DENSITY, DISTRIBUTION AND FACTORS INFLUENCING SEA STARS IN SELECTED ISLANDS OF LAKSHADWEEP, INDIA

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CERTIFICATE

This is to certify that Ms. Sharmila Jayaram has carried out original research titled "DENSITY, DISTRIBUTION AND FACTORS INFLUENCING SEA STARS IN SELECTED ISLANDS OF LAKSHADWEEP, INDIA" in partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2012 to June 2013. We here by certify that this work has not been submitted for any other degree to any other university.

11/7/13

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CONTENTS

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SUMMARY

Coral reefs are the most fragile, complex and diverse ecosystem on earth. But recently, they are under severe threat due to both natural (climate change, storms and disease outbreaks) and anthropogenic factors (overexploitation, coastal developmental activities and pollution). As evident from earlier studies, a major factor causing degradation of coral reefs is due to an asteroid species belonging to phylum Echinodermata which is considered second to storm damage. Thus to analyze the condition in Lakshadweep Islands I assessed the density of asteroids in four Islands of Lakshadweep. It was found that the five species detected belonging to three families (Oreasteridae, Linckiidae and Acanthasteridae) were having varied density across the four islands. Overall density estimates of the asteroids ranged from 0.05(S.E = 0.02) to 0.80(S.E = 0.09) per 250 square meter. The asteroid density was highest in the uninhabited Island named Bangaram. Correspondence Analysis (CCA) showed that major gradients in environmental variables influenced asteroid species distribution. Sample scores on ordination axis 1 were strongly correlated with water pH, water depth and dead coral. Out of the three strongly correlated environmental variables pH was found to be the most ecologically important variable that affects the asteroid distribution. Corallivorous asteroid population outbreaks are becoming a boon to the coral reef ecosystem all over the world and contribution of water pH variation to this outbreaks are being studied well. Thus management strategies in Lakshadweep Islands that accounts the variation of water pH are required to conserve the coral reef ecosystem.

CHAPTER ONE

1.1. INTRODUCTION

The Indian Ocean accounts over 30% of the global ocean area having a marine biodiversity of around 34,989 known species (Wafar et al. 2011). India, among the other Asian countries is the only country which possesses a proper inventory on marine biodiversity which in turn is much lower when compared to other terrestrial species inventories (Norse 1993; Venkataraman and Wafar 2005). Out of the 34 phyla of marine fauna reported in the world, 32 phyla are represented in India (Venkataraman and Wafar 2005).The Coastline of India extends from 8000 km to 10,000 km adjoining continental regions and offshore islands and a very wide range of coastal ecosystems such as estuaries, lagoons, mangroves, backwaters, salt marshes, rocky coasts, sandy stretches and coral reefs (Venkataraman and Wafar 2005).

In the marine biome, coral reefs are hotspots of species richness and endemism, with the 10 richest reefs accounting for between 44% and 54% of restricted-range marine species (Roberts et al. 2002). Global coral reef cover in Indian Ocean accounts for 30% having an area of about 0.2 million km^2 (Wafar et al. 2011). Coral reefs, 'flowers of sea' are equally diverse as tropical rain forests in terrestrial world (Cesar 2000). Coral reef is a complex system which harbors algae, seaweeds, sea grass, echinoderms, fin fishes, crabs, bivalves, gastropods, cephalopods, urchins, mollusks, sponges, various marine vertebrates including large assemblages of fishes, and coral polyp itself (Thomas 2011). Coral reefs are formed by the assemblage of tiny polyps. Polyps may or may not secret calcium carbonate obtained from sea which makes it hard (Veron 2000; Miththapala 2008). Based on the presence and absence of calcareous skeleton they are named as soft and hard corals. Hard corals can be of different types like massive, columnar, encrusting, tabular, foliaceous, branching, digitate and mushroom type. Some of the soft corals are fire and lace, black or thorny, sea fans and sea whips (Miththapala 2008).

Although the present exact total extent of coral reefs in world is unknown, still an estimate by UNEP, 1988 says it exceeds up to 600,000 km^2 and global area of near-surface reefs is estimated about 255,000 km^2 (UNEP 1988; Spalding and Grenwell 1997). It is estimated that worldwide the shallow coral reefs occupy only 284,300 km^2 which is only 0.9% of the total world oceans (Spalding et al. 2010). In India the total coral reef area is 5,790 km^2 which is distributed in 4 major regions that is Lakshadweep; Gulf of Mannar; Gulf of Kutch; and Andaman and Nicobar

Islands (Wilkinson 2006; Planning commission of India 2007). It is estimated that Indian coral reefs shelters about 262 hard coral species, 145 soft coral species, and 1,200 fish species. A strategy was being developed by National Biodiversity Strategy Action Plan in the year 2004 to include coral reefs and protect them under Wildlife (Protection) Act of 1972. For the year 2012, Convention on biodiversity has chosen marine biodiversity (which includes coral reefs) as the theme for International day for biological diversity (IDB) (CBD 2012).

Echinoderms are one of the most conspicuous and geometrically structured animals in marine ecosystem have gained attention as early as in 17th century. Most of the echinoderms are associated with coral reefs (James 2008). Echinoderms belong to the phylum Echinodermata, which once was remarked as "one of the best characterized and most distinct phyla of the animal kingdom" by Bathy in 1900 (as reviewed by Hyman 1955). The Echinoderms are enterocoelous coelomates having a pentaradiate construction (abnormal ones also recorded by James 1989), without defined head or brain, with a calcareous endoskeleton, often bearing spines or protuberances externally and with a water vascular system of coelomic nature that is send outside through podia and communicates with the external medium by pores or cluster of pores (Hyman 1955; Seshappa 1981; Chhapgar 2006). There are approximately 7,000 species of extant echinoderms and 13,000 echinoderm species as fossils across the world coral reefs (Pawson 2007; James 2008; TOLWEB 2012).

Based on literature, in India Echinoderm species number is varying like 651-765 (Venkataraman and Wafar 2005; Sastry 2007; Wafar et al. 2011). Phylum Echinodermata has five well-defined clades: Crinoidea (sea lilies and feather stars), Ophiuroidea (basket stars and brittle stars), Asteroidea (sea stars), Echinoidea (sea urchins, sand dollars, and sea biscuits), and Holothuroidea (sea cucumbers) (TOLWEB 2012). The phylum Echinodermata is symbolized by sea star, a universal symbol of the marine realm (Pawson 2007). Sea stars belonging to one of the largest class, Asteroidea are free living, slow growing (Birkeland et al. 1971) eleutherozoan echinoderms moving on the oral surface with a flattened and flexible body (Hyman 1955). There are varying species numbers like 1600 (TOLWEB 2012), 1800 (James 2008), 2100 (Pawson 2007) which are found throughout the world's oceans out of which there is 158 (Sastry 2007), 180 (Venkataraman and Wafar 2005) and 200 (James 2008) species of sea stars in India which is highest when compared with other Indian Ocean countries. There are seven orders in class

Asteroidea: Brisingida, Forcipulatida, Notomyotida, Paxillosida, Spinulosida, Valvatida and Velatida (Pawson 2007, TOLWEB 2012). India harbors species belonging to all these seven orders of class Asteroidea (Sastry 2007).

1.2.REVIEW OF LITERATURE

Although a huge number of invertebrate communities in coral reef ecosystem are known to the science, very little has been studied of their response to habitat modification (Leray et al. 2012). The global level of echinoderm studies especially in class Asteroidea is mainly focused on feeding ecology, chemical ecology, reproduction and developmental stages. A study on global diversity and phylogeny of the class Asteroidea was done very recently by Mah and Blake 2012. Species level studies that have been carried out in sea starsare embryology (in Washington, Chia 1968), reproduction investment of *Leptasterias hexactis* (in Deadman bay, George 1994); larval development of *Pteraster tesselatus* (In North America, McEdward 1992); substratum selection, development and growth of *Mediastera equalis* (in San Juan Islands, Birkeland *etal.* 1971) development of *Astropecten gisselhrechti*(In Japan, Komatsu and Nojima 1985); brooding and development in *Anasterias minuta* (In Argentina, Gil et al. 2011); competitive interaction of *Leptasterias polaris* and *Asterias vulgaris* (Gaymer and Himmelman 2002). Studies on the feeding ecology of various sea star species are: Sub-Antarctic sea star *Anasterias minuta* (In Argentina, Gil and Zaixso 2008); feeding behavior of *Evasterias troschelii* (In Washington, Christensen 1957); *Leptasterias polaris* and *Asterias vulgaris* (in Gulf of St. Lawrence, Gaymer et al. 2002); selective feeding of *Pisaster giganteus* and *Pisaster ochraceus* (in Southern California, Landenberger 1968); Differences in relative abundance and size structure of the sea stars *Pisaster ochraceus* and *Evasterias troschelii* (Puget Sound, Washington, USA) among habitat types (Rogers and Eliott 2013)

The chemical ecology is studied in Antarctic sea stars (McClintock and Vernon 1990; McClintock et al. 2003) like *Perknaster fuscus* (in Antarctica, McClintock et al. 1992, 1994, 2000; Kong et al. 1992), *Acodontaster conspicuous* (DeMarino et al. 1997), *Granaster nutrix* and *Neosmilaster georgianus* (McClintock et al. 2006) and *Odontaster validus* (McClintock et al. 2008a, 2008b). The natural antifouling defenses of sea stars were studied by Guenther 2007 and Guenther et al. 2009 in North Queensland, Australia. The role of chemical signals in the orientation behavior of *Asterias forbesi* was studied by Moore and Lepper

1997 in Massachusetts. The effects of bioaccumulation and PCBs (polychlorinated biphenyls) and heavy metals in sea stars were studied in North Sea (Danis et al. 2006). Studies on foraging characteristics of sea stars are mainly on: *Luidia clathrata* (McClintock and Lawrence 1985); foraging strategy of *Leptasterias polaris* (Rochette et al. 1994); prey selection of four sea stars (Gaymer et al. 2004); prey and predator (*Pisaster ochraceus*) interaction (Menge et al. 1994).

