POPULATION BIOLOGY AND ECOLOGY OF *ARTEMIA* FROM SALINAS OF SOUTH EAST COAST OF INDIA

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TO MY DEAR BROTHER JOYCE

CERTIFICATE

This is to certify that thesis entitled "Population biology and ecology of **Artemia** from salinas of south east coast of India" is the bonafide record of the research work carried out by **Mr. Joslet Mathew** under my supervision and that no part thereof has been presented for the award of any other degree.

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DECLARATION

I hereby declare that this thesis entitled **"Population biology and ecology of Artemia from salinas of south east coast of India"** has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

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PREFACE

For the successful rearing of larvae of marine fishes and crustaceans in hatcheries where intensive aquaculture is practised the availability of suitable food is an essential pre-requisite. The cyst of the brine shrimp, Artemia forms one of the most important sources of food for the larvae. The demand for good quality Artemia cyst is far more than the present production level and the insufficient cyst supply sometimes is the major bottle-neck in the proper functioning of hatcheries the world over.

Artemia occurs in the natural salt lakes as well as in man-made salt pans. Efforts are being made to identify new natural habitats of brine shrimp, besides augmenting the production through extensive and intensive culture operations to meet the demands of the expanding aquaculture industries. Despite the availability of volumnous literature on Artemia in general, information on population biology and ecology of brine shrimp in natural environment, practicularly from India, is extremely poor. Hence the present study was designed to collect information on the population biology and ecology of Artemia from salinas of south east coast of India.

This thesis deals with the population characteristics of Artemia and the effect of different environmental parameters on the different stages of Artemia in a salina at Tuticorin, south east coast of India.

The present investigation was carried out from 1985 to 1987. The study was initiated by undertaking a survey to find out suitable

Artemia habitats along the south east coast of India and a perennial salina with an area of 0.25 ha was selected at Karapad (Tuticorin). Weekly samplings were made for two full calender years (1986-87) to collect the different stages of Artemia population as well as the different environmental parameters.

The thesis comprises of the following sections: Introduction, materials and methods, systematics, biology and distribution of Artemia, results and discussion, summary and bibliography. The section on results and discussion gives the characteristics of Artemia population in the salina, the seasonal variations of different environmental parameters in the salina and their effects on different stages of Artemia population. Description of an experiment conducted to show the sudden changes of salinity on different stages of Artemia is also given as a separate section.

Introduction explains the importance of aquaculture, origin of aquaculture, hatchery production of fish and shellfish seeds, the role of live food organisms and artificial diets in the dietary regime of cultivable fishes and shellfishes, the importance and advantages of Artemia as a live food in hatcheries, the details of the relevant studies carried out by other workers in different parts of the world including India and the need for taking up the present work.

Materials and methods gives a detailed description of the methods and techniques adopted for sampling the Artemia population and different environmental parameters. The method used for statistical analysis is also given.

The section on systematics, biology and distribution of Artemia gives an idea of the taxonomic position of Artemia, its biology and life cycle, types of Artemia habitats, distribution mechanisms, the places in Asia where Artemia occur and Artemia find-spots in India.

The first part of results and discussion section deals with the population characteristics of Artemia, the occurrence and relative abundance of different stages of Artemia such as nauplii, juveniles, preadults, cyst bearing adults and nauplii bearing adults and their variations during the pre-summer, summer and post-summer seasons. Analysis of variance (ANOVA) was conducted to find out the statistical significance.

The second part of the results and discussion section deals with the seasonal variations of different environmental factors like hydrographic (temperature, pH, salinity and dissolved oxygen); nutrients, (ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, inorganic phosphate and silicate); biological (gross primary productivity, number of algal cells and number of predatory insects) and meteorological parameters (rainfall, wind velocity and sunshine) in the salina and their influence on the different stages of the Artemia. Correlation matrix was constructed to see the influence of the above mentioned parameters on different stages of Artemia.

The third part of the result is regarding an experiment conducted in the laboratory and describes the impact of sudden changes in salinity on different stages of Artemia population. ANOVA was conducted to find out the statistical significance of the actual observation.

The summary gives the contents of research work and the bibliography forms the last part of the thesis.

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I thank and praise the ALMIGHTY GOD for granting me wisdom and sound health throughout the course of study.

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INTRODUCTION

Controlled production of marine and freshwater fishes in an economic way is the prime target of most aquaculture entrepreneurs. Aquaculture can be defined as a general term for the production of valuable biomass in confined bodies of water plus the sum of biological techniques required for the rearing and maintenance of target biota. Culture of microalgae, seaweeds, molluscs, shrimps and fishes can be carried out in stagnant, aerated or flowing freshwaters, brackish waters and marine waters (Bardach et al., 1972).

Culture of fishes in ponds has been practised since ages in several countries. The origin of fish culture in China in attributed to Wen Fang, the founder of the Chou dynasty. This has been reported in Fan Li's *fish culture classic* dated as back as 460 B.C. (Bardach, 1968). The initial practice of rearing carps for mere pleasure slowly gave way to culturing of fish for food. The Japanese practiced oyster culture as early as 2000 B.C. The Japanese and Philippines along with Chinese have been the poineers in developing intensive aquaculture techniques. Now several other countries around the world have adopted culture practices as their major business.

Edible marine products have a world wide acceptance. The recognition of the high nutritional value of many of these marine animals has further increased their demand. The higher initial investment, rising cost of fuel and limited resources coupled with fluctuations in capture fish production have often resulted in shortage of supply to the markets. The increasing gap between the supply and demand of preferred marine food products, especially shrimps, and the obvious potential for intensified fish production in inland and brackish waters have further induced entrepreneurs all over the world to take up aquaculture activities.

India also has taken up culture of fishes and shellfishes and is slowly replacing the traditional type of culture practices with semi-intensive and intensive methods where higher yields are achieved in shorter periods. Traditional aquaculture has been practiced since long in the coastal low-lying estuarine regions within India (Muthu, 1978). Though India has developed several techniques for culture of various species groups, there still exists biotechnical and economic obstacles. Substantial improvements at various levels are needed to have control over reproductive biology and achieve higher production.

The steady increase in the number of fish and shellfish farms has resulted in a demand for seeds of cultivable fishes and shellfishes throughout the year. The acute shortage of seeds in the wild during all the months of the year, prompted establishment of hatcheries, where, the marine fishes/shellfishes could be induced to spawn and the larvae reared upto a stage when they could be transferred to the growout ponds.

Larval production and rearing in hatcheries depend on several inputs and large scale mortality was a frequent factor associated with them (Mohamed and Laxminarayana,1983). Studies on the causative factor leading to mass mortality, revealed that the food item supplied have a vital function on the survival rate of the larvae (Mohamed and Laxminarayana, 1983). The nutritive value of the food supplied also had an important role. Larvae fed with highly nutritious food items had healthy growth and showed minimum mortality due to nutritional deficiencies (Muthu, 1983a,b; Kulasekarapandian, 1987).

Several studies (May, 1970; Lasker et al.,1970; Murphy, 1970; Mock, 1973; Liao et al.,1971; Ivleva, 1973; Masters, 1975; Kinne, 1977; Silas and Muthu, 1977; Ukeles, 1977; McVey, 1983; Nellen, 1986; Kulasekarapandian, 1987) have been carried out to identify suitable live food items to be fed to fish and shellfish larvae reared in the hatcheries. Naturally available zooplankton and phytoplankton were tried and their suitability was studied. Of these, rotifers, Artemia, Moina etc. have been identified as excellent diet for fish and shellfish larvae (Seale, 1933; Rollefsen, 1939; May, 1970; D'Agostino and Provasoli, 1970; Mock, 1974; Howell, 1973; Sulkin, 1975; Sulkin and Epifano, 1975; Kittaka, 1976; Conklin and Provasoli, 1978; Watanabe et al., 1978; Schluter, 1980; Trotta, 1980; Frieda B Taub, 1982; Muthu, 1983a,b; Kulasekarapandian, 1987).

These live food organisms play an important role in the dietary regime of cultivable fishes and shellfishes, particularly in the larval stages. They form nutritionally balanced diets. They are nonpolluting and readily accepted by the cultured organisms (Muthu, 1983a,b; Kulasekarapandian, 1987).

The scarcity of these live food forms in nature throughout the year led to the formulation of artificial diets. These artificial diets were nutritionally balanced and prepared on a large scale and stored appropriately, to be used whenever needed (Ahemed Ali, 1982a; Alikunhi et al., 1980). The advantage of artificial diet was that it could be used as an alternative when the live food was not available. But, unlike the live food organisms, they were not very stable under water and often resulted in turbidity and rapid deterioration of water quality. So, till this day natural live food organisms are preferred as the ideal food for larval diet.

Existing literature reveals that among the few species utilized as live food, the brine shrimp Artemia comes in for prime consideration (Seale, 1933; Rollefsen, 1939; Wickins, 1972; Serfling et al.,1974; Shelsser and Gallagher, 1974; Annonymous, 1978; Schauer et al., 1979; Sorgeloos et al., 1975; Sorgeloos, 1978, 1980; Beck et al., 1980). Artemia has been found to be a suitable food for a diverse group of cultivated organisms. For example : Homarus americanus (Gallaher et al., 1976), Macrobrachium rosenbergii (Aquacop, 1977), Penaeus kerathurus (San Feliu et al., 1976), P. aztecus (Venkataramaiah et al., 1973), Callinectes sapidus (Millikin et al., 1980), Solea solea and Scophthalamus maximus (Aronovich and Spektorova, 1971), Sparus auratus (Alessio, 1974) and Dicentrarchus labrax (Barahona - Fernandes and Girin, 1976).

Kinne (1977) has indicated that more than 85% of the marine animals, cultivated so far, has been fed with Artemia. In most cases, it is the freshly hatched nauplii that is used to rear the larval stages of crustaceans and fishes. (Jones, 1972; Brick, 1974; Christensen and Yang, 1976; Gopalakrishnan, 1976; Provenzano and Goyi 1976; Spectrorova and Doroshevi, 1973; Sulkin et al., Johns et al.,1980; Manzi and Moddox, 1980; Milliken et al., 1980). Studies of Reeve (1963), Von Heting (1971), Helfrinch (1973), Sheleser and Gallagher (1974), Stults (1974), Gallagher and Brown (1975), Kelly et al. (1977), Purdom and Preston (1977), Anonymous (1978), Watanabe et al. (1978) and Claus et al. (1979) indicated that adult Artemia can also be used as live food in aquaculture.

Even five decades ago, Seale (1933) and Rollefesen (1939) described the high nutritive value of the nauplii of this potential species as a live food. Since then, much attention has been given to the maximum production of Artemia and its application as food to various cultured species. The principal reason why brine shrimp larvae are so widely used for aquaculture purpose is that, their culture can be started from an apparantly inert source, the inactive dry embryos or cysts which need only be hatched.

When kept vaccum-dry, cysts remain viable for years; they can be easily transported all over the world and easily hatched to nauplii within approximately 24 hours on immersion in sea water. Intense research by scientists in many advanced countries under the guidance of the Artemia Reference Centre in Belgium, has proved that Artemia is the best live food (Sorgeloos, 1980), available in the salt pans, which can transform the entire aquaculture the world over, as also salt production by ensuring much higher quality of natural salt produced in the pans (Davis, 1980).

Extensive research on various aspects of brine shrimp has been carried out at various institutes and mass rearing techniques have been reported (Bossuyt and Sorgeloos, 1980; DE Los Santos *et al.*, 1980; Primavera *et al.*, 1980; Robichaux, 1980; Versichele and Sorgeloos, 1980; Beck *et al.*, 1980; Bruggeman *et al.*, 1980; Fujita *et al.*,1980; Tobias *et al.*, 1980; Vanhaecke and Sorgeloos, 1980; Sorgeloos, 1980; Sorgeloos and Kulasekarapandian, 1984; Camra and Rocha, 1987; Jumalon and Ogburn, 1987; Vu Do Quynch and Nguyen NgocLam, 1987; Bhargava *et al.*, 1987). In spite of the progress achieved, Sorgeloos *et al.* (1979) indicated that much fundamental as well as practical research is still necessary to optimize the achievements obtained so far. The recognition of the existence of potential areas along our coastal zone for brackish water prawn and fish culture has enhanced *Artemia* culture in India. In this regard, intensive research to study the biology and ecology of *Artemia* in the natural habitat is imperative.

Artemia populations are found from tropical to temperate regions and from temporary ponds to large salt lakes (Loffler, 1961; Por, 1968; Persoone and Sorgeloos, 1980; Melack, 1983; Dana, 1984) and are adapted to a broad range of habitats. Compared to brine shrimp's biology, ecological studies on the *Artemia* are very meagre. (Persoone and Sorgeloos, 1980). In large temperate lakes such as Mono Lake and Great Salt Lake, annual salinity changes are small and seasonality is determined primarily by the temperature cycle (Lenz, 1987). The population dynamics of *Artemia* in these two lakes have been studied (Manson, 1967; Wirick, 1972; and Lenz, 1980, 1982, 1984, 1987) and two major generations have been reported per year. Gillespie and Stephens (1977) estimated upto five generations in the Great Salt Lake. *Artemia* in Fallon ponds, Nevada (USA) also has similar instar distribution pattern like that of Mono Lake (Dana,1984). A comparative life history study of Artemia found in Mono Lake and Layason island was done by Lenz and Dana (1987).

Conte and Conte (1988) studied the abundance and spatial distribution of Artemia in Lake Abert, Oregon (USA). Mitchell and Geddes (1977) reported the distribution of Artemia within a salt work in South Australia and Geddes (1979) listed other localities where Artemia occurs in Australia. Marchant and Williams (1977a) studied the population dynamics of brine shrimp in two salt lakes in Western Victoria, Australia. Biomass estimation of Artemia in lake Grassmere, Marlborough, New Zealand, has been done by Haslett and Wear (1985). This study was of commercial interest as it ascertained whether adequate yields of Artemia could be filtered from ponds without deliteriously affecting reproductive potential or placing currently satisfactory levels of high salt production at risk. The role of Artemia in maintaining a healthy biological system in salt production has been well documented by Davis (1977, 1980).

Wear and Haslett (1987) studied the biology and ecology of Artemia from the Lake Grassmere, Newzealand. The population dynamics of the Australian brine shrimp, Parartemia zietziana was studied by Geddes (1975a, 1975c, 1980; Marchant and Williams, 1977a). Shallow tropical and subtropical hyper-saline ponds, which have smaller annual temperature range, become uninhabitable for Artemia during parts of the year due to salinity fluctuations (Lenz, 1987). Though tropical lakes may desiccate as ephemeral temperate ponds, studies on Caribbean and Indian lakes have shown that the disappearance of Artemia may also be due to extreme dilution. Such reports are available from Curacao and Bonaire, Anilles (Kristensen and Hulscher - Emeis, 1972); Vepallodai and Tuticorin, South India (Ramamoorthi and Thangaraj, 1980) and Didwana Lake, Rajasthan, India (Bhargava et al., 1987).

According to Floris (1933), the first investigation on brine shrimp in Yugoslavia was in Capod'Istria by Steurer (1903). Barigozzi (1946) observed that these Artemia were parthenogenetic. Rodriguez (1987) reported the presence of Artemia populations in solar salt works in the southern province of Cadiz, Spain. The presence of Artemia and Brachilla populations in the coastal lagoons and salt pans of Sardinia, Italy were observed by Mura et al. (1987). The occurrence of Artemia in Shurabil Lake, Iran was reported by Ahmadi (1987).

In addition to the above studies on population distribution of Artemia, several works on population variation related to the ecological conditions have been carried out. Spitchak (1980) reported the ecological conditions of Artemia habitats in the USSR. Castro et al. (1987) presented primary data such as geographical location, climate, mean temperatures, precipitation and soil type for Artemia population from eight sites in Mexico. Studies on the effect of different temperatures on the biology of Artemia in different salinities were done by Radchenko (1985). Usually Artemia tolerates extreme ranges of salinity, pH and other environmental conditions but is intolerant to substance like potassium (Martin and Wibur, 1921; Boone and Becking, 1931).

Jennings and Whitaker (1941) studied the effect of salinity upon the rate of excystment of Artemia. Ecological factors affecting the hatchability of Artemia cyst in inland saline lakes were studied by Sawchyn (1987). Sato (1966a,b) discussed the effect of pH and ions on hatching of Artemia cyst.

Cole and Brown (1967) studied the chemistry of different Artemia habitats. Chemical composition of Mono Lake was reported by Manson (1967). Stephens and Gillespie (1976) studied the nutrient concentrations of Great Salt Lake and found that the concentration of phosphates are comparatively higher than nitrogen compounds.

Phytoplankton forms the food of Artemia in natural habitats. Artemia can attain high densities in their natural habitats (Bradbury, 1971; Wirick, 1972; Gillespie and Stephens, 1977; Ramamoorthi and Thangaraj, 1980; Scelzo and Volgar, 1980; Lenz, 1984). Artemia is a voracious feeder on phytoplankton (Anderson, 1958; Manson, 1967; Wirick, 1972). As in the case of other zooplankters (Frost 1972), the grazing rate of Artemia is very high (Reeve, 1963; Lenz, 1982). Conte and Conte (1988) studied the major algal species found in the Artemia habitat, Lake Abert, Oregon (USA). Majic and Vukadin (1987) reported the major phytoplankton genera found in the Artemia biotope of Yugoslav Salt Works.

It has been observed that the size of brood also correspondingly reduces with decrease in algal density, during summer season. This has been observed in major Artemia habitats like Mono Lake (Lenz, 1982; Dana and Lenz, 1986), Great Salt Lake (Wirick, 1972), Bocachica Salt Lake (Scelzo and Voglar,1980), Pomerije and Burgas Lakes (Ludskanova 1974) and Layson lagoon (Lenz and Dana 1987). This has been attributed possibly due to limited food availability (Browne, 1982).

Manson (1967) and Wetzel (1975) made primary productivity studies in Mono Lake and Great Salt Lake respectively and observed a high rate of annual primary production in these salinas. But during summer, the primary production and algal mass were low due to the grazing of the Artemia population (Wirick, 1972). Similar low primary production has been measured in Artemia habitats such as Solar Lake, Sinai (Cohen et al., 1977b), Salterns in Mexico (Javor, 1983), and Little Manitou Lake, Canada (Haynes and Hammer, 1978).

Edmondson (1966) suggested that high predation and competition are the limiting factors restricting Artemia to the higher salinity habitats. Nimura (1987) suggested a probable reason why Artemia is confined to isolated confined waters. The absence of Artemia from other habitats is due to its inability to withstand predation (Persoone and Sorgeloos, 1980). Not only insects (Bhargava et al., 1987) but also other invertebrates like copepod (Kristensen and Hulscher Emeis, 1972) predate on Artemia causing mass disappearance of Artemia especially during low saline periods. Among the vertebrates, water birds have been identified as one of the major predator on Artemia in natural habitats. (Carpelan, 1957; Bradbury, 1971; Winkler, 1977; Mac Donald, 1980; Wear and Haslett, 1987; Bhargava et al., 1987).

Eventhough extensive studies have been carried out on the Artemia population in general, in different parts of the world, studies in relation to ecology is very much limited. Ecological studies on Artemia population in Bocachica Lake, Margarita Island, Venezuela were conducted by

Kristensen (1971) and Scelzo and Volgar (1980). Vieira and Galbano (1985) and Majic and Vukadin (1987) have carried out preliminary ecological studies in relation to different hydrological parameters such as temperature, pH, dissolved oxygen and salinity in the salt works of Portugal and Yugoslavia respectively. In addition to the above works, studies were also made on the nutrients like nitrite, nitrate and phosphate and their influence on Artemia population (Vieira and Galbano, 1985). The effect of environmental parameters on cyst formation in Artemia was studied by Berthalemy - Okazaki and Hedgecole (1987). Iwasaki (1976) reported the reproductive pattern of Artemia with regard to food and temperature.

In most of the southeast Asian countries like Philippines, Thailand Vietnam etc., existence of natural populations of Artemia has not been recorded probably due to failure of dispersion and adverse climatological conditions, especially monsoon climates (Sorgeloos,1978; Persoone and Sorgeloos, 1980). However, occurrence of Artemia in many habitats in these countries has come into picture by artificial inoculation in the system (Hutasing,1977; Vos and Tunsutapanich, 1979; Sorgeloos, 1980; Tunsutapanich, 1980; Sahavacharin, 1981; Vanchaecke, 1983; Vos et al.,1984; Mot, 1984).

With regards to the work on Artemia in India, the available information is very much limited. The occurrence of Artemia has been reported only from few pockets such as Bombay (Kulkarni, 1953), Sambar Lake (Baid, 1958), Tuticorin (Royan et al., 1970), Karsewar Island (Achari,1971), Gulf of Kutch (Royan, 1979), Vedaranyam (Basil et al., 1987) and Didwana Lake (Bhargava and Alam, 1980).

Studies on Artemia in relation to its ecological aspects is very much limited in the world in general and in India in particular. In this context, the report of Persoone and Sorgeloos 1980, "Among the 2700 papers of the recently updated Artemia bibliography, it is hard to find more than 50 articles which are strictly ecologically oriented" is worth mentioning.

Ramamoorthi and Thangaraj (1980) and Ramanathan and Natarajan (1987) have covered some basic ecological factors such as temperature, pH, dissolved oxygen, salinity etc. from the Tuticorin area in relation to the occurrence of Artemia. Similar basic studies from two distinct geographically isolated lakes are also known from the works of Basil et al. (1987) (Vedaranyam) and Bhargava et al. (1987) (Didwana Lake, Rajasthan). The studies of Bhargava et al. (1987) also covers the estimation of nutrients like nitrite, nitrate, phosphate and silicate. However, there is still paucity of information in this field especially related to the ecological factors in a given area.

The necessity for this indepth study is felt very much appropriate especially in the present day context of India, popularising shrimp culture and establishing number of hatcheries in later part of 1980's. On the information collected through Marine Product Export Development Authority (MPEDA) and other state fisheries departments, it is hopefully aimed that the production from culture will be doubled to the extent of 50,000 tonnes from the existing production of 25,000 tonnes by the turn of this centuary. Correspondingly the present area under culture of 60,000 ha will be stepped upto 1 lakh, with the establishment of chain of hatcheries in all maritime states (G. Santhanakrishnan, pers. commun.).

Therefore, need for having more indepth studies on Artemia related to many relevant ecological parameters in an area, is felt very much. Keeping this view in mind, the present study has been initiated to know more about the Artemia population relating to the maximum environmental parameters such as hydrographical, nutrients present in the habitat, food availability, meteorological and predation. This is very much in tune with a recent report emphasising the scope for detailed studies on population biology and ecology of Artemia resulting from the delibrations arrived through a recent symposium organised on Artemia by Bay of Bengal Programme (BOBP, FAO) at Madras in 1989 (Vishnu Bhat and Easwaraprasad, 1989).

MATERIALS AND METHODS

The present study was carried out for a period of two full calender years, from January 1986 to December 1987, covering all the seasons, in a salina at Tuticorin, south east coast of India (latitude 8°50'N) longitude 78°8'E as shown in (Fig. I). This salina had an area of 0.25 ha with an average depth of 1.0 metre. It was perennial in nature, with high saline water (51-140 ppt). Further, it was surrounded by salt pans and the water of the salina was at times pumped into the salt pans for salt production (Plate-I). In the present study the calender year was divided into three seasons namely the pre-summer (January to March), summer (April to September) and post-summer (October to December) on the basis of temperature prevailing at Tuticorin

A definite sampling period for collection of Artemia has not been followed by earlier workers. Lenz (1980), Ramamoorthi and Thangaraj (1980) and Ramanathan and Natarajan (1987) adopted monthly collections. Other workers (Lenz and Dana, 1987; Bhargava *et al.*, 1987) followed fortnightly sampling. It is logistic to refer in this context that Artemia attains maturity within a short period of about two weeks from the time of hatching and it goes on releasing nauplii/cysts once in 5-10 days during its life period of about 6 months (Sorgeloos, 1980; Sorgeloos and Kulasekarapandian, 1984). It is therefore ideal to have the sampling at least once in a fortnight. However, in order to have a better coverage and clear picture of different age groups of Artemia existing in the

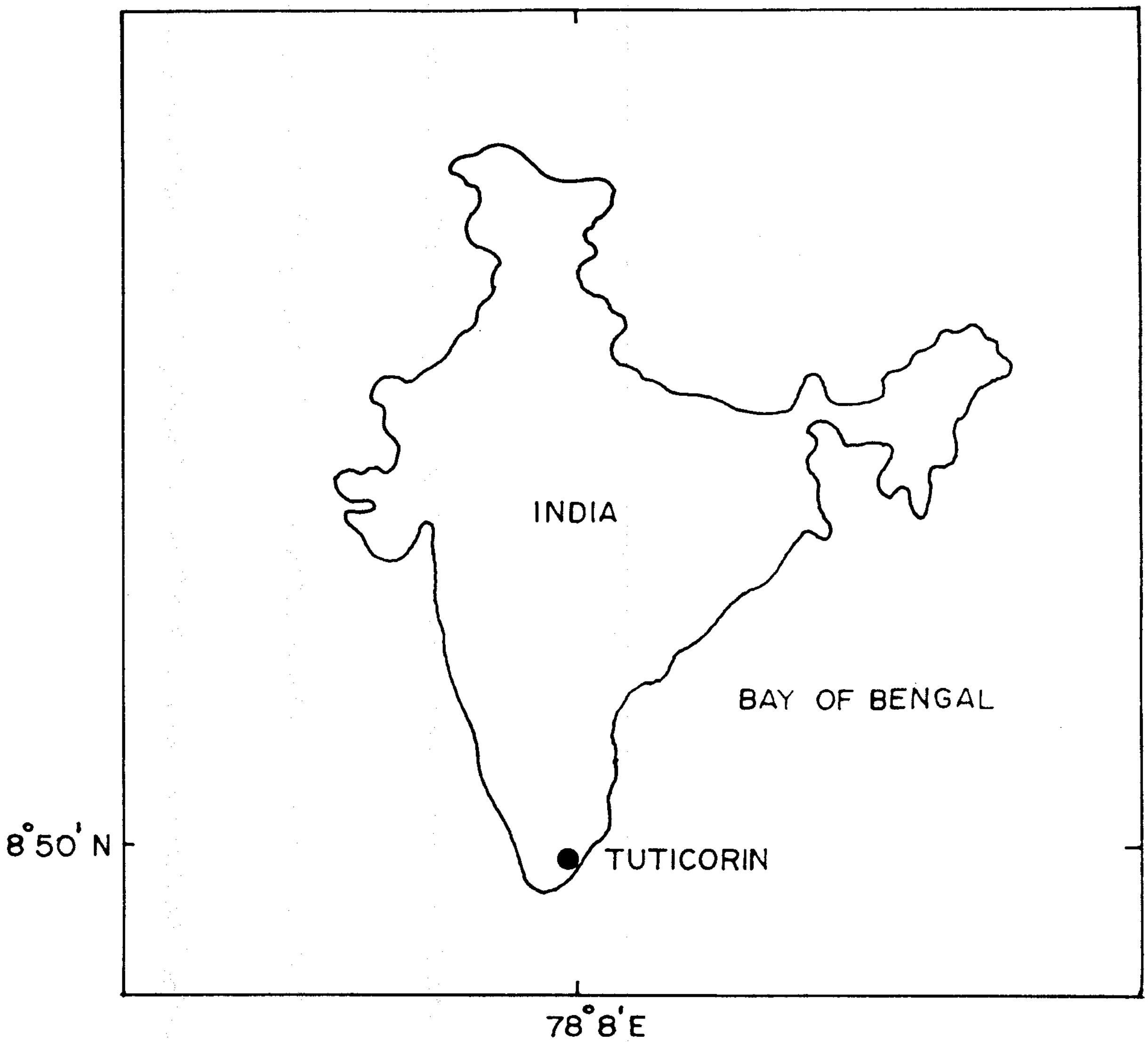


Fig. 1. Map showing location of the site where the present study was carried out.

salina, weekly sampling has been followed in the present study. In addition, data on environmental parameters were also simultaneously collected.

Population studies involved collection of representative samples of the Artemia population and predatory insects in the salina. The environmental parameters, analysed, were water temperature, pH, salinity, dissolved oxygen, nutrients like ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, inorganic phosphate and silicate, gross primary productivity and algal density. The meteorological parameters like rainfall, wind velocity, and sunshine were also collected.

Literature reveals that Artemia shows an uneven distribution in its habitat (Sorgeloos, 1980). Lenze (1980) based on his studies in Mono Lake, reported that the Artemia showed vertical migration behaviour. Sorgeloos (1980) has also referred to congregation of Artemia at the surface of the ponds, especially during morning hours. The normal grouping behaviour of Artemia has also been reported by Persoone and Sorgeloos (1980). Further, considerable importance has not been given by earlier workers regarding sampling time. With reference to the work carried out on this species in India (Ramamoorthi and Thangaraj, 1980), the time of collection has not been specified. Under these circumstances, it was felt that the time of sampling should be standardized necessarily. For this purpose, close observations on the distribution of Artemia was made continuously for more than a month. It was observed that during early morning hours, the distribution of Artemia was more or less uniform. This was proved by frequent sampling at different hours and at different points in the area, selected for the study. Therefore in the present study samples were collected during 06.00 to 08.00 hours in the morning. Further, collections were made from 150 points so as to have a logistic coverage and effective sampling inclusive of the points, having congregated distribution. The collection method used in the present work is the same as that adopted by Haslett and Wear (1985).

A wooden four logged (approximately 3 m) Catamaran was used to traverse the entire length and breadth of the salina. Collections were made using a plastic bucket of 2 litre capacity. This was poured into a scoop net made of bolting silk No.10. On covering all the 150 points the animals collected in the scoop net were slowly transferred into a bucket containing saline water and transported to the laboratory for further studies.

On reaching the laboratory, the different animal communities in the sample were sorted. Artemia were segregated and counted under a dissection microscope and classified into nauplii, juveniles, preadults and adults according to the description of Provasoli and Shiraishi (1959). Adult Artemia were further identified and classified as cyst bearing (ovi parous) (Plate II) and nauplii bearing (ovoviviparous) (Plate III) in order to get an idea about its reproductive activity. Total count of the predatory insects, were also taken into account to identify the extent of predation in the habitat. The data was expressed as total number of animals per litre of water.

