Chapter 1

GENERAL INTRODUCTION

CONTENTS

"***Biodiversity is our most valuable but least appreciated resource.***"

E. O. Wilson, *The Diversity of Life*

1.1 Biodiversity: Concept & Level

"Biodiversity" is a frequently used term in the field of science and is very popular with society. In the last few decades, biodiversity concerns have been at the center of conservation efforts globally. This term has been defined in 12 formal published definitions (Gaston and Spicer, 2004). Among these, the most significant and far-reaching of these is that contained in the Convention on Biological Diversity (CBD). The convention states that "Biological diversity" is defined as the variability among living organisms from all sources including the inter-alia, terrestrial, marine, and aquatic ecosystems and the ecological systems of which they are key components; this includes diversity within species, between species, and the ecosystem (Convention on Biological Diversity, 1992) or in simple words "the variety of life." The biological diversity is recognized at three different levels (species, genetic, ecosystem), but usually, only one is investigated, which is species diversity. All levels of biodiversity are interconnected, and impact at any level can trigger responses from the other components of biodiversity.

Species diversity is the variation and abundance of species or organisms in certain habitat or region. The evolution of species has probably been because of habitat diversity. This diversity could be assessed by the number of species present in a particular region. The term biodiversity is commonly used as a synonym for species diversity. It is simply referred to as the species' richness in terms of the number of species in a site or habitat. Global diversity is usually expressed by the total number of species of different taxonomic groups. As mentioned earlier, approximately 1.4 million species have been described.

Genetic diversity is the combination of various genes within species and between species. It includes genetic variation between different populations of single species and the genetic variation within the single population. Genetic variations can be measured using recent techniques such as allozyme analysis, DNA fingerprinting, and DNA sequencing.

Ecosystem diversity is a variety of habitats that occur within a defined region. The depletion of ecosystem diversity may be considered the ultimate cause of the loss of species and genetic diversity. Community diversity is used as a synonym for ecosystem diversity. It should not be confused with habitat diversity, commonly used for different species of animals with different habitats.

Biodiversity and ecosystem functioning are directly linked to human wellbeing through ecosystem services. In the widest sense, they benefit societies from ecosystems (Millennium Ecosystem Assessment, 2005). Nowadays, Biodiversity and ecosystem services are declining worldwide; thus, there is a need to protect biodiversity for human society. Biodiversity is the basic requirement for human existence. In order to meet the need for food, health, and other necessities of the growing human population, it is of prime importance. There are diverse biodiversity regions, but the marine ecosystem is considered the most diverse, productive, and significantly valuable. Man depends on this ecosystem and its organisms to harness the energy, food, medicine, fuel, fertilizer, and many other industrial products.

1.2 Marine Ecosystem and Biodiversity

Oceans cover about 70% of the planet's surface and hold an abundance of biodiversity, with marine and coastal environments being home to 97% of all species on earth. Marine ecosystems and their biological diversity are essential for life on earth. They play a crucial function in global nutrient recycling and climate regulation and provide humans with a wide range of resources and services. Globally, life in our seas produces one-third of the oxygen we breathe, and human consumption of seafood makes up our animal protein supply and is particularly important as a protein source for the population in developing countries. Marine ecosystems are fundamentally different from terrestrial and freshwater ecosystems. The biomass per unit area in the marine ecosystem may be less than in terrestrial or freshwater ecosystems, but it should be remembered, however, that the terrestrial systems are essentially two-dimensional, with the majority of living material concentrated in 10–100 m thick layer only. On the other hand, the oceans have an average depth above 3500 m, and almost two-thirds of the Earth is deep-sea, with 84% of the ocean area and 98% of its area below 2,000 m (Costello et al., 2010). About 250000 valid marine species (non-microbial) are described and, like many other species, still waiting to be described. Life in the deep sea is complex, dynamic, and specialized. The biological diversity is not equally distributed over the different coastal habitats; like sandy and muddy shores are less diverse in terms of biodiversity because of the absence of surface for attachment and limited food sources; than salt marshes and rocky shores which have medium diversity, while the estuaries and lagoons are richly diverse, as they also function as a shelter, breeding and nursery grounds for many species. The mangrove and coral reef sustain high species diversity. The Indo-Pacific region possesses the world's highest marine biodiversity in terms of species richness and unique ecosystems (Keyse et al., 2014).

India is one of the 12 mega-diverse countries globally and supports four terrestrial biodiversity hotspots, highly biodiversity-rich, but endangered eco-regions (Myers et al., 2000). India's coastline is about 7516.6 km long, with the mainland contributing 5422.6 km and the offshore islands contributing 2094 km (Andaman and Nicobar Islands: 1962 km; Lakshadweep Islands: 132 km) (Ahmad, 1972; Kumar et al., 2006). The Indian coastline consists of 43% of sandy beaches, 11% of the rocky coast, and 46% of mudflats and marshes (Kumar et al., 2006). The coastal area is divided into the west coast and the east coast. Both the coasts are significantly different in their geo-morphology. India's western coast is occupied by the rocky shore habitat, while the east coast of India mostly has sandy beaches, mudflats, lagoons, and marshes. In India, the marine biodiversity research work has been going on for a long time, and there are several marine groups studied well by many researchers. However, there are numbers of living and endangered (some extinct) organisms, about which there is no proper literature available. There are more than about 17,802 species of marine flora and fauna occurring in Indian waters. Among fauna, the maximum diversity is reported for Mollusca (3, 370 sp.), followed by Crustacea (2, 394 sp.).

Crustaceans exist in the fourth-largest diversity, and they are the second most abundant diverse animal group on the planet. They abundantly inhabit the coastal marine environment of the tropical and subtropical regions. Their distribution ranges to an abyssal zone depth of 6000 and up to 2000 meters above average sea level in the mountains in the marine ecosystem. Decapods crustaceans are the most common invertebrates inhabiting the coastal marine habitat. Out of all the decapods crustaceans living in the different marine habitats, one of the best known and most interesting target groups is the shrimp.

