CHAPTER 2

Review of Literature
2.1. Mangroves Vegetation

2.1.1. Status and Distribution of Mangroves in India

India with a long coastline of about 7516.6 km, including the island territories (Anonymous, 1984), had a mangrove cover of about 6,749 km², the fourth largest mangrove area in the world (Naskar and Mandal, 1999; Sahu et al., 2015). Sunderbans in West Bengal account for a little less than half of the total area under mangroves in India. After West Bengal, Gujarat and Andaman and Nicobar Islands have maximum mangroves (FSI, 2013; Sahu et al., 2015). In India, mangroves occur on the West Coast, East Coast and Andaman and Nicobar Islands, but in many places they are highly degraded. Mandal and Naskar (2008) reported that mangroves in India can be broadly categorized into deltaic, backwater-estuarine and insular types according to Thom’s (1982) classification of estuary habitats. Deltaic mangroves are found along the east coast within the deltas of the Ganges, Mahanadi, Krishna, Godavari and Cauvery Rivers (Jagtap et al., 1993; Mandal, 1996; Sahu et al., 2015; Sanyal et al., 1998; Untawale and Jagtap, 1992). Estuarine mangroves are found in the estuaries of the Indus, Narmada and Tapti Rivers on the west coast (Sahu et al., 2015). They are also growing in the backwaters, creeks and neritic in lets of these areas. Insular type of mangroves is found in the Andaman and Nicobar Islands (Blasco and Aizpuru, 1997; Dagar et al., 1991; Mandal and Naskar, 2008; Naskar and Mandal, 1999; Sahu et al., 2015).
2.1.2. Typical Mangrove Zonation Pattern

Spatial variation in species occurrence and abundance has been noted in differing ecosystems throughout the world (Davis, 1940; Johnstone, 1983; Macnab, 1968; Mendelssohn and McKee, 2000; Rabinowitz, 1978a-c; Semeniuk, 1980; Smith, 1992). Zonation of plant communities in intertidal habitats is especially distinct and often results in monospecific bands of vegetation occurring parallel to the shoreline. Zonation pattern in mangrove forests vary geographically. For example, the pattern reported by Davis (1940) for Florida mangroves shows *Rhizophora mangle* (red mangrove) occupying the seaward position, followed by *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove) in the most landward position. That pattern may be contrasted with a profile for northeastern Australia (Queensland), which is not only more complex due to a higher species diversity, but the relative position of congeneric species in the intertidal is reversed from that species in Florida (e.g., *Avicennia* in the seaward position and *Rhizophora* in the landward position) (Smith, 1992). Mangrove zonation pattern may also vary on a regional scale. Occurrence of species may differ across an estuary, apparently in response to differences in freshwater input, i.e., eight species found at the seaward end of the estuary may be absent from the headwaters (Bunt et al., 1982). The zonation pattern receives a global attention, however, is also endorsed the variation of species diversity and dominance on a local scale (i.e., across the intertidal zone). In any particular forest, the low intertidal zone will be typically dominated by a different species than that in the high intertidal zone. Differences in elevation and frequency of tidal flooding across the intertidal generate gradients in abiotic and biotic factors that influence mangrove survival and growth.
2.1.3. Biomass Production of Mangroves in India and Abroad

Mangrove trees are found along tropical and subtropical coasts and are the only known woody halophytes. A part of their productivity may flow into adjacent ecosystems, or conversely, they may receive organic materials from estuarine or oceanic ecosystems (Kristensen et al., 2008; Ong, 1993). The biological and ecological aspects of mangroves have been studied worldwide (Boto and Wellington, 1984; Cox and Allen, 1999; Hutchings and Saenger, 1987; Lugo and Snedaker, 1974; Odum and McIvor, 1990; Twilley, 1995; Twilley et al., 1986). In the Caribbean region important studies were conducted by Garrity et al. (1994), Lugo and Bayle (1992), Twilley et al. (1992). Most researchers deal with pattern of primary productivity, nutrient cycle and detrital export in riverine mangroves, whereas fringe and scrub mangrove have been studied to a lesser extent (Alongi et al., 1992; Lee, 1995; Twilley et al., 1992). The field survey of mangrove biomass and productivity is comparatively difficult due to muddy sediment conditions and the heavy weight of the wood. The peculiar tree form of mangroves, especially their unusual roots, has long attracted the attention of botanists and ecologists (Tomlinson, 1986). The survival of mangroves in soft muddy substratum is generally support by their root system to maintain a bottom-heavy tree form (Ong et al., 2004) or a low ratio of top biomass to root biomass (Komiyama et al., 2000). Mangroves might allocate a great deal of biomass to their roots which may produce peculiar conditions for ecosystem processes in root zones owing to the anaerobic conditions.

