1. INTRODUCTION

1.1 PREFACE

India has a coastline of 7,516 km, adjoining the continental regions and the offshore islands and a very wide range of coastal ecosystems such as estuaries, lagoons, mangroves, backwaters, salt marsh, rocky coast, sand stretches and coral reefs, which are unique biotic and abiotic properties and processes (Venkataraman and Wafer, 2005).

The phylum mollusca is one of the most conspicuous and familiar invertebrates. It is second largest group only to arthropods in numbers of living animal species (Ponder and Lindberg, 2004) far behind the ‘Arthropods’ 1,113,000 but well ahead of Chordates 52,000 (Ruppert et al. 2004). It has been estimated that there are about 200,000 living species in total (Ponder and Lindberg, 2004) and 70,000 fossil species (Brusca, and Brusca, 2003). The first mollusca appeared as early as Cambrian period, approximately 500 million years ago. The molluscs are soft-bodied animal, which have developed the capacity of building their own houses. Molluscs inhabit all types of habitats except aerial. The geographical distribution of molluscs is worldwide and they are abundant in littoral, shallow and sub littoral waters.
Molluscs contribute significantly to the total marine fish catch of the world. They have been given more importance, because they have both ecological and economically importance to mankind (Hughes, 1986). There are about 93,000 named molluscan species (Haszprunar, 2001) which include 23% of all named marine organisms (Rebecca Hancock, 2008). In India, 5070 species of Mollusca have been recorded of which, 3370 species are from marine environment (Venkataraman and Wafer, 2005), while rest from the freshwater and terrestrial environment. They have been exploited worldwide for food, ornamentation and pearls throughout human history. Geologic evidence from South Africa indicates that systematic human exploitation of marine resources started about 70,000 to 60,000 years ago (Volman, 1978).

The molluscs are classified into six classes namely Monoplacophora, Amphineura, Bivalvia, Gastropoda, Scaphopoda and Chephalopoda. Among the six classes, bivalves constitute one of the major classes in the phylum mollusca. Compared to the gastropods, the bivalvia are more restricted group and have a specilisation devoted to a narrower range of pattern. Bivalves are more sedentary though in most of them the foot is still well developed. Very few however crawl over the substrate in the primitive molluscan way. Many species burrow into soft sand and mud or even bore into rock and wood, a large
number are permanently anchored to the ground, and among these the foot is usually reduced and sometimes quite lost.

According to Encyclopedia Britannica (1978) no group of aquatic invertebrates is of greater economic importance than the bivalves. Marine bivalves are abundant in coastal and estuarine waters of India (Jones, 1970). The bivalve fishery is constituted, mainly by clams, mussels and, oysters (Jones and Alagarswami, 1973). In tropical countries many bivalve species represent a source of inexpensive animal protein of high nutritional value. Most commonly utilized bivalves for food include clams (Veneridae), sea-mussels (Mytilidae) and edible oysters (Ostreidae) (CSIR, 1962). Annual harvests of bivalves for human consumption represent about 5% by weight of the total world harvest of aquatic resources (Roberts, 1999). In India eight species of oysters, two species of mussels, 17 species of clams, six species of oysters, four species of giant clams, one species of window-pane oyster are exploited extensively from marine regions. However, they are exploited in large quantities by traditional methods and sold in live and dried conditions in the market for human consumption (Venkataraman and Wafer, 2005; Chatterji et al. 2002).

Hornell (1916) considered as a father of marine fisheries research in India, was a pioneer to throw light on the importance of bivalve resources in India. According to Hornell (1916, 1917) bivalves are reported to provide protein rich flesh and calcium rich shells.
Further, the shells are also used in paper, rayon, leather, carbide, cement and fertilizer industries (Srinivasan, 1994) and also used as objects of barter, tools, ornaments, ceramic industries and for animal feed processing industries (CWCS, 1997). Hence bivalve exploitation is an important economic activity that provides the local population with significant revenue and a major protein source (Ajonina et al. 2005).

In India, among bivalves green mussel *Perna viridis* emerging as one of the important commercial bivalve fisheries because of improved culture techniques (Joseph, 1998). It constitutes about 14% of total bivalve landing in India (CMFRI, 2003). It is one of the economically important marine species (Chatterji et al. 2002) not only a rich source of protein for human consumption, but also its extract (prepared from Indian green mussel) showed high antiviral activity when tested with various viral strains such as influenza, hepatitis, RSV and Herpes (Bichurina. et al. 1994). There are 28 species of bivalves and 65 species of gastropods which are important in shell trade and for edible purpose (Nair and Rao, 1974).