Gujarat is the western proximity of India and harbors the longest coastline of approximately 1650 km. The state's coastline is divided primarily into three coastal areas, *i.e.,* the Gulf of Kachchh, the Saurashtra coast, and the Gulf of Khambhat. The first study on marine biodiversity was undertaken by Hornell (1916), who studied marine faunal diversity in the coastal area of Okha Mandal and the Gulf of Kachchh. In 2002, NIO reported marine biodiversity mainly, the Gulf of Kachchh. They reported 200 fish species, 5 sea turtle species; 3 species of marine mammals; 70 sponge species; 200 species of molluscans; 27 prawn species, 15 species of echinoderm, and several crab species. ICMAM (2002) has listed 32 gastropod species: 31 bivalve species, 2 crustacean species, 2 Anthozoa species, 2 Scaphopoda, a few Polychaetas, sponge, and coral species from the Gulf of Kachchh. Recently Trivedi et al. (2015) reviewed crustacean fauna and compiled a checklist of 157 species (Table 1.1). The marine fauna of Gujarat is rich and varied. Gujarat's coastline encompasses almost all types of intertidal habitat, from hyper-saline, estuaries, salt marsh, mudflats to sandy and rocky shores with every degree of exposure and widely different profile. The subtidal habitats are equally diverse and abundant.

Table 1.1 Crustacean diversity of Gujarat state with India's comparison (Radhakrishna et al., 2012; Trivedi et al., 2015; Venkataraman and Raghunathan, 2015; Samuel et al. 2016).

Species group	**No of Species (Gujarat)**	**No of Species (India)**
ssIsopods	1	33
Amphipods	1	132
Barnacles	2	104
Anomuran crabs	6	162
Brachyuran crabs	113	250
Prawn and Shrimp	30	364
Lobsters	3	30
Stomatopods	1	139
Total	**157**	**1214**

1.3 Study Model- Prawn and Shrimp

Prawns and shrimps belong to Order Decapoda, infraorders Dendrobranchiata and Pleocyemata, respectively, and they are one of the most important and diverse crustacean groups. Prawns are the most significant food source with great economic importance as both capture and culture fisheries. Shrimps also have been attractive due to their high diversity throughout their evolutionary history and ornamental values. Some species may not have commercial value but are important to form an integral part of the tropical marine system's food web. They are widely distributed in marine, brackish, estuarine, and freshwater systems from the equator to the Polar Regions. The commercial marine species are generally found in shallow or moderately deep-water regions along the continental shelves at less than 100m depth, and some are found even at nearly 5700m depth. Many shrimp species are pelagic, but most of the species are benthic, living on various hard and soft substrates like rock, mud, sand, shell particles, or a mixture of these fragments species are symbiotically associated with other marine organisms.

The terms' shrimp' and 'Prawn' are not related to any known taxonomic taxa**.** Although the term "shrimp" is used for the smaller species, while "prawn" is for the larger ones. There is no clear difference between both words and usages throughout various countries and regions that is often ambiguous or reverse. **In this study, the terms 'shrimp' is used for smaller species (suborder Pleocyemata) and 'prawn' for larger species (suborder Dendrobranchiata).**

1.4 Review on the History of taxonomy and systematics of prawns and shrimps

Early classification of the Order Decapod grouped all shrimp-like decapods into a single group, Natantia, referring all its members to the common adaptation to swimming. The remaining decapods have all been grouped into the Reptantia, due to the "epibenthic nature" of its members (Bauer, 2004). Natantia was identified as paraphyletic. The present classification scheme for the decapod includes two suborders: Dendrobranchiata and Pleocyemata. Dendrobranchiata consists mainly of shrimp-like decapod groups, while Pleocyemata, apart from shrimp-like decapods (Carideans and Stenopodideans), includes lobster and crab-like decapods. Natantia's monophyletic grouping was also dismissed.

The early classifications of order Decapoda were reviewed by Spence Bate (1888), Borradaile (1907), Calman (1909), Balss (1957), Glaessner (1969), Felgenhauer and Abele (1983), and in detail by Monod and Forest (2012).

They reviewed, based on the available names, classification, and their detailed hierarchies. De grave et al. (2009) mentioned the taxon authorities, author names, and most of the discussion was about those names specified by the International Code of Zoological Nomenclature (ICZN) and the names of the family group.

The common ancestor of all decapods is thought to have been shrimp-like. Therefore, lobster and crab classes reflect overall morphological conditions derived from them. Both morphological and molecular phylogenetic studies support shrimp-like decapods' fundamental position within the order (Abele and Felgenhauer, 1986; Chace, 1992; Porter et al., 2005), as does the fossil records (Feldmann and Schweitzer, 2010; Jones et al., 2014). The relationship between and within the different shrimp-like suborders of decapods is not conclusive. Although both Dendrobranchiata and Pleocyemata monophyly are well supported in previous works (Burkenroad, 1983; Chace, 1992; Bracken et al., 2009a, 2009b; Tavares et al., 2009), the precise relationship between Caridea, Stenopodidea, and Reptantia (a monophyletic group) is unclear, as are the relationships of the families within Dendrobranchiata, Stenopodidea, and Caridea (Fransen and De Grave, 2009). In the last few decades, the systematic order Decapoda is getting stable due to various morphological and molecular tools. The taxonomy of suborder Dendrobranchiata has not changed much apart from adding a few new genera and species (Pérez Farfante and Kensley, 1997). The suborder Dendrobranchiata is currently represented by 533 species belonging to 68 genera and 9 families (De Grave and Fransen, 2011).

Thalassinidea group of decapods has been subject to much controversy for a long time; the relationships between subordinated families have not been studied carefully and unambiguously established. They were unified for many years under the name thalassinidea and considered as infraorder Anomura. Thalassinidea were split into four families: Axiidae Huxley, 1879, Laomediidae Borradaile, 1903, Thalassinidae Dana, 1852, and Callianassidae (Borradaile, 1903). In the late twentieth century, based on morphological data Thalassinide separate from Anomura and comprising three superfamilies Thalassinoidea, Callianassoidea, and Axioidea (Poore, 1994). The recent classification separated the paraphyletic group Thalassinidae into two infraorders, originally described by De Saint Laurent (1979a, 1979b) as **Axiidea** and **Gebiidea**. Based on the phylogenetic (morphological and molecular) hypotheses, all the families are divided between these two infraorders. Families: callianassidae, callianideidae, ctenochelidae, micheleidae, strahlaxiidae considered under axiidea and other families, namely, axianassidae, laomediidae, thalassinidae, and upogebiidae considered under Gebiidea. Infraorder Axiidea and Gebiidea are currently represented by 423 and 129 species, respectively (De Grave et al., 2009).