Over the years, forest ecologists have developed various methods to estimate the biomass of forests. Three important methods are usually adopted for estimating forest biomass: the harvest method, the mean-tree method and the allometric method. In a mature mangrove forest, the total weight of an individual tree often reaches several tons (Komiyama et al., 2005). Therefore, the harvest method cannot be easily used in mature forests and in itself is not reproducible because
all trees must be destructively harvested. The mean-tree method is utilized only in forests with a homogeneous tree size distribution, such as plantations. The allometric method estimates the whole or partial weight of a tree from measurable tree dimensions, including trunk diameter and height, using allometric equations. This is a nondestructive method and thus useful for estimating temporal changes in forest biomass by means of subsequent measurements. However, the site- and species-specific dependencies of allometric equations pose a problem to researchers because tree weight measurement in mangrove forests is labour-intensive.

Allometric equations for mangroves have been developed for several decades to estimate biomass and subsequent growth. Most studies have used allometric equations for single stemmed trees, but mangroves sometimes have multi-stemmed tree forms, as often seen in Rhizophora, Avicennia and Excoecaria species (Clough et al., 1997; Dahdouh Guebas and Koedam, 2006). Clough et al. (1997) showed that the allometric relationship can be used for trunks in a multi-stemmed tree.

On both the species and site-specific issues of allometry, Chave et al. (2005) and Komiyama et al. (2005) proposed the use of a common allometric equation for mangroves. The common allometric equation that Komiyama et al. (2005) proposed is based on the pipe model (Shinozaki et al., 1964) and the static model of plant form (Oohata and Shinozaki, 1979). These models predict that the partial weight of the trunk at a certain height physically sustains the weight of the upper tree body, regardless of tree species and locality.

By using these two theories, Komiyama et al. (2005) derived equations with trunk diameter and wood density as parameters and found good fits with a number of mangrove samples from Thailand and Indonesia (Komiyama et al., 1988; Tamai et al., 1986).
2.1.4. Major Influence of Environmental Variables on the Growth and Distribution of Mangrove Species

Berger and Hildenbrandt (2000) endorsed that the mangrove tree architecture and maximum trunk diameter are highly variable and depend on several stress factors such as pore water salinity or water logging. Waring and Major (1964) reported that several environmental factors determines the actual distribution of mangrove species, although each plant has a certain tolerance for each factor. Many previous authors revealed that the mangrove plants are preferred saline habitat and several studies have attempted to correlate salinity with the standing crop of vegetation and productivity (Chen and Twilley, 1998, 1999a; Lugo, 1980; Mall et al., 1987; Ukpong, 1991). Species zonation pattern of mangrove forest primarily depends on tidal inundation behavior and also influenced by sediment characteristics (Banerjee, 1987; Naidoo, 1980; Saha and Choudhury, 1995; Walsh, 1974; Watson, 1928). Salinity is an important factor which influences the species composition and distribution of the mangrove forest due to their different ability to support high and fluctuating salinity between mangrove plants (Robert et al., 2009; Verheyden et al., 2005). Many authors reported that the distribution of mangrove species primarily controlled by salinity gradients (Ball, 1998; Ukpong, 1994). Patches and zones of forest composition result from complex gradients of hydro-edaphic conditions, such as nutrient limitation (Boto and Wellington, 1984; Feller, 1995; Ukpong, 1998) and salinity (Cintron et al., 1978; Lugo, 1978; Mckee, 1993; Nickerson and Thibodeau, 1985). The pH of sediment also affects the plant growth significantly, primarily due to the change in availability of both essential elements such as phosphorus (P) as well as non-essential elements such as aluminium (Al) that can be toxic to plants at elevated concentrations (Black, 1993; Slattery et al., 1999; Woodroffe, 1967). The importance of both salinity and pH for the growth of mangroves has been emphasized
by Wakushima et al. (1994a, 1994b). Lovelock et al. (2005) reported that many mangrove sediments have extremely low nutrient availability which varies between mangroves species and also within a mangrove stand to a large scale (Feller et al., 2003a). Additionally, nutrient availability has repeatedly been found to be an important factor limiting productivity in mangroves (Boto and Wellingto, 1984; Feller et al., 2003b; Feller et al., 2015; Onuf et al., 1977).

