Ecological Studies of Zooplankton in Polluted Freshwaters in Delhi

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CERTIFICATE

The studies included in this thesis entitled ECOLOGICAL STUDIES OF ZOOPLANKTON IN POLLUTED FRESHWATERS IN DELHI have been carried out at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work is original and has not been submitted in part or full for for any other degree or diploma of any University.

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INTRODUCTION

There has been an alarming increase in the degradation of water quality in recent years. Whereas the domestic wastes, treated or untreated, and the industrial effluents, are directly discharged into the rivers, all surface waterbodies receive with the runoff from their catchments a variety of organic and inorganic substances which impinge on the water quality. These various inputs cause changes in the physical and chemical as well as biological characteristics of the waterbodies. A major change brought about by organic pollution, is the lowering of dissolved oxygen level which sets in a series of other chemical and biological changes, and ultimately affects the whole aquatic community. Enrichment of the water with nutrients, released during decomposition of organic matter or entering directly, is another major problem of most common occurrence which affects directly the flora and fauna of the aquatic ecosystems. Initially, the nutrient enrichment accelerates the growth of certain planktonic algal species and hence, increases productivity of the water body. This is commonly termed as eutrophication. Excessive eutrophication however, often results in a decline of the biotic community.

The biotic community of an aquatic system normally comprises of the planktonic organisms which include the phytoplankton (producers), zooplankton (consumers) as well as the bacteria (decomposers). Other organisms include the bottom dwelling invertebrates (benthos) and fish. The zooplankton comprise mostly of micro-crustaceans (Cladocera and Copepoda) and Rotifera, Zooplankton occupy a central position in the aquatic food chains between the autotrophs and other heterotrophs. They play an important role in both the grazing and detritus food chains; they feed on phytoplankton or detritus (including bacteria) and in turn they are the major source of food for various planktivorous fish. Thus the zooplankton directly control the ecosystem properties such as production and nutrient cycling.

During the past one hundred years or so, there have been numerous studies of zooplankton covering various aspects of their biology and ecology in different parts of the world (see Hutchinson 1967, Wetzel 1983). It is observed that in general, increasing eutrophication of waterbodies also alters the zooplankton communities (Brooks 1969, Hall et al. 1970, O'Brien and de Noyelles 1974). In an oligotrophic system, the grazing food chain is dominated by smaller and edible phytoplankton. As the phytoplankton communities become composed of partly inedible species (blooms of large Cyanophyta and Dino- flagellates) and greater detritus levels lead to increased bacterial populations, the resultant change in the food supply causes a shift in zooplankton community structure. This is mani- fested in their species composition, biomass and life strategies, mainly due to enhanced predation pressure by increase in planktivorous fish and invertebrate pre- dators which selectively feed on large bodied zooplankton. These food chain relationships of zooplankton with the phytoplankton on one hand and the fish and other invertebrates on the other, have been emphasised in recent studies on restoration of freshwaters through biomanipulation (Shapiro et al. 1975, Shapiro 1980, Benndorf 1988, van Donk and Gulati 1988 and Gulati et al. 1990).

Obviously, an understanding of the nature of zooplankton community, its dynamics and interactions with phytoplankton and other biota at different levels of eutrophication and pollution is essential to developing appropriate strategies for management of freshwater resources. In India, there exists a large bulk of published information on the zooplankton of different water bodies from different parts of the country. Brief reviews of these reports (Michael 1980, Gulati and Wurtz-Schulz 1980) indicate that studies on the cause effect relationships bet- ween the zooplankton community and habitat factors, the interactions among diff-erent zooplankton, and between zooplankton and phytoplankton, and the role of zooplankton in ecosystem processes have rarely been made in India.

With these large lacunae in our knowledge of zooplankton in mind, studies on zooplankton dynamics in relation to levels of pollution and the phytoplankton community have been planned. It is proposed to investigate the temporal changes in the phyto- and zooplankton communities in several temporary and permanent water bodies, to study under laboratory conditions the feeding behaviour of impor-tant zooplankton species, and to study the effects of manipulating the zooplankton community on the phytoplankton community.

As a first step towards the planned study, a detailed review of the literature on the subject, particularly in India, has been undertaken. A survey in and around Delhi has been made to select the waterbodies and preliminary experiments have been conducted to standardise the methodology of culturing algae and zoo-plankton, and of feeding of zooplankton. This dissertation includes the review and these exploratory studies conducted during the period August 1990-April 1991.

LITERATURE REVIEW

The extensive literature on zooplankton spans a wide spectrum of fields: from their systematics and geographical distribution to spatial and temporal variations in the composition of zooplankton community in different waterbodies, vertical migration, reproductive biology and population dynamics, food and feeding behaviour, predation, production and responses to various physical and chemical factors of the environment (Wetzel 1983,). These studies can be grouped into three major categories:

a) Distribution and species diversity

b) Reproductive biology

c) General ecology

DISTRIBUTION AND SPECIES DIVERSITY

There is a large amount of literature on systematics and distribution of species of various small and large groups of zooplankton in different parts of the world, and several general monographs are available for the Rotifera, Cladocera and Copepoda (Brooks 1959, Wilson and Yeatman 1959, Ruttner-Kolisko 1974). In the tropics also, mostly fragmentary data has been brought together at least on a national basis in Asia, Africa and South America (see Dussart et al. 1984).

In the tropical water bodies, research on zooplankton has been directed mainly towards describing species, systematics, and zoogeography (Nilssen 1984) but even then they are lagging behind studies in North temperate zone. A brief review of the literature on the systematics, distribution and ecology of tropical freshwater zoo-plankton on a global scale has been attempted by Dussart et al. (1984). They have summarized the widely scattered literature with comments. Some general distribution patterns are visible. The present understanding of species composition indicates a lower diversity as the Equator is reached (Fernando 1980a, b). It has been suggested that the density and species composition is largely influenced by rainfall and temperature, as well as by the drastic fluctuations in the water level (Fernando and Rajapaksha 1983). Other factors also play a significant role. For example, in the tropics, *Daphnia* is represented by only six of a total of fifty species and its total occurrence is very low. The possible reasons for it could be fish predation or indirect effects of temperature via food type, feeding efficiency, fecundity, metabolic rate, gamogenesis and similar factors (Fernando et al. 1987).

In India large number of taxonomic studies have been concentrated on small portions of the country. The dominant zooplankton of Indian freshwaters belong to the genera *Keratella, Brachionus, Asplanchna, Euchlanis* (Rotifera), *Daphnia, Ceriodaphnia, Chydorus, Alona* (Cladocera) and *Mesocyclops, Cyclops, Diaptomus, Acanthodiaptomus* (Copepods). A perusal of the literature shows that vast areas are still untouched. This is specially true for protozoa which have been almost totally ignored. Although many limnological studies have been conducted, the distribution pattern is not clear due to a paucity of taxonomical data which leads to incomplete and often wrong identification.

The Indian Cladocera have been reviewed with emphasis on their taxonomy in a monograph by Michael and Sharma (1988). The planktonic copepods of freshwater ecosystems have been described by Sehgal (1983). Other important works on copepopds taxonomy are by Khan (1981), Reddiah (1964), Reddy (1988), Sewell (1934, 1951) and Silas (1971). Rotifer taxonomy has attracted the attention of a number of researchers who have described rotifers from different regions of the country. A synopsis of taxonomic studies on Indian Rotatoria has been prepared by Sharma and

Michael (1980). The rotifers of North India have been described by Arora (1962, 1963, 1964, 1966), Vasisht and Battish (1969, 1970, 1971, 1972), Das and Akhtar (1976), Sarma (1988) and Nayar (1965, 1968). In Southern India, Dhanapathi (1974, 1976), Naidu (1967), Pasha (1961) have contributed to the systematics of rotifers. Sharma (1988) has described the lecanid rotifers of North East India.