The classification of infraorder Caridea Dana, 1852 has been revised many times due to the huge diversity (Ortmann, 1890; Alcock, 1901; Borradaile, 1907; Calman, 1909; Bouvier, 1917; Holthuis, 1955; Balss, 1957, Chace, 1992, Holthuis, 1993). Christoffersen (1986, 1987, 1988a, 1988b, 1989, 1990) published a series of publications and suggested caridean systematics changes. Bracken et al. (2009a) recently questioned the superfamily arrangement within caridea. The current classification system is based on adult external morphological characteristics established by Chace (1992) and Holthuis (1993). Infraorder caridea currently contains 3438 species belonging to 389 genera and 39 families (De Grave and Fransen, 2011).

Systematic of Infraorder **Procarididea** Felgenhauer and Abele, 1983 have been attracted interest and debated since it was described. Chace and Manning (1972) established the genus *Procaris*, the family Procarididae, and separate superfamily Procaridoidea within infraorder Caridea. They highlighted several common morphological features in Dendrobranchiata and Stenopodidea. Later in 1983, Felgenhauer and Abele recognized four major taxa Dendrobranchiata, Caridea, **Procarididea,** and Stenopodidea based on a comparative morphological dataset. Infraorder Procarididea currently contains 6 species belonging to 2 genera and 1 family (De Grave and Fransen, 2011).

Infraorder **Stenopodidea** Spence Bate, 1888, was separated from the other taxa based on the exception of trichobranchiate gills. However, many of the proposed characters do exhibit some overlap with either Dendrobranchiata or Caridea. Up to 1986, this group consisted of a single-family (stenopodidae Claus, 1872). In 1986, Schram separated them into two based namely stenopodidae (comprising mostly free-living species) and spongicolidae (comprising mostly of sponge-associated species). In 2006, Alvarez and his team described a new family Macromaxillocarididae from an anchialine cave in the Bahamas. Infraorder Stenopodidea currently contains 83 species belonging to 12 genera and 3 families (Chen et al., 2016).

The prawn and shrimp fauna have been studied extensively for taxonomical and systematic research worldwide. So many researchers have compiled the list of shrimps and prawns from the different regions of the world at different periods (Alcock, 1901; Alcock, 1905; Alcock, 1906; Holthuis, 1980; Chace, 1992; Holthuis, 1993; Dworschak, 2000; Kazmi and Kazmi, 2010; Yaldwyn and Webber, 2011; Poupin et al., 2013). The taxonomy of prawn and shrimps is very confusing because of the cryptic species, and many synonyms are available for different species, so the compilation of valid species is needed. De grave et al. (2009) compiled a list of living and fossil genera of decapod crustaceans, and they listed 4492 species of prawn and shrimp. Recently De Grave and Fransen (2011) have reviewed detailed literature published on Dendrobranchiate, Stenopodidean, Procarididean, and Caridean shrimps from around the world and reported 4048 valid species belonging to 471 genera. The Caridean shrimps are a highly diverse and second commercially important group. Most commercial shrimps and prawns belong to the superfamily Penaeoidea (Dendrobranchiata); currently, there were only less than 300 species of prawns and shrimps of global economic value, and only about 100 of them majorly share of the annual world catch (Chan, 1998).

The research work on prawn and shrimp fauna of India has a long history. The first study was initiated by Fabricius (1775), who described a new species *Alpheus malabaricus*, from the Malabar Coast of the western region of India. He also described the three species of the *Palaemon* genus and two species of the *Alpheus* genus from "Indian Orientali" without mentioning the type locality (1798). In 1830, H. Milne Edwards described a new species, *Acetes indicus*. Later, Milne Edwards (1834) reported seven species of penaeid prawns like *P. monocerosl, P. indicus, P. monodon, P. affinis, P. brevicornis, P. crassicornis, P. styliferus,* and a species of sergestid, *Acetes indicus* from coastal waters of India. In 1857, Guérin-Méneville described *Alpheus rouxii* (=*Alpheus lottini* Guérin-Méneville, 1838) from Bombay (Maharashtra state). Heller (1865) reported three new species of Caridea shrimps, *Alpheus crassimanus* (=*Alpheus lobidens*), *Anchista notata* (=*Harpiliopsis depressa*), and *Leander distans* (nomen dubium) from the east coast of India. He also reported *Hippolyte gibbosus* from Nicobar Island, which is now accepted as *Saron marmoratus* (Olivier, 1811). Miers (1878) reported five species of penaeid prawn from India, including two species *Penaeus dobsoni* (=*Metapenaeus dobsoni*) and *Penaeus hardwickii* (=*Mierspenaeopsis hardwickii*) from Mangalore, west coast of India. In 1881, Bate reported seven species of penaeid and one species of sergestid shrimp from Indian waters. Later, Wood-Mason, and Alcock (1891a) described a new species *Sergestes rubroguttatus,* now accepted as *Deosergestes rubroguttatus*. Henderson (1893) documented nine species of palaemonid prawns, one species of *Caridin*a, six species of alpheids, one species of genus *Rhynchocinetes* from Tamil Nadu during the studies on the carcinological fauna of India. Remarkable work on deep-sea shrimps was carried out during the marine exploratory survey by Royal Indian Marine Survey Ship "Investigators" at the end of the 19th century. The specimens obtained during this expedition were described and published in a series of papers by Wood-Mason and Alcock (1891a-c), Alcock, and Anderson (1894, 1899), Alcock (1901, 1905, 1906) from Indian waters.

