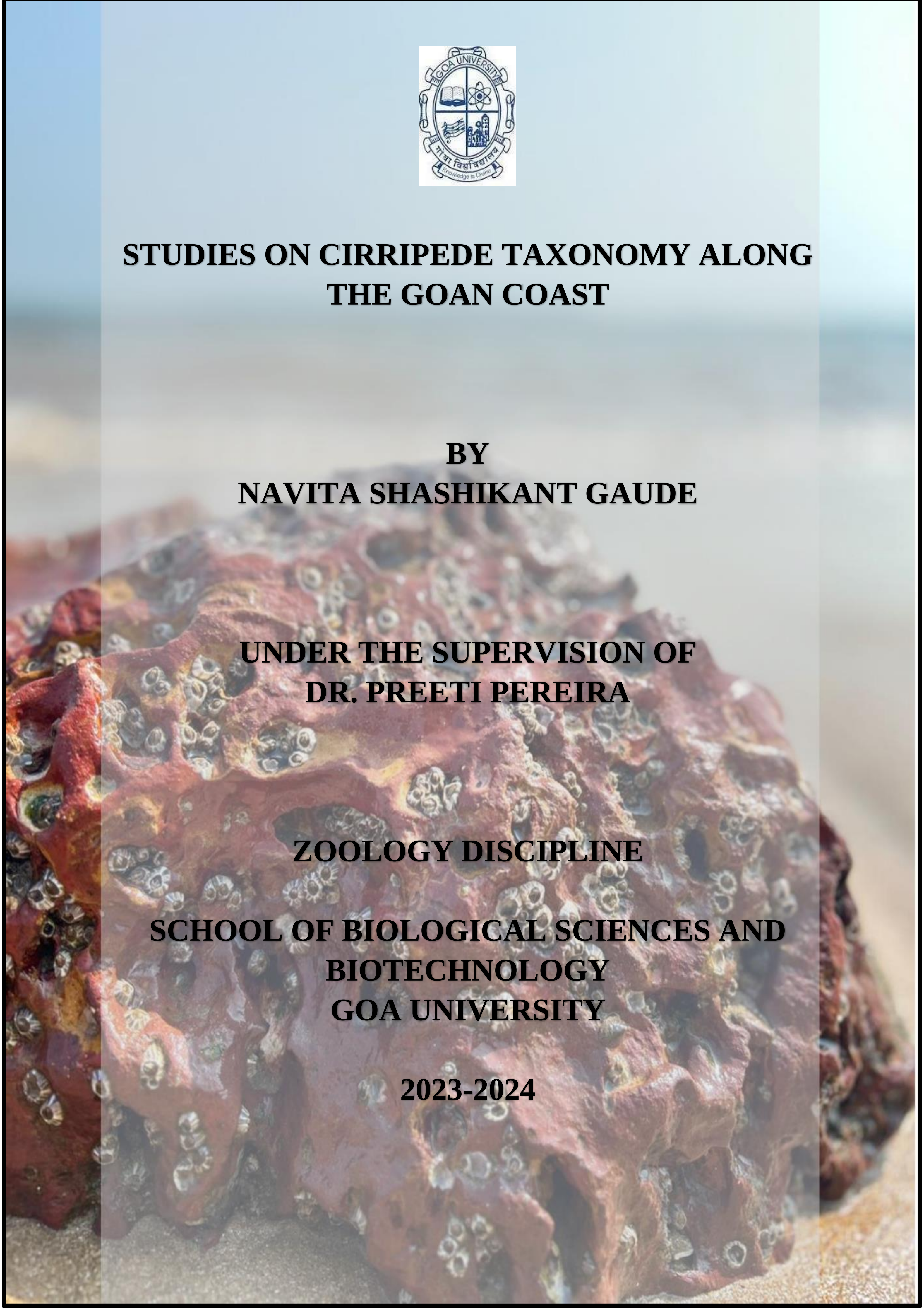

STUDIES ON CIRRIPEDE TAXONOMY ALONG THE GOAN COAST

BY

NAVITA SHASHIKANT GAUDE

UNDER THE SUPERVISION OF

DR. PREETI PEREIRA

ZOOLOGY DISCIPLINE

SCHOOL OF BIOLOGICAL SCIENCES AND BIOTECHNOLOGY

GOA UNIVERSITY

2023-2024

Studies on Cirripede Taxonomy along the Goan coast

A Dissertation for

Course code and Course Title: ZOO-651 Dissertation

Credits: 16

Submitted in partial fulfilment of Master's Degree in Zoology

by

NAVITA SHASHIKANT GAUDE

Seat Number: 22P0440020

ABC ID: 472-419-916-555

PRN: 201905799

Under the Supervision of

DR. PREETI ANTONETTA PEREIRA

School of Biological Sciences and Biotechnology
Zoology Discipline

GOA UNIVERSITY

APRIL 2024

Examined by:

SBSB, M.Sc., Zoology
Taleigao
Plateau, Goa
403206
GOA UNIVERSITY

Seal of the School

DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Studies on Cirripede Taxonomy along the Goan coast" is based on the results of investigations carried out by me in the Zoology at the School of Biological Sciences and Biotechnology, Goa University under the Supervision of Dr. Preeti Antonetta Pereira and the same has not been submitted elsewhere for the award of a degreeor diploma by me. Further, I understand that Goa University or its authorities will be not be responsible for the correctness of observations / experimental or other findings given the dissertation.