The outbreaks of *Acanthaster planci* are major concern all around the world and factors influencing its outbreaks are studied vastly. The first outbreak was recorded in 1960's in Great Barrier Reef, Australia (Chesher 1969) then afterwards following once every decade mostly in Pacific and Indian Ocean (Cameron et al. 1991). Molecular studies indicate that there are four species of crowns of thorn sea star from the Red Sea, the Pacific, the Northern and the Southern Indian Ocean (Vogler 2008; Vogler 2012). The major causes of the outbreaks are terrestrial run off (increase in phytoplankton which are food for its larvae, Birkeland 1982; Olson and Olson 1989; Fabricius et al. 2010) and low salinity caused by heavy rainfall, loss of its natural predators (Sebens 1994). The outbreaks on different coral reef sites are studied: in American Samoa (Birkeland 1982), in Moorea Island (Faure 1989; Trapon et al. 2011), in Great Barrier Reef (De'ath and Moran 1998; Devlin and Brodie, 2005), In Colombian Pacific (Narváez and Zapata 2010), in Hawaiian Archipelago and Johnston Atoll (Timmers et al. 2011), and in Central Pacific Ocean, using molecular techniques the spatial scale at which *A. planci* outbreaks can propagate through larval dispersal was evaluated (Timmers et al. 2012).

Studies on echinoderms especially in sea stars in India are scanty as compared to global studies. The studies are mostly concentrated on inventories and identification of species in different places in India (James 1989; Venkataraman and Wafar 2005; Sastry 2007). Most of the works in India has been done by Dr. D.B. James on taxonomy, zoogeography, ecology, conservation and management, parasites and animal associations, biotoxicity, *Beche-de-mer* industry, development, hatchery and culture of echinoderms. Specific notes were prepared on sea starsidentified from the Indian seas (James 1996; James et al. 2001) and developmental studies on *Pentaceraster regulus, Asterina burtoni* (James 1973; 2001) were also done. Survey and case studies were conducted for assessing *Acanthaster planci* bringing havoc to the coral reefs throughout the world (Pillai et al. 1989). The distribution of echinoderms across inter tidal zone was studied by James 1982 and it was understood that most of the echinoderms live in the mid littoral zone 60% and others in infra-littoral zone 25% and in supra-littoral zone only 15%. The habitat destruction poses threat to the echinoderms living in inter tidal regions by marine pollution, coral quarrying, removal of sea grass and algae as manure for coconut plantation (James 1982a). Thus looking into total extends of asteroid study carried out in India; this study is an important ecological study to assess the status of density, distribution and factors influencing asteroids in Lakshadweep Archipelago.

1.3. OBJECTIVES

1. To assess the status of asteroids in terms of density and distribution in selected Islands of Lakshadweep.
2. To determine the factors influencing the density and distribution of asteroids in selected Islands of Lakshadweep.

1.3.1. Key questions

1. Does the density and distribution of asteroids reflect any patterns across the reefs?
2. What are the factors that govern the density and distribution of different asteroid species?

1.4. STUDY AREA

The study area for the dissertation was Lakshadweep Islands, the smallest union territory of India in Arabian Sea is located in western Indian Ocean about 225-445 km off the west coast of India. It occupies an area of 32 km^2 situated between latitudes 8°N and 12°N and longitudes 71°E and 74°E. The total coastline length of Lakshadweep Islands is 132 km, which is approximately 1.6 % of India's total coastline. The islands have a lagoon area of about 4200 sq. km., territorial waters covering an area of 20,000 km^2, continental shelf of 4000 km^2 and an EEZ of 0.4 million km^2. The height of the land above the sea level is about 1-2 m. Lakshadweep is comprised of 11 inhabited islands and 16 uninhabited islands attached islets, 4 newly formed islets and 5 submerged reefs thus there are 36 islands in total. The inhabited islands are Kavaratti, Agatti, Amini, Kadmat, Kiltan, Chetlat, Bitra, Andrott, Kalpeni and Minicoy (PCI, 2008). All Lakshadweep islands are of coral origin and some of them like Minicoy, Kalpeni, Kadmat, Kiltan and Chetlat are typical atolls (Apte 2009; Arthur 1999). Coral reefs are present in a group of twelve atolls, three reefs and five submerged banks. Most atolls have a northeast, southwest orientation with an island on the east, a broad well developed reef on the west and a lagoon in between. Biodiversity of Lakshadweep waters in terms of invertebrates and vertebrates can be stated as 93 species of marine algae, 406 species of molluscs, 58 species of echinoderms, 86 species of annelids, 736 species of fish, 2 species of amphibians, 18 species of reptiles and 95 species of birds (Apte et al. 2010). The economies of the Islanders are dependent on coconut cultivation and tuna fishing (PCI, 2008). Major threat related to them is coral mortality and bleaching as after effects of 1998 El Nino, 2004 *tsunami*, dredging, sedimentation, coastal erosion, oil pollution (trade route between Africa, Arabia and west coast of India) by human activities (James 2011).

The study was conducted in four islands taking two uninhabited and two inhabited islands into consideration. The uninhabited islands are Bangaram, Suheli and the inhabited islands are Agatti and Kavaratti. Agatti is an inhabited island having a population of 7072 people which is 459km away from the Kerala coast ($10^0$51'N $72^0$11'E) with lagoon area of 17.5 km^2 and a land area of about 2.7 km^2. There is a small island named Kalpitti at the southern edge of the Agatti Island. Bangaram ($10^0$55'N $72^0$16'E) is an uninhabited island 7 km north east of the Agatti Island along with another island called Tinakkara ($10^0$56'N $72^0$18'E) having a combined lagoon area of 46.25 km^2 covering a land area of 2.30 km^2 with a shallow lagoon enclosed by the coral reef. Kavaratti ($10^0$33'N $72^0$36'E) is the capital island of Lakshadweep 350 km off the Kerala coast having a lagoon area of 4.9 km^2 and land area of 4.22 km^2 with a population of 10,113 people. Suheli is another uninhabited island along with Cheriyakara ($10^0$02'N $72^0$15'E) and Vallyakara Island ($10^0$8'N $72^0$18'E) with combined lagoon area of 78.96 km^2. It is located 52 km to the south west of Kavaratti Island (Apte et al. 2010).

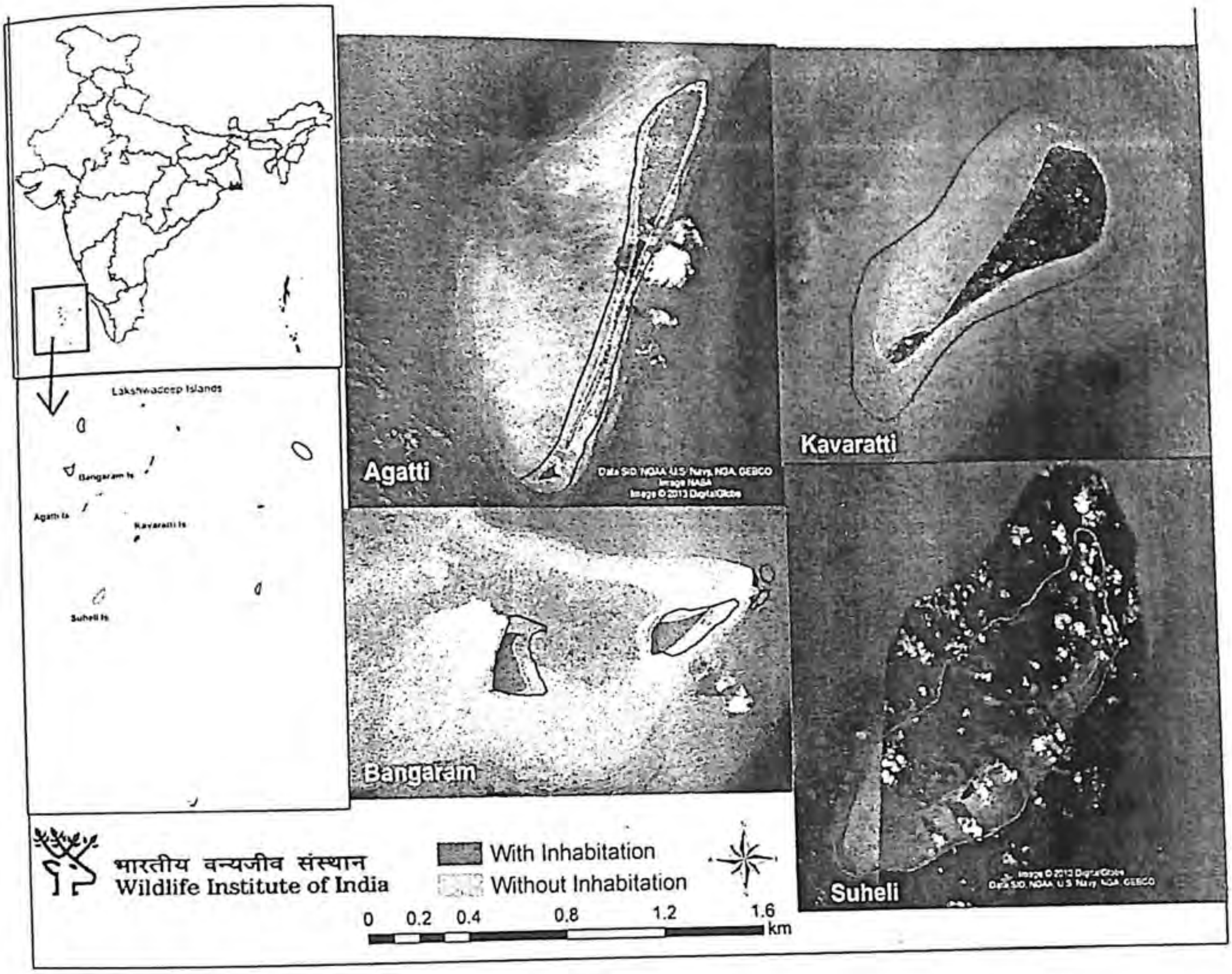

Figure 1. Map showing extensive study area: Agatti, Kavaratti and Bangaram, Suheli