Generally the zooplankton community in most freshwaters is constituted by five to eight dominant species and several rarer forms (Goldman and Horne 1983), a phenomenon observed in Indian freshwaters also. The high altitude lakes in India are oligotrophic and poor in species diversity and biomass (Zutshi et. al. 1980). In these lakes *Keratella cochlearis, Asplanchna priodonta, Anuraeopsis fissa, Dia- phanosoma brachyurum, Daphnia pulex, Sida crystalina, Ceriodaphnia reticulata, Alona rectangula, Cyclops vicinus* and *Mesocyclops leukarti* are prominent taxa.

The zooplankton fauna of some of the large reservoirs used for hydropower generation, fish production, irrigation and drinking water supply have been studied; for example, Amravathi (Sreenivasan 1965) Sathanur and Krishnagiri (Sreenivasan 1968), Aliyar (Sreenivasan 1970), Ajwa (Jayandougar 1980), Hussain Sagar (Ghosh and George 1989) and several reservoirs in central India (Unni 1985), The zooplankton fauna are poor in diversity and abundance as these major reservoirs were at a lower trophic state. It consists mainly of rotifers, few species of cladocera (*Chydorus sphaericus, Ceriodaphnia cornuta, Daphnia carinata, India-lona ganapatii, Moina dubia, Sida* sp.) and copepods (*Mesocyclops leukarti* and species of *Allodiaptomus., Heliodiaptomus and Neodiaptomus*).

The species diversity and composition in freshwaters is directly linked to the trophic state. Total zooplankton biomass generally increases with increasing trophic state and in accompanied both by species and group replacements within cladocera and copepods, the macrozooplankton. There is an increase in the importance of microzooplankton consisting of rotifers and ciliated protozoans (Bays and Crisman 1983).

Most of the freshwater bodies in India are polluted with varying levels of nutrient enrichment. In almost all the aquatic habitats, rotifera dominate the species list with more than fifty percent of the zooplankton species belonging to this group.

REPRODUCTIVE BIOLOGY

The growth, reproduction and life cycle of most freshwater zooplankton have been extensively investigated in the temperate regions. Rotifers and most cladocerans reproduce by diploid female parthenogenesis for many generations during the main growing season. Environmental stress conditions like reduction in temperature, food availability and overcrowding induce the production of haploid males and female by meiosis. The rates of growth and development of instars in cladocera are directly proportional to temperature. Increased food supply increases the rate of population development by increasing the number of eggs per brood or fecundity (Wetzel 1983).

In India, biology of some cladocera like *Daphnia carinata* (Navaneetha- krishnan and Michael 1971, Murugan and Venkatraman 1977), *Daphnia lum-holtzi* (Sharma et al. 1984), *Daphnia longispina* (Sharma and Pant 1987) *Simeo-cephalus acutirostris* (Murugan and Sivaramakrishnan 1973. and Murugan 1977), *Ceriodaphnia cornuta* (Murugan 1975a), *Moina micrura* (Murugan 1975b) have been studied. Different species of the same genus show similarity in develop-ment pattern and differ mainly in the duration of different stages of their life cycles which in turn is influenced by the environmental temperature.

The number of instars in *Daphnia carinata* increases from nine at 35 ^{0}C to sixteen at 15 ^{0}C (Venkatraman and Job 1980) and the duration of an instar from twenty four hours at 35 ^{0}C to 125 hours at 13 ^{0}C. The shorter development time in the tropics may be viewed as a mechanism to build up the population before unfavourable environmental conditions set in. The only report on the biology of a rotifer, *Brachionus patulus*, is by Sarma (1988).

Jana and Pal (1985a,b) have studied the effect of different culture media on the relative growth and egg production in *Daphnia carinata* and *Moina micrura*. They found that the growth rate was highest in a medium containing organic subs-tances like *Madhuca indica* oilcake. The population growth in most media exhibits an unimodal curve.

The general trend in Indian studies has been towards short term studies as a result of which various changes in the ecosystem cannot be followed over a period of time so as to be of predictive value. A holistic approach to understand the func-tioning of the ecosystem and the various ecological processes has been lacking as workers have concentrated on isolated components. The rivers which are the life line of the country are yet to be studied and majority of the limnological work has been confined to smaller ponds and lakes mainly due to resource constraints.

POPULATION DYNAMICS

The seasonality is not universally the same, nor is it the same for all the groups of zooplankton. The classical bimodal pattern of seasonal succession most commonly found in the temperate zone, is not evident in the tropics.

The population dynamics of planktonic rotifers is complex and genera-lisations can't be made. In the temperate regions perennial species occur that exhi-bit maxima in early summer and the cold stenothermal species develop maxima in winter and early spring. This seasonal succession is clearlty guided by temperature, food quality and quantity (Wetzel 1983). Cladocerans differ amongst species in their population dynamics. Some species are perennial and tide over winter in low population densities as parthenogenetic females and they exhibit one or more irregular maxima. The aestival species exhibit have a distinct diapause and develop maxima in the spring and summer. The life cycle of freshwater cyclopoid copepods has a period of growth followed by a period of diapause induced by changes in temperature, photoperiod, reduced food availability, low dissolved oxygen levels and increase in predation pressure. In temperate regions diapause varies from lake to lake whereas in the tropics resting stages have not been observed.

The zooplankton standing crop in most Indian waters shows a cyclic pattern in its seasonal succession with two or more peaks. The peak populations have been recorded at different times of the year in different water bodies. In the Kashmir lakes, rotifers peaked in September and copepods were maximum in January and April (Kundangar and Zutshi 1985).

In the subtropical Kumaon lakes, Sharma and Pant (1984) report a bimodal pattern. In the Nainital lake the summer peak was shared by rotifers and copepods and the autumn peak comprised exclusively of copepods.

In a freshwater swamp in Bihar (Nasar 1983), rotifers exhibited two peaks, one in December dominated by *Brachionus quadridentatus, Keratella tropica* and *Filinia monstrosa,* and the other in June dominated by *Brachionus angularis* and *Asplachna sp.* Cladocera peaked in December and were dominated by *Simocephalus elizabethae* and *Daphnia pulex.* Copepod peaks were observed in December and August, both dominated by *Diaptomus blanci.* George (1969) reported rotifer peaks in April and February and Cladoceran peaks from January to April.

There are also a few studies of population dynamics of individual species. Sharma and Pant (1987) have reported that *Daphnia longispina* has a bimodal growth curve with maxima in summer and autumn. During the May peak, birth rates and growth rates remain high and the death rate remains low. The September peak coincides with the highest birth, growth and death rates. They accounted these high rate by the death of juveniles which fell easy prey to fry and finger-lings. Murugan (1989) studied the population dynamics of *Moina micrura* in a eutrophic pond. The population maxima in March was found to be due to increase in mean brood size, rise in water temperature and reduction in egg development time.

DIURNAL MIGRATIONS

Most of the zooplankton exhibit marked diurnal migration through the water column in response to light regimes. Most of the species migrate upwards to more superficial regions as darkness approaches and return to the deeper areas at dawn. Its adaptive significance lies possibly in avoidance of predation by fish which are often visual feeders.

