Chapter I

General Introduction
Crabs, a large cluster of primarily aquatic arthropod crustaceans, comprise about 35,000 species. This cluster also includes barnacles, water fleas, shrimps and lobsters. Morphologically, Crustacea are characterised by the presence of two pairs of antenna, three types of paired chewing appendages, and varying numbers of paired legs. All crustacean appendages, except antenna, are biramous. Most of the members possess compound eyes, and have tactile hairs all over the body that project from the cuticle.

Crabs emerged in Jurassic period (Schweitzer and Feldmann, 2010). However, the *Imocaris*, a Carboniferous primitive crab, is also known from its fossil carapace (Schram and Mapes, 1984). Adaptive radiation of crabs took place in the Cretaceous period and is linked with the breakup of Gondwana, or the concurrent radiation of bony fishes which are crabs’ main predators (Wagele, 1989). Crabs were earlier thought to be a monophyletic group, but presently two distinct lineages are distinguished, the new world lineage and the old world lineage (Sternberg *et al*., 1999).

Crab possess a pair of prominent clawed legs chela and their movement is a sideways walk, which, because of the articulation of the legs make a sidelong gait more efficient (Vidal-Gadea *et al*., 2008). Some crabs that include the raninids, *Libinia emarginata* (Vidal-Gadea and Belanger, 2009) and *Mictyris platycheles* (Sleinis and Silvey, 1980), walk forwards and backwards. There are also crabs capable of swimming, notably the Portunidae and Matutidae (Ng *et al*., 2008).

The basic body plan of crabs consists of an expanded carapace formed by the fusion of the head and thoracic somites, and reduced abdomen which is tightly folded underneath the thorax. Carapace size and shape vary with species, and is an important taxonomic character. Crabs shed their carapace (moulting) at intervals replacing with new and larger ones to accommodate the growing body.

The size of crabs varies from the few millimeter sized Pea Crab (Pinnotheres members) (Kannappan *et al*., 2012) to the Japanese Spider Crab
**Macrocheira kaempferi** having a leg span of four meter (Schmitt, 1965 and Martin and Davis, 2001). The distinguishing sexual dimorphism is the shape of the abdomen, which is triangular in males, but broad and round in females (Guerao and Rotllant, 2009).

Crabs belong to the order Decapoda, the members of which are mainly marine. Out of 112 families of Decapoda so far reported, only 20 families are fresh water or terrestrial. Based on the gills they possess, the order Decapoda are divided into two suborders: Dendrobranchiata, the ancestral group (prawns) and Pleocyemata (true crabs, shrimps and lobsters). The former possess branched gills and the latter have lamellar gills. The suborder Pleocyemata include ten infraorders *viz.* Stenopodidae, Caridea, Astacidea, Glyphidea, Axiidea, Gebiidea, Achelata, Polychelida, Anomura and Brachyura. The infraorder Brachyura represents the true crabs.

Typically crabs have a pair of chelipeds and four pairs of walking legs or periopods. In brachyuran crabs the first pair of walking legs are fully chelate which is used for holding and carrying food, digging, holding the females during copulation and also for warning signal. Walking legs are placed bilaterally. The mouth parts, visible under the carapace are specialised to manipulate and chew food. The eyes are stalked and protrude from the front of the carapace.

‘True crabs’, the most intensively investigated group among crustacea of the infra order Brachyura, are the most diverse group of crustaceans. True brachyuran crabs are often confused with hermit crabs of the infra order Anomura (false crabs) (Ingle, 1983 and Rahman *et al.*, 2008). In general, brachyurans are easily distinguished from anomurans by the four pairs of well developed walking legs; the anomurans have only three pairs of clearly visible legs, with the fourth pair being very small and normally positioned under the abdomen and hence not visible externally (Ng *et al.*, 2008).

Ng *et al.* (2008) estimated 6793 taxa in crabs, that come under 1271 genera and sub genera, 93 families, and 38 super families. Yeo *et al.* in 2008 opined
that the number of new freshwater crab species awaiting discovery ranges from 128 to 846. Many tropical mangrove ecosystems are still not well explored and many grapsids and ocypodids are awaiting formal discovery (Ng et al., 2008). The marine habitats also are still poorly surveyed, with the deep sea providing far richer habitat than previously believed.

Crabs’ distribution cover a wide range of environmental conditions, and hence have diverse ecological and physiological adaptations. The vertical distribution of crabs in the biosphere ranges from the ocean depth down to 6000 meters, and the mountain heights up to 2000 meters above sea level (Ng et al., 2008). Many land crabs exhibit amphibious life, needing to return to water to release their zoea larva. Many of the crabs are entirely fresh water forms and, some are adapted even to live in transient water bodies like tree holes (Bayliss, 2002 and Cumberlidge and Vannini, 2004), dew (Ng et al., 2008) and between axils of leaves (Cumberlidge et al., 2002).

Little (1990) has suggested two adaptive radiation trends of marine crabs to colonise into fresh water or terrestrial environments, namely the ‘direct route’ and the ‘indirect route’. According to ‘direct route’ theory the marine crabs invaded terrestrial environment through intertidal and littoral marginal habitats, whereas, according to ‘indirect route’ theory the marine crabs invaded the fresh water habitat first and subsequently into terrestrial habitat. This implies that the invasion of crabs from the marine into the extra marine environments might have undergone transient ecological phase in the mangrove swamp and brackish water habitats. The important key to this invasion of crabs is the evolution of appropriate reproductive and developmental traits (Diesel et al., 2000). The necessary traits include a life cycle free from the sea, production of yolk rich eggs, abbreviated larval development, or direct development (Rabalais and Gore, 1985).