Green mussels are large, with shells typically reaching 80-100 mm in length and occasionally growing larger than 160 mm (Rajagopal et al. 2006). They live for approximately three years (Power et al. 2004). *Perna viridis* is able to grow in optimum temperature and salinity, successfully reproduced them once or twice a year in coastal and estuarine environment. They are colonizing mostly habitats such
as bridges, channel markers, buoys, mangrove roots, fishing boats, sea walls and sea weeds. Most species of \textit{P. viridis} live successfully on rocky shores by attaching themselves by a proteinaceous byssus thread. They are mostly secondary consumer and ciliary mucus filter feeders, they feed phytoplankton, zooplankton and other suspended fine organic material. In India rocky shores habitats are more along the west coast, when compared to east coast. In east coast, the rocky shore is found at very few places such as Vizakapatnam, Covalong, Pondicherry, Poombuhar, Tranquebar and Kanyakumari. Among them Rocky shores (Tranquebar) inhabit a verity of molluscan fauna. Several reasons such as fast growth of mussels because of favourable hydrological and geoclimatical condition (Velayudhan et al. 2000) in Kerala, availability of seed from nearby coastal areas (Appukuttan 2001), the availability of loan and subsidies from banks and development agencies (Asokan et al. 2001; Vipinkumar et al. 2001) have been identified as contributory factors for this development along the northern Kerala coast, which serves to indicate the popularity of mussels in the local diet. According to Power et al. (2004) \textit{P. viridis} is a formidable spatial competitor. In view of the above considerations, one of the commercially important mussels \textit{P. viridis} has been chosen for the present investigation.
Water is the universal solvent required for all living organisms. The chemistry of water reveals much about the metabolism of the ecosystem and explains the hydrobiological inter-relationship. The physicochemical parameters of water and the dependence of all life process of these factors make it desirable to consider water as an environment (Gowinda et al. 2009). Hydrographical studies are the important one associated with flora and fauna of the marine and estuarine environments. Environmental conditions play an important role in promoting the accuracy and abundance of commercially exploitable marine resources (Ivelle, 1966). Maintenance of water quality is essential for the survival of the aquatic communities in the coastal, land and other wetland environments (Padhi and Padhi, 1999). A thorough knowledge of the hydrographs of any biotope is indispensable to evaluate the quality of environment and its influence on the biological fertility.

Coastal zone and estuaries are important ecological systems and resources for a variety of uses, such areas are subjected to a variety of socio-economic drivers. Producing increased pressures and impact, this can lead to environmental stress or even affect public health (Cave et al. 2003; Belzunce et al. 2004; Sundaramanickam et al. 2008). With the sudden increase of population and rapid economic development, these areas are facing many ecological problems. Such problems have been assigned mostly to an excess of nutrient,
associated with industrial and municipal waste water (Balls, 1992), forestry and agriculture (Bell, 1991) and the above factors produce ecological impact over biological communities. Knowledge of the environmental parameters of shallow water area is an essential prerequisite to understand the composition of animal inhabitant and their distribution, dispersal and zonation within the vast and interior areas of the coastal waters (Arularasan, 2009). The substratum provides attachment, shelters and nourishment that are fundamental needs for a marine organism (Nair and Thamby, 1980). That way these influence the distribution of the organisms (Nielson, 1950: Clampitt, 1973). The nature of the substrates and other physical conditions such as upwelling are doubtless important factors controlling the local distribution of species in intertidal environment.

Indian coastal and estuarine environment are considered to be potential areas for mussel resources. Knowledge on the environmental parameter is of most importance to understand the distribution and colonizing of most marine organisms. In the coastal environments, study of hydrographical features such as salinity, dissolved oxygen content, temperature and turbidity are known to exert influence on the distribution patterns of intertidal communities (Thorson, 1950). Murugan and Ayyakkannu (1991) observed the nature and distribution of flora and fauna in the Uppanar estuary in relation to physical and chemical characteristics of the water. Studies relating to the influences
of environmental factors on intertidal communities particularly in molluscs have been carried out by Ankel (1936), Berg (1975), Pihl (1986), Stoner et al. (1996), Christy ponni (2007) and Arularasan (2009). Likewise the estuarine dynamics in relation to meteorological and environmental parameters was well documented by Reddy et al. (1993), Pillai et al. (2000), Rajasegar (2003), Jonas Gunasekaran (2003), Soundarapandian et al. (2009), Sankar et al. (2010) and Srilatha et al. (2012). Numerous investigations have been carried out on mussel ecology from all over the world. But, so far literature related to a portion of Nagapattinam coast is lacking, hence the present study was undertaken.