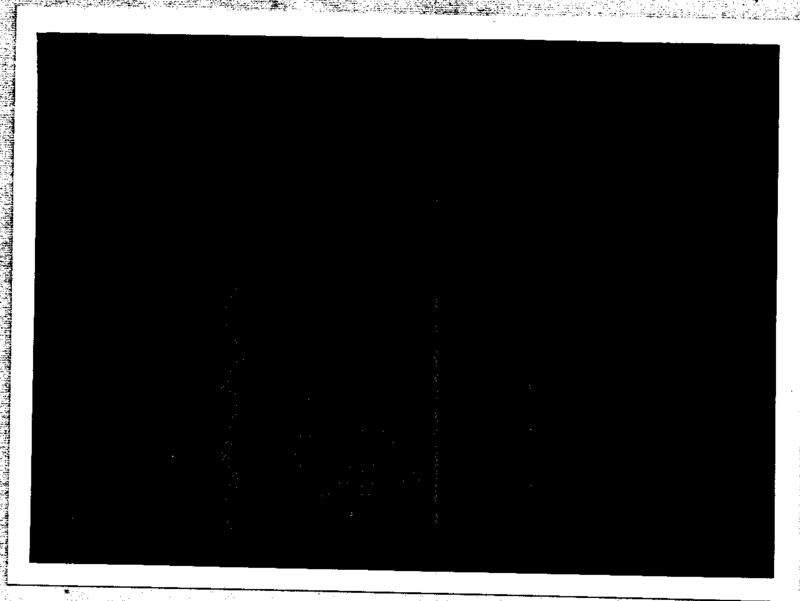


Plate III. Photograph showing the brood pouch of adult Artemia carrying nauplii (ovoviviparous mode of reproduction)

Temperature:

Water temperature was taken at the time of sampling for population analysis. A high precision thermometer having markings from 0°C to 50°C was used for this purpose.

pH:

pH was determined using a ECIL digital pH meter. The samples collected for estimating the salinity were used for pH determination. Readings were directly taken from the pH meter.

Dissolved oxygen:

To estimate the dissolved oxygen in the water, samples were carefully collected in 125 ml corning reagent bottles with BOD stoppers. Totally 6 samples were collected, 4 from corners and 2 from the centre of the salina and the average value was recorded. Since the salina had an average depth of 1 metre, samples were taken only from the surface. The collection bottles were washed twice with ambient water before sampling. Care was taken to avoid the entry and trapping of air bubbles during sampling. One ml of Winkler A and one ml of Winkler B was immediately added to the bottle containing the water sample. The stopper was carefully replaced without trapping air bubbles and the precepitate was dispersed uniformly throughout the bottle by shaking.

Standard Winkler method was used to determine the dissolved oxygen content (FAO 1975). The outline of the method is as follows:

The precipitate was dissolved in the laboratory using one ml of sulphuric acid. The solution was titrated against sodium thiosulphate solution. Starch was used to note the end point and the sodium thiosulphate solution was standardised during every set of titration using 0.005 N potassium iodate. Mean value of the three titrations was taken for calculation. Then the dissolved oxygen concentration was calculated using the formula.

$$= \frac{\text{Vol. of thiosulphate} \times N_2 \times 8 \times 1000 \times R}{100 \times 1.429}$$

Where,

N_2 = Normality of thiosulphate

R = 1.01 correction factor

1.429 = the weight of oxygen in milligram.

Salinity:

Samples for salinity estimation were collected in 200 ml polyethylene narrow mouthed bottles from 5 cm below the water surface. Initially, the bottles were rinsed twice with the surrounding water. The salinity was determined by Mohr's titration method (Strickland & Parson, 1968). The outline of the Mohr's titration method is as follows:-

10 ml of the standard seawater was titrated against silver nitrate solution using potassium chromate as indicator, to standardise the silver nitrate solution. Then 10 ml of the sample was titrated against the

standard silver nitrate solution in the same way. Care was taken to see the exact end point colouration in all the samples. the standard seawater was obtained from the Oceanography Institute, Copenhagen. Each sample was titrated thrice and the mean titre value was taken. Salinity of the sample was calculated using the formula:

$$\frac{V_2 \times S}{V_1}$$

Where,

V_1 = Volume of silver nitrate for 10 ml of standard seawater

V_2 = Volume of silver nitrate used for 10 ml sample.

S = 34.99, salinity of standard seawater.

Nutrients:

Water samples for nutrient analysis were collected in 500 ml narrow mouthed polyethylene bottles, washed twice with the ambient water, at 5 cm depth from the surface. The bottles were preserved in ice box containing ice till the analysis was carried out. A ECIL Senior spectrophotometer model GS 865 D with a wave length range of 200-930 nm was used to measure the colour intensity developed. The mean of triplicate analyses, was taken into account as the observed value.

Ammonia-nitrogen:

Ammonia-nitrogen was determined following the phenol hypochlorite method (Solorzano 1969). The following methodology was employed in the present analyses. To 50 ml of the sample and blank, 2 ml of phenol solution (prepared by dissolving 10 gm of phenol in 100 ml methanol and 2 ml of 0.5% sodium nitroprusside) was added. To this 5 ml of oxidising reagent (prepared by mixing 100 ml of 100 gm trisodium citrate and 5 gm of sodium hydroxide dissolved in 500 ml of water and 25 ml of sodium hypochlorite solution which was above 1.5 N) was also added. The developed colour was read spectrophotometrically at 640 nm. Amount of ammonia was represented in μg-at/l.

Nitrite-nitrogen:

Nitrite was determined by the Azo Dye method (Bendschneider and Robinson 1952). The determination of nitrite is based on the classical Griess's reaction in which the nitrification, at pH 1.5 - 2.0 is coupled with N(1-napthyl) ethylenediamine to form a highly coloured azo dye with an absorption maxima at 545 nm. This was measured spectrophotometrically.

The methodology used was the same as that of nitrate after reducing the sample through the amalgamated cadmium reduction column (FAO, 1975). Amount of nitrite was represented in μg-at/l.

Nitrate-nitrogen:

Nitrate-nitrogen was estimated using cadmium reduction column as per Solyom and Carlberg (1975). Nitrate is reduced to nitrite almost quantitatively by amalgamated cadmium column. The nitrite is then determined according to the classical Griess's reaction. The outline of the method followed (FAO, 1975) is presented below.

75 ml of the sample was run through the amalgamated cadmium column. First 10 ml of the sample flowing through the column was discarded and the next 10 ml used to wash the flasks. Then 50 ml was collected in two flasks of 25 ml each. To 25 ml of the reduced sample and the blank sample, 0.5 ml sulphanilamide reagent (prepared by dissolving 8 gm of sulphanilamide in a mixture of 80 ml concentrated hydrochloric acid and 420 ml of water) was added.

After not less than 3 minutes and not longer than 8 minutes 0.5 ml of NNED (N-(1-napthyl)- Ethylenediamine solution, (prepared by dissolving 0.8 gm in distilled water and diluted to 500 ml) was added to the sample. the absorbance was measured against the blank in the spectrophotometer at 545 nm. Amount of nitrate is represented in µg-at/l.

Inorganic phosphate:

the inorganic phosphate was estimated using the method described by Murphy and Riley (1962). The outline of the method is presented below:

The acid-molybdate solution was prepared by mixing 200 ml of 9.1 N sulphuric acid with 45 ml of 0.073 M ammonium heptomolybdate solution and then adding 5 ml of 0.1 M potassium antimony tartrate solution. From each sample, two 250 ml subsamples were separately taken, of which one was regarded as the sample and other as turbidity blank. To each of the subsample, 0.7 ml of the acid molybdate solution was also added. After five minutes, the sample was measured against its turbidity blank in the spectrophotometer at 882 nm. The amount of phosphate is represented in μg-at/l.

Silicate:

Silicate in the water sample was estimated by the method of Cirow N Robinson as reported by Strickland & Parsons (1968).

In a plastic conical flask, 3 ml of the acid-molybdate reagent, 15 ml of water sample and 5ml of distilled water was taken. After 10 minutes, 15 ml of reducing reagent (Metol Sulphite to oxalic acid + 25% sulphuric acid) was added and the solution made upto 50 ml. The solution was allowed to stand for 3 hours. The optical density of the sample was measured at 812 nm. For calibration, standard solution (Silicic acid) was taken with different concentrations and a standard graph was plotted. Silicate content was represented in μg-at/l.

Algal collection and identification:

Water samples were collected and analysed to identify the presence of different algae and its variation, according to the method followed by Ramamoorthi and Thangaraj (1980). Field identification was done using a hand lens and in the laboratory these were further studied under the microscope to confirm their identity. Unicellular algae were counted with a previously calibrated haemocytometer.

Primary Production:

Primary production was estimated weekly by light and dark bottle technique (Gaarder and Gran, 1927). Corning reagent bottles of 125 ml capacity with BOD stoppers were used for this purpose. The dissolved oxygen values for the initial bottle was estimated immediately. Three replicates of the light and dark bottles were used. 125 ml 'Corning' reagent bottles coated twice with black paint and then wrapped with black rexin cloth were used as 'dark' bottles.

After filling the bottles, precautions were taken as in the case of estimating dissolved oxygen. The light bottles were suspended at the same depth of collection by using poles. The dark bottles were tied in black rexin bags and suspended along with the light bottles. After 4 hours, the oxygen in the light and dark bottles were fixed using Winkler A and B solutions and brought to the laboratory for further analysis.

The difference between the light and dark bottles was taken as gross production. Whereas that of the light and the initial bottles was taken as net production. The calculation was done as follows(Strickland and Parsons, 1968).

Gross production =

$$mgC/m^3/day = \frac{605.f.(V(LB)-V(DB)}{PQ}$$

Net production =

$$mgC/m^3/day = \frac{605.f.(V(LB)-V(IB)}{PQ}$$

Where,

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

V(LB) V(DB) and V(IB) = Sodiumthiosulphate titre values obtained from the titrations of light, dark and initial bottles respectively.

PQ = Photosynthetic quotient here taken as 1.2

Meteorological parameters:

Meteorological parameters were also collected on sampling days. The data was collected from the meteorological station, Port Trust, Tuticorin, situated very near to the study area. The meteorological parameters, collected, were rainfall (in mm), wind velocity (kilometer/hr) and sunshine (bright hrs/day).

Statistical Analysis:

All statistical analyses were carried out according to Snedecor and Cochran (1967). Monthly mean and standard deviations were calculated for all the parameters. For the convenience of analyses two years data were pooled together and analyses were done on the combined data. The statistical methods used were analysis of varience (ANOVA) and construction of correlation matrix. All analyses were computed at Central Marine Fisheries Research Institute, Cochin, Kerala, India.

SYSTEMATICS, BIOLOGY AND DISTRIBUTION OF ARTEMIA

Occurrence of Artemia in different parts of the world is well known for ages and it has been observed that there exists species variation and also differences in strains, according to the geographical distribution. Therefore, in order to have a basic understanding, a brief account has been given below on its systematics, biology and distribution.

The first written record of the existence of the brine shrimp dates back to 1756 by Schlosser (Kuenen and Bass-Becking, 1938). Later it was described by Linnaeus (1758) as Cancer salinas. After about one centuary, Schmankewitsh (1875) divided the species into several new species, sub-species and strains on the basis of observed morphological differences. In 1910, Daday, reclassified the different salt water Artemia species as one single polytypic species, Artemia salina (Linnaeus). The systematic position of Artemia as referred by Sorgeloos and Kulasekara-pandian (1984) is as follows:

Phylum	:	Arthropoda
Class	:	Crustacea
Subclass	:	Branchiopoda
Order	:	Anostraca
Family	:	Artemiidae
Genus	:	Artemia

The binomen Artemia salina L. is taxonomically no longer valid (Bowen and Sterling, 1978). The Artemia population, which existed in the salt ponds of England were referred to as Artemia salina (Sorgeloss, 1980). Those biotopes have been reclaimed and this species no longer exists in that area.

Crossing experiments of different Artemia populations revealed reproductive isolation of several groups of populations (Halfer-Cervini et al., 1968; Barigozzi, 1972, 1974; Clark and Bowen, 1976) and has led to the recognition of sibling species to which different names have been given according to the international conventions of taxonomical nomenclature (Bowen and Sterling, 1978). So far, 20 bisexual strains have been classified into five sibling species (Bowen et al., 1978). They are: Artemia tunisiana (Europe), A. franciscana (North, Central and South America), A. monica (Mono Lake - California, USA), A. persimilis (Argentina) and A. urmiana (Iran).

Due to the important differences that is found among the parthenogenetical strains of brine shrimp, the species definition in the genus Artemia is difficult (Abreu-Grobois and Beardmore, 1980). Recently it has been suggested that exact sibling species of a bisexual strain can be identified through cross-breeding test with known sibling species (Bowen et al., 1978). Abreu-Grobois and Beardmore (1980) have suggested that until speciation in brine shrimp, especially in the parthenogenetical strain, is more clearly understood, only the genus designation 'Artemia' should be used.

The adult brine shrimp is approximately half an inch in length. It is characterized by an elongated body with 2 stalked complex eyes in the head region, 11 pairs of thoracic appendages and an abdomen that ends in a furca covered with spines (Fig.2). Females are slightly larger when compared with males in bisexual strains. Sexes can be easily distinguished in the adult stage. The male is distinguished by the presence of large claspers, which are over-developed antennae, at the head region, while the female has a large ventral egg sac. Both parthenogenesis and sexual reproduction exist in Artemia, but it varies with different strains and races (Abreu-Grobois and Beardmore, 1980; Persoone and Sorgeloos, 1980; Brown and Mac Donald, 1982).

The brine shrimp thrives very well in natural seawater but does not possess any anatomical mechanism against predation (Persoone and Sorgeloos, 1980). It however has developed a very efficient ecological defense mechanism by their physiological adaptation to a medium with very high salinity, where its predators cannot survive. Moreover, they are capable of synthesising very efficient respiratory pigments to cope with low oxygen level that may occur at high salinities (Persoone and Sorgeloos, 1980). They also have the ability to produce dormant cysts which can remain viable in extreme environmental conditions when juveniles and adults are wiped out (Persoone and Sorgeloos, 1980). According to Sorgeloos (1980), the reproductive behaviour of Artemia is as follows: In the bisexual strains, precopulation in adult Artemia is initiated by the male by grasping the female between the uterus and the last pair of thoracopods with its muscular claspers that can open and close. The

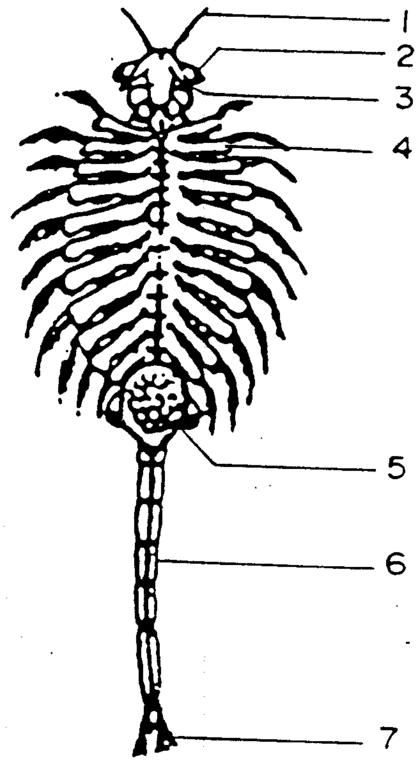


Fig. 2. Adult Artemia (Female)

1. ANTENNULE
2. LATERAL COMPLEX EYE
3. ANTENNA
4. THORACIC APPENDAGES
5. BROODSAC (UTERUS)
6. ABDOMINAL SEGMENTS
7. FURCA

couple can swim around in this so called "riding position" for long periods of time, beating their thoracopods in a synchronized fashion.

The eggs develop in the paired ovaries, situated on both sides of the digestive tracts behind the thoracopods. Once ripe, the oocytes are transferred via the oviducts into the unpaired brood sac or uterus. It is during this moment that copulation takes place. The penis is introduced into the uterus aperture and the sperm released. Fertilization is internal.

Under favourable conditions, the fertilized eggs develop into free swimming nauplii (Ovoviviparous mode of reproduction). In extreme conditions, for example, high salinity, low oxygen levels or food shortage, shell glands present in the uterus become active and accumulate a brown secretion. The embryos develop only upto the gastrula stage after which they are surrounded by a thick shell or chorion (secreted by the brown shell gland). They then enter a state of dormancy or diapause and are deposited (Oviparous mode of reproduction). Fecundity varies with the strains, geographical distribution and food availability (Luduskanova, 1974; Browne, 1982; Lenz, 1982; Dana and Lenz, 1986). Each female on an average can produce 60-150 eggs (Brown et al.,1984). Artemia eggs are brownish in colour, spherical in shape with a diameter of about 300 mm (Sorgeloos, 1980). The eggs usually float and are blown ashore, where they accumulate and dry (Plate-IV).

Upon immersion in seawater, the biconcave cysts hydrate, become spherical and the embryonic metabolism is resumed within the shell.

Several mechanisms are involved in the restarting of the biological clock of the embryo (Sorgeloos, 1973). After about 24 hours, the cyst shell bursts and the embryo appears, surrounded by the hatching membrane. Within a few hours, the embryo leaves the cyst shell completely and hangs underneath the empty shell to which it is still attached (Umbrella stage). The development of nauplius is completed inside the hatching membrane and within a short time, the hatching membrane is ruptured and the free swimming nauplius is set free. Freshly hatched nauplii measures about 400-500 microns in length and weigh about 0.002 gm. It is coloured brownish-orange and has 3 pairs of appendages. An unpaired median eye is situated in the head region. In this instar I stage, no food is being taken up (Sorgeloos and Kulasekarapandian, 1984), since the animal's digestive system is not functional yet. After about 12 hours, the animal moults into the second larval stage, which can feed on small food particles.

According to Sorgeloos (1980), generally Artemia grows and differentiate through about 15 moults, the moulting occurring after every 1-4 days from the time of hatching, depending on temperature. After 9 moults the sexes are differentiated and after about 12 moults, sexually mature adults are ready for mating (Masters, 1975). A 20 fold increase in dimension and 500 fold increase in biomass occur when the nauplius grows into an adult (Gilchrist, 1958; Reeve, 1963).

In Artemia, swimming is effected by eleven pairs of thoracic appendages fringed with hairs. Artemia feed on particulate matter of biological origin as well as on living organisms of appropriate size (algae and diatoms). But brine shrimps are non-selective feeders and ingest anything in the size-range of 1 to about 50 microns (Reeve, 1963). The younger ones eat essentially the same type of food but of a lesser particle size (Masters, 1975).

Salt lakes and brine ponds with Artemia population are found world wide. Decades ago Artemia has been recorded from over 80 saline habitats in many countries on the five continents (Abony, 1915; Arton, 1922; Stella, 1933; Mathias, 1937). However, many of the ancient salt pans, salt lakes and salt works where brine shrimp were reported to occur have been destroyed or abandoned. Typical examples are the disappearance of the brine shrimps in Germany and Great Britain (Persoone and Sorgeloos, 1980).

The recent Artemia find-spots are scattered through out the tropical, subtropical and temperate climatic zones, along the coastlines as well as inland and sometimes at hundreds of miles from the sea. On the basis of chemical composition, Artemia biotopes are classified into thalassohaline and athalassohaline (Persoone and Sorgeloos, 1980). Thalassohaline waters are concentrated seawater with sodium chloride as major salt. They make up most of coastal Artemia habitats where brines are formed by evaporation of seawater in land-locked bays or lagoons, well known under the common name of salt pans. The best example of this type is the Great Salt Lake in Utah, (USA) (Persoone and Sorgeloos, 1980). Athalassohaline Artemia biotopes are all located inland and are characterized by an ionic composition that differ from natural seawater. They are sulphate and carbonate waters. Chaplin Lake in Saskatchenan, Canada (Hammer et al., 1975) and Mono Lake in

California, USA (Manson, 1967) are the examples respectively.

Distribution of Artemia is discontinuous in many places of the world and does not occur in all salt water bodies. The main reason for this is that Artemia cannot migrate from one saline biotope to another via the seas, because it does not have any anatomical defense mechanisms against predation by carnivorous aquatic organisms like larger crustaceans and fishes (Persoone and Sorgeloos, 1980). the principal dispersion mechanisms of Artemia are transportation of cyst by wind and water fowl (Loffler, 1964; Horne, 1966; Bowen et al., 1978; Mac Donald, 1980), as well as deliberate human inoculation in solar salt works (Davis, 1977; Bowen et al., 1978; Geddes, 1980; Abreu-Grobois and Beardmore, 1980).

In Asia, the occurrence of Artemia has been reported from China (Tientsin, Tsjingtao), India (Bombay, Jamnagar, Karsewar Island, Kutch, Sambar Lake, Tuticorin), Iraq (Abu-Graib, Baghdad), Iran (Lake Rezaiyeh, Schor-gol) Israel (Eilat North and South, Kalia potash work, Solar Lake), Japan (Changadao Yamaguchi, Seto Naikai) and Turkey (Camalti saltern, Ismir) (Persoone and Sorgeloos, 1980).

The earlier studies on the occurrence of Indian strain of Artemia have indicated their availability from different localities. Kulkarni (1953), Baid (1958), Royan (1979) and Bhargava and Alam (1980) reported the occurrence of Artemia from Bombay, Sambar Lake, Gulf of Kutch, and Didwana Lake (the north west part of India) respectively. But, there is no record of the presence of Artemia from the north-east part of the country. In south India, occurrence of Artemia was reported from Tuticorin (Royan et al., 1970), Karsewar Island (Achari, 1971) and Vedaranyam (Basil et

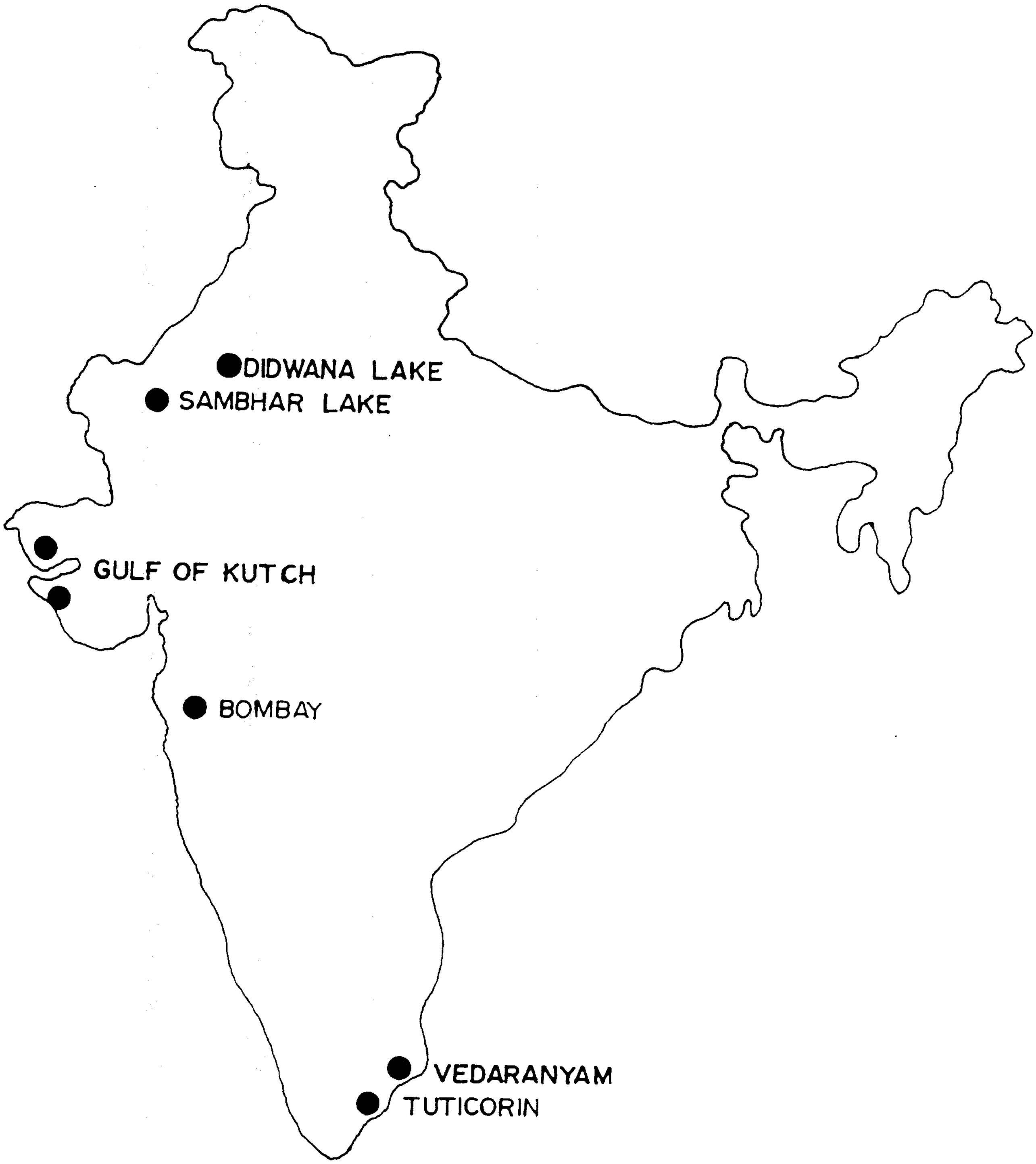


Fig. 3. ● ARTEMIA FIND-SPOTS IN INDIA

et al., 1987) (Fig.3). All these studies on Indian strains have shown that only parthenogenetic strains are available in these areas. However, Lal Mohan (1980) has reported the occurrence of bisexual strain in Tuticorin area.

Morphologically the parthenogenetic strains are slightly larger in size than the bisexual strains. The biology of both strains are similar. The reproductive characteristics are valid for both strains, except that fertilization does not take place in the parthenogenetic strain and the embryonic development starts as soon as the egg reach the uterus (Sorgeloos and Kulasekharapandian, 1984).

During the present study of 2 years at the salina in Tuticorin, only the parthenogenetic females were encountered. This is fully in agreement with the earlier studies of most of the Indian workers.

RESULTS AND DISCUSSION

PART - I

CHARACTERISTICS OF ARTEMIA POPULATION IN THE SALINA

As already known from the volumes of literature in *Artemia* population, there exists wide fluctuations in the distribution in general and population size varies in one and the same area between different seasons (Geddes, 1980; Lenz, 1980; Scelzo and Voglar, 1980; Persoone and Sorgeloos, 1980; Lenz and Dana, 1987; Wear and Haslett, 1987; Bhargava *et al.*, 1987; Ramanathan and Natarajan, 1987; Conte and Conte, 1988). Though, a few studies have been carried out in Indian region, on *Artemia* population the information available is mostly based on monthly samplings. (Ramamoorthi and Thangaraj, 1980; and Ramanathan and Natarajan, 1987). But as already reflected in the earlier pages, *Artemia* attains maturity within a short span of about fifteen days, and releases nauplii or cysts during every 5-10 days. Hence, inorder to have a better understanding of the population, it is logical to have a study being carried out at fortnightly intervals in correspondence with the life history of the animal. In the present study an attempt has been made to study the population variation at weekly intervals, with a view of having better coverage and clear picture of different age groups, existing in the population.

Tuticorin, the place selected for the study has unique climatic conditions. This place experiences invariably low rainfall, high temperature, correspondingly higher salinity in the salinas, as could be seen from the data presented elsewhere in the thesis. Because of such climatic conditions it is extremely difficult to differentiate and demarkate different seasons like summer, winter, monsoon and spring. Therefore, in the present study, for the purpose of presenting the results to the utmost effective manner, an attempt has been made to divide the months into different seasons mainly based on temperature parameter. Accordingly, in the present study the results are presented in three seasons namely the pre-summer season (January, February and March), summer season (April, May, June, July, August and September) and post-summer season (October, November and December).

The structure of the population was studied for with reference to seasons for a period of two years (1986 and 1987). The total number as well as the occurrence of different stages such as nauplii, juveniles, preadults, cyst bearing adults and nauplii bearing adults were found to vary in different seasons. During the pre-summer season of 1986, all stages of Artemia except the cyst bearing adults were observed. The nauplii were dominant group (41.04%), followed by the juveniles (31.02%), preadults (19.84%) and the nauplii bearing adults (8.09%) (Fig. 4).