CHAPTER TWO

DENSITY, DISTRIBUTION AND FACTORS INFLUENCING ASTEROIDS

2.1. INTRODUCTION

Based on the literature review it was found that in Lakshadweep Islands the class Asteroidea is represented by 38 identified species (Sastry 2007) and only 23 species is recorded through specimens (James 1989). But all these species are not lagoon living only very few among the above mentioned sea star species are found inside the lagoons. The species found during my study were *Culcita schmideliana, Culcita novaeguineae, Linckia laevigata, Linckia multiflora* and *Acanthaster planci.* Culcita genus belongs to the family Oreasteridae which is characterized by the reticulate skeleton enclosing the papular areas in its meshes (Hyman 1955). The members of this family either have broadly based arms or else none as in the case of *Culcita schmideliana* and *Culcita novaeguineae*. *Culcita* has plump pentagons with scarcely any arms and the entire skeleton is concealed by the leathery surface embedded with granules. *Culcita novaeguineae* and *Culcita schmideliana* are known by the name Pin cushion sea star which is characterized by its cushion shape and rounded arms which gives the species a disc shape. It is a bottom dweller and usually inhabits a sandy substrate. It is found to inhabit the exposed reef flats and terraces of eastern Indian Ocean and also the western and central Pacific Ocean (Yamagutchi 1975). It is a corallivore species and the over abundance of it is considered to be great threat to the coral reef ecosystem. It is a selective nocturnal feeder with special preference to *Pocillopora, Porites, Monitopora*, *Acropora* and *Favis* species (Krupp 1985).

Linckia laevigata, and *Linckia multiflora* belong to the family Linckiidae which occur in lagoons, reef crests, coral rubble banks, and algal ridges (Laxton 1974; Thompson and Thompson 1982). It is characterized by pentamerous symmetry smooth surface, small disk, long, flexible cylindrical arms and reduced conspicuous marginal plates (Hyman 1955). It inhabits in the shallow waters in tropical and sub tropical zones specially indo pacific seas. *Linckia laevigata* is mostly seen in blue colour but are found in apricot, pink, gray and purple (Williams and Benzie 1998). It mainly feeds on coralline algae and detritus (Coleman 2007, Laxton 1974). *Linckia multiflora* is small but is abundantly found in the sub tidal and inters tidal areas of reefs of temperate and tropical waters (Rideout 1978). It is characterized by the small pentamerous body having numerous coloring (ecophenotypes) mostly as mosaic patches making it difficult to sight since it merges with environment. Another peculiarity of this species other than its cryptic nature and heavily armoured body is that the variation in number (4-8) and length of arms (Crawford 2007). Any change in climate can have adverse effects on the population, behavior and anatomy of *Linckia multiflora. Acanthaster planci* is the second largest sea star belonging to the family Acanthasteridae characterized by thorny and multi armed structure hence the name crowns of thorn. There are many color morphs of crowns of thorn and one of the recent molecular studies indicate that there are four species of crowns of thorn sea star from the Red Sea, the Pacific, the Northern and the Southern Indian Ocean (Vogler 2008; Vogler 2012). *Acanthaster planci* are voracious coral feeders with a selective feeding preference on species belonging to the genus *Acropora, Porites, Pocillopora, Stylopora, Monitopora, Goniopora, Fungia, Goniastrea, and Pavona* (Pratchett 2007). This feeding behavior of crowns of thorn sea star have resulted in outbreaks which are triggered by various factors like terrestrial run off (Birkeland 1982; Olson and Olson 1989; Fabricius et al. 2010) and low salinity, loss of its natural predators and climate change (Sebens 1994).

Sea stars (asteroids) inhabit various types of habitat like benthic bottoms, hard, rocky, sandy or soft bottom (McClintock and Lawrence 1985) where they remain quiescent at times open or else concealed. Usually sea stars have a slow rate of movement usually by crawling on the bottom which may vary with different species (Hyman 1955). Sea star as a benthic dweller has an important role to play and any distinctive fluctuation in their population dynamics can result in both bottom up and top down effect in ecosystem (Menge and Sanford 2013). There are many natural and anthropogenic factors with influence the abundance and distribution of Asteroids in intertidal zone. Environmental conditions set the distribution limits within the intertidal zone for many species. Anthropogenic stresses have a range of effects on the physiology and behavior of intertidal organisms, influencing their metabolism, activity patterns, respiration, growth, reproductive output and immune responses (Smith 2010). Their distribution is dependent on the availability of abundance of foraminiferans, nematodes, ostracods, gastropods, bivalves and crustaceans, in addition to coral species, sediments and detritus belonging to their diet (Seshappa 1981; McClintock and Lawrence 1985; Chhapgar 2006). Asteroids are associated with a wide variety of species as parasites and commensals like ciliate protists, ctenophores, annelids, snails, copepods, barnacles, amphipods and pearl fish (Hyman 1955; James unpublished). Temperature, salinity (in *Luidia clathrata* by Watts and Lawrence 1990), light intensity and wave action are factors that contribute the distribution of shallow water asteroids in various habitats (Hyman 1955). The density and distribution of intertidal organisms like asteroids are spatially and temporally variable resulting in patchy distributions (Smith 2010). The various factors affecting asteroids in intertidal region as mentioned by Smith 2010 are water and air temperature, oxygen levels, wave-exposed areas vs. wave-sheltered habitats, site aspect and shore type, water salinity, water conductivity, water pH levels, presence of prey, storm action and human disturbance. The effect of environmental stress (Petes et al. 2008) on the predatory sea star species was studied to evaluate the climate change effect on them especially of temperature fluctuations (Szathmary 2009; Broitman 2009; Sanford 2002).

2.2. METHODOLOGY

2.2.1. Sampling Design

Based on the reconnaissance survey the study species were found to be present in reef zone which is located at the end of the lagoon near the reef wall of all the three zones: Reef, mid and shore zone. Most of the studies have used line transects (50 m, Rumrill 1989; Faure 1989 and Osborne 2011; 30 m long point intercept transect with 2m swath and 3 m interval, Blanchette 2009; 22 m horizontal transect at different tidal heights with 1m apart, Szathmary 2009; 30 m, Sanford 2002), belt transects (6 m x 90 m, Gaymer et al. 2004; 1-2 m wide and 10- 30 m long, Menge et al. 1994), manta board surveys (30 m along-slope by 10 m down-slope, Cameron et al. 1991) and tow diver surveys (25 m x4 m, 50 mx 10 m, Timmers *et al.* 2012) to study the Asteroids across the world. In this study the reef zone was sampled through belt transect of 25 x 10m which is specifically designed for unequal sample areas. The entire belt was searched thoroughly 5m on both sides covering a total swath of 10m. The quadrat size that has been used in earlier studies are 0.25 m^2 (Rumrill 1989; Menge et al. 1994), 3- 5 m^2 (Faure 1989). In this study for quantifying substrate types a 1x1m quadrat was laid at every 5 m intervals alternatively on both sides of the transect. The belt transects were laid both perpendicular and parallel to the reef wall to cover the maximum area in reef zone. The Asteroids was thoroughly searched in coral reef, inside crevices and the sea floor across the lagoon reef and small stones were turned over to search small Asteroids (James 1982a). In the human inhabited Islands the number of transects were Agatti – 47; Kavaratti – 30 and in uninhabited islands the number of transects were Bangaram – 35; Suheli – 32.

The asteroids are exposed to aerial and aquatic conditions on a daily and tidal basis. Varying vertical and horizontal gradients of physical factors have been found to play a role in determining the distribution of these intertidal species. Out of all the existing natural and anthropogenic factors affecting the abundance and distribution of Asteroids, only few important possible ones were taken. The dependent variables were recorded are density, abundance, diversity of the Asteroid species in lagoon reef. In each quadrat the natural factors like water and substrate properties were jotted down. The covariates mentioned below were used to relate with dependent variables during the analysis to come up with conclusions on the sea star density and distribution in lagoon reefs of selected islands of Lakshadweep.

1. **Water temperature:** The temperature affects the foraging and movement of Asteroids (Smith 2010).The temperature was recorded using digital thermometer (310 Thermometer CIE and Multi thermometer).
2. **Water depth:** The depth profile of each quadrat was measured using a depth rod (hand made with PVC pipes and measuring tape).
3. **Water salinity:** Salinity is likely to vary between open coastal areas and protected areas and both low and high salinity levels cause stress on intertidal species (Smith 2010). The salinity was measured using Salinometer (optical portable salinometer).
4. **Water pH:** The pH was measured using pH meter (PH-035 (ATC) pH meter and pH ep Pocket sized pH meter) to determine changes in water chemistry like increase in carbon di oxide which reduces pH and in turn affects the prey abundance.
5. **Wave action:** In each quadrat the information whether it is a wave exposed or wave sheltered will be noted down. It is noticed that the organisms in wave-exposed areas have added physical stresses and less thermal stress than those wave-sheltered areas (Smith 2010).
6. **Aspect:** The site aspect like east, west, south, north was recorded to determine whether physical factors have an effect on the abundance and distribution of Asteroids.
7. **Substrate:** The substrate and terrain type was recorded in each transect. The substrate type was classified as live corals, dead corals, coral boulders, coral rubble, sand and sea grass. The substrate terrain was broadly divided into flat, undulating and slope terrain. All were recorded in terms of percentages.