Feeding habit wise crabs are carnivores (eg. *Scylla serrata*), herbivores (eg. *Taliepus dentatus*) or omnivores (eg. *Neosarmatium meinerti*) (Hill, 1976;
Dahdouh-Guebas et al., 1999 and Palma et al., 2011). Ecological associations such as mutualism (Stachowicz and Hay, 1996, 1999 and Yennawar and Tudu, 2011), commensalism (Lamberts and Garth, 1977) and parasitism (Sun et al., 2006) are observed among crabs.

Economically crabs are important as a major food source. Apart from that, the chitin extracted from crab’s exoskeleton has several medical applications: as a dietary supplement because of its fat absorbing capabilities, for waste water treatment, as plant fertilizer, as plant growth enhancer and as a fungicide (Ghaouth et al., 1992; Goosen, 1996; Hennen, 1996; Ohta et al., 2001 and Burrows et al., 2007).

The ecological significance of crabs in the ecosystem depends on the habitat and is either direct or indirect (Wolcott and O’Connor, 1992). In estuarine ecosystem, burrowing and foraging by *Uca* species significantly enhances the productivity of marsh grass *Spartina alternifolia* (Bertness, 1985). In coral reef community they prevent death of corals by regulating algal over growth (Coen, 1988). In mangroves, insular maritime forests and coastal terrestrial forests, land crabs directly influence forest composition by limiting tree establishment and recruitment by differential consumption of seeds, propagules and seedlings along with the nutrient, chemical and the physical environmental gradients (Lindquist et al., 2009). Based on studies in Christmas island rain forest ecosystem in the Indian ocean, Green et al. (2008) reported that a single species of omnivorous crab, *Gecarcoidea natalis*, play a significant role in regulating seedling recruitment and litter dynamics. This crab predates seedlings independent of the type of vegetation present in the rainforest community.
1.1. The Mangrove Ecosystem

Mangrove forests are one of the most productive ecosystems in the whole Biosphere. They exist at the interference between land and sea and are distributed in the tropical and subtropical latitudes ranging from 30° N to 30° S (Tomlinson, 1986). Northern extension of this limit occur in Japan (31°22′N) and Bermuda (32°20′N). The southern extension is in New Zealand (38°03′), Australia (38°45′) and on the east coast of South Africa (32°59′S) (Spalding et al., 1997 and Kathiresan, 2007 a).

Mangrove ecosystems occur in 112 countries (Bhatt and Nayar, 2012), covering a total area of 20 million hectares. South East Asia supports the world’s largest area of mangroves extending over 6.8 million hectares. It is mainly distributed across Indonesia (60%), Malaysia (12%), Myanmar (9%), Papua New Guinea (9%) and Thailand (5%) (Giesen et al., 2007).

The two major mangrove regions of the biosphere are the Eastern hemisphere mangroves and the Western hemisphere mangroves. The mangroves of Eastern hemisphere include East Africa, Indo-Malaysia and Australia. The Eastern hemisphere is also considered as the place of origin of mangroves, and hence this region is designated as **Old World Mangroves**. The western hemisphere mangroves include West America, East America and West Africa forming the **New World Mangroves**. Old world mangroves have more plant species diversity than new world mangroves. The former region has 49 species and 11 in the latter (Duke, 1992).

Mangrove forests can be considered as evolutionary hot spots where terrestrial species have re-adapted to marine life, and marine species have undergone the transition to terrestrial species (Cannicci et al., 2012). Mangrove forests are also referred to as tidal forests, mangrove swamps, coastal woodlands, oceanic rain forests, walking forests in the sea and green wall of the sea. In fact, mangroves evolved from rain forest trees over 50 million years ago (Duke, 1995 and Ellison et al., 1999).
Mangrove trees are unique in their adaptation to the distinct environmental requirements of the intertidal habitat (Tomlinson, 1986). Apart from their unique and typical ecological features, mangrove ecosystems are of great environmental and socio-economic significances as they protect coastal areas from wind, soil erosion and siltation, protect coral reefs and sea grass beds, supply wood and other minor forest produces, provide habitat and nutrients for a number of organisms, and support fisheries and livelihood (Kathiresan and Bingham, 2001).

Mangrove ecosystem holds unique set of flora and fauna. The vegetation represents plant communities consisting of evergreen trees, shrubs, herbs, climbers, epiphytes, bacteria, fungi, algae and lichens. Mangrove flora fall under two categories, True Mangroves and Mangrove Associates. True mangroves, also referred to as ‘eumangroves’, have high degree of salinity tolerance and habitat specificity (Tomlinson, 1986). Mangrove associates on the other hand are the land plants, which tolerate salinity only to a lesser degree (Tomlinson, 1986).

Mangrove plants have uniquely evolved with structural and physiological modifications that help them to survive and reproduce in the harsh environment of high salinity, tidal water current, anoxic soil and high wind velocity (Kathiresan, 2007 b). To cope up with these conditions they have developed breathing roots, buttress roots, extensive supporting roots, salt excreting leaves, and viviparous propagules. The presences of specialised flotation tissues in propagules promote long distance aquatic dispersal. The mangrove plants regulate salt concentration through a combination of salt exclusion (Rhizophora sp., Avicennia sp. and Ceriops sp.), salt excretion (Acanthus sp., Aegiceras sp. and Sonneratia sp.) and salt accumulation (Xylocarpus sp., Rhizophora sp., Avicennia sp. and Sonneratia sp.) (Kathiresan, 2007 d).