In 1903, Nobili recorded 9 penaeid prawn species from Chennai, Pondicherry, Bombay, and Mahe regions. Later, Coutière (1903, 1905, and 1921) documented 30 species of Alpheid shrimps, of which ten species were then newly described from the Lakshadweep Islands. Alcock (1906) published a comprehensive catalog of penaeid prawns of India. Kemp (1915), while studying the fauna of Chilika Lake (Odisha), described six species *Pontophilus hendersoni* (=*Philocheras hendersoni)*, *Periclimenes demani (=Cuapetes demani)*, *Urocaris indica* (=*Phycomenes indicus*), *Ogyrides striaticauda*, *Alpheus paludicola* Kemp, 1915 and *Athanas polymorphus* Kemp, 1915. He also documented 39 species of pontoniine shrimps from Indian waters, which is considered a major addition to the list of Indian caridean shrimps (Kemp, 1922). He contributed to the first occurrence of *Rhynchocinetes hendersoni* in Indian waters, from the Gulf of Mannar, Andaman, and Nicobar Islands (Kemp, 1925; Radhakrishnan et al., 2012), which was recently reappointed as *Cinetorhynchus hendersoni* (Kemp, 1925). In 1930, Gravely reported four species of *Alpheus* and one species of *Synalpheus* from Kursadi Island (Tamil Nadu state). Natarajan (1942) documented 12 penaeid prawns and four sergestid shrimps from the Travancore coast. Lebour (1938) described a new species *Synalpheus herdmaniae*, from Tuticorin. Pillai (1954) reported *Callianassa maxima* and noted the natural history aspect of *Thalassina anomala* from the Gulf of Mannar. Kunju (1960) reported five species: *Parapenaeopsis hardwickii (=Mierspenaeopsis hardwickii)*, *Atypopenaeus compressipes*, *Parapenaeopsis acclivirostris* (=*Batepenaeopsis acclivirostris*), *Metapenaeopsis novaeguineae,* and *Trachypenaeus curvirostris* (=*Trachysalambria curvirostris*) first time from the west coast of India (Bombay). The occurrence of symbiotic crustaceans associated with other echinoderms was also recorded from the Gulf of Mannar (Sankarankutty 1962) and Andaman and Nicobar Islands (Sastry, 1977, 1981). George and George (1964) documented the caridean shrimp, *Thalassocaris lucida,* in the stomach of *Neothunnus macropterus* (fish). Rao and Kartha (1966) reported ghost shrimp *Callianassa (Callichirus) audax* de Man, 1911, from the Southwest coast of India with the description of the male specimen. In

1976, Thomas documented four species of the genus *Alpheus* from the Southeast and Southwest coast of India. Bhuti (1976), in his unpublished thesis, reported a total of 15 species of Alpheids, including two new species from the western coast of India. These species are *Alpheus sankollii* and *Alpheus banneri,* which are not accepted on WoRMS. George and Muthu (1968b) gave a taxonomic note of genus *Metapenaeopsis,* including a new record of *M. barbata* (De Haan) from Indian waters. *M. barbata* can be easily differentiated from the other closely related species based on the absence of a basial spine on the second pereiopod. During the period, they described a new species of *Solenocera waltairensis* from the east coast of India (George and Muthu, 1968a).

During the International Indian Ocean Expedition, Menon and Williamson (1971) documented the taxonomy and distribution of 3 species of the genus *Thalassocaris* with a description of new species *Thalassocaris obscura* from Indian waters based on the adult and their larvae. Mohamed and Rao (1971) also documented 32 species of prawns and shrimps from Cochin Backwaters. In 1970 Thomas, the first time recorded the species *Metapenaeopsis borradaili* (De Man) from the Minicoy Island (Lakshadweep). In 1970, Sankolli studied the Thalassinoidea of Maharashtra state and reported four species, *i.e., Laomedia astacina*, *Callianassa (Callichims) kewalramanii* (=*Balsscallichirus masoomi*), and *Upogebia kempi* and *Thalassina anomala.* Later, He described a new species *Upogebia (Upogebia) kempi* Sankolli, 1972, a junior synonym of *Upogebia kempi* Shenoy, 1967 (Sankoli, 1972). George (1972) recorded the zoogeographic distribution of Indian penaeid prawn species. In 1972a, Muthu described a new species *Parapenaeopsis indica* (=*Mierspenaeopsis indica*) from Kakinada, the East coast of India. At the same time, he redescribed the *Metapenaeopsis gallensis* (Pearson, 1905) from Indian waters and compared it with the closely related species (Muthu, 1972b). Thomas (1972) described a new species *Trachypenaeopsis minicoyensis,* from Lakshadweep.

George et al. (1973) reported five species; *Periclimenes (Periclimenes) rex (=Periclimenes rex)*; *Leander urocaridella* (*Urocaridella urocaridella*); *Rhynchocinetes durbanensis*, *Synalpheus stimpsonii,* and *Stenopus hispidus* from the Gulf of Mannar, East coast of India. Thomas described a new species Achuthankutty, and George (1973), and Achuthankutty and Nair (1976) described two new species of the genus *Acetes, i.e., A. sibogalis* and A*. orientalis* from Cochin backwaters and Goa, respectively. Thomas (1974) reported three penaeids species and one species each of alpheid and gnathopsyllid shrimps from the Lakshadweep Islands. In 1976, Silas and Muthu described a new species *Metapenaeus krishnartii,* from the Andaman Islands. Pathan and Jalihal (1977) studied the importance of some penaeid prawn genera of Konkan, northwest coast of India, and revalidated the genus *Mangalura* Miers, 1878 by designating *Metapenaeus dobsoni* as its genotype. In 1978, Kagwade reported *M. kutchensis* from Bombay with a detailed description of thelycum and petasma.