8. **Disturbance:** The disturbance may directly influence Asteroids or indirectly by affecting its prey (mussels, bivalves, gastropods). The disturbance was noted in terms of coral breakage by tourism, fishing, hunting and waste disposal.
9. **Diameter of arm:** The measurement of diameter of the arm was done from arm tip to middle of the species using a measuring tape.
10. **Weight:** The weight of the sea stars was measured using a spring balance (ESAL spring scale, Champion tubular scale) outside the water.

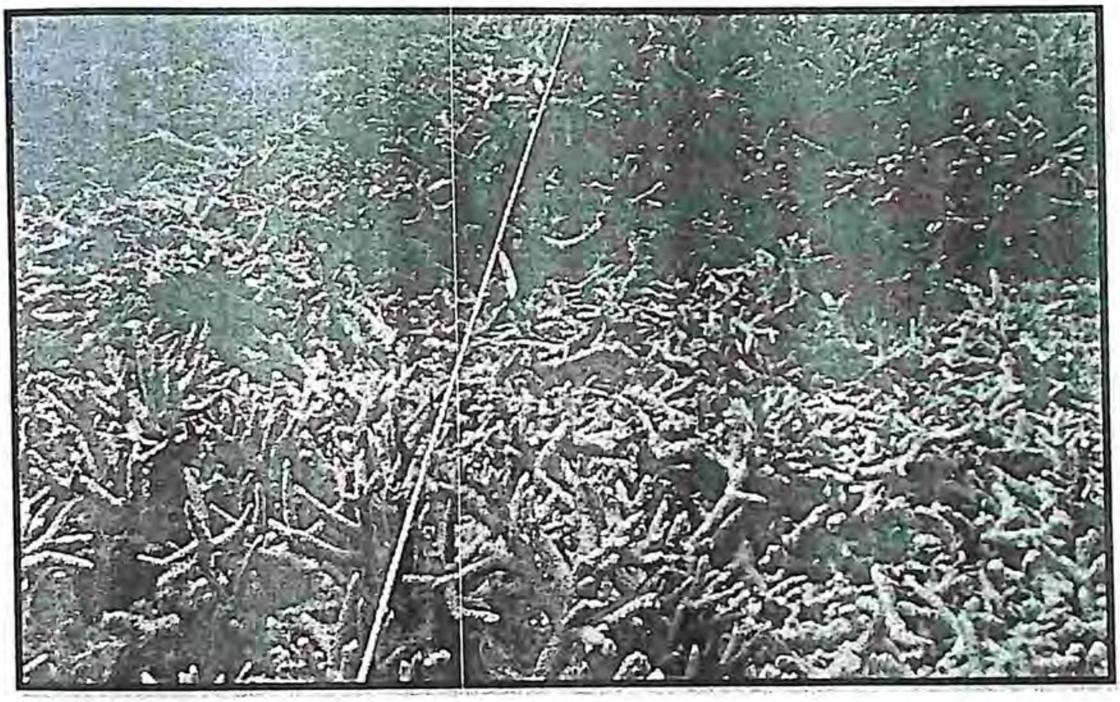

Plate 1. The 25 m transect rope laid in the reefs for surveying sea stars

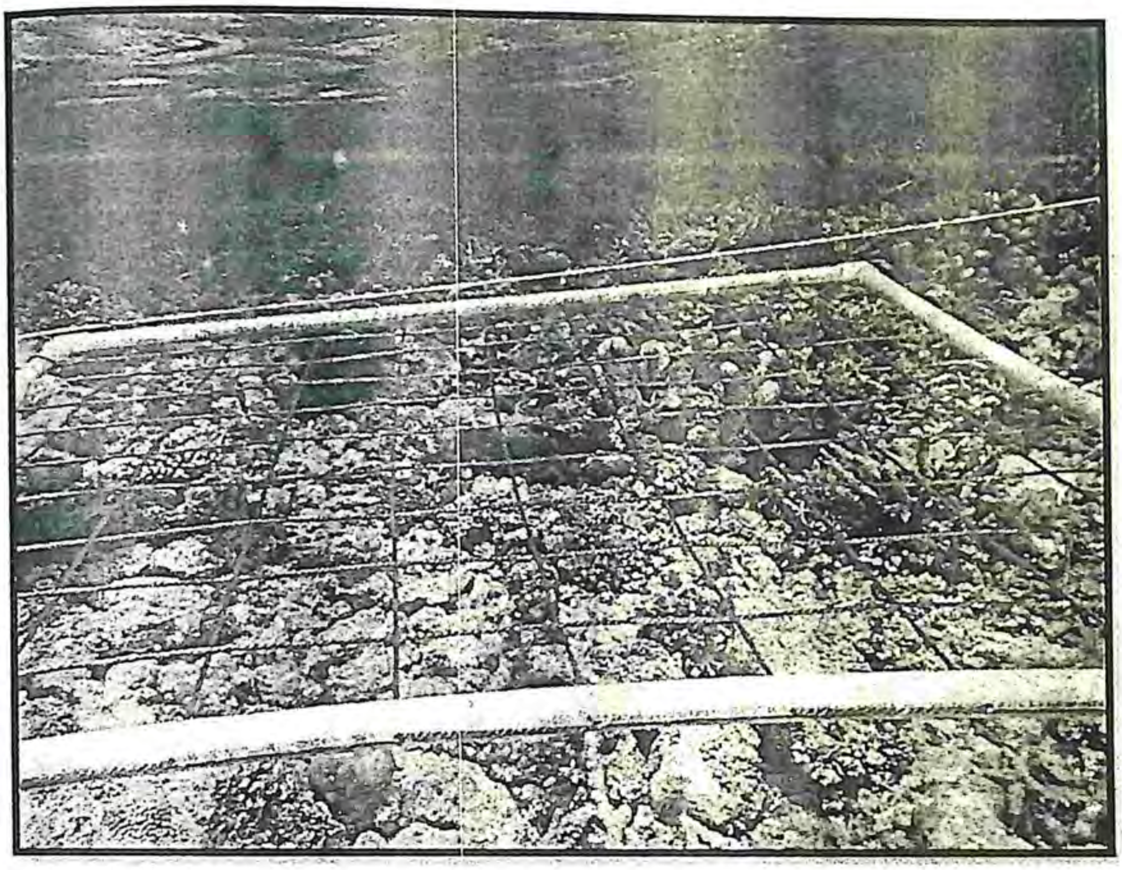

Plate 2. Quadrats laid at 5m of the 25m transect for substrate quantification.

2.3.ANALYSES

Each Island was surveyed as individual experimental units and the belt transects were considered as bound plots. Observed densities in bound plots could only be considered as representatives of the Islands and hence could not be extrapolated to compute the overall densities of asteroids in the Islands. A mean of the asteroid densities of the bound plots were calculated for each island which in turn was used to compare with the other parameters in the study. One way analyses of variance (with α=0.05) (Sokal and Rohlf 1981) were carried out to contrast between islands with and without human habitation for asteroid densities. Tests for normality and homogeneity of variance were carried out to see whether or not the data is violating the assumptions of the one way analysis of variance. It was found that the mean asteroid density of islands violated the assumption of homogeneity of variance (from Levene's test) and thus a Kruskal-Wallis test was done which is basically a nonparametric test excluding this assumption.

Candidate generalized linear models (GLMs) were constructed to determine factors influencing the asteroid densities per $250m^2$. The densities of Asteroids were represented as count data, thus Poisson family of error distribution was used in the models. The predictor variables were tested for colinearity. The model selection was done on the basis of AICc values. Models with delta AICc values of two or less were selected from the set of candidate models (Burnham and Anderson 2002). Analyses were carried out using the free statistical software R (version 3.0.1, R core team 2013)

Correlation matrix was created in NCSS 8.0 Software to see if there is any correlation between the various covariates. Canonical Correspondence Analysis (CCA) using the computer program PC ord version 4.0 was used to explore patterns of variation in asteroid species distribution explained by the environmental variables recorded. Density data for asteroid species were used for the construction of main matrix, and environmental variables were selected as second matrix. The eigenvalues of CCA and correlations between site scores of CCA with environmental variables justify an ecological interpretation of results (Jongman *et al.*, 1995). CCA is an ordination technique that incorporates multiple regressions, with the ordination axes constrained as linear combinations of environmental variables (ter Braak 1986). Biplot was created in order to explain the relationship between asteroid species distribution and environmental variables. Species are indicated as circles, plots as triangles and environmental variables as arrows. Arrows indicate environmental variables and its lengths indicate from relative importance and the directions of which are obtained from the correlation of the variable to the axes. The importance of variables is proportional to the length of the arrows. The orthogonal projection of a species point onto an environmental arrow represents the approximate centre of the species distribution along that particular environmental gradient. Monte Carlo permutation tests were used to test significance (Hope 1968) of the relation between asteroid species and the environmental variables. The most important variables were selected based on the variance each explained without considering other environmental variables.

