1. INTRODUCTION

The oceans cover over 70% of the planet surface area and account for 99% of the volume that is known to sustain life. Marine ecosystems such as estuaries, coral reefs, marshes, lagoon, sandy and rocky beaches, mangrove forests and seagrass beds are all known for their high biological productivity, which provide a wide range of habitat for many aquatic flora and fauna. It also provides important food resources and many services to human beings. Much of the world’s wealth of biodiversity is found in highly diverse marine and coastal habitats. Coastal zone represents 18% of the earth surface, providing home for 60% of the human population. About 70% of the world’s cities with population more than 1.6 million are located in coastal zone and 90% of the world fish catch is obtained from this zone. Interestingly, the hydrosphere of the coastal zone is only about 8% of that of the world ocean but represents about 18 to 33% of total primary production. This zone is bio-geochemically more important as it buries and mineralizes 80 to 90% of organic matter and serves as a sink for an estimated 50% of the global carbonate deposition (Millennium Ecosystem Assessment, 2005). This zone has high
biological potential as it serves as feeding, nursery and spawning grounds with rich biodiversity and as an intermediary biotope between marine and freshwater environments (Venkataraman, 2003).

1.1. Coastal and Marine Biodiversity in India

Biodiversity is the variety within the living organism or among and between living organisms. It can be recognized into four hierarchical definition of biodiversity that includes landscape diversity, ecological diversity, species diversity and genetic diversity. One of the most important ecosystems of the planet earth is the marine ecosystem, variety and variability of organism and their habitat related to marine ecosystem is termed as Marine Biodiversity (Venkataraman and Wafar, 2005). Thus Marine ecosystem comprises of all the organisms surviving in the marine habitat and their interaction with each other and other biotic and abiotic factors.

India is one of the peninsular countries with Indian Ocean, Arabian Sea and Bay of Bengal as main sea boundaries and a coastline of 7516.6 kms and an Exclusive Economic Zone (EEZ) of 2.02 million km² adjoining the continental regions and the offshore islands and a very wide range of coastal ecosystems, which are characterized by unique biotic and abiotic properties and processes (Venkataraman, 2003). The Indian coastline is distributed among 9 coastal states
(Tamil Nadu, Kerala, Karnataka, Andra Pradesh, Odissa, Maharastra, Gujarat, West Bengal, Goa) and 4 union territories (Pondichery, Andaman and Nicobar islands, Lakshadweep islands and Diu and Daman). In addition to that the Indian continental shelf (4,68,000 sq.km) has special significance, as it is a zone of intensive biogeochemical activity, which are special habitat for coral reefs (Anonymous, 2000). Coral reefs are found in the Palk Bay, Gulf of Mannar, Gulf of Kutch, central west-coast of India, Lakshadweep and Andaman and Nicobar islands. About 208 species of hard corals belonging to 60 genera have been so far described (Venkataraman et al., 2003) while the highest diversity of corals have been recorded from Andaman and Nicobar islands.

The reef bio-composition is quite significant in India which includes 180 species of benthic algae, 14 species of seaweeds, 12 species of seagrasses, 108 species of sponges, 4 species of lobsters, 103 species of echinoderms, 600 species of fin fishes and also a good number of species of crabs, bivalves, gastropods and cephalopods each in Lakshadweep and Andaman and Nicobar islands (Devaraj, 1997).

In terms of mangrove habitats, India is in 14th place among 22 countries which contain the world's major mangrove forests. The Sundarbans make up the single largest contiguous block of mangrove forest in the world, with 40 percent of the area occurring in India that
have great economic value and this has been heavily exploited, both in western and southern coasts of India and much of the originally extensive mangrove habitat have been removed due to coastal developments.

Large seagrass beds are present in Palk Bay and the Gulf of Mannar of Bay of Bengal. However, along most of the coast of western India dense seagrass beds are uncommon and not extensive, probably because of the degree of exposure and turbidity of these waters. There are some seagrass beds in the Lakshadweep and they are possibly extensive around the Andamans and Nicobars (Anonymous, 2010). It is estimated that perhaps five percent of the seagrass beds of the Indian Ocean had been destroyed by dredging or land-filling.

