GENERAL CONSIDERATIONS

The earth's most valuable resource today is the diversity of its biological capital or the "Biodiversity". Biodiversity is a popular way of describing the diversity of life on earth: it includes all life forms and the ecosystems of which they are a part. It forms the foundation for sustainable development, constitutes the basis for the environmental health of our planet, and is a source of economic and ecological security for future generations. Yet biodiversity is under serious threat. Its ecological roots are neglected. Paving and populating, consuming and polluting, human activities are having a great adverse impact on our living nature. Human activities and - more fundamental - underlying structural factors and material processes in our society are causing species to vanish at an unequaled rate. We are losing biodiversity at an unprecedented rate. Biological resources are renewable resources, but they are being exploited at rates that exceed their sustainable yield. Human destruction of habitat, whether exploited for commercial or subsistence reasons, poses the greatest threat.

One such habitat under serious threat from human activities is the aquatic habitat. Many global conservation organizations, including RAMSAR convention, have identified the aquatic biodiversity to be the most threatened of all biodiversity. Despite its critical status worldwide, freshwater biodiversity has not gained the attention afforded to other elements of biodiversity (Master, 1991; Stein and Chipley, 1996; Olsen *et al.*, 1998; Pringle *et al.*, 2000). This inadequate attention has resulted in lack of knowledge and insufficient data. This is true for all freshwater ecosystems including, the rivers of India. Very little information exists on the biodiversity of the rivers and the factors regulating these. With the pollution of rivers and other water bodies growing at an unprecedented scale in India, the survival of hundreds of river-based species of plants and animals is gravely endangered today. Disposal of domestic and industrial effluents in rivers is one of the most serious threats to its biotic diversity (Gopal, 1997).

The banks of the river, riparian zone, can be seen as an extension of the river continuum, with an "energy driver association" acting upon the in-stream biology (Cummins, 1993). This zone influences several elements of the riverine habitat, including temperature, cover and food. Loss of vegetative cover and undercut banks can decrease the amount of suitable habitat, thereby reducing stream productivity and carrying capacity. Streambank vegetation also can be an important source of food for aquatic organisms. In addition to preventing pollution and sedimentation, the diverse vegetation of the riparian zones provide an environment in which a large variety of fauna is sustained. The densely packed vegetation is also home to numerous insects, birds and mammals, which help in regulating the riverine fauna as many of the aquatic organisms form their diet. Leaf litter from the riparian zone provides detritus to the detritivorous communities of the river. Thus the flora and fauna of the riparian zone has a profound influence on the riverine ecosystem.

During the present study flora as well as fauna of both the river and its riparian zone have been studied. The study area included River Vishwamitri and its riparian zone. Vishwamitri takes its origin from the hills of Pavagadh, which are approximately 45Km Northeast of Vadodara City. The Vishwamitri river is joined upstream by another rivulet called 'Surya' which also originates from Pavagadh hills. Downstream River Jambua joins the Vishwamitri river near Makarpura. The River then continues its course in southerly direction till it joins the Dhadhar River at Pingalvada, 24Km south of Vadodara.

The city of Vadodara has developed on the very banks of this river. Today, however, this River has lost its importance and has been reduced to a sewer. Continued disposal of domestic sewage into this river has changed the quality of the water from its origin to its end, thus affecting the various life forms living in it. Till date whatever few studies have been carried out were related to the algal flora of River Vishwamitri. Hence, a need was felt to carry out a composite study, enlisting the existing biodiversity, both the flora and the fauna, of the river as well as its riparian zone and identifying the dominant zooplankton community and further studying the community structure and seasonal factors affecting its dynamics

River Vishwamitri during the monsoon is in spate and the banks are flooded. After monsoon, the water level goes down, exposing the banks throughout. In the month of September the banks are muddy showing sparse vegetation. The permanent vegetation consists of the tree species. However, the riparian zone of River Vishwamitri had relatively poor tree diversity. Only eight tree species belonging to four different families were found during the present study. Four species of shrubs were located belonging to four different families. Nine species of climbers were also located, which belonged to five families. Herb species dominated the riparian vegetation. There were as many as 29 families of herbs represented by 76 species. *Cynodon dactylon*, a species of grass survives in spite of the flooding during the rainy season and forms the dominant community of mud flats. Five species of aquatic hydrophytes were also found in the River Vishwamitri. *Typha angustata* forms reed beds at many places in the River. *Potamogeton pectinatus*, *Utricularia* sp. and *Vallisneria spiralis* are emergent hydrophytes while *Hydrilla vercillata* is a submerged hydrophyte found in the aquatic zone of the River.

