601		

MEAN COMPARISONS			REMARKS
T1		T2	N.S.
T1		T3	SIG
T1	-	T4	SIG
T2		T3	SIG
T2	-	T3	SIG
T3		T4	N.S.

TABLE - 2:34

DISTRIBUTION OF PRAWN SEED IN DIFFERENT STATIONS (NO/HAUL)

		F87	M	A	M	J	J	A	S	O	N	D	J88	F88	M	A	M	J	J	A	S	O	N	D	J89
	P. indicus	32	40	28	12	10	7	3	5	7	19	24	24	41	51	26	14	9	8	3	7	10	26	31	32
ST. I	M. dobsoni	20	22	12	13	10	6	5	7	9	41	20	18	34	28	16	12	9	6	5	6	8	10	14	20
	M. monoceros	7	5	3	2	7	3	0	2	1	3	4	6	12	7	6	5	3	4	9	0	2	3	4	9
	P. indicus	12	18	20	10	14	5	3	6	6	10	14	14	34	32	18	10	7	6	4	5	12	16	24	20
ST. II	M. dobsoni	12	14	10	8	6	4	3	5	7	9	9	10	13	15	14	9	7	4	3	4	6	10	12	12
	M. monoceros	3	0	4	0	1	2	1	3	1	0	1	2	1	4	1	5	2	1	1	2	0	1	2	3
	P. indicus	0	0	0	0	0	2	0	0	1	3	1	0	0	0	0	0	0	1	0	0	2	0	0	0
ST. III	M. dobsoni	0	0	0	4	6	7	3	2	3	4	3	0	0	0	0	8	7	2	2	0	1	2	3	2
	M. monoceros	0	0	0	3	2	4	2	2	1	4	1	2	0	0	0	0	3	1	0	0	2	4	2	1
	P. indicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
ST. IV	M. dobsoni	0	0	0	0	3	2	1	3	4	2	5	2	0	0	0	0	0	3	1	6	2	3	3	0
	M. monoceros	0	0	0	0	2	4	0	0	3	1	4	0	0	0	0	0	1	0	4	3	1	3	6	0

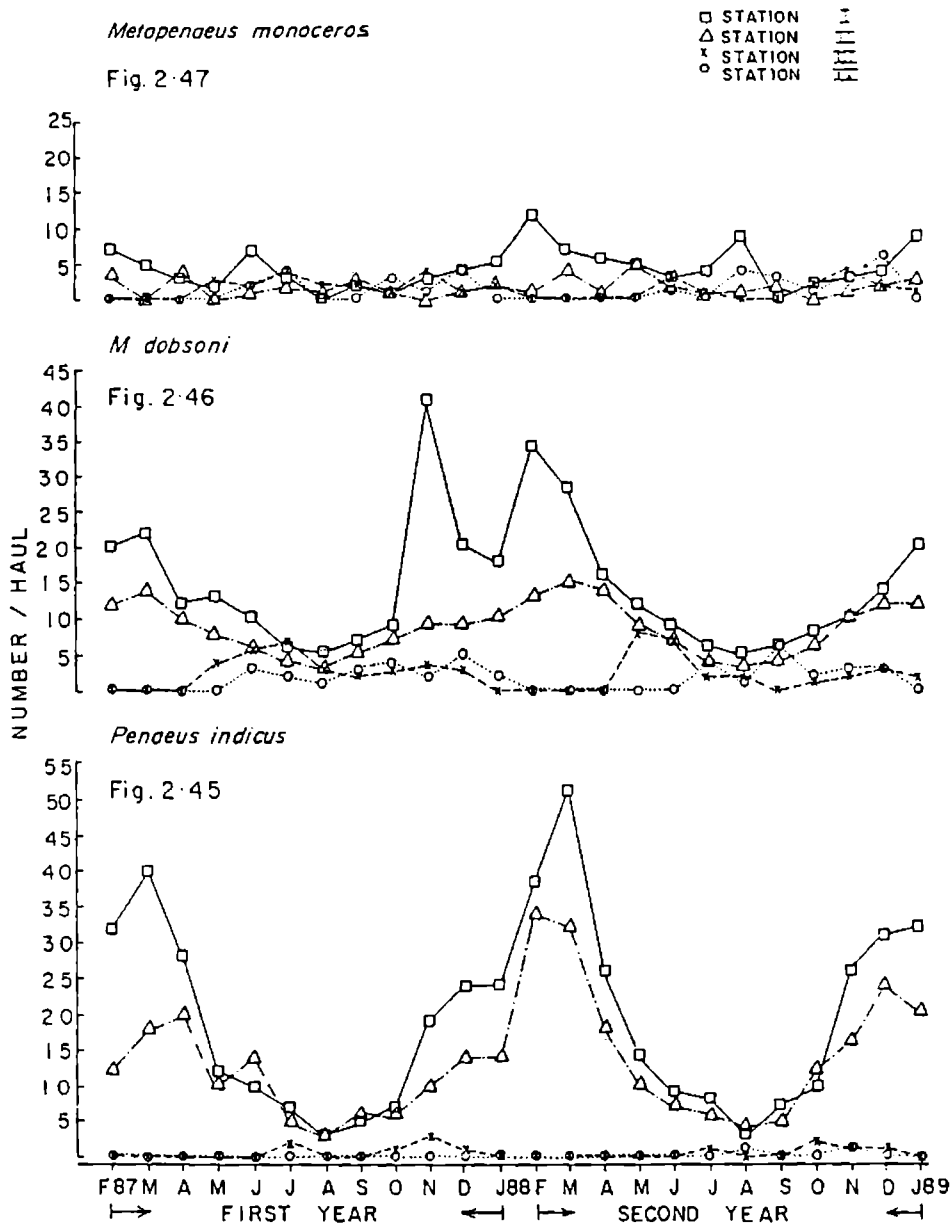


Fig 2.45 to 2.47 Distribution of penaeid prawn seed in different stations.

TABLE - 2:35

ANOVA

Penaeus indicus

SOURCE	DF	SUM.SQR	MEAN SQR	F-VAL	REMARKS
TREAT	3	6723.877	2241.292	35.18	HI SIG (1%)
ERROR	92	5861.083	63.707		

MEAN COMPARISONS		REMARKS
T1	T2	SIG
T1	T3	SIG
T1	T4	SIG
T2	T3	SIG
T2	T4	SIG
T3	T4	N.S.

TABLE - 2:36

ANOVA

Metapenaeus dobsoni

SOURCE	DF	SUM.SQR	MEAN SQR	F-VAL	REMARKS
TREAT	3	2630.583	876.861	31.38	HI - SIG (1%)
ERROR	92	2570.751	27.443		

MEAN COMPARISONS			REMAKRS
T1	-	T2	SIG
T1	-	T3	SIG
T1		T4	SIG
T2	-	T3	SIG
T2	-	T4	SIG
T3		T4	N.S

TABLE - 2:37

ANOVA

Metapenaeus monoceros

SOURCE	DF	SUM.SQR	MEAN SQR	F-VAL	REMARKS
TREAT	3	148.78	49.594	10.41	HI SIG (1%)
ERROR	92	438.208	4.763		

MEAN COMPARISONS			REMARKS
T1	-	T2	SIG
T1		T3	SIG
T1		T4	SIG
T2	-	T3	N.S
T2		T4	N.S
T3	-	T4	

TABLE - 2:38

DETAILS OF GRAIN SIZE ANALYSIS OF THE FOUR STATIONS

STATION	MONTH	PERCENTAGE OF SAND	SILT	CLAY	SOIL TYPE
I	Feb to May (Pre-monsoon)	85.0	7.80	7.20	SANDY SOIL
	June to Sept. (Monsoon)	90.56	5.44	4.00	SANDY SOIL
	Oct. to Jan. (Post-monsoon)	78.30	13.00	8.70	SANDY SOIL
II	Feb to May (Pre-monsoon)	79.20	12.4	8.4	SANDY SOIL
	June to Sept. (Monsoon)	87.00	10.00	3.00	SANDY SOIL
	Oct. to Jan. (Post-monsoon)	71.60	18.80	9.60	SANDY SOIL
III	Feb. to May (Pre-monsoon)	42.30	12.56	45.14	SANDY CLAY
	June to Sept. (Monsoon)	44.60	11.93	43.47	SANDY CLAY
	Oct to Jan. (Post-monsoon)	41.30	15.32	45.38	SANDY CLAY
IV	Feb to May (Pre-monsoon)	27.90	17.63	54.77	SANDY CLAY
	June to Sept. (Monsoon)	34.70	18.53	46.77	SANDY CLAY
	Oct to Jan (Post-monsoon)	33.80	19.82	46.38	SANDY CLAY

sandy clay. Percentage of sand varied from 41.3% to 44.6%. Highest sand percentage was recorded during monsoon season (44.6%) and lowest in post-monsoon. During post-monsoon percentage of silt and clay was high 15.32% and 45.38% respectively.

Station IV

Station III and IV showed similarity in the nature of soil. The type of soil was sandy clay. Sand percentage varied from 27.9% to 34.7% highest percentage was recorded during monsoon. Clay content was high during pre-monsoon 54.47% and silt percentage recorded its maximum during post-monsoon (19.82%).

DISCUSSION

Hydrographical conditions of the estuary are influenced by the tides from the sea and the fresh water flow from the rivers and land run off. The total annual rainfall during 1987-88 and 1988-89 was 2764.9 mm and 2575.8 mm. Though the total rainfall received during 1988-89 was slightly lesser than that of 1987-88, while comparing the monsoon rainfall the total monsoon rain was high during 1988-89, (1848.9 mm) to 1488.3 mm in 1987-88. Moreover, in Kayamkulam estuary the barmouth will remain closed during April-May to June-July. So during April to July there is not direct connection with the sea and the estuary is isolated. Seasonal changes in temperature a characteristic feature of the hydrography of estuaries was well marked in the study area. During April-May the temperature was high compared to other months. This is mainly due to low rainfall and water exchange.

In the monsoon temperature was less. Moreover in all the stations the bottom temperature was lower than surface temperature a characteristic feature found in tropical estuaries. In this estuary the sea water influence was more during January, February and March and that of fresh water during June, July, August, September. When the estuary is isolated from the water exchange, evaporation and seepage account for the rise in salinity. High salinity value of 34 ppt was recorded during this period near the barmouth area. High values of 22 to 28 ppt was recorded at the northern and southern extension of the estuary during this period. This observation does not agree with that of Mary John (1958) according to whom, the maximum salinity attained during the pre-monsoon period is only 19.3 ppt. The present observations agrees with that of Sivankutty Nair (1971) and Kuttyamma (1980a). During monsoon with the rain water and river discharge the salinity gradually decreased. It was also found that the bottom water salinity was higher than surface water salinity. This observation agrees with the salinity condition discribed by Sivankutty Nair (1971).

Oxygen is one of the crucial environmental factors, indicating the quality of water. Foehrenbach (1969) observed that the oxygen content can be a reflection of organic loading, nutrient input and biological activity. The depletion of oxygen was one of the most remarkable features of hydrogen sulphide polluted area. As the most reduced form of sulphur, hydrogen sulphide has a high oxygen demand of 2 mole oxygen per mole of hydrogen sulphide Fenchel and Riedl (1970). In water it reacts rapidly with dissolved oxygen and causes oxygen depletion. The decomposition of organic matter have contributed to low values of dissolved oxygen in the sulphide polluted

area. From the present observation it is evident that in Station III and IV (polluted area) low oxygen was recorded. When the sulphide in the water and sediment was high. This agrees with the findings of Bass-Becking and Wood (1955), Berner (1967), Fenchel (1969).

According to Von Brand (1946) critical oxygen concentration are higher at higher temperature. The present observation also showed that the lowest oxygen concentration was reached, both in the surface and bottom especially during pre-monsoon period, when the temperature reached a maximum. The rate of oxidation of organic matter is influenced by temperature and the presence of certain bacteria (Hynes, 1966). This can be attributed to the low dissolved oxygen level in Station III and IV during pre-monsoon. However, dissolved oxygen content in Station I and II was higher than that of station III and IV in all the months. During monsoon period the dissolved oxygen values were higher than the pre-monsoon in all the stations. This is due to the heavy precipitation and river flow diluting the polluted area considerably.

Bagander and Niemisto (1978) found that pH in oxidised surface sediments may vary between 7.5 and 8.3 and in reduced surface, between 6.9 and 7.5. The pH value in the anoxic sediment was recorded to range from 6.0 to 8.5 (Teal and Kanwisher, 1966; Cohen et al, 1977; Hansen et al, 1978; Kaplan et al, 1979; and Krumgalz et al, 1980). Brewer and Goldman (1976) have discussed that the decomposition of marine organic matter essentially leads to the liberation of nitric acid. Cohen et al (1977) explained that the decrease in pH is probably caused by the fermentation process of highly active heterotrophic oxidation of photosynthesic sulphur bacteria and cyano

bacteria may further enhance the decrease of pH (Cohen et al, 1975). The reducing environment was responsible for the acidic pH in water and sediment at the polluted area. Azis and Nair (1983) noticed a decrease in pH due to retting activity at Edava-Nadayara Paravur backwaters. As hydrogen sulphide is one of the main pollutant in the retting area the present observation agrees with the observation of Azis and Nair (1983).

The variation of pH noted in the clear area (Station I and II) during the present study agrees with the observation of Sivankutty Nair (1971).

Hydrogen sulphide content in water seems to increase with increase in temperature, decrease in oxygen content in water, salinity and pH. It was also found that the phosphate level also was high with high hydrogen sulphide in water in polluted area. Sulphide in the sediment also showed a similar trend as hydrogen sulphide in water. More sulphide in sediment was observed in highly reduced environment where the Eh value was highly negative. The organic carbon content of the sediment also showed high values in sulphide polluted area though the organic carbon value showed a negative correlation with sulphide.

Hydrogen sulphide was observed more in the water during pre-monsoon period. It was observed only in the polluted area (Station III and IV). Bottom water values were considerably higher than surface water. Similarly total sulphide of sediment was also observed more during pre-monsoon period. Total sulphide in sediment was positively correlated to hydrogen sulphide in water such observation was also made earlier by Unnithan et al (1975); Remani (1979) in Cochin backwaters and Silas (1985). During the pre-monsoon period hydrogen sulphide values increased to a maximum and with the commencement

of monsoon a drop in the values were noted at the polluted area (Station III and IV). Azis and Nair (1983) reported a range of 0 to 52.46 mg/l for extensive retting grounds of Edava - Nadayara - Paravur backwaters. Remani (1979) recorded only a maximum total sulphide value of 4.33 mg/l at Vaduthala coconut retting ground during pre-monsoon period. During the present observation hydrogen sulphide value in bottom water ranged between 0 to 161.2 µg - at/l which is much less than that reported by Azis and Nair (1983) and Remani (1979). This can be mainly due to two reasons (1) Earlier workers have determined the total sulphide present in the water which includes all forms of sulphide in the water (2) They have carried out the study in retting area which is intensively polluted with sulphide and other chemicals.

Due to lack of water circulation and the increase in the uptake of oxygen in the sediment with increased temperature (Nedwell and Flood gate, 1972; Pearson and Rosenberg, 1978; Howarth and Teal, 1979 and Rosenberg, 1980) the bottom water becomes anoxic which results in the proliferation of sulphur reducing bacteria as sulphate is quantitatively the most important electron acceptor for the oxidation of organic material (Kaplan et al, 1963; and Jorgensen and Fenchel, 1974). This leads to the production of hydrogen sulphide. Wheatland (1954) recorded the increase of sulphide roughly getting doubled for each 10°C rise in temperature. Low level of sulphide 4 µg at/l may act as a source of sulphur for plant growth (Crawford et al,1979) but higher concentration become highly toxic to animals (Theede et al,1969).

During the closure of bar mouth tidal flow was stopped and an almost stagnant condition prevailed during April May. This resulted in the increase of hydrogen sulphide and total sulphide due to sulphate reduction. Hetero-

tropic bacteria can catalyse the sulphate reduction (Tuttle and Janmarch, 1973 and Pfenning and Bieble, 1976) and it requires an organic source of energy and sulphate as a terminal hydrogen acceptor (Ivanov, 1968; Berner, 1972 and Raman and Bella, 1974).

Sulphate reduction by bacteria takes place only in environments with negative redox-potential (Postgate, 1959). This observation clearly justify the highly reduced values of Eh recorded during the present study. Moreover total sulphide was recorded maximum when the sediment showed very low Eh value.

Low value of hydrogen sulphide in the surface water compared to bottom water can be attributed to the rapid oxidation of hydrogen sulphide in the surface water (Hansen et al, 1978).