Sankolli and Shenoy (1979) described a new genus and species *Troglindicus phreaticus*, from Ratnagiri, northwest coast of India. Banner and Banner (1979) examined the alpheids collection collected during the International Indian Ocean Expeditions in 1962-1964. They reported ten species from India. George attempted a comprehensive review of Indian prawns in 1979. In 1980, Lalitha Devi documented three caridean prawns from Kakinada, *i.e., Heterocarpoides levicarina (=Procletes levicarina), Pandalus longicauda (Plesionika longicauda*), and *Pontocaris pennata.* In 1984, Rao documented two species *Funchalia villosa* and *Funchalia balboae* (=*Pelagopenaeus balboae*) from the Southwest Arabian Sea. Jayachandran and Joseph (1989) discussed the palaemonid shrimps of the southwest coast of India. In 1990, Suseelan, documented two species, namely, *Heterocarpus sibogae* and *Plesionika williamsi* first time from off Kollam, Kerala coast. Out of these two species, *P. williamsi* was a new record from India. Ramaseshaiah and Murthy (1991) recorded *Metapenaeopsis tolensis* from the Coromandel Coast. Achuthankutty and Nair (1993) reported two species, namely, *Penaeus japonicus and Penaeus canaliculatus, the* first time from the Goa waters. Reddy (1995) reported seven palaemonid species, five species of alpheid, two species of atyid, and one species of pasiphaeids from Chilika Lake, Odisha. Suseelan (1996) recorded 118 species of prawns contributing to India's commercial prawn fisheries.

In 2003, Ramakrishna and Talukdar listed 27 species belonging to 3 families and 7 genera from the Digha coast of West Bengal. Chanda and Bhattacharya (2002, 2003, 2004) described three new species, namely, *Melicertus similis* (*Penaeus similis*), *Fenneropenaeus konkani* (=*Penaeus Konkani*), and *Parapenaeopsis longirostris* from the Indian coast. Dineshbabu (2004) documented a new record of *Parapenaeus fissuroides indicus* from the Indian waters with notes on fisheries and biology. Jayachandran (2005) recorded the presence of 46 species of marine palaemonid shrimps from the Indian seas. Karuppasamy et al. (2006) recorded 29 species belonging to 19 genera and 11 families from the eastern Arabian Sea. Kathirvel et al. (2007) reported 84 species of commercially important penaeid shrimps from India and added notes on their economic importance and geographic importance. Kurup et al. (2008) were reported 11 species of deep-sea shrimps from the Kerala coast. Jayachandran (2010) listed 59 species of palaemonid shrimps with the taxonomic and distribution notes. Komai and Shanis (2011) described a new species *Parastylodactylus sulcatus* based on three male specimens from India's Southwest coast. In 2011, Prakash and his team reported *Pycnocaris chagoae* shrimp associated with sea cucumber (*Labidodemas* sp.) from Lakshadweep Islands. Shanis et al. (2012) listed 24 species of Pandalid belonging to 6 genera with a new record of *Plesionika adensameri* from India. In 2014, Pillai and his coworkers observed the monthly and seasonal diversity of crustacean bycatch of the CFH (Chennai Fisheries Harbour) from June 2005 to December 2009. They listed 16 species of prawn. Pillai and Thirumilu (2013) rediscovered the *Glyphocrangon investigatoris* Wood-Mason and Alcock, 1891 from Indian water after a century. Later Rajakumaran and Vaseeharan (2014) surveyed 59 species of penaeidae shrimp observed along the Southeast coast of India.

Vaitheeswaran (2014) has reported the occurrence of *Axiopsis consobrina*, in the Gulf of Mannar. Prakash et al. (2015) documented 6 species of caridean shrimps from the Gulf of Mannar and Lakshadweep. Four species, namely, *Ancylomenes magnificus*, *Periclimenes soror*, *Stegopontonia commensalis*, *Gnathophyllum americanum,* and *Gnathophylloides mineri* are new records from the Indian water. Prakash et al. (2016) listed 16 species of coral reef caridean and stenopodid shrimps from Indian water with additional ornamental status remarks. They have reported three species, namely, *Stenopus hispidus* Olivier, 1811, *Lysmata debelius* Bruce, 1983, and *Lysmata amboinensis* De Man, 1888, from the Gulf of Mannar, Tamil Nadu based on morphology and color pattern.

Rath and his coworkers consolidated a checklist of 49 species of prawns of the Godavari estuary, Andhra Pradesh, including 6 new penaeids and Palaemonid prawns (Rath et al., 2016). The suborder Dendrobranchiata in Indian waters is represented by 2 superfamilies having 155 species belonging to 54 genera and 7 families. In contrast, three infraorders represent suborder pleocymata: Axiidea (5 species, 4 genera), Caridea (199 species, 78 genera), and Stenopodidea (5 species, 5 genera) having 209 species and 87 genera (Samuel et al., 2016). Yang et al. (2017) reported *Heterocarpus chani* from Southern India and identified the more distinctive characters between *H. chani* and *H. gibbosus*. Purushothaman et al. (2017) reported two species of the genus *Solenocera namely, S. barunajaya* and *S. rathbuni* first time from the Southwest coast. Kuberan et al. (2018a) reported two species of deep-sea shrimp *Parapontocaris levigata* and *P. bengalensis,* from India's southwestern coast. Later they recorded the rare occurrence of the deep-sea caridean shrimp *Pasiphaea alcocki* (Wood-Mason & Alcock, 1891) from Kerala after three decades (Kuberan et al., 2018b). Sathiya and Valarmathi (2018) had assessed the diversity of marine shrimp species along the coast of Nagapattinam, Tamil Nadu, and 10 species were identified. Later in 2019, they recorded a deep-sea caridean shrimp *Glyphocrangon investigatoris* Wood-Mason & Alcock, 1891 from the Arabian Sea. Recently Komai et al. reported two mud shrimp, namely *Upogebia hexaceras* (Ortmann, 1894) and *Upogebia nithyanandan* (Sakai, Türkay & Al Aidaroos, 2015). Bharathi et al. (2019) described a new species *Periclimenella agattii,* from Agatti Island, Lakshadweep. Later Akash et al. described a new species of the genus *Urocaridella* Borradaile, 1915, *U. arabianensis* from the Lakshadweep Islands with the taxonomic comparison on the genus. Jose and his team (2020) reported two species of the genus *Lysmata* Risso, 1816, from the Arabian sea (Lakshadweep Island) viz. *L. hochi* Baeza & Anker, 2008, and *L. amboinensis* (De Man, 1888).