2.4. RESULTS

During the study five species of asteroids were observed from the four sampled Islands. Out of these five species (Plate1 to 6), two were cushion stars of genus *Culcita*: *Culcita schmideliana, Culcita novaeguineae* and two of *Linckia* genus: *Linckia laevigata, Linckia multiflora* and one belonged to *Acanthaster* genus: *Acanthaster planci*. In the four Islands that were sampled the overall mean asteroid density (per $250m^2$) was found to be 0.27 (S.E = 0.03) and separately in each Island were Agatti 0.23 (S.E = 0.04), Kavaratti 0.25 (S.E = 0.05), Bangaram 0.44 (S.E = 0.07) and Suheli 0.14 (S.E = 0.04). The overall density of all the five asteroid species are given in the table 1 and the asteroid species wise densities across the islands are given in the table 2. The asteroid densities (excluding *Acanthaster planci*) did not differ significantly between Islands with and without human habitation (Kruskal-Wallis chi-squared = 0.72, df = 1, p = 0.40). The density of *Acanthaster planci* was compared between the inhabited and uninhabited Islands by doing one way ANOVA and was found to be insignificant (F value = 1.61, p = 0.21) (figure 1). Various models (candidate generalized linear models, GLMs) were created of which the models having AICc values of two or less (first three models) were selected (table 3).

Correlation matrix showed that only pH and water temperature had a correlation of about p = 0.506. The CCA-biplot of asteroid species and environmental variables shows the relationship between asteroid species distribution and environmental variables (ordination diagrams figure 2 and 3). The first three axes of CCA explained 24.2 % of the cumulative variance in species data (table 4). The third axis is having a low eigenvalue of 0.064 which were less important in ecological terms and are not considered further (table 4). The sample scores on the first CCA axis were most strongly correlated with *Culcita schmideliana* and *Linckia multiflora* and sample scores on the second CCA axis were most strongly correlated with *Culcita novaeguineae* and *Linckia laevigata* (table 5). Variables on axis 1 explained more variation than those on axis 2 (table 6, 7, 8). The sample scores on the first CCA axis were most strongly correlated with pH and depth where as dead corals were. Canonical Correspondence Analysis ordination diagrams of asteroid species and environmental variables (figure 2). (from the values in table 6). Correlations between environmental variables confirmed results of CCA analysis with axis 1 most strongly correlated positively with pH (r = 0.61) and negatively with depth (r = -.67) table 9. The p value (0.02) of Monte carlo tests explains how well the data justifies the species-indicated that the species were significantly related to the environmental variables supplied $p = 0.02$ which is < 0.01 the significant value.