In the present study nutrient level was low in sediment and water during the pre-monsoon period and with the commencement of south west monsoon the nutrients concentration increased and high values were observed in monsoon. It was observed elsewhere that fresh water inflow during the monsoon period brings large quantities of nutrients from the surrounding areas (Sankaramarayamam amd Qasim, 1969; Murthy and Verrayya, 1972; Ansari and Rajagopal, 1974; Nagarajaiah and Gupta, 1983; Subash, 1986).

The concentration of phosphorus was high in the polluted area (Station III and IV) than that of clear area (Station I and II). Phosphorus in water and sediment was positively correlated to hydrogen sulphide in water and total sulphide in sediment in Station III and iV. In station I and II (clear area) phosphorus showed negative correlation to temperature whereas in station

III and IV phosphorus showed positively correlation to temperature. The present investigation also revealed a similar relationship with oxygen in polluted area.

Phosphorus content in the sediment was low compared to that of surface and bottom water. In station I and II high phosphorus value in surface and bottom water was obtained during monsoon whereas in station III and IV the maximum phosphorus value was noticed in pre-monsoon period. The bottom water phosphorus value was higher compared to surface water value. The difference in the depth profile is not so well marked. This probably indicated that phosphorus contribution of the estuary is largely depend upon external sources such as land drainage and fresh water run off. However if direct relationship between phosphorus and fresh water discharge does exist one would except maximum values during monsoon period when the fresh water ingress is more, that too in the surface water. However from the data obtained in the present study, indicating that these may be some other mechanism for phosphorus enrichmet in the estuary. Phosphorus is one of the elements easily subject to retrogradation in an acidic medium as well as in a basic one.

Osugi et al (1932), (Sited in Kawaguchi, 1950) and Lu and Chung (1964) have studied the solubities of various phosphate minerals under different pH values and they observed that solubilities of most phosphates increased under alkaline condition, such a relation was noted in Station I and II during monsoon period and also agrees with the observations of Sankaranarayanan and Qasim (1969) in Cochin backwaters.

In station III and IV phosphorus values were at its peak during pre-monsoon. Similar observation was also made by Nair et al (1987) in a polluted area in Ashtamudi lake. The present observation of high phosphorus value during pre-monsoon when high sulphide content in water and sediment may be due to the desorption that would occur under extreme conditions of oxygen depletion (Jitts, 1959) and also possibly in places where hydrogen sulphide is present (Pomeroy et al, 1965; Li et al, 1972, Kufel, 1976; Crawford et al, 1979 and Krom and Berner, 1980). Buffer system maintains the phosphate concentration of water by appropriate desorption and adsorption reactions. Comin et al (1983) suggested that low proportion of soluble reactive phosphorus was related to the abundance of detritic or decomposing organic material.

Mollah et al (1975) in an investigation of soil and water phosphorus content in ponds have stated that available phosphorus of water and soil showed an inverse relationship while in certain other ponds such a relationship was not observed. The present observation agrees with the observation of Mollah et al (1975) that in all the stations the sediments phosphorus was lower than that contained in water. The low values of available phosphorus in sediment may be mainly due to the presence of stable phosphorus forms in the sediment which is not available. This is explained by Iron Sulphur Phosphorus system by Golterman, 1967.

Nitrate content was high during monsoon in sediment and water. The sediment nitrate was comparitively lower than that of water. Surface and bottom nitrate concentration showed very less variation. The instantaneous increase in nitrate concentration is seems entirely due to fresh water discharge from rivers and land run off (Ewins and Spencer, 1967) similar observation

was also made at Korapuzha estuary (Rao and George, 1959), Cochin estuary (Sankaranarayanan and Qasim, 1969; Manikoth and Salih, 1974), Ashtamudi estuary (Rajan, 1972; Nair et al, 1987) and Paravur estuary (Azis and Nair, 1983).

The minimal values of nitrate in the estuary (Station I and II) during the pre-monsoon period when the conditions are predominantly marine suggest that the contribution of nitrogen from the sea is very little (Sankaranarayanan and Qasim, 1969). The occurance of high values of nitrate during June to October suggests that these are associated with the monsoon when the fresh water influx is maximum. The present observation revealed that in Station IV the nitrate concentration was very low during pre-monsoon compared to that of other stations. Such observation was reported by Azis and Nair, (1983) in Paravur estuary and Nair et al (1987) in Ashtamudi estuary. Crawfod et al (1979) and Callender and Hammond (1982) opined that low nitrate concentration was noticed when ammonia concentration was high.

There is notable difference in the values of nitrate and nitrite. The nitrite values are much lower than those of nitrate. Similar observation was made by Sankaranarayanan and Qasim (1969) in Cochin back waters and Nair et al (1987) in Ashtamudi estuary. Maximum nitrite value was observed when the estuary remain fresh water dominated. The lower nitrite content than nitrate in all the stations is due to denitrification process (Spotte, 1979). In sulphide polluted area the nitrite depletion is induced by a denitrification process initiated by bacteria in the absence of dissolved oxygen.

The importance of Redox-Potential (Eh) for the biological and chemical processes in marine sediments has been discussed earlier by several authors

(Bass Becking et al, 1960; Berner, 1963; Fenchel, 1969 and White field, 1969). The sandy clay soil contained maximum level of organic matter with low Eh values (in polluted area) whereas the case was reverse at sandy soil (in clear area). Throughout the period of study the Eh values always showed negative values. In station I and II (clear area) the Eh values shown were much higher than that of station III and IV (polluted area). In station I and II the Eh value ranged from -26 to -90 mv whereas in station III and IV the values ranged from -136 to -345 mv. This clearly indicates that the low Eh value (-345 mv) was shown in area where sulphate reduction by bacteria takes place (Postgate, 1959). This also confirms the highly reduced nature of the sediment coupled with anoxic condition.

Highly reduced condition prevailed during pre-monsoon period when the salinity, temperature and sulphide in water and sediment was high. It was also coupled with low pH and low nutrient content in water and sediment. With the onset of monsoon the Eh value slowly improved as the polluted area get diluted with the fresh oxygenated water.

Change in Eh has been attributed to the reducing activity of the sedimentary sulphur bacteria (Berner, 1963 and Matheron and Baulaigue, 1968). Ramm and Bella (1974) and Cohen et al (1977) noted Eh drop as a result of sulphide production and the former attributed the pH drop to the production of carbon dioxide and organic acids.

The percentage of organic carbon in the sediment varies with stations and seasons. High organic carbon values were observed in Station III and IV. The seasonal pattern of organic carbon varies with stations. In station I and II maximum organic carbon content was noted during pre-monsoon period

whereas in station III and IV the maximum values were observed during post-monsoon period. Similar observation was also made by Silas (1985) in Pillai-madam salt water lagoon. The low percentage of organic carbon during post-monsoon period when the water was anoxic and acidic with high sulphide content in sediment is due to the remineralisationing of organic carbon during sulphate reduction, 2 moles of organic carbons are oxidised to carbon dioxide for every mole of sulphate reduced (Richards, 1965 and Jorgensen, 1977). About fifty to ninety percent of the mineralisation of total organic matter was observed to be through sulphur cycle (Jorgensen and Fenchel, 1974 and Jorgensen, 1977). The carbon dioxide produced during the reaction would reduce the pH of water. Methanogenesis is a major mechanism in the anaerobic environment (Strayer and Tiedye, 1978) by which carbon and electrons leave the sediment (Rudd and Hamilton, 1978) by the reduction of carbon dioxide or by the fermentation of organic matter especially carbohydrates (Deuser, 1975). Methane diffuses into the water column and if the critical concentration for the bubble formation is reached (Klots, 1961) by ebullition it is lost to the ecosystem at the air water interface. Methane production is considered the rate limiting step in carbon metabolism (Hungate, 1966 and Toerien and Hattingh, 1969). Devol (1983) suggested that the methane oxidising agent was sulphate. Here the organic carbon content of the sediment declined as the system became more anoxic and thus implying sulphate reduction or methanogenesis.

The sediment of polluted area was black in colour with high percentage of clay and silt. The sediment also had high sulphide content and organic carbon whereas the clear area was sandy. The blackening of mud in the polluted area was due to the local chemical reaction resulting in reduction

of sulphate into sulphide (Hynes, 1966). The present observation is in agreement with the observations elsewhere by Unnithan et al (1975), Remani (1979), Azis and Nair (1983) and Nair et al (1987). Moreover, the benthic macro fauna population was abundant in clear area with sandy soil.

It is well established that the quantitative and qualitative distribution of benthic fauna has a direct relationship with the type of bottom deposits. The physical nature of the substratum acts as a limiting factor to a great extent (Thorson, 1957; 1958; Sanders, 1958; Johnson, 1971). It was observed that polychaetes, tanaids, amphipods, isopods, bivalves, gastropods and nematods were the major groups of animals collected from the clear sea (Station I and II) with sandy substratum. On the other hand in polluted area ie station III and IV only polychaetes were observed. Though polychaetes were present in both clear area and polluted area the number per unit area was significantly lower in polluted area than clear area. If the total number of the animals were taken into consideration, station I and II (clear area) recorded the maximum, whereas the polluted area (station III and IV) recorded the minimum. It was already reported by many workers based on their studies in Cochin backwater. Desai and Krishnankutty, 1967; Kurian (1972) and Pillai 1979, that higher biomass is associated with substratum having higher percentage of fine sand, with small percentage of silt and the minimum biomass found in clayey bottom. Thus in the present study it is evident that the poor faunal abundance at the polluted area in comparison with clear area is due to the effect of hydrogen sulphide. Crustaceans being detritophagus their distribution and abundance is more related with the availability of the detritus rather than the physical nature of the bottom. However, in the present study a complete absence of crustacean fauna was observed in the polluted area,

though these stations have large quantities of organic detritus. The anoxic condition created by the decomposition of organic matter and production of hydrogen sulphide may favour only the most tolerant deposit feeding benthic animals to survive. More over, the high percentage of organic carbon observed in the polluted area during post-monsoon period have affected the distribution and abundance of bottom fauna. Relationship between the distribution and abundance of benthos and percentage organic carbon have been studied by many workers (Bader, 1954; Sanders, 1958; Sanders, 1968; Kurian, 1969 and Ganapathi and Raman, 1973). Kurian (1969) suggested that high productivity of benthos in the estuary may be due to high percentage of organic matter and the faunal density showed no direct relationship.

Unnithan et al (1975) and Remani (1979) also reported that the accumulation of organic material beyond the tolerance level affects the survival and consequent reduction in the total number of crustaceans at selected areas in Cochin backwater. Fincham (1969) suggested that the distribution of shallow water amphipods may be correlated with pollution and related factors such as low levels of dissolved oxygen. This is well established in the present study by the complete absence of this group in polluted area with low oxygen content. Similarly though the substratum at the polluted area is suitable for the burrowing polychaetes, their scarcity in the area may be due to the anaerobic condition and the presence of high sulphide content in the sediment. Molluscans being suspension feeders generally prefer a substratum with well sorted fine sand. Though the substratum at polluted area is suitable for molluscs, they were completely absent there. Perhaps due to the anoxic condition and presence of high sulphide content. Barder (1954) while studying the abundance of the bivalves in relation to percentage organic carbon, has

observed the decrease in population above 3% of organic carbon. He points out that beyond this concentration products of bacterial decomposition and decline in the available oxygen becomes limiting factor.

The role of estuary as a nursery ground for many of the commercially important prawns are well known. This estuary supports an extensive juvenile prawn fishery for penaeid prawns such as Penaeus indicus, Metapenaeus dobsoni and M. monoceros Studies on the availability and distribution of prawn seeds in Kayamkulam estuary revealed that P. indicus was the dominant group followed by M. dobsoni. A diminishing trend of distribution of prawn seed from Station I to IV was noted during the present study. If the total number of prawns of the three species were taken into account. Station I and II recorded the maximum and in station III and IV the total number was minimum. The species wise distribution also showed a same trend. P. indicus distribution in the clear area and polluted area showed a significant difference. Similarly M. dobsoni and M. monoceros distribution was significantly different in clear area and polluted area. Due to anoxic condition and presence of hydrogen sulphide the polluted area became unsuitable for prawn seeds to grow. Azis and Nair (1983) reported the absence of fish seeds in the retting area. Hynes (1966) also reported that fishes showed less preference to the low oxygen area. Ambika Devi (1988) also reported the absence of prawn and fish seeds in the sulphide polluted retting ground in Vaduthala.

From the present study it has become much clear that the presence of hydrogen sulphide in the water and total sulphide in the sediment reduced the presence of oxygen in water, pH of water, soil and the soil became highly reduced with low Eh and heavy organic carbon. This condition also affected

the benthic macro fauna population.

The absence/scarcity of prawn seeds in the polluted area can be attributed to the fact that they avoid the sulphide biome with low oxygen, pH, highly reduced soil and it is also important that prawns being benthic mainly depend on the benthic population for their food. So their absence in the polluted area also affects the presence of prawns in this area. Moreover M. dobsoni is more resistant to hydrogen sulphide toxicity than P. indicus (Vide Chpater I). This may be the reason for the presence of more number of Metapenaeus spp in the polluted area than P. indicus.

3

EFFECT OF HYDROGEN SULPHIDE ON THE GROWTH AND SUBSTRATUM SELECTIVITY OF Penaeus indicus

INTRODUCTION

Prawns form a prominant export commodity among marine organisms and its demand in the international market is increasing day by day. New price levels are being reached every year for this comodity. As the demand is much higher that what we can supply from the capture fishery the idea of developing prawn culture is gaining more attention recently. Many countries have developed scientific methods for increasing the pond production by adopting semi-intensive and intensive culture techniques.

In south-east Asia the culture of prawns and fishes has been practised for the last several centuries. These include the pond culture practices of Malaysia and Singapore involving several penaeid species (Tham, 1955, 1968; Hall, 1962), catching prawns from the extensive tambaks of Indonesia and from the brackish water ponds in Formosa (Kesteven and Job, 1957), the Sugpo Culture of the Philippines (Villadolid and Villaluz, 1951; Delmendo and Rabanal, 1956; Caces Borja and Rasalan, 1968), the large scale filtration of prawns in the paddy fields of the Malabar Coast (Gopinath, 1956; Panikkar and Menon, 1956; George et al., 1968; George and Sebastian, 1970) and the culture of prawns in the salt water bheries of Sunderbans in the West Bengal (Hora and Nair, 1944; Natarajan, 1985). George (1974) carried out a comparitive study of the specieswise yield and economics of the traditionally

operated seasonal and perennial ponds of the Vypeen Island in Central Kerala.

Chaudhary (1985) has described the present status of prawn culture in the brackish water areas of Kerala. Suseelan (1975) studied the growth and feeding habits of Penaeus indicus in the salt pan reservoirs of Manakkudy. Muthu et al (1981) observed the growth of P. indicus in relation to stocking density for the culture of this species in the fields.

Growth rate of Penaeus indicus in the culture systems and in the natural systems had been studied by several workers (George, 1975; Sultan, 1973; Sampath and Menon, 1975; Suseelan 1975; Muthu, 1978; Mammen et al. 1980; Nair et al. 1982 and Gopalan et al. 1982).

The density of population and availability of space for individual may have direct impact on the growth of prawns (Kunju, 1978).

Many problems have cropped up in the course of developing reliable techniques of pond management to increase production from ponds. Retardation of growth, sudden mortalities due to ecological reasons and incidence of diseases are some of the problems that have confronted the prawn culturists. The importance of chemical and biological processes taking place in the pond bottom to the growth and production of prawns stocked in the ponds is only being realised by the prawn culturists. Although hydrogen sulphide is an ubiquitous component of the pond soil it has been neglected in most of the ecological studies of prawn ponds. Shigueno (1972) studied the prawn culture ponds for the extent of pollution due to accumulation and decomposition of organic matter in the bottom sand by measuring the oxidation reduction-potential. Sun et al (1987) studied the quality distribution and variation

of soluble sulphide at different periods and its relation to dissolved oxygen. He has also noted its effect on prawns and the preparation of new and old ponds. Hui Yen et al (1987) reported that presence of sulphide in the soil and low levels of dissolved oxygen in the bottom water leads to growth retardment and sluggish shrimp activities.

Prawn culture in ponds is distinguished from all other aquacultures because of the particular behaviour of prawns which spend a greater part of the day embedded in the bottom soil. It is clear that the nature of the pond bottom will greatly influence their growth and survival. It is common to see the bottom mud blackened by hydrogen sulphide produced by bacterial activity. Since their natural substratum is predominently muddy and the prawns mostly feed or benthic organisms and detritus the degree of adaptation to a muddy substratum with reference to their feeding efficiency may be an important factor governing their growth and survival. Experiments conducted by Balasubramanian et al (1979) on Metapenaeus dobsoni have shown that its preying efficiency decreased with increasing quantities of mud. Williams (1958) found that the nature of substratum is a factor in shrimp distribution. Lalithambika Devi et al (1980) studied the preying efficiency of P. indicus in relation to different concentrations of mud in the substratum and compared with that of M. dobsoni.

