CHAPTER 1 INTRODUCTION

PHYLUM CNIDARIA

CLASS ANTHOZOA

ORDER ZOANTHIDAE

REVIEW OF LITERATURE

AIMS AND OBJECTIVES

LACUNA

FLOW OF THESIS

1.1 INTRODUCTION

Tropical ecosystems are well known to be harbouring rich diversity of flora and fauna. These biogeographic regions also support rare and endangered species. The marine ecosystems of tropics are best examples of the same. One such example for marine ecosystem is of corals, which play a crucial role in the ecosystem. Gradual colonization of the organisms called polyps form one of the unique habitat of marine ecosystem called the Reef ecosystem. Reef ecosystem is designated as tropical rainforests of the aquatic environment by many authors because of the presence of vast food resources and favourable conditions (Erez, 1990; Folke *et al.*, 2004). There are many species of flora and fauna which are endemic to the reef ecosystems and are not found anywhere else. However, these habitats are continuously being threatened due to a number of anthropogenic activities such as waste disposal, crude oil extraction, their transport and by sedimentation as a natural process. Using Remote sensing techniques, it has been shown that the reef flats in India are approximately 1270 km^2 (Ramamoorthy, 2012). Reefs are distributed in Gulf of Kachchh, Lakshadweep islands, Andaman and Nicobar Islands, Palk Bay and Gulf of Mannar. The reef ecosystem supports diverse animal communities with animal communities ranging from Poriferans to Pisces and with difference in geographical areas, the diversity of a reef ecosystem changes. They facilitate the breaching of tidal waves and act as buffer against the shoreline erosion. Besides molluscs, crabs and other fishery, this ecosystem does sustain the livelihood of over 30 to 40 million people globally. In addition, recent studies report that some reef-associated organisms are the natural raw material source for many other organisms (Ramamoorthy, 2012). The invertebrate communities of a benthic intertidal zone act as the major indicators of changes in the environmental factors due to their immobility or restricted mobility, sediment deposition, longer life span and presence of taxonomically diverse organisms to study the ecosystem.

Phylum Cnidaria one of the prime benthic invertebrate taxa, comprises exclusively of marine forms. The phylum is represented by organisms with two life forms: Polyp (Sedentary) and Medusoid (Motile). Radial or biradial symmetry is observed characterized by mouth being the single opening in the body (Fig. 1.1). Nematocysts (Stinging cells) are present, which act as offensive or defensive organ (Hessinger and Lenhoff, 1988). Benthic cnidarians are symbiotic with zooxanthellae- *Symbiodinium*.

Kingdom: Animalia
Phylum: Cnidaria
Class: Anthozoa (Ehrenberg, 1834)

1.2 CLASS ANTHOZOA:

The exact number of anthozoans are still not clear (Burnett *et al.*, 1997; Reimer *et al.*, 2007), however, Philipp and Fautin (2009) described 100 species. Anthozoans are reported from intertidal zone to the deep oceans. Anthozoa currently contains 7,500 extant species (Zhang, 2011). Reproduction in anthozoans has been observed to be taken place by both sexual and asexual methods. Venkatraman and Wafar (2005), have reported 600+ species of anthozoans and 842+ species of Cnidarians along the Coast of India. However the exact number of the species is still equivocal.