Amongst the aquatic fauna rotifers form the dominant component. Fifty-nine species belonging to 23 genera and 17 families have been recorded. Out of the 17 families, sixteen are Monogononts while only one family belongs to the order Digononta.

Three species of freshwater molluscans are found in the study area, each belonging to a different family. They occupy second trophic level in the food chain and are the chief source of food for birds such as herons, lapwings and sandpipers.

Three species of earthworms and one species of leech have been recorded from the loose and moist soil of the riparian zone. They form the food material for various birds and animals thus constituting an important link in the foodchain.

Arthropods are found to form the predominant group of terrestrial invertebrates in riparian zone of River Vishwamitri. Many species are semi-aquatic such that they spend only a part of their lives in the water. Additionally, arthropods also contributed to the zooplankton fauna of the River. Two species of copepods and nine species of cladocerans belonging to four different families were identified.

In the riparian zone insects are found to be the predominant group amongst the invertebrates. Fifty-four species of insects have been recorded; most of which are terrestrial. However, some aquatic species such as *Ranatra* and *Cybister* were also recorded. Larval forms of many terrestrial insects such as *Ephemera*, *Anopheles*, *Culex*, etc. are found in water. Fourteen species of spiders belonging to five families were also reported in the present study. The probable reasons for their diversity in riparian zone could be the presence of diverse microhabitats present in the riparian zone. Small depressions on the wet ground provides hiding place to the ground dwelling spiders (both ground hunters and ground weavers), whereas vegetation around the banks provides enough space for the weavers to snare their webs for catching their prey and also provides hunting grounds to the foliage hunters. Since the insect population in the study area is also high, the availability of large prey base could be one of the reasons for the survival of this spider community in the riparian zone. The spiders form a part of the diet for many birds, reptiles and amphibians.

The fish diversity of the river is very low. The few species that have been recorded are found in the upper half of the river. The reason that the lower stretches of the river do not support any fish life could be attributed to the fact that the values of dissolved oxygen are far below the necessary mark. It is well known that level of dissolved oxygen below 4-5milligrams per liter affect fish health and levels below 2milligrams per liter can be lethal to fish. As dissolved oxygen levels in water drop below 5.0mg/L, aquatic life is put under stress. Oxygen levels that remain below 1-2mg/L for a few hours can result in large fish kills. This could be the reason for very low fish diversity in the river in the lower stretches of the river.

Five species of amphibians are found in the study area. The obligate dependence on water and moist surroundings has led a large number of anurans to inhabit this area, which is an ideal habitat for anurans as it provides practically everything that an anuran needs for its survival. The five species of amphibians recorded from the river belong to two families namely Ranidae and Bufonidae. The moist conditions, fairly good vegetation and large insect population are very congenial for a variety of amphibians.

Ten species of reptiles have been recorded in the riparian zone of River Vishwamitri. These included four species of snakes such as checkered keelback, Rat snake, John's Earth Boa and Blind snake. Common Garden lizard, Fan throated lizard, Common skink, Snake skink and Northern House Gecko were the other species of reptiles recorded from the riparian zone. Crocodiles too have been recorded in the present study. Though the river does not support a healthy population of fish, a good number of crocodiles have been recorded. And majority of these has been recorded from the middle stretch of the river that passes through the city area and where biotic interference is highest. A preliminary observation has revealed that the crocodiles mostly depend on the stray dogs, pigs and the cattle for their source of food. It is believed that when river Vishwamitri, was in spate in 1995, some of the young crocodiles, which were present in the Ajwa dam, were swept into the river and since then have been surviving there.