In January, the total Artemia population ranged from 42 to 58 ind/l. Among the different stages the nauplii showed a clear dominance over the other stages and formed 47.83% of the total Artemia population during the month. However, a gradual decline in the number of nauplii

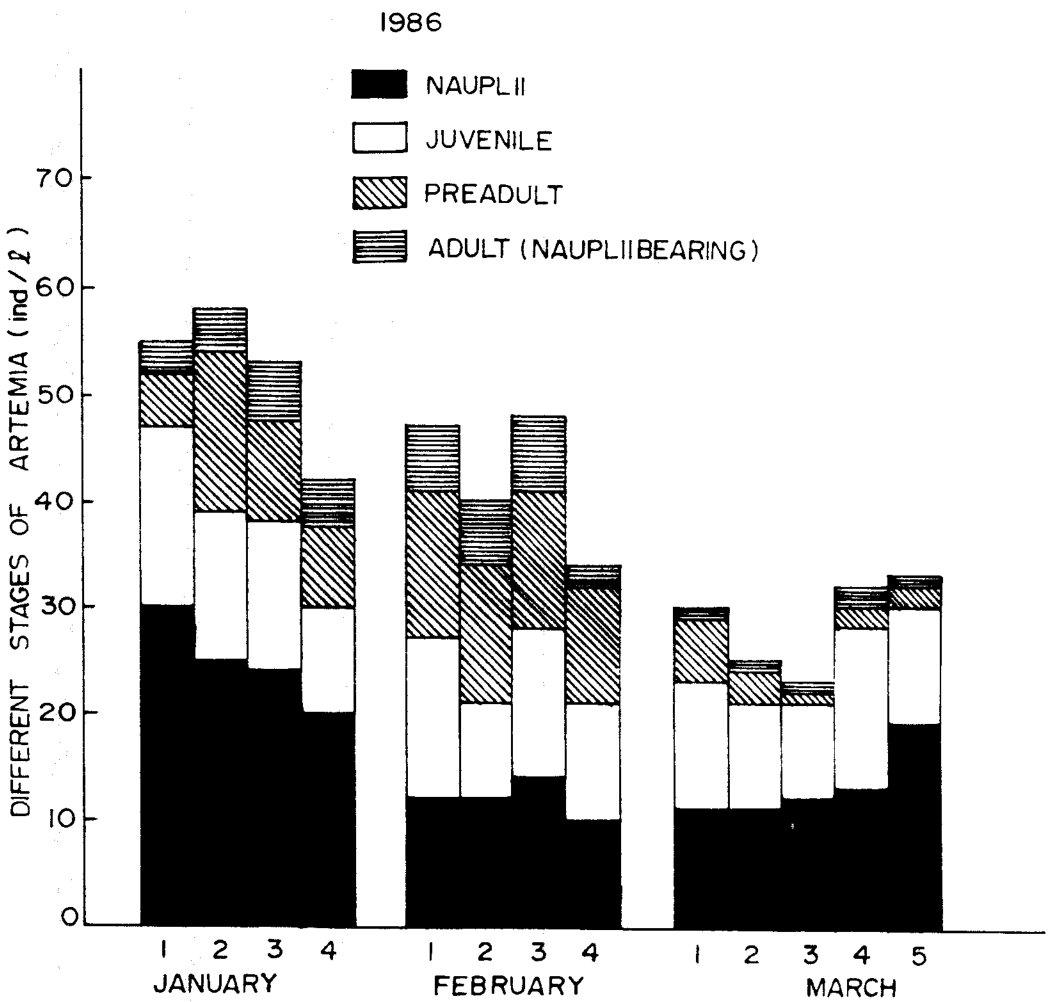


Fig. 4. Weekly contribution of the different stages of Artemia to the total population in the presummer season (1986)

Table 1. Abundance of different stages of Artemia population during the pre-summer season (1986)

Stages of Artemia population (Individuals/litre)	JANUARY				FEBRUARY				MARCH				
	*(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	30	25	24	20	12	12	14	10	11	11	12	13	19
Juveniles	17	14	14	10	15	9	14	11	12	10	9	15	11
Preadults	5	15	10	8	14	13	13	11	6	3	1	2	2
Cyst bearing adults	0	0	0	0	0	0	0	0	0	0	0	0	0
Nauplii bearing adults	2	4	5	4	6	6	7	2	1	1	1	2	1
Total	54	58	53	42	47	40	48	34	30	25	23	32	33

*(Numbers 1, 2, 3, 4 and 5 represent the weeks of the month)

from 30 to 20 ind/l was noticed from the first to the last week of January. The juvenile stage showed a similar trend. They formed 26.56% of the total population but its number declined from 17 to 10 ind/l from the first to the fourth week of January. The preadults on the other hand showed a reverse trend. their number gradually increased from the first week to last week of the month. Preadults formed 18.36% of the total Artemia population and they contributed 5, 15, 10 and 8 ind/l respectively during the first, second, third and fourth weeks of the month. The nauplii bearing adult population comprising 7.25% of the total count, also showed an increasing trend from 2 to 4 ind/l during the month (Table-1).

The total population number of Artemia during February ranged from 34 to 48 ind/l. The nauplii formed 28.41% of the total count per litre. They contributed 10 to 14 ind/l during each week of the month. The occurrence of juveniles were almost equal to that of nauplii. It comprised 28.99% of the total count and contributed 15, 9, 14 and 11 ind/l respectively during the first, second, third and fourth week of the month. The preadults also contributed to the Artemia population considerably and formed 30.17% of the total count during the month. The adults formed 12.43% of the total count and contributed on an average 5 ind/l per week (Table-1).

The total Artemia population during March showed a general reduction and the total number of animals ranged between 23 and 33 ind/l. The nauplii and juveniles contributed 46.15% and 39.86% with an average distribution of 13 and 11 ind/l per week respectively. The preadults formed 9.79% of the total monthly count and contributed 6, 3, 1, 2 and 2 ind/l during the first, second, third, fourth and fifth week (Table-1).

The *Artemia* population during the summer season, comprising the 6 months (April, May, June, July, August and September), was characterised by the appearance of cyst bearing adults (Fig. 5 and Tables 2 and 3). In general, their number showed an increasing trend with each consecutive month and towards the third and fourth week of August and the whole of the September the entire population comprised only of cyst bearing adults. Further, the total *Artemia* count per litre showed a steep decline from April to September. It declined from 213 numbers in April to 43 numbers in September. All stages of *Artemia* were well represented during the first half of the summer season (April, May and June) of 1986 (Fig. 5 and Table 2) after which the cyst bearing adults showed a clear dominance (Table 3).

In April, the total *Artemia* count ranged between 33 ind/l in the first week and 72 ind/l in the fourth week. The nauplii,juveniles, preadults nauplii bearing adults and cyst bearing adults contributed 57.28%, 28.64%, 8.92%, 4.69% and 0.47% respectively of the total *Artemia* population. A gradual increase in the number of nauplii was observed from the first week (18 nauplii/l) to the fourth week (40 nauplii/l). The juveniles showed a similar trend and their number increased from 10 juveniles/l in the first week to 20 juveniles/l in the fourth week. The preadult contributed 3, 4, 4, and 8 ind/l and the nauplii bearing adults 2, 2, 3 and 3 ind/l during the respective weeks. Cyst bearing adults were observed during the fourth week of the month and they contributed only 1.39% of the total population during the week (Table 2).

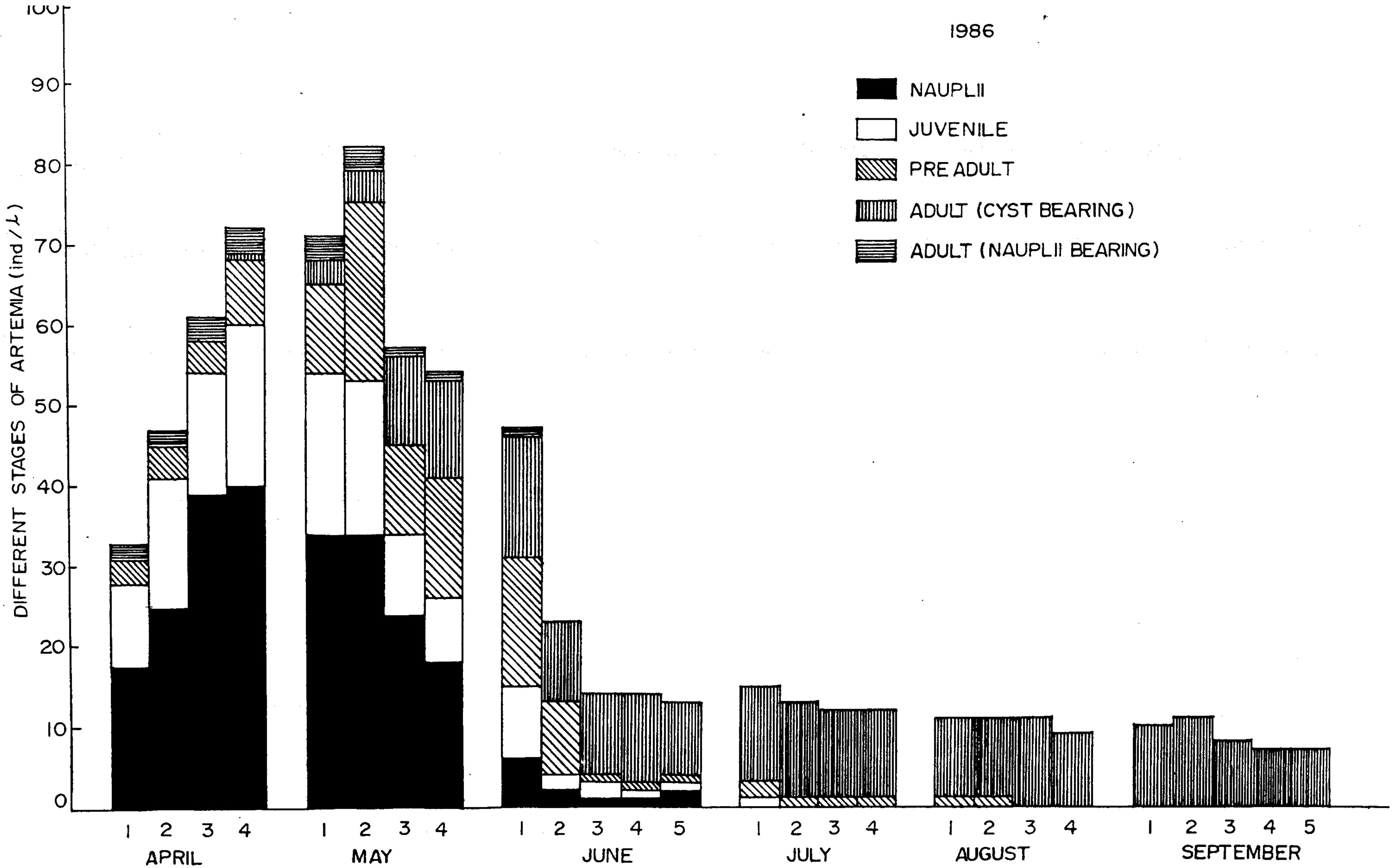


Fig. 5. Weekly contribution of the different stages of Artemia to the total population in the summer season (1986).

Table 2. Abundance of different stages of _Artemia_ population during the first half of summer season (1986)

Stages of _Artemia_ population (Individuals/litre)	APRIL				MAY				JUNE				
	* (1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	( )	(2)	(3)	(4)	(5)
Nauplii	18	25	39	40	34	34	24	18	6	2	1	1	2
Juveniles	10	16	15	20	20	19	10	8	9	2	2	1	1
Preadults	3	4	4	8	11	22	11	15	16	9	1	1	1
Cyst bearing adults	0	0	0	1	3	4	11	12	15	10	10	11	9
Nauplii bearing adults	2	2	3	3	3	3	1	1	1	0	0	0	0
Total	33	47	61	72	71	82	57	54	47	23	14	14	13

*(Numbers 1, 2, 3, 4 and 5 represent weeks of the month)

Table 3. Abundance of different stages of Artemia population during the second half of summer season (1986).

Stages of Artemia population (Individuals/litre)	JULY				AUGUST				SEPTEMBER				
	* (1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	0	0	0	0	0	0	0	0	0	0	0	0	0
Juveniles	1	0	0	0	0	0	0	0	0	0	0	0	0
Preadults	2	1	1	1	1	1	0	0	0	0	0	0	0
Cyst bearing adults	12	12	11	11	10	10	11	9	10	11	8	7	7
Nauplii bearing adults	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	15	13	12	12	11	11	11	9	10	11	8	7	7

* (Numbers 1, 2, 3, 4 and 5 represent weeks of the month)

In May the total count of Artemia population ranged from 54 to 82 ind/l (Table 2). The nauplii dominated and comprised 41.67% of the total count, followed by preadults (22.35%), juveniles (21.59%), cyst bearing adults (11.36%) and nauplii bearing adults (3.03%). The nauplii contributed 34 ind/l during the first as well as the second week. The number then declined and it contributed 24 and 18 ind/l respectively in the third and fourth week. The number of juveniles during the first, second, third and fourth week was 20, 19, 10 and 8 ind/l respectively. The contribution of the preadults to the total population fluctuated every week. In the first week 11 preadults/l were recorded, it increased to 22 preadults/l in the second week, decreased again to 11 preadults/ in the 3rd week and then increased to 15 preadults/l in the fourth week. The nauplii bearing adults on the other hand showed a steady decline and its number decreased from 3 to 1 ind/l from first week to the fourth week of the month. But the number of the cyst bearing adults increased from 3 ind/l in the first week to 12 ind/l in the last week. The total Artemia population showed a steady decline during June. Its total number reduced from 47 ind/l in the first week to 13 ind/l in the last week (Table 2). A steady increase in the number of cyst bearing adults was observed during this month. An interesting factor noticed was the decline in the number of all stages (nauplii, juveniles, preadults and nauplii bearing adults except that of cyst bearing adults from the first to the last week of the month (Fig. 5). The number of nauplii declined from 6 ind/l in the first week to 2 ind/l in the fourth week. The corresponding decline observed in the case of juveniles was from 9 ind/l to 1 ind/l. The preadults count also declined from 16 ind/l in the first week to 1 ind/l in the last week. Only a single nauplii bearing adult was observed during the month. It occurred during the first week. The number of the cyst bearing adults ranged from 9 ind/l to 15 ind/l during the month.

The latter half of the summer season (July, August and September) was dominated mainly by the cyst bearing adults (Fig. 5 and Table 3). The total count of Artemia population was quite low and the total number ranged between 52 (in July) to 42 (in September). The cyst bearing adults formed 94.16% of the total Artemia population during the 3 months and comprised 100% of the population during the third and fourth week of August and all five weeks of September. The nauplii were totally absent in the sample (Table 3). The juveniles were noticed only in the first week of July. They formed 1.92% of the total population of the month. The preadults contributed 9.6% in July. The contribution of the preadults to the total Artemia population further declined and they formed only 4.7% in August (Fig. 5).

The post-summer periods (October, November and December) was characterised by the rapid increase in total count of Artemia and the reappearance of nauplii, juveniles, preadults and nauplii bearing adults (Fig. 6 and Table 4). The cyst bearing adults occurred during the initial weeks of October and it totally disappeared thereafter. The nauplii in general dominated in the total count during the season and formed 54.19% followed by juveniles (23.07%), preadults (16.49%), nauplii bearing adults (4.88%) and cyst bearing adults (0.87%).

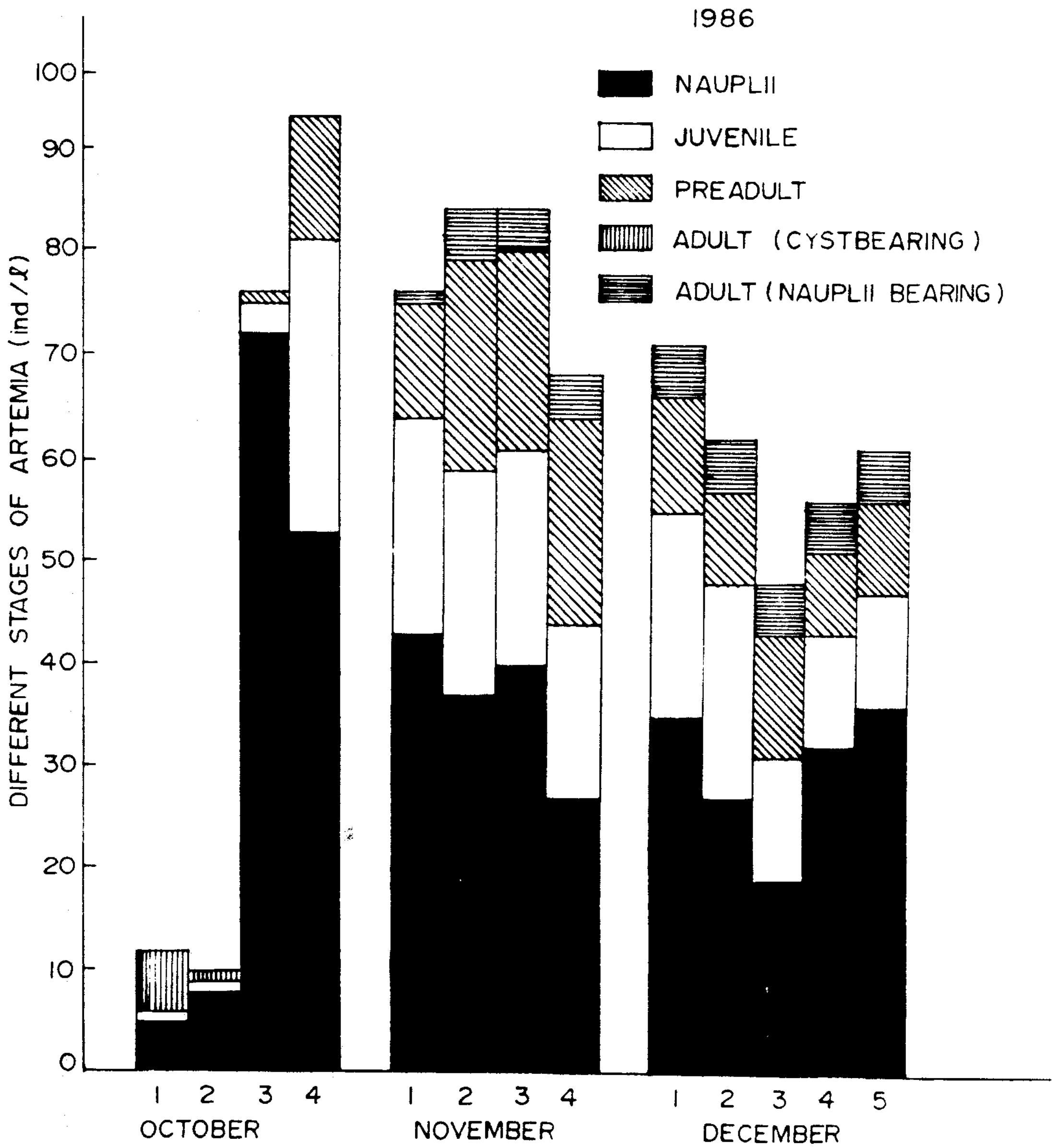


Fig. 6. Weekly contribution of the different stages of Artemia to the total population in the post-summer season (1986)

Table 4. Abundance of different stages of _Artemia_ population during the post-summer season (1986)

Stages of _Artemia_ population Individuals/litre)	OCTOBER				NOVEMBER				DECEMBER				
	* (1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	5	8	72	53	43	37	40	27	35	27	19	32	36
Juveniles	1	1	3	28	21	22	21	17	20	21	12	11	11
Preadults	0	0	1	12	11	20	19	20	11	9	12	8	9
Cyst bearing adults	6	1	0	0	0	0	0	0	0	0	0	0	0
Nauplii bearing Adults	0	0	0	0	1	5	4	4	5	5	5	5	5
Total	12	10	76	93	76	84	84	68	71	62	48	56	61

*(Numbers 1, 2, 3, 4 and 5 represent weeks of the month

During October 1986, the total count showed a sudden and steep increase from 12 ind/l in the first week to 93 ind/l in the fourth week. The nauplii formed 72.25% and their number increased from 5 ind/l in the first week to 72 ind/l in the third week and then decreased to 53 ind/l in the fourth week. The juveniles contributed 17.28% and their number per litre increased from 1 in the first week to 28 in the last week. Preadults were observed only in the 3rd (1 ind/l) and 4th (12 ind/l) week and they comprised 6.8% of the total population. The cyst bearing adult occurred only during the first two weeks of October and they comprised only 3.66% of the total count (Table 4).

A similar trend was noticed during November 1986. The total number ranged from 68 to 84/l. The cyst bearing adults were totally absent. The number of nauplii ranged from 27 to 43/l and they comprised 47.12% of the total count. The juveniles comprised 25.96% of the total population. An average of 21 juveniles/l were observed during the first 3 weeks afterwhich it declined to 17 juveniles/l. Preadults were observed throughout the month and their number increased from 11/l in the first week to 20/l in the last week. They comprised 22.4% of the total population. The number of nauplii bearing adults increased from 1/l in the first week to 4/l in the last week, and they formed 4.48% of the total count (Table 4).

In December, the total count of Artemia population ranged from 8 ind/l to 71 ind/l. The total number did not follow a definite trend and fluctuated every week. In the third week a minimum number of 48 ind/l was noticed. The maximum number of 71 ind/l was obtained during the first week of December (Table 4). The nauplii dominated during all the weeks and formed 50% of the total count of the month. The contribution of the juveniles, preadults and the nauplii bearing adults were 25.17%, 16.44% and 8.39% respectively. The number of juveniles reduced from 20/l in the first week to 11/l in the last week. The pre-adults also showed similar trend and their number decreased from 11/l in the first week to 9/l in the last week. The number of nauplii bearing adults remained uniform throughout the month and 5 /l were recorded in each week.

Studies on population characteristics during the different seasons of 1987 revealed that the distribution of different stages of Artemia did not follow a similar pattern as the previous year. The total number as well as the appearance and disappearance of certain stages of Artemia did not seem to follow a definite set pattern. During the year the total number of Artemia /l was very high but none of the stage was recorded during the latter half of November and the whole of December (Fig. 7, 8 and 9 and Tables 5, 6, 7 and 8).

During the pre-summer season, all stages occurred in the collections (Fig. 7 and Table 5). The total number ranged from 252 in January to 105 in March. In February, 157 individuals were recorded. The total population ranged from 53 ind/l to 72 ind/l in January. The nauplii dominated and comprised 50% of the total Artemia population followed by the preadults (20.4%), juveniles (16.37%) and the nauplii bearing adults (13.4%). Cyst bearing adults were absent during this month.

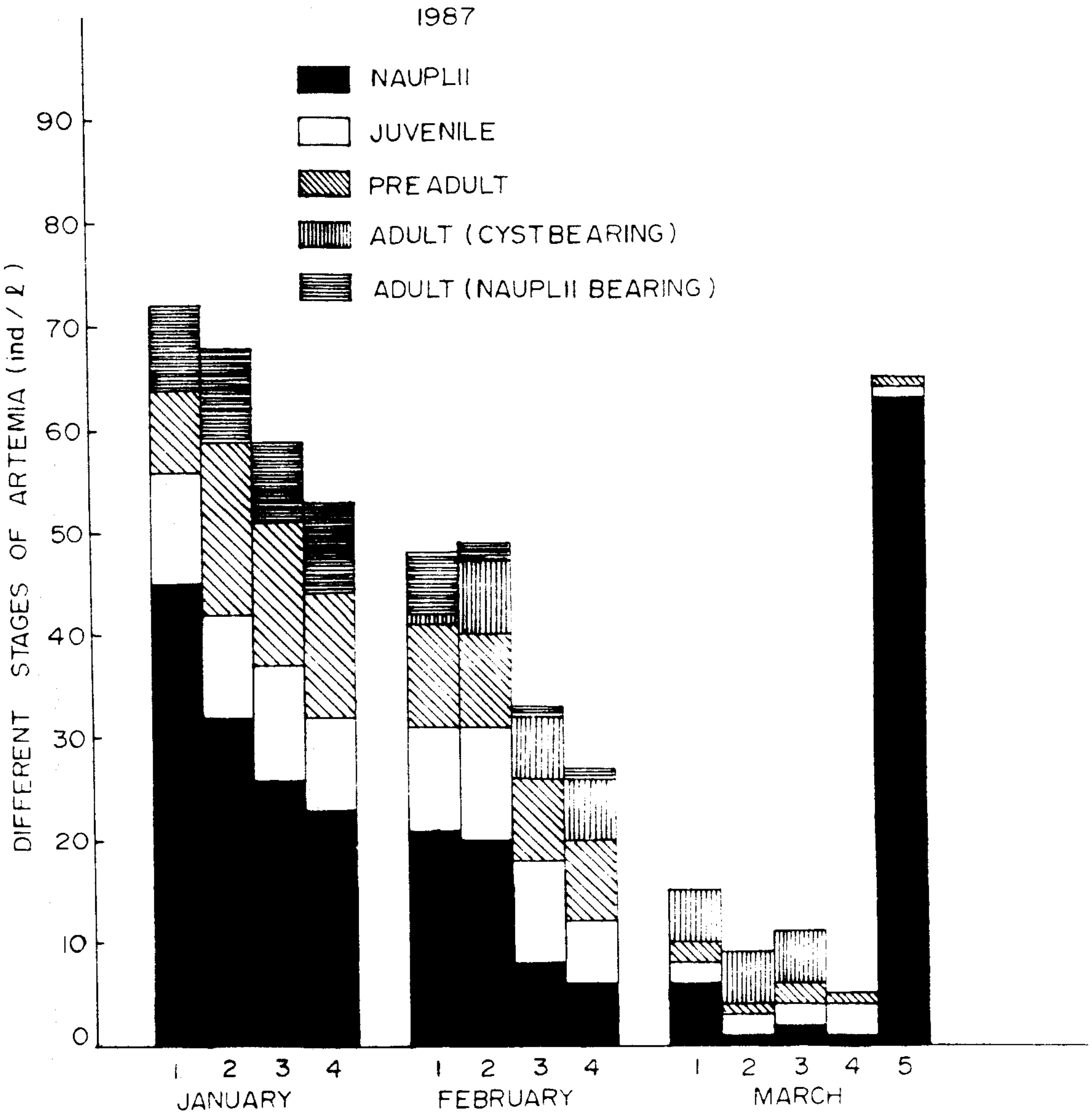


Fig. 7. Weekly contribution of different stages of Artemia to the total population in the pre-summer season (1987)

Table 5. Abundance of different stages of Artemia population during the pre-summer season (1987.)

Stages of Artemia population (Individuals/litre)	JANUARY				FEBRUARY				MARCH				
	*(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	45	32	26	23	21	20	8	6	6	1	2	1	63
Juveniles	11	10	11	9	10	11	10	6	2	2	2	3	1
Preadults	8	17	14	12	10	9	8	8	2	1	2	1	1
Cyst Bearing Adults	0	0	0	0	1	7	6	6	5	5	5	0	0
Nauplii bearing adults	8	9	8	9	6	2	1	1	0	0	0	0	0
Total	72	68	59	53	48	49	33	27	15	9	11	5	65

*(Numbers 1, 2, 3, 4 and 5 represent the weeks of the month)

Though the nauplii dominated, they showed a decreasing trend and its number reduced from 45/l in the first week to 23/l in the last week of January. The number of preadults on the other hand, increased from 8/l in the first week to 12/l in the last week. The distribution of juveniles and nauplii bearing adults remained around 10/l per week and 9/l per week respectively.

The total count in February, ranged from 27 ind/l to 49 ind/l (Fig. 7 and Table 5). The cyst bearing adults appeared in the first week of February and their number increased from 1/l in first week to 6/l in the last week. The nauplii continued to decline but still formed the most dominant group of the total population. It comprised 35.03% of the total count and its number reduced from 21/l in the first week to 6/l in the last week. The contribution of juveniles and pre adults to the total count was 23.57% and 22.29% respectively. The number of juveniles ranged between 6 numbers/l and 10 numbers/l per week and that of preadult from 8/l to 10/l per week. The nauplii bearing adult formed 6.3% of the total count and their number per litre reduced from 6 in the first week to 1 in the last week.

The total individual count/l in March fluctuated from 5 to 65 ind/l (Fig. 7 and Table 5). During the first week, 15 ind/l were observed. It reduced to 9 ind/l in the second week, increased to 11 ind/l in the 3rd week and again declined to 5 ind/l in the 4th week and then increased suddenly to 65 ind/l in the last week (Table 5). The sudden increase was brought by the steep increase in the number of naupli. The nauplii contributed to 69.52% of the total Artemia population and its number increased from 6 ind/l in the first week to 63 ind/l in the last week. Cyst bearing adults formed the next dominant group and they contributed to 14.29% of the total count. They were observed only during the first 3 weeks of the month (Fig. 7). The juveniles contributed to 9.52% of total number. On an average, 2 juveniles/l were distributed per week. The preadults comprised 6.67% of the total count. Nauplii bearing adults were not encountered during this month.

The Artemia population continued to show an increasing trend during the first half (April, May and June) of the summer season. Then it gradually declined during the second half (July, August, September). (Fig. 8). The Total population during this season ranged from 27 individuals to 379 individuals. Nauplii predominated during the first half but the cyst bearing adults gained dominance during the second half of the season.

In April, the juveniles and nauplii contributed 37.91% and 36.46% respectively. The number of nauplii declined from 35/l in the first week to 8/l in the third week and in the fourth week it again increased to 40/l (Fig. 8 and Table 6). The distribution of juveniles, however remained around 26 ind/l during each week. The preadults comprised 18.77% of the total population. Its number increased from 1/l in the first week to 16/l in the last week. Nauplii bearing adults occurred only during the last two weeks of the month. They comprised 6.86% of the total count. Cyst bearing adults were not at all encountered during this month.

In May, the distribution of different stages showed a similar pattern as that in April (Fig. 8). Nauplii constituted 45.58% and their

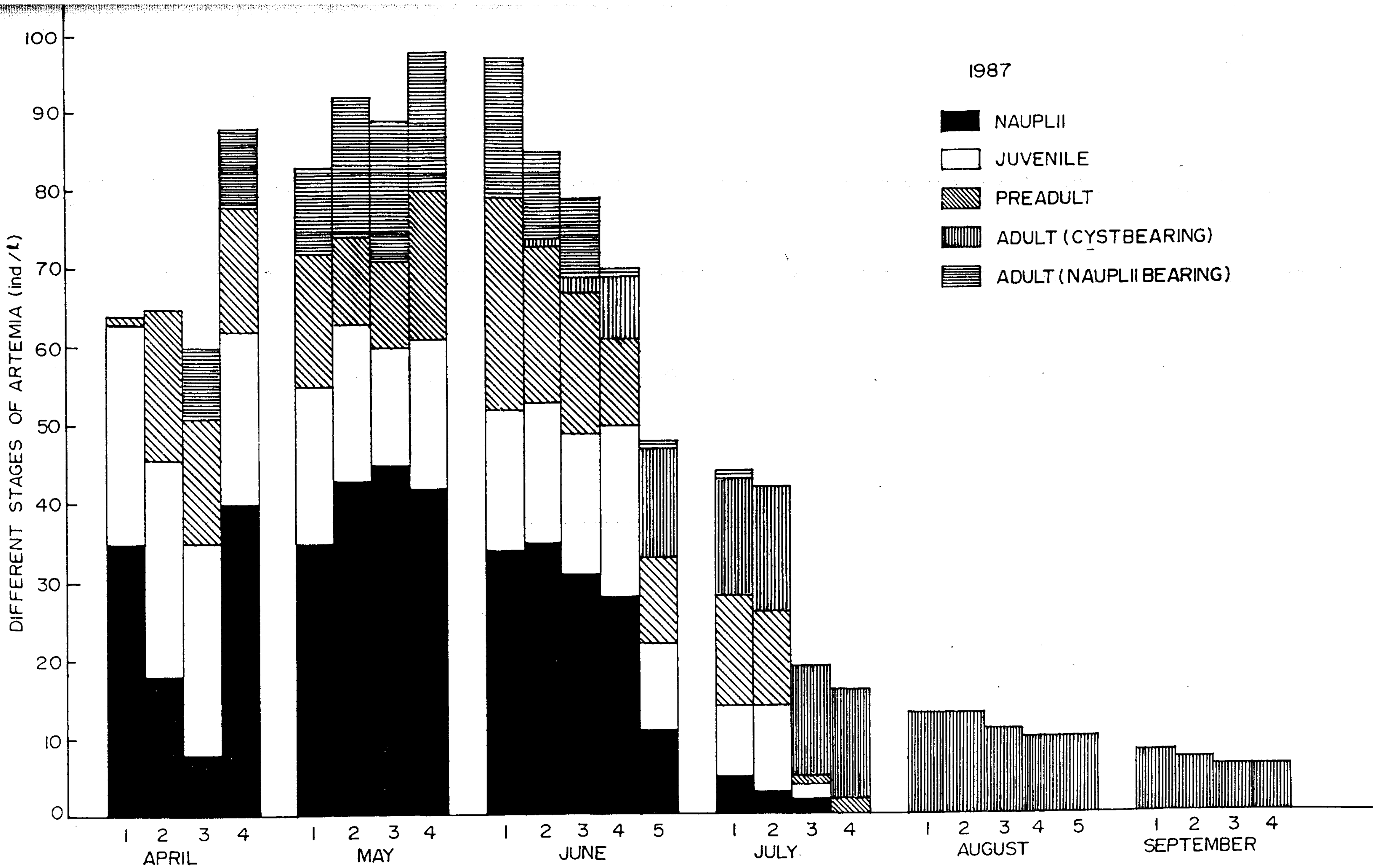


Fig. 8. Weekly contribution of the different stages of Artemia to the total population in the summer season (1987).