Substratum preference for settlement is known for several species of penaeid prawns (Achuthankutty, 1988; Staples D.J, 1980; Achuthankutty and Nair, 1982; Achuthankutty and Nair, 1983). Ruello (1973) opined that the distribution of prawns within the nursery ground may be attributed to their physiological needs with growth or food preference.

In view of these the present study was carried out to known the effect of hydrogen sulphide in the growth of prawns and to study the behaviour of prawns in hydrogen sulphide containing substratum.

MATERIAL AND METHODS

Experiments were designed to study the effect of hydrogen sulphide on the growth of Penaeus indicus. For this purpose two ponds were selected at the Government Fish Farm Ayiramthengu. One of the selected pond was not regularly used for fish/prawn farming. The area was impounded and some prawns and fishes get into this area during the high tide. Soil samples were analysed and found that hydrogen sulphide was present in the interior of the pond. But the presence of sulphide was not uniform and there were patches where hydrogen sulphide could not be detected. In this context six pens of 4 m^2 each were erected in the sulphide rich area (POND-A). Similarly in the second pond where sulphide could not be detected in the soil, six pens were erected in the sulphide free area as control (POND-B). Pond 'A' and Pond 'B' were 500 m apart. Water exchange in the ponds was carried out by tidal flow.

Of the six pens erected in Pond 'A' (Experimental pen) three pens were used for growth experiment without supplementary feeding and remaining three pens for experiment with supplementary feeding. Similarly in Pond 'B' (Control pen) also three pens were used as control without feeding and the rest with feeding. Tidal water could freely flow in and out of the ponds through the sluice. The pens were stocked with P. indicus post larvae on January 1987 and the experiment continued upto April 1987, a period of 90

days. The same experiment was repeated again during the next year 1988 from January to April for 90 days.

Construction of Pens

Pens were constructed with velon screen (1 mm mesh size) fixed on wooden reapers (5 cm x 5 cm size) of 2 m length which were fixed to the soil 2 m apart so as to get 4 m^2 area. 5 cm x 3 cm wooden reapers were also fixed in between the 5 cm x 5 cm wooden reapers. Velon screen were attached firmly to the wooden reapers by keeping small 2cm x 0.5cm thin reapers and nailing them from outside. Coir rope was tied firmly to the lower end of the velon screen and driven into the soil so as to protect the pen from the entry of other prawns, fishes and crabs. After fixing the pen, mud from outside pen area was heaped to the four boundaries on the outer side of the pen to demarkate the bottom velon screen and also to give extra strength. Water depth in the pen was 85cm to 100cm and the top edges of the pens were about 30cm above the water level. Six such pens were constructed in the sulphide area and six in non sulphide area.

Stocking

P. indicus post larvae were used for stocking in the pen. The stocking density of the seeds were fixed to 5 nos/m^2 (Suseelan, 1975; Muthu et al., 1981, Thirunavukkarassu, 1983).

Prawns of the size range 25-28mm were collected from the estuary. Stocking was carried out in the early morning hours after recording their length and weight.

Supplementary Feeding

Clam meat was used as supplementary feed. Feed was given twice daily at the rate of 10% of body weight (wet weight).

Growth Study Monitoring

At every 15 days interval the prawns in each pen (Both experimental and control) were caught by using a small meshed scoop net and their average length and weight were recorded. After taking the measurements they were released back to the respective pen. The sides of the pen and the velon screen were frequently checked for damages and cleaned to avoid clogging of the mesh.

Harvesting

After completing 90 days from the date of stocking the prawns were harvested using a scoop net and by hand picking. This was done by entering into the pen, to ensure complete harvest of the stocked prawns.

Hydrographical and Sedimentological Parameters

To study the fluctuations in the ecological parameters of the culture pens (both experimental and control) surface water, bottom water and sediment samples were taken regularly at 15 days interval till the completion of the experiment.

The following parameters, Temperature, Salinity, pH, Dissolved oxygen, Hydrogen sulphide, Nitrate-Nitrogen, reactive phosphorus of the surface and bottom water were estimated. Soil samples were also taken from the pens

to determine the total sulphide, pH, Redox Potential (Eh) and Organic Carbon. Samples were taken during the early morning hours, with great care to avoid diffusion of air.

For water sampling 500 ml plastic bottle was used. Water samples for hydrogen sulphide and dissolved oxygen estimation were collected using separate 60 ml bottles. Surface water samples were collected by carefully dipping the cleaned bottle into the water. Bottom water samples were collected after getting into the pen at the sampling point. The stoppered bottle was slowly lowered in a slanting position with the mouth end slightly up. When the mouth of the bottle was just above the soil-water interface the stopper was removed. After the bottle was filled with water it was tapped repeatedly to release any air bubbles sticking to the sides and then stoppered and brought to the surface. Samples for estimation of hydrogen sulphide and dissolved oxygen were also collected in the same way. During sampling care was taken not to disturb the bottom of the pen. Both water and sediment samples were collected from the same point. Water samples were taken first and then the sediment samples were collected. Immediately after sampling winkler A and B were added to oxygen sample and N - I N dimethyl - P Phenelyne diamine dihydrochloride and ferric chloride solutions were added to hydrogen sulphide sample. From the main sample in the 500 ml bottle, sub - samples were siphoned out into 100 ml plastic bottles. The samples were not exposed to direct sun light and transferred immediately to the laboratory. The samples for hydrogen sulphide estimation were kept for colour development and later filtered and colorimetrically estimated. The colour was retained for 24 h.

The temperature of the water was recorded using an ordinary thermometer with 0 - 50°C graduations as soon as the water was collected.

Sediment samples were taken by a Van Veen grab. Immediately after removing the grab from the water, sediment samples were transferred into small sampling bottles (wide mouth plastic bottles) and zinc acetate solution was added to the total sulphide samples. Similarly soil samples were taken to determine Eh and pH. The sample bottles were closed and kept intact. The samples were transferred to laboratory at the earliest.

Chemical Analysis Vide material and methods of Chapter II.

Substratum Selectivity Studies

During the growth study experiment considerable difference in growth was observed between experiment (Prawns grown in hydrogen sulphide area) and control (hydrogen sulphide free area) and no pronounced difference in growth was observed between feeding and non feeding experiments in the hydrogen sulphide area. In the light of this observation two experiments were designed and conducted to study the substratum selectivity of two size groups (40 - 45mm and 85-90mm) of Penaeus indicus under uniform conditions in the absence of food and feeding behaviour on different types of substratum.

For substratum selectivity study the following experiment was performed in an aquarium tank as designed by Williams (1958) with slight modifications. An aquarium tank (76x45x30cms) was incompletely partitioned into 3 compartments, by vertical wooden partitions, so that the prawns could move freely from one compartment to the other. One compartment was provided with washed sea sand, another with a mixture of sea sand and dry powdered clay

and the third compartment was provided with wet black hydrogen sulphide containing soil taken from the sulphide rich area of the ponds. The substratum was 5cm deep in all the compartments. Filtered estuarine water of 28 ppt salinity was poured slowly over the sand bottom and was allowed to flow gently into the other compartments. The water level was gradually increased to a height of about 18 cm above the surface of the substrates. Water was allowed to settle for about one day and then total sulphide in the substrates were estimated by taking sample of soil from each compartment every day. 10 numbers of P. indicus were introduced into the aquarium tank. The tanks were covered with removable velon screens to keep the animals from jumping out. No attempt was made to regulate the amount of light entering the tanks. The room was dark at night. Occasionally aeration point was kept in the sand bottom compartment for 20-30 minutes and the dissolved oxygen level was maintained not less than 2 ml/l. 50% of the water was changed daily. The distribution of animals in three compartments of the tank was noted thrice a day at 10.00 h, 18.00 h and 02.00 h. Duration of the experiment was 10 days. Dead animals were replaced by new live ones. Separate experiments were conducted for both the size groups (40-45mm and 85-90mm). Fresh animals and substrates were used for each new trail. If no preference for or avoidance of any substratum was exhibited, prawns would have distributed uniformly in all the compartments.

The experiment for both the size groups (40-45mm and 85-90mm) were repeated twice in a randomized latin square design which allowed each bottom type to occur in every position once. The design required three different arrangements of substrates as three substrates were used. Distribution of prawns in the three compartments and all the replicates were compiled

and mean value was statistically analysed (ANOVA).

Feeding Behaviour on Different Types of Substratum

For the feeding behaviour experiment two size groups (40-45mm and 85-90mm) of prawns, P. indicus were used. The experiments for each size group was conducted separately in three aquarium tanks (76x45x30cm) with three different substrates. (The experiments were repeated twice for each size group and the mean value was used for statistical analysis. Of the three aquarium tanks, one was provided with 5cm thick layer of washed sea sand, another with sea sand and dry powdered clay (3:1) and third with wet bottom soil from the culture pond containing H_2S. In each tank, filtered brackish water of 30 ppt salinity was added to a depth of 18cm and 10 prawns of P. indicus were introduced.

First 40-45mm size group animals were used for the experiment. After completion of the experiment next size group (85-90mm) was used. The animals were fed with frozen squid meat twice daily at 8 AM and 4 PM. At every feeding time 10 nos. of 1 cm^2 squid meat piece were given in each tank. Left over meat pieces were collected and counted. From this the number of meat pieces consumed by the animals was noted. The duration of each set of experiment was 14 days and 25% water from each tank was exchanged every day.

The estimation of total sulphide in the substratum and the hydrogen sulphide in the water from each tank were done once a day. No sulphide could be detected in the sand and clay substratum and sand above substratum either in water or soil. Sulphide was present in the pond soil substratum

through out the experiment (3 mg/g 1.2 mg/g of soil) whereas hydrogen sulphide could not be detected from the water. Aeration was provided for 20-30 minutes at 3-4 hours intervals in all the tanks through out the experiment period.

The significance of the difference in feed intake by two size groups of the prawns in the three different substratum were tested statistically (ANOVA).

RESULTS

Hydrography

The data on different hydrographical and sedimentological parameters were collected from all the experimental and control pens at fifteen days interval for two growth periods of ninety days each in two successive years 1987 and 1988. In 1987 (First year) the period of the experiment was from 11th January to 10th April and in 1988 (Second year) the period extended from 3rd January to 3rd April. Mean values of the hydrographical and sedimentological parameters of the experimental and control pens are presented in Table 3:1 and 3:2. Separate data was collected for feeding and non feeding experiments and the respective controls.

Temperature

Experiment - Non Feeding

Temperature showed a variation (Fig. 3:1) from 28.8°C to 29.5°C in the surface water and 28.5°C to 29.0°C in the bottom water of the first year. In the second year, temperature showed a similar trend, it ranged between 28.5°C to 29.5°C in the surface water and 28.0°C to 29.0°C in the bottom water

(Fig. 3:15). Both surface and bottom water temperature showed a gradual increase from the start of the experiment to the end of 90 days experiment. Surface water temperature was always higher than bottom water temperature.

Control - Non Feeding

Temperature variation was almost same for both the years (Fig. 3:1 and 3:15). Temperature ranged from 28°C to 29.7°C in the surface water and 27.8°C to 29.2°C in the bottom water during the first year experiment. In the second year the trend was same as that of the first year. Temperature ranged from 28.1°C to 29.8°C and 27.7°C to 29.2°C in the surface and bottom water respectively. Gradual increase in the temperature was noticed from the start to the end of the experiment in both the years.

Experiment - Feeding

Temperature showed a fluctuation from 28.5°C to 29.5°C and 28.0°C to 29.1°C in the surface and bottom water respectively in the firsst year (Fig. 3:2). During the second year (Fig. 3:16) it ranged from 28.4°C to 29.7°C and 28.0°C to 29.3°C in the surface and bottom water respectively. Surface water temperature values were higher than bottom water values.

Control - Feeding

Gradual increase in temperature of surface and bottom water was noted from the start till the end of the experiment (Fig. 3:2 and 3:16). In the firsst year temperature ranged between 28.3°C to 29.5°C in the surface water and 28.0°C to 29.0°C in the bottom water, whereas in the second year it was 28.0°C to 29.6°C and 27.7°C to 29.2°C in the surface and bottom water respectively.

Salinity

Experiment - Non Feeding

Salinity showed similar fluctuation as temperature (Fig. 3:3). Salinity of the water gradually increased towards the end of the experiment. Lowest value was recorded during January and highest during April. Salinity showed a variation from 21.42 ppt to 29.64 ppt in the surface water and 22.23 ppt to 30.12 ppt in the bottom water during the first year whereas in the second year salinity ranged from 20.15 ppt to 29.14 ppt and 20.81 ppt to 29.91 ppt in the surface and bottom water respectively (Fig. 3:17). Surface water salinity was less than the bottom water salinity.

Control - Non Feeding

Salinity variation is given in (Fig. 3:3 and 3:17). Salinity ranged between 20.62 ppt and 29.32 ppt in the surface water and 21.56 ppt to 30.21 ppt in the bottom water during the first year. In the second year the trend was almost the same as that of first. Salinity variation was from 19.75 ppt to 29.26 ppt in the surface and bottom water.

Experiment - Feeding

Salinity variation is given in (Fig. 3:4 and 3:18). Higher salinity was observed towards the end of the experiment. In the first year salinity ranged from 21.53 ppt to 29.42 ppt in the surface water and 22.12 ppt to 30.17 ppt in the bottom water. In the second year the variation in surface water salinity was from 20.61 ppt to 29.35 ppt and in bottom water it was from 21.32 ppt to 29.77 ppt (Fig. 3:18). Bottom water salinity was higher than that of surface water.

Control - Feeding

Salinity variation (Fig. 3:4 and 3:18) was more or less the same as found in earlier cases. In the first year salinity ranged from 20.54 ppt to 29.12 ppt (surface water), 21.44 ppt to 30.15 (bottom water) and 20.04 ppt to 29.32 ppt (surface water), 20.93 ppt to 30.18 ppt (bottom water) in the second year. Bottom water salinity was higher than surface water salinity. Salinity showed a gradual increase from the start to the finish of the experiment.

Dissolved Oxygen

Experiment - Non Feeding

Variation in dissolved oxygen content is given in Fig. 3:5 and 3:19. Dissolved oxygen content ranged from 3.90 ml/l to 3.24 ml/l (Surface water) and 2.64 ml/l to 1.91 ml/l (Bottom water) during the first year (Fig. 3:5). In the second year dissolved oxygen showed variation from 3.92 ml/l to 3.13 ml/l (surface water) and 12.70 ml/l to 1.60 ml/l (bottom water) (Fig. 3:19). Gradual decrease in the dissolved oxygen content was observed from the start of the experiment till the end. Bottom water dissolved oxygen values were lower than that of surface water values.

Control - Non Feeding

Variation of dissolved oxygen content in surface and bottom water is evident in the Fig. 3:5 and 3:19. Dissolved oxygen content ranged from 4.43 ml/l to 3.80 ml/l (surface water) and 4.04 ml/l to 3.64 ml/l (Bottom water) during the first year. In the second year it was 4.72 ml/l to 3.77 ml/l (surface water) to 4.54 ml/l to 3.54 ml/l (Bottom water). Dissolved oxygen content showed a

decreasing trend towards the end of the experiment and the lowest value was recorded at that time. Dissolved oxygen content of surface water was higher than that of bottom water.

Experiment - Feeding

Variation of dissolved oxygen is given in Fig. 3:6 and 3:20. It showed a variation from 3.76 ml/l to 3.17 ml/l in the surface water and 2.64 ml/l to 1.73 ml/l in the bottom water during the first year. In the second year surface water dissolved oxygen content ranged from 3.88 ml/l to 3.12 ml/l and bottom water dissolved oxygen varied from 2.72 ml/l to 1.47 ml/l. Dissolved oxygen showed a gradual decreasing trend from the day of stocking to day of harvest. Bottom water values were much lower than the surface water dissolved oxygen value.

Control - Feeding

Fluctuation of dissolved oxygen is given in Fig. 3:6 and 3:20. Higher values were observed during the month of January (period of stocking) and gradually the values showed a decreasing trend. In the first year the dissolved oxygen content fluctuated from 4.36 ml/l to 3.51 ml/l (Surface water) and 4.20 ml/l to 3.38 ml/l (Bottom water) whereas in the second year it was ranged between 4.48 ml/l to 3.86 ml/l (Surface water) and 4.36 ml/l to 3.62 ml/l (Bottom water). Though the surface values were higher than the bottom values the difference was considerably less.

pH

Experiment - Non Feeding

Fluctuation of pH is given in the Fig. 3:7 and 3:21. In the first year

the pH showed a variation from 8.24 to 8.14 in the surface water and 7.63 to 7.36 in the bottom water whereas in the second year the pH fluctuated from 8.26 to 8.20 (Surface water) and 7.60 to 7.30 (Bottom water). Surface water pH was higher than the bottom water pH.