I hereby authorize the University authorities to upload this dissertation on the dissertation repository or anywhere else as the UGC regulations demand and make it available to any one as needed.

Gaude.

Navita Shashikant Gaude

Seat no: 22P0440020

Date: 09/04/2024

Place: Goa University

COMPLETION CERTIFICATE

This is to certify that the dissertation report **"Studies on Cirripede Taxonomy along the Goan coast"** is a bonafide work carried out by **Ms Navita Shashikant Gaude** under my supervision in partial fulfilment of the requirements for the award of the degree of **Masters of Science** in the Discipline Zoology at the School of Biological Sciences and Biotechnology, Goa University.

Dr. Preeti Pereira
Assistant Professor
Zoology Discipline, Goa University

Date: 08/04/2024

SBSB, M.Sc., Zoology ★ GOA UNIVERSITY ★ Taleigao Plateau, Goa 403206

Prof. Benard F. Rodrigues
Dean of the School of Biological Sciences
and Biotechnology, Goa University

School Stamp

Date: 8-4-24
Place: Goa University

Dean of School of Biological Sciences
& Biotechnology
Goa University, Goa-403206

CONTENTS

PREFACE

Cirripedes (crustaceans) are sessile benthic organisms. Cirripedes are distributed worldwide and are considered as problematic organisms as they are marine biofouling creatures and have a tendency to settle on any hard surfaces (Ships, docks, in fishing industries and any other man-made objects). Though cirripedes are considered as problematic in fishery industries, they are ecologically important and play a vital role in maintaining the functioning of marine ecosystem. Also, in Countries like Japan, China, Spain and Portugal; cirripedes are considered as economically important organisms, in terms of ornamental, fertilizer, food and also in dentistry.

However, cirripedes are ecologically and economically important organisms, yet taxonomic account is understudied except for a few cirripedes. Recruitment and settlement are crucial for any sessile organisms, as many factors influence the settlement rate. The ability of any benthic organism to recruit and settle demonstrates sustainability of particular population in specific habitat.

This study aims to uncover the taxonomic account of cirripedes along Goan coast. As date back not much data was available for the same. Also, aims to examine the recruitment and settlement patterns of barnacles as studying this provide insight knowledge of marine ecosystem health. As settlement rate of barnacles are being affected by various factors like salinity, pH, water current, chlorophyll *a* concentration, etc.

AKNOWLEDGEMENT

This dissertation work was possible because of support and encouragement of several individuals, to whom I extend heartfelt gratitude in embarking this project, I was fortunate to have guidance and constant support of my project supervisor Dr. Preeti Pereira. Whatever I have done is only due to her mentoring and I thank her for that. I am deeply grateful to Dr. Preeti Pereira for sharing immense knowledge, for providing accessory instruments and also accompanying in the field.

I am grateful to Senior Professor Benard F. Rodrigues, Dean of the School of Biological Sciences and Biotechnology for permitting me to carry out dissertation work. I extend my sincere appreciation to Dr. Nitin Sawant, Program Director M.Sc. Zoology for granting permission to access laboratory facilities throughout my dissertation work. I would also like express my gratitude towards the teaching staff of Zoology discipline, Dr. Minal Desai Shirodkar, Dr. Shanti Dessai, Dr. Shamshad Bi Shaikh, Dr. Avelyno D'costa and Ms. Gandhita Kundaikar for their suggestions, feedbacks and encouragement in the dissertation work. I would also like to express my gratitude to non – teaching staffs, Mr. Vithal Naik, Ms. Heena Shaikh, Mr. Madhukar Parulekar and Mr. Diptesh Palkar for providing assistance in the laboratory.

A special thanks to all my friends, for their suggestions and help during sampling. Also, I owe a dept of gratitude to my respected parents for their unwavering support, encouragement and accompanying in the study site throughout this dissertation.

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The cirripedes (Barnacles) are sessile crustaceans, residing in the intertidal and benthic region of marine environment. The current study investigated the intertidal cirripedes along the coast of Goa. A total of six species belonging to 4 genera and 3 families were recorded. Shell morphology and arthropodal characters were used in identifying the species to provide the first taxonomic account of reported species along the Goan coast. Recruitment and settlement pattern of cirripedes was studied by providing substrates, of which only two substrates were occupied by barnacle recruits: Roof tile and granite. Of this two, roof tile showed high number of recruits. However, in the pilot study, granite and cement boulder surfaces were occupied by barnacles.