About 844 species of marine algae are recorded from India (Venkataraman and Wafar, 2005). Of these, several species are exploited commercially on a large scale in different parts of the country. Marine invertebrate diversity is high in India, however, there is not enough study in this group (Venkataraman and Wafar, 2005; Anonymous, 2010). Many invertebrates that are of economic importance are harvested; there is evidence that some molluscs and crustaceans have been overexploited, and species such as the coconut crab, horseshoe crab and many species of spider conches are of conservation concern.
The prochordates Balanoglossus *Pychodera flavavery* has localized distribution in the Krusadai Islands of Gulf of Mannar. Similarly, Ascidians such as *Herdmania* and *Eceinascidia*, and Amphioxus *Branchiostoma lanceolatus* are also found in this region. Five of the seven species of sea turtles found worldwide are reported to occur in Indian coastal waters (Kar and Basker, 1982, Bhupathy and Saravanan, 2003). They are the olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*) and loggerhead (*Caretta caretta*). Except the Loggerhead, the remaining four species nest along the Indian coastline. A significant proportion of world's olive ridley population migrate every winter to Indian coastal waters to nest on beaches in Odisha, as well as along other parts of Indian coast. Since all the five species of sea turtles are protected under Wildlife Protection Act (1972), as well as the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES), there exists no commercial or international trade of marine turtles or turtle products in India (Anonymous, 2010).

Globally threatened marine and coastal bird species such as the Spot-billed Pelican *Pelecanus phillipensis* and the Lesser Adjutant *Leptoptilos javanicus* are found in India. Important Birds Areas (IBA) along coasts include the Gulf of Kutch, Gulf of Mannar, Coringa,
Pulicat and Chilka Lake etc. The seabirds of the region are poorly known and do not appear to be abundant in off-shores of India, the Sundarbans are an important staging and wintering area for gulls and terns. Many of the atoll islands in the Lakshadweep -Chagos chain have many seabird colonies, such as Pitti and Balaapani in the Lakshadweep and several of the Chagos Archipelago islands (Anonymous, 2010).

About 25 species of marine mammals are known to occur in Indian water (Venkataraman and Wafar, 2005; Anonymous, 2010). In Indian Ocean, large mammals such as baleen, sperm whales etc., and small cetaceans are present, some of which are not well known, and many of which are harvested either intentionally or incidentally. The Indian Ocean populations of the humpback dolphin *Sousa chinensis* and the spotted dolphin *Stenella attenuata* are considered to be at risk; the distribution of the latter appears to be closely correlated with mangroves. The distribution of the dugong extends over most of the region, but appreciable numbers are no longer found. The most important areas for this species are the Gulf of Mannar, Palk Bay, Gulf of Kutch and Andaman and Nicobar islands (Anonymous, 2010).

1.2. Biodiversity in Gulf of Mannar Biosphere Reserve

The Gulf of Mannar Biosphere Reserve was set up in 1989 jointly by the Government of India and Government of Tamilnadu.
This biosphere reserve extends from Rameswaram to Tuticorin at a distance of 140km. There are 21 islands, all uninhabited running almost parallel to the coastline of Gulf of Mannar. The Gulf of Mannar Marine National Park has the core area of about 560 Km$^2$ from Rameswaram to Tuticorin lying within the Gulf of Mannar Biosphere Reserve covering an area of 10,500 Km$^2$ on the south-east coast of India. The Biosphere Reserve comprises of different habitats such as estuaries, mudflats, beaches, forests of the near shore environment, including marine components like algal communities, sea grasses, coral reefs, salt marshes and mangroves. It is one of the world’s richest regions from marine biodiversity perspective and the first Marine Biosphere Reserve in Southeast Asia. The rich biological diversity of this region is largely due to the presence of diversified habitat such as seaweed beds, coral reefs, mangroves, rocks and sandy shores.

Gulf of Mannar is considered as “Biologists’ paradise” for it inhabits large number of species of flora and fauna. Gulf of Mannar is endowed with a rich variety of marine organisms because its biosphere area includes variety of coastal ecosystems. These ecosystems support a wide range of fauna and flora including rare cowries, cones, volutes, murices, whelks, strombids, chanks, tonnids, prawns, lobsters, pearl oysters, sea horses, sea cucumbers etc. In terms of biodiversity, about 3,600 species of marine organism were reported in the Gulf of Mannar.
Biosphere Region, which includes 117 species of corals (Patterson et al., 2007), 147 species of seaweeds (Kaliyaperumal, 1998), 13 species of seagrass (Rajeswari and Anand, 1998), 17 species of sea cucumbers (James, 2001), 510 species of finfishes (Durairaj, 1998) 106 species of shellfishes such as crabs (Jeyabaskaran and Ajmal Khan, 1998), 4 species of shrimps (Ramaiyan et al., 1996) and 4 species of lobsters (Susheelan, 1993).

Recent study on mollusc indicates, 5 species of polyplacophorans, 174 species of bivalves, 271 species of gastropods, 5 species of scaphopods (new records) and 16 species of cephalopods (Deepak and Patterson, 2004). There are 17 species of mangroves, of which Pemphis acidula is endemic to this region. Seasonally migrating marine animals, like whales, dolphins and turtles, also form part of the rich biodiversity of the Gulf of Mannar Biosphere Reserve. The Krusadi Island is home to an endemic organism called Balanoglossus (Ptychodera fluva), a taxonomically unique living fossil that links vertebrates and invertebrates (Melkani et al., 2006).