The river and the riparian zone together support a good diversity of bird species and thus these form the most striking group of vertebrates in the study area. A total of seventyseven bird species have been recorded during the present investigation. These belong to thirty different families, thus constituting the largest group of vertebrates. Family Muscicapidae is the largest avian family in the study area with a total of eleven species. The members of this family are terrestrial. The second largest family is Charadriidae with a total of nine species, comprising of mostly waders. Majority of the bird species recorded in the present study are resident, however a few species such as Wagtails, Rosy Pastors, Sandpipers, Snipes, etc. are migratory.

A few mammalian species are also recorded from the study area. Eight species belonging to six different families have been found. Most frequently encountered amongst these are the palm squirrels and the langurs.

As stated earlier Rotifers form the dominant zooplankton community. The taxonomic analysis of this group revealed the presence of 59 species, belonging to 23 genera and 17 families. Out of the 17 families, sixteen (94%) are monogononts while only one family belongs to the order digononta, thus representing just 6% of the total rotifer population. Out of the sixteen-monogonont families eleven belong to order Ploimida, four to order Flosculariacea and a single family belongs to order Collothecea. A single family and a single species represent the order Digononta.

Brachionus angularis, B. caudatus, B. falcatus, B. forficula, B. quadridentatus, Anueropsis fissa, Keratella tropica, K. procurva, Euchlanis dilatata, Mytilina ventralis, Lepadella patella, L. ovalis, L. luna, L. crepida, L. papuana, L. bulla, L closterocerca, Filinia opoliensis, F. longiseta and *Testudinella patina*, which have been described by Michael and Sharma (1980) as the most common species from India, are also recorded from River Vishwamitri.

The Lecanidae family has the maximum representation, a total of eighteen species. Out of the total 33 Lecane (s.str.) reported from India, 8 are found in River Vishwamitri. Out of a total of 23 species of Lecane (*Monostyla*) reported from India, 9 are found in Vishwamitri and from the 3 species of Lecane (*Hemimonostyla*) reported, one species has been recorded from the present study.

Sharma and Michael (1980) described Brachionidae with 31 species reported from India to be the next in order of abundance after the Lecanidae. Similarly in River Vishwamitri, Brachionidae, having five genera and 15 species forms the second largest group. An abundance of *Brachionus* species, which is characteristic of many tropical waters, has been reported by a number of workers (Green, 1972; Chengalath *et al.*, 1974; Pejler, 1977;

Fernando, 1980a; Sharma and Michael, 1980 and Sharma, 1983) and similar results were obtained in the present study. The genus *Brachionus* is represented by nine species from River Vishwamitri. The *Brachionid* genus *Keratella* is represented by two species *viz. Keratella tropica* and *Keratella procurv. Platyias quadricornis*, another Brachionid species that is widely distributed in India has been reported only once from River Vishwamitri. Both the species, *Anueropsis fissa* as well as *A. coelata* were found frequently in River Vishwamitri.

One species each of Notommatidae, Trichotridae, Synchaetidae and Dicranophoridae have been recorded from Vishwamitri River. *Rotatoria neptunia* is the only species of Bdelloid rotifer identified from the study area.

During the present study morphological variations have also been observed in a few *Brachionid* species. It was seen that in *B. calyciflorus*, forms lacking posterolateral spines were larger than those with posterolateral spines. It was also observed that different morphological forms were present in the same samples suggesting that no relation exists between the physicochemical factors, food and variations in the length of the spines. Thus these forms could probably be attributed to the stage of growth as indicated by Arora (1966).

Yoshinaga *et al.* (2001) stated that animal populations live in a diversity of environments and therefore a complex mixture of environmental factors regulates their population dynamics. Tebutt (1993) observed that the physicochemical characteristics of water have a direct bearing on the faunal composition of ponds. Zooplankton species succession and spatial distribution result from differences in ecological tolerance to various abiotic and biotic environmental parameters (Marneffe *et al.*, 1998). Rotifers, due to their high turnover rates are particularly sensitive to changes in water quality (Sladecek, 1983). In addition to the changes in the physicochemical composition, interspecific and intraspecific composition, pollution level and the presence or absence of predators are some factors influencing rotifer species composition and structure (Kaushik and Saksena, 1995). These changes in community structure can be explained numerically with diversity index.

Though contradictory reports exist on whether or not seasonality exists in the rotifer community, during the present study a very distinct periodicity was observed in the rotifer community of River Vishwamitri. The highest species diversity, as indicated by Shannon-Wiener diversity, was observed during the postmonsoon season. The species number was also maximum during the post monsoon season. Least species diversity was observed during the winter season. This condition was prevalent at all the stations.