Keywords: Lepalidae, Chthamalidae, Balanidae, Megabalanidae, Settlement, Recruitment

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Barnacles are sessile crustaceans and are omnipresent in marine environment on hard surfaces from intertidal to deep sea regions (Chan & Hoeg, 2015). Taxonomists has been attracted towards barnacles, since barnacles were first classified into cirripedes by Burmeister (1834). According to Chan et al. (2021), class thecostracan is classified into three subclasses Facetotecta, Ascothoracida and Cirripedia. This class now comprises about 1400 species world-wide (Chan et al., 2009; Trivedi et al., 2021). Further, Cirripedia comprises three superorders: free-living, stalked and sessile species that make up the Thoracica; endoparasites in crustacean host- the rhizocephalan and the barnacles that bore into gastropod shells, known as Acrothoracica (Chan et al., 2009; 2021). Barnacles are meroplanktonic; they are planktonic organisms throughout their larval stage and transition to benthic organism in the adult stage (Sulistiono et al., 2017).

India is a home for diverse marine habitats and invertebrate fauna. About 144 species of barnacles have been reported in India, distributed among 75 genera and 19 families (Trivedi et al., 2021). A large number of studies were carried out on coral associated barnacles from the coral reefs of Andaman and Nicobar Islands and Northern Bay of Bengal and on other hand most of the sponge associated barnacles were studied from Eastern India and Southern Indian Ecoregions (Trivedi et al., 2021).

Goa being small state, has a coastline of 109 sq. km. Intertidal diversity of Goa has not been explored in detail. Five barnacle species have been reported from Goa, *Octolasmis grayi, Striatobalanus amaryllis, Amphibalanus amphitrite, Amphibalanus variegatus* and *Megabalanus tintinnabulum* (Nandankumar, 1990; Gaonkar & Anil, 2013; Trivedi et al., 2021). The most well studied barnacle from the Goan coast is the *Amphibalanus amphitrite*, a dominant macrofouling organism of Indian coastline (Gaonkar & Anil, 2013).

Barnacles with a calcareous shell are acorn and gooseneck, the former affixed directly to the substratum and later settled on substratum via a stalk or peduncle. Most of the acorn barnacles consists of 8-6 parietal plates. Once they settled on substrate, soon, they start to secrete proteinaceous substance around their stroma. Within two days the exoskeleton becomes rigid and looks like an adult barnacle shell (Metzler et al., 2020). While goose barnacles settled on substratum via a stalk. Goose barnacles comprises five or more than five plates. They exhibit gregarious behavior by forming colonies on floating debris, this helps them to reproduce and survive more efficiently in the pelagic habitat (Whitehead et al., 2011). Their larvae are long-lived than other barnacles.

Barnacles are world's most abundant, widely distributed and ecologically significant marine crustaceans. Usually, many suspension feeding barnacles settled on rocky bottoms. Although some epibiotic taxa favor growing on the roots of mangroves or other marine plants, on invertebrates (molluscan shell, marine sponges, corals, crustaceans) or vertebrates (whales, turtles) and also settled on man-made objects (Ship's hull) (Brickner & Hoeg, 2010). In some countries barnacles are considered as expensive seafood and some are biofoulers and hence are economically and ecologically important species (Anil et al., 2012; Trivedi et al., 2021). Also, thoracican barnacles plays an important role in food chain as they are suspension feeders. Also, barnacles are used in decorative purposes and fertilizers in country like Japan (Chan et al., 2009; Parmar et al., 2018). Barnacles attaches themselves via adhesives that they release from cement gland, this adhesive has many applications like, one of the studies reveal that barnacle cement were being used in dentistry (Parmar et al., 2018), also the biochemical properties of barnacle cement are being used in bioinspired glues (Burns et al., 2017).

Most of the free-living barnacles are hermaphrodite, internal cross fertilization is the norm for majority of balanomorph barnacles. Life cycle consists of two larval forms in pelagic phase; nauplius and cyprid. Nauplius undergoes molting by producing four to six planktotrophic stages. And final molts turn into non-feeding cyprid stage which is responsible for finding a suitable habitat, where it can attach itself to the substrate and metamorphosis into juvenile sessile adults (Chan et al., 2009). Adult barnacles are well protected by exoskeleton which is made up of protein, secreted in cement gland. This exoskeleton has window plates (operculum) on top, made up of two terga (singular tergum) and two scutum, that helps the barnacles to extend their cirri out from the shell for the purpose of respiration and feeding (Chan et al., 2009; Metzler et al., 2020).

Recruitment is a process by which juvenile organisms find a habitat and establish themselves whereas settlement refers when cyprids metamorphosized into juveniles. By studying the recruitment patterns, one can evaluate the intertidal ecosystem biodiversity. Barnacles are one of the major biofouling communities of intertidal region. The non-feeding cyprid larva is responsible for finding a site for settlement (Zega et al., 2007). Settlement and recruitment are crucial point for any epibenthic or intertidal communities. Hence, the provision of appropriate substrate is prerequisite for initial recruitment of benthic population, whereas post-settlement processes such as physical disturbance, competition for space or food and mortality affect recruitment success later (Buschbaum, 2001). According to Gaonkar & Anil (2013), settlement is generally consistent on various substrates, but recruitment varies greatly. The densities of settlers and recruits vary significantly over time on all spatial scales. (Caffey, 1985; Scrosati & Holt, 2021; Satumanatpan et al., 2001).