1.3. Molluscan diversity in India

The history of malacological studies in India is immense and interesting. The studies on Indian molluscs were initiated by the Asiatic Society of Bengal and the Indian museum of Calcutta
Molluscs contribute the second largest invertebrate group on earth, next only to insects (Bouchett, 1992) and constitute a natural resource of sizable magnitude in many parts of the world. They are an age-old group represented among the early fossils, a group of great diversity in size, distribution, habitat and utility. The range of their distribution is as extensive in space as in time since it inhabits terrestrial, marine and freshwater habitats. They include members from the tiny estuarine gastropod *Bithynia* and small garden snails to the Giant clam *Tridacna* or the Giant squid *Architeuthis*.

The estimated number of species of molluscs today is about 135,000 species (Abbott, 1989), of these 31,000-100,000 are marine, 14,000-35,000 are terrestrial and about 5,000 are freshwater species (Abbott, 1989; Seddon, 2000). Among recorded species about 3270 species are found in marine habitat (Subba Rao and Dey, 2000) which constitute 7.62% of the world mollusc resources (Ramakrishna and Alfred, 2007). Oysters, mussels, clams, pearl oysters and chank are the important molluscs, exploited in India from time immemorial. Gastropod and bivalve fisheries are of sustenance nature and are used for edible purposes, as a source of lime, as decorative shells or for industrial purpose. The molluscs sustain regular and very productive fisheries in our waters. Only a few of the mussels, clams and oysters
are now generally eaten and even these are more a poorman’s food. In Gulf of Mannar Biosphere Reserve, About 484 species of molluscs were reported in Gulf of Mannar region, out of which 260 species are gastropods (Melkani et al., 2009; Kanniyan and Venketraman, 2008).

1.4. Strombid Gastropods

The shells of strombid family show five unusually distinctive genera, each of which has its own popular name; e.g., *Strombus* (conches), *Terebellum* (torpedos), *Tibia* (shinbone shells), *Lambis* (spider shells) and *Varicospira* (beak shells). Many shells in the Strombidae family – particularly *Strombus* and *Lambis* are ornamented, have colorful patterns and they are generally solidly constructed. However, the *Terebellum* and *Tibia* genera are not typical of the other genera and tend instead to be more delicately constructed. The *Terebellum* shell, for example, can be easily mistaken as an olive shell. Conches and spider shells have a pronounced notch at the front end, called the stromboid notch, through which the gastropod protrudes its eye. A widely flared lip, sometimes larger than the main shell body, is a characteristic feature especially for *Strombus* and *Lambis*.

Mature *Lambis* shells typically show 4 - 5 hollow spines radiating out 180 degrees or more from the flared lip. *Terebellum* and *Tibia* shells do not share features common to most
other conch shells and are rather unique. Nevertheless, in spite of many differences in shell morphology, the anatomy and functions of the live molluscs are common to the entire family; i.e., a narrow, peculiarly arched foot bears a relatively small operculum at its end. This arrangement enables the mollusc to kick or leap for escaping predators, rather than gliding like most other gastropods. Also, a complex eye can be protruded from a long stout stalk at the front end. All these features in the living animals are hall marks that clearly identify the Strombidae family, including, e.g., the Terebellum and Tibia mollusks (Poppe and Tagaro, 2006).

Among the marine molluscs, the family Strombidae is one of the diverse group of gastropods (Mesogastropoda) in terms of species number as well as in their wide range of distribution. The shells of strombid gastropods show a wide variety of forms ranging from small and fusiform to large and elaborately ornamented with strongly flared outer lip (Latiolais et al., 2006). So far 9 species of strombid gastropods are reported from the Gulf of Mannar coast. They are: Strombus rubbosa, Strombus canarium, S. gibberulus, S. mutabilis, Lambis lambis, L. chiragra, L. scorpius, L. millepeda and Terebellum terebellum (Ramesh et al., 2008). So far, these resources are largely looked as a source of commercial products which have resulted in overexploitation rather than appreciating their ecological values.
Moreover, human activities such as multiplication of mechanized boats, indiscriminate collection of seaweeds, improper fishing methodology, indiscriminate killing of young ones, trawl net operation, coastal developments and discharge of industrial effluents have caused considerable decline in population during the last decades.