The investigation of diel migration has received some attention of Indian workers (Michael 1964, George 1961, Saha et al. 1971, Saxena and Bhaskaran 1981, Verma 1967, Nasar 1978, Kumar et al. 1978, Krishnamurthy and Visweshwara 1965, Khan et al. 1970, Jana 1974, Expedith et al. 1989 and Dey and Lahon 1988). These authors have reported the concentration of zooplankton in the surface layers of water during night and their descent to the deeper strata during the daytime. The migration is shown to be influenced by the photoperiod and the seasonal changes have been reported in the pattern of vertical migration.

GENERAL ECOLOGICAL STUDIES

The ecology of zooplankton in the tropics and subtropics is poorly known in spite of a great increase in studies on zooplankton in the tropics.

PRODUCTION

The production rates of specific population of zooplankton refer to the net productivity or the sum of all biomass produced in growth, including gametes and exuviae of moulting minus maintenance losses from respiration and and excretion. The manner in which production rates of a specific population are estimated depends upon the particular life cycle, reproductive characteristics and generation times (Wetzel 1983). A complete review of zooplankton production studies has been made as a part of IBP synthesis by Morgan et al. (1980). The data on the tropical aquatic systems is scanty. In general, positive correlation exists between the rates of production of zooplankton and phytoplankton. Much of the autotrophic production is not utilized by herbivorous zooplankton, but instead enters the detrital pathway. Efficiency of assimilation of ingested food is higher in juvenile stages than in the adults.

In India zooplanktonic production has received very little attention. Vass and Zutshi (1983) who computed zooplankton biomass in Dal lake in Kashmir reported that on an yearly basis, the average biomass is 4.1 g dry wt/m2. However production rates have not been estimated in any study.

FOOD AND FEEDING RELATIONSHIPS

Zooplankton can be grouped into herbivores which graze on phytoplankton and carnivores which predate on other zooplankton. The herbivores are usually filter feeders whereas the carnivores are raptorial feeders. The productivity of filter feeding zooplankton is usually higher than that of predacious zooplankton.

The feeding behaviour of cladocera and copepods has been investigated intensively in the north temperate water bodies. These studies are devoted mainly to the effectiveness of food ingestion and assimilation by these animals and also to the effect of consumption on the food population. Filtration of water to remove particulate organic matter is the dominant mode by which most cladocerans collect and ingest food. In terms of energy or mass flow, ingestion represents the greatest of all interactions between an animal and its environment (Peters 1984). The feeding studies besides giving qualitative and quantitative information about zooplank-ton and phytoplankton, are also useful in understanding the energy flow, mineral cycling and competition among various zooplankton. The feeding studies can be used also to predict (a) the future density and composition of phytoplankton community or (b) the amount of zooplankton production available to fish, leading in turn to the prediction about fish stocks.

Feeding rate or ingestion rate is a measure of mass or energy flow into the animal expressed as cells ingested per individual per unit time. Grazing rate or filtration rate is the volume of food suspension from which a zooplankton would have to remove all cells in a limited time to provide its measured ingestion rate. The feeding rate is a product of grazing rate and food concentration.

Feeding and grazing methods have been reviewed by Peters (1984). He has discussed the pros and cons of the various methods, conditions for usage and factors affecting the feeding rates. A number of studies indicate that the feeding rate stabilises or decreases as the concentration of the food particles increases. Feeding rate is constant above the incipient limiting concentration of food. Above this concentration, the rate of movement of the thoracic appendages that collect the food decreases (Wetzel 1983).

Filtering rates have been found to increase with increasing body length and temperature till a given point after which it decreases. A positive correlation exists between the body size and the size of the particles ingested. A large amount of literature exists on the kind of food, effect of various environmental factors on feeding rates, selectivity of feeding and assimilation efficiencies of various various zooplankton.

Among all cladocera, *Daphnia* species have been the focus of most investigations on the feeding and nutrition. *Daphnia* has an important role in lake ecosystem and if it is free from predation, it is instrumental in controlling phytoplankton biomass by grazing. Peak *Daphnia* biomasses cause predictable clear water phases during seasonal succession in many lakes (Lampert et al. 1986). The vast literature on feeding by *Daphnia* in the temperate zones covering all the aspects such as kind of food, filtering rate in different species, factors affecting filtering rates and consumption of blue green algae, has been reviewed by Lampert (1987).

In India very few studies on the food and feeding rates of zooplankton have been done. Some general observations on food and feeding habits of a few crustacea were made by Khan (1984) and Vasisht and Sharma (1986). Singh (1972) studied food and feeding of *Rhinediaptomus indicus*, a herbivore zooplankton. He demonstrated increased feeding at night on the basis of diurnal variation of food in the gut. Royan(1976) made studies on the gut contents of *Leptoscheriella maduraiensis*, a branchiopod .

ZOOPLANKTON AND POLLUTION

Pollution can be of two major types, one when the pollutant is toxic and results in the mortality of the organisms with only the tolerant species surviving, and the other when the pollutant causes nutrient enrichment leading to the development of phytoplankton bloom, change in predator abundances and other physico-chemical conditions. There would be a consequent change in zooplankton composition, biomass and life strategies. The total zooplankton biomass increases with lake productivity and is accompanied both by species and group replacements within the Cladocera and Copepoda - the macrozooplankton; and there is an increase in microzooplankton population consisting of rotifers and ciliate protozoa.

With the increase in trophic levels, the importance of planktivorous fish increases. Since they are size selective predators, the larger herbivorous Cladocerans fall prey to them. The impact of cyclopoid predation in eutrophic lakes has been demonstrated to be more important than fish predation (Gliwicz et al. 1978). Inter- and intraspecific competition between different sized herbivores over available size range of food (phytoplankton), may alter the size and structure of zooplankton communities. Inhibition of filtering rates through mechanical interference associated with filamentous and colonial blue green algae, as well as chemical antagonism due to the toxic substances produced by them can decrease the abundance of zooplankton, particularly Cladocerans in eutrophic lakes. The microzooplankton have a greater dependence on bacteria as a food source. The maintenance of these populations requires bacterial concentration which are found in eutrophic water bodies only. Thus microzooplankton in general and ciliated protozoans in particular display a strong positive relationship with increasing trophic state (Bays and Crisman 1983).

In India some studies have been made to correlate the zooplankton abundance to the trophic status of the water bodies. However, to use zooplankton as bioindicators of water pollution, the most suitable zooplankton species need to be identified. This requires detailed taxonomic studies and the pollutants involved along with the biotic and abiotic components of the ecosystem affected are to be taken into account. A review of the studies on zooplankton as indicators of water quality shows rotifers to be the common indicators of eutrophication (Arora 1966, Mahajan 1981, Saxena 1987). Arora (1966) pointed out that *Brachionus angularis, Brachionus calyciflorus, Filinia longiseta, Filinia terminalis* are forms occurring predominantly in polluted waters. Billgrami et. al. (1985) reported that *Keratella cochlearis, Brachionus plicatilis, and Filinia sp* are common rotifer indicators. Sampath et al. (1979) characterised the Cauvery river into saprobic and polysaprobic zones at sewage and distillery outfalls on the basis of a pronounced *Rotatoria rotaria* population. *Monostyla hamata* and *Monostyla bulla* were found in clean water zone while *Brachionus angularis* and *Brachionus calyciflorus* were observed in mildly polluted zones.