The mangrove plant community does not exhibit much diversity in plant species composition. The total number of plant species in any given mangrove area is relatively less when compared to a tropical forest having the same land area. Recent
estimate shows that there are 65 species of true mangrove plants belonging to 22 genera under 16 families (Kathiresan and Bingham, 2001). The most commonly occurring plant species in mangroves throughout the world belong to the family Avicennaceae and Rhizophoraceae (Hogarth, 1999).

Several of the mangrove plant species are endemic. Aegiceras floridum and Camptostemon philippensis are found only in Indonesia. Likewise Avicennia integra and Ceriops australis are confined to Australia. Rhizophora annamalayana is the only endemic mangrove species reported from India and restricted to Pichavaram mangroves at Tamil Nadu (Kathiresan, 1995, 1999). In addition to endemism, discontinuous distribution of mangrove plant species is also observed. Sonneratia alba has populations in East Africa, India, Sri Lanka and Australia. While S. obovata found in between Thailand and Indonesia only, Aegialitites rotundifolia is restricted to Bay of Bengal and Andaman Sea (Saenger, 1998). Camptostemon schultzii occur in Indonesia and northern Australia (Duke, 1992 and Kathiresan, 2007 d).

Adaptation of roots of mangrove plants varies in accordance with the diversity of physicochemical factors of the habitat (Duke, 1992). The roots adapted in different ways are the stilt root of the genus Rhizophora, the pneumatophores of Avicennia, Sonneratia, Lumnitzera and Langicularia, the knee roots of Bruguiera and Ceriops, buttress roots of Xylocarpus and Heritiera and the cable roots of Excoecaria and Avicennia. All these aerial roots with their basic function of gas exchange also provide additional mechanical support in the harsh environment. They also possess specialised lenticels (pores) that help to respire in anoxic condition. However, the mangrove genera viz. Aegiceras, Kandelia, Osbornia, Scyphiphora and Nypa do not have aerial roots.

The faunal distribution within mangrove forests depend on the ability of their resistance to water loss, their demand from protection against sun, the level of water table, the degree of the soil consolidation, and the availability of microflora and
microfauna or organic debris as nutritional sources (Macnae and Kalk, 1962). The faunal elements in mangrove include both visiting and resident. For the visiting fauna mangrove is a transitionary habitat in their life cycle for feeding, breeding and nesting. Even though the visiting fauna of mangrove are more diverse than the resident, they are not typically adapted to the stressful environmental condition of the mangrove ecosystem.

The resident mangrove fauna are mainly benthic in habit and are divided into infauna and epifauna. Infaunal organisms burrow and penetrate the substratum, and predominantly comprise brachyuran crabs, polychaetes, wood borers, mud burrowing bivalves, and gobiid fishes. Epifauna include gastropod, sessile bivalves like oysters and Modiolus sp. and crustaceans represented by barnacles (Ramakrishna and Rao, 2013). The larger animals among benthic fauna are mud skippers, crabs, oysters and snails.

1.1.1. Mangrove zonation

Mangrove zonation is a regular series of vegetation bands parallel to the coastal line (Tomlinson, 1986). These zones are often monospecific which varies with geographic region. In Florida and Caribbean islands Rhizophora mangal occupy the seaward zone with Avicennia germinans and Langicularia racemosa in the landward area (Chapman, 1976 and Ellison and Farnsworth, 1993). This pattern changes in Australia where Avicennia species grow in the seaward region and Rhizophora species towards landward position. Within the same geographical area mangrove zonation is modified by topography that determines tidal and fresh water run-off, and by sediment composition and stability (Semeniuk, 1980, 1983). Vegetation found in the seaward end of the estuary may be absent in head waters.

Different hypotheses have been proposed to explain mangrove forest zonation. According to an early hypothesis by Davis (1940), the zonation of mangrove plant species is a progressive successional development from pioneer species on the
water edge to a climax ecosystem at the point where the mangrove reaches furthest inland. According to him, the mangrove induce accumulation of sediment that result in the rising of soil level making the habitat suitable for the invasion of next higher mangrove. This hypothesis depends upon the capacity of the colonizing species to cling to sediments to build up land. As per this explanation, succession due to land building does not contribute to mangrove zonation though the evidences show that mangrove responds to coastal propagation.

Hypothetical explanation by Thom (1967) for mangrove forest zonation considers coastal geomorphology to be important in determining physical and chemical condition for regional differences in zonation pattern of mangrove development. However, geomorphology as an explanation for mangrove zonation pattern is not considered to be satisfactory, because it provides no insight as to how the interaction of geomorphological process with mangrove vegetation causes segregation of species.

The propagules dispersal hypothesis (Rabinowitz, 1978) states that mangrove with heavier propagules will colonise nearer to the shore, and the lighter one will establish in further into the land, such as Rhizophora species which have larger and heavier propagules, are found in the lower intertidal area. This hypothesis also is considered to be unsatisfactory because there are several examples of species with small propagules, such as Sonneratia sp. and Avicennia sp., being found in the low intertidal area (Smith, 1992).

According to another explanation differential predation of propagules by grapsid crabs across the intertidal zones eliminate some species from certain positions, thereby influencing the zonation pattern (Smith, 1987 b and Smith et al., 1989). Over-predation of seedlings of a particular mangrove species over a long period alters the forest composition (Cannicci et al., 2008).

The physiological specialisation of certain mangrove species also limits its distribution to suitable sector of the gradient where physicochemical condition differ
(Ball, 1980 and McKee, 1993, 1995). Further, interspecific competition removes the weaker ones from the location, which over a long period of time also determines the overall mangrove zonation (Ball, 1980).