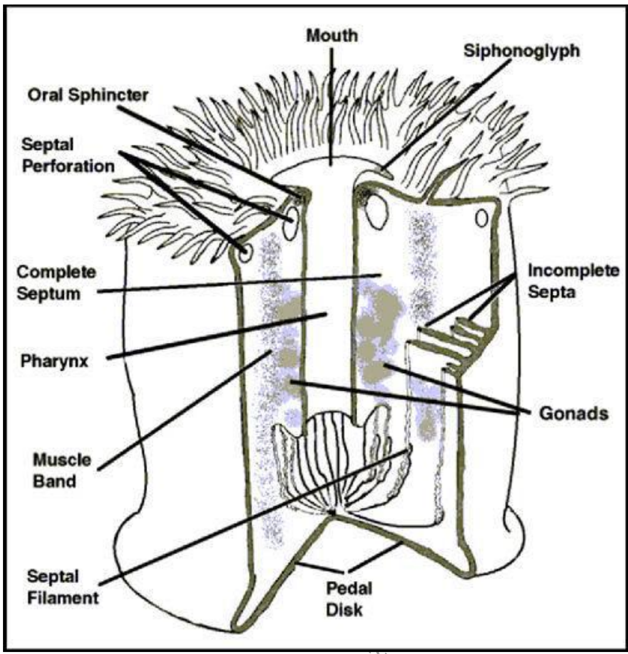

Figure 1. 1: Sketch showing the internal anatomy of Anthozoa. (Source: Kozloff, 1990)

The class Anthozoa comprises of two Sub classes viz. Octocorallia and Hexacorallia. The classification of the anthozoans is as follows:

Class **Anthozoa** Ehrenberg, 18341 (2 subclasses)

→ Subclass **Hexacorallia** Haeckel, 1866 (6 orders) (Table- 1.1)

→ Order **Zoanthidea** (2 suborders)11

→ Suborder **Brachycnemina** Haddon and Shackleton, 1891 (3 families)

→ Family **Neozoanthidae** Herberts, 1972 (1 genus, 1 species)

→ Family **Sphenopidae** Hertwig, 1882 (2 genera, 42 species)

→ Family **Zoanthidae** Gray, 1840 (3 genera, 45 species)

→ Suborder **Macrocnemina** Haddon and Shackleton, 1891 (4 families)

→ Family **Epizoanthidae** Delage and Hérouard, 1901 (1 valid genus, 2 genera inquirenda, 43 valid species, 3 species inquirenda)

→ Family **Hydrozoanthidae** Sinniger, Reimer and Pawlowski, 2010 (2 genera, 5 species)

→ Family **Microzoanthidae** Fujii and Reimer, 2011 (1 genus, 2 species)

→ Family **Parazoanthidae** Delage and Hérouard, 1901 (6 genera, 29 species)

→ Family **Abyssoanthidae** Reimer and Fugiwara, 2007 in Reimer *et. al.*2007 (1 genus, 2 species)

Table 1. 1: Systematics of Hexacorallia (Adapted from Daly *et al.*, 2003)

Order	Exoskeleton	Habit	Mesenterial filament	Siphonoglyph	Marginal sphincter muscle	Mesentery arrangement
Actiniaria	Absent	Solitary or colonial	Unilobed or trilobed	None to two or more	Endodermal, mesogloeal, or none	Monomorphi or dimorphic coupled pairs
Antipatharia	Proteinaceous	Colonial	Unilobed	Two	None	Monomorphic coupled pairs
Ceriantharia	Absent	Solitary	Trilobed	One	None	Monomorphic coupled pairs
Corallimorpharia	Absent	Solitary or colonial	Unilobed	None	None	Monomorphic coupled pairs
Scleractinia	Calcareous	Solitary or colonial	Unilobed	None	None	Monomorphic coupled pairs
Zoanthidea	Absent	Solitary or colonial	Trilobed	One	Endodermal, mesogleal or none	Dimorphic coupled pairs

1.3 SUB-CLASS HEXACORALLIA

Subclass Hexacorallia is termed so due to the presence of hexamerous symmetry, comprising of different orders viz., Actinaria, Antipatharia, Ceriantharia, Corallimorpharia, Scleractinia and Zoanthidae. This subclass comprises of about 4,300 extant species. Most common genera *Zoanthus* and *Palythoa* are major components of coral reef fauna in both Atlantic and Indo-Pacific. The key to Hexacorallia has been described below (Table 1.2)

There has been scarce literature available for zoanthids along the Indian coast. Most of the study on Zoanthids has been reported on the biological effects of the Zoanthid alkaloids, toxic effects of Zoanthid extracts etc. Sphenopidae family is well known for heavy incrustation of sand and detritus (Haywick and Mueller, 1997) therefore sectioning and internal examination is impossible virtually for this group (Reimer *et al.*, 2010). The trait of sand incrustation is unique to zoanthids among cnidarians and has several advantages over both calcification and well developed muscle formation. Under some ocean conditions viz. ocean acidification, it has been theorized that calcifying organisms increasingly cannot form skeleton which negatively impacts such species ability to compete and survive (Kurihara, 2008).

