1.0 INTRODUCTION

Estuaries and coastal regions are regarded as complex ecosystems influenced by physical and chemical factors both temporally and spatially (Mc Cluskey, 1989). They are among the most productive ecosystems in the world (Mc Cluskey, 1989). They form the dynamic boundary between fresh and salt water and are thought to be an important interface for biological reactions (Zimmermann, 1977). They are often characterized by wetlands, marshes and swamps mostly with mangrove vegetation submerged in water for a greater period of the day (Odum, 1988). Large number of aggregates, which are fragile, amorphous microscopic particles of different forms and sizes (Grossart and Simon, 1993), in the water body are a conspicuous feature of the estuarine environment (Eisma, 1992). Particles are defined as biogeochemical molecules or subdivisions of matter characterized by properties of mass and observable position in space and time. These particles in aquatic ecosystems may be classified as "organic" comprising viruses (0.02 – 0.3µm), bacteria (>0.22-1 µm), picoplankton (<5 µm), polysaccharide strings and sheets (3 to >100 µm) and detritus (0.5 – 2500 µm) and "inorganic" comprising clay minerals (200-1000 nm), aluminosilicates (200-1000 nm) and iron colloids (100 – 500 nm) or a combination of both. Most aggregates are formed by the physical coagulation of smaller particles including microaggregates, phytoplankton, fecal pellets, organic debris and clay mineral particles (Alldredge, 1989). They also include organisms, like bacteria, protozoans and metazoans which are components of the aggregates in
estuaries (Goulder, 1976, 1977; Grieser, 1988; Eisma, 1992; Laybourne-Parry et al., 1992; Rogerson and Laybourne-Parry, 1992a, b; Kies 1995; Zimmermann and Kausch, 1996), each with their own communities of attached micro-organisms in various nutritional states. This physical aggregation process may be enhanced by exudates, exopolymers and products of cell lysis generated by attached microorganisms which increase the stickiness of colliding particles and form a mucilaginous matrix in which many components become embedded (Alldredge, 1989). Flocculation is an important process in controlling the settling velocities of particles and during the tidal cycles there may be changes in the particle size distribution in estuaries (Dyer, 1986). Most of the aggregated materials are in the turbid zone where the freshwater in the river mixes with seawater (Kies, 1995). In estuarine waters, phytoplankton, plankton detritus and heterotrophic consumers provide an obvious source of suspended particles (Laane, 1982). The organisms living in and on aggregates form an important part of the plankton ecosystem, aggregating small particles and breaking down preferentially larger ones (Jackson et al., 1987; Gorsky et al., 2000). The nature of particles and their adsorption capacities determine the magnitude of the bacterial colonization (Hoppe, 1984). By providing a substrate for organisms, the aggregates may influence heterotrophic turnover of organic material. Their abundance may be a sign that there is a more complex food web in pelagic waters. Caron et al., (1982) thought that aggregates are important loci of microbial activity in the water column, similar to the much
larger oceanic 'marine snow' aggregates. Particles play a significant role as transport agents as microorganisms associated with them sink at rates, which are potentially several orders of magnitude higher than a single unattached cell. However, the abundance and size of aggregates show considerable seasonal (Kies, 1995; Zimmermann and Kausch, 1996) and spatial variation (Kies, 1995).

Particle associated bacteria may be considered as a separate population in estuaries. The proportion of total bacterial abundance attached to particles is generally less than 10% (Zimmerman, 1978; Kirchman and Mitchell, 1982) but can vary from a few percent to 98% of total bacterial abundance in different aquatic regions (Iriberri et al., 1987). Such large variations in the percentage of the attached bacteria are being attributed to physical (viz. turbidity, salinity, temperature, light, turbulence) and chemical characteristics (distribution of nutrients) of the water column (Almeida and Alcantara, 1992). Particle bound bacteria are also relatively numerous in some fresh water and estuarine environments (Ducklow, 1982). Evidence is accumulating in studies on rivers, that as the freshwater flows into the sea the degree of attachment decreases with increasing salinity (Goulder et al., 1980; Wright, 1978).