Though the relative importance of such diverse factors is currently not known, and vary with geographical regions, a combination of all such mechanisms may be determining the ultimate outcome. Compared to the floral zonation, a very stable and clear zonation is not discernible with regard to the faunal component. The fauna may exhibit a temporal zonation depending on changes in environmental conditions.

1.1.2. Trophic dynamics

As the leaves of mangrove vegetation contain large amount of indigestible cellulose, lignin, tannin and wax, the primary level consumption of live leaves by terrestrial herbivores is very little or practically nil (Tomlinson, 1986). So, high litter production and litter fall are typical features of mangrove ecosystem. The detritus rich mangrove floor provides a very contusive condition for benthic fauna. It is the fungal and bacterial decay of the litter that form the nutrients for almost all organisms of mangrove ecosystem. Of all benthic macrofauna, crabs are the most important taxa with regard to number and total biomass (Dahdouh-Guebas et al., 1997). The mangrove crabs, by shredding and eating the litter, break litter into fine particles which are much more readily colonised by bacteria and fungi (Giddins et al., 1986). Here, benthic fauna maintain the cycling of nutrients, thereby promoting a large food web operating within the mangrove ecosystem. Thus, mangrove ecosystem has inherent capacity to recycle carbon, nitrogen and sulphur. This perhaps is the only ecosystem that recycles sulphur and makes it available to other organisms (Bhatt and Nayar, 2012). Being at the intertidal zone there is the possibility of litter to be lost due to tidal activity. However, this possibility of litter loss is prevented to a large extent by the benthic fauna, especially the molluscs and crustaceans inhabiting in the mangrove floor through litter consumption and litter translocation (Ashton, 2002).
1.1.3. Ecological functions

Several vital ecological functions are attributed to mangroves. They are efficient barriers against cyclones, hurricanes and tsunamis thereby protecting the foreshores (Upadhyay et al., 2002 and Kauffman and Cole, 2010). This protective function has become evident after Indian Ocean tsunami (Radhika, 2006). This especially is critical for the tropical countries having a long coastal line which is periodically battered with cyclones and hurricanes.

The dense network of supporting roots, breathing roots, and stilt roots bring about sediment trapping (Upadhyay et al., 2002). Through such sediment trapping, the networks of roots contribute to shoreline stabilization and consequently prevent erosion. They also act as an efficient biological waste water treatment system by lowering BOD, and are an excellent sink for heavy metals like cadmium, led, mercury and zinc (Sarangi et al., 2002). Through the sedimentation and heavy metal fixation, mangrove protects adjacent coral reef and sea grass bed ecosystem from pollution and siltation.

Mangrove flora aid in the control of global climatic change by fixing high amount of carbon dioxide, thereby stabilizing atmospheric carbon. They fix greater amount of carbon dioxide per unit area, than phytoplankton do in the tropical oceans (Kathiresan and Bingham, 2001). Moreover, mangrove leaves produce flavanoides that serve as Ultraviolet screen compounds making the environment safe from the deleterious effect of UV-B radiation (Moorthy and Kathiresan, 1997 a, b and Kathiresan, 2007 d).

Mangrove ecosystems are the nursing, breeding, nesting and spawning ground for a variety of bivalves, shrimps, crabs, fishes, birds, reptiles and even mammals (Hanley, 1993). One hectare of mangrove can yield 767 kg of wild fish and crustaceans, which is more than the yield from an extensive aquaculture field of the
same area. It has been reported that 90% of all marine mammals spend some part of their life cycle in mangrove ecosystems (Benfield, 2002).

1.1.4. Economic importance of mangroves

Apart from the ecological services, mangrove support several human requirements like food, fodder, wood for fuel, honey, fiber, wax, tannin and medicine (Rao, 1986). Due to the high caloric value, mangrove twigs are used for making charcoal and fire wood. Pneumatophores are used to prepare stoppers and floats. Mangrove flora attracts honey bees and facilitates apiculture and hence is excellent for apiary. Sunderban is estimated to provide employment to several thousand people through honey extracting that has an annual turnover of 111 tons (Krishnamurthy, 1990). The mangroves provide seeds for aquaculture and it is estimated that an annual yield of about 540 million seeds of *Paenaeus monodon* for aquaculture is obtained from Sunderbans alone (Chaudhuri and Choudhury, 1994). The leaves of *Avicennia marina* is widely used as fodder for buffaloes, sheep, goats and camels, where as *Nypa* leaves are used to thatch roof, and for making mats and baskets (Upadhyay *et al.*, 2002 and Kathiresan, 2007 e). Several mangrove plant derivatives are used as indigenous medicines. *Excoecaria agallocha* leaves are used for the treatment of leprosy, the leaves of *Bruguiera gymnorrhiza* for diarrhea and blood pressure, *Rhizophora mucronata* for angina and *Acanthus ilicifolius* for asthma and rheumatism (Upadhyay *et al.*, 2002 and Kathiresan, 2007 e).