1.4 ZOANTHIDEA

Zoanthids are divided into the suborders Macrocnemina and Brachycnemina. These organisms form the major benthic fauna of the tropical and subtropical regions (Karlson, 1980). As exception, most Zoanthids belonging to suborder Macrocnemina are also found in temperate regions. Zoanthids are the most common organisms found in the intertidal reef flat regions where widespread coral growth is not taking place (Herberts, 1971; Cooke, 1976; Sebens, 1982). Apart from their intertidal distribution, these are also found in the subtidal regions of the tropical areas (Wood, 1957; Carlgren, 1951).

Species of the zooxanthellate genera *Zoanthus* (Family: Zoanthidae) and *Palythoa* (Family: Sphenopidae) within the suborder Brachycnemina are dominating along the intertidal zone (Burnett *et al.* 1997; Swain 2010; Irei *et al.* 2011). The systematics of Zoanthidea as described by Fautin (2008) was without the molecular techniques as the current research has advances. Thereby, Macrocnemic zoanthids are now described as the primitive origins than the Brachycnemic zoanthids (Reimer *et al.*, 2008; Reimer *et. al.* 2007, 2008a, b; Sinniger and Haussermann 2009; Swain 2009b). All zoanthids have a double row of tentacles and a single siphonoglyph. The variation in number and colouration of the tentacles, oral disk, manubrium, size of oral disk and the patterns in oral disk are used for the identification of the zoanthids.

1.4.1 FIFTH MESENTERY

In the actinopharynx, five mesenteries are observed from the dorsal directives (opposite the siphonoglyph). The fifth mesentery is characterized by two parts: (1) microcneme (an incomplete mesentery that is little more than a slight protrusion of mesoglea and endoderm, never extending to the actinopharynx), or (2) macrocnemic (a complete mesentery that extends to the actinopharynx). These characters have been defined as the Zoanthidea suborders Brachycnemina and Macrocnemina (Haddon and Shackleton, 1891) (Fig. 1.2, 1.3).

Apart from the key described by Reimer (2010), there has been no other key. Till date, several studies have been attempted to find out new morphological or histological characters that efficiently discriminate between zoanthid genera and species. Characters such as the cnidome and sphincter muscle anatomy have been investigated by Ryland and Lancaster, 2003; Herberts, 1972 and Lwowsky, 1913, but none of these researches have proved to be an efficient and applicable method of identification for zoanthids over a wide range of taxa. Molecular techniques are seen to be an effective tool for the revision of taxonomy and presently this classification is now being revised by Burnett *et al.* 1997; Reimer, 2004; Sinniger *et al.*, 2005; Reimer *et al.* 2006; Sinniger and Haussermann 2009. Walsh and Bowers (1971) have described 60 species of zoanthidae family. Amongst the above species, a few have been reported the Indian regions.

Some zoanthids are observed to encrust sand and other materials imbibed from water into their ectoderm and mesoglea for their structural strength (e.g., Haywick and Mueller, 1997). The amount of encrustation varies with zoanthid species and mostly seen in the Family Sphenopidae. The maximum encrustation has been observed in *Palythoa spp* of approximately 45% to 60% encrustation by weight (Haywick and Mueller, 1997). Zoanthids which incorporate such materials, are specific in the size range of the articles (Haywick and Mueller 1997). Major part of the mesoglea comprises of the sand particles viz., the calcium carbonate particles and arginine. Three genera are recorded for the study belong to the Sub-order Brachycnemina are Genus *Palythoa, Isaurus* and *Zoanthus*(Table 1.3).

Apart from the Genus *Savalia* (Family Sphenopidae), all other Genus secrete a skeleton (Haeussermann, 2003).