On the whole, however, the highest number of rotifer species has been observed at station III. A total of 40 rotifer species belonging to 16 genera and 11 families are recorded from this station during the study period. This is followed by station I which has a total of 37 species belonging to 17 genera and 12 families. Station II has the highest number of genera, however, the total number of species is less compared to stations I and II. The number of rotifer species decreases drastically at station IV and this decline continues even up to station V. A total of 12 rotifer species belonging to 10 genera and 7 families are located from station IV. At station V, 10 species belonging to 6 genera and 5 families have been located. Community similarity between various stations has been calculated using Jaccard's index. This reinforces the fact that each site shares the greatest number of species with the closest other region and fewest species with the most remote region. Thus the number of species similar to station I and II is 52% while that between station I and V is a meager 21%. This pattern holds true for the rest of the stations as well

Many species were found which are exclusive to a particular sampling station. Twenty species of rotifers, out of a total of 59 species are exclusive to any one particular station. Thus 33.9% species of rotifers in River Vishwamitri are exclusive species. Additionally it is seen that station III supports the maximum number of such exclusive species. This station harbors a total of 12 exclusive species accounting for 63% of the total twenty exclusive species. This is followed by station I having a total of 5 exclusive species thus accounting for 21%. Station II is next, harboring 3 exclusive species and accounting for 15.8% of the exclusive species. Sites IV and V do not support any of the exclusive species.

Apart from the exclusive species, some species occur throughout the course of the river at all the stations and have been termed as common species. Six such species were found in River Vishwamitri, thus constituting 10.2% of the rotifer community.

Four species occur at four stations, i.e 6.8% of the species can be found at any four stations. Seven species occur at only three stations i.e. 11 % species occur at three stations. Twenty-three species occur at only two stations, thus showing that 38.98% of the species can be found at only two stations.

As was stated earlier, a definite periodicity has been observed in the rotifer community during the sampling period. Mengestou *et al.*, (1991) stated that the seasonality of rotifers can been ascribed to a number of climatological and biological factors. Herzig (1987) from an intensive study of the Rotifera from temperate lakes, observed that some central factors such as physical, chemical limitations, food and mechanical interference, competition, predation and parasitism regulate rotifer succession. Thus it could be possible that the changes in the season that affect the quality of water might be affecting the rotifer community. In addition to this, biotic impacts of predation, food and habitat could be other factors influencing the structure and composition of the rotifer community. Hence, seasonal physicochemical changes in water and the attendant changes in the rotifer community were monitored

Temperature has been described as an important factor that determines the population dynamics of rotifers (Ruttner-Kolisko, 1975; Hofmann, 1977). In the present study it is observed that rotifer diversity is maximum in the post monsoon season when the temperature ranges between 24.8°C and 25.8°C. When the water temperature increases in the summer (26.9°C - 27.5°C) a decrease in the rotifer population is observed. In the winters also when the water temperatures falls drastically, a subsequent decrease in the rotifer population has been observed. It may be believed that the rotifers need an optimum temperature for survival and when the temperature varies from the optimum the rotifer population decreases drastically. The effects of temperature on zooplankton populations have often been linked with biotic effects such as increase in filamentous cyanophytes or predators (Threlkeld, 1987). More direct mechanisms include temperature sensitivity of metabolism or life history characteristics (Hebert, 1978; Taylor and Mahoney, 1988). Thus it can be said that temperature does not solely decide when and where a species will occur. Its influence is mainly indirect enhancing or retarding development and cooperating with other biotic and abiotic factors.

In the present study it was observed that the pH values ranged between 7.51 and 9.01 showing that the pH is neutral to alkaline. This observation is consistent with the observations of Subramanian *et al.*, (1987) who stated that irrespective of the geology, climate etc., the pH of Indian river waters is predominantly alkaline. The pH values are the lowest during the postmonsoon season and range between 7.52 and 7.76 at all the stations. This is also the season when the rotifer diversity is maximum. During the summer the pH range is between 7.74 and 8.80 while the rotifer diversity is moderate. Least diversity has been observed in the winter months when the pH ranged between 7.70 and 8.35. When pH and rotifer diversity were correlated, a significant negative correlation was observed. Moreover, even a slight alteration in the pH may lead to perceivable changes in the rotifer community.