Various factors that affect the settlement and recruitment of barnacles, may be biotic or abiotic factors. Changes in salinity, temperature and water current can disperse the phytoplankton abundance, which is a major source of food for both larval and adult populations. These physical and biological factors work together to influence settlement (Chan, 2006; Gaonkar & Anil, 2013). The breeding, reproductive and settlement of barnacles are being positively affected by chlorophyll *a* concentration and tidal pattern along with other factors mentioned above (Sahu et al., 2015; Scrosati & Ellrich, 2016). Also, when cyprids initiate settlement on substrate, they release their carapace and are sometimes affected by bacteria (Hoeg et al., 2012).

Goa being the coastal state of India and is the home for several marine organisms, but there is a dearth of data on Goan marine fauna. This study aims to investigate the settlement of invasive barnacle species. This study also intended as a contribution towards the taxonomy of Cirripedia using arthropodal characteristics, so as to form a baseline for future research.

1.2 AIM AND OBJECTIVES

The objectives of this study are-

- To study the Taxonomy of Barnacles.
- To study the Diversity and Distribution of Barnacles along Goan coast.
- To study the settlement and recruitment of barnacles.

1.3 HYPOTHESES

Barnacles are macrofouling organisms and have tendency to colonize any substrate.

Dearth of literature on taxonomic records of Barnacles of Goan coast, which has potential of describing new species and regional records.

1.4 SCOPE

It is important to know the intertidal community, as it plays a vital role in marine ecosystem. As this study mainly focusses only on morphological characters and is intended to contribute to a species inventory of Barnacles of Goa. Barnacles being suspension feeders, act as biomonitor in marine ecosystem (Reis et al., 2011). Different species of barnacles can accumulate different level of heavy metals. Barnacles can be used as model organisms for toxicity and heavy metal pollution studies in the marine habitat. Studies may also be conducted on the tidal effects on cirral length, as intertidal barnacles expose continuously to wave action during high tide.

CHAPTER 2: REVIEW OF LITERATURE

Crustacea is a diverse subphylum and encompasses about 52,000 species worldwide. Crustaceans are widely distributed throughout the world and are important arthropods inhabiting aquatic ecosystem (Trivedi et al., 2015; Parmar et al., 2018). Among crustaceans, barnacles are omnipresent, found in all marine environments from intertidal zones to deepest region of the ocean (Chan & Hoeg, 2015; Trivedi et. al., 2021). About more than 1400 species are present worldwide (Innocenti, 2006; Chan et al., 2009; Trivedi et al., 2021; WoRMS 2024). Chan et al. (2021) reviewed barnacle classification up to genus, including both fossils and extant barnacle species. Accordingly, class thecostraca comprises 2116 species belonging to 14 orders, 65 families and 367 genera. Barnacles were first classified by Burmeister (1834). Darwin (1854) and Pilsbry (1916) came up with monographs on barnacles and made significant contributions to taxonomy of barnacles. Henry & Mclaughlin (1975) related *Amphibalanus amphitrite* to other taxa and a key have been provided of all redescribed complex taxa.

External shell morphological keys of few cirripedes were provided by Pitombo (2020). Chan et al. (2009) gave arthropodal keys of barnacles reported in Taiwan. Later Chan & Cheang (2015) discovered *Chthamalus williamsi*, in Taiwan waters, based on external characters it belongs to *challengeri* subgroup but from molecular analysis it formed different clade, thus making it new species. Achituv (1980) gave description of *Chthamalus barnesi* for the first time and compared its morphological characters with other already reported Chthamalids. Most of the chthamalids barnacles look similar externally, Southward & Newman (2003) and Shahdadi & Sari (2010) come up with arthropodal key characters to distinguish them. *Amphibalanus amphitrite* and *Amphibalanus improvisus* are dominant species of American coast, recent study revealed the presence of *Amphibalanus amphitrite* at unidentified places of Northern-Central Chile (Carlton et al., 2011; Chen et al., 2014; Carlton et al., 2021).

Using shell morphology and arthropodal characters, checklists of barnacles from different region of the world are provided with description of each species; from Gulf of Mexico reported 78 species (Spivey, 1981), Madagascar and adjacent waters reported a total of 26 species (Ren, 1989), from Pakistan coast 15 species were reported (Rizvi & Moazzam, 2006), from Persian Gulf and Gulf of Oman total of 43 species recorded (Shahdadi et al., 2014), Ninety-seven species from Moluccas, of which 2 were unidentified (Pitriana et al., 2020), Andaman Sea and Gulf of Thailand reported 10 species (Pochai et al., 2017) and Singapore and neighboring waters reported 48 species (Jones & Hosie, 2016).