Molluscs are remarkably diverse with regard to their external morphology and in size; they range from microscopic clams, snails (< 1 mm) to giant oceanic squids and the massive tridacnid clam on Indo-Pacific coral reefs. Shell morphology within a species changes due to environmental parameters which influence shell shape and colour. The general morphology of molluscs was described from the earliest expedition by various authors (Haller, 1893; Berg, 1895; Abbott, 1954; Little, 1965). Taxonomy and general biology of *P. viridis* have been reviewed by Linneaus (1758), the Mytilidae, or true mussel demonstrates a great deal of variation in morphological features which are taxonomically important in bivalvia (Siddal, 1980). The anatomical studies are more important in molluscs and they are soft bodied
animals. These animals have undergone a peculiar reorganization in their basic anatomy. Studies on the morphology, anatomy and histology of *P. viridis* can be helpful for comparing species of mussels belonging to the family *Mytilidae*. So, the anatomical studies are directly related to the animal’s mode of life (Stella *et al.* 1992). Only a few studies are related to morphology, anatomy and histology and hence the present study.

Estimation of biochemical-constituents like protein, carbohydrate and lipid will help to assess their nutritional value of the species. Xavier (1996) reported that a newer species should be recommended for human consumption only after assessing the nutritive value of the species with regard to its nutritional merits. Shell fish also provide high quality protein with all the dietary essential amino acid for maintenance and growth of the human body. For this reason, shell fish should be considered a low fat, high protein food that can be included in low-fat diet (King *et al.* 1990). Bivalves 'as seafood' are considered important next to fish and prawn from the nutritive point of view. They have been consumed for thousands of years (Li *et al.* 2007). *P. viridis* has been a culturable species and a cheap protein source in many Asian countries including China, Philippines, Thailand and India (Wong and Cheung, 2001). Rochanaburaman (1980) reported that the green mussel (Tahong in Tagalog) *P. viridis* was formally known as *Mitylus smaragninus*. It is popularly consumed by man and the latter is used as
food for other economically important species such as *Penaeus monodon* and *Scylla serrata*. The green mussel, *P. viridis* enjoys a wide distribution along the west coast and east coast of India and has good economical potential. Babu *et al.* (2012) reported that the bivalves in the coastal line could form an important source of food, raw material for village industries indigenous medicine, etc, and it is widely used as a cheaper food source for coastal area people. Among the bivalves, mussels are eaten mainly cooked, as starter or as a main dish, and in these forms, offer more consumption opportunities than oysters (Girard and Mariojouls, 2003). Mussels’ consumption is considered popular and convivial by many and the recent attention to value adding operations match growing consumer expectations about convenience and quality. Moreover, the importance of away from home consumption is significant and reflects the popularity of “mussels and chips” dishes served in many restaurants and brasseries (Girard and Mariojouls, 2003). Marine invertebrates are known to store biochemical energy in the reproductive and or somatic body parts to be utilized during different phases of the life cycle (Giese, 1969). While reviewing the biochemical composition of the molluscan body, he stated that the biochemical constituents of the body parts would be more informative than the study of the whole body. A few literatures are available regarding the seasonal variations in the biochemical composition of the individual body components of bivalves, accordingly studies on biochemical of *P. viridis* assumed importance.
The marine environment is the ultimate receptacle for most chemical contaminants originating from land-based activities, such as agriculture run-off, industries, power plant effluent discharges, residential activity, fishing and boating. Earlier reports also documented that although sea foods are rich sources of vitamins, minerals, proteins and omega-3 polyunsaturated fatty acids, they are also major source of trace metals (Sidhu, 2003; Nasreddine and Parent-Massin 2002). Marine animals can uptake and accumulate heavy metals in both dissolved phase and dietary source, and in the process of uptake or bioaccumulation, animals themselves will adjust to a variety of physiological mechanisms of tolerance to resist the toxic effects of heavy metals, including releasing organic compounds to form extracellular complexes with metal ions, increasing the synthesis of metallothionein (MT) for metal homeostasis and detoxification (Grill et al. 1985; Cajaraville et al. 2000; Berthet et al. 2003). To reveal the presence of pollutants and to measure their toxic effect biological indicators can be used, which are suitable for prediction of the expected toxic influence of known or unknown substances. Metals’ accumulations in living organisms lead to concentrations of several orders of magnitude higher than those of the surrounding water (Casas et al. 2008). Despite this the relationship between the concentration of a metal in the aqueous phase and in an organism is far from straightforward as the accumulation ratio depends on many factors; some of
them have an environment origin (temperature, pH, salinity, etc.), whereas others, are related to biological factors like age, sex, sexual maturity stage, etc., (Mubiana et al. 2006).