1.1.5. Indian mangroves

Indian mangrove forests are located along the coastal lines of nine states and three union territories. The overall Indian mangrove cover is estimated to be 4662.56 km² (FSI, 2011) harbouring three types of mangrove habitats viz. deltaic, backwater-estuarine, and insular. Deltaic mangrove habitats occur in East coast of Ganga, Bhramaputhra, Mahanadhi, Krishna, Godavary and Kavery. Estuarine types occur in the funnel shaped estuaries of Indus, Narmada and Tapti in West coast. Insular
type mangroves occur in the Andaman and Nicobar islands. Fifty nine percent of Indian mangroves are situated along the East coast, 28% along the West coast and the remaining 13% in Andaman Nicobar islands (FSI, 2011). Luxuriant growth of mangroves in the East coast is attributed to the nutrient rich alluvial soil formed by the Ganga, Bhramaputhra, Mahanadhi, Krishna, Godavary and Kavery and the perennial supply of fresh water along the deltaic coast (Bhatt and Kathiresan, 2011). West coast mangroves are smaller because of the narrow coastal zone, absence of major west flowing river and steep slope due to the Western Ghats (Bhatt and Nayar, 2012). In India the largest mangrove cover occur in West Bengal (2152 km²), followed by Gujarat (1046 km²) and Andaman Nicobar islands (615 km²) (FSI, 2009).

Indian mangroves are found to be inhabited by about 4011 species that include 920 plant species, and 3091 animal species (Bhatt and Kathiresan, 2011). In the universal scenario no other country is recorded to have that much species in mangrove ecosystem as in the Indian mangroves. Of the flowering plants of Indian mangroves 39 are true mangrove species and 86 mangrove associates, comprising 56% of the world mangrove species. Mangrove species diversity is highest in the state of Orissa (101 species) and lowest in Gujarat (36 species) (Bhatt et al., 2013).

The actual number of different faunal species that exist in different regions of Indian mangroves is not fully known due to scattered data, absence of comprehensive compilation of the available data and lack of extensive field surveys. Faunal assessment so far carried out in India indicates that there are 55 species of prawns and lobsters (Bhatt and Kathiresan, 2011 and Bhatt and Nayar, 2012), 138 species of crabs (Sethuramalingam and Khan, 1991; Hemal 1997; Chadha and Kar, 1999; Roy and Das, 2000; Bhatt and Kathiresan, 2011 and Bhatt and Nayar, 2012), 308 species of molluscs (Ganapathi and Rao, 1959; Subha Rao, 1968; Balasubrahmanyam, 1994, Santhakumaran, 2000 and Kathiresan, 2004) and 711 species of insects (Das and Roy, 1989; Mandal and Nandi, 1989, Veenakumari et al., 1997 and Kathiresan, 2004).
The vertebrate fauna comprise 546 species of fishes, 13 amphibians, 85 reptiles, 433 birds and 70 mammal species (Bhatt and Nayar, 2012).

Based on the IUCN status of mangrove fauna, of the 41 invertebrates assessed, four are endangered, another four species are vulnerable and one species critically endangered. In Sunderbans alone four species of reptiles (Chelonia mydas, Eretmochelys imbricate, Demochelys coriacea, and Caretta caretta), three species of birds (Leptoptilos javanicus, Sarkiodorus melanotus, and Cairina scutulata) and five species of mammals (Muntiacus muntjac, Bubalis bubalis, Rhinoceros sondaicus, Cervus deruches and Axis porcinus) are found to be locally extinct (Chaudhuri and Choudhury, 1994 and Bhatt and Nayar, 2012). In addition, Sunderbans is well known as the habitat of the endemic and endangered Royal Bengal tiger (Panthera tigris).

1.1.6. Mangroves of Kerala

Though Kerala state has a coastal line which extends about 590 km, the mangrove ecosystems are highly localised or patchy, and represent only one percent of Indian mangroves (Basha, 1991). The total area of Kerala mangrove in the remote past was 700 km² (Ramachandran et al., 1985) and has dwindled to the present status of about 17 km² (Basha, 1992). According to FSI (2009) reports, Kerala holds only 5 km² mangrove area, which does not account for many smaller patches scattered all along the coast. However, this small mangrove area in Kerala harbors 38% of the eumangrove species (15 species) occurring in India. The first description of the mangrove plants of Kerala is provided by Van Rheede (17th century) in his book Hortus Malbaricus. According to a recent estimate by Anupama and Sivadasan (2004) there are 15 true mangrove species and 49 associates. The dominant plant species in Kerala mangrove are Avicennia officinalis and Rhizophora mucronata. Studies have shown that mangroves of Kerala have evolved in the tertiary period and developed to the present day status by the early quaternary period (Thanikaimony, 1987).
Several vertebrate and invertebrate forms inhabit the mangrove systems of Kerala. Kurup (1996) reported several avian species in the mangrove patches of Kerala coast. Puthuvypu mangroves of Cochin harbours 70 bird species, 10 mammals, 12 reptiles, 12 fishes, and three amphibians (Gopikumar et al., 2008). Mangalavanam mangroves at Ernakulum district supports 41 species of birds (Jayson, 2001). This area supports 51 species of spider coming under 40 genera and 16 families (Sebastian et al., 2005), which represent 27% of the total families recorded from India. The mangroves of North Malabar have 109 bird species, of which 34 are migratory (Khaleel and Sreeja, 2013). Kerala mangroves harbor five species of polychaetes, 24 arachnids and 33 species of butterflies (Radhakrishnan, et al., 2006) also.

1.1.7. Threat and degradation

Mangroves are the most threatened habitats in the world consequent to the demographic explosion and resultant unsustainable development. Over exploitation for fire wood, charcoal and timber, reclamation for urban and industrial development, shrimp farming, and dumping of pollutants are the other serious causes for mangrove forest loss. Shrimp farming alone caused a loss of 65,000 hectares of mangrove in Thailand (Upadyay et al., 2002). Such data suggest that during the past 25 years about 3.6 million hectors of mangrove cover have been lost, corresponding to about 20% of the global mangrove area in 1980 (FAO, 2007). At regional level, Asia suffered the largest net loss, which is more than 1.9 million hectares since 1980 (FAO, 2007).