Bacteria attached to particles are considered to be very important for at least three reasons. First, the metabolic activity of associated bacteria differs
from that of the unattached bacteria (Crump et al., 1998). These particle-
associated bacteria are generally larger and more active per cell than
unattached bacteria (Goulder, 1977; Kirchman and Mitchell, 1982; Unanue et
al., 1992). Secondly, particle bound bacteria may contribute to re-
mineralization of particulate carbon. Particles are known to be favorable
microenvironments for bacteria compared to the surrounding water because
of the availability of potential substrates for growth which is facilitated by
organic components of particles, adsorbed matter and possibly an increased
flux of the dissolved nutrients during sinking (Reviewed by Fletcher, 1991;
Kirchman, 1993). It is an important step for bacteria to attach to the surface of
particle in the degradation of particulate organic matter (Kato, 1984). In many
estuaries a significant fraction of total bacterial carbon production is due to
particle attached bacteria (Griffith et al., 1994). Thirdly, bacteria attached to
particles (> 1 μm diameter) are larger prey and thus may be important for
bacteriovores. Moreover, particle bound bacteria may improve the nutritional
quality (Heinle et al., 1977) of the detrital particles for grazing by zooplankton
(Kirchman, 1983). In the Columbia River estuary (USA), the principal
consumers of bacterial biomass are detritivorous metazoans (Simenstad et
al., 1994a). Particle attached bacteria can have a very different role in a food
web because they may be directly grazed on by larger metazoans, bypassing
consumption by protozoan grazers and “short-circuiting” the microbial loop
(Baross et al., 1994)
As highlighted above, the particle-associated dynamics is a significant component of the temperate estuaries. Most of the studies in the temperate waters have been limited to one or two factors. Obviously the role of the particle-associated bacteria in microbial trophic dynamics is not yet well understood. Hence information on the microorganisms on aggregates in estuarine environments is very much limited (Laybourne-Parry et al., 1992; Rogerson and Laybourne-Parry, 1992a, b; Crump and Baross, 1996). The tropical estuaries are very different as they are marked by the monsoonal effect and have less variation in temperature. It would therefore be highly pertinent to elucidate the role of particle-associated bacteria in the carbon flux of our estuaries.

This study deals with the two estuarine systems along the Goa coast, the Mandovi and the Zuari and their converging point off Cabo meeting the Arabian Sea. The Mandovi-Zuari estuarine system consists of the Mandovi-Zuari rivers, their tributaries and the man-made channel, the Cumbarjua canal which joins both the rivers upstream about 15 km from the mouth of Zuari. They are not only influenced by tides but also by the mangroves, an unique ecosystem where three different pathways (i.e. particulate, DOC and leachate) lead to bacterial production. The Mandovi and Zuari rivers characterized by mixed semi-diurnal tides, strong tidal currents and their perennial connections with the Arabian Sea, support a life line of 11.69 lakhs (1991 census) who depend on these estuaries mainly for fisheries and other
activities like navigation etc. Moreover this region receives very heavy annual rainfall (107cm) especially during the monsoon season (June – September). This ecosystem thus becomes one of the most variable environments for the study of trophic relationships. The problem is viewed in a holistic manner involving factorial matrix both direct and indirect in order to understand the role of these bacteria in the overall carbon flux in the estuaries. The present work investigates:

1. The factors affecting particle-associated dynamics.
2. The significance of particle associated bacteria in a tropical estuarine system.
   a) The importance and dominance of particle-associated bacteria
   b) The role of particle-associated bacterial biomass production
   c) The metabolic activity of associated bacteria.
3. The parameters responsible for variation in the estuarine network and development of a regression model.

The present work is the first composite information on the seasonal dynamics of particle-associated bacteria in the tropical estuaries. It envisages using the regression models to predict some of the microbial parameters so as to aid the development of better management practices for these systems. In fact this study forms the first report for India.