The coastal waters of the **Gujarat state** support a huge diversity of prawns and shrimps. However, this group is less studied than other crustaceans such as the infraorders Brachyura and Anomura. They have been studied for various aspects like fisheries production, catch composition, biology, aquaculture, and socio-economic, etc. by many researchers in different periods (George et al., 1963; Ramamurthy, 1963a; 1963b; Ramamurthy, 1967; CMFRI, 1969; Deshmukh, 1975; Sarvaiya, 1981; Rao, 1983; Pillai and Gopalakrishnan, 1984; Gopalakrishnan et al., 1985; Joseph and Soni, 1986; Gopalakrishnan and Raju, 1987; Gopalakrishnan et al., 1987; Joseph and Soni, 1990; Pravez et al., 1992; Deshmukh, 2006; Pradhan, 2011; Dash et al., 2012; Ghosh et al., 2012).

The first comprehensive study on the taxonomy of prawns of the Gujarat state was carried out by George et al. (1963). They had described a new species of prawn, *i.e., Metapenaeus kutchensis* from the Gulf of Kachchh. Previously it was misclassified as *M. monoceros* or *M. affinis*. In 1964, Ramamurthy reported the distribution of *Metapenaeus stebbingi* Nobili, 1904, from the Gulf of Katchchh. Pérez Farfante, 1987 described a new species form *Pseudaristeus protensus* from Gujarat. George and Rao (1968) described a new species *Metapenaeus alcocki,* from the Gulf of Kachchh. The systematic study on the three species of the genus *Metapenaeus* (*M. alcocki*, *M. krishnatrii,* and *M. kutchensis*) was taken up by Miquel in 1982. Naik et al. (1991) reported 22 species of penaeid prawns and 6 species of carideans shrimps. In 2004, Chanda and Roy reported 14 species of penaeid prawns from the Gujarat coast, of which *Metapenaeus eboracensis* and *M. mastersii* (=*Metapenaeus ensis*) were new records to India. Subba Rao and Sastry (2005) reported 14 species of penaeid prawns and 4 species of carideans shrimps from the Gulf of Kachchh. Saravanakumar et al. (2007) reported *Thalassina anomala* Herbst, 1804, from the Gulf of Kachchh. Trivedi et al. (2015) had reviewed the literature available on the crustacean fauna of Gujarat and compiled a checklist. They reported a total of 30 species belonging to 12 genera and 5 families with the maximum species diversity reported from Saurashtra (25 species) followed by Gulf of Kachchh (21 species) and Gulf of Khambhat (10 species).

Even though **Dendrobranchiata** and **Pleocyemata** classification has a long and rich history, fundamental questions remain about their classification and evolution-even at higher taxonomic levels. Undoubtedly, in the long run, molecular phylogeny can and will further guide our quest for a natural classification.

Systematics takes taxonomic studies a step further by clarifying new approaches and hypotheses that can be used to identify the organism. This classification is based on similarities of traits and possible evolutionary mechanisms. In the 1950s, William Henning, a German biologist, suggested that the systematics should represent the established history of lineages, an approach he called phylogenetic systematics.

1.5 Phylogeny

The history or development of descent from a group of taxa such as species from their common ancestors, including ***branching and sometimes absolute ages of divergence, also applied to the genealogy of genes derived from a common ancestral gene*** **(Futuyma, 1998).**

The term phylogeny was initially used to study the evolutionary relationships between species. According to modern evolutionary theory, all the organisms on earth have originated from a common ancestor, which means that any set of organisms or species, extant or extinct, is related. This evolutionary relationship is called phylogeny. The evolutionary relationships among genes and organisms can be explained attractively using phylogeny. Phylogenetics infers trees from observations about existing organisms using **morphological** and **molecular** data. The different kinds of data can be used to study the evolutionary relationships among genes and organisms. The traditional way to estimate the link between species is to compare their morphological traits (Linnaeus, 1758). Taxonomy is still based mainly on morphology. The increasingly available molecular information, such as nucleotide or amino acid sequences, and restriction fragment length polymorphisms (RFLPs), can also be used to infer phylogenetic relationships. Phylogenetic analysis establishes the relationships between genes or gene fragments by understanding the collective history of the genes or gene fragments

Both the morphology and molecular analysis-based methods are important. The basic bio-molecular hierarchy of all organisms is the same, and the morphology of an organism is the manifestation of its molecular profiles. Thus, the combination of morphological and molecular analysis methods strengthens the exercise of organisms' evolutionary relationship to a great extent.

1.5.1 Morphological Phylogeny

The phylogenic relationships have been traditionally studied based on morphological data. Researchers used different characteristics to establish the relationships between organisms and species. The scientists realized that not all shared traits are useful in evolutionary study. This finding resulted in the form of cladistics. "Cladistics" is phylogenetic relationships based on shared, derived characteristics of organisms. There are two types of characteristics primitive and derived. The primitive traits are characteristics of organisms present in the ancestor of the group of organisms under study. They do not signify anything about species relations within a group as they are inherited from the ancestor to all the group members. Derived traits are characteristics of organisms, which have evolved within the studied group. The ancestor did not have such features. They are very useful because they can help explain why some species have similar characteristics. A possible reason why this trait did not appear in the group's ancestor was that it has originated from a more recent ancestor (Unda, 2005).

1.5.2 Molecular Phylogeny

Molecular Phylogenetics applies a combination of molecular and statistical techniques to infer evolutionary relationships among organisms or genes. Researchers are focusing on molecular phylogenies in contrast to phylogenies based on characteristics like rostrum and telson shape, etc., *i.e.*, morphological characters. With molecular phylogenetics, the differences between organisms or species are measured on the proteins and RNA coded in the DNA, *i.e.,* on amino acid and nucleotide sequences.