Table 6. Abundance of different stages of Artemia population during the first half of summer season (1987)

Stages of Artemia population (Individuals/litre)	APRIL				MAY				JUNE				
	*(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	35	18	8	40	35	43	45	42	34	35	31	28	11
Juveniles	28	28	27	22	20	20	15	19	18	18	18	22	11
Preadults	1	19	16	16	17	11	11	19	27	20	18	11	11
Cyst bearing adults	0	0	0	0	0	0	0	0	0	1	2	8	14
Nauplii bearing adults	0	0	9	10	11	18	18	18	18	11	10	1	1
Total	64	65	66	8	83	92	89	98	97	85	79	70	48

*(Numbers 1, 2, 3, 4 and 5 represent the weeks of the month)

Table 7. Abundance of different stages of <u>Artemia</u> population during the second half of summer season (1987)

Stages of Artemia population (Individuals/litre)	JULY				AUGUST				SEPTEMBER				
	*(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	5	3	2	0	0	0	0	0	0	0	0	0	0
Juveniles	9	11	2	0	0	0	0	0	0	0	0	0	0
Preadults	14	12	1	2	0	0	0	0	0	0	0	0	0
Cyst bearing adults	15	16	14	14	13	13	11	10	10	8	7	6	6
Nauplii bearing adults	1	0	0	0	0	0	0	0	0	0	0	0	0
Total	44	42	19	16	13	13	11	10	10	8	7	6	6

*(Numbers 1, 2, 3, 4 and 5 represent the weeks of the month)

number increased from 35/l in the first week to 45/l in the third week, then slightly declined to 42/l in the last week. Juveniles contributed 20.44% of the total count and their number ranged from 15/l to 20/l. The preadults formed 16.02% of the total population. Their number decreased from 17/l in the first week to 11/l in the second and third week. That then increased to 19/l in the last week. The nauplii bearing adults contributed 17.96%. Their number increased from 11/l in the first week to 18/l in the second, third and last week (Table 6).

During June, the nauplii comprised 36.67% of the total Artemia population and their number gradually decreased from 34/l in the first week to 11/l in the last week. Juveniles and preadults were equally distributed and each contributed to 22.96% of the Artemia population. The cyst bearing adults occurred during the season and were observed from the second week onwards. Their number increased from 1/l in the second week to 14/l in the last week (Fig. 8 and Table 6). Their contribution to the total population was 6.6%. The nauplii bearing adults comprised 10.81% of the total population and their number decreased from 18 in the first week to 1/l in the last week.

The second half of the summer season was characterised by the general decline in the total number of Artemia population. The cyst bearing adults on the other hand showed a steady increease and they formed the entire Artemia population during August and September (Fig. 8 and Table 7).

In July, the cyst bearing adults predominated and comprised 48.76% of the total Artemia population. On an average 15 cyst bearing adult per litre per week were recorded. The preadults were the next dominant group and they comprised 23.97% of the total number. They showed a steep decline from 14/l in the first week to 2/l in the fourth week. The juveniles and nauplii showed similar trends. The juveniles comprised 18.18% of the total population and their number decreased from 9/l in the first week to 2/l in the third week. The nauplii contributed 8.26% of the total population. Their number decreased from 5/l in the first week to 2/l in the third week. Nauplii and juveniles were not recorded in the last week (Table 7).

During the post-summer months (October, November and December (Fig. 9 and Table 8), a sudden increase in the total Artemia population was observed, in the first week of October (73 ind/l). Subsequently, the population declined to 3 ind/l in the first week of November. Thereafter none of the Artemia stages were encountered in the collection.

During October, the nauplii comprised 57.06% of the total population. Its number decreased from 70/l in the first week to 1/l in the last week. The juveniles formed 38.65% of the total count. They varied from 3 ind/l in the first week to 41 ind/l in the second week, 18 ind/l in the third week and 1 ind/l in the last week. Preadults formed 4.29% of the total Artemia population. They were not encountered in the first week of the month. During the second and third weeks, 2 ind/l were observed and in the last week it increased to 3 ind/l. Cyst bearing as well as nauplii bearing adults were not observed during the month (Table 8).

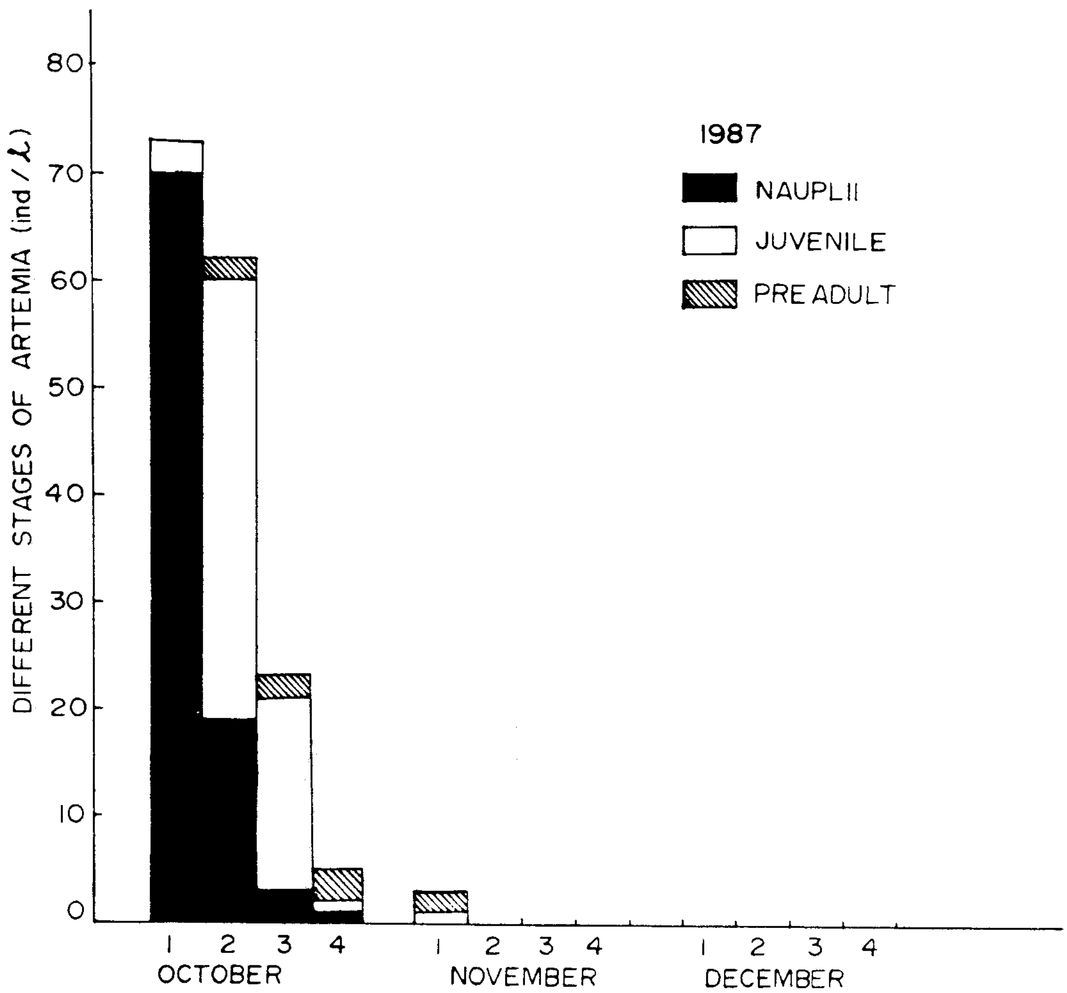


Fig. 9. Weekly contribution of the different stages of Artemia to the total population in the post-summer season (1987).

Table 8. Abundance of different stages of Artemia population during the post-summer season (1987)

Stages of Artemia population (Individuals/litre)	OCTOBER				NOVEMBER				DECEMBER				
	*(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)
Nauplii	70	19	3	1	0	0	0	0	0	0	0	0	0
Juveniles	3	41	18	1	1	0	0	0	0	0	0	0	0
Preadults	0	2	2	3	2	0	0	0	0	0	0	0	0
Cyst bearing adults	0	0	0	0	0	0	0	0	0	0	0	0	0
Nauplii bearing adults	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	73	62	23	5	3	0	0	0	0	0	0	0	0

*(Numbers 1, 2, 3, 4 and 5 represent the weeks of the month)

In November, only the juveniles (1 ind/l) and preadults (2 ind/l) were encountered in the sample. These stages were also observed only during the first week of the month.

The results presented here were based on the exact number of different stages collected during different months and seasons of the year under study. But, for the purpose of having a critical view of the population variation during different months and seasons of the year, the individuals were grouped according to seasons and the same were compared with the corresponding season of the following year as given in Fig. 10. In order to get an overall picture of the variations in different developmental stages in two years (1986 and 1987) a combined analysis was also made as shown in the Fig. 11.

The occurrence and contribution of the different stages to the total population of Artemia in the site during the different seasons varied greatly (Fig. 10). During the pre-summer season of 1986, all stages of Artemia except the cyst bearing adults, were encountered in the sample. The total number declined from 207 in January to 143 in March and the nauplii formed the most dominant component. Similar trend in the total Artemia count was observed during the pre-summer season of 1987 in which the total population from 252 numbers in January to 105 numbers in March and nauplii dominated the population. However, during pre-summer season of 1987 (February and March), cyst bearing adults were also observed.

The total Artemia population during the summer season ranged from 42 to 264 and 27 to 379 numbers during 1986 and 1987 respectively.

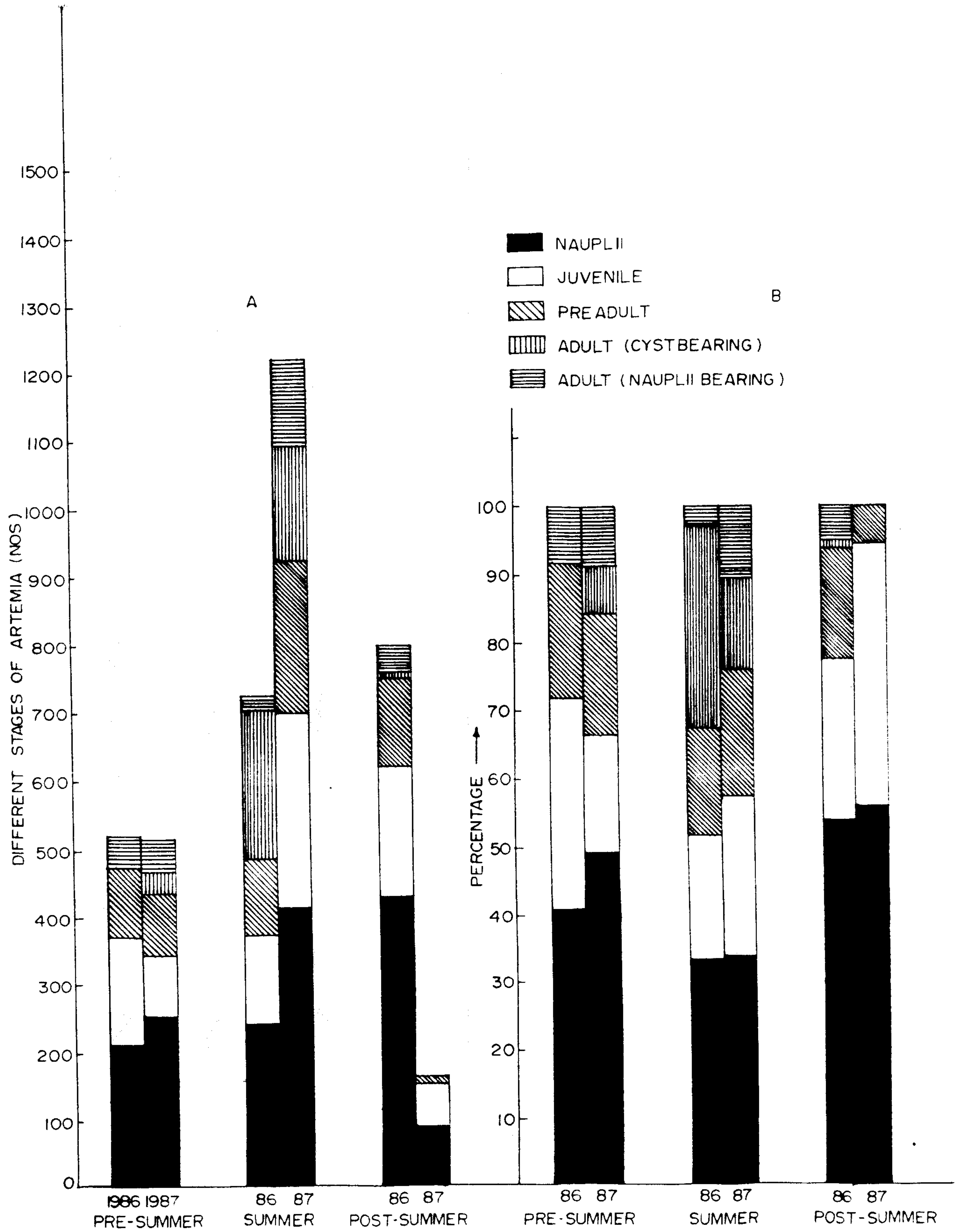


Fig. 10. Contribution in numbers (A) and in percentage (B) of the different stages of Artemia to the total population during the three seasons.

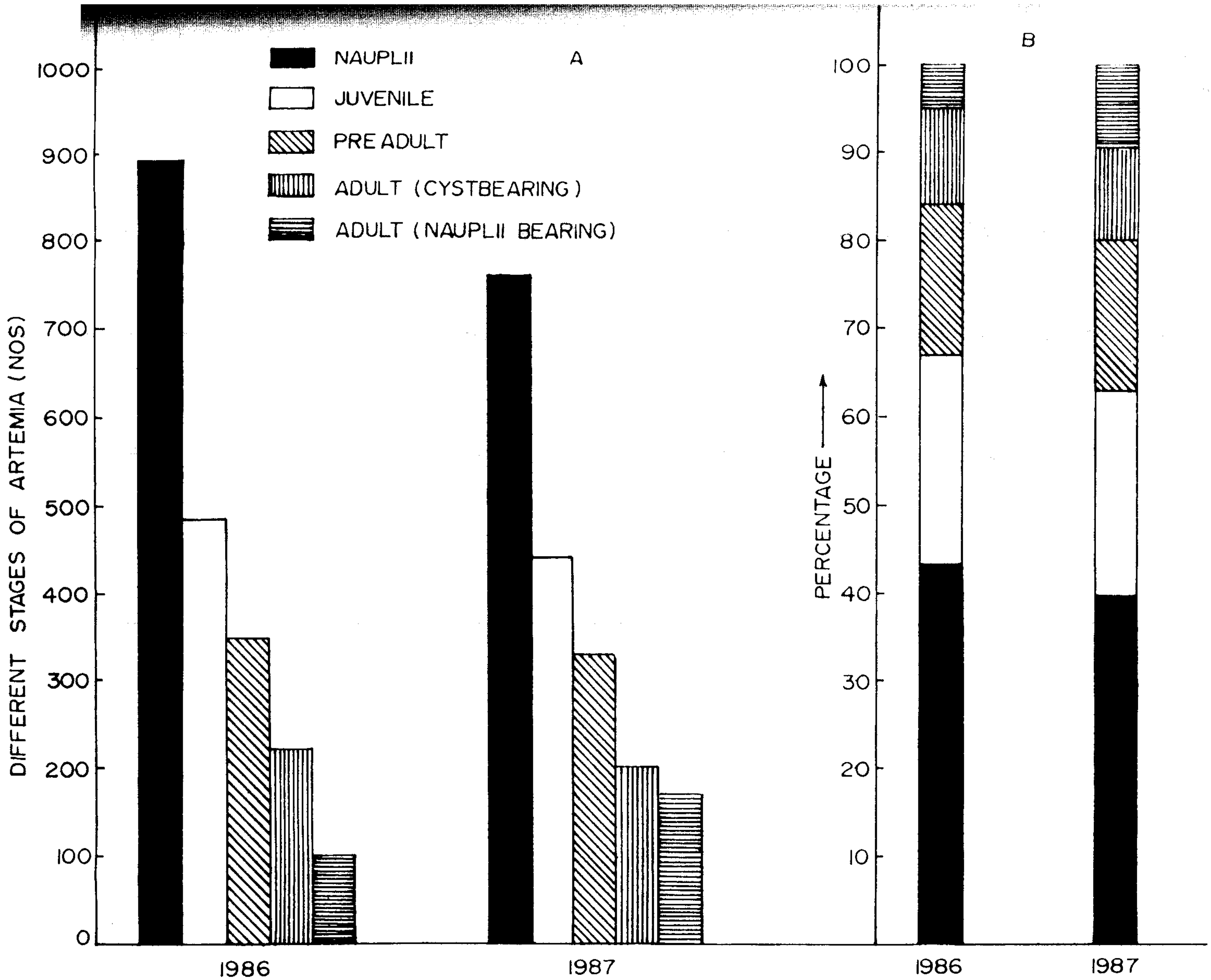


Fig. 11 Annual contribution in numbers (A) and in percentage (B) of the different stages of Artemia to the total population.

In 1986, summer season the total count gradually increased from April to May and then declined rapidly from June onwards (Fig. 5). The total population count remained quite high during April, May and June of 1987 and then started declining rapidly as in the case of 1986 (Fig. 8). In 1986, the cyst bearing adults appeared during the fourth week of April. The nauplii bearing adults were also present with them. The number of nauplii bearing adults gradually declined from 10 in April to 0 in July. The number of the cyst bearing adults on the other hand increased from 1 in April to 43 in September (Table 2 and 3). In 1987, the cyst bearing adults were collected from the site even before the commencement of the summer season, but they totally disappeared during April and did not appear during May also (Table 5 and 6). The cyst bearing adults reappeared again during the second week of June and their number gradually increased from 25 in June to 59 in July and then it declined to 27 in September (Table 6 and 7). Unlike in 1986 summer season the nauplii bearing adults formed an important component of the population during April and May of 1987. Their number ranged from 19 in April to 65 in May. However, in September, the entire population in the site during both the years comprised only of the cyst bearing adults.

The post-summer season was marked by the steep increase in total Artemia population count; reappearance of the nauplii, the juvenile, the preadult stages and disappearance of the cyst bearing adults. During 1986, the total Artemia population increased from 12 ind/l in the first week of October to 93 ind/l in the last week of October, then it gradually declined to 56 ind/l in the last week of December. However, in 1987 the number suddenly increased to 73 ind/l in the first week of October and rapidly declined to 3 ind/l in the first week of November, and thereafter completely disappeared from the site. The nauplii, juveniles, and preadults reappeared during both years but the nauplii bearing adults occurred only during 1986 (November and December).

The total Artemia population count during the two years were compared (Fig. 11). During 1986, it was 2045 numbers. The nauplii was dominated (891) followed by the juveniles (484), the preadults (348) the cyst bearing adults (222) and the nauplii bearing adults (100) respectively (Fig. 11). The total population during 1987 was 1903 numbers, which was slightly less than that of 1986. Out of this total the nauplii were 762 numbers, juveniles were 440 numbers, preadults were 328 numbers, cyst bearing adults were 203 numbers and the nauplii bearing adults were 170 numbers (Fig. 11). In spite of the slight variations noticed in the total numbers, the percentage composition of the different stages were almost the same for the different stages of Artemia except the nauplii and nauplii bearing adults (Fig. 11). The nauplii, juveniles, preadults, cyst bearing adults and the nauplii bearing adults comprised 43.57%, 23.67%, 17.02%, 0.85% and 4.89% respectively during 1986. The corresponding contribution of different stages during 1987 was 40.04%, 23.12%, 17.24%, 10.67% and 8.93%. The percentage of nauplii during 1986 was slightly more than 1987, but the percentage of the nauplii bearing adult showed a reverse trend and its percentage during 1986 was less than that of 1987. The seasonal variation of the different stages of Artemia population were statistically analysed using one-way analysis of variance

Table 9. Mean and standard deviation of different stages of Artemia population during the seasons of study.

Different Stages	Presummer	Summer	Postsummer
Nauplii	18.28 ± 7.6	13.09 ±15.22	20.72 ±16.69
Juvenile	9.82 ± 4.14	8.37 ± 8.85	9.90 ± 8.51
Preadult	7.99 ± 4.87	6.59 ± 6.05	5.45 ± 6.89
Adults (Cyst bearing)	1.33 ± 2.16	7.23 ± 4.69	0.29 ± 0.71
Adults(Nauplii bearing)	3.53 ± 3.05	2.84 ± 3.62	1.41 ± 2.24
Total Artemia population	40.97 ±15.21	38.13 ±28.98	37.78 ±31.66

ANOVA TABLES

Table 10. Nauplii Vs. Seasons

Source	D.f.	Sum. Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	181.702	90.851	0.47	N.S.
Error	15	2869.619	191.308		

Table 11. Juveniles Vs. Seasons

Source	D.f.	Sum. Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	8.995	4.498	0.08	N.S.
Error	15	838.933	55.929		

Table 12. Preadults Vs. Seasons

Source	D.f.	Sum.Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	19.454	9.727	0.27	N.S
Error	15	539.490	35.966		

Table 13. Adultscyst bearing Vs. Seasons

Source	D.f.	Sum.Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	168.035	84.018	9.26	HI.SIG(1%)
Error	15	136.123	9.075		

Mean comparisons		Remarks
Pre-summer	Summer	SIG
Pre-summer	Post-summer	N.S.
Summer	Post-summer	SIG

Table 14. Adults nauplii bearing Vs. Seasons

Source	D.f.	Sum. Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	13.983	6.992	0.76	N.S.
Error	15	137.543	9.170		

Table 15. Total Artemia population Vs. Seasons

Source	D.f.	Sum. Sqr	Mean Sqr	F-Val	Remarks
Seasons	2	36.840	18.420	0.03	N.S.
Error	15	10370.120	691.341		

(ANOVA). The one-way ANOVA was done by taking the three seasons as treatments for each of the different stages of Artemia population and also the total Artemia population for the period of 2 years of study. It is clear from the ANOVA (Table 10) that the nauplii population in terms of numbers did not vary significantly between seasons (P 0.01). The same trend was noticed for juvenile population (Table 11) preadult population (Table 12), and adult nauplii bearing population (Table 13). The total Artemia population also did not vary significantly between seasons (Table 14). But the variation in adult cyst bearing stage was highly significant between the seasons (P 0.01) (Table 15). It was further observed that the variations between pre-summer and summer, and summer and post-summer seasons were also significant.

DISCUSSION

The different stages of *Artemia* in the salina showed definite distribution pattern within month as well as between months. Seasonal as well as annual variations were also observed during the present study of two years.

Earlier studies on the distribution pattern of the different stages of *Artemia* have shown that the numerical number of different stages of *Artemia* at a given time are not uniform. Seasonal variations in number of the different stages of *Artemia* in Mono Lake has been described by Lenz (1980) and Lenz and Dana (1987). They have reported that the adult population dominated during summer and the first instar during the overwintering season with densities as high as 20000 and 25000 ind/m^3. Scelzo and Voglar (1980) also have reported similar fluctuations based on their studies at Bocochica Salt Lake, Margarita island. They have also reported that adults are much fewer in number compared to the younger stages and occurred throughout the year.

Geddes (1980), based on his studies in Australian *Artemia* habitats reported on the fluctuations of the total population, but he has noticed the total disappearance of adults from the site during May. Wear and Haslett (1987) have made observations on the stagewise abundance of *Artemia* in Newzealand. They have reported the appearance of nauplii during late October and early November, followed by juveniles and adults by mid-November. Adults were proportionately few in number, compared to the nauplii and juvenile stages. High Artemia biomass was present during late spring and summer. Conte and Conte (1988) studied the abundance and spacial distribution of Artemia in Lake Abert, Oregan (U.S.A.). They have noticed the peak abundance of adult Artemia during mid-summer season (August and September) in 1981. But during 1982, peak abundance was observed in July.

In India, occurrence of Artemia was reported only from few places. Bombay (Kulkarni, 1953) Sambar Lake (Baid, 1958), Didwana Lake (Bhargava and Alam, 1980) Gulf of Kutch (Royan, 1979), Vedaranyam (Basil et al., 1981), Karsewar Island (Achari, 1971) and Tuticorin (Royan et al., 1970). But they did not conducted any detailed studies on Artemia population. Earlier studies on Artemia population in the country has shown that only the parthenogenetic strains are available. However, Lal Mohan (1980) based on his studies at Tuticorin has reported a rare occurrence of both the males and females, Ramamoorthi and Thangaraj (1980) have reported the existence of cyst bearing adults and nauplii in Tuticorin. They have observed wide fluctuations in the population during different seasons, and peak abundance was noticed in August, but have not described the abundance of each stage comprising the total population. Ramanathan and Natarajan (1987) have also conducted studies based on their monthly sampling at Tuticorin, and have observed fluctuations in the total population during their period of study Bhargava et al. (1987) have described the occurrence of the different stages of Artemia in Didwana Lake, and their abundance during the different months of the year.

In the present study, the distribution pattern of the total population as well as the various stages comprising the total population has been studied in detail. The Artemia population in the salina consisted only of the parthenogenetic variety, as reported by most of the Indian workers. The population structure showed great fluctuations within the year, as well as between the years. While November recorded the maximum number of animals in 1986, it was in May, that maximum numbers were seen during 1987. As earlier studies on Artemia population in India is confined only to a maximum period of one year or less, no reference, as to why such annual changes in population structure occur, is available. The probable reasons for such fluctuation in the present study has been given in the following chapters, relating to ecological parameters.

The percentage contribution of the different stages namely nauplii, juveniles, preadults, cyst bearing adults and nauplii bearing adults differed during the different months and consequently during different seasons. The nauplii were abundant during November of 1986. In 1987 this stage was abundant during May. So in general the nauplii showed a dominance during the post-summer season in 1986 and in the first half of summer season in 1987. The number of nauplii were inversely related to the cyst bearing adults as their number decreased, the number of cyst bearing adults increased. The juvenile is an intermediate stage between the nauplii and preadult stage and their number in the population is directly related to the number of nauplii in the site. This was clearly evident from the distribution pattern observed in the present study. The occurrence of this stage has been reported by Bhargava et al. (1987) in the Didwana

Lake. The pattern of abundance of these juveniles in the present study were similar to that observed in the Didwana Lake.

The preadults also showed a fluctuation pattern of distribution. Their number and distribution pattern were influenced by the number of nauplii and juvenile in the salina. However, this stage is very important from the view of the future structure of the population in the area. They may either develop into the cyst bearing or nauplii bearing adults. In the present study they abundantly occurred during the month of November, in 1986 and in June during 1987.

The adults comprised of two types of population - the cyst bearing and the nauplii bearing. They usually occurred separately but mixed population with a dominance of one type was observed during certain months.

In 1986 the cyst bearing adults were dominant during July, August, September and October. The nauplii bearing adults in January, February, March, November and December. Mixed populations of adults were seen during April, May and June. In 1987, only the cyst bearing adults were seen in March, August and September, the nauplii bearing adults in January, April and May and the mixed populations in the months of February June and July. The existence of mixed population at Tuticorin was reported by Ramamoorthi and Thangaraj (1980) and Ramanathan and Natarajan (1987). The reason for the occurrence of only cyst bearing adults in certain months have been explained in detail in the chapter pertaining to environmental parameters.

Though the abundance of different stages of Artemia showed a great range in occurrence during the different months within a year, an overview of their occurrence for the two years of study did not revealed significant differences between the seasons for most of the stages. The statistical analysis conducted (Tables 10, 11, 12, 13, 14 and 15) showed that only the cyst bearing adults had highly significant difference between the seasons. Here also the significant variations were obtained only during the pre-summer and summer and summer and post-summer seasons. the pre-summer and post-summer seasons did not show significant variation.

In general, it can be concluded that the Artemia population at the study site comprised of five stages and their abundance and distribution varied widely during the different months. However, statistically significant values are observed only for the cyst bearing adults. This is probably due to their dominance and exclusive composition of the stage during particular months of the year.