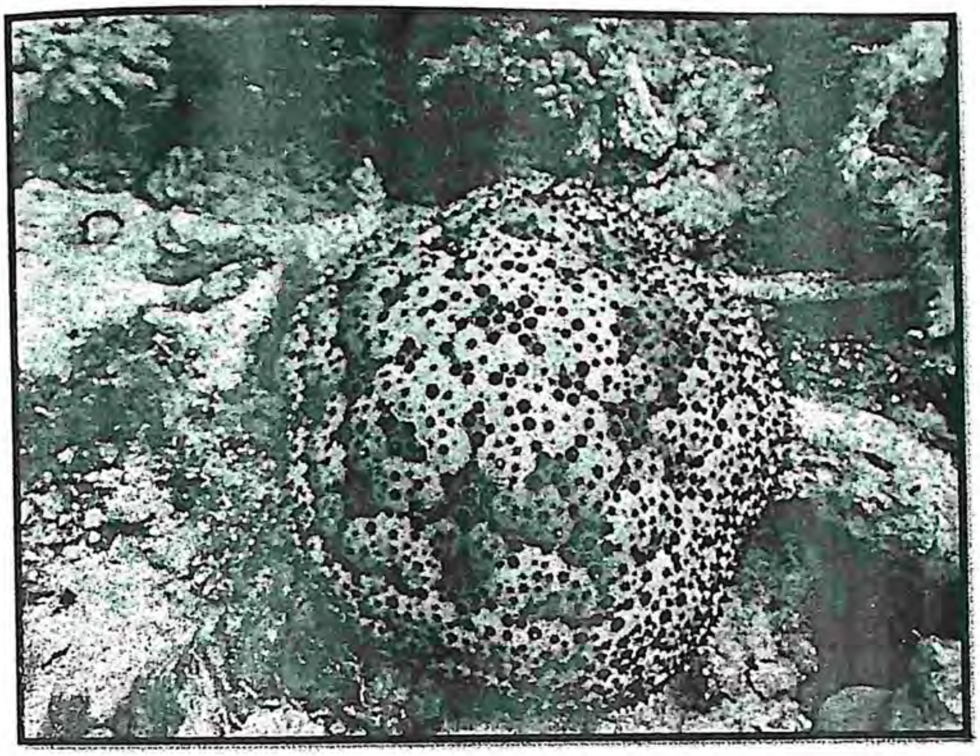

Plate 3. *Culcita schmideliana* in dead coral habitat

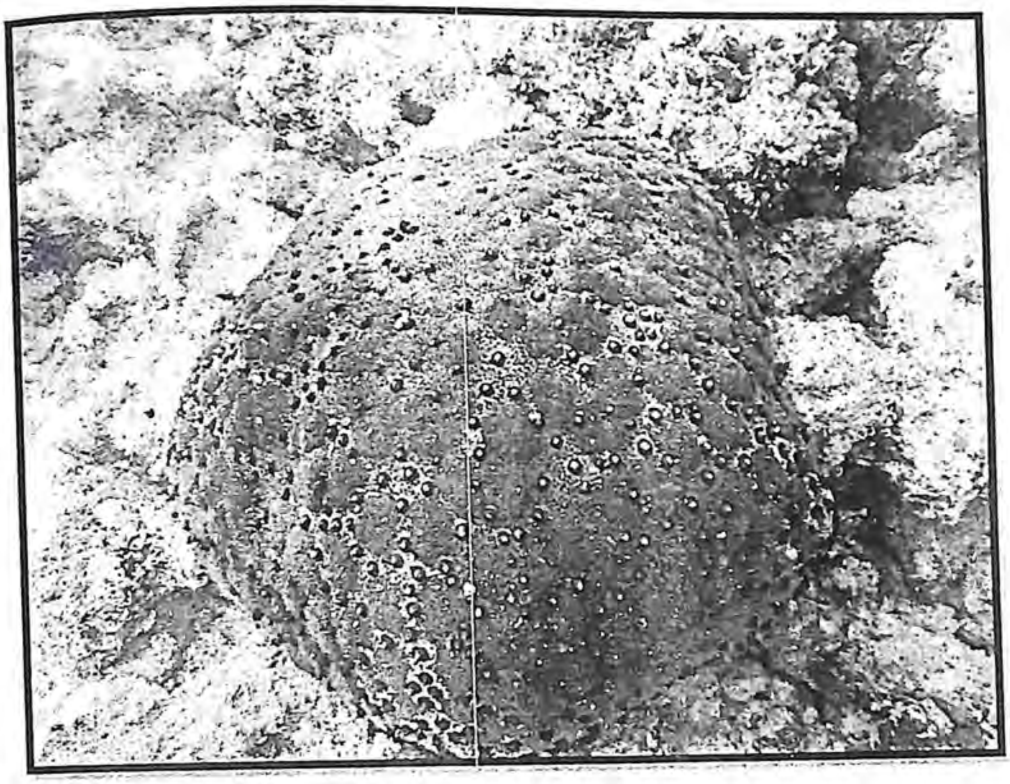

Plate 4. *Culcita novaeguineae* in coral boulders habitat

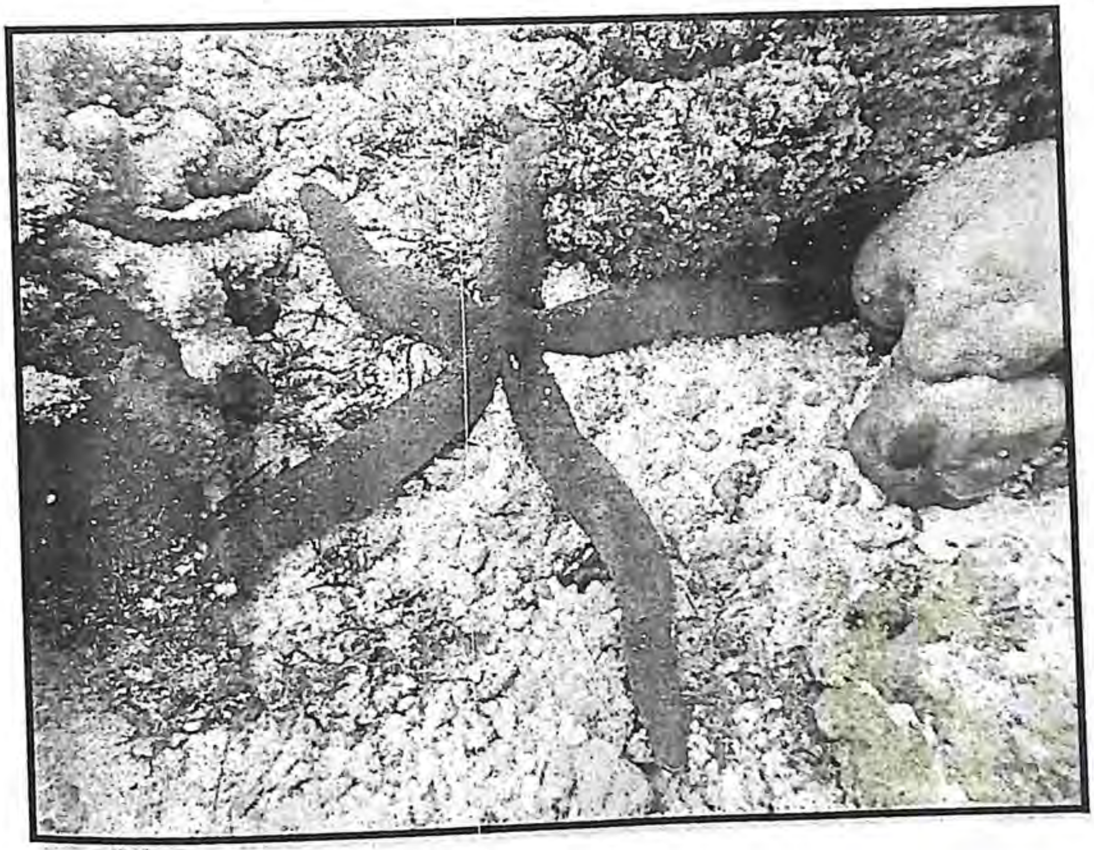

Plate 4. *Linckia laevigata* in sand habitat

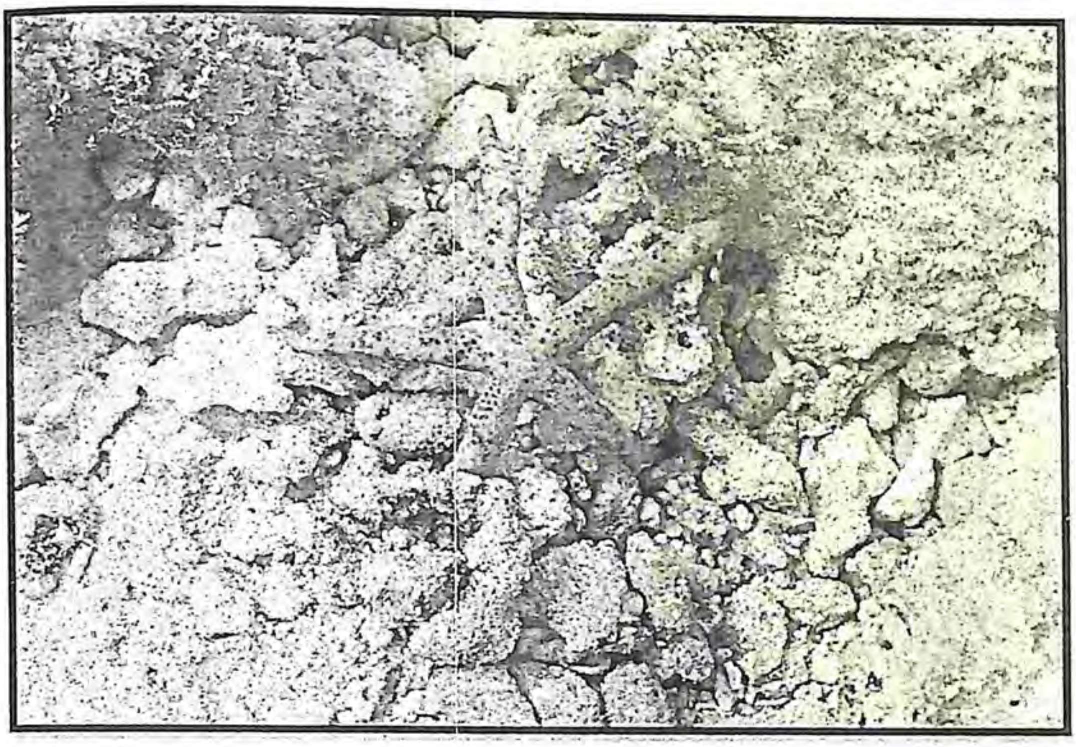

Plate 5. *Linckia multiflora* in coral rubble habitat

Plate 6. *Acanthaster planci in* live coral habitat

Table 1. The overall densities (per 250 m^2) of Asteroids species as observed in the four islands of Lakshadweep Archipelago

SPECIES NAME	MEAN	S.E
Culcita schmideliana	0.80	0.09
Culcita novaeguineae	0.05	0.02
Linckia laevigata	0.15	0.04
Linckia multicolor	0.21	0.06
Acanthaster planci	0.13	0.04

Table 2. The densities (per 250 m^2) of Asteroids species as observed in each of the four islands of Lakshadweep Archipelago.

	ISLAND NAME							
SPECIES NAME	**Agatti**		**Kavaratti**		**Bangaram**		**Suheli**	
	Mean	**S.E**	**Mean**	**S.E**	**Mean**	**S.E**	**Mean**	**S.E**
Culcita schmideliana	0.70	0.11	0.73	0.14	1.60	0.26	0.19	0.08
Culcita novaeguineae	0.02	0.02	0.00	0.00	0.09	0.06	0.09	0.05
Linckia laevigata	0.09	0.04	0.10	0.06	0.17	0.09	0.25	0.12
Linckia multicolor	0.32	0.14	0.00	0.00	0.40	0.12	0.00	0.03
Acanthaster planci	0.04	0.03	0.40	0.13	0.00	0.00	0.19	0.08

Table 3. Generalized linear models constructed to determine factors influencing the Asteroid density (per 250 m^2)

Model	AICc value	delta
Depth	**426.66**	**0.00**
pH	**427.75**	**1.09**
Depth + Live coral + pH	**427.98**	**1.32**
Depth + Live coral + pH + coral boulder + coral rubble	429.50	2.84
Live coral	429.55	2.90
Null	430.53	3.88
Coral boulder	431.38	4.72
Coral rubble	432.00	5.34

Table 4. Eigenvalues of the first four axes of canonical correspondence analysis (CCA) and the amount of variance explained of the species data and of the species-environment relation by the CCA axes.

Number of canonical axes: 3			
Total variance ("inertia") in the species data: 2.3018			
	Axis 1	**Axis 2**	**Axis 3**
Eigenvalue	**0.389**	**0.104**	0.064
% of variance explained in species data	16.9	4. 5	2.8
Cumulative % explained in species data	**16.9**	**21.4**	24.2
Pearson Correlation, Spp-Envt*	**0.671**	**0.384**	0.294
Kendall (Rank) Corr., Spp-Envt	**0.353**	**0.265**	0.125

* Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables. Set to 0.000 if axis is not canonical.

Table 5. Final scores for asteroid species as observed in the four islands of Lakshadweep Archipelago.

Species name	**Final scores**		
	Axis 1	**Axis 2**	**Axis 3**
Culcita schmideliana	**-0.510**	-0.372	0.299
Culcita novaeguineae	0.362	**-1.522**	-4.627
Linckia laevigata	-0.322	**2.597**	-0.663
Linckia multiflora	**2.201**	-0.012	0.392

Table 6. Canonical coefficients between the site scores on the first three constrained axes and environmental variables generated by canonical correspondence analysis of 96 bound plots excluding *Acanthaster planci.*

VARIABLE	STANDARDIZED			ORIGINAL UNITS			Std.Dev
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3	
1 Live coral	-0.097	-0.087	-0.028	-0.010	-0.009	-0.003	9.45
2 Dead coral *	**0.313**	0.030	0.042	0.022	0.002	0.003	14.00
3 Bleached coral	0.112	0.103	0.025	0.266	0.244	0.058	0.42
4 Coral Rubble	0.088	0.133	0.022	0.004	0.006	0.001	21.50
5 Coral Boulder	0.102	0.046	0.019	0.006	0.003	0.001	16.50
6 Sand	0.096	-0.071	- 0.183	0.005	-0.003	-0.009	20.80
7 Sea grass	-0.088	-0.056	-0.061	-0.036	-0.023	-0.025	2.46
8 Water Ph*	**0.307**	0.178	-0.109	2.532	1.471	-0.896	0.12
9 Water temp	-0.190	0.001	0.121	-0.204	0.002	0.130	0.93
10 Water Depth*	**-0.320**	0.243	-0.037	-0.884	0.671	-0.103	0.36
11 Water Salinity	-0.005	-0.084	0.098	-3.467	-57.627	67.483	0.00

* The indication of strongest correlations.

Table 7. Intra-set correlation scores for 11 Environmental variables as observed in the four islands of Lakshadweep Archipelago.

VARIABLE	INTRA-SET CORRELATIONS			BIPLOT SCORES		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
1 Live coral	-0.415	0.010	0.219	-0.259	0.003	0.055
2 Dead coral *	**0.551**	-0.005	0.382	**0.343**	-0.002	0.096
3 Bleached coral	-0.105	0.116	0.050	-0.065	0.037	0.013
4 Coral Rubble	0.105	0.296	-0.043	0.065	0.095	-0.011
5 Coral Boulder	0.201	0.198	0.067	0.126	0.064	0.017
6 Sand	0.101	-0.248	-0.783	0.063	-0.080	-0.198
7 Sea grass	-0.045	-0.209	-0.393	-0.028	-0.067	-0.099
8 Water Ph*	**0.601**	0.497	-0.167	**0.375**	0.160	-0.042
9 Water temp	0.103	0.210	0.194	0.064	0.068	0.049
10 Water Depth*	**-0.671**	0.515	-0.073	**-0.419**	0.166	-0.018
11 Water Salinity	0.050	-0.235	0.299	0.031	-0.076	0.076

* The indication of strongest correlations.

Table 8. Inter-set correlation scores for 11 Environmental variables as observed in the four islands of Lakshadweep Archipelago.

Variable	Inter-set Correlations		
	Axis 1	Axis 2	Axis 3
1 Live coral	-0.278	0.004	0.065
2 Dead coral *	**0.369**	-0.002	0.112
3 Bleached coral	-0.070	0.045	0.015
4 Coral Rubble	0.070	0.114	-0.013
5 Coral Boulder	0.135	0.076	0.020
6 Sand	0.068	-0.095	-0.231
7 Sea grass	-0.030	-0.080	-0.116
8 Water Ph*	**0.403**	0.191	-0.049
9 Water temp	0.069	0.081	0.057
10 Water Depth*	**-0.450**	0.198	-0.021
11 Water Salinity	0.033	-0.090	0.088

* The indication of strongest correlations.

Table 9. r values and tau values of the environment variables showing correlation with asteroid species excluding *Acanthaster planci*.