Environmental, social and economic impacts are associated with the decline and degradation of mangroves world over. The mangrove loss in Vietnam was due to defoliants used during the Vietnam War, logging, and aquaculture, has led to coastal erosion, salinity intrusion, and decline in natural shrimp and mud crab populations (Hong and San, 1993). In South East Asia, mangrove forests have been leveled for large aquaculture projects even though the habitat may be productive up to five times, than aquaculture fields (Hatcher et al., 1989). The magnitude of
anthropogenic impact on mangrove has alarmingly increased leading to loss of 60% to 
80% of the mangrove forest cover that existed in the 1960s (Spalding et al., 1997).

In the Indian scenario with increasing anthropogenic pressure and climate 
change, the mangrove forests are being destroyed severely, with the result that even the 
species currently distributed widely in Indian mangrove forest may decline in the nearest 
future (Bhatt and Kathiresan, 2011). Habitat loss and fragmentation, poor ecosystem 
health, reduction of freshwater and tidal water flow, poor natural regeneration, influence 
of invasive species, over exploitation of mangrove resources, construction of buildings 
and aquaculture practices are the major threat to the mangrove ecosystem in India.

India lost about 30% of the mangrove cover in the last 25 years, and at 
present holds 4662.56 km² (FSI, 2011). Compared to an assessment in 2009, there has 
been an increase of 23.34 km² in Indian mangrove cover which is mainly because of the 
massive mangrove plantations and protective measures in the state of Gujarat, Orissa, 
Tamil Nadu and West Bengal (FSI, 2009, 2011).

The principal causalities contributing to the decline of mangrove in 
Kerala state are use of mangrove area for cultivation, especially paddy and coconut, 
reclamation of mangrove land for real estate business, over dependency and 
unsustainable intensive exploitation of mangrove resources by local people, increase of 
salinity, cattle grazing, construction of railway lines, ports, harbors, unscientific 
aquaculture practices, oil pollution, indiscriminate exploitation for tourism and related 
activities, coconut husk retting and strengthening of coastal borders with strong walls 
(Anupama and Sivadasan, 2004 and Siddappa, 2011). An important factor with 
reference to the mangrove conservation of Kerala state is that 90% mangroves in Kerala 
are under private ownership, a situation that weakens the implementation of rules for 
protecting the existing mangroves (Siddappa, 2011).
1.2. Plant–animal Interaction in Mangroves

Interactions among species create a complex network linking species, communities and ecosystems. They contribute considerably to community and ecosystem functions, and significantly influence the environment and life style of the interacting species (Abrahamson, 1989). This dynamic scenario provides several forms of interaction, some mutualistic, others antagonistic or commensalistic, which are defined on the basis of whether the effect of these interactions are beneficial, harmful or neutral for each interacting species.

Plant-Animal interactions are a set of crucial dynamic process in any ecosystem. It can be broadly defined as the relationship occurring between an organism in the Kingdom Animalia and Kingdom Plantae. Several such interactions demonstrate the evolutionary principles and influence the functioning of the biosphere. Until the first half of 20th century the interaction between species, especially plants and animals, received only limited attention with the exception of pollination studies. When species interaction studies received serious attention, novel ecological concepts such as key stone species (Paine, 1969, 1995; Terborgh, 1986 and Bond, 1993) and nuclear tree species (Janzen, 1998) have emerged. These concepts tremendously altered the approach to species conservation and management.

Though plant-animal interactions have been an important subject of investigation in tropical and neotropical forests (Janzen, 1966 and Howe and Westley, 1988) studies in this aspect have only recently been attempted with reference to mangrove forest. Prior to 1980’s structural aspects and ecosystem dynamics of mangrove forests were thought to be influenced by abiotic process from a bottom-up hierarchy. Investigations on interspecific interactions among different organisms, brought out a paradigm shift concerning ideas about mangrove forest structure, composition and ecosystem dynamics (Canicci et al., 2008).
Plant-animal interactions in mangrove ecosystem can be grouped into invertebrate-plant interactions and vertebrate-plant interactions. The former mainly include insect-plant, pollinator-plant, gastropod-plant and crab-plant interactions. The latter group consist of birds-plant and mammal-plant interactions. Among these, gastropod-plant and crab-plant interactions play important role in nutrient cycling and maintenance of mangrove forest structure and thereby the overall dynamics of mangrove ecosystems.

Gastropod-mangrove interaction is a well known association. Gastropods store or trap nutrients (litter) in the mangrove ecosystem, increase the rate of leaf degradation, influence seedling recruitment by propagule predation and rearrange mud surface in mangrove forest floor (Fratini et al., 2004 and Bosire et al., 2008). Fratini et al. (2004) reported that in Kenyan mangroves Terebalaria palustris consumes five times more Rhizophora mucronata leaves than that of the plants produce during a single ebb tide. Moreover they also feed leaves during high tide too, by using chemosensors (Fratini et al., 2004). Terebalaria palustris have negative influence on mangrove restoration programme by consuming their propagules (Dahdouh-Guebas, 2001), especially the propagules of Avicennia marina and species of Rhizophora. Another important effect brought out by large gastropods is the destabilisation of the sediment due to the track left by their heavy shell. The presence of adult T. palustris induces mud surface rearrangement, decrease the abundance of meiofaunal community and cause complete disappearance of cyaobacteria carpet (Carlen and Olafsson, 2002).