The use of zooplankton as bioassays in pollution studies has been practiced widely throughout the world. *Daphnia magna* has been most commonly used in these studies. In India also some studies have been made. Khangarot et al. (1987, 1989) have studied toxicity of various metals to *Daphnia magna*. Rao and Sarma (1986, 1990) have reoported the interaction of food density and DDT concentration on the population dynamics and structure of a rotifer *Brachionus patulus*. The effect of changes in food level and toxicity of cadmium to cladoceran species has been studied by Chandini (1988, 1989). Toxicity of petroleum pollutants (Panigrahi et al. 1989), endosulfan and carbaryl (Krishna and Chockalingam 1989) on various zooplankton has also been studied.

BIOMANIPULATION

The concept of biomanipulation is based on experimental manipulation of planktonic communities which can help restore eutrophic lakes. The various biomanipulation studies have been reviewed by Gophen (1990) and Shapiro (1990). Eutrophication is not just a simple interaction between the nutrients and algae but leads to a complex change in the whole ecosystem and in most cases the results are not well understood. The success of biomanipulation depends upon a large number of factors which have to be well understood to use food web controls:

1. The nutrient and other physical conditions causing abundance of inedible blue green and green algae, their toxicity and correlations between different types of blue greens,

2. Various interactions within the zooplankton community (like competition) and with organisms at a higher trophic levels (e.g., predation),

3. The upper limit of the external and internal phosphorous load which should not exceed if foods web manipulations are to be successful,

4. Various ways to maintain an optimum density of zooplanktivorous fish which also control other invertebrate predators of zooplankton, and

5. Alternative approaches to increase herbivorous zooplankton, viz. creation of various kinds of refuges safe from predators like a macrophyte refuge.

FIELD STUDIES

An exploratory survey was made of several temporary and permanent ponds in and around Delhi to list the common zooplankton taxa occurring soon after the rainy season and to examine these shallow water bodies for basic physico-chemical characteristics.

STUDY AREA

Delhi (28^0 12'-28^0 53' N latitude and 76^0 50'-77^0 23'E longitude), lies on the west bank of river Yamuna, although a major part of this metropolitan city also sprawls on the east bank (Fig. 1). Climatically Delhi lies in the subtropical semiarid zone of northern India. It has an extreme climate with a severe summer and relatively mild winter. The maximum mean monthly temperature approaches 45.2 ^{0}C during the summer (May-June) and the monthly mean minimum during the winter is 7.5^{0}C. The average annual rainfall is 600 mm and most of it falls in the monsoon season (July to September). There is a large variation in rainfall in different years; it ranges from less than 300 mm to above 1200 mm.

All waterbodies, both lotic and lentic, in and around Delhi are in various stages of eutrophication as they receive domestic waste and urban runoff. Most of the standing waterbodies are stagnant pools in roadside depressions which get filled with drainage water as well as rain water. The average depth of these waterbodies is less than one meter.

SAMPLING SITES

Five permanent and four temporary ponds were sampled during the study. Sites 1 to 5 were permanent ponds and sites 6 to 9 were temporary. Their location and salient features are as follows:

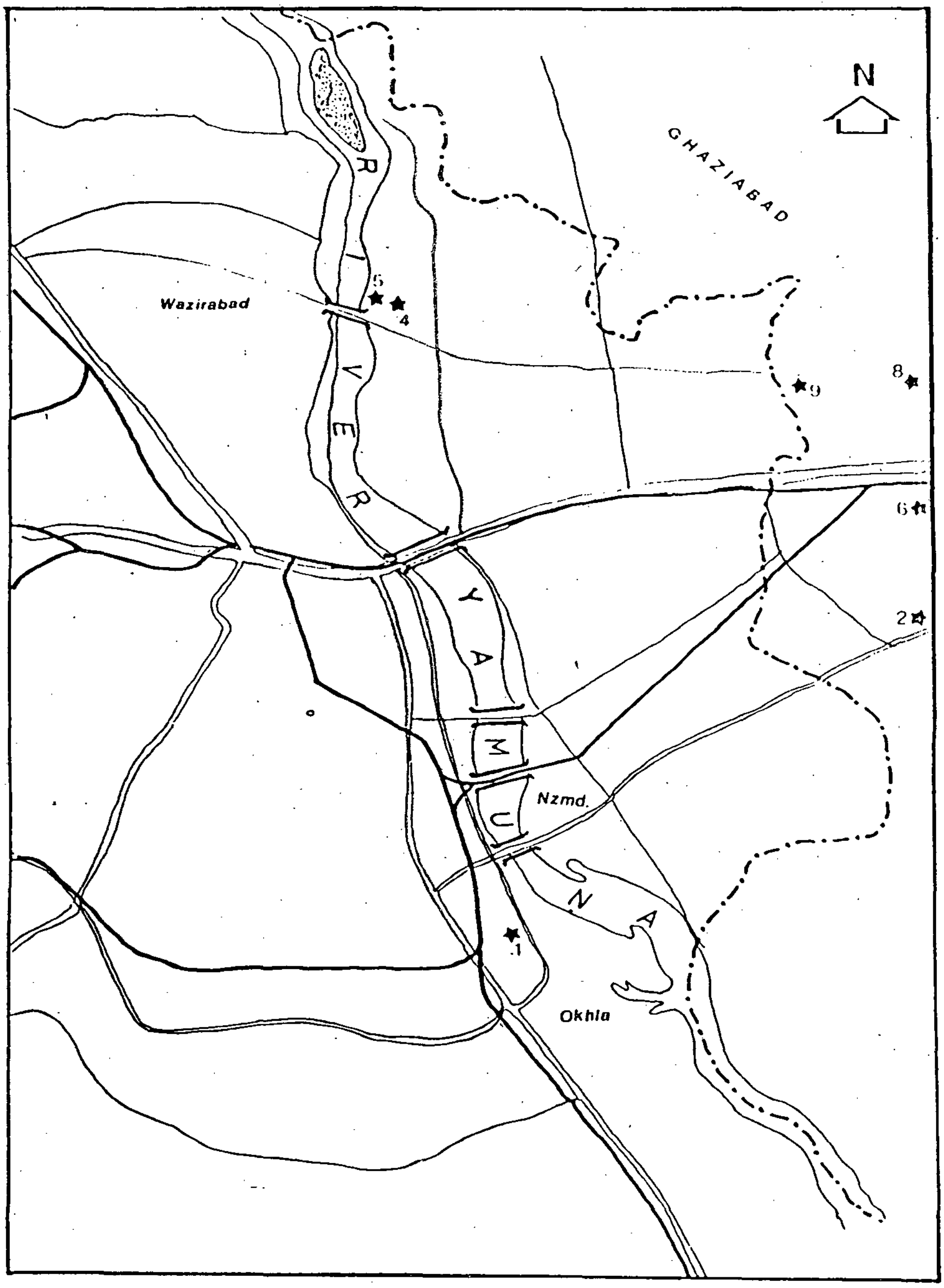

Fig. 1. Map of a part of Delhi showing some of the sampling sites marked *. The numbers correspond to those mentioned in the text.

Site 1: This shallow pond is situated on the road side near the Nizamuddin Bridge off the Ring road. It received domestic waste water from the adjacent slums. The pond was covered by a dense *Microcystis* bloom.

Site 2: This pond is located on the road side near the turn from Delhi-Dadri road towards Mohan Nagar, and isclose to Vaishali housing colony. The pond water was very clear. It was more than one meter deep on its southeastern side and very shallow on northern side. There was no apparent phytoplankton growth and only a few very small (1-2 um) chlorococcales could be observed. A few patches of *Lemna* and *Spirodela* also occurred. The pond received drainage water and runoff from the surrounding fields.

This pond, hereinafter referred to as Vaishali pond, was sampled more frequently, and its water chemistry studied in more detail because of its certain interesting features.