Control - Non Feeding

pH fluctuation is ploted in Fig. 3:7 and 3:21. Surface water pH showed pronounced fluctuation. In the first year surface water pH fluctuated from 8.37 to 8.31, while that of bottom water varied from 8.22 to 8.10 and in the second year the pH ranged from 8.37 to 8.28 (Surface water) and 8.25 to 8.12 (Bottom water).

Experiment - Feeding

Variation of pH is given in Fig. 3:8 and 3:22. In the first year pH fluctuated from 8.32 to 8.12 (Surface water) 7.70 to 7.36 (Bottom water) whereas in the second year pH ranged between 8.31 to 8.12 in the surface water and 7.71 to 7.28 in the bottom water. Bottom water pH was considerably less than surface water pH.

Control - Feeding

Fluctuation of the water pH ploted in Fig. 3:8 and 3:22. pH ranged between 8.46 to 8.26 (Surface water) 8.25 to 8.15 (Bottom water) during the first year. In second year pH ranged between 8.32 to 8.25 (Surface water) and 8.17 to 8.11 (Bottom water). pH showed fluctuation during the 90 days of observation. Bottom water pH was lower than that of surface water.

Nitrate - Nitrogen

Experiment - Non Feeding

Nitrate in surface and bottom water showed wide fluctuation (Fig. 3:9 and 3:23). In the first year Nitrate ranged from 10.14 µg - at NO_3 - N/l to 5.81 µg - at NO_3 N/l (Surface water) and 9.72 µg at NO_3 N/l to 5.43 µg at NO_3 N/l (Bottom water). During the second year nitrate value showed fluctuation from 8.76 µg at NO_3 - N/l to 6.11 µg at NO_3 - N/l in the bottom water. In both the cases higher values were observed during the commencement of the experiment in the month of January and the value gradually decreased to the least at the end of the experiment in the month of April.

Control - Non Feeding

Nitrate of the water showed pronounced variation (Fig. 3:9 and 3:23). Nitrate values ranged from 11.03 µg - at NO_3 - N/l to 5.17 µg - at NO_3 - N/l (surface water) and 9.62 ug - at NO_3 - N/l to 5.01 µg - at NO_3 - N/l (bottom water) during the first year whereas in the second year the values showed a variation from 9.37 µg at NO_3 - N/l to 5.63 µg at NO_3 - N/l in the surface water and 9.26 µg - at NO_3 - N/l to 5.50 µg - at NO_3 - N/l Nitrate values showed a decreasing trend from the beginning of the experiment to the end in both surface and bottom water.

Experiment - Feeding

Nitrate fluctuation in the surface and bottom water is given in Fig. 3:10 and 3:24. Nitrate showed a variation from 9.62 µg at NO_3 - N/l to

5.73 µg at NO_3 - N/l (surface water) and 8.90 µg at NO_3 - N/l to 5.21 µg - at NO_3 - N/l (bottom water) during the first year. In the second year the values ranged between 10.26 µg - at NO_3 - N/l to 6.61 µg at NO_3 - N/l (surface water) and 8.79 µg - at NO_3 - N/l (bottom water). Here again the nitrate showed more or less a similar trend as in earlier cases.

Control - Feeding

In the first year (January 87 to April 87) nitrate in surface water ranged from 10.23 µg - at NO_3 - N/l to 5.66 µg at NO_3 - N/l and in bottom water it ranged from 9.65 µg at NO_3 N/l (surface water) and 5.40 µg - at NO_3 N/l (bottom water). Nitrate values gradually decreased from the start to the end of the experiment (Fig. 3:10 and 3:24). In the second year nitrate values ranged from 10.11 µg - at NO_3 - N/l to 5.77 µg - at NO_3 - N/l (surface water) and 9.02 µg at NO_3 - N/l to 5.43 µg - at NO_3 - N/l (bottom water).

Reactive phosphorus

Experiment - Non Feeding

The fluctuation of reactive phosphorus is given in Fig. 3:11 and 3:25. In the first year reactive phosphorus ranged from 3.73 µg - at PO_4 P/l to 4.56 µg at PO_4 P/l in the surface water and 3.42 µg - at PO_4 - P/l to 5.88 µg - at PO_4 - P/l in the bottom water. In the second year reactive phosphorus showed a fluctuation from 3.92 µg at PO_4 - P/l to 3.14 µg at PO_4 - P/l to 3.90 µg at PO_4 - P/l in the surface water and 3.60 µg at PO_4 P/l to 4.59 µg at PO_4 - P/l in the bottom water. Reactive phosphorus in the bottom water showed an increasing trend from the beginning

of the experiment to the end of the experiment whereas in surface water the trend was different it showed wide variation in values.

Control - Non Feeding

The reactive phosphorus of surface and bottom content water is given in Fig. 3:11 and 3:25. In the first year the surface and bottom water reactive phosphorus values ranged from 2.89 µg - at PO_4 P/l to 4.75 µg at PO_4 - P/l and 2.56 µg at PO_4 P/l to 4.50 µg at PO_4 P/l respectively. Similarly in the second year the values fluctuated from 2.96 µg at PO_4 P/l to 4.28 µg at PO_4 P/l in the surface water and 3.06 µg at PO_4 - P/l to 4.04 µg - at PO_4 P/l. In this case reactive phosphorus value showed a decreasing trend from the start to the end of the experiment in both surface and bottom water.

Experiment - Feeding

Variation of reactive phosphorus is given in Fig. 3:12 and 3:26. In the first year the values ranged from 2.84 µg - at PO_4 - P/l to 3.88 µg at PO_4 - P/l in the surface water and 3.26 µg - at PO_4 - P/l to 4.37 µg at PO_4 - P/l in the bottom water where as in the second year the value ranged from 3.42 µg - at PO_4 - P/l to 4.76 µg at PO_4 - P/l and 3.85 µg at PO_4 P/l to 5.63 µg - at PO_4 - P/l in the surface and bottom water respectively. The reactive phosphorus content increased in bottom water towards the end of the experiment.

Control - Feeding

Reactive phosphorus of the water showed drastic change (Fig. 3:12

and 3:26). In the first year the values ranged from 3.12 µg at PO_4 P/l to 4.52 µg at PO_4 P/l in the surface and bottom water respectively whereas in the second year the values fluctuated between 2.53 µg at PO_4 P/l (surface water) to 2.27 µg - at PO_4 - P/l to 3.69 µg at PO_4 P/l (bottom water). Reactive phosphorus of the surface water showed a decreasing trend from the start to the end of the experiment whereas in the bottom water reactive phosphorus values showed an increasing trend towards the end of the experiment.

Hydrogen Sulphide

Experiment - Non Feeding

In the surface water no hydrogen sulphide was detected whereas in bottom water hydrogen sulphide showed fluctuation from 15.37 µg - at /l to 87.56 µg at /l in the firsst year (Fig. 3:13) and 18.65 µg at /l to 89.61 µg - at /l in the second year (Fig. 3:27). Hydrogen sulphide content in the water gradually increased towards the end of the experiment, i.e. in the month of April in both the years.

Control - Non Feeding

No hydrogen sulphide was present in surface and bottom water in both the years.

Experiment - Feeding

Hydrogen sulphide was detected only in the bottom water and it ranged from 20.45 µg - at /l to 54.65 µg at /l in the firsst year and 22.46 µg - at/l to 103.51 µg at /l in the second year (Fig. 3:14 and 3:28).

Control - Feeding

Hydrogen sulphide was not present in both surface and bottom water during first and second year.

Sedimentology

pH

Experiment - Non Feeding

The soil was acidic and pH showed fluctuation (Fig. 3:29) from 6.40 to 6.26 in the first year and 6.43 to 6.20 in the second year. pH fluctuation showed almost a decreasing trend from the beginning of the experiment to end.

Control - Non Feeding

In the first year sediment pH showed variation from 7.69 to 7.54 and 7.72 to 7.50 in the second year. The trend of pH fluctuation is given in Fig. 3:29.

Experiment - Feeding

Sediment pH showed wide range of fluctuation during the experiment period (Fig. 3:30). pH ranged from 7.43 to 6.38 in the first year and in the second year the range was (6.34 to 6.18) comparitively lower than that noted in the first year. pH showed a decreasing trend towards the end of the experiment.

Control - Feeding

pH showed small range of fluctuation from 7.61 to 7.51 in the first year and 7.71 to 7.48 in the second year (Fig. 3:30).

Redox Potential (Eh)

Experiment - Non Feeding

Eh of the sediment also showed a similar variation pH of sediment. The Eh values exhibited a decreasing trend from January (starting period of the experiment) to April (termination of the experiment) (Fig. 3:31). Eh value ranged from -186 mv to -289 mv in the first year and -184 mv to -278 mv in the second year.

Control - Non Feeding

Eh gradually decreased from the commencement to the end of the experiment. In first year Eh gradually decreased from -18 mv to -62 mv end in the second year the decrease was from -21 mv to -52 mv (Fig. 3:31).

Experiment - Feeding

Here also Eh showed the same trend as above. The Eh value ranged from -173 mv to -257 mv in the first year and -163 mv to -303 in the second year. Highly reduced values were observed towards the end of the experiment (Fig. 3:32).

Control - Feeding

In the control also the trend of Eh variation was same as in the experiment but the values were much higher than that of the experimental pens.

Eh fluctuated from -29mv to -70 mv in the first year and -28 mv to -67mv in the second year (Fig. 3:32).

Organic carbon

Experiment - Non Feeding

Organic Carbon of the sediment exhibited a pronounced fluctuation from 3.20% to 2.83% in the first year whereas in the second year the range was from 3.07% to 2.70%. Organic carbon mainly showed a decreasing trend towards the end of the experiment (Fig. 3:33).

Control - Non Feeding

The trend of organic carbon in the control pen was just the reverse of what was found in the experimental pen. The Organic Carbon value fluctuated from 2.76% to 2.36% in the first year and 2.03% to 2.06% in the second year. Organic carbon values gradually increased towards the end of the experiment (Fig. 3:33).

Experiment - Feeding

The range of organic carbon in the sediment was from 3.14% to 2.56% in the first year and 3.28% to 2.61% in the second year. The values showed an increasing trend towards the close of the experiment (Fig. 3:34).

Control - Feeding

The range of organic carbon was from 2.82% to 2.08% and 2.32% to 2.06% in the first and second year respectively (Fig. 3:34). In the control pen sediment organic carbon gradually increased towards the end of the

experiment.

Total Sulphide

Experiment - Non Feeding

Total sulphide in the sediment gradually increased from 1567.7 µg at /g to 3176.4 µg at/g and 1432.5 µg at/g to 3240.5 µg at/g in the first and second year respectively (Fig. 3:35).

Control - Non Feeding

No total sulphide was found in the sediment during both the years conducted in two successive years 1987-1988.

Experiment - Feeding

Total sulphide in the sediment gradually increased from the beginning and the highest value was attained at the end of the experiment (Fig. 3:36). The initial value was 1321.5 µg at/g 1932.2 µg - at/g in the first and second year. This value gradually increased and the highest value of 2986.7 µg at/g and 5239.2 µg at/g was reached at the end of the experiment.

Control - Feeding

In the control pen total sulphide was not present through out the period of experiment.

Growth Experiment

In order to study the effect of hydrogen sulphide on the growth of prawns experiments were conducted in 4 m^2 pen. To compare the growth

in the experimental pen (area where hydrogen sulphide is present) controls were also maintained in separate pen where the water and sediment was free from sulphide pollution. Experiments were conducted with supplementary feeding and without supplementary feed to get a comparison on the effect of feeding on growth in sulphide containing area. Out of the six replicates first three replicates were done during 1987 January to 1987 April and the second three replicates ie fourth, fifth and sixth replicates were carried out during 1988 January to 1988 April.

Length and weight measurements were taken at every fifteen days interval in all the six replicates and given in table.

Growth Experiment without Supplementary Feeding

In the first second and third replicates the average initial size of prawn stocked were 25.8 mm, 26.2 mm and 25.3 mm in the experimental pen with an average initial weight of 36 mg, 37 mg and 38 mg respectively. In the control pen the initial size was 25.6 mm, 26.2 mm, 25.2 mm and their initial weight was 38 mg, 38 mg and 37 mg respectively.

In the fourth, fifth and sixth replicates the average initial size were 25.6 mm, 26.2 mm and 25.4 mm with an average initial weight of 40 mg, 41 mg and 40 mg respectively in the experimental pen. In the control pen the initial size of the animals were 25.4 mm, 26.2 mm, 25.4 mm with an initial weight of 39 mg, 40 mg and 38 mg.

These prawns were reared for 90 days and attained a size of 82.3 mm, 87.2 mm, 88.1 mm, 87.3 mm, 90.1 mm and 86.2 mm with final weight of 4174 mg, 3800 mg, 415 mg, 4776 mg, 4841 mg and 5409 mg in the first

to sixth replicate in the experimental pen. The growth of prawn in the control pen was far better than that of the experimental pen. The final size of the prawns in the six replicates were 105.4mm, 104.4mm, 96.2mm, 104.2mm, 106.6mm and 105.1mm with an average weight of 9170mg, 8747mg, 9663mg, 9966mg, 9841mg and 9697mg respectively (Table 3:3 and Fig. 3:37a to f, Fig. 3:39a to f).

There was marked variation in the growth and survival of prawn in the experimental pen and control pen. In the six replicates the survival rate in the experimental pen varied from 25% to 35% whereas in the control pen the survival varied from 65% to 75%.

The growth rate was also found high in control pen than that of the experimental pen. In the experimental pen the growth in length for the first replicate was 0.627 mm/day. In the rest of the replicates the growth rate (in length) was 0.677 mm/day, 0.697 mm/day, 0.685 mm/day, 0.71 mm/day, 0.664 mm/day whereas in the control pen the growth in length was 0.886 mm/day, 0.868 mm/day, 0.788 mm/day, 0.875 mm/day, 0.893 mm/day and 0.885 mm/day in the first to the sixth replicate.

Similarly the growth in weight also was less in the experimental pen when compared to the control pen (Table 3:4).

The growth in weight observed in the experimental pen was 45.97 mg/day 41.8 mg/day, 45.7 mg/day, 52.62 mg/day, 53.3 mg/day and 59.65 mg/day in the first, second, third, fourth, fifth and sixth replicate respectively. At the same time the growth rate for the six replicates in the control pen was 101.14 mg/day, 96.76 mg/day, 106.95 mg/day, 110.3 mg/day, 108.9 mg/day

and 107.32 mg/day.

Growth Experiment with Supplementary Feeding

In the second set of experiment where supplementary feeding was given the size of prawn stocked was 40 mg in the first replicate, 35 mg in the second replicate, 37 mg in the third replicate, 41 mg in the fourth replicate, 40 mg in the fifth replicate and 38 mg in the sixth replicate with an initial average size of 26.2 mm, 25.5 mm, 26.4 mm, 25.0 mm, 25.7 mm and 27.2mm respectively in the first to sixth replicate in the experimental pen.

In control pen the size of the prawn at the time of stocking was 26.0mm 26.4mm, 25.1mm, 25.6mm, 26.5mm, and 27.1mm with an average initial weight of 38mg, 35mg, 36mg, 39mg, 40mg, and 36mg in the first to sixth replicate.

After 90 days the prawns in the experimental pen attained a size of 101.4mm, 100.3mm, 103.2mm, 100.3mm, 103.4mm, 104.3mm with an average weight of 4700 mg, 4966mg, 5167mg, 4523mg, 4628mg and 4378mg in the first to sixth replicate, whereas the prawns in the control pen showed an improved growth and reached a size of 114.1mm, 112.2mm, 111.3mm, 115.1mm, 120.1mm, 122.2mm with an average weight of 13222mg, 12455mg, 12414mg, 12171mg, 11909mg, 12152mg in the first to sixth replicate (Table 3:5 and Fig. 3:38a to f; Fig. 3:40a to f).

The survival rate in the control pen was almost double than that of the experimental pen. In the experimental pen the survival rate varied from 25% to 35% whereas in the control pen the rate of survival ranged 75% to 80% in the six replicates (Table 3:4).

Growth rate (in length) was also found more in the prawns reared in the control pen than that in the experimental pen.

In the six replicates the growth in length was 0.835mm/day, 0.831mm/day 0.853mm/day, 0.836mm/day, 0.863mm/day and 0.856mm/day in the experimental pen. On the contrary in the control pen the growth in length was 0.978 mm/day, 0.953mm/day, 0.957mm/day, 0.994mm/day, 1.04mm/day and 1.05 mm/day in the first to sixth replicate (Table 3:4).