1.5 REVIEW OF LITERATURE

Studies of zoanthids have been done from Florida to Japan coasts. From the Caribbean coast of Panama, *Zoanthus sociatus*, *Zoanthus solanderi*, *Palythoa caribaeorum*, *Palythoa variabilis*. Sinniger *et al.* (2005) have emphasized the difficulties on the taxonomic identification in Zoanthidea with differences in their puzzling diversity also based on their DNA sequences.

From the Persian Gulf, reports on *Zoanthus sansibaricus* inclusive of five morphotypes, *Palythoa* cf. *mutuki*: two morphotypes and *Palythoa tuberculosa*: one morphotype are there. With reference to *Palythoa tuberculosa* and *Zoanthus sansibaricus*, reported to be widespread from western and eastern Pacific Ocean; covering an entire region from Great Barrier Reef (Burnett *et al.*, 1997; Ryland and Lancaster, 2003), New Caledonia (Sinniger, 2006), Japan (Reimer *et al.*, 2004, 2006a, 2011; Reimer, 2007), Galapagos (Reimer *et al.*, 2008), Singapore (Reimer and Todd, 2009) and Indian Ocean (Herberts, 1972). From the Caribbean region, 37 *Palythoa* species (including *Protopalythoa*) and 11 *Zoanthus* have been reported. In southern Japan, 6 or 7 brachycnemic species are commonly present, with diversity decreasing in areas where ocean temperatures fall below 15-16°C in winter (Reimer *et al.*, 2008a) suggested that the importance of high dependency on temperature. *Palythoa, Zoanthus, Isaurus, and Terrazoanthus* species have been recorded from Florida and their phylogenetic analysis showed that they have a close relationship between those obtained from the Pacific Ocean. Presence of eleven species has been reported from shallow waters of Florida's intertidal zone; four *Zoanthus spp*. namely *Z. sociatus*, *Z. aff. pulchellus*, *Z. pulchellus*, and *Z. solanderi*; five *Palythoa* spp. : *P. caribaeorum*, *P. grandiflora*, *P. grandis*, unknown *Palythoa* species related to *P. variabilis*, and *P. aff. clavata*, as well as one *Isaurus tuberculatus*, and one undescribed *Terrazoanthus* species. Zoanthids high intraspecific morphological variability. Patterns of plastic changes have been shown to be affected by shaded colonies exhibiting larger polyps as compared to non-shaded colonies. The presence of plastic responses facilitates colonization in a wider range of habitats.

There are several species of undescribed macrocnemic zoanthids from the Galápagos. A new family was created named Hydrozoanthidae was created which had recorded two species. Based on the substratum, these Macrocnemina species were found, the genus of which are separated.

Zooxanthellae are single-celled dinoflagellate algae, majorly belonging to Genus *Symbiodinium*. Intensity of light and temperature are two major factors which affects the diversity of these symbionts in their host species. Based on molecular phylogenetic studies, *Symbiodinium*, the associated zooxantehllae, is currently divided into nine clades of unknown taxonomic rank (Pochon and Gates, 2010).

Species of the genus *Palythoa* (Family Sphenopidae) generally associate with subclade C1-related *Symbiodinium* in Japan and in Indian Ocean, and with clade D in the Indian Ocean (Burnett 2002, Reimer *et al.* 2006d, Reimer and Todd, 2009). However, a great variation within *Zoanthus sansibaricus* (Family Zoanthidae) has been observed from the Ryukyu Islands to be associated with subclade A1 in intertidal areas where the intensity of light is high with subclade C1z sensu Reimer *et al.*, (2007) in most areas (Reimer *et al.*, 2006, 2007), and with another subclade (related to C1) at >7 m in depth (Kamezaki *et al.*, 2013).

In the Persian Gulf, *Palythoa tuberculosa* and *Palythoa mutuki* have been found to be associated with subclade C1; *Zoanthus sansibaricus* with subclade C3 and its derivatives and *Zoanthus kuroshio* with C15/C91-related *Symbiodinium*.

An important finding from the study of Reimer *et al.*, 2011, was the phylogenetic difference between *Z. kuroshio* and *Z. vietnamensis* which was referred to be *Z. aff. vietnamensis* in Reimer *et al.* 2011).