Site 3: This large oxbow pond is at the far end of the bund, in the floodplain of river Hindon. The phytoplankton consisted of Chlorococcales. It was very rich in macrophytes, particularly lotus (*Nelumbo nucifera*), water hyacinth (*Eichhornia crassipes*), *Hydrilla verticillata, Ceratophyllum, Potamogeton, Vallisneria, Wolffia microscopica,* and *Spirodela polyrhiza*

Site 4: This pond is situated on the east bank of the river Yamuna on the rod leading to Sonia Vihar. It had a large stand of *Phragmites* and *Salvinia*.

Site 5: This pond is located near site 4, on the other side of the road. It often gets connected to the river. This pond is overgrown with aquatic macrophytes- *Salvinia molesta, Eichhornia crassipes* and *Vallisneria spiralis*

Site 6: This pond is situated about 1/2 km away from site 2. The water was dark in colour and it did not have any phytoplankton. A portion of the water body was covered with *Eichhornia crassipes.*

Site 7: This pond is situated opposite to the Hindon Air Base. It was receiving domestic wastewater from the surrounding village, and was like a sewage lagoon. There was no phyto-plankton or macrophyte growth.

Site 8: This pond situated near Pasaunda village had abundant growth of *Volvox* which imparted a green colour to the water. Some members of Euglenophyceae were also noted. There was no macrophyte growth.

Site 9: This pond is situated on the Wazirabad-Ghaziabad road near DLF Tower. There was no macrophyte growth. *Volvox* and some other small green algae were observed.

METHODS OF SAMPLING

Water samples were collected by hand from the surface only in one litre polythene bottles. Water samples were stored in the laboratory in a refrigerator at about 10 ^{0}C until further analysis.

Physico-chemical Parameters

DO, temperature, pH, conductivity of the water were measured in the field on-site with the help of portable probes (Schott Gerate: pH CG 818, temperature and DO: CG 867 and conductivity: CG 857).

Methods described by APHA (1985), Fresenius et al. (1988) and Trivedi and Goel (1984) were followed for the chemical analysis. Nitrate - nitrogen was estimated spectrophotometrically following sodium salicylate reduction method. Inorganic phosphorous was assessed spectrophotometrically by the stannous-molybdate method. Total hardness, calcium and magnesium were determined complexometrically by the EDTA titration method. Chloride was estimated titrimetriaclly using silver nitrate. Sodium and potassium were determined by Atomic Absorption Spectrophotometer.

Zooplankton Estimation

Zooplankton were sampled by a plankton net having a mesh size of 10 um. It was hauled from bottom to top. The depth samples at site 2 (Vaishali pond) were collected using a sampler designed on the siphon mechanism. The quantitative samples ware carried in 250 ml polythene jars whereas other samples for zoolpankton culture were carried in large plastic jars filled with filtered pond water. The zooplankton were separated from larger invertebrate organisms under the binocular microscope and then preserved in 4 % sucrose-formalin solution.

For quantitative estimates, the samples were adjusted to known volumes and the organisms were counted in one ml subsample in a Sedgwick-Rafter cell using a binocular stereo-microscope.

RESULTS

The data in Table 1 show that various ponds surveyed during September 1990 did not differ much in their water temperature (28 to 30 ^{0}C) and pH (6.43 - 7.70) but exhibited large variation in the dissolved oxygen (DO) content and conductivity. The differences in the DO content (measured in early morning hours only) may be due to the differences in the level of organic pollution and the development of algal blooms. High conductivity of water (4500 us and 5300 us) in two permanent ponds at sites 2 and 3 could be attributed to high salinity of soils in their catchment as evident from thick white salt encrustations on the soil surface.

The distribution of various zooplankton taxa in the sampled ponds is given in Table 2. Copepoda is represented by only one genus *Mesocyclops* which occurs abundantly in all water bodies. Among the eight taxa of Rotifera, *Brachionus* is the most common genus, followed by *Keratella* and *Monostyla*.

Table 1. Physical and chemical characteristics of the field sites during September 1990.

Site	Temperature ^0C	pH	Conductivity uS	Diss. O_2 mg/L
1	28.7	6.43	868	0.7
2	28.3	7.52	4500	1.9
3	28.1	7.31	5300	11.2
4	30.1	6.70	367	10.7
5	29.4	6.64	371	4.9
6	28.4	6.75	1069	0.9
7	29.4	7.11	947	1.4
8	29.5	6.85	410	4.4
9	29.8	6.61	362	6.6

Table 2. Zooplankton recorded from different ponds around Delhi during September 1990

Taxa	Sites 1	2	3	4	5	6	7	8	9
Cladocera									
Daphnia sp.	-	-	++	-	-	-	-	+	++
Daphnia magna	-	+++	-	-	-	-	-	-	-
Ceriodaphnia sp.	++	-	++	+	-	-	-	-	-
Moina sp.	+	-	+	-	-	-	-	-	-
Chydorus sp.	+	-	+	-	-	-	-	+	-
Alona sp.	+	-	+	-	-	-	-	-	-
Copepoda									
Mesocyclops sp.	++	++	++	++	+	+	++	++	+
Rotifera									
Brachionus sp.	++	-	+	+	+	++	-	-	+
B. angularis	-	-	-	-	-	-	-	+	+
B. quadridentatus	-	-	-	-	-	-	-	+	+
Keratella sp.	+	-	-	-	-	++	++	++	+
Monostyla sp.	+	-	-	+	-	+	+	+	+
Filinia sp.	-	-	+	-	-	+	-	-	-
Platyias sp.	-	-	-	-	-	-	-	+	+
Hexarthra sp.	-	-	-	-	-	-	+	-	-
Ostracoda	-	++	++	+	-	-	-	-	-

Table 3. Density of zooplankton (no. per liter) in Vaishali pond during March and April 1991

Sampling Point	Organisms	17 March 1991		4 April 1991	
		Surface	Bottom	Surface	Bottom
	Daphnia	213	136	6	8
A	*Mesocyclops*	220	240	5	30
	Daphnia	703	240	60	2
B	*Mesocyclops*	123	0	100	24
	Daphnia	552	20	10	0
C	*Mesocyclops*	228	10	5	12
	Daphnia	190	-	6	-
D	*Mesocyclops*	57	-	5	-

- denotes that the water was very shallow and hence, only one sample was taken.

Table 4. Physicochemical characteristics of water in Vaishali pond

Sampling points / Parameters	17 March 1991 A	B	C	D	4 April 1991 A	B	C	D
Conductivity (mS)	3.89	3.85	3.85	3.85	4.14	4.25	4.24	4.23
DO (mg/L)	4.5	6.7	6.8	6.0	1.9	3.6	2.8	3.1
pH	6.66	6.85	6.75	7.50	7.91	6.96	7.46	7.51
Temperature oC	20.0	19.9	20.8	20.5	24.3	25.1	25.3	25.3
Tot. Hardness (mg/L)	654	662	662	662	720	710	730	720
Calcium (mg/L)	326	284	144	144	222	220	211	207
Magnesium (mg/L)	328	284	144	144	40	39	49	49
Chlorides (mg/L)	220	217	216	219	241	250	254	237
Potassium (ug/L)	41.7	38.8	35.8	33.7	30.5	31.2	33.6	33.1
Sodium (ug/L)	799	781	836	695	690	685	710	709
NO_3-N (ug/L)	3	3	3	3	1.7	1.7	1.7	1.7
PO_4-P (mg/L)	0.23	0.24	0.16	0.37	0.1	0.1	0.08	0.1

Date of Sampling

Ostracods were found only in some permanent ponds. Cladocera, represented by six taxa, were relatively less abundant. *Daphnia* and *Ceriodaphnia* were more common taxa.