The conventional method of identifying species is on the basis of morphological characters, although most recent methods rely on molecular taxonomy. Often morphologically similar species create problems at species level identification, which can be resolved by molecular barcoding using cytochrome c oxidase 1 (COI) gene, which has been amplified using LCO1490 and HCO2198 genes (Pritriana et al., 2020; Riani et al., 2021; Motro et al., 2023; Moesges et al., 2023).

According, Trivedi et al. (2021) India is home for 144 barnacle species, from which Goa has reports of only 5 species (*Octolasmis grayi*, *Amphibalanus amphitrite*, *Amphibalanus variegatus*, *Striatobalanus amaryllis* and *Megabalanus tintinnabulum*). In Gujarat Trivedi et al. (2015) provided a checklist of crustacea in which they recorded 2 barnacle species. Later Trivedi et al. (2021) reported 11 species to Gujarat. Also, Parmar et al. (2018) reported species mostly from Saurashtra coast which has rocky shores. In Indian Ocean, *Chthamalus withersi* and *Chthamalus Challengeri* are only Chthamalidae recorded at Mumbai, but Karande & Palekar (1963) recorded *Chthamalus malayensis* from Naval Dockyard, Cuffe Parade, Colaba, Chaupati, Mazagon, Versova and Madh Island, Mumbai, India.

Throughout their larval phase barnacles are planktonic, but as they mature, they transition into sessile benthic organisms and are found attached to variety of hard substrates (Chan, 2006; Sulistiono et al., 2017). Barnacles are considered as one of the dominant macrofouling community in world, as they have tendency to settle on any hard surfaces including molluscan shells, man-made objects, whales, turtle shells, crustaceans, etc. (Brickner & Hoeg, 2010; Carlton et al., 2011; Burns et al., 2017). Most of the goose barnacles prefer to settle on floating debris within pelagic waters (Whitehead et al., 2011). *Amphibalanus amphitrite* is a most common and globally distributed fouling barnacle (Desai & Anil, 2005; Chen et al., 2014; Calton et al., 2011).

In addition to diversity, few reports have been published on recruitment, settlement and ecology of cirripedes. The settlement and recruitment are crucial for any intertidal organisms (Gaonkar & Anil 2013; Burns et al., 2017). Few studies have been conducted on selective settlement, cyprid larvae settled on living mussels, as no other substrate available in the vicinity (Buschbaum, 2001). The finding of Barbosa (2016) suggest that recruitment of juveniles and settlement of larvae could be significantly influenced by reproductive activity in the vicinity and availability of food in the open water. Olivier et al. (2000) conducted field experiments, concluded that, the larval supply showed little correlation to the intensity of settlement. Settlement and recruitment depend on physical as well as biological factors. There have been significant variation in the densities of settlers and recruits on all spatial scales at any given time (Caffey, 1985; Connell, 1985; Desai & Anil, 2005; Satumanatpan & Keough, 2001; Lagos et al., 2005; Gaonkar & Anil, 2013). Larsson et al. (2016) conveyed that water flow is one of the factors that affect barnacle settlement. Also, biofouling intensity was significantly affected by two major factors, Chlorophyll-*a*, salinity (Sahu et al., 2015; Barbosa et al., 2015; Scrosati & Ellrich, 2016) and food availability (Anil & Kurian, 1996).

According to Gaonkar & Anil (2013) overall settlement patterns remained relatively consistent across various substrates, while recruitment displayed substantial variation. With light recruitment, mortality between juveniles and adults was unaffected of initial density however, with heavy recruitment, mortality was density dependent (Connell, 1985). Scrosati & Holt (2021) suggested that over time, recruit size changed dramatically. Recruitment is the key factor in determining the intertidal barnacle population (Lagos et al., 2005).

CHAPTER 3: METHODOLOGY

3.1 STUDY SITE

This study was carried out along the coast of Goa, located on southwestern coast of India. Coastline of Goa is directly exposed to Arabian Sea with rocky shoreline and thus provides a suitable substrate for sessile organisms. Few rocky shores were, representative of the entire Goan coast, were selected to explore the barnacle diversity. The survey locations are mapped in Fig. 3.1.1 and their respective geographical coordinates are provided in Table 3.1.1.

To understand the recruitment and settlement preferences of Barnacles a different site was selected at Banastarim. Banastarim mangrove region lies between Latitude 15° 29’ 49.398’’ N and Longitude 73° 57’ 19.3572’’ E. Banastarim is considered as wetland of Goa as major west side of it is surrounded by river. Cumbharjua canal runs through Banastarim and meets the river Zuari. The selected area has two mangrove species: *Rhizophora apiculata* and *Acanthus ilicifolius*.