Similar observation was noticed in the per day increase in weight. Growth in weight was also found more in control pen than that of the experimental pen. Growth in weight observed in experimental pen was 51.77mg/day, 54.78mg/day, 57.0mg/day, 49.8mg/day, 50.97mg/day and 48.2mg/day whereas in control pen was 146.48mg/day, 138.0mg/day, 137.53mg/day, 134.8mg/day, 131.87mg/day and 134.62mg/day in the first to sixth replicate.

In general it was noticed that the prawns in the experimental pen where sulphide was present showed less growth in length and weight than that of the prawns in the control pen. It was also noted that the per day growth increment (in length and weight) was also less in the prawns grown in sulphide polluted area. Though the concentration of hydrogen sulphide was less than the lethal level for prawns, the presence of sulphide in the water and sediment affected the growth and survival of prawns. It was also found that many of the prawns grown in the experimental pen showed sluggish movement and were soft whereas the prawns grown in control pen were active and hard.

Statistical analysis also revealed that the growth of prawns in experimental pen and control pen differed significantly. It was also noticed that

the rate of feed intake was significantly different between the experimental and control pen (Table 3:6).

Distribution of P. indicus in Different Substrates

The distribution of P. indicus (40-45mm and 85-90mm) in different substrates (hydrogen sulphide containing soil, sandy clay soil and sandy soil) at 10.00 h, 18.00 h and 00.02 h for 10 days is given in Table 3:7. The experiment was carried out in the laboratory. The temperature and salinity was maintained at 26°C (±0.4°C) and 27 ppt (±1.02) respectively during the period of experiment.

Both the size groups of P. indicus notably can burrow into the soil in sandy and sandy clay substrates. During the period of the experiment the animals were found moving around in the different substrates. But the prawns were found burried only in sandy and sandy clay substrate. Most of the animals were found burried during the day with only the eye and a portion of the rostrum visible. At night the prawns moved freely in all substrates. It was found that both the size groups (40-45mm and 85-90mm) were not seen frequently in the hydrogen sulphide containing substrate. In otherwords they showed less interest to stay in hydrogen sulphide containing soil. On the other hand the prawns spent much of their time in sandy clay and sandy substrates. 40-45mm size animals showed much preference to sandy clay substrate than to sand substrate and hydrogen sulphide soil. Similarly 85-90mm size prawns also did not prefer the hydrogen sulphide containing substrate. They preferred both sandy clay and sand substrates.

Statistical analysis showed significant difference in the distribution

TABLE - 3:1

Mean values of the hydrographical and sedimentological parameters of the experimental and control pen where no supplementary feed was given

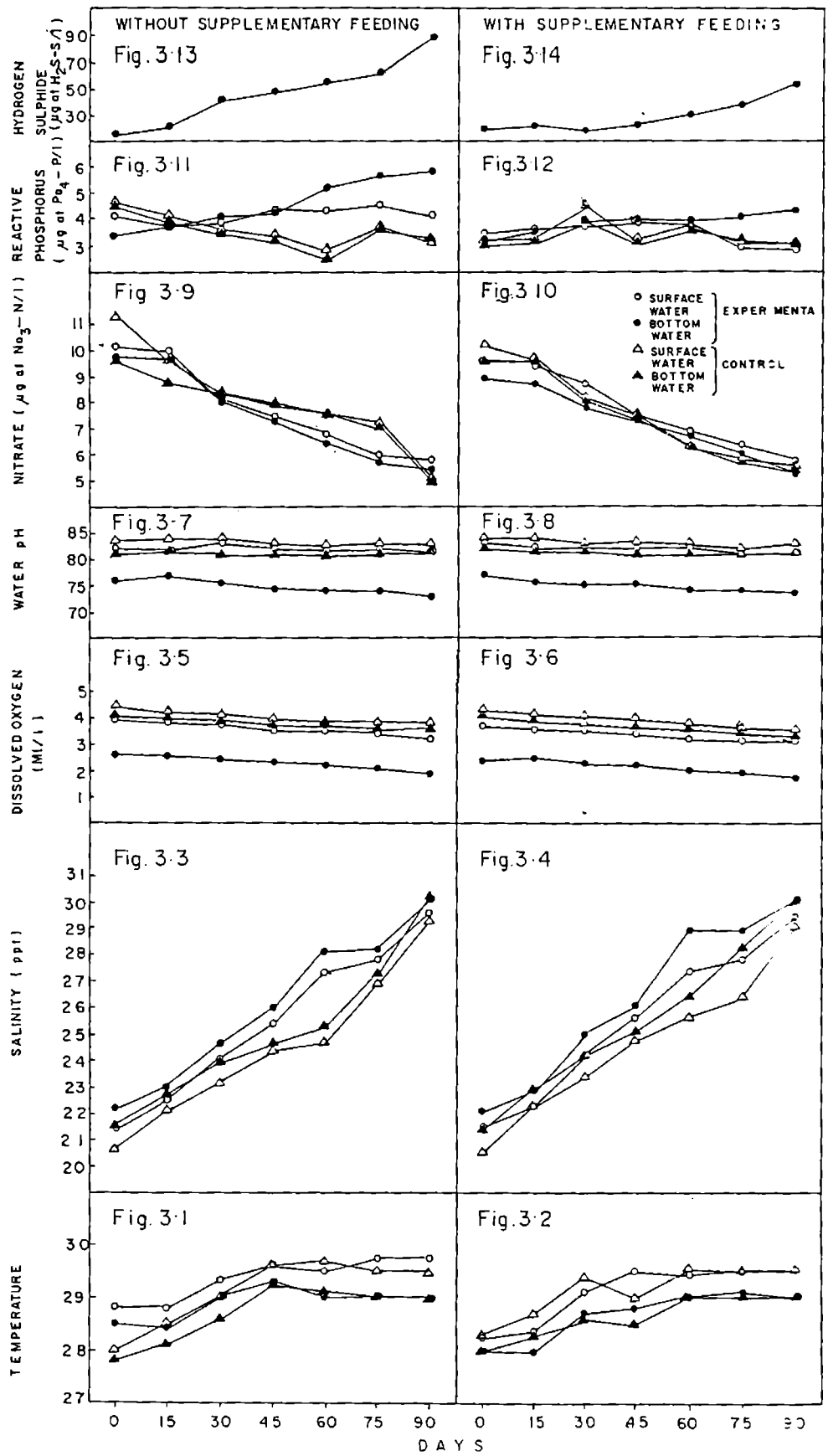
Days	WATER														SEDIMENT			
	Temperature °C		Salinity (ppt)		Dissolved oxygen (ml/l)		pH		Nitrate (µg-at/l)		Reactive Phosphorus (µg-at/l)		Hydrogen Sulphide (µg-at/l)		pH	Eh	Organic carbon	Total sulphide
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom		(-mv)	%	(µg-at/g)
EXPERIMENT - NON-FEEDING (FIRST YEAR)																		
0	28.8	28.5	21.42	22.23	3.90	2.64	8.24	7.63	10.14	9.72	4.17	3.42	0	15.32	6.35	-186	3.20	1567.7
15	28.8	28.4	22.51	23.08	3.82	2.56	8.17	7.60	9.96	9.63	3.73	3.76	0	21.62	6.38	-201	2.93	1623.2
30	29.3	29.0	24.15	24.78	3.76	2.42	8.31	7.53	8.12	8.00	3.96	4.02	0	42.32	6.40	-214	3.16	1781.3
45	29.6	29.3	25.42	26.05	3.61	2.30	8.23	7.46	7.46	7.37	4.31	4.21	0	48.76	6.32	-232	2.87	1923.4
60	29.5	29.0	27.34	28.14	3.54	2.24	8.19	7.43	6.82	6.44	4.37	5.23	0	56.52	6.24	-256	2.86	2496.7
75	29.5	29.0	27.86	28.27	3.48	2.18	8.20	7.40	6.03	5.72	4.56	5.64	0	61.03	6.30	-277	2.92	2932.5
90	29.5	29.0	29.64	30.12	3.24	1.91	8.14	7.36	5.81	5.43	4.12	5.88	0	87.56	6.26	-289	2.83	3176.4
EXPERIMENT - NON-FEEDING (SECOND YEAR)																		
0	28.5	28.0	20.15	20.81	3.92	2.70	8.26	7.52	8.76	8.33	3.62	3.60	0	18.65	6.43	-184	3.07	1432.5
15	28.0	27.7	22.23	23.31	3.96	2.51	8.12	7.60	9.32	9.01	3.76	3.71	0	30.47	6.40	-190	2.89	1634.5
30	29.0	28.3	24.76	24.83	3.82	2.43	8.14	7.53	9.12	8.92	3.90	3.82	0	44.45	6.37	-198	3.02	1722.6
45	29.5	28.9	25.32	25.89	3.60	2.20	8.24	7.42	7.79	7.75	3.88	4.00	0	40.62	6.38	-224	2.96	1940.2
60	29.5	28.9	27.41	28.23	3.44	1.96	8.23	7.36	7.13	6.78	3.92	4.22	0	51.35	6.27	-243	2.73	2153.9
75	29.5	29.0	27.21	28.34	3.20	1.82	8.17	7.35	6.72	6.42	3.63	4.31	0	66.44	6.23	-267	2.81	2732.5
90	29.6	29.0	29.14	29.91	3.13	1.60	8.20	7.30	6.11	5.87	3.14	4.59	0	89.61	6.20	-278	2.70	3240.5
CONTROL - NON-FEEDING (FIRST YEAR)																		
0	28.0	27.8	20.62	21.56	4.43	4.04	8.32	8.12	11.03	9.62	4.75	4.50	0	0	7.57	-18	2.42	0
15	28.5	28.1	22.14	22.78	4.22	3.92	8.43	8.22	9.65	8.71	4.12	3.92	0	0	7.69	-31	2.51	0
30	29.0	28.6	23.23	24.06	4.10	3.95	8.37	8.18	8.36	8.25	3.62	3.54	0	0	7.61	-44	2.36	0
45	29.6	29.2	24.43	24.57	3.96	3.86	8.35	8.12	8.04	7.92	3.40	3.21	0	0	7.62	-39	2.47	0
60	29.7	29.1	24.72	25.32	3.84	3.70	8.27	8.10	7.65	7.60	2.89	2.56	0	0	7.54	-48	2.73	0
75	29.5	29.0	26.94	27.31	3.86	3.66	8.32	8.16	7.24	7.18	3.76	3.66	0	0	7.63	-54	2.76	0
90	29.5	29.0	29.32	30.21	3.80	3.64	8.31	8.10	5.17	5.01	3.16	3.21	0	0	7.60	-62	2.74	0
CONTROL - NON-FEEDING (SECOND YEAR)																		
0	28.1	27.7	19.75	20.12	4.72	4.54	8.36	8.21	9.37	9.26	3.92	3.76	0	0	7.72	-21	2.06	0
15	28.6	27.9	22.23	22.65	4.61	4.43	8.37	8.25	8.62	8.43	4.28	4.04	0	0	7.67	-30	2.34	0
30	29.0	28.8	23.13	24.17	4.67	4.32	8.28	8.22	9.16	8.59	3.84	3.72	0	0	7.63	-42	2.42	0
45	29.6	29.1	24.58	25.06	4.42	4.14	8.34	8.20	8.61	8.46	3.92	3.90	0	0	7.54	-51	2.54	0
60	29.8	29.2	24.64	25.58	4.03	3.82	8.27	8.24	7.31	7.24	3.56	3.50	0	0	7.61	-49	2.68	0
75	29.5	29.0	27.10	28.11	3.85	3.62	8.29	8.16	6.74	6.75	3.20	3.16	0	0	7.50	-48	3.03	0
90	29.8	29.2	29.26	30.27	3.77	3.54	8.30	8.12	5.63	5.50	2.96	3.06	0	0	7.50	-52	2.82	0

TABLE - 3:2

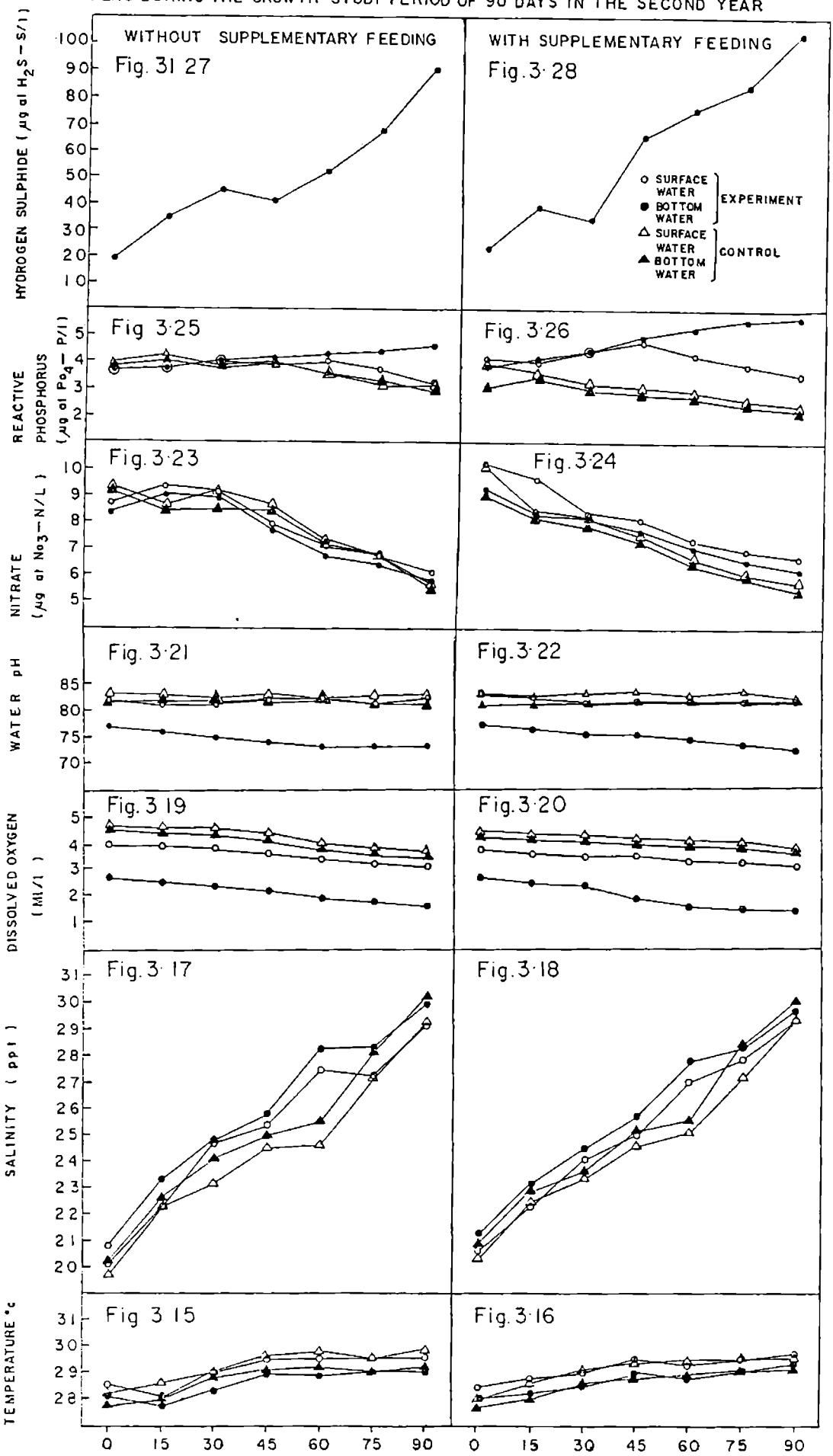
Mean values of the hydrographical and sedimentological parameters of the experimental and control pen where supplementary feed was given