Diversity and distribution of zooxanthellate zoanthids *Palythoa mutuki*, *Palythoa tuberculosa* and *Zoanthus* sp. was studied on the rocky intertidal areas at Dwarka, Veraval, Sutrapada, Dhamlej and at Kodinar along the coastal Saurashtra, Gujarat, India. Maximum density and abundance of the species was observed at Dwarka, Sutrapada and Veraval (Bhattji *et al.,* 2010; Pandya and Mankodi, 2013; Trivedi and Vachhrajani, 2014). Maximum density of the species was observed in the large tide pools filled with water. The lower intertidal area of Veraval and Sutrapada are mostly covered by large tide pool while small size tide pools were observed at Veraval. The present study reports the distribution patterns of three different zoanthid species along the coastal Saurashtra, Gujarat. Significant variations were observed for different kinds of ecological attributes like density, abundance and frequency of occurrence for different zoanthid species. Different kinds of abiotic factors also plays a significant role in the spatio-temporal distribution of the zoanthid species.

The Atlantic and the Pacific oceans do not show much difference in shallow water zoanthid diversity. Though most of the shallow water Zoanthids exhibit a wide range of distribution in the tropical zone, a few for example *Z. praelongus* Carlgren (1954) and *I. maculatus* show a limited distribution to Western Australia and from Fiji (Muirhead and Ryland, 1985). *Palythoa tuberculosa* have been observed to be more phenotypically plastic than Z. sansibaricus. Although both the species are having a wide range of distribution and occupying different niche, *Palythoa* was observed to be a good colonizer.

In recent years, research has begun to investigate the diversity of zooxanthellate zoanthids (Anthozoa: Hexacorallia: Zoantharia) from Saurashtra coast (Pandya and Mankodi, 2013). Distribution of the genera *Zoanthus*, *Isaurus* (Family Zoanthidae) and *Palythoa* (Sphenopidae) roughly follows the course of the water current along the Saurashtra coast, (Fig. 1a). The genus *Isaurus* has only been previously reported from a few sites in Saurashtra, there are numerous documented samples of *Zoanthus* and *Palythoa* spp. from (Pandya and Mankodi, 2013; Pandya et al., 2014 and Uchida, 2001; Reimer *et al.*, 2006; Reimer *et al.* 2006).

Polyp sampling revealed that *P. tuberculosa* is a protandrous hermaphrodite over its life cycle, but has an annual protogynous hermaphroditic cycle. Fecundity was highest in the center of the colonies. High fecundity and long larval developmental periods suggest high investment in sexual reproduction (Babcock and Ryland, 1990; Acosta *et al*., 2001).

Studies on the associates of *Palythoa caribaeorum* on shores in northeastern Brazil recorded the abundance of Mollusca as the major associates followed by Crustacea, Nematoda, and Polychaeta respectively. Barnacles have been observed to be negatively affected due to zoanthid overgrowth. Zoanthid has been note to grow on red coralline algae0. Apart from the invertebrate fauna, Piscean community has been observed to be the major predator and find a refuge in the colonies during the low tides. Molluscans, Annelids and Crustaceans have been found under the mats and the colonies which act as the nursery in the intertidal environment. Anthropogenic activities directly or indirectly affect some ecological parameters in an intertidal community causing a change in the associated fauna.

Zoanthids produce two main types of alkaloids responsible for their bright pigmentation, and the zoanthamine type identified from the genus *Zoanthus*. Very few and scanty studies have been found with respect to Zoanthids along the coast of India. Most of the research has focused on microbial analysis and physiological analysis of the organisms. For example, Antifilarial activities have been studied by Lakshmi, *et al.*, (2004) against human filarial worms. Kaladharan, *et al.* (2011), have reported the bleaching effect in *Zoanthus sociatus* along the intertidal zone of Kerala Coast. The zoanthids collected from Saurashtra Coast are being studied for the neurotoxic effects by Raghubir *et al.*, 2013. The study of zoanthids is an important research subject for a wide variety of research, particularly in biochemistry-related investigations. Palytoxin was isolated for the first time from *Palythoa* by Moore and Scheuer (1971), and norzoanthamine, a promising compound to treat osteoporosis has been from a *Zoanthus* sp. by Fukuzawa *et al*. (1995). Behenna *et al.*, (2008) have reported more bioactive compounds from Zoanthids and have also described them to be promising organisms for other biological compounds. Though Palytoxin was said to be produced from *Palythoa*, later researchers showed it to be produced by a bacteria *Ostreopsis spp.*