Bivalve molluscs are the most widely used bioindicators, in monitoring studies (Goldberg et al. 1975, 1983; Phillips, 1990; Lau and Wong, 2003; Krishnakumar et al. 2006 and Verlecar et al. 2008). In this respect, *P. viridis* has been used as a biological monitoring of metal pollution in tropical and subtropical coastal waters (Chong and Wang, 2001). It represents one of the most effective and informative methods to detect and to identify marine contaminations and characterize the possible effects of contaminations on biological resources and the quality of their marine habitats. However, the metal level in the different soft tissues of *P. viridis* has not yet been as widely reported as those in the total soft tissue. However, information on levels of trace metals in natural populations of green mussel *P. viridis* from south east cost (Tranquebar, Thirukkadaiyur and Thirumullaivasal) of Nagapattinam district is lacking. Hence the present study was planned to assess the levels of selected trace metals like Fe, Mn, Zn, Cu, Cr, Cd, Pb and Ni in water, in different body parts and whole animal tissues of male and female *P. viridis* from various habitats. Hence the present investigation was carried out.
Length-weight relationship (LWR) is of great importance in fishery resource assessment (García et al., 1998; Haimovice and Velasco, 2000; Park and Oh, 2002) and further the length and weight are two basic components in the biology of species at the individual and population levels. Le Cren (1951) reported that LWR serves two purposes viz; (i) To establish a mathematical relationship between two variables (L&W) and (ii) To know variation from the expected weight for various length groups. In molluscs, the growth rate of various body characteristics is not uniform, with the result that the relative proportions of the body change with an increase in body size. Growth rate in mussels vary not only from place to place but also within the same population. Hickman (1979) stated that mussels growing on shore were wider, less high, and heavier and increased slower than mussels grow in suspension. Brown et al. (1976) working on a population *M. edulis* from northern Ireland concluded that size dimensions were generally more variable and shell thickness is generally greater in the intertidal species.

A number of factors induce morphometric change in bivalves. These include season (Mason, 1969; Page, 1988), temperature (Almada Villela et al., 1982; Thompson, 1984; Lee, 1986) salinity (Lee 1986; Kauutsky et al., 1990; Margus, 1991) age and size of mussel (Mossop, 1922; Seed, 1968), light (Stromgren, 1976; Neilson and Stroemgren, 1985), Population density (Harger, 1972; Hosomi, 1987),
food supply and tidal height (Yamada, 1989), Pollution (Seed and Richardson, 1990). The growth lines on the shells of temperate molluscs are said to be the valuable pointers of age. But in tropical waters, on account of limited variations in environmental parameters, much difference in growth line is not discernible (Rajagopal, 1982; Shuchuan Lee and Shyn-Minchao, 2003; Shu-chuan and Shyn-Min choo, 2004; Gaur, 2005). The change in growth rate between one part and the whole organism is termed as allometry. As there is no previous work on LWR and Allometry in *P. viridis* from the Nagapattinam coast waters these aspects was also undertaken presently.