Days	WATER: Temperature °C Surface	Temperature °C Bottom	Salinity (ppt) Surface	Salinity (ppt) Bottom	Dissolved oxygen (ml/l) Surface	Dissolved oxygen (ml/l) Bottom	pH Surface	pH Bottom	Nitrate (µg-at/l) Surface	Nitrate (µg-at/l) Bottom	Reactive Phosphorus (µg-at/l) Surface	Reactive Phosphorus (µg-at/l) Bottom	Hydrogen Sulphide (µg-at/l) Surface	Hydrogen Sulphide (µg-at/l) Bottom	SEDIMENT: pH	Eh (-mv)	Organic carbon %	Total sulphide (µg-at/g)
EXPERIMENT - FEEDING (FIRST YEAR)																		
0	28.5	28.0	21.53	22.12	3.76	2.64	8.32	7.70	9.62	8.90	3.45	3.26	0	20.45	7.43	-173	3.14	1321.5
15	28.6	28.0	22.36	22.86	3.67	2.51	8.26	7.61	9.40	8.76	3.62	3.50	0	21.62	7.32	-192	3.06	1523.7
30	29.1	28.7	24.21	25.02	3.51	2.32	8.29	7.53	8.72	7.84	3.74	3.81	0	18.50	7.03	-204	2.94	1762.5
45	29.5	28.8	25.26	25.11	3.43	2.23	8.20	7.57	7.65	7.32	3.88	3.90	0	22.54	6.72	-211	3.04	1832.2
60	29.4	29.0	27.42	28.93	3.24	2.06	8.23	7.44	6.94	6.71	3.76	3.98	0	30.72	6.42	-246	2.92	2014.4
75	29.5	29.1	27.81	29.36	3.12	1.90	8.16	7.40	6.43	6.06	2.92	4.12	0	37.98	6.40	-249	2.73	2492.9
90	29.5	29.0	29.42	30.17	3.17	1.73	8.12	7.36	5.73	5.21	2.84	4.37	0	54.65	6.38	-257	2.56	2986.7
EXPERIMENT - FEEDING (SECOND YEAR)																		
0	28.4	28.0	20.61	21.32	3.88	2.72	8.31	7.71	10.26	8.79	4.03	3.85	0	22.46	6.34	-163	3.28	1932.2
15	28.7	28.2	22.32	23.14	3.64	2.56	8.27	7.62	9.62	8.31	3.98	4.06	0	20.73	6.30	-181	3.12	2153.1
30	29.0	28.5	24.14	24.51	3.51	2.41	8.18	7.55	8.30	8.20	4.32	4.30	0	33.57	6.27	-211	2.84	2357.9
45	29.5	29.0	25.06	25.76	3.54	1.94	8.22	7.54	8.12	7.74	4.76	4.90	0	64.93	6.28	-238	2.87	2732.4
60	29.3	28.8	27.60	27.81	3.32	1.66	8.18	7.43	7.32	7.03	4.26	5.24	0	74.95	6.25	-253	2.76	3665.7
75	29.5	29.1	27.88	28.33	3.28	1.51	8.13	7.39	6.90	6.58	3.83	5.52	0	82.37	6.28	-265	2.70	4153.1
90	29.7	29.3	29.35	29.77	3.12	1.47	8.12	7.28	6.61	6.26	3.42	5.63	0	103.51	6.18	-303	2.61	5239.2
CONTROL FEEDING (FIRST YEAR)																		
0	28.3	28.0	20.54	21.44	4.36	4.20	8.44	8.25	10.23	9.65	3.22	3.02	0	0	7.60	-29	2.12	0
15	28.7	28.3	22.34	22.89	4.12	3.92	8.46	8.22	9.73	9.53	3.36	3.24	0	0	7.57	-29	2.08	0
30	29.4	28.6	23.41	24.18	4.10	3.81	8.39	8.20	8.21	8.11	4.52	3.80	0	0	7.55	-51	2.21	0
45	29.0	28.5	24.80	25.12	4.06	3.76	8.37	8.16	7.62	7.44	3.21	3.14	0	0	7.53	-43	2.45	0
60	29.5	29.0	25.73	26.56	3.82	3.60	8.30	8.15	6.34	6.30	3.87	3.76	0	0	7.51	-57	2.59	0
75	29.5	29.0	26.47	28.36	3.66	3.42	8.26	8.17	5.91	5.84	3.12	3.26	0	0	7.62	-60	2.62	0
90	29.5	29.0	29.12	30.19	3.51	3.38	8.32	8.15	5.66	5.40	3.14	3.12	0	0	7.61	-70	2.82	0
CONTROL FEEDING (SECOND YEAR)																		
0	28.0	27.7	20.04	20.93	4.48	4.36	8.30	8.17	10.11	9.02	3.98	3.69	0	0	7.71	-28	2.06	0
15	28.6	28.0	22.47	23.06	4.37	4.22	8.27	8.11	8.43	8.21	3.52	3.46	0	0	7.68	-40	2.12	0
30	29.2	28.6	23.44	23.77	4.31	4.14	8.32	8.14	8.16	7.93	3.12	2.96	0	0	7.56	-54	2.24	0
45	29.4	28.8	24.64	25.18	4.26	4.03	8.30	8.16	7.54	7.32	3.06	2.82	0	0	7.59	-47	2.32	0
60	29.5	28.9	25.13	25.63	4.15	3.98	8.25	8.13	6.63	6.42	2.79	2.61	0	0	7.52	-59	2.28	0
75	29.5	29.1	27.26	26.84	4.03	3.81	8.31	8.10	6.01	5.92	2.53	2.41	0	0	7.48	-61	2.15	0
90	29.6	29.2	29.32	30.18	3.86	3.62	8.26	8.11	5.77	5.43	2.32	2.27	0	0	7.51	-67	2.22	0

VARIATION OF HYDROGRAPHICAL PARAMETERS IN THE EXPERIMENTAL & CONTROL PENS DURING THE GROWTH STUDY PERIOD OF 90 DAYS IN THE FIRST YEAR



VARIATION OF HYDROGRAPHICAL PARAMETERS IN THE EXPERIMENTS CONTROL PENS DURING THE GROWTH STUDY PERIOD OF 90 DAYS IN THE SECOND YEAR



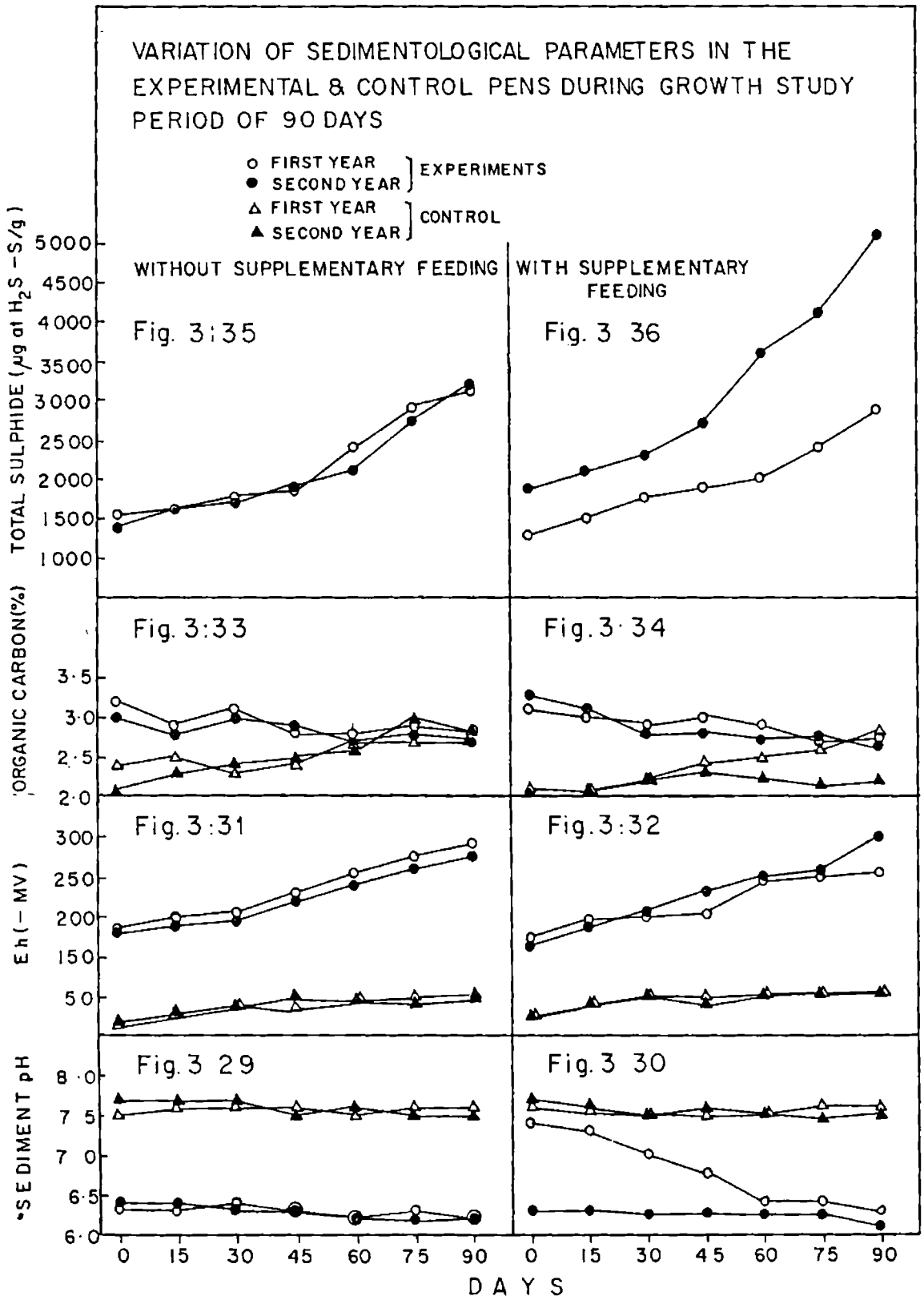
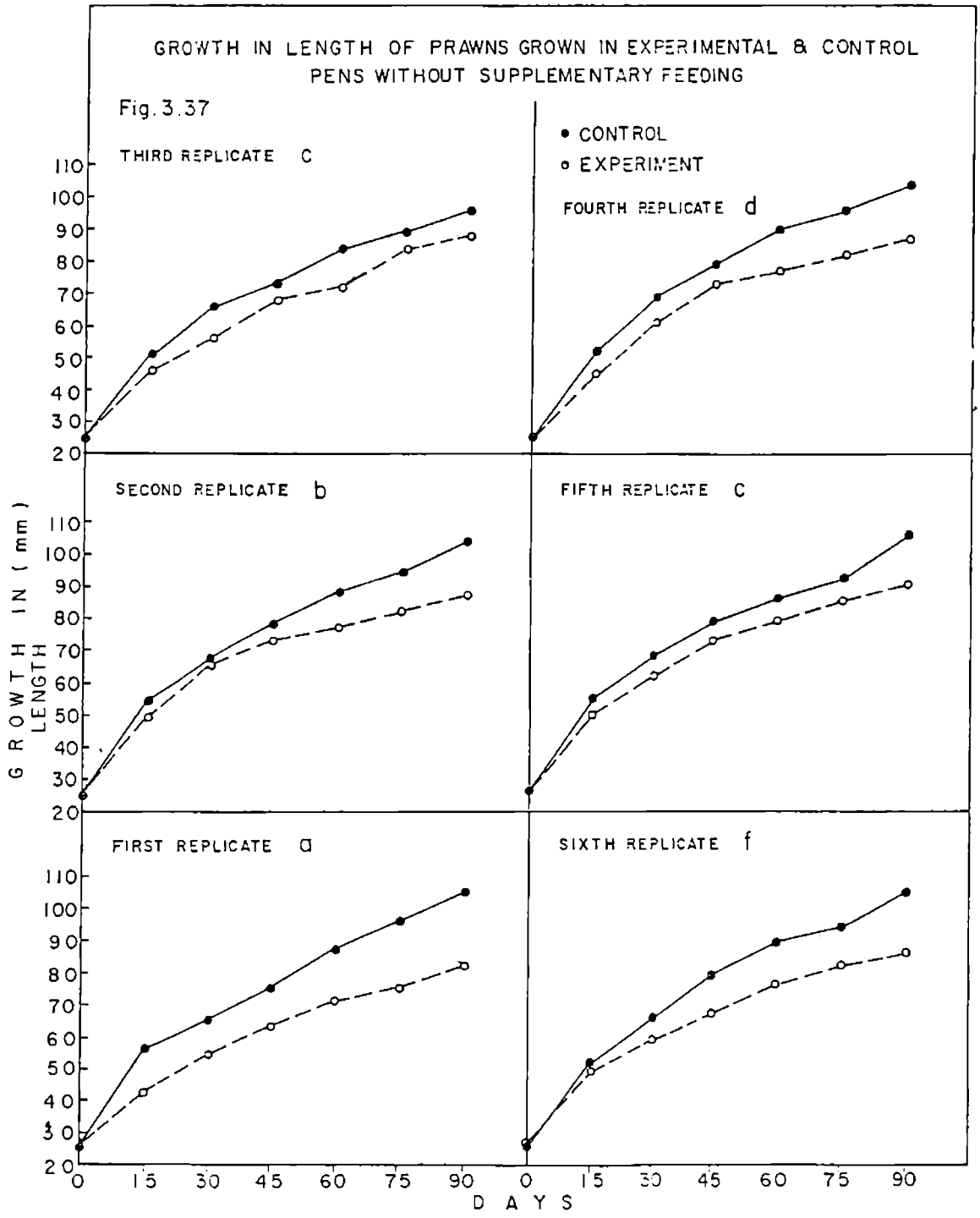

VARIATION OF SEDIMENTOLOGICAL PARAMETERS IN THE EXPERIMENTAL & CONTROL PENS DURING GROWTH STUDY PERIOD OF 90 DAYS
o FIRST YEAR
● SECOND YEAR
EXPERIMENTS
△ FIRST YEAR
▲ SECOND YEAR
CONTROL
WITHOUT SUPPLEMENTARY FEEDING
WITH SUPPLEMENTARY FEEDING
Fig. 3:35
Fig. 3 36
Fig. 3:33
Fig. 3·34
Fig. 3:31
Fig. 3:32
Fig. 3 29
Fig. 3 30
TOTAL SULPHIDE (µg at H2S - S/g)
ORGANIC CARBON(%)
Eh(- MV)
SEDIMENT pH
5000
4500
4000
3500
3000
2500
2000
1500
1000
3·5
3·0
2·5
2·0
300
250
200
150
50
8·0
7 5
7 0
6·5
6·0
0 15 30 45 60 75 90
0 15 30 45 60 75 90
DAYS

TABLE - 3:3

Average length and weight measurements of prawns grown in experimental and control pens without supplementary feeding.

Replicates	Days	EXPERIMENT		CONTROL	
		Average Weight (mg)	Average Length (mm)	Average Weight (mg)	Average Length (mm)
First replicate	0	36	25.8	38	25.6
	15	1342	42.8	1593	56.3
	30	2146	54.6	3142	65.5
	45	3034	63.5	5665	75.4
	60	3518	71.1	7313	87.2
	75	4024	75.2	8632	96.5
	90	4174	82.3	9170	105.4
Second replicate	0	37	26.2	38	26.2
	15	1232	49.6	1532	54.3
	30	2394	65.5	3076	67.5
	45	3115	73.1	5497	78.6
	60	3526	77.4	6894	88.4
	75	3758	82.2	8314	94.5
	90	3800	87.2	8747	104.4
Third replicate	0	38	25.3	37	25.2
	15	1347	46.6	1625	51.4
	30	2239	56.2	3454	66.5
	45	3058	68.4	5962	73.2
	60	3669	72.3	7981	84.5
	75	3981	84.6	8998	89.2
	90	4151	88.1	9663	96.2
Fourth replicate	0	40	25.6	39	25.4
	15	1456	45.5	1802	52.3
	30	2347	61.3	3840	69.2
	45	3579	73.3	6232	79.4
	60	4123	77.6	8164	90.5
	75	4518	82.4	9585	96.4
	90	4776	87.3	9966	104.2
Fifth replicate	0	41	26.2	40	26.2
	15	1374	50.4	1675	55.3
	30	2476	62.9	3778	68.8
	45	3965	73.8	5998	79.5
	60	4314	79.5	8472	86.4
	75	4772	75.4	9432	92.5
	90	4841	90.1	9841	106.6
Sixth replicate	0	40	26.4	38	25.4
	15	1272	49.2	1842	52.3
	30	2982	59.3	3436	66.4
	45	4291	67.4	6292	79.4
	60	4871	76.2	8487	89.2
	75	5294	82.6	9368	94.5
	90	5409	86.2	9697	105.1


GROWTH IN LENGTH OF PRAWNS GROWN IN EXPERIMENTAL & CONTROL PENS WITHOUT SUPPLEMENTARY FEEDING
Fig. 3.37
• CONTROL
○ EXPERIMENT
THIRD REPLICATE C
FOURTH REPLICATE d
SECOND REPLICATE b
FIFTH REPLICATE e
FIRST REPLICATE a
SIXTH REPLICATE f
GROWTH IN LENGTH (mm)
DAYS
0 15 30 45 60 75 90
20 30 40 50 60 70 80 90 100 110