1.2.1. Role of crab community in the mangrove ecosystem

Among the detritus dependant fauna which influence nutrient cycling and forest structure of mangroves, it is the crustacean group that plays a major role in the process. The brachyuran crabs (Grapsidae) are the prominent taxa with regard to the number of species and total biomass (Dahdouh-Guebas et al., 1997). More than 300 species of brachyuran crabs are reported from mangroves worldwide. Two families,
Grapsidae and Ocypodidae account for 80% of the species diversity in the mangroves (Tan and Ng, 1994). They are permanent residents in mangrove ecosystems with densities of 10-70 individuals m$^{-2}$ (Macintosh, 1984 and Khan and Ravichandran, 2007). Such high density and diversity of these crabs is the result of their morphological, physiological and behavioral adaptation to this unique ecosystem. Majority of the Grapsid crabs in the mangroves belong to the subfamily Sesarminae, with many of them coming under the largest genus *Sesarma*. Some of the more commonly reported species in the literature are *Aratus pisonii*, *Metopograpsus latifrons* *M. messor*, *M. thukahar*, *Neosarmatium meinerti*, *N. smithi* and *Parasesarma plicatum*.

Crabs aerate the mangrove sediments by burrowing (Micheli *et al.*, 1991), modify topography and sediment grain size distribution (Warren and Underwood, 1986), trap energy within the mangrove forest (Robertson, 1986; Robertson and Daniel, 1989; Lee, 1998 and Ashton, 2002), create microhabitat for other fauna (Bright and Hogue, 1972 and Gillikin *et al.*, 2001) and contribute to secondary production (Lee, 1997). Mangrove crabs increase the amount of nutrients and decrease the sulphide concentration in sediments (Smith *et al.*, 1991), alter structure and composition of the forest (Smith, 1987 a and Cannicci *et al.*, 2008), litter turnover (Lee, 1998, 2008) and play a key role in the dynamics of mangrove ecosystem (Smith 1987 a, b).

The potential role of crabs in nutrient cycling in mangrove communities is recognized and well accepted. Based on studies on the Australian mangrove forests Smith *et al.* (1991) suggested that crabs might occupy keystone position in the overall ecology of Australian mangrove forests. Malley (1978) studied the feeding ecology of the crab *Chiromanthes onychophorum* and concluded that ‘crabs are the significant agent for mangrove leaf degradation to detritus sized particles in swamp areas where it is abundant’. Robertson (1986) in his study in Northeastern Australia showed that the leaf consuming crab *Sesarma messa* removed 28% (154g m$^{-2}$ yr$^{-1}$) of the annual litter fall and consumed 78% or more of this within six hours of burial (Robertson, 1986).
Lee (1989) based on his studies at Hong Kong, showed that crabs (*Chiromanthes* sp.) are capable of removing more than 57% of the daily litter production. According to Micheli *et al.* (1991) the amount of litter consumed by the crab *Sesarma meinerti* and *Cardisoma carnifex* and the soil mixed up by their burrowing activity indicate their primary importance in the ecology of East African mangroves.

The activities of the crabs are critical to mangrove ecosystem in two ways. First by collecting leaves and other plant materials, crabs conserve the nutrients within the forest ecosystem of mangroves. Secondly, by shredding and eating the litter, the crabs break them into smaller particles which are readily colonised by bacteria and fungi, thus accelerating nutrient cycling (Giddins *et al.*, 1986). The assimilation rate of leaf litter by crabs is generally low (<50%) and the remaining dry mass of the material is egested out as faecal matter, resulting in high faecal production by crabs (Lee, 1993 and Cannicci *et al.*, 2008). The digestion processes of crabs enhance the nutritional quality of faecal matter, which is thus exploited by benthic invertebrate consumers (Cannicci *et al.*, 2008). Lee (1997) demonstrated that *Perisesarma messa* faeces (at least two day old) were significantly richer in nitrogen, and less rich in tannin than in unprocessed leaf, which is a source of better quality food than the mangrove litter, for benthic amphipods. Experiments by Werry and Lee (2005) and Nordhaus *et al.* (2006) also provided similar results. Such studies emphasize the immense importance of mangrove crabs in accelerating the process of decomposition of mangrove leaf litter and the litter turnover.

The burrowing habit of crabs imparts an indirect effect. Smith *et al.* (1991) found that reduction in crab abundance led to increased sulphide and ammonium concentration in soil that is accompanied by reduced productivity and reproductive output of mangrove plants. An indirect effect of crabs’ burrowing habit is a decrease of the mangrove canopy biomass following a reduction in the density of fiddler crabs (Bertness, 1985). Burrowing by crabs also increases soil drainage, soil oxidation-
reduction potential, and the in-situ decomposition of below ground plant debris (Smith et al., 1989). With regard to modification of the soil environment, Sherman (2003) suggested that crabs serve a role similar to that of the earth worms in the temperate zone, or termites in the old world tropics, or even at a more intensive scale.

In mangrove ecosystems crabs not only play a key role in nutrient cycling, but also a major role on the substantiate structure of the forest (Smith, 1987a, b, c; Cannicci et al., 2008 and Lindquist et al., 2009). Crabs feed voraciously on the propagules and seedlings of several mangrove plants, and hence profoundly influence the establishment of seedlings (Lindquist and Carroll, 2004). Consumption of *Avicennia marina* seedlings by crabs has been responsible for the disjunct zonation of *A. marina* at several mangrove localities. In other words, crabs regulate the over population of particular mangrove species thereby promoting diversity in the mangrove forests.

Four theoretical models have been proposed to explain the impact of propagule/seedling predation by mangrove crabs on vegetation structure, viz. the dominant predation model, canopy gap mediated model, flood-regime model and spatio-temporal biocomplexity model.