Intertidal community is exposed to continuous flux in the water availability and water temperature remains the major abiotic factor affecting the symbiotic organisms viz., Zoanthids. Though the zoanthids are found in the tropical and subtropical zones, Zoanthids have been observed to be affected by changes in water temperature and the diversity has been observed to reduce greatly in low temperatures. *Palythoa* (Sphenopidae) and *Zoanthus* and *Isaurus* (Zoanthidae) are found in tropical and subtropical reef environments throughout the world and seasonal changes in morphological condition of Symbiodinium (Reimer *et al,*. 2007) and thermal bleaching (Kemp *et al.,* 2006) have previously been recorded in these two genera.

Phase-shift is being observed amongst animal-animal and animal-algae in rocky intertidal zones. The degradation of water quality plays an important role in the shift from corals to algae dominant reefs (Bellwood *et al.,* 2004; Knowlton and Jackson, 2008).

1.6 LACUNAE:

The diversity of many marine organisms has by far been unknown from the coast of India. Gujarat harbouring the longest coast line amongst all the states of India, is still lacking the record of diversity of macrobenthic fauna. Most of the studies have been restricted to Gulf of Kachchh and Gulf of Khambhat. Scarce reports are found on the marine invertebrate diversity. The observations done by most of the researchers along the Saurashtra Coast were mainly restricted to Scleractinians, Molluscans and Arthropods. However since last few years, more studies have been conducted on other macrobenthic fauna such as Cnidarians also. Till date, no complete report have been found with respect to the taxonomic diversity of all the macrobenthic invertebrates has been generated. Therefore in view of above review of literature, the above topics were selected and undertaken as a research which follows the following aim and objectives were set. During the course of research, it was known that due to insufficient taxonomic records of the morphological characters and details, a primary key generation became mandatory. However, further research is required on Zoanthids and other macrobenthic fauna to provide a complete checklist with photographs for other researchers.

Table 1. 2: Key To Orders Of Non- Skeletalized Hexacorallia (Fautin, 2006)

1A.	Colonial	Zoanthinaria
1B.	Solitary	2
2A.	Polyp encased in felt- like tube	Ceriantharia
2B.	Polyp naked or without adherent detritus	3
3A.	Tentacles in two distinct cycles	Ceriantharia
3B.	Tentacles around margin only or not arrayed in cycles	4
4A.	Tentacles arising from oral disk (perhaps from margin as well)	Actiniaria
4B.	Tentacles arising only at margin	5
5A.	Aboral end rounded/ pointed, unattached	Actiniaria
5B.	Aboral end flat, adherent or not	6
6A.	Column encrusted with sand/ other debris	Zoanthinaria
6B.	Column smooth	Actiniaria