In view of the above considerations the present work was designed with the following objectives:

### 1.2 Objectives of the study

1. To study the population density of *P. viridis* in the study area

2. To estimate the influence of environmental factors (rainfall, temperature, salinity, dissolved oxygen and pH) and nutrient contents (phosphate, nitrate, silicate and calcium) on the population distribution of *P. viridis* in the study area

3. To update our knowledge on morphology, anatomy and histology of the study animal
4. To estimate the biochemical composition on selected organs and whole animal in respect of protein, carbohydrate and lipid

5. To analyze the accumulation of trace metals in water and their bio-concentration factors in different soft tissues of *P. viridis* in the sampling areas

6. To observe the length-weight relationship, and allometric relationship among various morphological characters of *P. viridis*
1.3 Review of literature

The literature relevant to the current study was collected and arranged as follows:

### Studies on population density

#### Indian region

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**Other than Indian region**

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## Hydrographical studies

### Indian region

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**Other than Indian region**
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1.4 Description of study area

The study was carried out in three stations of Nagapattinam district. The stations were fixed on the basis of variation in soil characteristics and pollution load and distance (Fig.1 & 2).

**Station 1 (Tranquebar)** (Long 79° 8’ E, Lat. 11°O’ N)

The station 1 is an intertidal rocky shore area, situated about 300 km south of Chennai. The coastal line along Tranquebar is a gently sleeping sandy beach without crops of weed covered slippery rocks between stretches of firm sand and masses of bricks and boulders from the ruins of an old 17th century Fort. The seaward face of which is now damaged and submerged due to encroachment by the sea. Besides these, ruins of a temple also produced many boulders and rocky portions which lie buried in the intertidal sands about 30–50 meters from the submerged Fort walls. The wave beaten cliffs along the beach cover a distance of 20-30 meters and extend into the sea about 5-10 meters below the low tide mark. The boulders and brick blocks located at the mid littoral zone are subjected to considerable wave action and water movements during ebb and flow. *P.viridis* inhabits the boulders and forms a thick carpet like growth on rocky surface and also binding in crevices and Uppanar estuary joints Bay of Bengal on the Tranquebar coast, which is 2 km away from the study area. During monsoon season the estuary is flooded by fresh water,
During the dry summer, estuarine mouth is often closed by formation of sand bars (Fig. 3, 4 & 5).

**Station 2 (Thirukkadaiyur)** (Long 79° 51’ E, Lat 11° 4’N)

A thermal power plant located area, Thirukkadaiyur is 5 Km away from station 1. It contains a number of concrete pillars towards the seaside for intake of water and also releases effluents into the sea. This area is dominated by wet agricultural lands, Irrigated by the river Cauvery and its tributaries Viz., Manjalar (Ammanar) as the major water source. Because of very large scale agricultural operations the area is called as “Granary” of Nagapattinam district. The study area bottom is consisting of sandy soil. The thermal power plant pillars are actually located along the coast line with gentle sleep sandy beach without crop of weeds. This nature of the shore provides shelter for various sandy inhabitants. The pillar of study area also provides shelter for lot of gastropods and bivalves. *P. viridis* attach to the surface of pillars by byssus threads colonizing submerged during high tide and exposed at the time of low tide. The depth of the study area is 1 to 2 m from the sea surface. Here also, a small scale of fishing activity is carried out by local fisherman groups for their local market (Fig. 6, 7 & 8).
Station 3 (Thirumullaivasal) (Long. 79°50’ E, Lat 11° 14’N)

It is one of the famous fish landing centre in Nagapattinam district. It is located 24 km away from station 1. Fishing is the main activity here. The fishermen communities mainly depend on the finfish, shellfish sales for their lively hood. They set a small sales market at the time of landing on the shore bank itself. The study area comprises of Uppanar estuary which enters to the Bay of Bengal. The estuary is considered to be a resourceful place for phytoplankton and zooplankton and also has rich potential for fin and shell fish production. This area is highly influenced by fresh water inflow throughout the year. The study area is subjected to long term fluctuations in physico-chemical features depending upon the seasonal tidal amplitudes and fresh water influx resulting in a continuous exchange of organic, inorganic plants and animal matters. The sea grass and damaged wood particles, mangrove roots and boat basal parts are the suitable places for the growth of *P.viridis*. The local people are interested to consume the study animal instead of other protein rich products (Fig. 9, 10 & 11).

Four seasons could be recognized at the study area based on rainfall viz., summer (April to June), pre monsoon (July to September),
monsoon (October to December) and post monsoon (January to March). The north east monsoon brings in heavy rainfall to the study area and is the deciding factor of the nature and extent of various seasons.