1.2.1.1. Dominance Predation Model (Smith, 1987a)

As per this model, based on studies in North Eastern Australia, the propagules predation leads to an inverse relationship between the rate of propagules predation of a particular species and its dominance in the forest canopy. Accordingly, it has been noted that *Avicennia marina* propagule predation is less where conspecific adult trees were common and high where *Avicennia* is rare.

Dominance predation model was tested in Australia (Clarke and Kerrigan, 2002), Malaysia (Smith et al., 1989), Kenya (Dahdouh-Guebas et al., 1997 and 1998), Belize (McKee, 1995). Florida (Smith et al., 1989), Panama (Sousa and Mitchell, 1999) and Micronesia (Allen et al., 2003). Studies by Smith et al. (1989) in
Malaysia and Florida brought out results compatible with dominance predation model. Several such studies led to alternative explanations (Dahdouh-Guebas et al., 1998; Clarke and Kerrigan, 2002, and Allen et al., 2003). Studies by McKee (1995), Sousa and Mitchell (1999) and Clarke and Kerrigan (2002) demonstrate that dominance predation model may apply strongly to mangrove species with small sized propagules having high palatability, where crab diet selectivity is most intense. In general, differential consumption of seeds/propagules in different habitats along with differential environmental factors are responsible for distinct spatial distribution of tree species.

1.2.1.2. Canopy Gap Model (Osborne and Smith, 1990 and Clarke and Kerrigan, 2002)

The model suggests a more intense predation of propagules in understory than in canopy gaps. Canopy gaps are formed by natural calamities (Wind storm, cyclones and tsunami) and biotic factors (feeding activity of wood borers), resulting in high irradiance which increase soil temperature, thereby limiting the activity of crabs in such areas (Smith 1987 c). Large canopy gaps help to serve as an area of refuge for mangrove propagules (Clarke, 2004 and Lindquist et al., 2009). However, studies by Krauss and Allen (2003) and Allen et al., (2003) showed no difference in the rate of propagule predation by canopy position. The exact reasons for this result are not clear and hence need further investigation.

1.2.1.3. Flood-regime Model (Osborne and Smith, 1990 and Clarke and Myerscough, 1993)

This model suggests that the duration available for semi terrestrial crab to forage on propagules may be related to inundation time, implying that predation is lower in the lower intertidal zone. However, Sousa and Mitchell (1999) found more propagule predation in low intertidal area than in upper intertidal area. According to them the predation pressure in the low intertidal area was due to abundance of herbivorous crabs. In contrast, high intertidal area was dominated by Uca sp., a detritus feeder.
1.2.1.4. Spatio-temporal Biocomplexity Model (Dahdouh-Guebas, 2001)

The temporal relationship between lagoon water level and degree of predation in some locations has also been reported by Dahdouh-Guebas (2001), who proposed this model. This recent model takes into account the role of propagule predators on vegetation structure, and the influence of local hydrography and anthropogenic effect on natural propagule predation. According to this model a sequence of spatio-temporally separated events influences one or more biotic and abiotic factors that lead to a particular mangrove structure.

1.3. Rationale of the Present Study

Mangroves are unique coastal ecosystems as they support specialised wetland communities of plants and animals. Our limited knowledge of the interaction of different components of the mangrove ecosystem seriously hampers the conservation and management efforts of this ecosystem. Intricate links involved in the nutrient cycling from one trophic level to the other, and the role played by the consumer species within the food web and their impact on the overall community structure and functioning of the mangrove ecosystem, are the main issues to be systematically addressed and analysed to overcome such inadequacies.

Mangrove forests generate considerable amount of detritus and hence support a diverse group of detritus dependent fauna and crabs are the dominant assemblages among them. Crabs through a diverse array of activities, plays a key role in the overall dynamics of mangrove ecosystem (Smith, 1987 a, b). The activity of crabs in mangrove ecosystem is crucial in two ways. They trap the litter in the forest floor, and conserve the nutrients and energy within the ecosystems, and by the selective feeding of the seedlings they can influence the recruitment of seedlings and thereby the structure and composition of mangrove forests. Inferences based on the results of recent studies on the influence of crabs on mangrove ecosystems indicate that crabs occupy a keystone position in the overall ecology of mangrove forests (Smith et al., 1991).
Propagule production, dispersal, establishment and recruitment of mangrove saplings are the important events in the life history of mangrove plants and any fluctuation in these events can bring about important structural changes in the ecosystem (Tomlinson, 1986). Studies by Dahdouh-Guebas et al. (1997) in Kenya, Smith (1987a, b) and Clarke and Kerrigan (2002) in Australia, Siddiqi (1995) in Bangladesh and Souza and Sampaio (2011) in Brazil have showed that the seedling predation by crabs have both positive and negative impacts on seedling recruitment in mangrove forests. However, no attention has been given to study the role of crabs in the mangrove systems in India so far. Further, research on the role of crabs in mangrove ecosystems of Kerala is a maiden attempt in India.

Information on crab-plant interaction would provide impetus to both the scientific knowledge and to the conservation and management of mangrove ecosystem of the country. Studies on the role of crabs in mangrove ecosystems become significant in the light of alarming decline in mangrove forest due to anthropogenic interference. It is against this backdrop that the present study on the role of brachyuran crabs in structure, composition and recruitment of mangrove forests was undertaken on selected mangrove ecosystems of Kerala by assessing:

- The structure and composition of mangrove species in the study areas.
- Identifying the crabs, their population structure, micro-habitat and feeding behaviour.
- The role of the crabs in seedling recruitment and mangrove forest structure.
- The influence of the crabs in the composition of the mangrove forest.