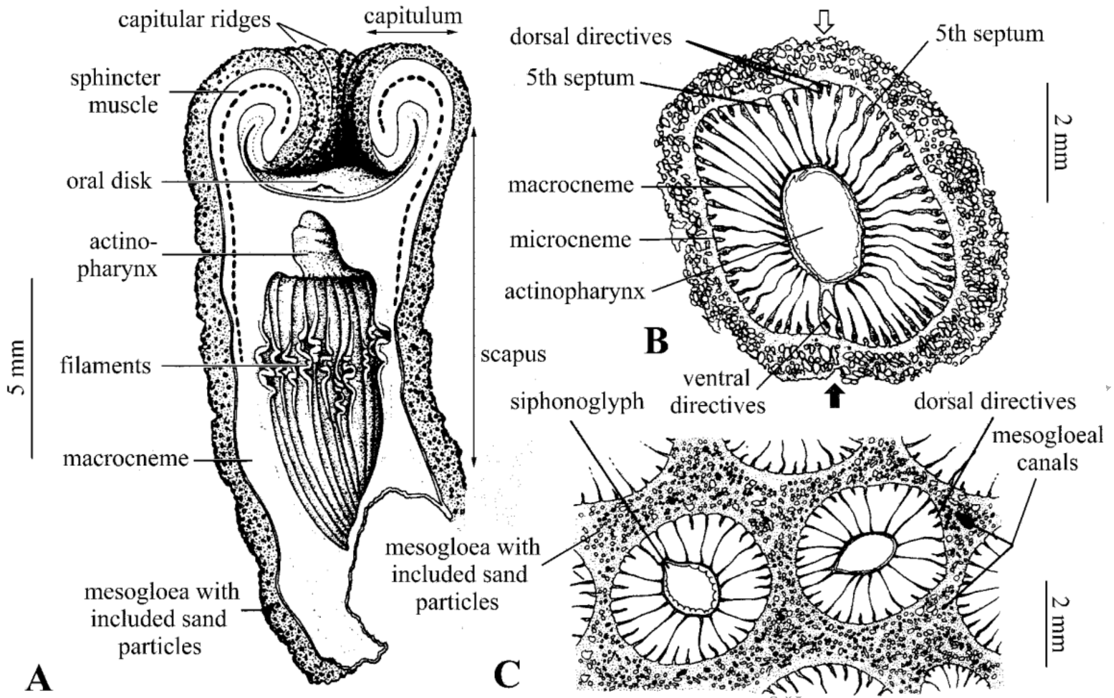

Figure 1. 2: Polyp Sections showing Brachycnemic and Macrocnemic mesentery

A: Longitudinal section of a single polyp; B: Transverse Section showing macrocnemic arrangement in a polyp (with the 5th mesentery complete); arrows depict the directives (black being ventral directive). C: Transverse section of *Palythoa caesia* showing polyps immersed in the coenenchyme and brachycnemic arrangement (Drawings by A. Muirhead.) (Adapted from Ryland and Lancaster, 2003)

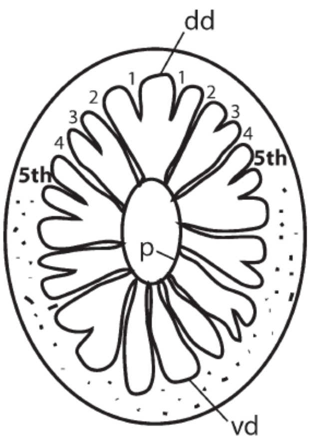

Figure 1. 3: Brachycnemic mesentery showing both directives

(Source: Key to identification of Shallow Water Brachycnemic Zooxanthellate Zoanthids, Reimer 2010).

Table 1. 3Table showing Genus of Sub-order Brachycnemina

Order: Brachycnemina (Haddon and Shackleton, 1891)	Sphenopidae (Hertwig, 1882)	*Palythoa* (Lamouroux, 1816) (117 species) SYNONYMS *Protopalythoa* (Verrill, 1900)
	Zoanthidae (Rafinesque, 1815)	*Isaurus* (Gray, 1828) (8 described species) *Zoanthus* (Lamarck, 1801) (31 described species)

1.7 AIM AND OBJECTIVES

To understand the diversity, distribution pattern of Anthozoans and their relation to ecological conditions.

To fulfil the above aim, the following **objectives** are set:

1) **Habitat characteristics of Saurashtra Coast.**
2) **Diversity of Anthozoans –Zoanthids.**
3) **Distribution Pattern of Zoanthids.**
4) **Associated Flora and Fauna with their inter-relationship.**

1.8 FLOW OF THE THESIS

There are five chapters in this thesis. Chapter 1 has introduced to the Anthozoans and Zoanthids in particular, their diversity, distribution, associates and competition. Chapter 2 deals with different study sites, their characteristics, zonation and the sampling procedures. Chapter 3 gives a comprehensive account of the diversity of the Zoanthids along the Saurashtra coast. The distribution pattern of the Zoanthids in the study area has been described in the Chapter 4. The associated Flora and Fauna have been described in the Chapter 5. At the end, Chapter 6 provides an overall conclusion.