PART - II

SEASONAL VARIATIONS OF DIFFERENT ENVIRONMENTAL PARAMETERS IN THE SALINA AND THEIR EFFECT ON THE DIFFERENT STAGES OF ARTEMIA POPULATION

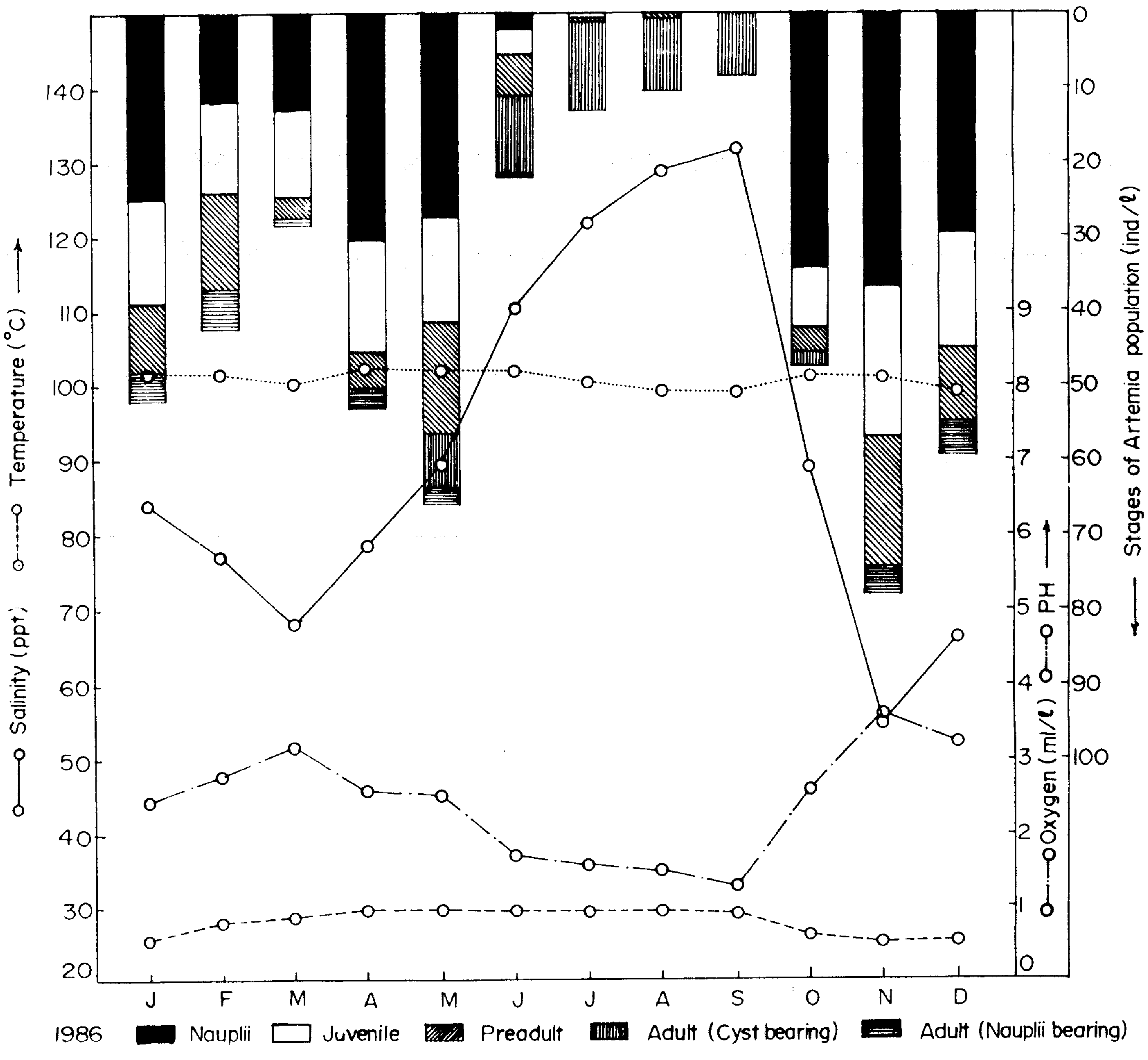
The seasonal monthly variation in different physico-chemical parameters like water temperature, pH, salinity, dissolved oxygen, (hydrographic); and nutrients (ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, inorganic phosphate and silicate); biological parameters like algal cells, gross primary production and predatory insect population and important meteorological parameters like rainfall, wind velocity and sunshine at the salina were studied.

HYDROGRAPHIC PARAMETERS

The monthly mean values of hydrographic parameters in relation to different stages of *Artemia* population during 1986 and 1987 are represented in the Figs. 12 and 13.

Water Temperature:

The water temperature during 1986 ranged from 25.35°C to 29.88°C (Fig. 12 and Table 16). Sudden increase or decrease in the water temperature at the site was not noticed during the three seasons. However,



140
130
120
110
100
90
80
70
60
50
40
30
20
Salinity (ppt)
Temperature (°C)
J
F
M
A
M
J
J
A
S
O
N
D
0
10
20
30
40
50
60
70
80
90
100
9
8
7
6
5
4
3
2
1
0
Stages of Artemia population (ind/ℓ)
PH
Oxygen (ml/ℓ)
1986
Nauplii
Juvenile
Preadult
Adult (Cyst bearing)
Adult (Nauplii bearing)

Table 16. Monthly mean distribution of hydrographic parameters (1986)

Hydrographic Parameters	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D	Mean S.D	Mean S.D.	Mean S.D	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Temperature	25.80	28.26	28.50	29.88	29.75	29.50	29.10	29.68	29.30	26.33	25.35	25.64
(°C)	±1.46	±0.21	±1.09	±0.29	±0.37	±0.50	±0.12	±0.56	±0.86	±0.95	±0.34	±0.66
pH	8.18	8.15	8.05	8.27	8.22	8.19	8.01	7.88	7.88	8.15	8.10	7.93
	±0.07	±0.04	±0.06	±0.06	±0.02	±0.07	±0.14	±0.09	±0.06	±0.09	±0.17	±0.04
Dissolved	2.46	2.78	3.18	2.58	2.52	1.72	1.58	1.51	1.29	2.60	3.59	3.24
Oxygen (ml/l)	±0.19	±0.21	±0.25	±0.25	±0.12	±0. 12	±0.03	±0.09	±0.13	±1.20	±0.57	±0.18
Salinity	83.79	76.80	68.03	78.65	89.77	110.70	121.85	129.17	132.18	89.07	54.97	66.53
(ppt)	±1.28	±7.02	±4.65	±1.50	±5.68	±7.71	±1.10	±2.37	±8.52	±32.20	±3.14	±3.74

ig. 13. Monthly mean distribution of the different stages of Artemia and the various hydrographic parameters in the salina (1987)

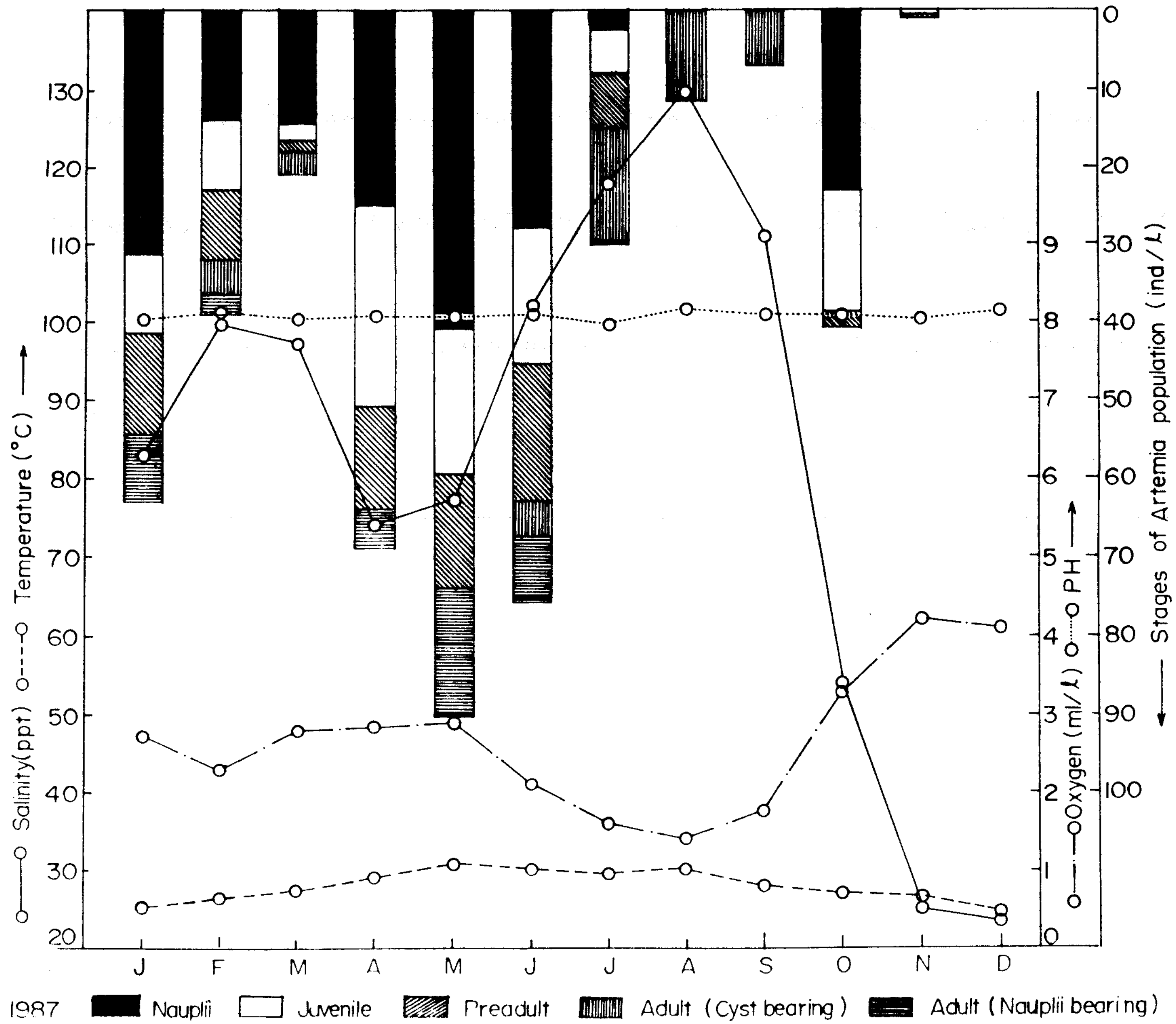


Table 17. Monthly mean distribution of Hydrographic parameters (1987)

Hydrographic parameters	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Temperature	25.25	26.40	27.68	29.33	30.92	30.08	26.60	30.00	28.22	27.20	26.80	24.68
(°C)	±0.95	±0.92	±0.94	±0.44	±0.33	±0.82	±0.82	±0.35	±1.06	±0.48	±0.67	±1.04
pH	8.06	8.12	8.01	8.09	8.06	8.10	7.98	8.14	8.13	8.19	8.06	8.17
	±0.02	±0.04	±0.13	±0.06	±0.05	±0.07	±0.12	±0.07	±20.06	±0.02	±0.08	±0.04
Dissolved	2.74	2.32	2.80	2.79	2.81	2.11	1.59	1.39	1.77	3.30	4.24	4.11
oxygen (ml/l)	±0.07	±0.30	±0.89	±0.53	±0.15	±0.41	±0.07	±0.06	±0.32	±0.20	±0.09	±0.11
Salinity	83.35	99.76	97.20	73.99	76.91	101.91	117.99	129.96	111.13	53.88	25.02	24.19
(ppt)	±7.07	±5.45	±3.05	±6.81	±3.18	±7.19	±3.79	±3.78	±16.98	±4.42	±1.71	±0.75

in the pre-summer season the temperature showed a slight increasing trend from January (25.80°C) to March (28.50'C). During the summer season the temperature did not show much variation and an average value of 29.53°C was recorded. In the post-summer season the temperature values showed a slight declining trend and it ranged from 26.33°C in October to 25.64°C in December.

The water temperature in 1987 was found to be higher and it was between 24.68°C and 30.92°C (Fig. 13 and Table 17). As in the previous year the temperature values showed a slight increasing trend from January (25.25°C) to March (27.68°C) and it continued till May (30.92°C). Thereafter, the temperature values remained without much variation till August (30.0°C). Then it declined from the last month of summer season (28.22°C) to the last month of post-summer season (24.68°C)

The temperature during both the years of study, showed almost similar pattern and it remained around 28.05°C.

Salinity:

The salinity values unlike the temperature values, showed sudden variations during the three seasons. During 1986, the salinity values ranged between 54.97 and 132.18 ppt with higher values during the summer season (Fig. 12 and Table 16). In the pre-summer season, the salinity values showed a steady declining trend from January (83.79 ppt) to March (68.03 ppt). In the successive months a steep increase in the salinity values was observed and it reached a peak in September (132.18 ppt).

The salinity then suddenly declined to 84.97 ppt in November, afterwhich an increasing trend was observed and it reached 66.53 ppt in December,

During 1987, the salinity values ranged between 24.19 and 129.96 ppt (Fig. 13 and Table 17). During the pre-summer season, the salinity gradually increased from 83.35 ppt in January to 99.76 ppt in February. Then it, slowly declined to 97.20 ppt in March. The declining trend continued during the first month of the summer season (73.99 ppt). Thereafter, the salinity values showed a sharp increase and the maximum value was recorded in August (129.96 ppt). In September, the salinity declined (111.13 ppt) and in December a low value of 24.19 ppt was recorded.

The salinity values during the corresponding seasons of the two years showed comparable trends, but distinct variations were noticed during the Pre-summer seasons. In 1986, the salinity showed a declining trend, but in 1987 the salinity values initially increased from January to February, afterwhich it declined in March. The peak salinity in 1986 was observed in the month of September (132.18 ppt). But in 1987 the peak was observed in August (129.96 ppt). In the initial phase of post-summer months, of both the years, the salinity values showed a steady declining trend. The trend continued till December in 1987. However, during 1986 higher values for salinity was noticed in December.

Dissolved oxygen:

During 1986, the dissolved oxygen values ranged between 1.29 and 3.59 ml/l (Fig. 12 and Table 16). In the pre-summer season the values gradually increased from 2.46 ml/l in January and reached a peak in March (3.18 ml/l). The oxygen content then slowly declined during the summer season. The lowest value was recorded in September (1.29 ml/l). During the post-summer season, an increase in dissolved oxygen was observed and the peak was in November (3.59 ml/l). Subsequently dissolved oxygen declined to 3.24 ml/l in December.

In 1987, dissolved oxygen varied from 1.39 ml/l to 4.24 ml/l (Fig. 13, Table 17). In the pre-summer season the dissolved oxygen values did not show much variation, but a slight decrease was observed during February (2.32 ml/l). Further decrease was noticed in the summer season. The lowest value was recorded in August (1.39 ml/l). Subsequently the dissolved oxygen gradually increased in the post-summer months and a maximum was recorded in November (4.24 ml/l). In December, it again decreased to 4.11 ml/l.

The present study indicated the dissolved oxygen in 1986 showed a steady increasing trend in the presummer season. Similar trend was not noticed in 1987 as it declined from January to February. In the summer season, it further declined in 1986 upto September and showed an increasing trend in the post-summer season. On the contrary, in 1987 summer, it gradually increased till May but declined in June-August and then slowly increased from September as in 1986.

pH:

During the year 1986, the pH did not show much variation through out the year and it ranged between 7.93 and 8.27 (Fig.12 and Table 16).

However, during the post-summer season monhs a slight declining trend was observed.

Comparable pH values were observed during 1987. The pH values ranged between 8.06 and 8.19 (Fig. 13 and Table 17). As in 1986, the pH values showed a declining trend in this year but a slight increase was noticed during December.

The pH values during first and last month of each season in 1986 and 1987 are summerised below.

	Pre-summer	Summer	Post-summer
1986	8.18-8.25	8.27-7.89	8.15-7.93
1987	8.06-8.21	8.09-8.13	8.19-8.18

NUTRIENTS

The monthly mean values of nutrients such as ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, inorganic phosphate and silicate in relation to different stages of Artemia population in the slina during 1986 and 1987 are represented in the Figs.14 & 15 and Tables 18 & 19 .

Ammonia-nitrogen:

During 1986, the ammonia-nitrogen content ranged between 1.60 and 3.74 µg-at/l (Fig. 14 and Table 18). It declined from January (1.95 µg-at/l) to February (1.75 µg-at/l) and then increased to 2.33 µg-at/l in March. Similar value of 2.3 µg-at/l was recorded in April

Fig. 14. Monthly mean distribution of the different stages of Artemia and the various nutrients in the salina (1986)

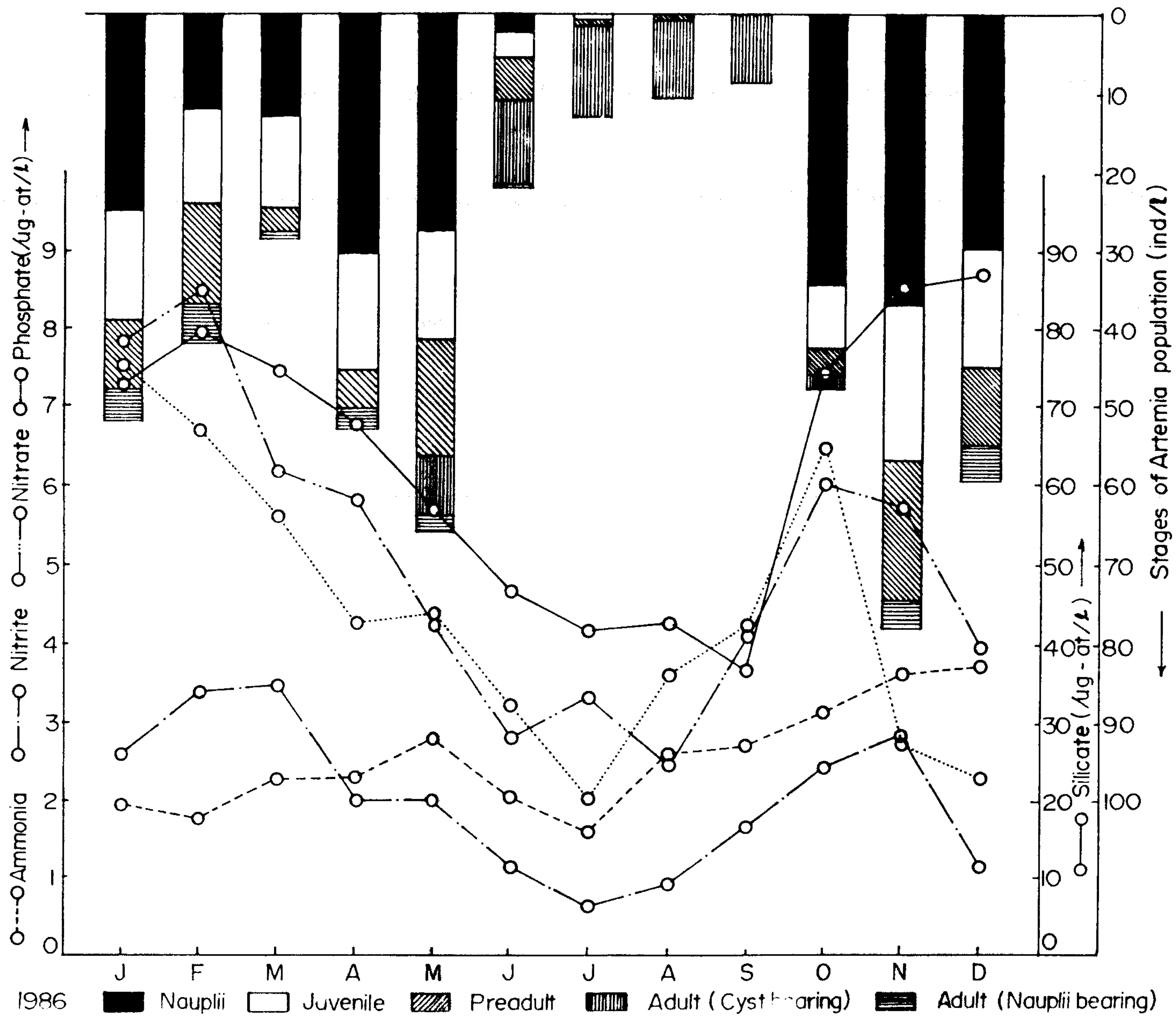


Table 18. Monthly mean distribution of nutrients (1986)

Nutrients (µg-at/l)	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Ammonia-nitrogen	1.95 ±0.16	1.75 ±0.31	2.33 ±0.47	2.30 ±0.51	2.82 ±0.63	2.05 ±0.14	1.60 ±0.16	2.63 ±0.22	2.73 ±0.29	3.16 ±0.32	3.66 ±0.33	3.74 ±0.74
Nitrite-nitrogen	2.60 ±0.09	3.44 ±0.50	3.47 ±0.31	2.06 ±0.39	2.08 ±0.31	1.16 ±0.17	0.65 ±0.15	0.89 ±0.20	1.69 ±0.17	2.45 ±0.41	2.81 ±0.62	1.16 ±0.51
Nitrate - nitrogen	7.85 ±0.50	8.52 ±0.66	6.18 ±1.09	5.82 ±0.24	4.26 ±0.22	2.81 ±1.08	3.35 ±0.34	2.50 ±0.38	4.16 ±0.84	6.00 ±1.08	5.73 ±0.63	3.99 ±0.51
Inorganic phosphate	7.52 ±0.87	6.73 ±0.22	5.63 ±0.31	4.26 ±0.53	4.35 ±0.37	3.24 ±0.42	2.03 ±0.29	3.62 ±0.30	4.23 ±0.32	6.45 ±1.11	2.77 ±0.54	2.31 ±0.32
Silicate	73.24 ±2.55	79.89 ±3.19	74.50 ±5.37	67.47 ±2.39	56.67 ±2.69	46.50 ±2.72	41.70 ±1.29	42.80 ±2.77	41.52 ±1.10	79.50 ±2.16	85.50 ±1.91	87.03 ±1.07

Fig. 15. Monthly mean distribution of the different stages of Artemia and the various nutrients in the salina (1987)

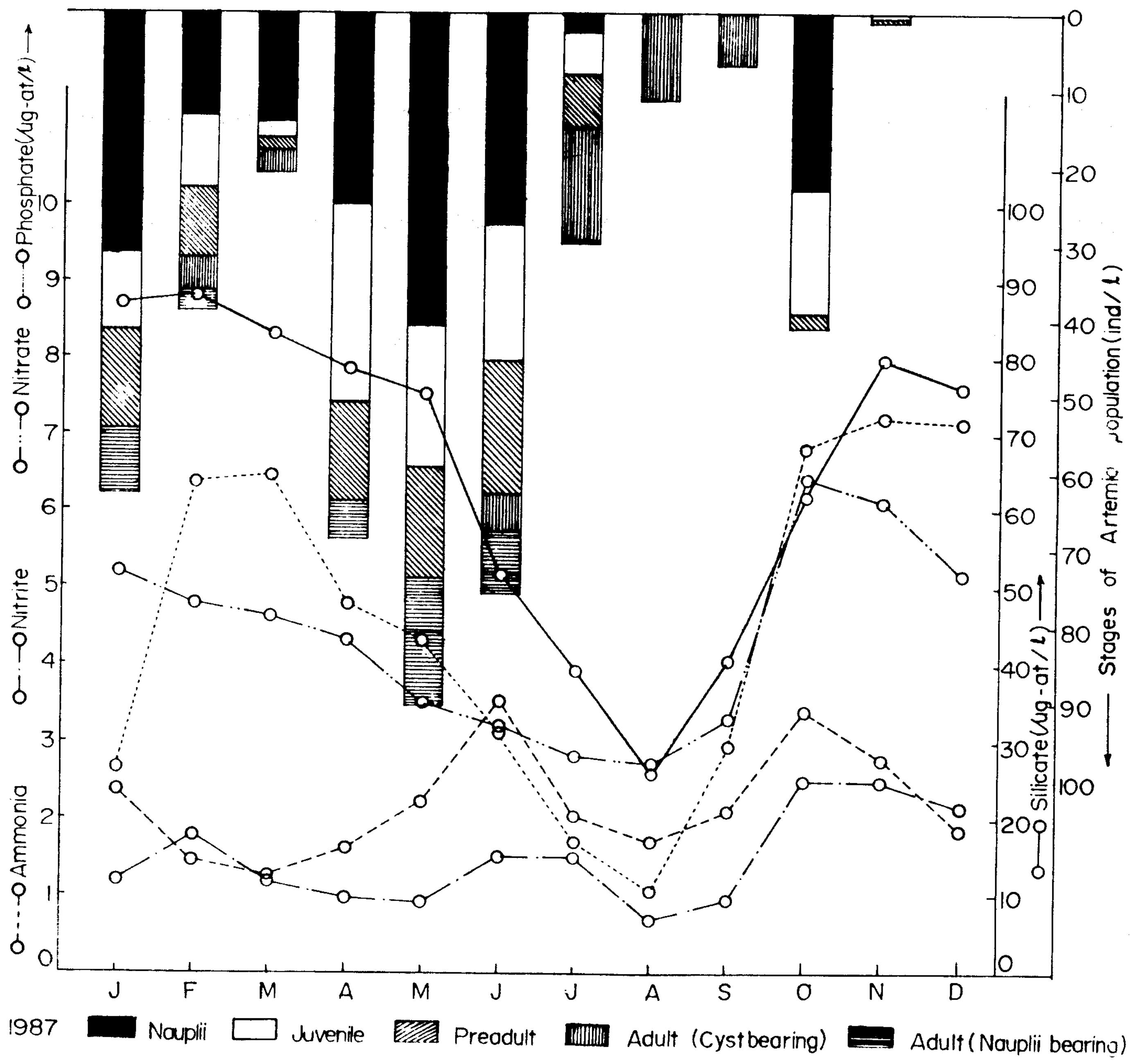


Table 19. Monthly mean distribution of Nutrients (1987)

Nutrients (μg-at/l)	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Ammonia-nitrogen	2.37 ±0.14	1.48 ±0.30	1.26 ±0.40	1.60 ±0.44	2.21 ±0.44	3.52 ±0.71	2.09 ±0.30	1.69 ±0.21	2.13 ±0.90	3.44 ±0.51	2.80 ±0.48	1.87 ±0.45
Nitrite-nitrogen	1.18 ±0.09	1.78 ±0.03	1.19 ±0.23	0.95 ±0.15	0.92 ±0.08	1.52 ±0.26	1.51 ±0.31	0.68 ±0.26	0.98 ±0.69	2.47 ±0.31	2.49 ±0.30	2.16 ±0.69
Nitrate-nitrogen	5.22 ±0.60	4.75 ±0.67	4.63 ±0.41	4.33 ±0.42	3.47 ±0.34	3.21 ±0.80	2.80 ±0.43	2.72 ±0.36	3.31 ±0.71	6.40 ±0.65	6.12 ±0.52	5.15 ±0.33
Inorganic phosphate	2.67 ±0.13	6.25 ±1.18	6.46 ±0.65	4.77 ±0.30	4.30 ±0.32	3.28 ±0.25	1.70 ±0.29	1.06 ±0.16	2.92 ±0.57	6.80 ±0.58	7.22 ±0.70	7.17 ±0.81
Silicate	86.96 ±1.59	87.61 ±1.31	83.26 ±3.59	78.71 ±1.21	75.31 ±2.57	51.65 ±3.01	39.23 ±2.51	26.41 ±2.82	40.05 ±9.38	61.75 ±9.74	79.60 ±5.82	76.23 ±5.19

and then it increased to 2.82 µg-at/l in May. the ammonia-nitrogen content then declined to (2.05 µg-at/l) in June and further declined to 1.60 µg-at/l in July. The values then steadily increased from August (2.63 µg-at/l) to December (3.74 µg-at/l).

The ammonia nitrogen values showed fluctuating trends during 1987 also (Fig. 15 and Table 19). The values decreased from January (2.37 µg-at/l) to February (1.48 µg-at/l) and further declined in March (1.26 µg-at/l). It steadily increased from April (1.60 µg-at/l) and reached a peak in June (3.52 µg-at/l). The value again declined from July (2.09 µg-at/l) to August (1.69 µg-at/l), afterwhich it again steadily increased to 3.44 µg-at/l in October. The values declined in November (2.80 µg-at/l) and continued to decline in December (1.87 µg-at/l).

Though the ammonia-nitrogen values fluctuated during both the years the pre-summer season recorded lower values. Peaks were observed during the summer season, but highest value (3.74 µg-at/l) during 1986 was noticed in December and whereas it was recorded in the month of June (3.52 µg-at/l) in 1987.

Nitrite-nitrogen:

During 1986, the nitrite-nitrogen content in the water ranged between 0.65 and 3.47 µg-at/l (Fig. 14 and Table 18). An increasing trend was noticed during pre-summer season and the values recorded during January, February and March were 2.6, 3.44 and 3.47 µg-at/l respectively. A declining trend was noticed during the initial period of the summer season, and the lowest value was recorded in July (0.65 µg-at/l). The nitrite-nitrogen content then steadily increased to 2.8 µg-at/l in November. In December the nitrite content once again sharply declined to 1.16 µg-at/l.

In 1987, in nitrite-nitrogen content varied from 0.68 to 2.49 µg-at/l (Fig. 15 and Table 19). As in the previous year the nitrite content showed an increasing trend from January (1.18 µg-at/l) to February (1.78 µg-at/l). In March, however, the value declined (1.19 µg-at/l) and continued to show a declining trend upto May when a low value of 0.92 µg-at/l was recorded. The nitrite-nitrogen content increased in June (1.52 µg-at/l) and remained the same during July (1.51 µg-at/l). Thereafter the value again declined to 0.68 µg-at/l in August. A steady increase was noticed since September (0.98 µg-at/l) and high values of 2.47 µg-at/l and 2.49 µg-at/l were recorded during October and November. December recorded lower nitrite value of 2.6 µg-at/l.

The nitrite-nitrogen values during 1986 and 1987 showed comparable trends. the value showed an increasing trend in the pre-summer seasons and recorded lowest values in the summer season. The nitrite content increased in the initial phase of the post-summer season and a sharp decline was noticed in December during both the years.