The history of molecular genetics dated to the early 1950s when F. Crick, and J. Watson, established the currently accepted model, the double helix of DNA structure. Since then, details of the structure and function of DNA and genes have been settled. Methods for DNA cloning, sequencing, and hybridization developed in the 1970s, and DNA amplification and automated sequencing, which were developed in the 1980s, enhance the development of various classes of DNA markers. The classical molecular technique for studying genetic variation at co-dominant Mendelian-inherited loci is allozyme electrophoresis. The protocol was developed in the 1960s and was dominated until the early 1990s. The first population genetic studies based on the analysis of mitochondrial DNA emerged with the work of Avise et al. (1979). The phylogeny concluded from a single marker gene or protein sequence only reflects that particular gene's evolution.

1.5.2.1 Mitochondrial Genes (mt DNA)

For the establishment of the species-level phylogenetic relationship, the mitochondrial DNA data can be a potent tool. The genetic order of the mitochondrial genes is variable, and massive non-coding DNA regions separate them. The mitochondrial genome often rearranges itself in so many mixed forms that will occur in the same cell. The use of mt DNA has become relatively common in phylogenetics and population genetic studies due to 1) Developments in mt DNA isolation methodology, 2) Use of restriction enzymes to detect nucleotide differences, 3) Developments in PCR methodologies and 4) Universal primers applicability for DNA amplification (Brown et al., 1982; Patwardhan et al., 2014). In most animals, the circular mitochondrial genome includes 24 genes for mt DNA translation (2 ribosomal RNAs: 12S, 16S; 22 transfer RNAs) and 13 protein-coding genes for the electron transport chain (fig. 1).

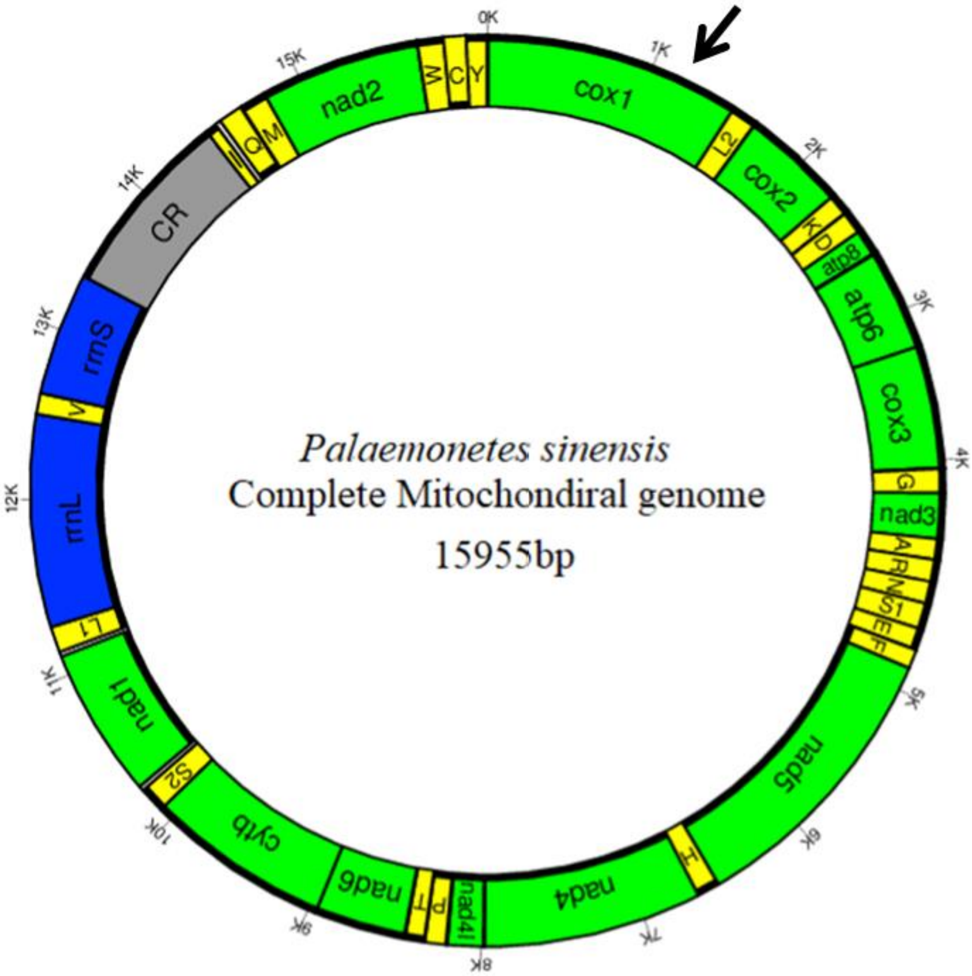

Figure 1 Mitochondrial genome of Chinese grass shrimp *Palaemonetes sinensis*. The position of Cytochrome oxidase I is indicated by an arrow. (Modified from Zhao et al., 2019).

1.5.2.2 Cytochrome oxidase I/II (COI/II)

The enzyme cytochrome c oxidase is a very well-known protein of the electron transport chain which drives oxidative phosphorylation. COI and COII genes code for two of seven polypeptide subunits in the cytochrome c oxidase complex. The MT-COI gene consists of approximately 894 bp. The COI gene is one of the most popular tools for the population genetic, intraspecific phylogenetic, and phylogeographic, and systematic studies across the animal kingdom (Avise et al., 1987). The COI sequences have been applied to study the Phylogenetics problems at a wide range of hierarchical levels in crustaceans from closely related species to genera and subfamilies, families, and even order and suborders. The cytochrome c oxidase subunit I is a slowly evolving gene compared to the other mitochondrial protein-coding genes and is mostly used to study the molecular phylogeny. Over the last decade, the field of DNA barcoding (COI sequencing) has emerged as a molecular method for species identification. The DNA barcodes are based on the amplification of a uniform region of the mitochondrial gene, sequenced, and analyzed by comparison to an open-access database, namely NCBI or BoLD.

Due to various morphological and molecular tools, in the last few decades, the classification of order Decapoda is getting stable. Phylogenetic studies of the Dendrobranchiata are numerous, both using morphological characters (Abele and Felgenhauer, 1986) and (even more) using molecular characters (Vazquez-Bader et al., 2004; Voloch et al., 2005; Ma et al., 2009). The morphological (Burkenroad, 1983; Christoffersen, 1990; Martin and Davis, 2001) and molecular data-based analyses (Porter et al., 2005) have been conducted to resolve internal relationships within the group, without a clear conclusion. The debate of Infraorder Procarididea was settled by Bracken et al. (2010), by using one mitochondrial and three nuclear genes confirmed the position of the family as a separate infraorder within order Decapoda.