ENVIRONMENT VARIABLE	AXIS 1		AXIS 2	
	r value	tau value	r value	tau value
pH	.606	.449	.370	.247
Depth	-.672	-.505	.486	.311
Dead corals	.367	.054	.071	-.009

Table 10. Monte Carlo test results- Eigen values and species-environment correlations

	EIGEN VALUES					SPECIES-ENVIRONMENT CORRELATIONS				
Axis	Real data	Randomized data Monte Carlo test, 99 runs				Real data	Randomized data Monte Carlo test, 99 runs			
	Eigenvalue	Mean	Min	Max	p	Correlation	Mean	Min	Max	p
1	0.389	0.179	0.079	0.393	**0.0200**	0.671	0.468	0.309	0.719	**0.0200**
2	0.104	0.089	0.022	0.186		0.384	0.340	0.175	0.498	
3	0.064	0.045	0.012	0.115		0.294	0.241	0.127	0.393	

p = proportion of randomized runs with eigenvalue/ species-environment correlation greater than or equal to the observed eigenvalue/ species-environment correlation; i.e., p = (1 + no. permutations >= observed)/ (1 + no. permutations) p is not reported for axes 2 and 3 because using a simple randomization test for these axes may bias the p values.

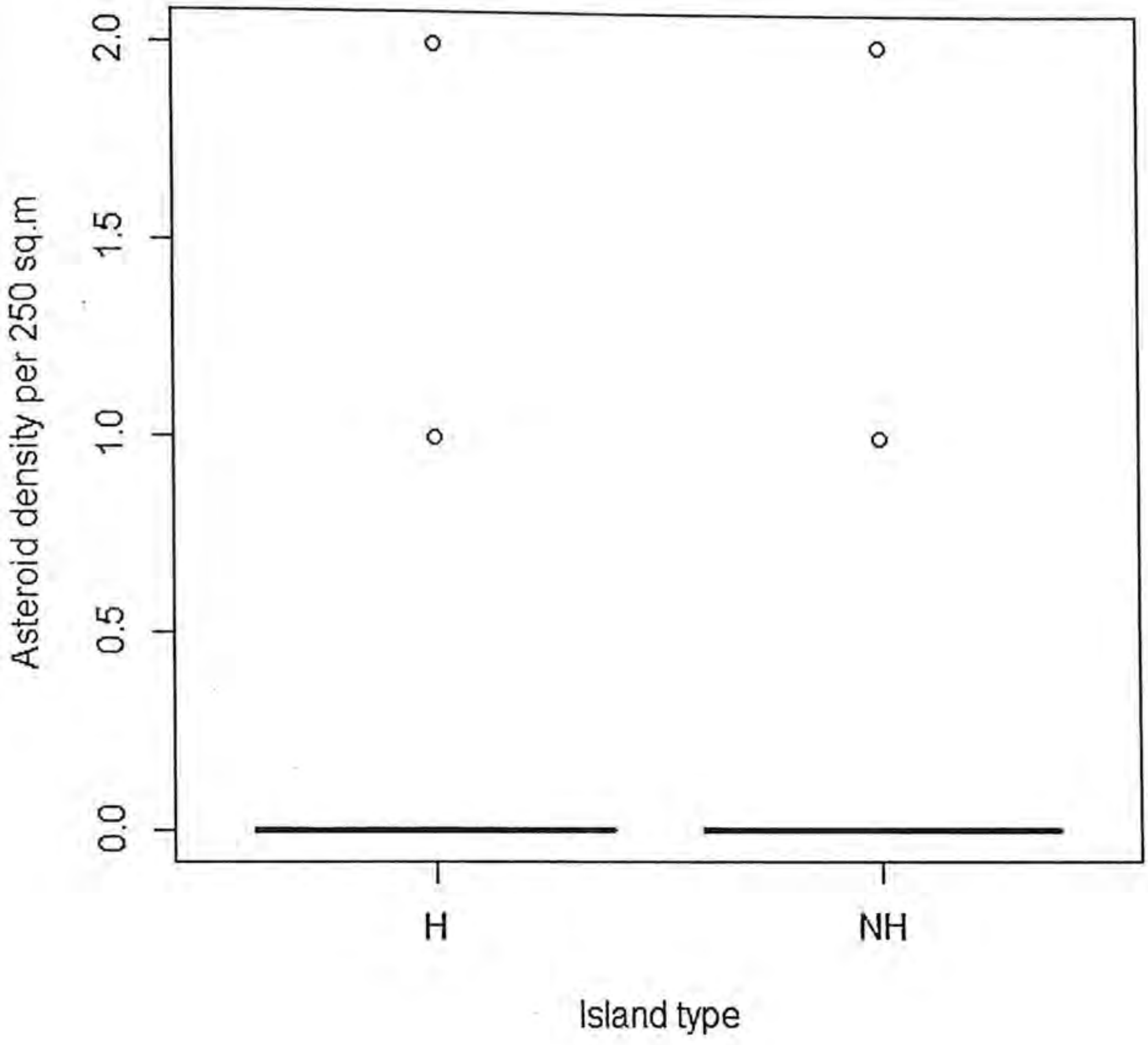

Fig.1 A box plot illustrating asteroid (only *Acanthaster planci*) density per bound plot in islands with and without human habitation in Lakshadweep Islands.

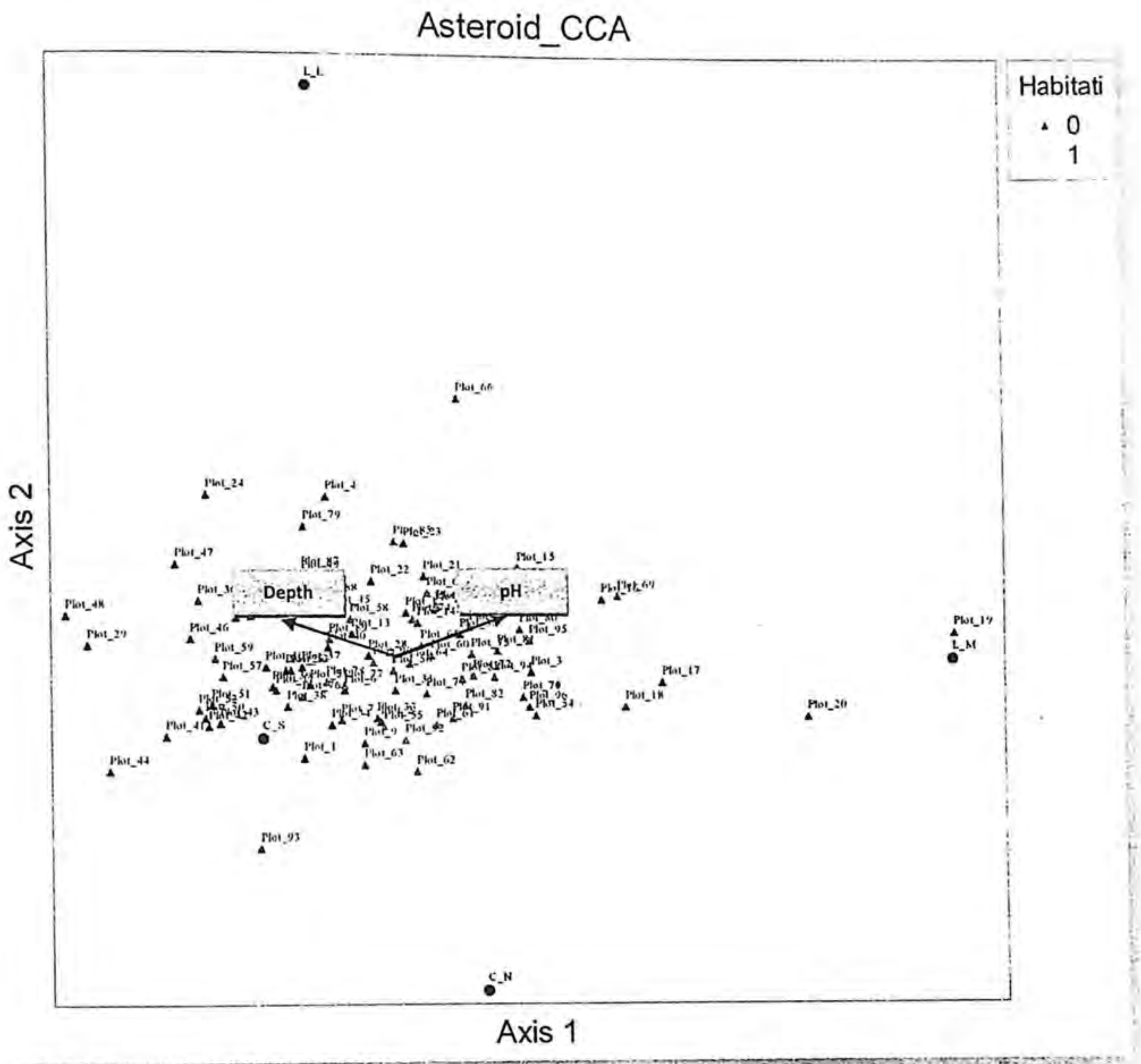

Fig.2 Biplot of species and environmental variables jointly reflecting asteroid species distributions along gradients of environmental variables with the grouping variable as habitation. Blue dots are the asteroid species, red triangles are human inhabited plots and green ones are human uninhabited plots. C_S - *Culcita schmideliana*, C_N - *Culcita novaeguineae*, L_L - L*inckia laevigata and* L_M *-Linckia multicolor*