3.2 MATERIALS AND METHODS

Specimen Collection and Identification

This study was carried out by using simple random sampling method (Sulistiono et al., 2017) Specimens were collected during September 2023 to January 2024 from the intertidal zone along rocky shore during low tide using hammer and chisel (Pitriana et al., 2020; Pochai et al., 2017). Live specimens were photographed and then collected. After removing out from the substratum, whole barnacle individuals were preserved in 70% ethanol for further analysis. Specimens were first identified based on shell morphology, that includes pattern and color of parietes plates and basal shell wall structure. The specimens were later dissected using stereozoom microscope (WESWOX OPTIK; SZM-100) and compound microscope (Infinity;

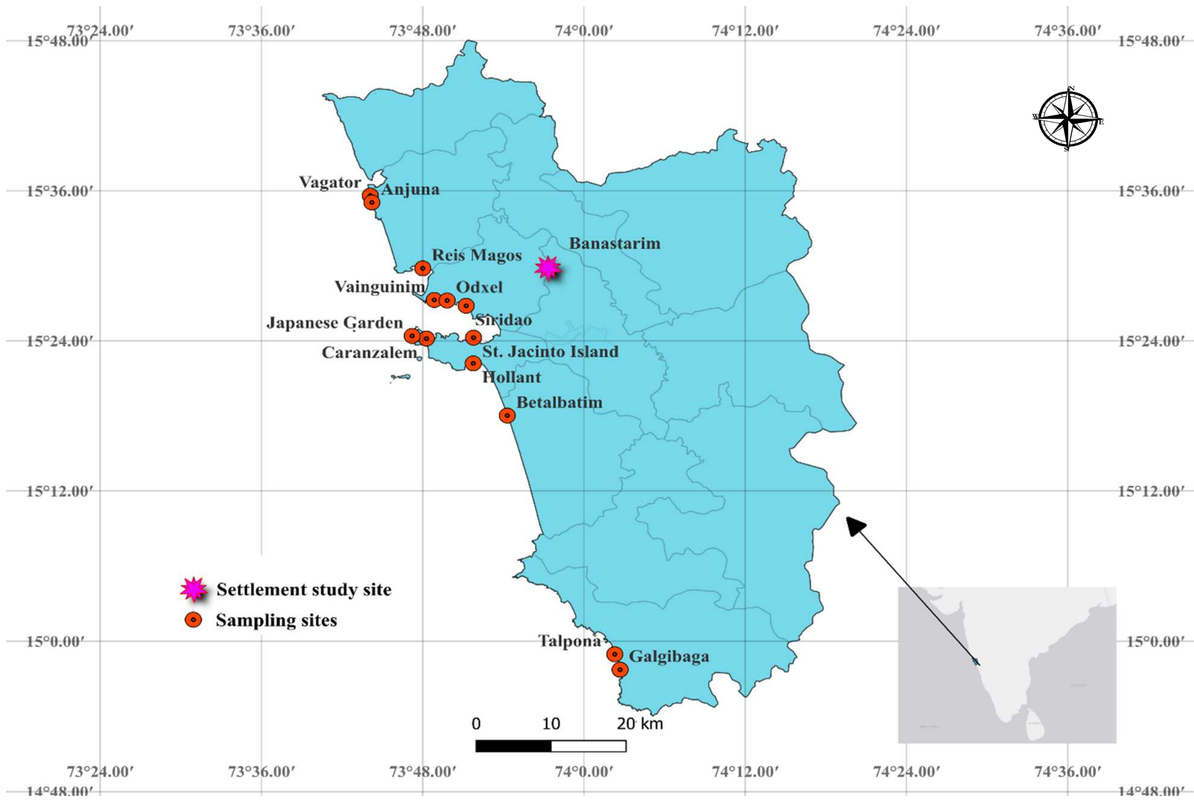

Fig. 3.1.1: Map Showing study site and sampling sites

Table 3.1.1: Showing Geographic coordinates of sampling sites

District	Location	GPS Coordinates		Tidal Exposure (in Meters)
		Latitude	Longitude	
North Goa	Vagator	15⁰35′36.9852″ N	73⁰44′5.8128″E	0.41
	Anjuna	15⁰35′4.0956″ N	73⁰44′12.9912″ E	0.11
	Reis Magos	15⁰29′47.6556″ N	73⁰48′0.162″ E	0.5
	Vainguinim	15⁰27′15.9768″ N	73⁰48′51.5736″ E	0.47
	Odxel	15⁰27′13.284″ N	73⁰49′48.9864″ E	0.16
	Caranzalem	15⁰24′10.8144″ N	73⁰49′48.9865″ E	0.17
	Siridao	15⁰26′48.0804″ N	73⁰49′48.9866″ E	0.4
South Goa	St. Jacinto Island	15⁰24′15.0336″ N	73⁰49′48.9867″ E	0.74
	Japanese Garden	15⁰24′23.3316″ N	73⁰49′48.9868″ E	0.01
	Hollant	15⁰22′11.6436″ N	73⁰49′48.9869″ E	0.55
	Talpona	14⁰58′57.0972″ N	73⁰49′48.9870″ E	0.37
	Galgibaga	14⁰57′43.4376″ N	73⁰49′48.9871″ E	0.37
	Betalbatim	15⁰18′1.3104″ N	73⁰49′48.9872″ E	0.9

micaps ECOCMOS510B) to observe arthropodal characteristics, including, mouth parts (labrum, mandible and maxillule) and cirri. Identification was carried out using published literature (Ren, 1989; Chan et al., 2009; Chan & Cheang, 2015; Pochai et al., 2017; Pitriana et al., 2020). The identified specimens were crossreferenced with the World register of Marine Species (WoRMS 2024).