Nitrate-nitrogen:

The nitrate-nitrogen content in the water, during the year 1986 ranged between 2.5 and 8.52 µg-at/l (Fig. 14 and Table 18). Higher values were observed during the pre-summer season with the highest value during February (8.52 µg-at/l). The value, subsequently decreased to 6.18 µg-at/l in March. The declining trend continued upto June in summer season, then it showed a slight increase in July (3.35 µg-at/l). The lowest value was recorded in August (2.5 µg-at/l). The nitrate-nitrogen content then showed a sharp increase in September (4.16 µg-at/l) and recorded high value of 6.0 µg-at/l in October. Thereafter, the nitrate-nitrogen content gradually declined and during November and December the values were 5.73 and 3.99 µg-at/l respectively.

In 1987, the nitrate-nitrogen content in water was 2.72-6.4 µg-at/l (Fig. 15 and Table 19). The values steadily decreased from January (5.22 µg-at/l) to August (2.72 µg-at/l). Then it slowly increased with the highest value in October (6.4 µg-at/l). During November and December the nitrate-nitrogen content recorded were 6.12 and 5.15 µg-at/l respectively.

Although, the nitrate-nitrogen values during the two years of observation showed a declining trend in the pre-summer season, the decline was gradual in 1987 unlike that in 1986. The declining trend which continued in the summer season also showed similar trends. In 1986, a sudden increase was noticed in July, such increase in nitrate-nitrogen values were not observed during 1987. The increase in nitrate content in the beginning of the post-summer season was sharp in both the years and the gradual decline in the nitrate-nitrogen content during December was also a common feature for both the years. In spite of the similar trends observed, the highest nitrate-nitrogen value during 1986 was observed in February (pre-summer season). Corresponding figure in 1987 was during October (post-summer season).

Inorganic phosphate:

In 1986, the inorganic phosphate content ranged between 2.03 and 7.52 µg-at/l (Fig. 14 and Table 18). During the presummer season the inorganic phosphate content steadily declined from January (7.52 µg-at/l) to April (4.26 µg-at/l). It remained at almost the same value (4.35 µg-at/l) during May, afterwhich it again steadily declined till July (2.03 µg-at/l). The inorganic phosphate content showed increasing trends from August (3.62 µg-at/l) and reached a peak in October (6.45 µg-at/l). In November the inorganic phosphate content sharply declined to 2.77 µg-at/l and a lower value of 2.31 µg-at/l was recorded in December.

During 1987, the range of inorganic phosphate content in the water was 1.06 to 7.22 µg-at/l (Fig. 15 and Table 19). Unlike the previous year, an increasing trend was noticed in the pre-summer season. The value increased from January (2.67 µg-at/l) to March (6.46 µg-at/l). The phosphate values then steadily declined from April (1.70 µg-at/l) and the lowest value of 1.06 µg-at/l was recorded in August. September, October and November recorded higher values of 2.92, 6.80 and 7.22 µg-at/l respectively. The phosphate content value showed a slight decrease in December when a value of 7.17 µg-at/l was recorded.

The trends in the distribution of inorganic phosphate content during the different seasons of 1986 and 1987 did not follow uniform pattern. While the inorganic phosphate content steadily declined during the pre-summer season of 1986, the value showed an increasing trend in the pre-summer season of 1987. In the initial phase of the summer season the inorganic phosphate content increased in May 1986 and then declined till July whereas in 1987 the phosphate content declined sharply and continued to decline till August. However, in the second half of the summer season, the inorganic phosphate content showed an increasing trend in both the year. The increasing trend continued in the post-summer season of 1987 but in 1986 the inorganic phosphate content sharply declined in October and further declined in December.

Silicate:

During 1986, the silicate content ranged between 41.52 and 87.03 µg-at/l (Fig. 14 and Table 18). In the first half of pre-summer season there was a slight increase in the silicate value from 73.24 µg-at/l (January) to 78.79 µg-at/l (February). Subsequently a declining trend was observed, from March (74.5 µg-at/l) to July (41.7 µg-at/l). August recorded slight higher value of 42.80 µg-at/l, but in September the silicate values declined to 41.52 µg-at/l. A sudden increasing trend was observed during the post-summer seasons and the values recorded during October, November and December were 79.50, 85.50 and 87.03 µg-at/l respectively.

During 1987, the silicate content ranged between 26.41 and 87.61 µg-at/l (Fig. 15 and Table 19). In the pre-summer season it increased from January (86.96 μg-at/l) to February (87.61 μg-at/l). In March, the silicate content declined slightly to 83.26 μg-at/l. The declining trend continued till August when the lowest value of (26.41 μg-at/l) was recorded. A sharp increasing trend was noticed from September (40.05 μg-at/l). The value recorded during October and November were 61.75 μg-at/l and 79.6 μg-at/l respectively. A slightly lower value of 76.23 μg-at/l was recorded during December.

The silicate value showed comparable trends during the two years. It increased slightly in February, afterwhich it declined throughout the pre-summer and summer seasons. However it sharply increased in the post-summer seasons. The silicate content showed a slight decline in December 1987, which was not observed in December 1986 but, in general the silicate content distribution were comparable during the 2 years of study.

BIOLOGICAL PARAMETERS

The monthly mean values of biological parameters like number of algal cells, gross primary production and number of predatory insects in relation to the different stages of *Artemia* population during 1986 and 1987 are represented in the Figs. 16 & 17 and Tables 20 & 21 .

Algal cell count:

The algae collected from the site included *Chlamydomonas* sp., *Pleurosigma* sp., *Dunaliella* sp., *Navicula* sp. and *Nitzchia* sp. In addition to these groups, filamentous forms like *Oscillatoris* sp., *Anabaena* sp.

Fig. 16. Monthly mean distribution of different stages of Artemia and the various biological parameters in the salina (1986).

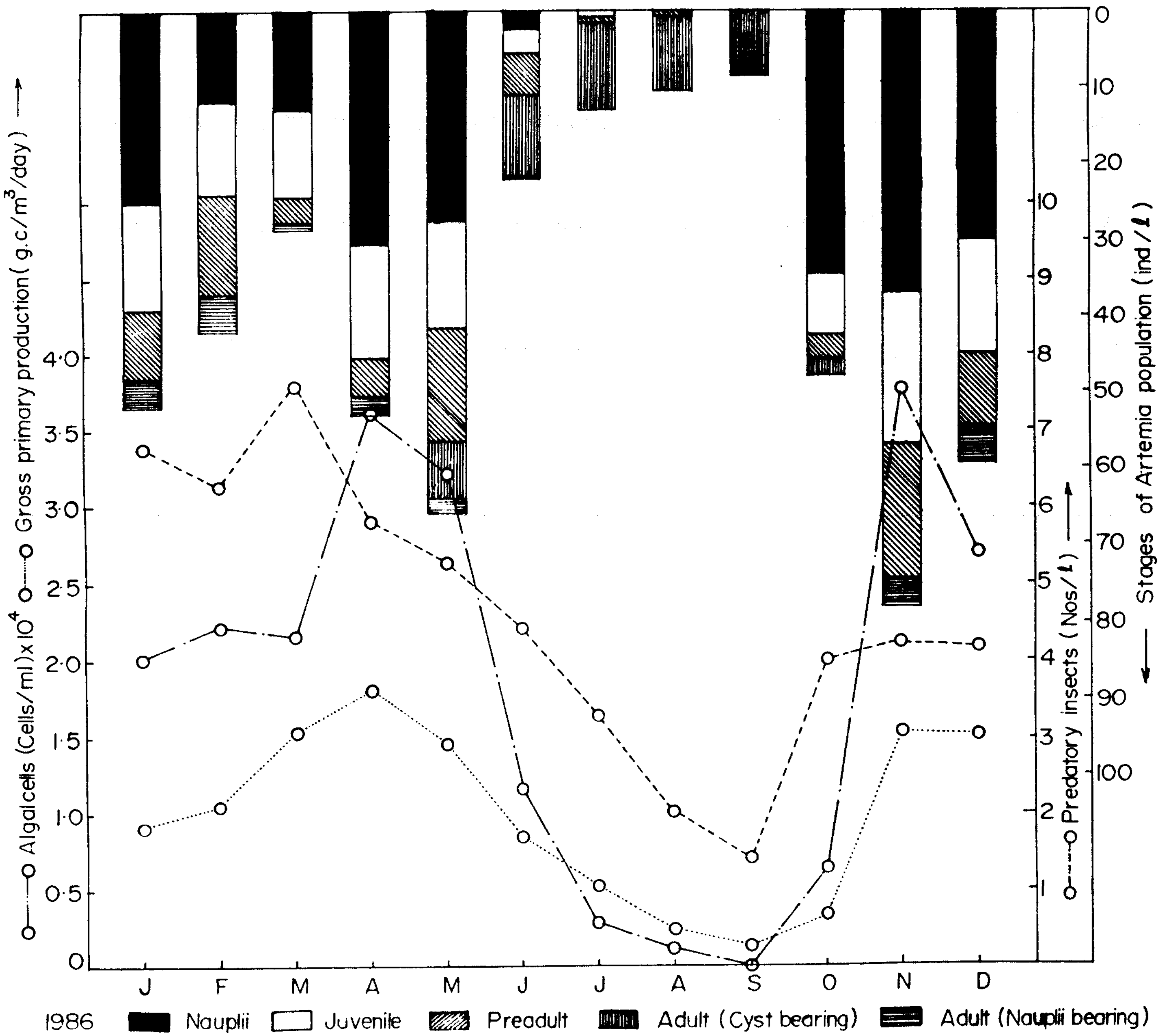


Table 20. Monthly mean distribution of Biological parameters (1986)

Biological parameters	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Algal cells (cells/ml) 10^4	2.00 ±0.32	2.18 ±0.69	2.16 ±0.59	3.60 ±0.33	3.21 ±0.21	1.16 ±0.65	0.28 ±0.16	0.13 ±0.25	0.00	0.64 ±0.28	3.78 ±0.28	2.70 ±0.67
Gross Primary productivity (gC/m^3 /day)	0.92 ±0.04	1.05 ±0.06	1.54 ±0.15	1.82 ±0.04	1.45 ±0.23	0.81 ±0.12	0.53 ±0.02	0.23 ±0.02	0.13 ±0.02	0.36 ±0.31	1.54 ±0.09	1.52 ±0.23
Predatory insects (Nos/l)	6.50 ±0.95	6.25 ±1.25	7.60 ±0.54	5.75 ±0.50	5.25 ±1.50	4.40 ±0.54	3.25 ±0.95	2.00 ±0.81	1.40 ±0.54	4.00 ±1.41	4.25 ±0.50	4.20 ±0.44

Fig. 17. Monthly mean distribution of different stages of Artemia and the various biological parameters in the salina (1987).

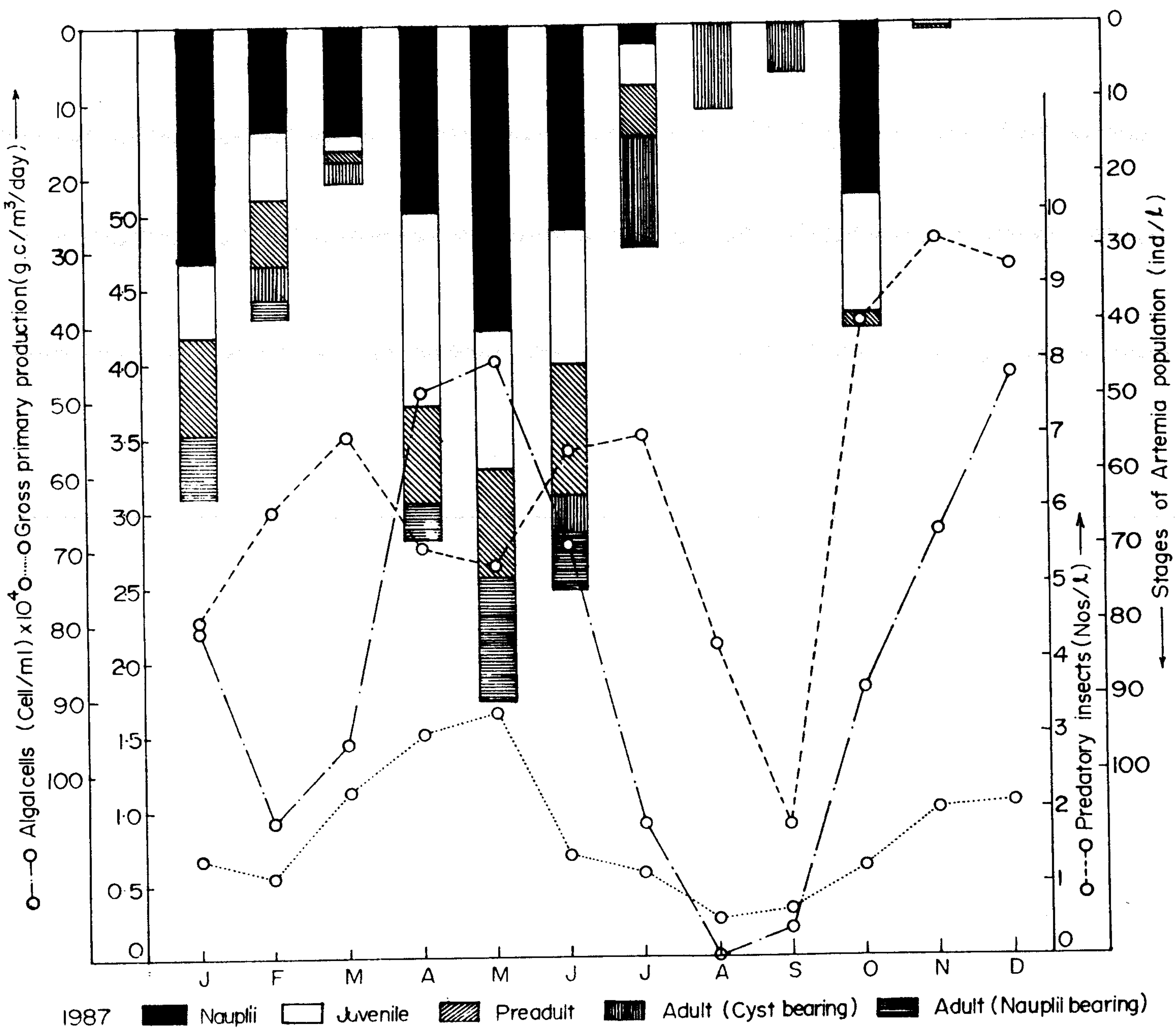


Table 21. Monthly mean distribution of Biological parameters (1987)

Biological Parameters	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Algal cells (cells/ml) x 10^4	2.20 ±0.57	0.93 ±0.15	1.47 ±0.31	3.79 ±0.04	4.00 ±0.00	2.75 ±1.08	0.90 ±0.41	0.00	0.19 ±0.23	1.80 ±0.70	2.85 ±0.78	3.91 ±0.08
Gross primary productivity (gC/m^3 /day)	0.66 ±0.05	0.55 ±0.02	1.14 ±0.35	1.53 ±0.11	1.67 ±0.07	0.69 ±0.23	0.56 ±0.05	0.27 ±0.03	0.31 ±0.10	0.62 ±0.13	1.04 ±0.14	1.55 ±0.16
Predatory insects (Nos/l)	4.50 ±0.57	6.00 ±0.81	7.00 ±1.00	5.50 ±1.29	5.25 ±0.50	6.80 ±1.09	7.00 ±1.41	4.20 ±1.30	1.75 ±0.50	8.50 ±0.57	9.60 ±0.54	9.25 ±0.50

and Spirogyra sp. were also observed in the salina. The representatives of the groups were similar during both the years.

In 1986, algae occurred in the water column (Plate V) during all the months except in September. However, it must be mentioned here that dead algae were found deposited at the bottom (Plate VI) during August and September. These dead algae usually do not float and so were not collected along with the surface water collections. The algal count during 1986 ranged between 0.13 x 10^4 cells/ml and 3.78 x 10^4 cells/ml (Fig. 16 and Table 20).

In January, a count of 2 x 10^4 cells/ml was observed, which slowly increased in February (2.18 x 10^4 cells/ml), March (2.16 x 10^4 cells/ml) and reached a peak in April (3.6 x 10^4 cells/ml). The algal count from May (3.21 x 10^4 cells/ml) onwards showed a declining trend and in September live algal forms were totally absent in the salina. In October (0.64 x 10^4 cells/ml), the algal cells reappeared and then reached a very high count of 3.7 x 10^4 cells/ml in November. In December, low value of 2.7 x 10^4 cells/ml was recorded.

The occurrence of algal cells in 1987 (Fig. 17 and Table 21) was similar as in 1986. They occurred during 11 months of observation and were totally absent during August. The count in January was 2.2 x 10^4 cells/ml and it declined to 0.93 x 10^4 cells/ml in February. In March, it increased to 1.47 x 10^4 cells/ml and continued to show a high count of 3.79 x 10^4 cells/ml in April and 4 x 10^4 cells/ml in May. In June, it declined to 2.75 x 10^4 cells/ml and by August it totally disappeared from the column and surface waters. Dead algal layer was observed at the bottom. In September, the algae reappeared and a count of 0.19×10^4 cells/ml was recorded. The algal density then increased to 1.8×10^4 cells/ml in October, 2.85×10^4 cells/ml in November and a high value of 3.91×10^4 cells/ml in December.

The algal cells during the pre-summer season of 1986 gradually increased but, in 1987 it initially declined and then showed an increasing trend. The initial phase of the summer season during both the years recorded increasing trends and high values, then it suddenly declined and totally disappeared by the end of the summer season. The algal cells reappeared in the post-summer season and showed a rapid increase in their count. It steadily increased till December 1987, but in 1986 the count declined in December.

Gross primary productivity:

During 1986, the gross primary productivity ranged from 0.135 to 1.920 $gC/m^3/day$ (Fig. 16 and Table 20). It showed an increasing trend from January (0.92 $gC/m^3/day$) to March (1.54 $gC/m^3/day$). The increasing trend continued and the maximum value of the year was recorded in April (1.82 $gC/m^3/day$). The gross production rate showed a declining trend from May (1.45 $gC/m^3/day$) and the lowest value was recorded in September (0.14 $gC/m^3/day$). Subsequently an increasing trend was observed and the values recorded during October, November and December were 0.36, 1.54 and 1.52 $gC/m^3/day$ respectively.

During 1987, maximum gross primary production was 1.67 $gC/m^3/$ day while the minimum was 0.269 $gC/m^3/day$ (Fig. 17 and Table 21) In January 0.66 $gC/m^3/day$ production was recorded. It declined to 0.55 $gC/m^3/day$. In February the productivity value slowly increased from March (1.14 $gC/m^3/day$) and the maximum peak was observed in May (1.67 $gC/m^3/day$). In June, the rate of primary production declined to 0.69 $gC/m^3/day$ and a very low value of 0.269 $gC/m^3/day$ was recorded in August. Subsequently an increasing trend in the gross primary productivity was observed and in October, November and December the gross productivity values were 0.618, 1.04 and 1.55 $gC/m^3/day$ respectively.

During the two years, comparable trends in primary productivity was seen. Though, the value decreased in February 1987, a general increasing trend was observed during the pre-summer seasons of the 2 years. The increasing trend continued during the first half of the summer season afterwhich it sharply declined and reached very low levels during September. The gross primary productivity increased in the postsummer season and highest value was recorded during November.

Predatory insect population:

The insects were counted whenever present in the sample. They voraciously feed on the different stages of Artemia and are generally called as 'predators'. The entire insect population observed in the present study were of Corixidae family.

The distribution of the insect during 1986 was studied (Fig. 16 and Table 20). In January 1986, 6.75 insects/l were recorded, but the insect population reduced to 6.25 Nos/l in February. It increased to 7.6 Nos/l in March. Their number then gradually declined to 5.75, 5.25, 4.4, 3.0, 2.0 and 1.4 per litre in April, May, June, July, August and September respectively. Higher figures of 4.0, 4.25 and 4.2 Nos/l were observed in October, November and December.

During 1987, the number of insects/l increased from 4.5 to 6 in February (Fig. 17 and Table 21). It further increased to 7 in March. The number declined in April (5.5/l) and May (5.25/l) and then increased again in June (6.8/l) and July (7.0/l). A steep decrease in their count was observed in August (4.2/l) and it further decreased to 1.75 Nos/l in September. The number sharply increased in October to 8.5/l. It further increased to 9.6 Nos/l in November, when the maximum No/l for the year was observed. In December also a higher value of 9.25 Nos/l was recorded.

The insect population during the pre-summer of 1986 remained around 6.5 Nos/l in January and February and then increased in March, while in the pre-summer season of 1987 the insect population showed a steady increase from January to March. A gradual decline was observed during the entire summer season of 1986, from April to September. However in 1987, the number decreased from April to May, but then increased in June and July. It then steadily declined during August and September. The postsummer season recorded increase in insect number during both the years. In 1986, the increasing trend was observed till December but in 1987 a slight decrease in number was observed in December.

METEOROLOGICAL PARAMETERS

The monthly mean values of meteorological parameters in relation to different stages of Artemia population during 1986 and 1987 are represented in the Figs. 18 & 19 and Tables 22 & 23.

Rainfall:

At Tuticorin, rainfall is limited to a few months during the year and the annual rainfall recorded during 1986 and 1987 were 352.1mm and 644.0 mm respectively.

In 1986, rainfall was recorded during the pre-summer as well as the post-summer months (Fig. 18 and Table 22). The values recorded during January, February and March were 4.5, 10.45 and 7.0 mm. Fairly good showers occurred in October (35.30 mm) and November (23.97 mm), In December rainfall of 4.04 mm was recorded.

The rainfall during 1987 extended during all the seasons (Fig. 19 and Table 23). January and February did not record any rainfall. In March 1987 the recorded rainfall was 14 mm and it increased to 14.5 mm in April. Rainfall was not recorded during May, June, July and August. During September 27.5 mm was recorded. October recorded high values of 33 mm. In November and December, the rainfall declined gradually and a monthly total of 30.2 and 30.75 mm were recorded respectively.

Fig. 18. Monthly mean distribution of different stages of Artemia and the various meteorological parameters at the salina (1986).

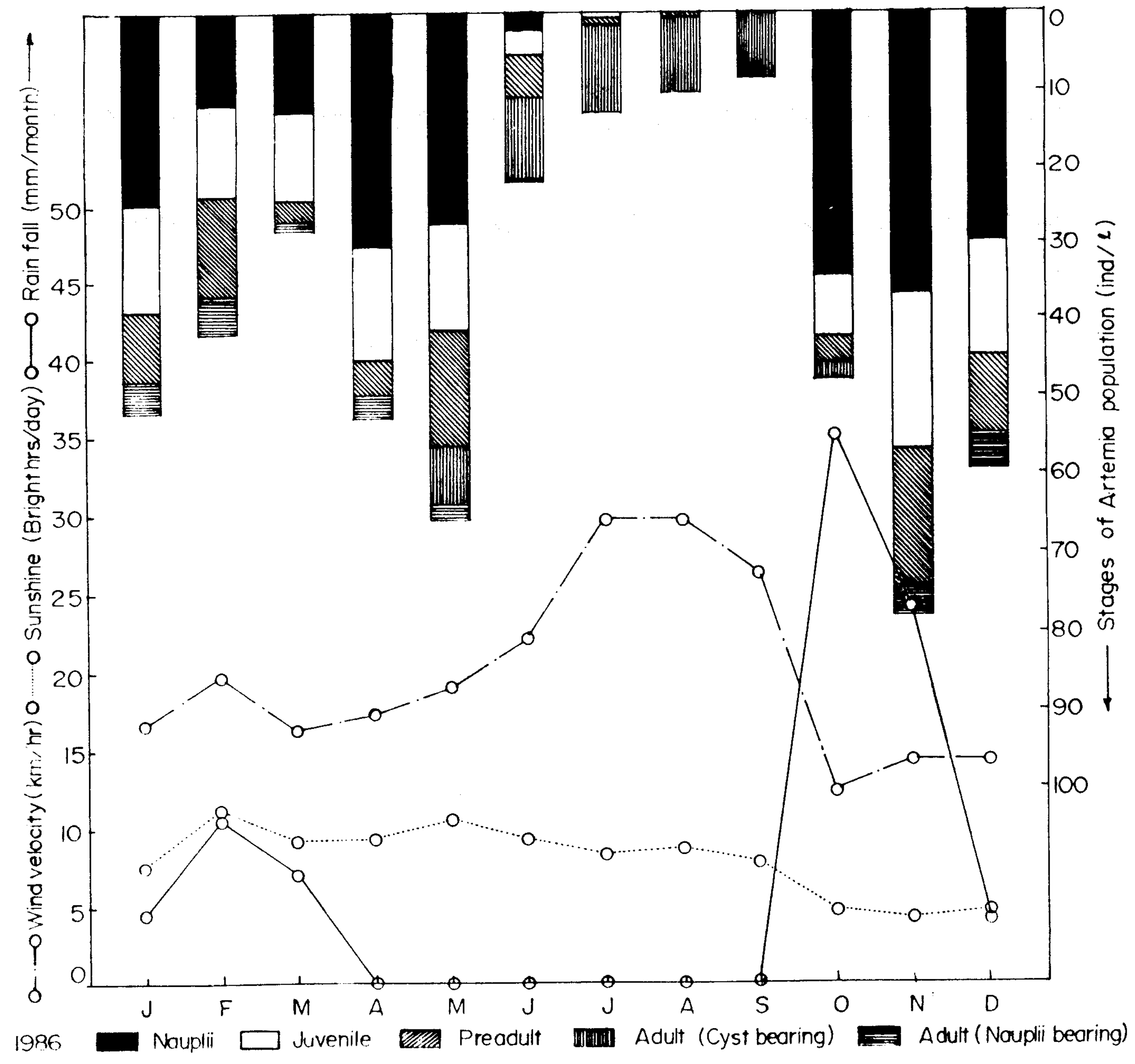


Table 22. Monthly mean distribution of Meteorological parameters (1986)

Meteorological parameters	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Rainfall	4.50	10.45	7.00	0.00	0.00	0.00	0.00	0.00	0.00	35.30	23.97	4.04
(mm/month)	±7.72	±12.06	±10.11							±24.02	±4.88	±1.01
Wind velocity	16.75	19.75	16.40	17.25	19.00	22.00	29.50	29.25	26.00	12.25	14.25	14.40
(Km/hr)	±5.37	±3.86	±4.97	±2.06	±3.26	±7.81	±1.73	±2.98	±8.12	±3.20	±2.62	±2.50
Sunshine	7.70	10.60	9.12	9.37	10.42	9.38	8.40	8.68	7.86	4.95	3.95	4.40
(Bright hrs/day)	±2.38	±0.77	±1.29	±2.02	±0.96	±2.45	±0.35	±2.03	±2.27	±2.63	±0.84	±0.79

Fig. 19. Monthly mean distribution of different stages of Artemia and the various meteorological parameters at the salina (1987).

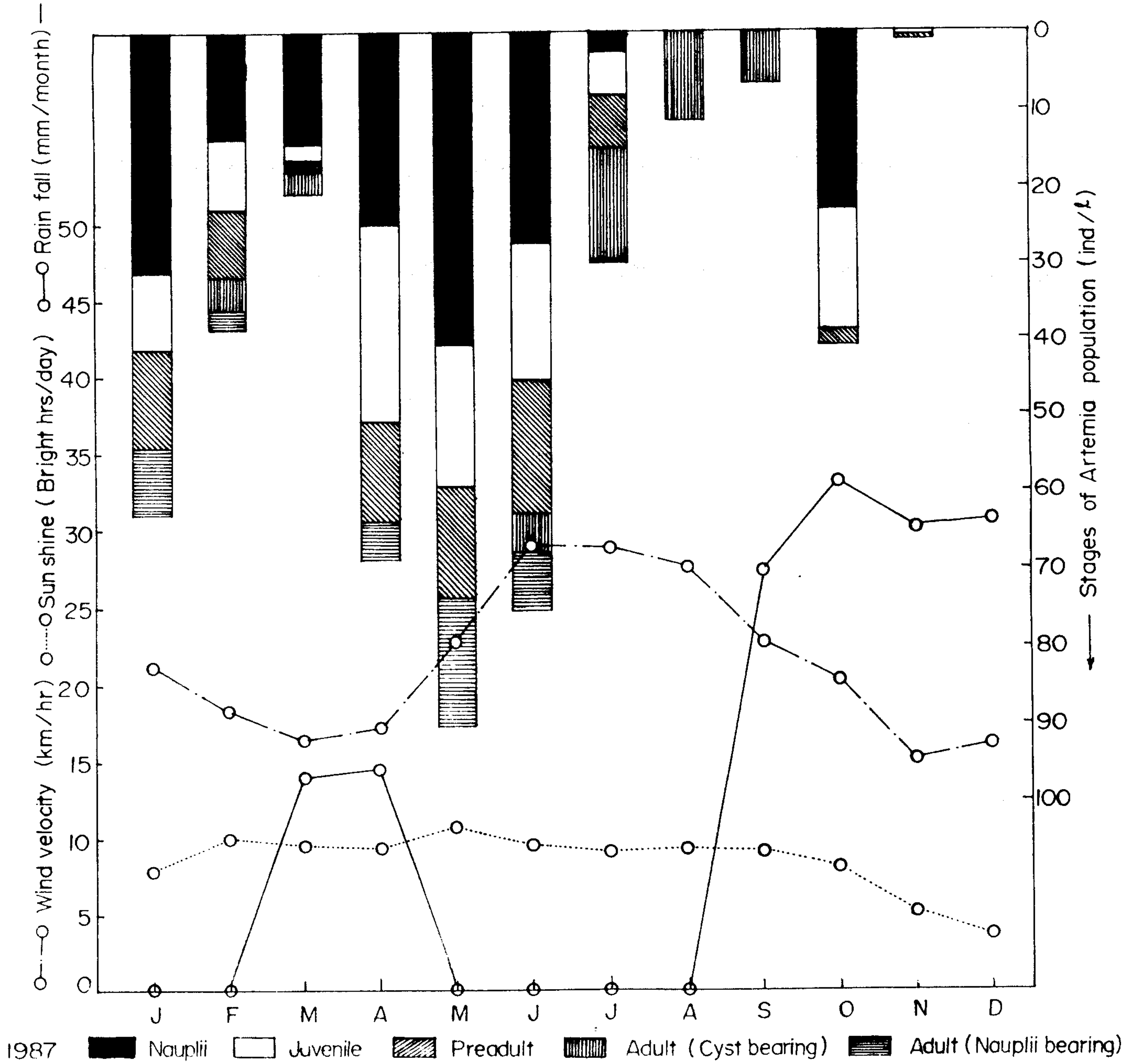


Table 23. Monthly mean distribution of Meteorological parameters (1987)

Meteorological Parameters	JAN. Mean S.D.	FEB. Mean S.D.	MAR. Mean S.D.	APR. Mean S.D.	MAY Mean S.D.	JUN. Mean S.D.	JUL. Mean S.D.	AUG. Mean S.D.	SEP. Mean S.D.	OCT. Mean S.D.	NOV. Mean S.D.	DEC. Mean S.D.
Rainfall (mm/month)	0.000	0.00	14.00 ±26.07	14.50 ±23.96	0.00	0.00	0.00	0.00	27.50 ±35.93	33.00 ±45.15	30.20 ±23.45	30.75 ±4.57
Wind velocity (Km/hr)	21.25 ±5.18	18.25 ±2.36	16.60 ±2.50	17.15 ±1.25	22.75 ±2.21	29.20 ±2.16	29.00 ±2.94	27.60 ±4.33	22.75 ±5.85	20.75 ±7.54	15.40 ±2.88	16.75 ±3.59
Sunshine (Bright hrs/day)	7.90 ±2.48	10.00 ±1.07	9.58 ±0.42	9.40 ±0.42	10.83 ±0.22	9.66 ±0.92	9.10 ±2.54	9.32 ±1.89	8.15 ±0.92	8.10 ±0.99	5.10 ±3.29	3.85 ±1.32

Both the years experienced rainfall during certain months of the year. While rain occurred during all the three months of the pre-summer season of 1986, it was restricted only to March in 1987. Summer season in 1986 did not recorded any rainfall but in 1987 showers were present in September. During both the years October recorded highest rainfall and it gradually declined during November and December.

