PREFACE
Water, the inseparable component of all kinds of life on this blessed planet earth, covers almost 71% of it's surface. This extensive sheet of water comprising varied ecosystems can be categorised as oceanic (saltwater), estuarine (brackish water) and inland (freshwater). The inland waters, principally the freshwater consisting of a kaleidoscopic range of water bodies- springs, streams, rivers, ephemeral pools, puddles ponds, lakes and reservoirs, constitute a dismal fraction of only 2.8% including snow, while 97.2% is the saltwater found in seas and oceans (Jonasson, 1993). Thus, freshwater bodies are one of the two major components of aquatic ecosystems that sustain the biosphere as a whole (Smith, 1990). Freshwater has been of vital importance for maintenance of nature’s balance and sustenance of life. Water is used for drinking, rearing of cultivable fishes, irrigation of crops, as also for several domestic chores. Therefore, naturally, establishment, growth, development and prosperity of all the known ancient civilisations took place in and around river valleys and freshwater bodies.

Though, drink, food and means of cleansing were the primeval man’s only concern with water, as time went on his descendants could hardly resist the mysteries of water. By early nineteenth century, with the invention of the microscope, his attention was drawn by ‘plankton’ the wondering plants and animals drifting in the water medium. Gradually the elucidation of several other factors which controlled the growth of these minute organisms and in turn the other life forms opened a new field of science/ ecology, generally called limnology. The term limnology was derived from the Greek word meaning pool.

Though studies of certain water based organisms, their feeding habits, propagation and behavior in water was undertaken during late 17th and 18th centuries, they were more of a ‘hydrobiological’ nature rather than fitting into the
limnological domain. Therefore, Elster (1974) covered barely a period of over hundred years in his attempt to write the history of limnology. Even though, Jung and Forbes were first to treat natural waters as ‘microcosms’, F. A. Forrel of Switzerland is considered as the founder of modern limnology, whose original work on the Swiss lakes was published in a classic entitled “Le Leman” (Lake Geneva), a limnological monograph in French (Schwoerbel, 1991 and Das, 1995). He was the first to study and elaborate the physical, chemical and biological characteristics of lakes and name the area of his study as ‘Limnology’. The credit of writing the first book on limnology in the year 1901 in German - "Handbuch der Seankunde All Gemene Limnologie" also goes to him. Further at the founding conference of the International Association of Theoretical and Applied Limnology in 1922 in Kiel, flowing waters were also assigned to the subject area of limnology, which therefore ceased to be merely the study of science of lakes and became instead the science of inland waters (Rodhe, 1974). Thus limnology is regarded as that branch of science which deals with the study of all phenomena pertaining to inland waters. Hence it is a composite of subjects like Zoology, Botany, Chemistry, Physics, Bacteriology, Meteorology, Geology in this omnibus study. It is now defined as the branch of science that deals with biological productivity of inland waters and all causal influences which determine it.

Globally, birth, early development and growth of limnology has been primarily in developed countries of temperate regions. This is because the initial impetus for freshwater investigations was felt almost concomitantly in both Europe and North America. Most of the pioneering work by the early limnologists and also that of their contemporaries got culminated into classic indispensable treatises on the subject (Hutchinson, 1957, 1967, 1976; Edmondson, 1959;

The limnological investigations in underdeveloped and developing countries of tropics and subtropics caught up relatively late (Talling, 1965; Belone and Coche, 1974; Peters, 1986). In Indian subcontinent, though the limnological research took off in early 1930's through the work of Pruthi and Sawell (Das, 1995), the pace was extremely slow for almost 3 decades that followed. But through the later period of over 3 decades there was a spurt in the limnological work along the length and breadth of the country. However, no extensive overviews/ reviews have come out embodying the scattered and assorted work, unlike in the west. All the same noteworthy few teams of workers in the field are Das, Kaul, Vasist and Zutshi and their co-workers in northern and central India; Jana, Michael and Bose and his associates in eastern India; and Chacko, Ganapati and his colleagues, Munawar, Sreenivasan and Zafer in southern India (references in mini-reviews and compiled books by Michael, 1980; Tonapi, 1980; Tripathi and Pandey, 1990; Shastree, 1991; Mishra and Trivedi,1993; Das, 1995).