Nutrients are made available to most forests from precipitation and dry atmospheric fallout and from the weathering of rocks and minerals. With little surface drainage entering from the surrounding environment, mangrove forests depend mostly on the nutrients from sediment (released from decomposed organisms) which may receive replenishment of nutrient supplies from periodic flooding. The vast majority of the nutrient pool of mangrove forests is stored in the sediment but not in the trees (Alongi et al., 2003). As in other tropical forests, nitrogen fixation in mangroves can be a significant source of nitrogen (Holguin et al., 2001). In a study on mangrove sediments in the Dominican Republic, nitrate concentrations in the sediment were found to be negligible, with the vast majority of inorganic nitrogen being in the form of ammonium (Sherman et al., 1998). Most investigations of nutrient limitations to mangroves have focused on the macronutrients nitrogen and phosphorus, which have both been implicated as the nutrients most likely limiting primary productivity of mangrove ecosystems (Krauss et al., 2008).

Salinity has a dual effect on plant growth via osmotic effect on plant water uptake and specific ion toxicities (Sheldon et al., 2004; US Salinity Laboratory, 1954). Several factors, such as temperature, humidity, stage of plant growth, moisture, texture, fertility of sediment etc., as well as their interactions influence plant response to salinity, which are not uniform and therefore present a complex mechanism. Although the strong correlations between mangrove species distributions and spatial variation of physical-chemical parameters (sediment and water) suggest
that interactions between the biotic and abiotic environment exist, the direction of the interaction is not clear. Species distribution patterns also have been correlated with salinity (Clarke and Hannon, 1970; Lopez-Portillo and Ezcurra, 1989; Macnae, 1968), sediment texture (Clarke and Allaway, 1993) and nutrient availability (Boto and Wellington, 1984). The mangrove sediment dynamics are largely regulated by both internal (flocculation, dissolution, mixing, etc.) and external (e.g. river input, agricultural runoff, pollution) factors. The biogeochemical processes in mangrove sediments are tightly coupled with the sediment texture and mineralogy, which in turn control the distribution of nutrients in sediments. The vertical distribution of nutrients in the mangrove sediments is a function of the physical forces, pH, temperature and redox potential (Carman et al., 1996; Hendricks and White, 2000). Many ecological factors strongly influence the well-being of mangroves and these include geographical latitudes, wave action, rainfall, freshwater runoff, erosion/sedimentation rates, aridity, salinity and nutrient inputs (Kjerfve et al., 1999; Perera et al., 2013). The mangroves species respond differently to different salinity regimes but most of the mangrove vegetation is more luxuriant in lower salinities (Kathiresan et al., 1996). The limitation in nutrients and trace metals varies with individual mangrove habitats. For example, potassium levels may be important in some regions. *Rhizophora apiculata* seedlings grow significantly better in plantation sites enriched with potassium (Kathiresan et al., 1994). Perusal of literature suggests that phosphorus availability may be an important factor in dwarf mangrove production, especially in carbonate dominated environments (Davis et al., 2001; Feller, 1995; Lovelock et al., 2004; McKee et al., 2002). Correlations between species and variables of sediment often are presented as evidence of environmental control over the distribution and abundance of a species (Patterson and Mendelssohn, 1991; Ukpong, 1992, 1994). However, it has become increasingly evident that individual plant species can exert strong
control over their sediment environment (Hobbie, 1992; Pastor and Post, 1986; Wedin and Tilman, 1990) and thus influence vegetation-sediment chemistry pattern. Nitrogen, phosphorus and potassium are elements essential to a variety of biological and chemical processes, both at the organism level (e.g. somatic growth, reproduction) and on the scale of ecosystems.