Settlement and Recruitment

Settlement and recruitment were studied at two different tide levels, low tide (0-0.2m) and high tide (0.4-0.8m) (Desai & Anil, 2005). The settlement and recruitment were observed monthly from September 2023 to March 2024. But recruitment initiated in mid-February, later weekly observations were done. Different substrates were used for settlement process, like, roof tile, granite, wood, plastic, glass and floor tile. In both the tidal levels, quadrats were marked, and placed all the mentioned substrates. Once settled on substrate, photographs were taken each week so as to determine the size, appearance and survival and also to keep the track on new recruits (Fig. 3.2.1). Because barnacles adhere to substrate permanently after larval settlement, these observations were made possible.

Week 2

Week 3

Week 4

Fig. 3.2.1: Showing recruitments on weekly basis on roof tile and granite

CHAPTER 4: ANALYSIS AND CONCLUSION

4.1 RESULTS

A total of six species distributed among 4 genera and 3 families have been recorded, in the present study, of which three are reported herein for the first time from the Goan coast. The most common species reported were *Amphibalanus amphitrite* and *Chthamalus malayensis* Identification was carried out using the morphological arthropodal characters and published literature (Chan et al., 2009; Pitriana et al., 2020; Trivedi et al., 2021). The species identity and systematics were verified using the WoRMS (2024).

Taxonomic account

Class Thecostraca Gruvel, 1905

Subclass Cirripedia Burmeister, 1834

Infraclass Thoracica Darwin, 1854

Order Scalpellomorpha Buckeridge & Newman, 2006

Family Lepadidae Darwin, 1852

Genus *Lepas* Linnaeus, 1758

Subgenus *Lepas (Lepas)* Linnaeus, 1758

Lepas (*Lepas*) *anatifera* Linnaeus, 1758

Synonyms: *Lepas anatifera* Linnaeus, 1758

Lepas anatifera Linnaeus, 1758: Chan et al. 2009: 48, fig, 38, 39 – Trivedi et al. 2021: 166, fig, 2J, 13

Lepas (*Anatifa*) *anatifera* Linnaeus, 1758: Jones & Hosie 2016: 254

Fig. 4.1.1a, 4.1.2, 4.1.3

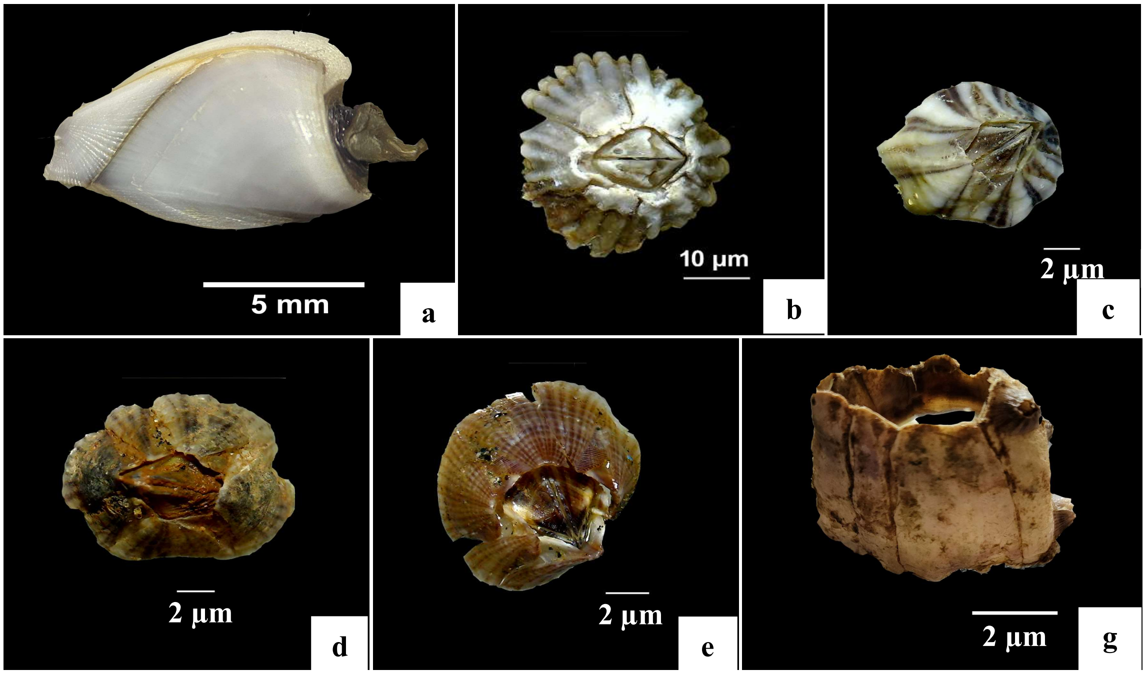

Fig. 4.1.1: Documented species in this study; a) *Lepas anatifera*, b) *Chthamalus malayensis*, c) *Amphibalanus amphitrite*, d) *Amphibalanus reticulatus*, e) *Amphibalanus variegatus* and f) *Megabalanus tintinnabulum*