Goa, the smallest state of the Indian Union covers an area of 3705 km² on the west coast and lies wedged between the states of Maharashtra and Karnataka. It was liberated after 400 years of the colonial Portuguese yoke much later than the rest of India in the year 1961. Unfortunately, the region was starved of higher educational facilities and noteworthy scientific pursuits for long unlike major counterpart of the country under the British rule. In the year 1966 the establishment of National Institute of Oceanography with it's headquarters in Goa gave a thrust to oceanographic/ estuarine research off the coast of the state along with rest of India (Kuchhal, 1991). But the limnological studies on the
limited freshwater resources of the state, to best of my knowledge, are confined to a couple of publications each on Mayem lake and Khandepar river by Desai and his associates (Desai, 1987, 1995; Desai et al., 1995; Bandiwdekar and Desai, 1998). However, all these studies were of relatively short duration of a year each with a slant on the effect of pollution through mine effluents. The work on Khandepar river is on physicochemical properties of water and on biological productivity, while one of that on Mayem lake centers around bacterial profile and the other encompasses physicochemical properties of water along with qualitative/semi-quantitative picture of plankton and benthos in terms of “few, rare and common”. Thus in reality, there was a near total lack of long term limnological information from a wholistic consideration on any water body of the region covering various angles like, physicochemical properties of water, plankton, productivity, macrophytes, fishes and the waterfowl.

Goa being a coastal state, the fishery is catchment oriented rather than culture intensive. Of late, brackish water fish culture has already come under heavy clouds of uncertainty in the country as a whole. The ingress of freshwater aquifers by saltwater and the deterioration of soil fertility to the point of no return - the two backlashes of the practice led to the intervention of the apex court of the land in the matter. Therefore the chances of revival and, especially the expansion/intensification of brackish water fish culture are meagre. Under the circumstances, it is all the more important that our attention is diverted towards freshwater pisciculture, at least extensive, if not intensive to cater to the ever increasing demand for animal protein by the human population. Selvaraj et al (1994) on the basis of his studies in Tamil Nadu showed that the inland fishery resources can be substantially augmented by suitably utilising the small tanks and reservoirs with an yield of even 100 kg/ha. Techno-economic survey (Anon,
1964) of erstwhile Union Territory of Goa Daman and Diu conducted immediately after liberation of the region from colonial rule stated that "...however, the detailed information about the sheet of water, their suitability for fish culture are not available". Even after a lapse of 3 decades since then, the situation is not much different with regard to comprehensive knowledge of freshwater bodies of the state.

Most of the freshwater bodies in Goa are shallow and are skirted by wetlands which are defined as "lands of transition between terrestrial and aquatic systems wherein water table is usually at or near the surface or the land is covered by shallow waters" (Woltsencroft et al., 1989). Some of the earlier reports (Whiteker, 1991; Heblekar and Shanbhag, 1992) showed that major wetlands in Goa harboured a considerable population of waterfowl. Further, Heblekar and Shanbhag (1992) not only recorded perceptible difference in the adjoining wetlands in terms of bird fauna supported by them, but also expressed their inability to delineate reasons for the difference, owing to the lack of systematic and detailed limnological information on these bodies. After Ramsar convention in the year 1971, the waterfowl and the inseparable entity the wetlands have been rightly attached with due importance, as the birds depending on their varied food habits occupy different trophic levels in the food web and play a significant role in the specialised ecosystem in more than one ways (Woltsencroft et al., 1989; Hussain and DeRoy, 1993; Qopal, 1995). The first ever report on the birds in general of Goa was only in the year 1976 by none other than the legendary birdman of India, late Dr. Salim Ali and his associate (Grubh and Ali, 1976). Later marginal additions and corrections to the list (Ripley, 1978; Saha and Mukherjee, 1981; Rane, 1984) as compiled by Zoological Survey of India accounted for a total of 208 birds (Saha and Dasgupta, 1992). All these
reports were based on a short duration opportunistic surveys generally not exceeding a week, the longest being that by Grub and Ali (1976) spread over 16 days. Authors themselves were open in admitting the inadequacy and incompleteness of the survey in these words- "The following list is obviously incomplete. It doesn't include many other species which might certainly occur in Goa either as residents or as immigrants, and it is hoped that further more extensive survey will be possible for the record to be completed". Of late a considerably long duration study on birds of Goa is being published (articles yet to be concluded as it seems to be in series) by Lainer (1999). It is to be noted that all these reports are more in the form of checklists and sight/ sound records, at the most accompanied by morphometric annotations of early collections and don't have any bearing on ecosystem/ habitat based ecological approach. Further, most of these studies except for the one under publication by Lainer were from forest belts rather than encompassing low lying areas and wetlands of coastal plains. Thus information on the wetland birds and their ecology in the coastal state of Goa is extremely scanty and sketchy, mostly in the form of compilations like Asian midwinter waterfowl census and outline information in the directory of Indian wetlands (Gramopadhye and Gowthaman, 1993; Sardesai et al, 1995). Not only was the Asian midwinter fowl census unable to proceed as planned, but also many of the compilers and participants themselves were skeptic about the plans, modalities and outcome (Menon, 1990).