Interestingly, the Vaishali Pond (site 2) had a very dense population of *Daphnia magna* Straus (Table 3) which was identified by its post-abdominal feature. It needs to be noted here that this species is common in temperate regions though it also occurs in subtropics (C.H. Fernando, personal communication). *Daphnia magna* has not been reported from India since its collection by Brehm (1936, 1953) from Kashmir and Bijapur (see Michael and Sharma 1988). Thus, the present survey yielded a new record for Delhi.

In view of the interesting find of *D. magna* and thefact that it was selected for feeding experiments, the water in the pond was analysed in some detail again in March and April 1991. The data (Table 4) show that the water had relatively low nitrate-N and phosphate-P concentration whereas it was rich in calcium, magnesium, sodium and potassium. Towards April, the free-floating duckweed *Lemna paucicostata* developed rapidly and the zooplankton density declined sharply (Table 3). The water analysis showed an increase in temperature, pH, conductivity and total hardness whereas sodium, potassium, nitrogen and phosphorus concentrations decreased to a small extent. The decline in zooplankton population appeared to be influenced more by the growth of duckweeds than the changes in water chemistry.

LABORATORY STUDIES

Some preliminary experiments were carried out in the laboratory on the feeding of *Daphnia magna,* with a view to standardise the methodology and to examine the effects of food concentration, animal size and density on the filtering rate of *Daphnia magna.* This involved the culturing of food organism, *Chlorella,* (Chlorophyceae), culturing of *Daphnia magna,* preparation of algal suspensions with different food density, selection of appropriate sized organisms and feeding trials.

ALGAL CULTURES

Chlorella was grown in inorganic media. Two different media, Chu 10 (Chu 1942) and KL (Kuhl-Lorenzon 1964), whose composition is given below, were tried. *Chlorella* grew better in KL medium, and hence this was finally used to culture it.

Composition of Chu-10 and KL media for algal culture.

Salt (mg/L)	Chu 10	KL
K_2HPO_4	10	-
KH_2PO_4	-	900
KNO_3	-	1000
Na_2HPO_4	-	280
Na_2CO_3	20	-
$MgSO_4.7H_2O$	25	250
$CaCl_2.H_2O$	-	25
$CaNO_3.4H_2O$	40	-
pH	6.5 - 7	6.8

Trace elements (ug/L)	Chu 10	KL
H_3BO_4	-	61
Na_2-EDTA	-	9300
$FeCl_3.6H_2O$	800	-
$FeSO_4.7H_2O$	-	6900
$CuSO_4.5H_2O$	-	3
$(NH_4)_2Mo_7O_4$	-	12
$MnSO_4$	-	169
$ZnSO_4$	-	287

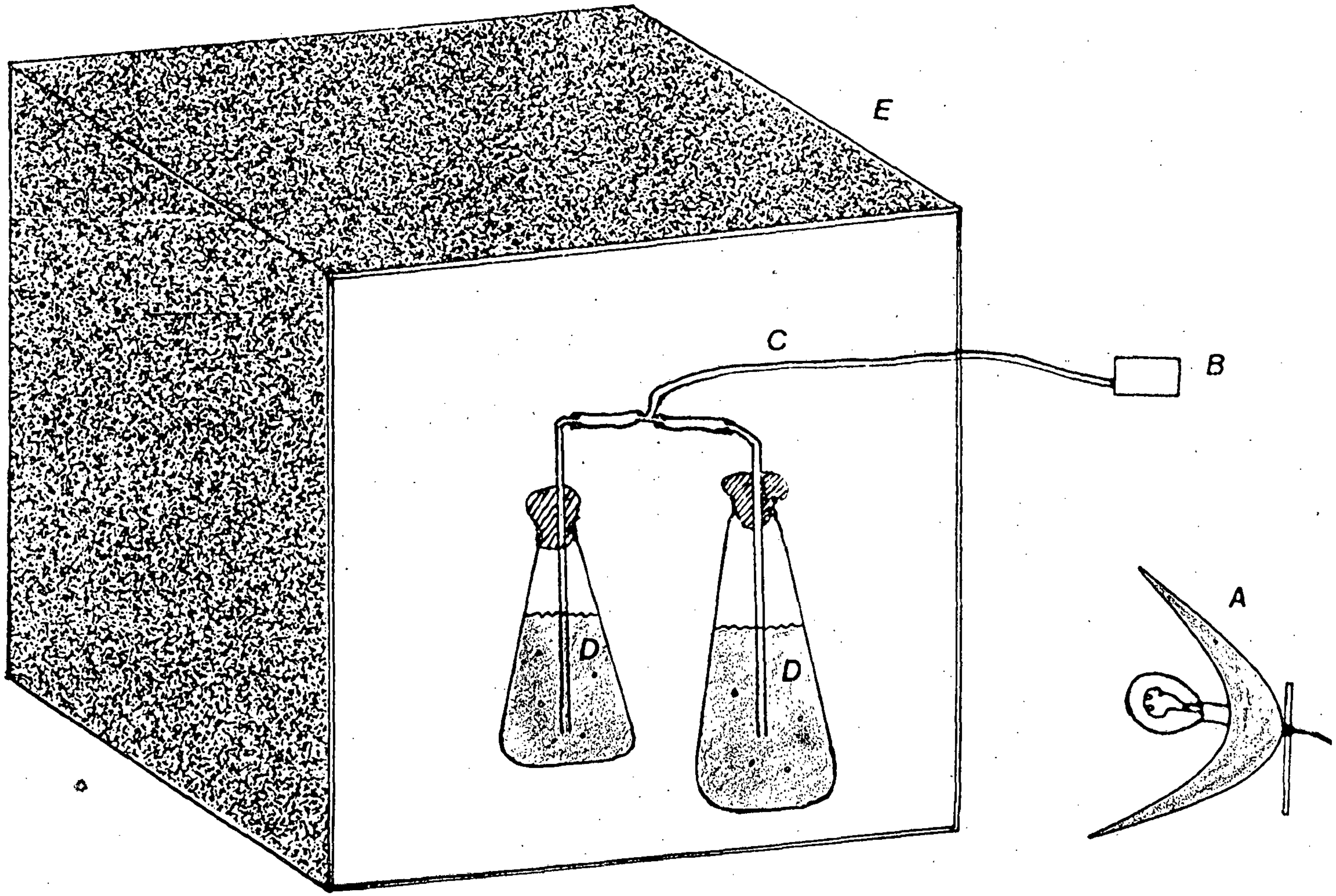

Fig. 2. Chamber for culturing algae.

A - Light source, B - Aerator pump, C - Silicon tube, D - Algal culture, and E - Cardboard chamber lined inside with aluminium foil

For culturing algae, one and two litre conical flasks were used. The culture assembly consisted of a conical flask with a glass capillary tube inserted through the cotton plug for aeration. Silicon tubing was used to connect the capillary tube to the areator and a cotton air filter was inserted in the middle to stop the passage of particulates into the medium. The whole apparatus, along with the medium minus the aerator, was autoclaved at 1.5 kg/cm^2 for 15 minutes.

Small cardboard boxes were used to fabricate a culture chamber (Fig. 2). The boxes were lined from inside with aluminium foil and illumination was provided by a 60 Watt incandescent lamp from outside. *Chlorella* grew very well at room temperature of 20 to 30 ^{0}C.

Subculturing was done every third day under sterile condition.