Dissolved Oxygen (DO) plays an important role in determining the occurrence and abundance of rotifer communities (Arora, 1966a; Nayar, 1966; Dhanapathi, 2000). In the present study it has been observed that the DO levels are highest during the winter season, when the rotifer population is at its lowest. Similarly, Mishra and Saksena (1998) from their studies also found that rotifers were inversely proportional to the dissolved oxygen. However, in the current study when the dissolved oxygen levels are the lowest in the summer season the rotifer population is not at its highest, in fact low rotifer counts are recorded in this season. Only during the post monsoon season the rotifer population is high but the dissolved oxygen levels are moderate. This suggests that there is no direct correlation between the dissolved oxygen levels and rotifer population.

Suspended solids have also been shown to play an important role in zooplankton community dynamics (Hart, 1990; Cottenie *et al.*, 2001). In the present study it is observed that the postmonsoon season has the highest levels of suspended solids as well as the rotifer diversity throughout the river. This is in complete agreement with Telesh (1995) who described rotifer diversity to be inversely proportional to transparency in highly turbid waters. Transparency in River Vishwamitri gets highly reduced in the postmonsoon season when the waters carry heavy loads of sediments from the surrounding areas and this has been shown to have a negative effect on the crustacean community (McCabe and O' Brien, 1983; Hart, 1987). In the present study the density of crustaceans and copepods were low during the postmonsoon season (Pilo *et al.*, unpublished). Thus predation upon the rotifers is greatly reduced. Threlkeld (1979) also suggested that biotic mechanisms in the seasonal changes of zooplankton assemblages involve changes in predation. In addition to the direct effect of suspended solids, increased turbidity, alters predator efficiency, which indirectly affects zooplankton community dynamics. On the whole, however, it can be seen that Station I, II and III, which have the highest rotifer diversity, have relatively low suspended solids as compared to stations IV and V, which have very high-suspended solids. Thus it would not be completely right to believe that the rotifer diversity is directly proportional to the suspended solids.

Gulati *et al.* (1992) indicated that the important factors to be examined for changes in zooplankton composition and abundance are zooplankton food and predation. Threlkeld (1979) also suggested that factors influencing the seasonal changes of zooplankton assemblage include changes in resource availability. Restrictions associated with lack of optimal food (Pejler, 1977) or diverse phytoplankton as food items (Burgis, 1974) are known to be the reason for low rotifer diversity in low latitude lakes (Lewis, 1979; Fernando, 1980b). Rotifers feed on detritus, algae, etc. while some are predatory. Most of the rotifers recorded from River Vishwamitri are herbivorous or detritivorous, suggesting that the phytoplankton constitute the major source of food. Any changes in the composition of these would lead to subsequent changes in the rotifer community. Moreover, analysis for linear relationship shows a significantly high positive correlation (r = 0.92) between the seasonal values of chlorophyll a and the rotifer diversity. During the postmonsoon season the chlorophyll a levels are highest, as is the rotifer diversity. And the lowest chlorophyll a levels are encountered in the winter season. The summer months show moderate chlorophyll a levels and concomitantly moderate rotifer diversity as indicated by the Shannon – Wiener and Margelef's index. It is also evident from the results that stations I, II and III have higher chlorophyll content as compared to stations IV and V, similarly the rotifer diversity at these stations are also lower as compared to stations I, II and III throughout the year.

Yet another reason for low rotifer diversity downstream could be attributed to the fact that the cyanophytes are disproportionately high at these stations (Pilo *et al.*, unpublished). It has been stated that blue green algae are not edible as they are toxic to rotifers (Fulton and Pearl, 1987). Filamentous cyanophytes decrease zooplankton-filtering rates by mechanical interference at high densities (Webster and Peters, 1978; Porter and Orcutt, 1980).