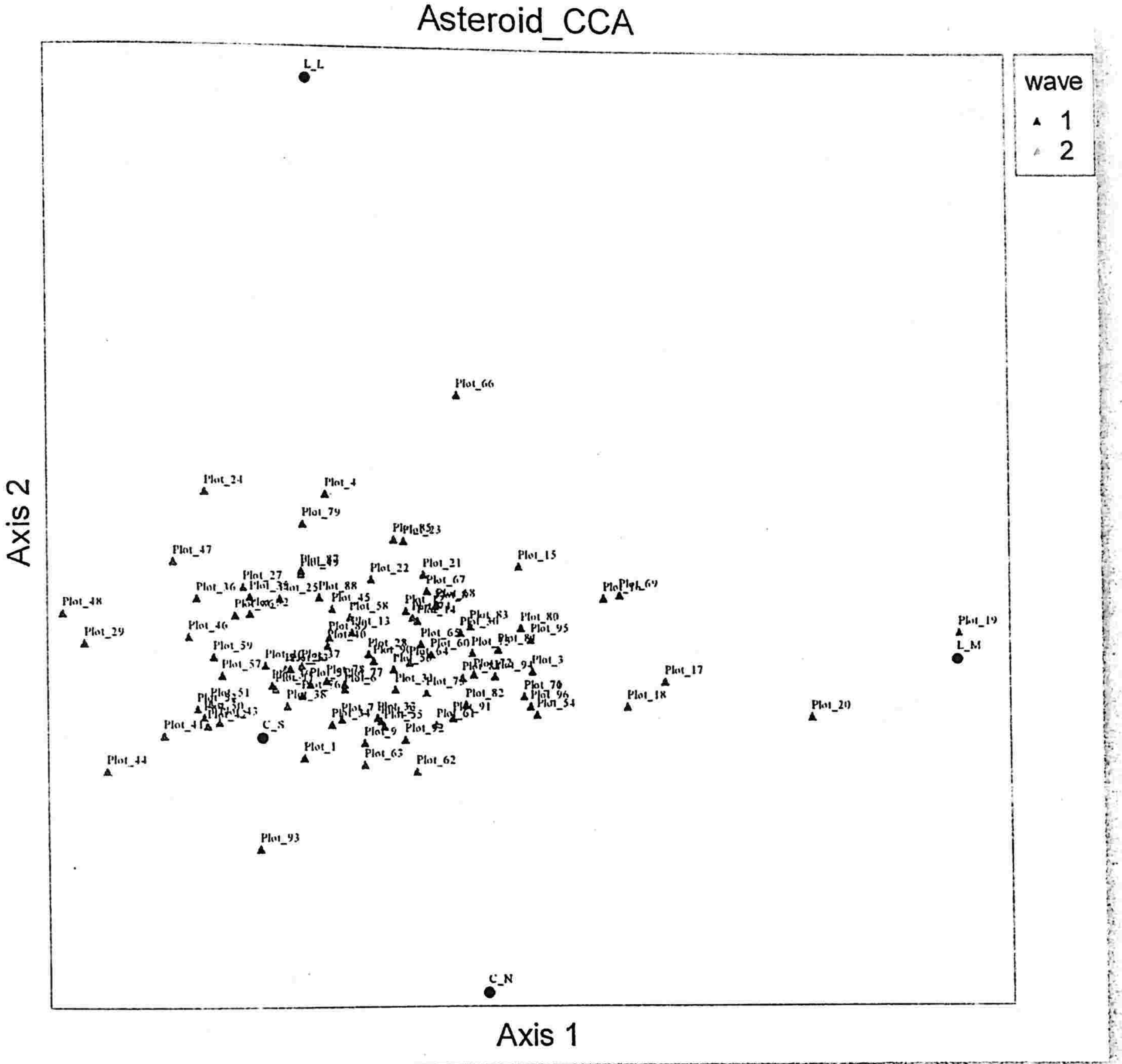

Fig.3 Simple scatter plot showing of asteroid species with the grouping variable as habitation. Blue dots are the asteroid species, red triangles are human inhabited plots and green ones are human uninhabited plots.: C_S - *Culcita schmideliana*, C_N - *Culcita novaeguineae*, L_L - *Linckia laevigata and* L_M -*Linckia multicolor*

2.5.DISCUSSION

Sea stars occupy the top trophic levels and are common predators in benthic communities. Based on the habitat, characteristic traits and prey features they vary in trophic position (predation, scavenging and coral grazing) and community importance (Menge and Sanford 2013). Studies discussing the factors influencing the density of sea stars: food availability (Hyman 1955; Seshappa 1981; McClintock and Lawrence 1985; Himmelman and Dutil 1991; Sanford 2002; Chhapgar 2006 and James unpublished), environmental factors (Petes et al. 2008; Szathmary 2009; Broitman 2009 and Smith 2010), habitat modification (James 1982a; Leray et al. 2012, Roger and Elliott 2013) are very few in number. The literature review denotes that human induced disturbances are one of the factors affecting Asteroids in intertidal region and they tend to act differently in different species (Smith 2010). The human induced disturbances can result in change in nutrient flow which in turn causes fluctuation of oxygen levels, water conductivity, pH level and ultimately water temperature and these factors influences the asteroid density and distribution (Smith 2010). The densities of the sea stars did not significantly vary between the inhabited and uninhabited Islands and thus failed to reject the null hypothesis. Due to low sample size of asteroid species my study could not explain the effect of human induced disturbance in asteroid density.

High eigenvalues for the first two axes indicated the occurrence of species in distinct groups and significant correlations of the axes with environmental variables indicated the effect of these variables on species grouping (table 4). Studies indicate that any variation from the normal range of pH level can result in the changing population dynamics and community structure (Smith 2010). The pH has significant positive associations with first axis and species that are distributed along the axis one are positively correlated to pH (figure 2). Thus distribution of *Linckia multicolor* and *Culcita novaeguineae* are positively correlated to pH where as *Culcita schmideliana* and *Linckia laevigata* is negatively correlated to pH. The decrease in pH levels may reduce the prey availability specially the mussel population which will affect most of the sea star species (Smith 2010, Menge and Sanford 2013). The distribution of some sea stars on the sea bed was also noticed to be dependent on the depth (Himmelman and Dutil 1991; Howell *et al*. 2002; Bell 2008) like in the case of *Acanthaster planci*. In this study it was found that depth is negatively linked to axis one and thus *Culcita schmideliana* and *Linckia laevigata* are positively correlated to depth as they are also negatively linked to axis one. Also the distribution of *Linckia multicolor* and *Culcita novaeguineae* were negatively correlated to depth which means they are distributed in less deeper areas. *Linckia laevigata* is sensitive to temperature, oxygen level, and pH and occupies a highest depth of 60m (Yamaguchi 1977; Magsino et al., 2000; Kochzius *et al.* 2009). *Linckia multicolor* is most abundantly seen in inter tidal and sub-tidal areas which are basically shallow depth areas (Ride out 1978). The maximum depth of *Culcita schmideliana* reaches to 92m (Rowe & Gates, 1995) where as *Culcita novaeguineae* is recorded from depth range of 7-10m (Ohta et al 2011). The densities of sea stars are also dependent on the presence of live and dead corals as explained in the case of *Acanthaster planci* and Culcita species (Goreau 1972, Thomassin 1976, Pratchett 2007). The studies indicate that dietary preference of *Culcita schmideliana* is mostly sponge, sea grass, detritus and rarely coral (Thomassin 1976) and for *Culcita novaeguineae* it is mainly detritus, algae, coral rubble and live coral (Goreau 1972). Also *Acanthaster planci* is a voracious corallivore species which has vast dietary preferences over coral species (Pratchett 2007). Even though dead corals showed a significant positive association with the asteroid distribution, due to a smaller r value (0.367) thereby could not properly explain the distribution pattern.

Brodie *et al.* 2005 noted that this trend with pH is different in *Acanthaster planci* where with the decrease in pH the species flourishes. In this study it was found that pH influences the distribution of asteroid species in the Lakshadweep Island. This is actually caused as a result of eutrophication that may dissolve more atmospheric oxygen and outcome is ocean acidification. The larvae of *Acanthaster planci* are planktonic feeders, hence during nutrient flow they feed on these planktonic booms leading to an outbreak (Birkeland 1982; Olson and Olson 1989; Fabricius et al. 2010). Menge and Menge 1974 have observed that sea stars that occupy the same kind of habitat or same diet tend to follow niche partitioning. *Acanthaster planci* feeds on the coral species more like an outbreak but *Culcita sps* feeds on a continuous basis in a controlled manner (reviewed by Bell 2008). And in this case it was found that the Island where *Acanthaster planci* was found to be abundant there *Culcita schmideliana* and *Culcita novaeguineae* either less abundant or completely absent and vice versa (table 2). Thus *Acanthaster planci* was omitted from the analysis because of the contradicting behavior and feeding pattern.

3. CONCLUSION

Environmental factors play important roles in influencing asteroid species distribution in the Lakshadweep Islands. The major environmental factors that are influencing the distribution of asteroid density are water pH and water depth. Across the four Islands a variation in the pH level was noticed. As explained in the discussion it is clear from the earlier studies that pH and depth along with various other environmental factors have a major role to play in the distribution of asteroid species. Sea stars are the common predators and scavengers of the benthic bottoms. Corallivorous asteroid species changes the community structure and population of not only coral reefs but many fauna that depends on it. The people of Lakshadweep Islands (which are basically coral Islands) are dependent on coral reef ecosystem or livelihood and survival. Destruction of coral reef biodiversity devastatingly will affect the economies of people of Lakshadweep Islands. Hence it is of great importance that the factors that trigger asteroid population outbreak be kept in control in order to sustain the coral reef biodiversity for eternity in Lakshadweep Islands. The change in the nutrient flow through eutrophication or sewage disposal leads to huge planktonic booms. This leads to the population outbreaks of corallivorous asteroids whose larvae are planktonic feeders. These nutrient flows are ultimate cause of the fluctuation in water pH in Lakshadweep Islands. In conclusion, differences in asteroid species distribution observed over the gradients of water pH should be taken into account while designing management policies in Lakshadweep Islands.

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