1.5. **Taxonomy of Strombid gastropods**

Biological diversity can be measured in ways ranging from simple counts of species or higher taxa to quantitative measures of morphological, functional or phylogenetic diversity (Harper and Hawksworth, 1994; Purvis and Hector, 2000), but the relationships between various measures of biodiversity remain poorly studied. Morphological diversity is one of the more intuitive measures of biodiversity (Williams *et al.*, 1994), but richness of species or higher taxa can be a poor predictor of morphological diversity, both for living biota as well as for extinct taxa (Foote, 1995, 1997; Roy and Foote, 1997; Roy *et al.*, 2001; McClain *et al.*, 2004). To date, studies of morphological diversity patterns in a phylogenetic framework have focused on vertebrates (Hulsey and Wainwright, 2002; Harmon *et al.*, 2003; Ricklefs, 2004, 2005), freshwater molluscs (Wilson *et al.*, 2004) or fossil taxa (e.g., Wagner, 1995, 1996); such analyses are lacking for living marine invertebrates. The morphological variation seen within
the marine gastropod family Strombidae (conchs and their kin) make them candidates for examining how morphological diversity scales with species richness.

All strombids exhibit determinate shell growth (Abbott, 1960; Vermeij and Signor, 1992), providing an unambiguous gauge of adult size and shape. Species in Lambis and Strombus genera are generally herbivores associated with shallow water reefs and grass beds. Both possess similar soft tissue anatomies, egg masses, and radulae (Abbott, 1961), which led Kronenberg (1998) to suggest that Lambis and Strombus belong together in a group within the Strombidae, even though their shells show striking morphological differences. In a previous study, Roy et al. (2001) examined the relationship between spatial patterns of morphological diversity and species richness in Strombus and Lambis but, because of the lack of a well-supported phylogeny, could not examine how species richness of individual clades of strombid gastropods are related to their morphological diversity.

Major taxonomic revisions of strombid gastropods were undertaken in 1960s (Abbott, 1960; 1961). Since then number of subgenera have been elevated to genera (Kronenberg, 1998), subspecies have been created (Mienis, 1971; Kronenberg and Vermeiji, 2002) and species have been carved from existing genera to new
monotypic genera (Kronenberg, 1998; Kronenberg and Vermeiji, 2002). Few studies, addressed the relationship among the strombid species using morphological data in Indo-Pacific regions (Stone, 2001).

Phylogenetic relationship within and between gastropod groups were studied using rRNA gene sequence by various workers (Tiller and Ponder, 1992; Rosenberg et al., 1994; Tillier et al., 1994; Tillier et al., 1996; Winnepenninckx et al., 1998; Wollscheid and Wagele, 1999; Yoon and Kim, 2000; Dayrat et al., 2001; Wollscheid et al., 2001). Moreover, most phylogenetic analysis based on nuclear rRNA gene sequences rendered conflicting results and their conclusion lacked sufficient support because of the low resolution of nuclear rRNA genes at taxonomic level (Grande et al., 2002). In order to overcome this problem, mitochondrial cytochrome oxidase gene (COI) has been widely used in differentiating phylogenetic affinities among several metazoan groups. First and foremost Folmer et al. (1994) listed DNA primers for amplification of mitochondrial cytochrome oxidase subunit I from diverse metazoan invertebrates, that has been widely used for discriminating the taxonomic distance, genetic structure and phylogenetic relationship between many gastropods at different taxonomic levels by various scientists (Stothard and Rollinson, 1997; Kurabayashi and Ueshima, 2000; Rawlings et al., 2001; Lydeard et al.,
2002; Grande et al., 2002; Peretolchina et al., 2006). Periodically, various DNA markers (primers) were reported for various groups of gastropods to study the genetic affinity between the species (Tie et al., 2002; Cardenas et al., 2006). Genetic variation and patchiness among population of *Strombus* was first reported from Florida region (Campton et al., 1992). Kojima et al. (1997) have studied the genetic differentiation among population of the Japanese *Turbo* shells. Species level phylogeography and evolutionary history of hyperdiverse marine gastropod genus *Strombus* (Freiheit and Geary, 2001) and *Conus* (Duda and Kohn, 2005) have been documented. Recently, Latilolais et al. (2006) studied the molecular phylogenetic analysis of strombid gastropods from Pacific Ocean using mitochondrial cytochrome oxidase gene and histone protein coding region.

Information regarding the genetic variation and molecular phylogeny on the marine gastropods is available in the Pacific Ocean, Indo-Pacific region, Carabian Sea and Japanese water. In India, few studies were carried out on genetic polymorphism among marine gastropods using allozymic analysis (Apte and Rao, 1992). DNA marker techniques were used to quantify the genotoxicity effects of heavy metals in western coast of India (Sharkar et al., 2008). The information on genetic diversity and molecular phylogeny of marine gastropods in India is still in rudimentary stage. Hence the present
study aims to document the current status distribution pattern, morphological diversity and phylogenetic relationship between different strombid species of Gulf of Mannar region. The main objectives of the present study are as follows:

1.6. Objectives

- Explore the morphological diversity and species richness in strombid genus *Strombus* and *Lambis* in Gulf of Mannar Biosphere Reserve.

- Study the phenotypic variation within and between species of *Strombus* and *Lambis*.

- Assess exploitation of strombid gastropods from the by catch.

- Evaluate strombid species available in trade.