Wind velocity:

During 1986, velocity of wind ranged between 12.25-29.5 km/hr (Fig. 18 and Table 22). It increased from 16.75 km/hr in January to 19.75 km/hr in February and then declined to 16.4 km/hr in March. During the summer season, an increasing trend was noticed and the maximum wind velocity was recorded in July (29.5 km/hr) and August (29.2 km/hr), with a subsequent decrease from September (26.00 km/hr) onwards. October, November and December recorded values of 12.25, 14.25 and 14.4 km/hr respectively.

During 1987, the wind velocity ranged between 15.2-29 km/hr (Fig. 19 & Table 23). The wind velocity showed a declining trend during the pre-summer season. It decreased from 21.25 km/hr in January to 16.6 km/hr in March. In the summer season the wind velocity increased and the maximum velocity was recorded during June (29.2 km/hr), followed by July (29 km/hr). August and September recorded lower wind velocities of 27.6 and 22.75 km/hr respectively. The values recorded in October, November and December were 20.75, 15.4 and 16.75 km/hr respectively.

The trends in wind velocity during, the pre--summer seasons of 1986 and 1987 were not similar. During 1986 the wind velocity gradually increased from January to February and then reduced in March, but in 1987, a gradual decrease in wind velocity was observed from January to March. The summer season showed similar trends in both years. The wind velocity gradually increased from April onwards, and reached a peak during June-July. It gradually declined during the end of summer season. The declining trend in wind velocity continued in Ocober and November in 1987 but it increased slightly in November 1986. During December both the years recorded higher values.

Sunshine

During 1986, sunshine ranged between 3.95 and 10.6 bright hrs/day (Fig. 18 and Table 22). In the pre-summer season, comparatively higher values were recorded, and the maximum value was recorded in February (10.6 bright hrs/day). April, May and June recorded respectively 9.37, 10.42 and 9.38 bright hrs/day. July recorded a lower value of 8.4 bright hrs/day. In August the sunshine increased to 8.68 bright hrs/day, afterwhich it decreased to 7.86 bright hrs/day in September, 4.95 bright hrs/day in October, 3.95 bright hrs/day in November and 4.40 bright hrs/day in December.

During 1987, the sunshine varied from 3.85 to 10.83 bright hrs/day (Fig. 19 and Table 23). It increased from January to February (from 7.9 to 10.0 bright hrs/day) in the pre-summer season and subsequently declined in March to 9.5 bright hrs/day and April to (9.4 bright hrs/day).

May recorded a higher value (10.83 bright hrs/day). Sunshine gradually declined from June (9.66 bright hrs/day) to July (9.1 bright hrs/day). In August a higher value of 9.32 bright hrs/day was observed after which it reduced to 8.15 bright hrs/day in September, 8.1 bright hrs/day in October 5.1 bright hrs/day in November and 3.85 bright hrs/day in December.

The sunshine during these 2 years showed a similar trend. It increased from January to February and declined in March. It showed a sudden peak during May. Then it slowly declined from May onwards least was observed in December.

MONTHLY MEAN STRUCTURE OF ARTEMIA POPULATION IN THE SALINA.

The monthly mean of total Artemia population in 1986 varied during different months with maximum number in November (59.60 ind/l) and minimum during September (8.60 ind/l) (Fig. 20 and Table 24). January recorded a total population of 51.75 ind/l. The nauplii contributed 24.75 ind/l, juveniles 13.75 ind/l, preadults 9.50 ind/l and the nauplii bearing adults 3.75 ind/l. In February, the total population showed a slight decline with a mean monthly total of 42.25 ind/l. The nauplii, juveniles, preadults and nauplii bearing adults contributed 12.00, 12.25, and 5.25 ind/l respectively. The total population further declined in March with a total mean population of 28.60 ind/l. The number of nauplii increased to 13.2- ind/l and the juveniles contributed 11.40 ind/l. The number of preadults however, declined to 2.80 ind/l with the nauplii bearing adults contributing a mere number of 1.20 ind/l. The cyst bearing adults were not represented in the population during these three months.

In April, the total mean population increased to 53 ind/l with an increased contribution of the nauplius and juvenile stages. Cyst bearing adults also occurred during this month and this stage contributed 0.25 ind/l. The nauplii bearing adults, the preadults, juveniles and nauplii were respectively 2.50, 4.75, 5.25 and 30.50 ind/l. In May, the mean values further increased to 66 ind/l with a greater representation of the cyst bearing adults (7.50 ind/l). The nauplii bearing adults contributed only 2 ind/l. The preadults, juveniles and nauplii contributed 14.75, 14.25 and 27.50 ind/l respectively during this month. In June, the total popu-

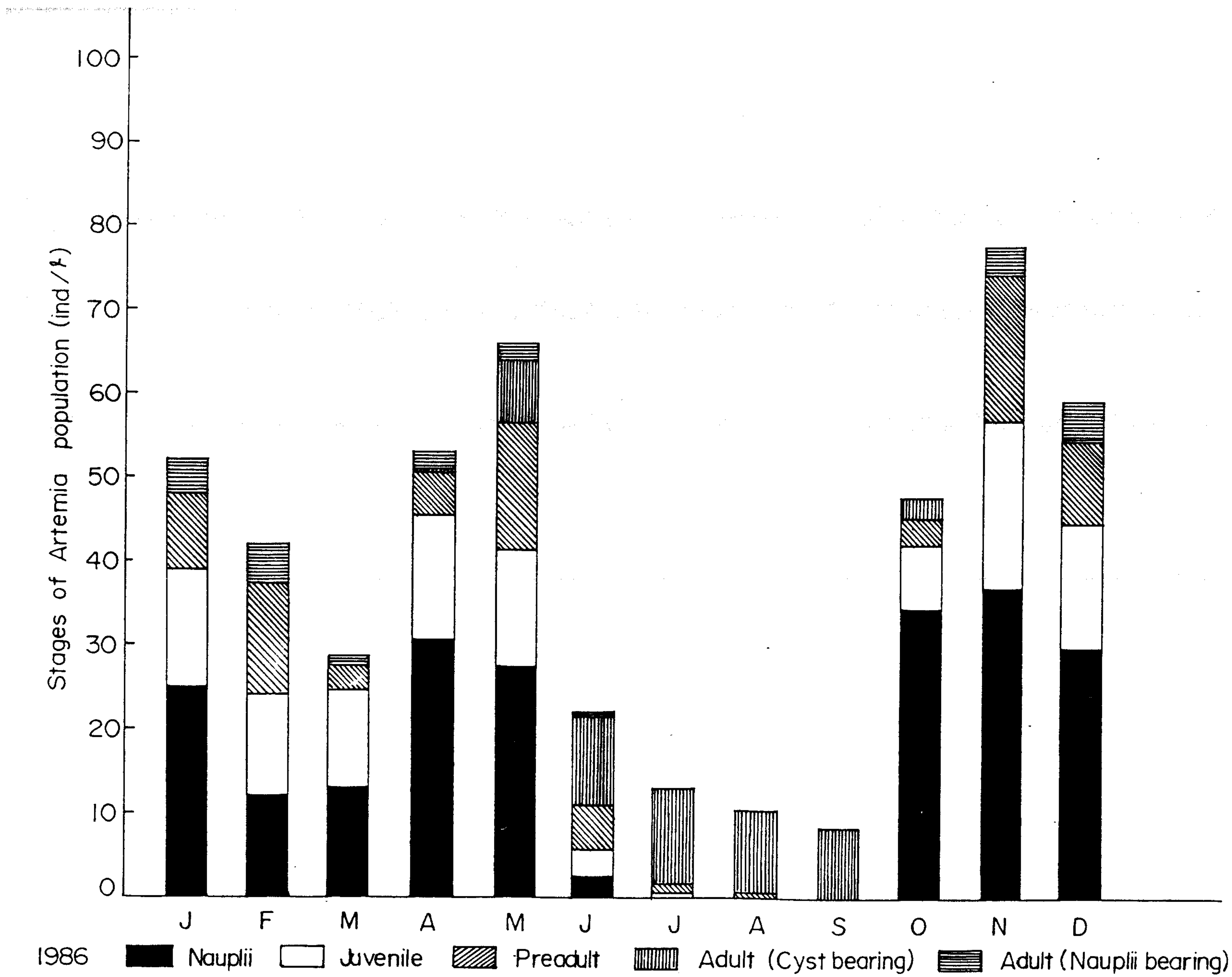


Fig. 20. Monthly mean distribution of the different stages of Artemia (1986)

Table 24. Monthly mean distribution of different stages of <u>Artemia</u> population (1986).

Different stages of	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Nauplii	24.75	12.00	13.20	30.50	27.50	2.40	0.00	0.00	0.00	34.50	36.75	29.80
	±4.11	±1.63	±3.34	±0.78	±7.89	±2.07				±33.27	±6.94	±6.97
Juveniles	13.75	12.25	11.40	15.25	14.25	3.00	0.25	0.00	0.00	8.25	20.25	15.00
	±2.87	±2.75	±2.30	±4.11	±6.13	±3.39	±0.50			±13.20	±2.22	±5.04
Preadults	9.50	12.75	2.80	4.75	14.75	5.60	1.25	0.50	0.00	3.25	17.50	9.80
	±4.20	±1.25	±1.92	±2.21	±5.18	±6.67	±0.50	±0.57		±5.85	±4.35	±1.64
Cyst bearing	0.00	0.00	0.00	0.25	7.50	11.00	11.50	10.00	8.60	1.75	0.00	0.00
adults				0.50	4.65	0.23	0.57	0.82	1.82	2.87		
Nauplii bearing	3.75	5.25	1.20	2.50	2.00	0.20	0.00	0.00	0.00	0.00	3.50	5.00
adults	±1.25	±2.2	±0.44	±0.57	±1.51	±0.44					±1.73	±0.00
Total	51.75	42.25	28.60	53.25	66.00	22.20	13.00	10.50	8.60	47.75	78.00	59.60
	±6.84	±6.55	±4.39	±16.93	±12.98	14.44	±1.41	±1.00	±1.82	±43.00	±7.65	±8.44

population drastically declined to a total mean value of 22.20 ind/l. Mean number of all stages declined and the nauplii bearing adult contributed 0.20 ind/l. The number of cyst bearing adults however, increased to 11/l. The nauplii, juveniles and preadults contributed 2.4, 3.0 and 5.6 ind/l respectively.

The declining trend of total population continued in July (13.0 ind/l) and was characterised by the total disappearance of nauplii as well as nauplii bearing adults in the population. The cyst bearing adults dominated (11.50 ind/l) followed by preadults (1.25 ind/l) and the juveniles (0.25 ind/l). In August, the total number further declined to 10.50 ind/l. Furthermore, the juvenile stage also disappeared. The cyst bearing adults contributed 10.0 ind/l and the preadults remained at 0.50 ind/l. September recorded the lowest mean population number of all the months of 1986 and the population consisted exclusively of the cyst bearing adults (8.60 ind/l).

In October, an increasing trend was observed. The total population increased greatly and a mean value of 47.75 ind/l was recorded, for this month. The nauplii, juveniles and preadults reappeared in the population with a dominance of the nauplii stage which contributed to 34.50 ind/l. The contribution of juveniles and preadults were 8.25 and 3.25 ind/l respectively. The mean population number further increased to 78 ind/l in November. An interesting observation during this month was the total disappearance of the cyst bearing adults and the reappearance of the nauplii bearing adults. The nauplii continued to dominate the population, with a contribution of 36.75 ind/l followed by the juveniles

20.25 ind/l, preadults 17.50 ind/l and the nauplii bearing adults 3.50 ind/l.

In December, the total population decreased but the stages that contributed to the population remained the same as the previous month. The nauplii dominated with a contribution of 29.80 ind/l followed by the juveniles (15.0 ind/l), preadults (9.80 ind/l) and the nauplii bearing adults (5.0 ind/l). The cyst bearing adults did not contribute to the population during this month also.

The mean total population showed variations during the different months of 1987 also. (Fig. 21 and Table 25). The minimum number of 0.6 ind/l was observed during November 1987. However, unlike in the previous year, the maximum number was observed in the month of May 1987 (90.50 ind/l). January recorded a total mean population of 63 ind/l, with the nauplii dominating the population. This stage contributed 10.25 ind/l, followed by the preadults (12.75 ind/l), the juveniles (10.25 ind/l) and the nauplii bearing adults (8.50 ind/l). The cyst bearing adults were not represented during this month. February recorded a decline in the total Artemia population with a mean number of 39.25 ind/l. In this month, cyst bearing adults also were observed in the population and they contributed to 5 ind/l. The nauplii bearing adults formed only 2.50 ind/l. The nauplii continued to dominate the population and they contributed 13.75 ind/l. The contribution of juveniles and the preadults were 9.25 and 8.75 ind/l respectively. The total population recorded a further decline during March and the nauplii bearing adults completely disappeared from the population. The nauplii however, continued to dominate the population with a mean number of 14.60 ind/l. The juveniles

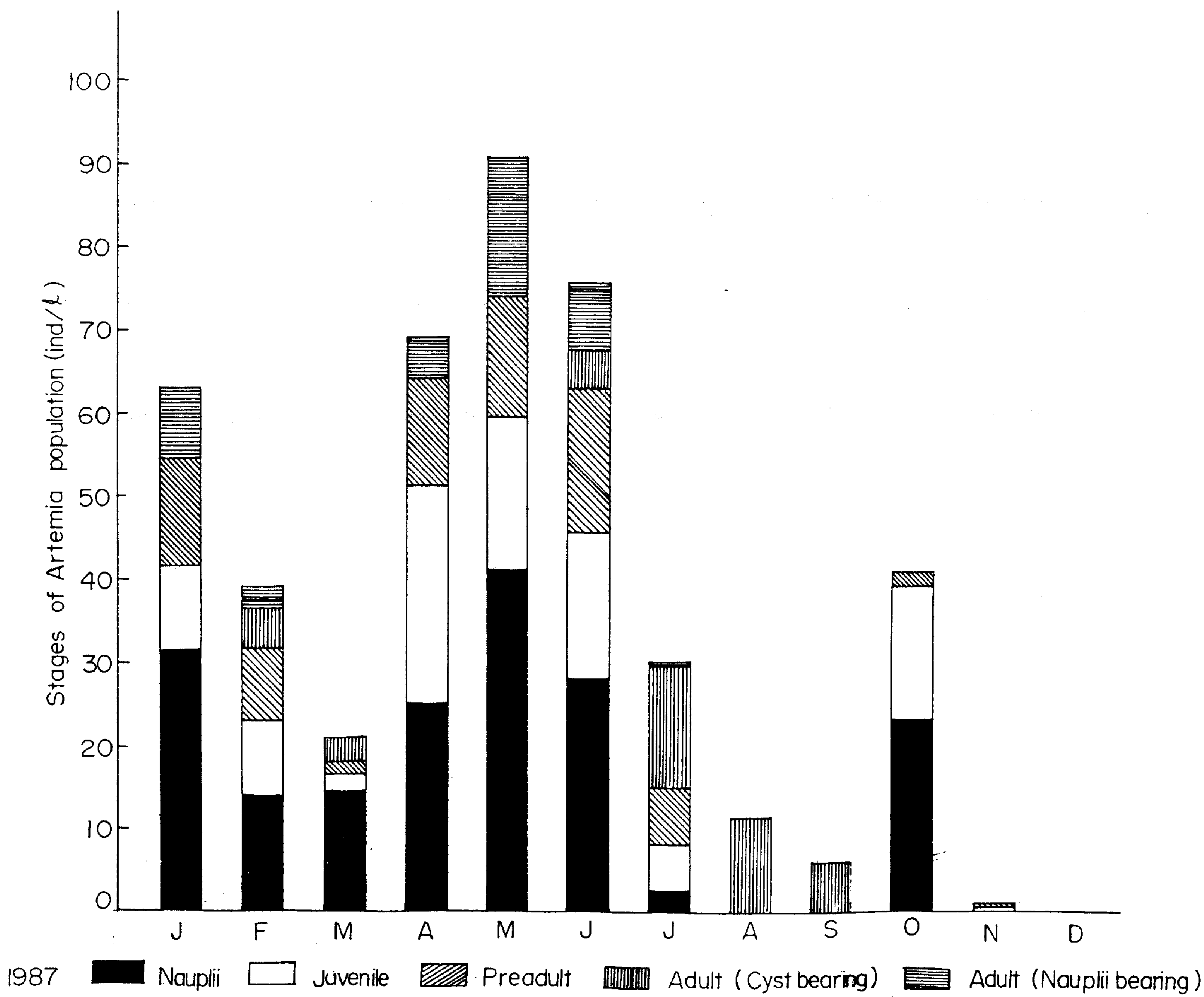


Fig. 21. Monthly mean distribution of the different stages of Artemia (1987)

Table 25. Monthly mean distribution of different stages of Artemia population (1987)

Different stages of Artemia population (Ind/l)	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.	Mean S.D.
Nauplii	31.50 ±9.74	13.75 ±7.84	14.60 ±27.13	25.25 ±14.86	41.25 ±4.35	27.80 ±9.78	2.50 ±2.08	0.00	0.00	23.25 ±32.19	0.00	0.00
Juveniles	10.25 ±3.77	9.25 ±2.21	2.00 ±0.70	26.25 ±2.87	18.50 ±2.38	17.40 ±3.97	5.50 ±5.32	0.00	0.00	15.75 ±18.46	0.20 ±0.45	0.00
Preadults	12.75 ±3.77	8.75 ±0.95	1.40 ±0.55	13.00 ±8.12	14.50 ±4.12	17.40 ±6.73	7.25 ±6.70	0.00	0.00	1.75 ±1.26	0.40 ±0.89	0.00
Cysts bearing adults	0.00	5.00 ±2.70	3.00 ±2.74	0.00	0.00	5.00 ±5.91	14.75 ±0.95	11.40 ±1.52	6.75 ±0.96	0.00	0.00	0.00
Nauplii bearing adults	8.50 ±0.57	2.50 ±2.38	0.00	4.75 ±5.50	16.25 ±3.50	8.20 ±7.25	0.25 ±0.50	0.00	0.00	0.00	0.00	0.00
Total	63.00 ±8.60	39.25 ±10.96	21.00 ±24.85	69.25 ±12.68	90.50 ±6.24	75.80 ±18.37	30.25 ±14.79	11.40 ±1.52	6.75 ±0.96	40.75 ±32.06	0.60 ±1.34	0.00

and the preadults contributed 2.00 and 1.40 ind/l respectively.

April recorded a sharp increase in the total population. Furthermore, the cyst bearing adults totally disappeared from the population. The nauplii, juveniles, preadults and nauplii bearing adults contributed 25.25, 26.25, 13.00 and 4.75 ind/l respectively. In May, the population (90.50 ind/l) showed a further increase in the total mean value with the continued absence of the cyst bearing adults. The nauplii dominated and recorded a value of 41.25 ind/l, followed by the juveniles (18.50 ind/l), preadults (14.50 ind/l) and the nauplii bearing adults (16.25 ind/l). The total population in June declined to 75.80 ind/l. The cyst bearing adults reappeared in the population and contributed a 5 ind/l. The nauplii bearing adults contributed 8.20 ind/l. The contribution of the preadults, juveniles and the nauplii were 17.40, 17.40 and 27.80 ind/l respectively.

In July the population further declined to 30.25 ind/l with a sharp reduction in the number of the nauplii bearing adults. It comprised only 0.25 ind/l of the total population. The number of cyst bearing adults on the other hand showed an increase and a value as high as 14.75 ind/l was recorded. The preadults, juveniles and the nauplii formed 7.25, 5.50 and 2.50 ind/l. August was characterised by the further reduction in total population and the exclusive composition of the entire population was only of the cyst bearing adults. They recorded a mean number of 11.40 ind/l. September continued to record only the cyst bearing adults but a further reduction in the total population was observed. September recorded a mean value of 6.75 ind/l.

In October the total population seemed to record a mean value of 40.75 ind/l. However, the cyst bearing adults totally disappeared and neither was the nauplii bearing adult present in the population. So during this month the Artemia population was completely devoid of the adult stages. The nauplii contributed 23.25 ind/l, the juvenile 15.75 ind/l and the preadults 1.75 ind/l. In November, the population once again showed a steep decline with the disappearance of the naupliar stages in addition to the absence of adult stages. The juveniles and the preadults also contributed only 0.20 and 0.40 ind/l respectively. In December, the entire population totally disappeared from the site.

CORRELATION MATRIX

Two correlation matrices were constructed to find out the relationship between the various physico-chemical, biological and meteorological parameters on one hand and the various stages of *Artemia* population on the other. The details are as given below:

A. Physico-chemical parameters

1. Salinity
2. Dissolved oxygen
3. pH
4. Phosphate
5. Nitrate
6. Ammonia
7. Silicate

B. Biological parameters

1. Algal cells
2. Gross primary production
3. Predatory insects

C. Various stages of Artemia population

1. Nauplii
2. Juveniles
3. Preadults
4. Cyst bearing adults
5. Nauplii bearing adults

Table 26. Mean and standard deviation of different characteristics (CHR)

	CHR	MEAN	S.D.
1.	Salinity	87.296	30.471
2.	Dissolved oxygen	2.543	0.870
3.	pH	8.101	0.147
4.	Phosphate	4.500	1.992
5.	Nitrate	4.729	1.660
6.	Ammonia	2.391	0.763
7.	Silicate	65.164	19.157
8.	Nauplii	16.278	16.459
9.	Juveniles	9.184	8.315
10.	Preadults	6.760	6.546
11.	Cyst bearing adults	4.246	5.105
12.	Nauplii bearing adults	2.705	4.247

Table 27. Correlation Matrix, showing the influence of physico-chemical parameters on different stages of <u>Artemia</u>.

	1	2	3	4	5	6	7	8	9	10	11	12
1.	1.000	-.965	-.271	-.551	-.592	-.249	-.689	-.352	-.373	-.181	0.795	-.159
2.	-.965	1.000	0.227	0.525	0.562	0.230	0.713	0.404	-.356	0.196	-.794	0.188
3.	-.271	0.227	1.000	0.377	0.434	-.152	0.121	0.253	0.232	0.165	-.268	0.030
4.	-.551	0.525	0.377	1.000	0.701	-.109	0.535	0.093	0.087	-.123	-.519	-.104
5.	-.592	0.562	0.434	0.701	1.000	0.061	0.614	0.316	0.322	0.155	-.659	0.030
6.	-.249	0.230	-.152	-.109	0.961	1.000	0.092	0.329	0.278	0.251	-.140	0.065
7.	-.689	0.713	0.121	0.535	0.614	0.092	1.000	0.475	0.456	0.364	-.774	0.330
8.	-.352	0.404	0.253	0.093	0.316	0.329	0.475	1.000	0.821	0.631	-.540	0.567
9.	-.373	0.356	0.232	0.087	0.322	0.278	0.456	0.821	1.000	0.749	-.562	0.546
10.	-.181	0.196	0.165	-.123	0.155	0.251	0.364	0.631	0.749	1.000	-.320	0.719
11.	0.795	-.794	-.268	-.519	-.659	-.140	-.774	-.540	-.562	-.320	1.000	-.444
12.	-.159	0.188	0.030	-.104	0.030	0.065	0.330	0.567	0.546	0.719	-.444	1.000

The results of the correlation between the physicochemical parameters and different stages of Artemia are given in Table 27.

Salinity had a negative correlation with nauplii (r = -0.35) and juveniles (R = -0.37). However, it was positively correlated with adult cyst bearing stage (r = 0.80). Dissolved oxygen, on the other hand, showed positive correlation with nauplii (r = 0.40) and juveniles (r = 0.36). However, it showed a negative correlation with cyst bearing adults (r = -0.79). pH did not show any significant positive or negative relationship with various stages of Artemia population.

Phosphate showed a negative relationship with cyst bearing adults (-0.52). Nitrate, like dissolved oxygen, showed positive correlation with both nauplii (r = 0.32) and juveniles (r = 0.32) and a negative relationship with cyst bearing adults. Ammonia similarly showed positive relationship with nauplii (r = 0.33) and juveniles(r = 0.28). However, it did not showed any significant relationship with the adult stages. Nitrite being an intermediary between ammonia and nitrate, was not taken into consideration for the construction of this correlation matrix. Silicate showed a positive correlation with nauplii (r = 0.48) juveniles (r = 0.46), preadults (r = 0.36) and nauplii bearing adult stage (r = 0.33). However, it showed a negative relationship with adult cyst bearing stage (r = -0.77).

The results of the relationship between biological and meteorological parameters with the different stages of Artemia are represented in the table 29. Algal cells showed a positive correlation with nauplii (r = 0.51), juveniles (r = 0.64), preadults (r = 0.59) and adult nauplii bearing

Table 28. Mean and standard deviation of different characteristics (CHR)

	CHR	MEAN	S.D.
1.	Algal cells	1.938	1.397
2.	Gross primary production	0.938	0.532
3.	Predatory insects	5.385	2.208
4.	Temperature	27.519	4.093
5.	Wind velocity	20.781	5.871
6.	Sunshine	8.177	2.367
7.	Rainfall	9.849	15.844
8.	Nauplii	16.278	16.459
9.	Juveniles	9.184	8.315
10.	Preadults	6.760	6.546
11.	Cyst bearing adults	4.246	5.105
12.	Nauplii bearing adults	2.705	4.247

Table 29. Correlation Matrix showing the influence of biological and meteorological parameters on different stages of *Artemia.*

	1	2	3	4	5	6	7	8	9	10	11	12
1.	1.000	0.885	0.514	-.198	-.432	-.120	0.116	0.509	0.641	0.585	-.699	0.537
2.	0.885	1.000	0.446	-.268	-.519	-.082	0.069	0.450	0.566	0.415	-.648	0.369
3.	0.514	0.446	1.000	-.123	-.335	-.131	0.326	0.081	0.208	0.106	-.459	0.029
4.	-.198	-.268	-.123	1.000	0.362	0.161	-.123	-.104	0.064	0.080	0.326	0.097
5.	-.432	-.519	-.335	0.362	1.000	0.470	-.445	-.357	0.301	-.059	0.633	0.030
6.	-.120	-.082	-.131	0.161	0.470	1.000	-.529	-.125	0.044	0.129	0.272	0.227
7.	0.116	0.069	0.326	-.123	-.445	-.529	1.000	-.006	-.046	-.026	-.329	-.289
8.	0.509	0.450	0.081	-.104	-.357	-.125	-.006	1.000	0.821	0.631	-.540	0.567
9.	0.641	0.566	0.208	-.064	-.301	0.044	-.046	0.821	1.000	0.749	-.562	0.546
10.	0.585	0.415	0.106	0.80	-.059	0.129	-.206	0.631	0.749	1.000	-.320	0.719
11.	-.669	-.648	- 0.459	0.326	0.633	0.272	-.329	-.540	-.562	-.320	1.000	-.444
12.	0.537	0.369	0.029	0.097	0.30	0.227	-.289	0.567	0.546	0.719	-.444	1.000

stage (r = 0.54). It showed a negative relationship with adult cyst bearing stage (r = -0.70). Gross primary productivity similarly showed positive correlation with nauplii (r = 0.45), juveniles (r = 0.57), preadults (r = 0.42) and adult nauplii bearing (r = 0.37) and negative correlation with adult cyst bearing stage (r = 0.65). Predatory insects showed a negative relationship with adult cyst bearing (r = -0.46).

Water temperature showed a positive relationship with adult cyst bearing (r = 0.33). Wind velocity showed a negative correlation with ;(r = -0.36) and juvenile (r = -0.30) but a positive relationship with adult cyst bearing (r = 0.63). Sunshine did not show any positive or negative relationship with the different stages of *Artemia*. Rainfall, however showed a negative relationship with adult cyst bearing (r = -0.35) and adult nauplii bearing (r = -0.29).

DISCUSSION

The fluctuations in the total *Artemia* population in the natural habitats as well as the sharp changes in the different stages contributing to the total population seems to be a common factor all over the world. Such fluctuations in the *Artemia* population have already been reported by Persoone and Sorgeloos (1980), Davis (1980), Geddes (1980), Lenz (1980, 1987), Scelzo and Voglar (1980), Ramamoorthi and Thangaraj (1980), Lenz and Dana (1987), Wear and Haslett (1987), Majic and Vukadin (1987), Ahmadi (1987), Ramanathan and Natarajan (1987), Bhargava *et al.* (1987) and Conte and Conte (1988) based on their studies in the respective countries.