Factors affecting the phytoplankton community would also indirectly affect the rotifer dynamics. In most freshwaters, phosphorous and nitrogen are limiting nutrient for phytoplankton growth (Plath and Boersma, 2001). Phosphate is an important nutrient, which controls plant growth (Hynes, 1978). In Vishwamitri River the values of Phosphate increases as sewage gets dumped into the river from station III onwards. Phosphate values are lowest at station I and gradually increase from there onwards. The highest values are found at station V. This trend is seen during all the seasons. The lowest total reactive phosphate levels are encountered during the postmonsoon season while the highest values during the summer. Thus it would be expected that phytoplankton diversity and consequently rotifer diversity would be highest in the downstream stations in the summer season. This is however, not the case. Both the phytoplankton levels (Pilo *et al.*, unpublished) and the rotifer diversity in the downstream stations are low. This could probably be due to the very low dissolved oxygen content in this stretch of the River. In fact when total reactive phosphate levels are low the rotifer diversity is high.

In case of nitrate nitrogen, the highest values are seen at the downstream station whereas low values in the upstream station. On basis of the seasons the highest values are seen during the postmonsoon while the lowest during the winter season. Accordingly high rotifer diversity is seen during postmonsoon season and low diversity during the winter. However, as far as the stations are concerned where high nitrate nitrogen values are present (downstream stations) the rotifer diversity is not correspondingly high. This could again be attributed to low DO levels at these stations.

Water pollution also affects the rotifer community. Archibald (1972), Verma *et al.*, (1984) and Kulshreshtra *et al.* (1989) observed that the species diversity is high in clean water and low in polluted waters. In River Vishwamitri the sewage pollution begins from station III, and in general, it has a greater diversity of rotifers throughout the year. However, towards station IV and station V the pollution load increases drastically as evidenced by the elevated BOD values and the low levels of dissolved oxygen. At these sites the suspended solid levels are also very high, which greatly reduces the transparency. This would in turn affect the light penetration required by the primary producers. All these factors combined probably account for the low diversity at these stations.

Presence of aquatic macrophytes also affects the zooplankton diversity. Lougheed *et al.* (1998) stated that patchy distribution of aquatic vegetation contributes to seasonal variability in water quality characteristics and the amount of habitat available for aquatic invertebrates. The macrophytes provide more diverse habitats (Van den Berg *et al.*, 1997). Development of vegetation increases structural complexity, thus providing more niches for rotifers. In River Vishwamitri macrophytes are present in highest numbers at station III followed by station II and I. Station IV and V have negligible macrophyte population (Pilo *et al.*, unpublished). This could be yet another reason for higher diversity in the first three stations. Beds of *Typha aunguata* present at stations II and III of River Vishwamitri could be another factor contributing to the high rotifer diversity at these stations, as opined by Telesh (1995). Further species like *Brachionus calyciflorus*, *B. quadridentatus* and *Filinia longiseta* have also been described to be dominant among macrophyte. All the above species were found at sampling stations II and III. Phytophilous species like *Platyias quadriornis*, *Mytilina* are abundant in macrophyte beds (Telesh, 1995). Similarly *Platyias quadricornis* has been reported from station III while *Mytilins ventralis* from station II of Vishwamitri.

Thus it can be seen that by and large station III seems to provide a better habitat for the rotifer population. This station never dries up since it receives domestic sewage throughout the year. Additionally, the levels of dissolved oxygen are relatively high. Besides this the reed beds present at this station, provide more varied microhabitats, which is needed, for the survival of the periphytic rotifers. These could also be the reason for high species diversity as well as higher number of exclusive species found at this station.

Thus it can be stated that pH and chlorophyll-a play a major role in influencing the rotifer community structure. Additionally, both the abiotic and biotic factors could be interacting with each other and their combined effect may be influencing the rotifer community structure.

The results of the present study form a comprehensive baseline data to assess and monitor the anthropogenic impact on the lotic ecosystem – The River Vishwamitri – as any change in the abiotic component of the ecosystem will be altering the structure of the existing biota. Further, the current study has opened up an important yet neglected branch of Zoology – the biology and ecology of rotifers. Finally, species like *Brachionus angularis, and Brachionus quadridentatus,* which have wider tolerance as evidenced by their ubiquitous nature, if subjected to mass culture, can be used as an alternative to *Brachionus calyciflorus* and *Brachionus rubens* which are less tolerant to changes in the quality of water. Efforts towards this direction are in progress.