ZOOPLANKTON CULTURES

Daphnia magna was grown in glass aquaria in dechlorinated tap water. Some of them were cultured in 250 ml and 500 ml beakers also. About 15 individuals were placed in a 250 ml beaker and 25 in 500 ml beakers. Unicellular algae *Chlorella sp.* (1-3 um) were added as food. These animals were kept at room temperature (20 to 25 ^{0}C) throughout the duration of the study. When the temperature increased above 25-28 ^{0}C, the animals were kept in an air conditionded room maintained at around 20 ^{0}C. They were kept in diffused light and the culture was aerated every day for two to three hours. The organisms were subcultured weekly. The organisms started growing to smaller size when dechlorinated water with very low conductivity was used. To rectify this pond water filtered through Whatman filter paper no. 1 was used. It yielded larger sized animals.

FEEDING EXPERIMENTS

The feeding experiments involve the following steps.

1. Preparation of algal suspension

One litre algal culture was centrifuged at 3000 r.p.m. for ten minutes and all the cells were harvested and resuspended in 25 ml of fresh sterile medium. A standard suspension of algae thus prepared was used to prepare differnt concentrations of food by dilution with dechlorinated tap water.

2. Preparation of organisms

The organisms were poured in a Petri dish. A lamp placed near the corner of the dish was used to attract these organisms. They were separated under a stereo microscope using a dropper and fine brush. These organisms were starved for about 30 minutes before being transferred to the experimental food concentration.

3. Feeding trials

For feeding experiments, the cell count method (cf. Peters 1984) was followed. Algal suspensions of desired food concentration (no. of cells per ml) were prepared in 500-ml beakers. Several replicates of each food density were taken. A known number of similar sized organisms were transferred to each beaker. Precaution was taken not to add any water to these beakers.

The beakers were wrapped with brown paper and covered from top to create darkness so that the algal cells may not grow in number. They were left undisturbed for two hours for feeding by the organisms. For each experiment controls sets with the algal suspension without the animals were also taken. All experiments were made in the laboratory where the water temperature during the feeding varied between 24.5 and 24.8 ^{0} C.

4. Fixing of organisms

After feeding, the animals from each beaker were seperated and fixed in sucrose formalin mixture. The body length of these organisms was measured using an ocular micrometer.

5. Counting of cells.

The cell density was measured before and after the exposure for required time. The suspensions were stirred thoroughly and three to four drops from each beaker were counted in a haemocytometer. All the four hundred squares were counted.

6. Calculation of filtering rates

The filtering rates were calculated using the Gauld's equation :

$$G = V \cdot (\ln Co - \ln Ct) / t N$$

where, G = Filtering rate in ml / animal / unit time.

V = Volume of the suspension, ml.

t = Length of time the animals were allowed to feed, hr.

N = Number of amimals in the solution.

Co = Initial cell concentration, number per ml

Ct = Final cell concentration, number per ml

The feeding rate (F) is calculated as the product of filtering rate and food concentration (G x Co).

EXPERIMENTAL CONDITIONS

Following three experiments were conducted:

a. **Effect of Food Concentration:** Five food density levels ranging from 4×10^5 to 20×10^5 were taken, and the number of organisms was kept constant. The food density could not be kept constant in all experiments as dilutions were made from different algal concentrates.

b. **Effect of Crowding:** To study the effect of crowding of feeding organisms, two experiments were made on different dates with 20 and 35 organisms per 250 ml algal suspension.

c. **Effect of Organism Size:** In another set of experiment, organisms measuring only one mm in body length were used in place of normal 2-mm sized organisms.

RESULTS

The data on filtering rates in the three experiments are given in Fig. 3 and those on the feeding rate are given in Fig. 4.

In experiment a, the filtering rate increased from a food concentration of 5.5×10^5 to 9.5×10^5 cells/ml and decreased later upto a density of 12.5×10^5 cells/ml. However, it increased again at a higher density 16.5×10^5 cells/ml. The feeding rate increased steadily with increasing food concentration.

In experiment b, with a higher density of organisms, both the filtering and feeding rates were very much lowered. The filtering rate increase from 4.5×10^5 to 8.5×10^5 cells/ml, and decreased thereafter at higher food concentration.

In experiment c, the smaller sized organisms filtered the food at a lower rate and the overall feeding rates remained low. The filtering rate decreased from 5×10^5 to 9×10^5 cells/ml, increased at 15.9×10^5 cell/ml density and again declined at a higher density. The feeding rate increased only upto a food concentration of 16×10^5 cell/ml.

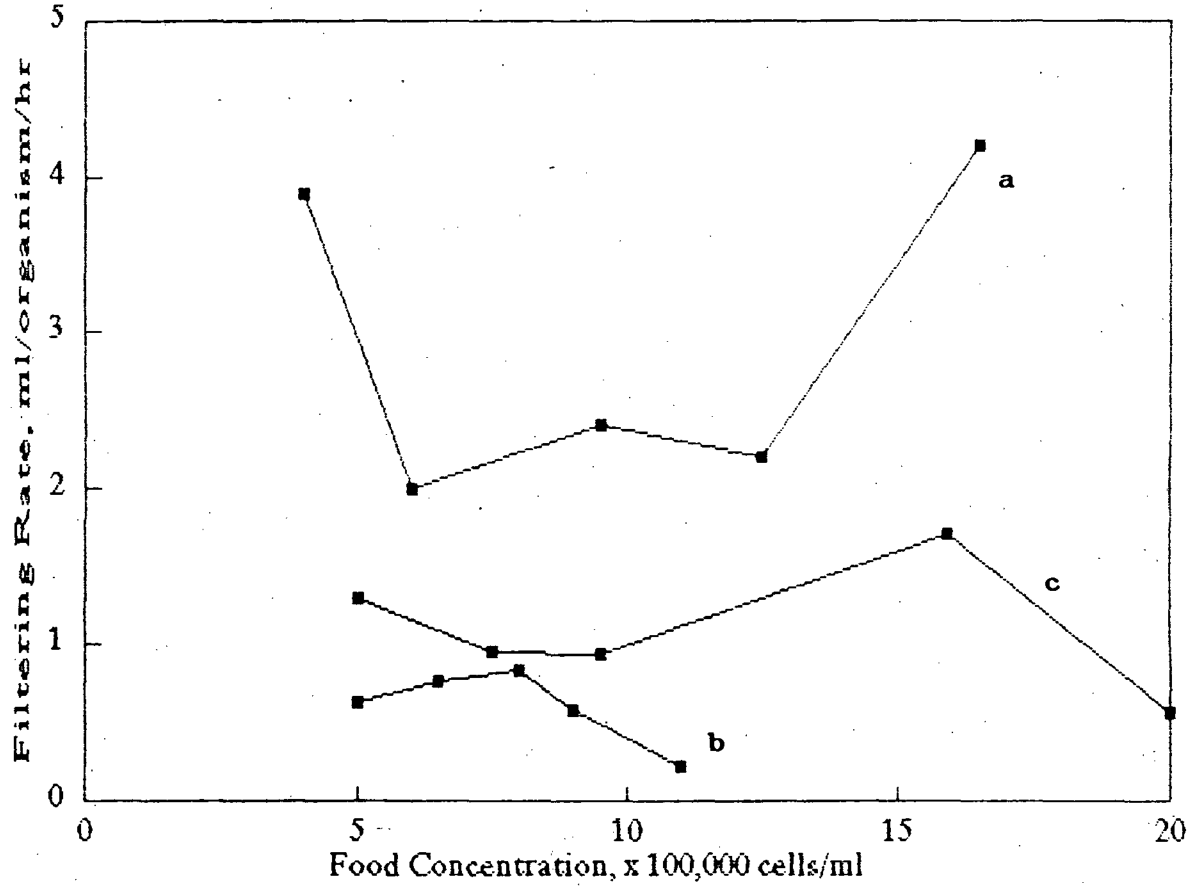

Fig. 3. Effect of food concentration on filtering rate of Daphnia

a - 20 large organisms per 250 ml;