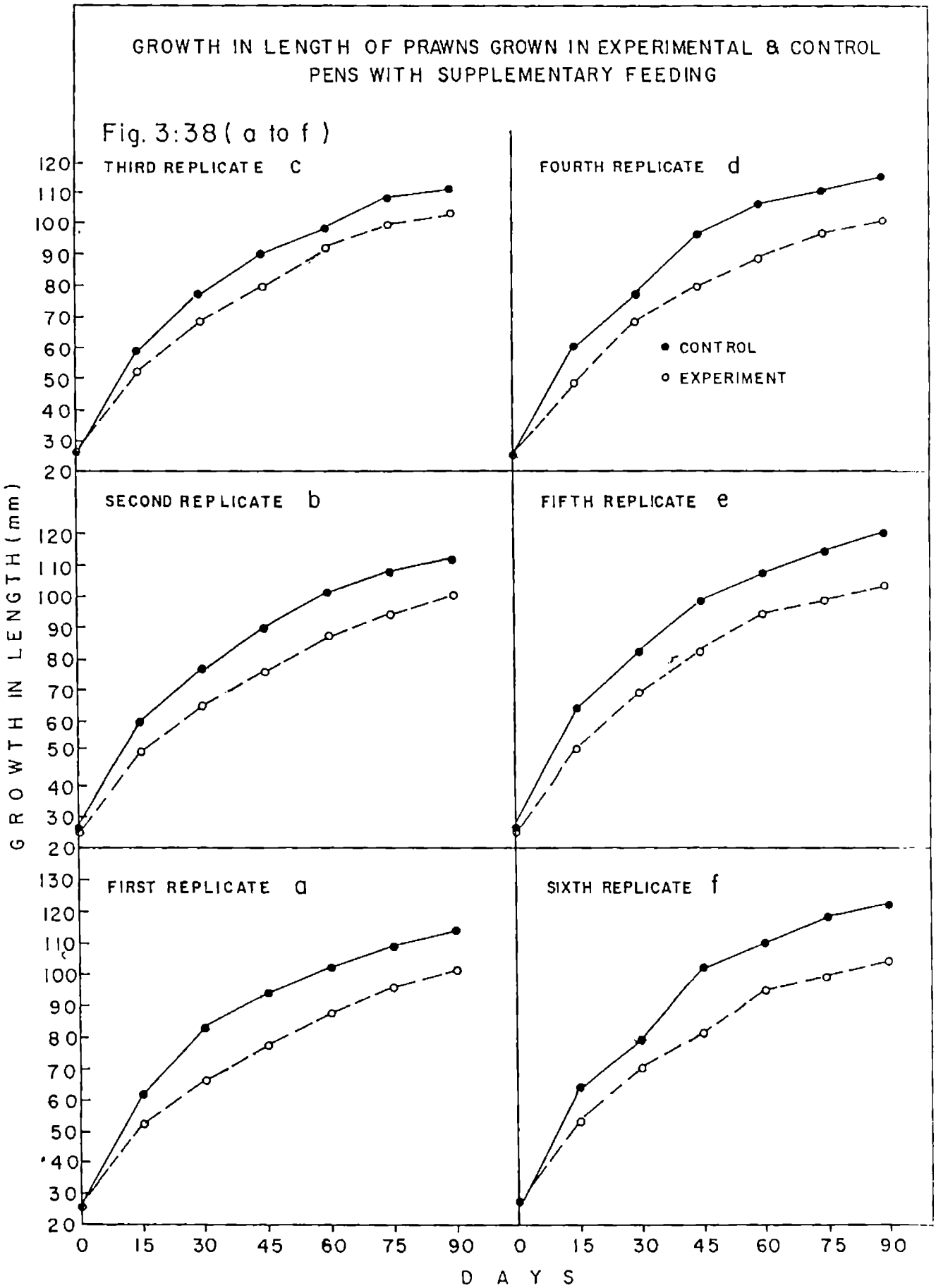

GROWTH IN LENGTH OF PRAWNS GROWN IN EXPERIMENTAL & CONTROL PENS WITH SUPPLEMENTARY FEEDING
Fig. 3:38 (a to f)
THIRD REPLICATE C
FOURTH REPLICATE d
SECOND REPLICATE b
FIFTH REPLICATE e
FIRST REPLICATE a
SIXTH REPLICATE f
● CONTROL
○ EXPERIMENT
GROWTH IN LENGTH (mm)
DAYS
0 15 30 45 60 75 90

TABLE - 3:4

Details of the growth experiment of Penaeus indicus

	Stocking Rate (Nos./M²)		Average Initial weight (mg)		Average Initial length (mm)		Average Final weight (mg)		Average Final length (mm)		Average Growth per day (mg/day)		Average Growth per day (mm/day)		Percentage/ Survival	
	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control	Exp.	Control
FIRST YEAR							WITHOUT FEEDING									
FIRST Replicate	5	5	36	38	25.8	25.6	4174	9170	82.3	105.4	45.97	101.14	0.627	0.886	35	70
SECOND Replicate	5	4	37	38	26.2	26.2	3800	8747	87.2	104.4	41.8	96.76	0.677	0.868	30	75
THIRD Replicate	5	5	38	37	25.3	25.2	4151	9663	88.1	96.2	45.7	106.95	0.697	0.788	30	70
SECOND YEAR																
FOURTH Replicate	5	5	40	39	25.6	25.4	4776	9966	87.3	104.2	52.62	110.3	0.685	0.875	25	65
FIFTH Replicate	5	5	41	40	26.2	26.2	4841	9841	90.1	106.6	53.3	108.9	0.71	0.893	30	70
SIXTH Replicate	5	5	40	38	26.4	25.4	5409	9697	86.2	105.1	59.65	107.32	0.664	0.885	25	75
							WITH FEEDING									
FIRST YEAR																
FIRST	5	5	40	38	26.2	26.0	4700	13222	101.4	114.1	51.77	146.48	0.835	0.978	25	75
SECOND	5	5	35	35	25.5	26.4	4966	12455	100.3	112.2	54.78	138.0	0.831	0.953	30	80
THIRD	5	5	37	36	26.4	25.1	5167	12414	103.2	111.3	57.0	137.53	0.853	0.957	35	75
SECOND YEAR																
FOURTH	5	5	41	39	25.0	25.6	4523	12171	106.3	115.1	49.8	134.8	0.836	0.994	30	80
FIFTH	5	5	40	40	25.7	26.5	4628	11909	103.4	120.1	50.97	131.87	0.863	1.04	30	75
SIXTH	5	5	38	36	27.2	27.1	4378	12152	104.3	122.2	48.2	134.62	0.856	1.05	35	80

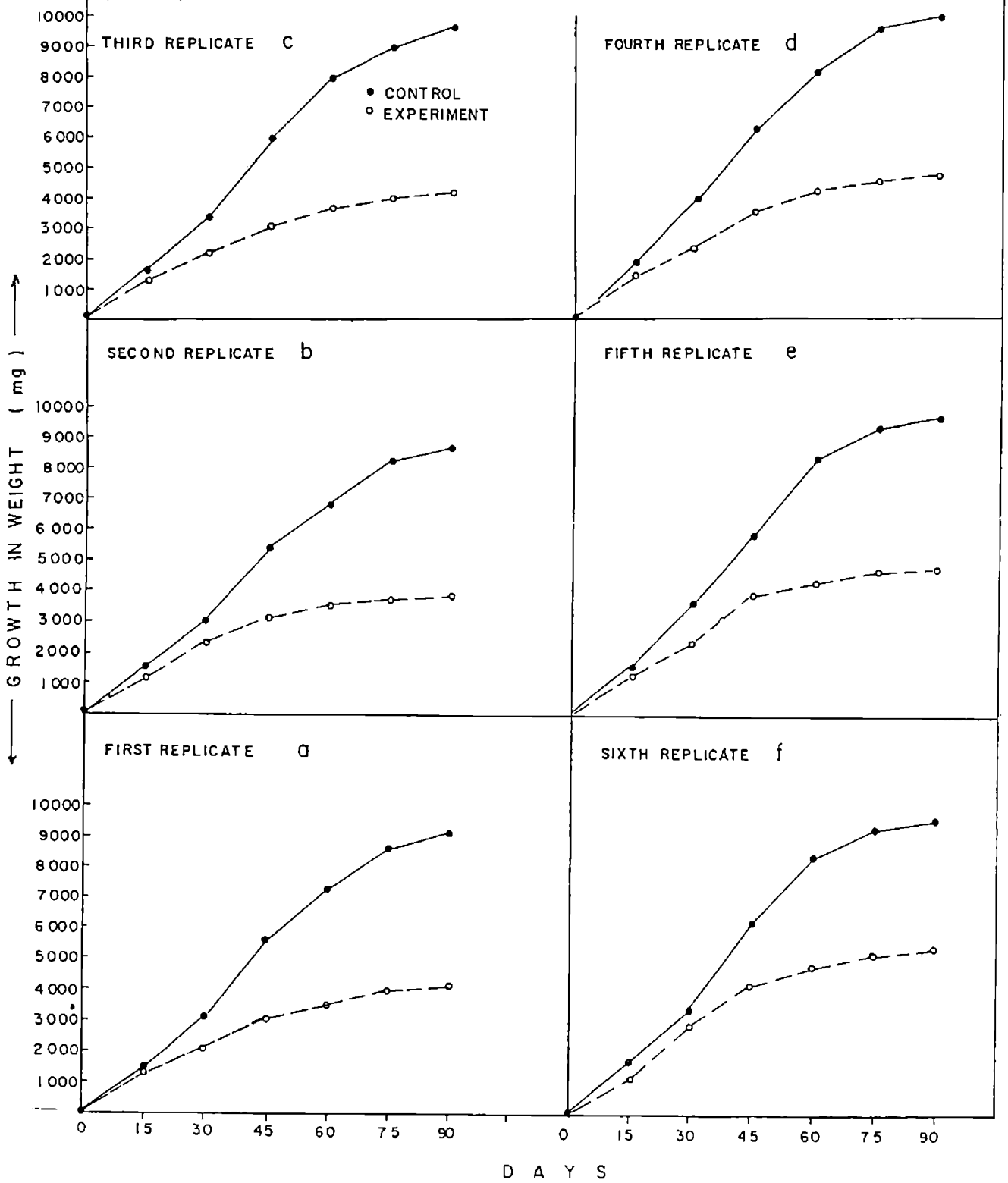
TABLE - 3:5

Average length and weight measurements of prawns grown in experimental and control pens with supplementary feeding.

Replicates	Days	EXPERIMENT		CONTROL	
		Average Weight (mg)	Average Length (mm)	Average Weight (mg)	Average Length (mm)
First replicate	0	40	26.2	38	26.0
	15	1502	52.3	2010	62.4
	30	2779	66.0	4179	83.6
	45	3442	77.4	6892	94.2
	60	4167	87.3	9207	102.7
	75	4439	96.5	12843	109.8
	90	4700	101.4	13222	114.1
Second replicate	0	35	25.5	35	25.4
	15	1685	50.7	2036	60.0
	30	2690	65.4	4886	77.2
	45	3572	76.3	7991	90.6
	60	4598	87.5	9583	101.1
	75	4789	94.6	11345	108.4
	90	4966	100.3	12455	112.2
Third replicate	0	37	26.4	36	25.1
	15	1887	52.3	1993	59.4
	30	2598	68.3	4768	77.3
	45	3828	79.6	6791	90.5
	60	4690	91.2	9210	98.7
	75	4989	99.8	11149	108.2
	90	5167	103.2	12414	111.3
Fourth replicate	0	41	25.0	39	25.6
	15	1724	48.6	2120	60.4
	30	2736	68.2	4102	77.4
	45	3986	79.5	6814	96.3
	60	4284	88.1	9782	106.2
	75	4506	96.2	11673	110.3
	90	4523	100.3	12171	115.1
Fifth replicate	0	40	25.7	40	26.5
	15	1609	52.3	1913	64.3
	30	2679	69.6	3872	82.4
	45	3943	82.2	6271	98.6
	60	4284	94.3	9312	107.8
	75	4572	98.2	10680	114.4
	90	4628	103.4	11909	120.1
Sixth replicate	0	38	27.2	36	27.1
	15	1423	53.4	1845	64.4
	30	2520	70.6	3890	79.2
	45	3986	81.5	6877	102.4
	60	4036	95.8	9354	110.5
	75	4234	99.2	11601	118.3
	90	4378	104.3	12152	122.2

Fig.3:39 (a to f)

GROWTH IN WEIGHT OF PRAWNS GROWN IN EXPERIMENTAL & CONTROL PENS WITHOUT SUPPLEMENTARY FEEDING



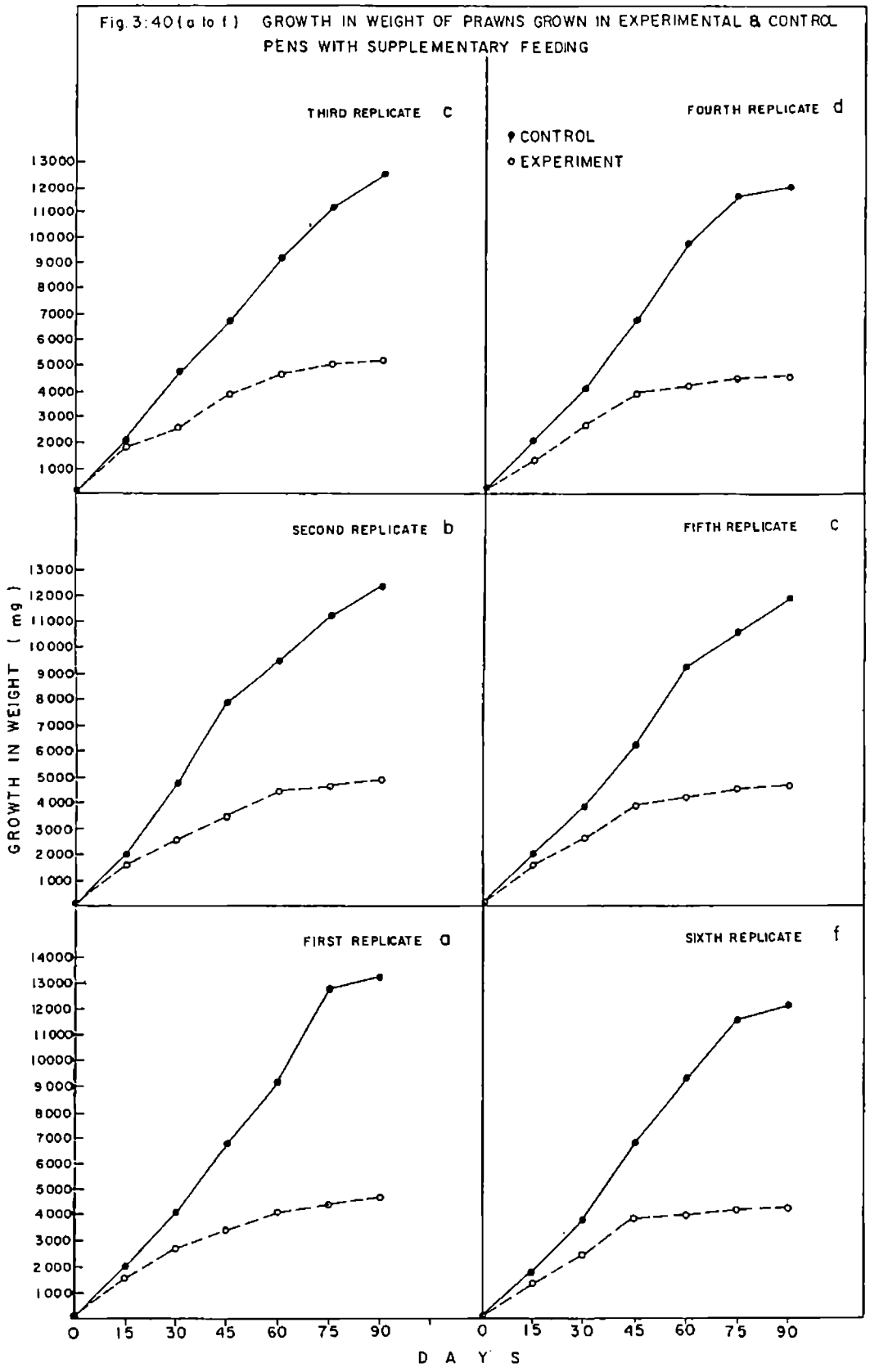


Fig. 3:40 (a to f) GROWTH IN WEIGHT OF PRAWNS GROWN IN EXPERIMENTAL & CONTROL PENS WITH SUPPLEMENTARY FEEDING
THIRD REPLICATE c
FOURTH REPLICATE d
CONTROL
EXPERIMENT
SECOND REPLICATE b
FIFTH REPLICATE e
FIRST REPLICATE a
SIXTH REPLICATE f
GROWTH IN WEIGHT (mg)
DAYS
0 15 30 45 60 75 90