The impact of certain important hydrographic parameters on the population structure has been described by many in other countries and by a few workers from India Sato (1967), Kristensen and Hulscher-Emeis (1972), Post and Youssef (1977), Vos and Tunsutapanit (1979), Geddes (1980), Lenz (1980), Scelzo and Voglar (1980), Persoone and Sorgeloos (1980), Spitchake (1980) and Dana (1982, 1984) have studied the influence of hydrographic parameters like salinity, dissolved oxygen, pH and temperature on *Artemia* population.

In India, impact of these hydrographic parameters on *Artemia* population has been reported by Ramamoorthi and Thangaraj (1980), Ramanathan and Natarajan (1987) and Bhargava *et al.* (1987). The

The comparison of the fluctuations of Artemia population and the important hydrographic parameters showed certain relationship in the present study also.

Among the four hydrographic parameters studied, salinity and dissolved oxygen values showed great variations (Fig. 12 & 13). Such fluctuations in salinity and dissolved oxygen at Tuticorin were also reported by Ramamoorthi and Thangaraj (1980) and Ramanathan and Natarajan (1987). The temperatures recorded during the different seasons in the present study did not reflect much great variations. This may be probably due to the uniform sampling time during morning hours. The pH also showed a very small range and it varied from 7.88 to 8.27 during the different months of the two years of study (Table 16 & 17). Similar observations in the pH values were noticed by Sato (1967), Ramamoorthi and Thangaraj (1980) and Bhargava et al. (1987).

While comparing the various hydrographic parameters with the total Artemia population (Fig. 12 & 13), it was seen that the mean total of the entire population was more when the salinity was between 55 and 80 ppt. The contribution of the nauplii during both the years were more when the salinity ranges were lower. Thus, during 1986, maximum number of nauplii were seen in the month of November when salinity was 54.97 ppt, and the same was observed in 1987 during May when salinity was 76.91 ppt. The juveniles and preadults also were abundant in the population when salinity ranges were between 55 and 80 ppt. Nauplii too co-existed with these stages, thus showing that this salinity range was suitable for the co-existence of all the three stages.

However, it was noticed that the preadults were abundant in the population when the salinity range was between 55 to 100 ppt. This may be due to the greater tolerance of this stage to the higher salinity ranges.

The preadults transformed either into the cyst bearing or nauplii bearing adults. The nauplii bearing adults occurred when the salinity ranges were between 55 to 120 ppt, and the cyst bearing adults, when salinity ranged between 80 and 130 ppt. Thus it was seen that both the nauplii bearing adults and the cyst bearing adults were present in the population when the salinity ranged between 80 and 120 ppt. Co-existence of both these adult populations has been reported earlier by Lenz (1980), Persoone and Sorgeloos (1980), Ramamoorthi and Thangaraj (1980) and Scelzo and Voglar (1980).

The appearance of cyst bearing adults and the disappearance of nauplii bearing adults in higher salinity ranges, suggests that salinity has a great role to play in the further development of the preadults in the salina at a given time. At higher ranges of salinity the preadults develop into the cyst bearing adult and the nauplii bearing adults already present in the population also convert into cyst bearing adults. The existence of only cyst bearing adults during high ranges of salinity has been reported earlier by Scelzo and Voglar (1980), Ramamoorthi and Thangaraj 91980), Bhargava et al. (1987) and Ramanathan and Natarajan (1987). The present study also showed similar trends and only cyst bearing adults were observed during high ranges of salinity.

The salinity showed a steady declining trend from September 1986 onwards and the value come down to 54.97 ppt. At the same time, an increase in the number of nauplii, juveniles, preadults and nauplii bearing adults were noticed (Fig. 12). However, in 1987, the salinity sharply declined to less than 25 ppt during November and December and the Artemia population totally disappeared from the site (Fig.13). This indicated that a salinity range of about 50 ppt is a requirement for the healthy survival of the Artemia population in the salina. Such disappearance of Artemia from the habitats when salinities decrease, have been reported by Persoone and Sorgeloos (1980), Ramamoorthi and Thangaraj (1980) and Scelzo and Voglar (1980). The dissolved oxygen and the salinity values seemed to have an inverse relationship. So when salinity ranges were high, the salinas had low dissolved oxygen. In 1986, when salinity value recorded a peak of 132.18 ppt, the dissolved oxygen value recorded was as low as 1.29 ml/l (Fig. 12). As the relationship between these parameters were inverse, the population number was more when the dissolved oxygen values were high and vice-versa. The nauplii, juveniles, preadults and the nauplii bearing adults preferred higher range of dissolved oxygen and were totally replaced by the cyst bearing adults when the dissolved oxygen reduced to 1.29 ml/l in 1986 and 1.39 ml/l in 1987.

As reported earlier, the temperature and pH did not show great ranges and so their clear cut impact on the population could not be specified during this period of study. However, Persoone and Sorgeloos (1980) have reported that the optimum temperature for the survival of Artemia is between 25°C and 30°C.

Distribution of nutrients in the *Artemia* habitats have been studied earlier (Stephens and Gillespie, 1976; Scelzo and Voglar, 1980; Wear and Haslett, 1987; Bhargava *et al.*, 1987; Majic and Vukadin, 1987). During the present study, the concentration of nutrients in the salina during different months was investigated. The important nutrients namely ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate and silicate in the salina showed a general trend during the two years of study. The nutrient values were higher during the pre-summer and the post-summer seasons. The source of these nutrients in the salina are mainly in the form of *Artemia* excreta (Moffet and Fisher, 1978), from the excreta of the birds visiting the salina for feeding on the different stages of *Artemia* (Persoone and Sorgeloos, 1980) and also from the adjacent areas during the rainwater inflow. As Tuticorin, experiences rain mainly in the late post-summer and only early pre-summer months, the nutrient values are higher during these seasons.

The fluctuations noticed in the nutrients had a bearing on the total *Artemia* population (Fig. 14 & 15). As already seen, the total mean population numbers were more during the pre-summer, post-summer and first half of summer seasons thus, showing a positive relationship with the nutrients. As all the nutrients studied showed similar trends it may be said, all the nutrients have a positive relationship with the total mean population number. On the other hand, the individual stages reacted differently to the nutrient content in the salina.

The nauplii, juveniles, preadults and nauplii bearing adults preferred higher nutrient ranges and the cyst bearing adults were abundant when the nutrient levels were lower.

A comparison of the nutrient levels and the hydrographic parameters described in the preceeding section shows that the nutrient had a positive relationship with the dissolved oxygen levels and a negative relationship with the salinity ranges. So during the peak summer seasons, the nutrient and dissolved oxygen values were low and the salinity values were very high. The total mean population number was high during the pre-summer, first half of summer and post-summer seasons. During these seasons, the population comprised mainly of the nauplii, juveniles, preadults and the nauplii bearing adults. The peak summer season was characterised by low total mean population numbers and abundance of the cyst bearing adults. However, in 1987 the occurrence of cyst bearing adults during February and March (Fig. 13) in spite of higher nutrient levels in the salina may be explained due to the conducive environment brought about by higher salinity ranges during this period. Similar distribution pattern of nutrients were observed by Stephens and Gilliespie (1976), Scelzo and Voglar (1980), Majic and Vukadin (1987) and Bhargava et al. (1987) in Great Salt Lake, Utah, Bocachica Lake, Venezuela, Yugoslav salt works and Didwana Lake, India respectively.

Among the biological parameters studied, the gross primary productivity and the algal cells present in the salina usually had a positive relationship with the total Artemia population (Fig. 16 & 17). Studies on the primary productivity as well as the algal cells in the Artemia habitat have been carried out in detail by several earlier workers (Manson, 1967; Wetzel, 1975; Cohen et al., 1977a,b; Winkler, 1977; Haynes and Hammer, 1978; Ramamoorthi and Thangaraj, 1980; Scelzo and Voglar, 1980; Javor, 1983; Bhargava *et al.*, 1987; Wear and Haslett, 1987).

During 1986 both these factors showed similar trends with higher values during April, May and November and lower value in September (Fig. 16). In 1987, the higher values were recorded during April, May, November and December and the lowest value during August (Fig. 17). The higher algal cell count as well as primary productivity values during the above months are probably due to the higher nutrient content available during those months as well as the preceeding month. The availability of higher nutrient levels in the salina directly influence the number of algal cells and consequently the primary productivity. The algal cells are the main food item of the different stages of *Artemia* and so their availability in plenty is beneficial to the population. Studies on these lines have already been carried out by Ramamoorthi and Thangaraj (1980) in Tuticorin and Bhargava *et al.* (1987) in Didwana Lake, Rajasthan The results of the present observation are similar to their studies.

However, in the present study, the *Artemia* population totally disappeared during the end of 1987, though both the primary production and algal cell counts were high in the salina. This is quite indicative that the hydrographic parameters, such as salinity, have a greater impact on the *Artemia* population. The decrease in the algal cells as well as primary productivity during June-September can be attributed to the very high salinity coupled with lower dissolved oxygen levels, in the salina during the period. Certain strains of algae are known to survive in high salinities upto 80 ppt, *Dunaliella* sp., Scelzo and Voglar 1980; *Chlamydomonas* sp., Majic and Vukadin, 1987). The same algal species were observed in the salina during the present study at higher salinities.

The insect population was represented only by one family (Corixidae) in the salina and was found to be highly predatory in nature. Occurrence of such predatory insects in the *Artemia* habitats have been reported by Persoon and Sorgeloos (1980). In India, also, the occurrence of such predatory forms have been reported by Ramamoorthi and Thangaraj (1980) in Tuticorin and Bhargava *et al.* (1987) in Didwana Lake.

Generally it was noticed that the insect population was abundant when the younger stages of *Artemia* occurred in greater numbers during the pre-summer and post-summer seasons (Fig. 16 & 17). At times, the greater number of insects adversely affected the population size. Such reduction in mean number of the population was observed during March 1986 and 1987, and during the last months of 1987, when the *Artemia* population completely disappeared from the salina (Fig. 17). Reports on the decrease and then total disappearance of the *Artemia* population have been reported earlier in India by earlier workers (Ramamoorthi and Thangaraj, 1980; Bhargava *et al.*, 1987). The reduction in the number of predatory insects during the summer season may be due to the non-availability of the younger stages of *Artemia* and the reduction in the total *Artemia* population.

Among the meteorological parameters studied, the rainfall was recorded only during the early pre-summer and post-summer seasons. Moderately high showers were recorded mainly during the post-summer seasons. Though, rainfall was recorded almost during the same months, during both the years, Tuticorin experienced more rainfall for longer duration in 1987 (Fig. 18 & 19).

The sunshine and wind velocity showed similar trends during the two years with longer sunshine hours and greater wind velocity during the summer months. These meteorological parameters directly affected the hydrographic parameters in the saline.

Rainfall in the area resulted in lowering of salinity and increase in dissolved oxygen levels. During post-summer season of 1986, an average of 21.10 mm rainfall was recorded in the area and the salinity gradually declined from 132.18 ppt in September to 54.97 ppt in November. In December the salinity was maintained around 65.53 ppt. Younger stages of Artemia again appeared in the population. Nauplii dominated during these periods. The number of nauplii increased from 34.50/l in October to 36.75/l in November (Fig. 18). The sudden increase in the number of nauplii is probably due to the hatching of the cyst produced in the salina when the salinity was high. Hatching of cysts when salinity is lowered due to rainfall has been already reported by Royan, 1979; Persoone and Sorgeloos, 1980; Scelzo and Voglar, 1980 and Bhargava et al., 1987.

In 1987, with rains the salinity decreased and a sudden increase in the number of nauplii were seen during October. Average rainfall recorded during the pre-summer season of 1987 was 31.32 mm. Due to the continued showers, the salinity declined to 25.02 ppt in November and further 24.19 ppt in December during which period. Artemia population totally disappeared from the salina (Fig. 13 & 19). The disappearance of the population from the site may be due to sudden and sharp decline in salinity of the saline due to continuous rainfall. Such instances, where the Artemia population disappeared due to lowering of salinity has been reported by Kristensen and Hulsch-Emeis (1972) Persoone and Sorgeloos (1980) Ramamoorthi and Thagaraj (1980) Bhargava et al., (1987) and Ramanathan and Natarajan (1987).

Longer durations and sunshine hours during summer season would have probably resulted in the increas of temperature in the salina. As temperature during the present study was measured only in the morning hours, no definite inference could be concluded from them. Since sudden and obvious changes were not noticed in the Artemia population at the site during the present study, it may be said that the temperatures in the salina did not increase beyond the tolerance limit of the Artemia.

The wind velocity in the area gives an indirect indication of the rate of evaporation. The higher the wind velocity, the greater the rate of evaporation. During summer season, the wind velocity was high and this must have increased the rate of evaporation and consequently resulted in increase of salinity in the salina.

From the foregoing studies, it is seen that the hydrographic, nutrients, biological and meteorological parameters in the salina interact with each other either positively or negatively and consequently affect the Artemia population in general and certain stages in specific. However it may be stated that the salinity has a profound influence especially on the occurrence of cyst bearing adults. The rise in salinity to around 120 ppt resulted in the disappearance of nauplii bearing adults. When the salinity in the salina was around 100 ppt during last week of February 1987, the cyst bearing adults were recorded in the population. But with the commencement of rain in March 1987, salinity declined and the cyst bearing adults gave way to the nauplii bearing adults. The occurrence of only cyst bearing adults when salinity ranges are around 120 ppt have already been recorded in the works of Ramamoorthi and Thangaraj (1980) and Bhargava et al., (1987) in Tuticorin and Didwana Lake respectively.

The salinity also had an impact on the total Artemia population in the salina. As already stated all the stages of Artemia other than the cyst bearing adults prefer lower salinity ranges. However, salinity ranges below 30 ppt was found to be unsuitable for the survival of Artemia population. It resulted in the total disappearance of the Artemia population from the site. Such disappearance of Artemia when lower salina conditions prevailed is in concurrence with the earlier studies of Kristensen and Hulscher-Emeis, (1972), Persoone and Soogeloose (1980), Ramamoorthi and Thangaraj (1980) and Bhargava et al. (1987).

The results of the correlation matrix, of the different environmental parameters with the different stages, were similar to the observations made in the field, thus further confirming the positive or negative effects of each parameter on the different Artemia stages as clearly described in the result section.

PART III

EFFECT OF SUDDEN CHANGES OF SALINITY ON DIFFERENT STAGES OF ARTEMIA

The salinity at the study site showed great variations during the course of the study period. During 1987, the values ranged from 129.96 ppt in summer season to as low as 24.19 ppt during the post-summer season when Tuticorin experienced showers. The *Artemia* population also showed fluctuations during the different seasons and was characterised by the total disappearance of the entire population or the disappearance of certain stages. Such wide fluctuations in *Artemia* population in general and of different stages have been reported by several previous workers (Kristensen and Hulscher-Emeis, 1972; Persoone and Sorgeloos, 1980; Ramamoorthi and Thangaraj, 1980; Scelzo and Voglar, 1980; Bhargava *et al.*, 1987). The possible main reason attributed for such sudden fluctuations was mainly due to sudden decrease in the salinity conditions which may be due to rainfall or dilution of the environment from other sources. All the previous studies have given only circumstantial evidences to the above conclusion and have not been supported by any experimental work. Therefore, in the present study it was felt appropriate to study the population variation by changing the salinity conditions at short intervals. With this view in mind, an experiment was conducted in the laboratory to see if the sudden changes in salinity actually effected the population structure of *Artemia*.

The experiment was designed in such a way that an *Artemia* population containing all developmental stages, collected at a particular time from a particular salinity range could be introduced into a series of salinity ranges at the same time. This was done with an aim to see how the sudden changes in salinity actually effected the different stages.

For the experiment, 9 ranges of salinity media (30-110 ppt) with an increase of 10 ppt at each range were prepared by mixing salt collected from the salt pans with freshwater. The prepared media were kept separately in 3 l glass beakers. The different stages of Artemia were collected from the salina (the study site). During the time of collection, the salinity at the site was 110 ppt. The stages collected included the nauplii, juveniles, preadults and adults (cyst bearing and nauplii bearing). Each stage was introduced separately into each salinity media. A uniform stocking density of 50 No/beaker of each stage was maintained. All stages were uniformly fed twice a day with rice bran suspension and the water in each beaker was renewed every day. Five replicates were maintained for each stage and salinity range, for best results. The 110 ppt salinity was considered as the control. Duration of the experiment was 5 days.

The different stages reacted differently to the different ranges of salinity. The mortality rates, observed in each stage in the different salinity ranges, are given in Table 30. The experiment showed that the adults were the most succeptible to the sudden changes in salinities, when they were transferred from 110 ppt to 30 ppt. The mortality rate was as high as 99.2%. The preadults were the next severely affected with a mortality rate of 76%, followed by juveniles (60.8%) and nauplii

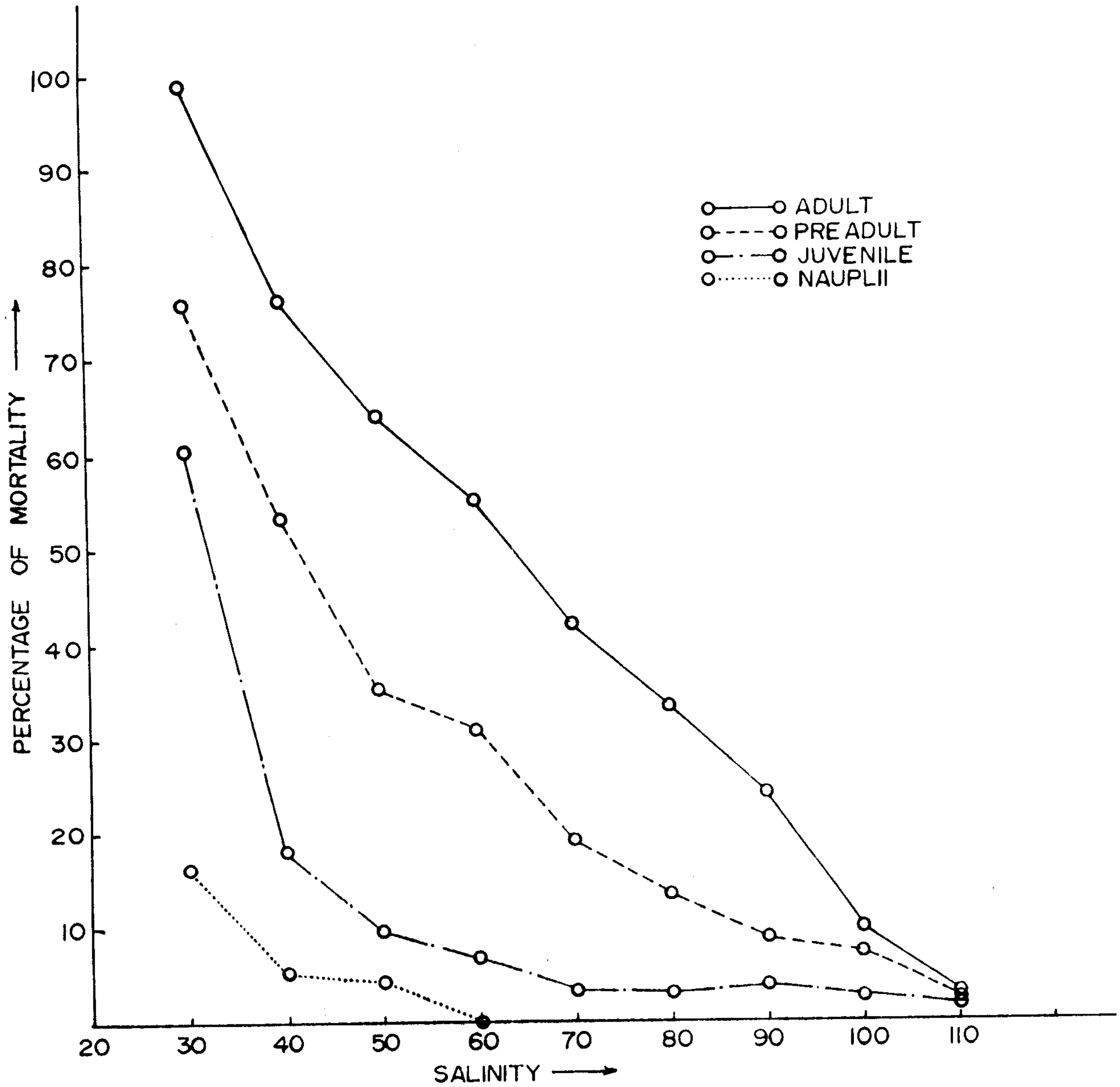


Fig. 22. Mortality percentage of different stages of <u>Artemia</u> when suddenly introduced into different ranges of salinity.

Table 30. Mortality rates of different stages of *Artemia* when introduced suddenly into different ranges of salinity.

Salinity change (ppt)	Resulted sudden decrease in salinity(ppt)	Percentage of mortality for a period of 5 days				Mean(T) (%)
		Adult(T1)	Preadult(T2)	Juvenile(T3)	Nauplii(T4)	
110 to 30 (R1)	80	99.20	76.00	60.80	16.00	63.00
110 to 40 (R2)	70	76.40	53.60	18.00	5.20	38.30
110 to 50 (R3)	60	64.00	35.20	9.60	4.40	28.30
110 to 60 (R4)	50	55.60	31.20	6.80	0.00	23.40
110 to 70 (R5)	40	42.80	19.20	3.20	0.00	16.30
110 to 80 (R6)	30	33.60	13.20	2.80	0.00	12.40
110 to 90 (R7)	20	24.00	8.80	3.60	0.00	9.09
110 to 100 (R8)	10	9.60	7.20	2.40	0.00	4.80
110 to 110 (R9)	0	2.80	2.40	2.00	0.00	1.80
Mean (R)		45.33	27.42	12.13	2.84	

Table 31. Two way Anova - Salinity Vs. Stages of populations

Source	Df.	Sum. Sqr	Mean. Sqr	F-Val	Remarks
Population	3	9343.024	3114.341	18.93	HI.SIG(1%)
Salinity	8	11932.960	1491.620	9.07	HI.SIG(1%)
Error	24	3948.817	164.534		

Comparison of specific populations

Mean comparisons	Remarks
T1-T2	SIG
T1-T3	SIG
T1-T4	SIG
T2-T3	SIG
T2-T4	SIG
T3-T4	N.S

COMPARISON OF SPECIFIC SALINITIES

Mean comoparisons			Remarks
R1	--	R2	SIG
R1	--	R3	SIG
R1	--	R4	SIG
R1	--	R5	SIG
R1	--	R6	SIG
R1	--	R7	SIG
R1	--	R8	SIG
R1	--	R9	SIG
R2	--	R3	N.S
R2	--	R4	N.S
R2	--	R5	SIG
R2	--	R6	SIG
R2	--	R7	SIG
R2	--	R8	SIG
R2	--	R9	SIG
R3	--	R4	N.S
R3	--	R5	N.S
R3	--	R6	N.S
R3	--	R7	SIG
R3	--	R8	SIG
R3	--	R9	SIG
R4	--	R5	N.S
R4	--	R6	N.S
R4	--	R7	N.S
R4	--	R8	N.S
R4	--	R9	SIG

(16.0%) (Fig. 22). The experiment showed that nauplii are the most tolerant to sudden decline in salinity with minimum mortality, followed by juveniles and preadults. The mortality rates of different stages in different salinity ranges are given in the Table 30 and Fig. 22.

Statistical analysis was conducted to observe the effect of salinity ranges on different stages. The results of the two-way ANOVA conducted is given in Table 31. ANOVA test in relation to ranges of salinity (30-110 ppt) Vs. percentage of mortality of total population was found to be highly significant (F = 18.93) at 1% level. The mortality in stages of Artemia in relation to salinity was also highly significant but at a lower level (F = 9.07).

The mean comparisons in all ranges of salinities on the percentage mortality of adult Vs. preadults Vs. juveniles Vs. nauplii revealed that, the salinity affected the survival of all stages of population in a significant way. But the percentage mortality of juveniles on comparison with nauplii showed a non-significant difference. This indicates that at salinity ranges of 30-110 ppt the mortality percentage of juveniles and nauplii were comparitively low with that of adults and preadults.

Sudden changes from 110 ppt to 30 ppt affects the survival of all stages of Artemia with high mortality rate (63%), in comparison with other salinity ranges. The mortality rate reduced to almost 50% at 40 ppt (38.3%) against the higher mortality rate experienced in 30 ppt (Table 30). In salinity ranges of 50 ppt Vs. 60 ppt the mortality rate of total population was more or less similar (28.3 and 23.4%

respectively). Whereas, the mortality rate was only 16.3, 12.4, 9.09, 4.89 and 1.8% respectively in the salinity ranges of 70, 80, 90, 100 and 110 ppt.

The 50 ppt salinity did not significantly affect the mortality of total population compared to 30 ppt and 40 ppt. Whereas in the 60, 70, 80, 90, 100 and 110 ppt salinity ranges, the mortality rate was less and not significant, as compared to 50 ppt.

When compared with 60 ppt, the mean comparisons of other salinity ranges showed less significant mortality percentage. At 70, 80, 80, 100 and 110 ppt salinities the replicate mean comparisons of the percentage mortality of total population was less significant in the variations.

The above experiment thus indicates that adults show a higher mortality rate than the preadults, juveniles and nauplii. When the salinity is suddenly decreased by dilution, nauplii is the least affected stage in the population. It was observed that a sudden decrease of 10 ppt (110 ppt to 100 ppt) in salinity resulted in only less than 10% mortality in adults, preadults and juveniles. Whereas a decrease of 40 ppt (100 ppt to 70 ppt) caused a mortality of 42.80%, 19.20% and 3.20% respectively in these stages. But higher mortality rate of 99.2%, 76%, 60.80% was observed in these stages when the salinity was suddenly reduced from 100 ppt to 30 ppt, a sudden reduction of 80 ppt. However, the nauplii were not affected much. This showed only a meagre mortality of 4.40%, 5.20% and 16% when the salinity was suddenly decreased from 100 ppt to 50 ppt (a reduction of 60 ppt), 40 ppt (a reduction of 70 ppt) and 30 ppt (a reduction of 80 ppt) respectively.

SUMMARY

1. A two year study in the salt pans of Tuticorin was taken up to know more about the population biology and ecology of _Artemia_ in the south east coast of India.

2. The study was carried out in a salina with an area of 0.25 ha, during 1986 and 1987.

3. Weekly samples of both the _Artemia_ population as well as the environmental parameters were taken regularly.

4. The _Artemia_ population was grouped into stages such as nauplii, juvenile, preadult, cyst bearing adults and nauplii bearing adults.

5. The _Artemia_ population was represented only by the parthenogenetic strain.

6. Seasonal distribution of _Artemia_ population showed that, nauplii, juveniles, preadults and nauplii bearing adults were abundant during the presummer, postsummer and first half of summer season. Cyst bearing adults dominated during the peak summer season.

7. The important hydrographical parameters studies were salinity, dissolved oxygen, water temperature and pH. Nutrients, in

the salina such as ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, inorganic phosphate and silicate were also studied. In addition, the study on gross primary production and algal cell concentration was carried out. The effect of predation by insects on Artemia, rainfall, sunshine and the wind velocity were also analysed.

8. These environmental parameters influenced the entire Artemia population as well as different stages comprising the population

9. Salinity has a negative influence on the total population size as well as the number of nauplii, juveniles, preadults and the nauplii bearing adults. In high salinity, cyst bearing adults predominated. Salinity ranged between 54.97 and 132.18 ppt in 1986 and 24.19 and 129.96 ppt in 1987.

10. Dissolved oxygen ranged between 1.29 and 3.59 ml/l in 1986 and 1.39 and 4.24 ml/l in 1987. It had a positive influence on the number of nauplii, juveniles, preadults and nauplii bearing adults. Cyst bearing adults showed a negative relationship with oxygen

11. Water temperature did not increase beyond the tolerance limit of Artemia. It ranged between 25.35 and 29.88°C in 1986 and 24.68 and 30.92°C in 1987 during morning hours.

12. Artemia population was not influenced by the observed variations in water pH, which ranged from 7.88 to 8.27 in 1986 and 7.98 to 8.19 in 1987.

13. Nutrients had a positive influence on the nauplii, juveniles, preadults and nauplii bearing adults. It had a direct relationship with gross primary production and the algal cell concentration.

14. Primary production and algal cell concentration have a direct relationship with each other and with all stages of Artemia population except cyst bearing adults. The gross primary productivity ranged between 0.13 and 1.82 $gC/m^3/day$ in 1986 and 0.27 and 1.67 $gC/m^3/day$.

15. The predatory insects found in the salina belonged to the Corixidae family and fed voraciously on the different stages of Artemia, at times causing total destruction of the population. Their number varied from 1.40 to 7.60/l in 1986 and from 1.75 to 9.25/l in 1987.

16. Rainfall directly influenced the salinity and dissolved oxygen in the salina and thus had an indirect impact on the different stages of Artemia.

17. Wind velocity and sunshine affected the salinity of the salina. The former ranged from 12.25 to 29.50 km/hr in 1986

and 15.40 to 29.20 km/hr in 1987. While the latter varied from 3.95 to 10.60 bright hrs/day in 1986 and 3.85 to 10.83 bright hrs/day in 1987.

18. The seasonal variations of the different stages of the *Artemia* population was analysed statistically using one-way analysis of variance (ANOVA). Significant variation was observed only in cyst bearing adults.

19. Correlation matrix of the environmental parameters with the different stages showed similar results as described above.

20. Experiment in the laboratory showed that sudden and deep decline in salinity resulted in high mortality of adult stages. The tolerance level of nauplii and juvenile stages to changes in salinity was greater than other stages. Sudden decrease in salinity to 90 ppt from the existing 110 ppt (reduction of 20 ppt) resulted in 24%, 8.80%, 3.60% and 0% mortality respectively in adults, preadults, juveniles and nauplii, while sudden decrease to 50 ppt from 110 ppt (reduction of 60 ppt) resulted in 64.0%, 35.2%, 9.6% and 4.4% mortality in respective stages of the population. Sudden decrease from 110 ppt to 100 ppt (reduction of 10 ppt) did not affect any stage significantly

21. The present study gives a detailed account of the *Artemia* habitat and the different environmental parameters that influences the *Artemia* population during different seasons of the year, and will form a guideline for all aquaculturists.

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