Short duration studies as of today in the form of preliminary reports (Whiteker, 1991; Heblekar and Shanbhag 1992), midwinter water fowl census (Hussain, 1990), naturalist's and tourism promoters checklists (Wagh, 1989; Harris, 1992,1996) highlighted the importance of one of the major wetlands of the state, the Carambolim Lake, as an abode of reasonably good number of
migratory birds besides resident species. Unfortunately a mega railway project - Konkan Railway, as per the original plan was to bisect the lake along its course. But timely intervention and stiff resistance by bird watchers, nature lovers, environmentalists and NGOs resulted in the realignment of the railway track along the western edge of the lake. The non-existence of systematic and scientific information on the lake ecology and biodiversity was not only an impediment in the settlement of dispute between the environmentalists and railway authorities, but also would have continued to be the handicap towards the assessment of post-implementation impact of the project on the lake in general and avifauna in particular. Though by the time I could take up the work, the track alignment was already in progress, truly going by the phrase 'better late than never' it was considered to be a prudent exercise to study all round limnological profile of the lake along with the detailed information on the avifauna utilising the fleeing moments before the trains started rolling, to serve as baseline data for comparison and also to continue the studies thereafter to gauge immediate impact of the developmental project, if any.

Since the advent of modern civilisation, ever increasing population, unabated industrialisation, callous negligence towards pollution, increased human greed has led to gross misuse of valuable resources of water, particularly freshwater. Unfortunately, it took large scale calamities such as Minamata tragedy of Japan, and acid rain of north America/ Canada, to generate an awakening about the vital need for checking pollution, reclaiming of derelict waters, and conservation/ judicious utilisation of water resources. In view of all this, considerable attention is being paid towards the study of inland waters by scientists, technologists and engineers alike (Patil and Gouder, 1981). As Goa is a small state with an ever increasing floating population owing to revenue
generating tourism, unescapable mining, infrastructural development projects such as road/rail network, and expeditious urbanisation has been taking a heavy toll of smaller freshwater bodies along with the adjoining wetlands. Under the circumstances the words of Einstein, "We can't solve the problems of today with the same level of thinking as we had when we created them", are all the more relevant. Therefore, not only hands-off protection of resources, but also proactive management is the need of the hour. This is feasible only when elaborate contextual information is readily available.

In this background, it was decided to conduct a detailed limnological analysis of 3 freshwater bodies namely Pilar Lake (PL), Carambolim Lake (CL) and Santa Monica Lake (SML) from the southern part of Tiswadi taluka of Goa. The study, being first of its kind in the region on such an extensive scale, was expected to lay the foundation, pave way, and stimulate studies of similar nature in future. It was also hoped that the study would throw light on the fishery potential of these lakes, initiating the process of judicious exploitation of these water bodies towards pisciculture, at least on an extensive plane. A clear picture was anticipated to emerge on culmination of the study on the biology of associated wetland birds, facilitating ecotourism, one of the lifelines of state's revenue. The study was also expected to help find an answer as to whether there was any impact of an immediate nature on the migratory/resident bird fauna owing to rail alignment and traffic by the edge of CL.

Why one more limnological study? And why these 3 water bodies only?

1) All the water bodies, small or large are supposed to be highly individualistic habitats. And hence the flora and fauna are usually known to vary widely and often unpredictably between the water bodies even within the same geographical area (Friday, 1987). 2) All the 3 lakes chosen for the study were located in
central Goa within —distance from Goa University, our headquarters, and hence readily accessible for intensive studies at regular intervals.3) Though they were close to one another, within a radius of 3 km they differed widely among themselves in many respects providing built in natural experimental set up for comparison. PL a natural permanent water body, smallest of the 3 with a surface area of just 3.34 ha, was the smallest of the three. CL and SML were man made lakes, the former being the largest and semi-permanent one with 40 ha of water spread while the later a permanent one with an intermediate size of 8.85 ha. 4) A multinational industry, the Novartis India Ltd (formerly Hindustan Ciba Geigy Ltd) within whose premises SML, one of the lakes chosen for the study was located came forward to lend laboratory space and support which came in handy as field station for on the spot analytical work whenever needed.

The comparative limnological study from a holistic perspective, thus carried out with special reference to life of water fowl, centered around five major arenas- physicochemical properties of water, plankton and planktonic primary productivity, sediment and the benthos, macrophytes and fishes and the waterfowl have been presented in the form of five separate chapters to follow.