b - 20 small organisms per 250 ml,

c - 35 large organisms per 250 ml

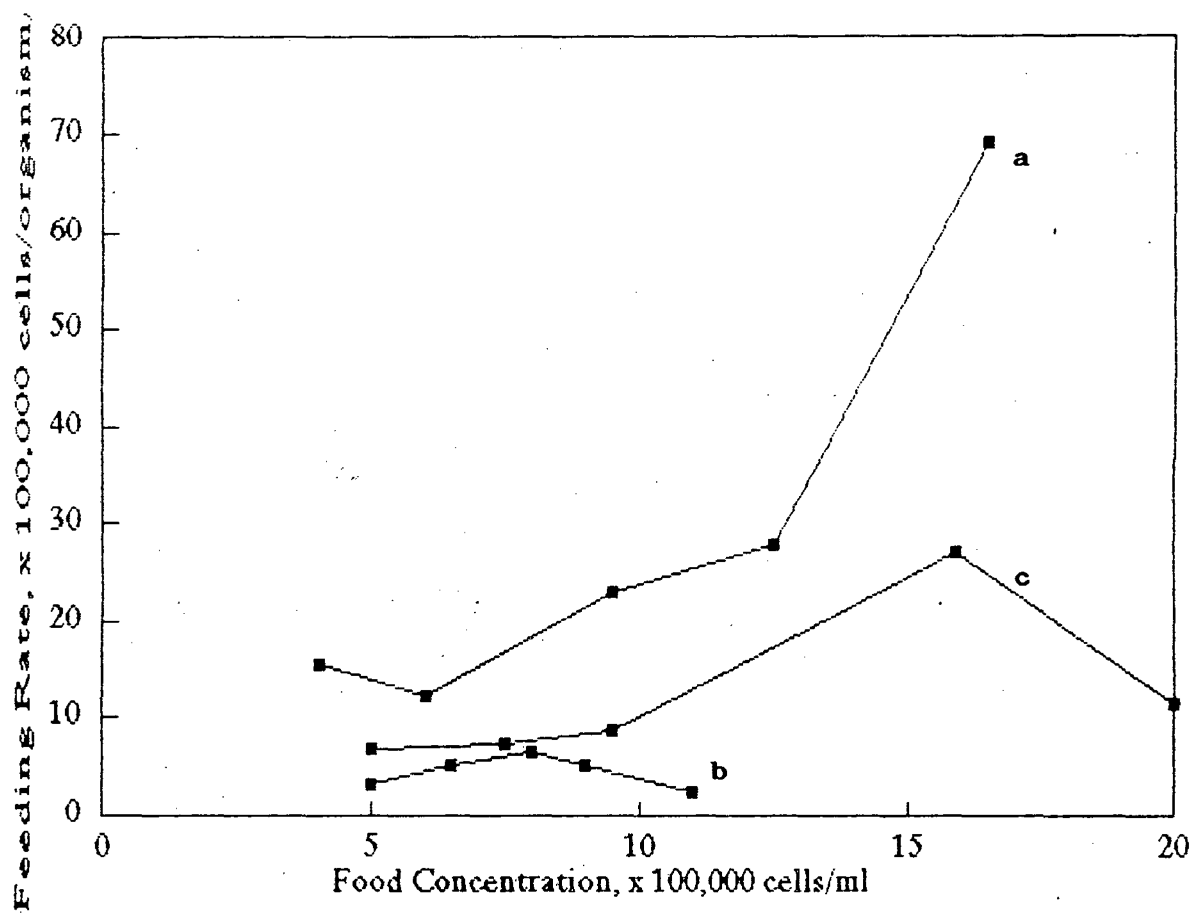

Fig. 4. Effect of food concentration on the feeding rate of Daphnia
a - 20 large organisms, b - 20 small organisms,
c - 35 large organisms

DISCUSSION

Numerous feeding studies on zooplankton, particularly Daphnia have shown that the ingestion rate increases with increasing food concentration until an incipient limiting level (ILL) is reached (Mcmahon & Rigler 1965, 1967, Kersting & Leeuw 1976, and Hayward & Gallup 1976). At this point the animals pass from a concentration at which feeding rate is constant to one in which filtering rate is constant. This change occurs normally between 1 and 10 ppm of food (Peters 1984). At densities above the ILL the animals control the ingestion rate by rejecting extra food from the food groove with the abdominal claw (Porter et al. 1982). The filtering rate decreases above the ILL because the high concentration of food hinders the movement of the appendages that collect the food.

The ingestion and filtering rates are usually dependent upn the body size (Burns & Rigler 1967, De Mott 1982). An increase of the filtering rate is expected with the square of the body length which is proportional to the area of filtering limbs. Larger particles are rejected by smaller organisms which have finer filters to retain efficiently smaller particles.

The results obtained in the present study do not indicate the standard curve though a lowering in the filtering rate is observed with the smaller size and at lower densities of the organisms. Since the experiments could not be made under controlled environments, a number of other factors could affect the result as discussed in detail by Lampert (1987).

One of the major limitations of the present study could be the choice of method used. Cell counting method is the oldest method for estimating grazing and ingestion rates. It is based on the observed changes in the number of cells counted before and after a suitable period of exposure to feeding animals. It is a less expensive, but time consuming method which is useful to study feeding rates in suspensions of mixed species and in natural waters. Problems arising from sedimention of algal cells during the feeding and in representative counts are partly circumvented by proper designing of the experiments.

Most of the recent feeding studies have, however, employed the radiotracer method which allows for a greater degree of accuracy, short exposure times, use of single animals and very low concentrations of food algae. This method can also be conveniently used for field studies. The main drawback of this method is that it cannot be used for long-term feeding and diel rhythm studies. It also requires very carefull handling. Further studies are planned to be made using this method.

SUMMARY

The objective of this study was to review the Indian literature on freshwater zooplankton and make some preliminary field and laboratory studies which would lead to long-term studies. An effort was made to standardise the methodology of culturing algae and zooplankton, and of feeding of zooplankton.

The review reveals many lacunae in our knowledge of freshwater zooplankton as most studies are descriptive and concerned only with the distribution of zooplankton in different water bodies. Studies on the ecological responses to various habitat factors and the interactions among different organisms, and their role in the ecosystem functioning are almost totally lacking. Their role in restoration of eutrophic water bodies is yet to be known.

A survey of a few permanent and temporary water bodies in and around Delhi, most of which are organically polluted, showed an abundance of the Rotifera. *Mesocyclops* (Copepoda) was found in all waterbodies. *Daphnia magna* found in one of the ponds is the first record of this species from this area.

Preliminary experiments on the filtering and feeding rates of Daphnia magna showed that in larger sized organisms (2mm long) the feeding rate increased with an increase in food concentration whereas in the smaller organisms, the filtering rate decreased. Crowding (upto 35 organisms per 250 ml volume) affected the filtering rate but the results did not indicate clear trend. The cell count method, one of the oldest and common methods used in feeding studies, does not yield satisfactory and reproducible results. Efforts will be made to improve the method and use the radiotracer method in future studies.

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