To resolve the taxonomic ambiguity in prawn and shrimps, the DNA barcoding technique has been used effectively. This method also assigns unknown organisms to individual species and increases the discovery of new species, characterization of the taxonomic and genetic diversity of different geographical regions (Williams et al., 2001; Mathews and Anker, 2009; Anker et al., 2009; Almeida et al., 2014; Salgado-Barragán et al., 2017). Yang et al. (2015) estimated the phylogenetic relationships and taxonomic status amongst 15 species of commercial deep-sea penaeid shrimp genus *Parapenaeus* and three subspecies Indo-West Pacific and the Atlantic Ocean using the five different genes (COI, 12S, 16S, NaK, and PEPCK). The results support the current systematics of *Parapenaeu*s.

DNA barcoding was also helpful in resolving the taxonomy of cryptic species complex, e.g., Alpheid shrimps. Bilgin et al. (2015) studied the genetic diversity of 12 shrimp species inhabiting Turkish coastal waters by sequencing the mtCOI gene. In six species, they observed two clades, and it suggested that they are cryptic species or historical genetic isolation of populations within species. In 2014, Bracken-Grissom et al. studied the molecular phylogenetics of American snapping shrimps allied to *Alpheus floridanus* using combining sequences of three ribosomal and protein-coding mitochondrial genes (16S, 12S, and COI). The morphological comparisons of type materials suggested that the two syntypes of *A. floridanus* belong to different species, and molecular results validate the separation. They examined the evolutionary relationships among the five species and one subspecies and discussed the species complex' biogeography patterns.

The molecular phylogenetic technique has long been known as an effective method to resolve these latent systematic controversies of Decapoda, including Caridea and other groups. Several caridean families have been studied in a broad-scale molecular framework in the last decade, followed by focused, systematic revisions including morphology. De grave et al. (2015) settled the systematic of two subfamilies (Palaemoninae, Pontoniinae) in Palaemonidae and established the phylogenetic relation using 16S, H3, and 18S. Liao et al. (2017) studied the molecular phylogeny of the family Pasiphaeidae, based on six mitochondrial and nuclear markers (12 S rDNA, 16 S rDNA, histone 3, sodium-potassium ATPase α-subunit, enolase, and ATP synthase β-subunit) from the 33 species and 19 species from 12 other caridean families. They concluded that some morphological characters used in the present systematic within Pasiphaeidae might not be synapomorphies, and the classification needs to be urgently revised.

Among the mtDNA markers, the 16S rRNA and COI have been used for the study of phylogenetic relationships among the prawn and shrimp species (Calo-Mata et al., 2009). They are useful for the study of interspecific differentiation of the species rather than for the intraspecific differentiation of the specimens (Hualkasina et al., 2003). Few studies based on the 16S rRNA have established the evolutionary relationship among shrimps at different classification levels (Lavery et al., 2004; Voloch et al., 2005).

1.6 Origin of the present study

During the literature survey about marine decapods occurring in Gujarat, it was observed that certain groups like brachyuran crabs are studied extensively. Still, other groups like prawns, shrimps and their distribution and diversity have not been studied to that extent. The earlier studies reported the maximum variety of commercial prawn species from the Gulf of Kachchh followed by the Saurashtra coast and the Gulf of Khambhat; however, this is not based on a thorough survey long coastline of Gujarat. Several habitats like mangroves, mudflats, and coral reefs have also not been sampled thoroughly in different distribution regions. A fishery bycatch being landed on other ports of Gujarat is also not studied well for deep-sea prawns. Despite having the most extended coastal area in the country, fewer prawn and shrimp species are reported from Gujarat than Indian decapod fauna. The coastal region of the Gujarat state supports various kinds of marine habitats like mangrove mudflats, open mudflats, coral reefs, rocky shore, and sandy shores along the central coastline as well as the islands. It suggests that Gujarat's coastal areas have a high potential of possessing greater diversity in terms of species richness, and a separate study is most required. The Geographical distribution and habitat preferences of shrimps are not described so far for most Western coastal regions of India and the Gujarat state.

1.7 Objectives of the Study- The present study was initiated with the following objectives.

1. Study the Diversity, morphological taxonomy, and distribution of marine prawns and shrimps.

I. Systematics of marine prawns and shrimps: A taxonomical approach

II. Distribution pattern and habitat preferences of prawns and shrimps in different coastal regions of Gujarat

2. Establish the phylogenetic relationship between prawn and shrimp species.

I. Morphological phylogeny of prawns and shrimps: A cladistic analysis.

II. A comprehensive phylogenetic analysis of prawn and shrimp based on mitochondrial COI sequence data.

Thesis Outline

This thesis work contains a general introduction to the necessary knowledge and principles explored, a review of past and current literature, study sites, and four research chapters (Chapter 3 to 6), and general conclusions.

Chapter 3 gives general identification characteristics, diversity data, and economic and ecological importance of prawn and shrimp species—a detailed account of systematics is incorporated in this chapter.

Chapter 4 gives the general introduction of habitat, factors, and selection criteria of habitat preference. This chapter also provides the biogeographical distribution and a detailed account of macro and micro-habitat choices of prawn and shrimp along Gujarat's coast.

Chapter 5 gives a general introduction and review of morphological phylogeny, importance, and limitations. This chapter also provides a morphological phylogeny based on the morphometric character of species.

Chapter 6 gives an introduction to molecular phylogeny. This portion's primary focus is on the reviews of multiple studies involving molecular phylogeny of various prawn and shrimp species from India. This chapter aims to investigate the phylogenetic relationship conducted within families and infra-orders.

The general conclusions review my thesis's main findings on the diversity, distribution, and molecular phylogeny of marine prawns and shrimps from the Gujarat state. This final component conclusion includes a broad discussion of possible limitations of the present study and future directions to understand and protect marine biodiversity.