TABLE - 3:6

ANOVA OF GROWTH STUDY OF PRAWNS

SOURCE	DF	SS	MSS	F	REMARKS
Due to H_2S	1	240.3	240.3	562.7	(HI SIG 1%)
Due to Feed	1	14.01	14.01	32.80	(HI SIG 1%)
Interaction	1	10.25	10.75	25.18	(HI SIG 1%)
Error	20	4.27	0.427		
	23	269.33			

TABLE - 3:7

Distribution of P. indicus in different substrates

Day	Type of Substratum	10 Hrs. (40-45mm)	10 Hrs. (85-90mm)	18 Hrs. (40-45mm)	18 Hrs. (85-90mm)	02 Hrs. (40-45mm)	02 Hrs. (85-90mm)
1.	H_2S Soil	1	0	2	1	0	0
	Sandy Clay	4	3	5	4	4	3
	Sandy Soil	5	7	3	5	6	7
2.	H_2S Soil	2	1	1	0	2	1
	Sandy Clay	4	5	4	3	5	4
	Sandy Soil	4	4	5	7	3	5
3.	H_2S Soil	3	2	2	2	1	1
	Sandy Clay	6	4	5	3	2	4
	Sandy Soil	1	4	3	5	7	5
4.	H_2S Soil	1	0	2	1	2	2
	Sandy Clay	3	6	3	4	4	3
	Sandy Soil	6	4	5	5	4	5
5.	H_2S Soil	2	3	4	2	3	2
	Sandy Clay	7	5	6	5	4	3
	Sandy Soil	1	2	0	3	3	5
6.	H_2S Soil	3	2	2	1	2	2
	Sandy Clay	4	5	6	5	7	3
	Sandy Soil	3	3	2	4	1	5
7.	H_2S Soil	3	2	1	3	2	0
	Sandy Clay	4	5	6	5	4	6
	Sandy Soil	3	3	3	2	4	4
8.	H_2S Soil	4	2	2	0	3	3
	Sandy Clay	5	4	5	6	3	6
	Sandy Soil	1	4	3	1	4	4
9.	H_2S Soil	3	2	4	2	3	2
	Sandy Clay	5	4	5	3	6	7
	Sandy Soil	2	4	1	5	1	1
10.	H_2S Soil	2	2	3	0	4	2
	Sandy Clay	5	4	5	4	5	3
	Sandy Soil	3	4	2	6	1	5

TABLE - 3:8

ANOVA OF SUBSTRATUM SELECTIVITY

SOURCE	DF	SS	MSS	F	REMARKS
Due to Soil	2	216.13	108.065	52.82	(HI SIG 1%)
Due to Size	1	0	0		(NOT SIG)
Interaction	2	37.74	18.87	9.23	(HI SIG 1%)
Error	174	356.13	2.046		
	179	610			

TABLE - 3:9

Feed acceptance of *P. indicus* in different substrates

(Data showns No. of pieces accepted by the prawns out of the 10 piece given)

Day	Feeding schedule	H_2S Soil (40-45mm)	H_2S Soil (85-90mm)	Sandy Clay (40-45mm)	Sandy Clay (85-90mm)	Sandy Soil (40-45mm)	Sandy Soil (85-90mm)
1.	8 Hrs. (A)	4	2	8	7	8	9
	18 Hrs. (B)	6	4	10	10	10	8
2.	(A)	3	2	9	8	8	9
	(B)	4	4	9	10	10	10
3.	(A)	3	4	7	8	7	6
	(B)	5	3	8	9	8	10
4.	(A)	4	3	8	6	9	9
	(B)	5	3	7	7	8	10
5.	(A)	2	3	8	7	8	9
	(B)	6	4	7	9	9	9
6.	(A)	4	2	8	9	7	6
	(B)	3	2	10	10	9	9
7.	(A)	4	3	7	6	6	7
	(B)	5	4	9	10	9	9
8.	(A)	3	2	7	9	10	9
	(B)	4	2	8	10	8	10
9.	(A)	4	3	8	9	8	9
	(B)	5	3	8	10	10	9
10.	(A)	3	2	8	10	9	10
	(B)	6	4	9	10	9	10
11.	(A)	2	3	8	7	10	8
	(B)	4	3	10	9	10	10
12.	(A)	3	3	7	7	7	9
	(B)	5	4	8	7	10	9
13.	(A)	3	3	7	8	9	9
	(B)	4	3	9	9	10	10
14.	(A)	4	2	8	8	8	9
	(B)	6	4	10	9	10	10

TABLE - 3:10

ANOVA OF FEED ACCEPTANCE IN DIFFERENT SUBSTRATUM

SOURCE	DF	SS	MSS	F	REMARKS
Due to Soil condition	2	966.22	483.11	441.6	(HI SIG 1%)
Due to Size	1	1.16	1.16	1.1	(NOT SIG)
Interaction	2	17.24	8.62	7.9	(HI SIG 1%)
Error	162	177.21	1.097		
	167	1161.83			

of prawns in hydrogen sulphide containing substrate and other substrates (sandy clay and sandy) the interaction was also found significant (Table 3:8).

Feed Acceptance in Different Substrates

Table 3:9 discipate the amount of feed accepted by two different size groups of prawns in three different substrates. The duration of the experiment was 14 days.

By comparing the values of the feed accepted it was found that 40-45mm size animals were accepting more feed from the sandy clay substratum than sandy and hydrogen sulphide substrates. The feed acceptance was found significantly low in hydrogen sulphide containing soil. There was no significant difference in acceptance of feed by 85-90mm size P. indicus from sandy and sandy clay substrate. This size group also showed a similar behaviour as 40-45mm size P. indicus by accepting very little food from the hydrogen sulphide containing soil. Statistical analysis also revealed the same (Table 3:10). In this experiment also the burrowing behaviour of P. indicus was very evident. During day time the prawns were found completely burried in sandy and sandy clay substrates.

DISCUSSION

In the culture pens (both experimental and control) the variation of hydrographical and sedimentological parameters are in accordance with that of the surrounding estuary from where the water is drawn (Vide Chapter II). As the period of culture is only for 90 days data on the hydrographical and sedimentological parameters were also collected for that period at every

fifteen days interval. Temperature and salinity gradually increased from January to April in both the years, a common feature of back waters during the pre-monsoon season. Similar observation was made by Gopalan et al (1982). Several workers (Williams, 1960; Zein-Eldin and Griffith, 1969, Venkataramaiah et al, 1974; Sreekumaran Nair and Krishnankutty, 1975; Paul Raj and Sanjeeva Raj, 1982) have stressed the importance of temperature and salinity on the survival and growth of prawns.

Sreekumaran Nair and Krishnankutty (1975) found that the growth rate of P. indicus is high in salinity of 10 ppt for post larvae and 30 ppt for juveniles.

Paul Raj and Sanjeeva Raj (1982) based on laboratory studies reported that the growth and survival of P. indicus was adversely affected at high salinity levels of 35 ppt and 45 ppt.

In the present study the salinity was within the safe level. Low at the time of stocking and gradual increase towards the end of the experiment, which suits the increasing salinity optima of the growing prawns.

The oxygen content in the experimental pen was lower than that in the control pen. Moreover the oxygen content also showed a gradual decrease from January to April particularly in the bottom water. In the experimental pen the bottom water oxygen was comparitively lower than the surface water oxygen. The oxygen level in the control pen was more than that in the experimental pen. The depletion of oxygen in the experimental pen can be attributed to the high oxygen demand of hydrogen sulphide present in the water and total sulphide present in the sediment. The low dissolved oxygen

levels in the bottom water will also enhance the toxicity of hydrogen sulphide (Adelman and Smith, 1972; Smith and Oseid, 1974). Gopalan et al (1982) reported that the low levels of oxygen in the high density culture systems results in low survival.

The water in the pens was rich in nutrients. The nutrient concentration in these waters were mainly influenced by the marine water and by the fresh water discharge as suggested by Sankaranarayanan and Qasim (1969). As the system was shallow the regeneration and the cycling of nutrients was also reflected by the high values in the surface waters. The low redox potential of the bottom sediment of the experimental pen along with the high organic carbon content indicated the highly reduced nature of the sediment where sulphide production was more. These pens therefore cannot support a rich bottom fauna which forms an important source of food for prawn.

At the same time in the control pen the nutrient level was better and the sediment was without sulphide pollution. The water and sediment conditions of the control pen was conducive for the fast growth of prawn and also supported a rich bottom fauna.

Several workers have recorded the rate of growth of Penaeus indicus in the culture systems as well as in the natural environment. The growth rates recorded were found to vary due to factors such as initial size of the seed at stocking, stocking density, environmental conditions of the fields and culture methods followed.

Growth rate was studied by Suseelan (1975) on prawns in the natural

ecosystem and he reported that P. indicus grew at the rate of 1.00 mm/day. Sundararajan et al (1980) reported an average growth in length of 1.41 mm/day from a culture period of 70 days with a stocking density of 3.7/m². He also reported that at a stocking density of 5/m² the growth in length and weight was 0.81 mm/day and 184.53 mg/day respectively.

Das et al (1982) reported that during 80 days of culture the average increase in length was 1.25 mm/day. In the same period growth in weight was 100 mg/day.

Unnithan (1985) observed growth in length of 1.22 mm/day to 1.33mm/day simultaniously with increase in weight of 111.1 mg/day to 133.3 mg/day in a 90 days culture experiment.

In the present study the growth in length observed in the control pen without supplementary feeding was 0.786 mm/day to 0.886 mm/day in the siz replicates. Whereas in the control pen with supplementary feeding the growth in length noted was 0.95 mm/day to 1.05 mm/day in the six replicates.

Growth in weight in the non-feeding and feeding controls in the present study ranged from 96.76 mg/day to 108.9 mg/day to 108.9 mg/day and 131.8 mg/day to 146.48 mg/day respectively. The observations on the growth of prawns in the control pen agrees with earlier observation and is comparable with those reported by Sultan et al (1973); Sampath and Menon (1975); Muthu (1978); Mammen et al (1980); Nair et al (1982); Sidharaju (1982); Gopalan et al (1982); Sriraman and Ananthanarayanan (1987).

The growth of prawns in the experimental pen was significantly different

when compared to that of the control. The prawn in the control pen attained more than 8.7 g to a maximum of 9.9 g when no supplementary feed was given whereas in the experimental pen the prawns attained a maximum weight of 5.4 g and a minimum of 3.8 g. In the experiment where supplementary feed was given significant difference in growth between experimental and control pen was observed. The growth rate (in length and weight) was significantly lower in prawns in experimental pen than that of the prawns reared in the control. From the results it is very evident that the presence of hydrogen sulphide in the water and total sulphide in the sediment coupled with low levels of dissolved oxygen is the main reason for the low growth rate (in length and weight). Moreover the survival is also high (65% 80%) in control pen than that in the experimental pen (25%-35%). Similar observations were made by Sun et al (1987) and Hui Yen et al (1987).

In the growth experiment where no supplementary feed was given the growth and survival rates of prawn in the experimental pen was very poor compared to that of prawns in the control pen. This can be attributed to the fact that with the increase in production of hydrogen sulphide in the bottom water and total sulphide in the sediment combined with low Eh and pH values reduced the availability of benthic organism which form the natural food of prawns. Moreover the presence of sulphide and low oxygen content in the water made this area unsuitable for the healthy growth of prawns.

In the present study the substratum preference of P. indicus was also studied. The experimental results showed that P. indicus exhibited preference to substratum. It does not prefer substratum with sulphide when compared to sandy clay and sandy substratum. Lalithambika Devi et al (1980) while

studying the preying efficiency in P. indicus and Metapenaeus dobsoni found that there is no significant difference in the preying efficiency with different concentration of mud or sand in the substratum. They also reported that P. indicus are very restive in clean fine sand substratum.

Rajalakshmi (1972) and Victor Chandra Bose et al (1978) reported that the seed of P. indicus were available in soft sand of shallow margin of estuary. Sosamma Eso (1988) observed that P. indicus aggregated more in sandy soil than soil having clayey nature.

From the present study it is clearly evident that P. indicus does not prefer substratum with hydrogen sulphide and this amply justifies the reason for poor growth and survival of prawns in the experimental pen where hydrogen sulphide was present.

Subsequently feed acceptence in the different substratum revealed that P. indicus accepted very little feed from the hydrogen sulphide containing substratum than the sandy and sandy clay substratum without hydrogen sulphide. The difference in feed acceptance in sandy clay and sandy substratum was not significant. This agrees with the observation of Lalithambika Devi et al (1980). Balasubramanian et al (1979) found that the preying efficiency was adversely affected with the increase in mud quantities compared to that of sand in Metapenaeus dobsoni.

Even if the hydrogen sulphide levels in the pen are not high enough to cause acute lethal effects, it should be remembered that concentrations as low as 0.0007-0.003 ppm un-ionised hydrogen sulphide if persisting for a long period could produce chronic toxicity effects such as retardation of

growth, lowering of fecundity, inhibition of spawning in fish and invertebrates (Smith and Oseid, 1975). In the amphipod Gammarus pseudolimanens food intake declined when hydrogen sulphide revel reached 0.05 ppm (Oseid and Smith, 1974).

In the growth experiment where supplementary feed was given, no improvement in the growth in weight was observed in the prawns in the experimental pen as compared to that in the non-feeding experiment. This observation was in accordance with the observation made in the feed acceptance experiment conducted in different substratum. In hydrogen sulphide containing substratum the rate of feed intake was very less compared to hydrogen sulphide free substrates. From the present observation it becomes evident that though supplementary feed is given, prawns (P. indicus) were relectant to accept feed from the substrate where hydrogen sulphide is present. On the contrary in the control pen higher growth rate was noticed when supplementary feed was given than that of the pen where supplementary feed was not given. This increase in growth rate (in length and weight) upheld the importance of supplementary feed in the prawn culture (Subramanian 1981).

From the present study it is clear that the presence of hydrogen sulphide in the pond water and sediment will affect the growth and survival of prawns.

The work presented in this thesis centred mainly around delinating the toxic effect of hydrogen sulphide on penaeid prawns and understand its influence on the ecology of estuary. The present investigation also involved characterization of the effects of hydrogen sulphide on the growth and behavioural responses of Penaeus indicus. The test animals employed during the present study namely P. indicus and Metapenaeus dobsoni are both ecologically and economically relevant.

The thesis embodying the details of the investigation has been organised into three chapters comprising Acute toxicity, influence of hydrogen sulphide on the ecology of estuary and effect of hydrogen sulphide on growth and substratum selectivity of penaeid prawn.

Each chapter has been partioned into various sections as Introduction, Material and Methods, Results and Discussion for a lucid presentation of the subject matter.

The chapter on Acute Toxicity includes an extensive survey of literature available on the topic. Information on the test animals employed, experimental medium, test chamber and the methodologies adopted for chemical analyses are detailed out under material and methods. The statistical techniques used for analysis and computation of data are also outlined. The results obtained are discussed. The most important finding was that smaller size groups were more resistant to H_2S than the larger size groups. Further, the toxicity of H_2S was drastically influenced by the pH of the medium; increased toxicity being associated with low pH. Of the two species tested,

P. indicus was found to be more sensitive than M. dobsoni to H_2S. The gills of the animals exposed to different concentrations of H_2S were black and the body soft.

The chapter on "Influence of H_2S on the ecology of estuary" involved comparison of the hydrographical and sedimentological parameters of H_2S polluted and unpolluted areas (clear area). The literature available relating to the study are reviewed. The material and methods employed are described and the technique followed listed. The results obtained revealed that the H_2S content in the soil and water had profound influence on the ecology of the estuary. Significant variation in the nutrient content of the soil and water column above were observed between sulphide polluted and non-polluted areas. Variations were also found in pH and Eh of the soil between the areas under study. The soil condition was highly reduced with heavy load of organic carbon in sulphide rich area when compared with non-polluted area; the condition in the latter case being distinctly better. Distribution of macrobenthic fauna and prawn seeds were also affected by the presence of sulphide in the soil and water. In sulphide polluted area macrobenthic animals were less. Prawn seeds were found avoiding the hydrogen sulphide present area.

The third chapter enlightens the information on the effect of H_2S on growth and substratum selectivity of P. indicus. The review of literature has taken into consideration the published literature on this aspect. The section on material and methods outlines the details of the experimental set up and other techniques adopted for the study. Results are described on the light of the data obtained. One of the conspicous features was that

the presence of H_2S in water and soil profoundly affects the rate of growth of P. indicus. The study also revealed that, growth of P. indicus (in length and weight) was less in areas where H_2S was present when compared with their counterparts in H_2S free area. P. indicus was found to exhibit characteristic substratum selectivity; preference being for a H_2S free substratum than area with H_2S. Food intake was also found to be significantly reduced in substratum with H_2S.

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