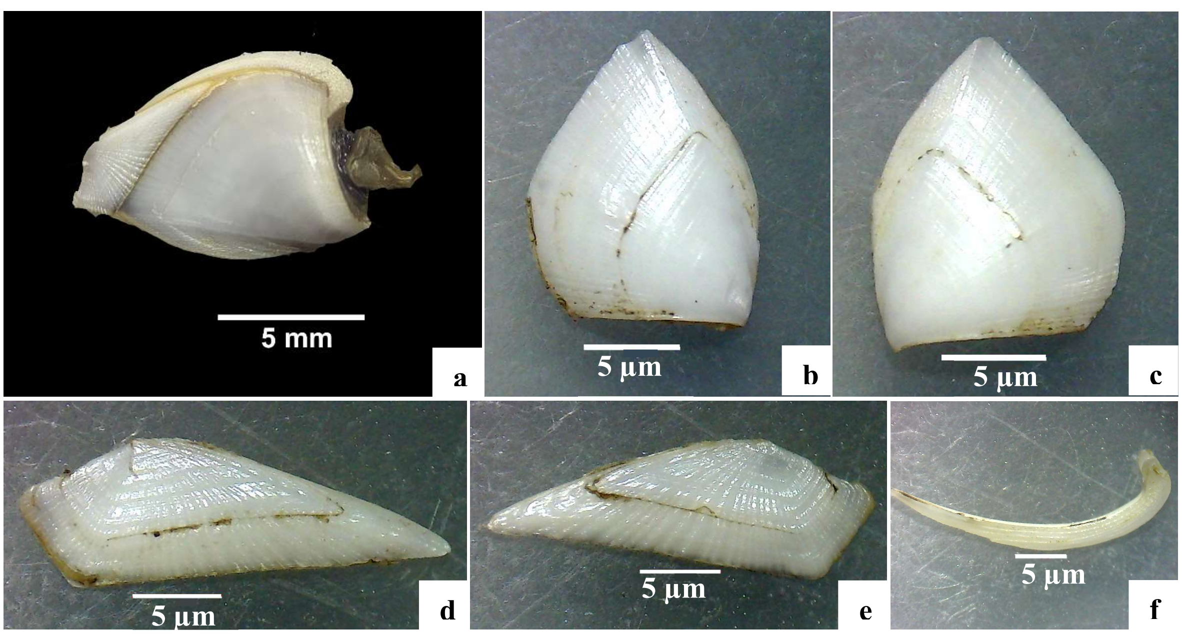

Fig. 4.1.2: External morphology of *Lepas (Lepas) anatifera;* a) Shell with blunt end of tergum, b, C) Scutum, d, e) Terga, f) Carina.

Material examined: Two specimens, 9 April 2024, Betalbatim (15º18′1.3104″N, 73º49′48.9872″E), Goa, India, collected from plastic debris, Coll. Anjelica D'mello.

Description: Shell with peduncle; capitulum with five plates (2 Terga, 2 scutum and a carina), smooth and radiating striations on the scutum and terga. Plates are thin and white. Carina forked at the base. Scutum concave in appearance. The tergum is quadrangular in shape with a slightly rounded or sharp edge; its tip nearly flat. Peduncle or stalk is brown in color and length of peduncle is variable as it grows. Maxillule notched, divided into 4 distinct sections. Mandible is with five teeth. Labrum comprises several small sharp teeth on cutting edge and margin concave. Mandibulatory palp is somewhat triangular and margin bears setae.

Remarks: The specimen examined herein follows the description provided by Chan et al. (2009) and Trivedi et al. (2021): upper tergal portion is blunt, maxillule notched in 4 different sections, labrum concave with several teeth setae on the cutting edge, mandibulatory palp triangular with dense setae on upper margin.

This species described herein resembles its congener *Lepas anserifera* Linnaeus, 1767, (Chan et al., 2009; Trivedi et al., 2021) but has few distinguishable characters such as the blunt upper tergal portion as opposed to pointed in *Lepas anserifera* and Maxillule of *Lepas (Lepas) anatifera* is notched as opposed to that of *Lepas anserifera* (Chan et al., 2009).

Distribution in India: This is the first report of *Lepas (Lepas) anatifera* from Goa. The species has previously been reported from Gujarat (Trivedi et al., 2021) and Chennai (Krishnamoorthy et al., 2007).

Elsewhere: *Lepas (Lepas) anatifera* is cosmopolitan in distribution (Chan et al., 2009) and is reported from India (Trivedi et al., 2021; Krishnamoorthy et al., 2007), Taiwan (Chan et al., 2009), Singapore (Jones & Hosie, 2016), Moluccas (Pitriana et al., 2020), Ketapang &

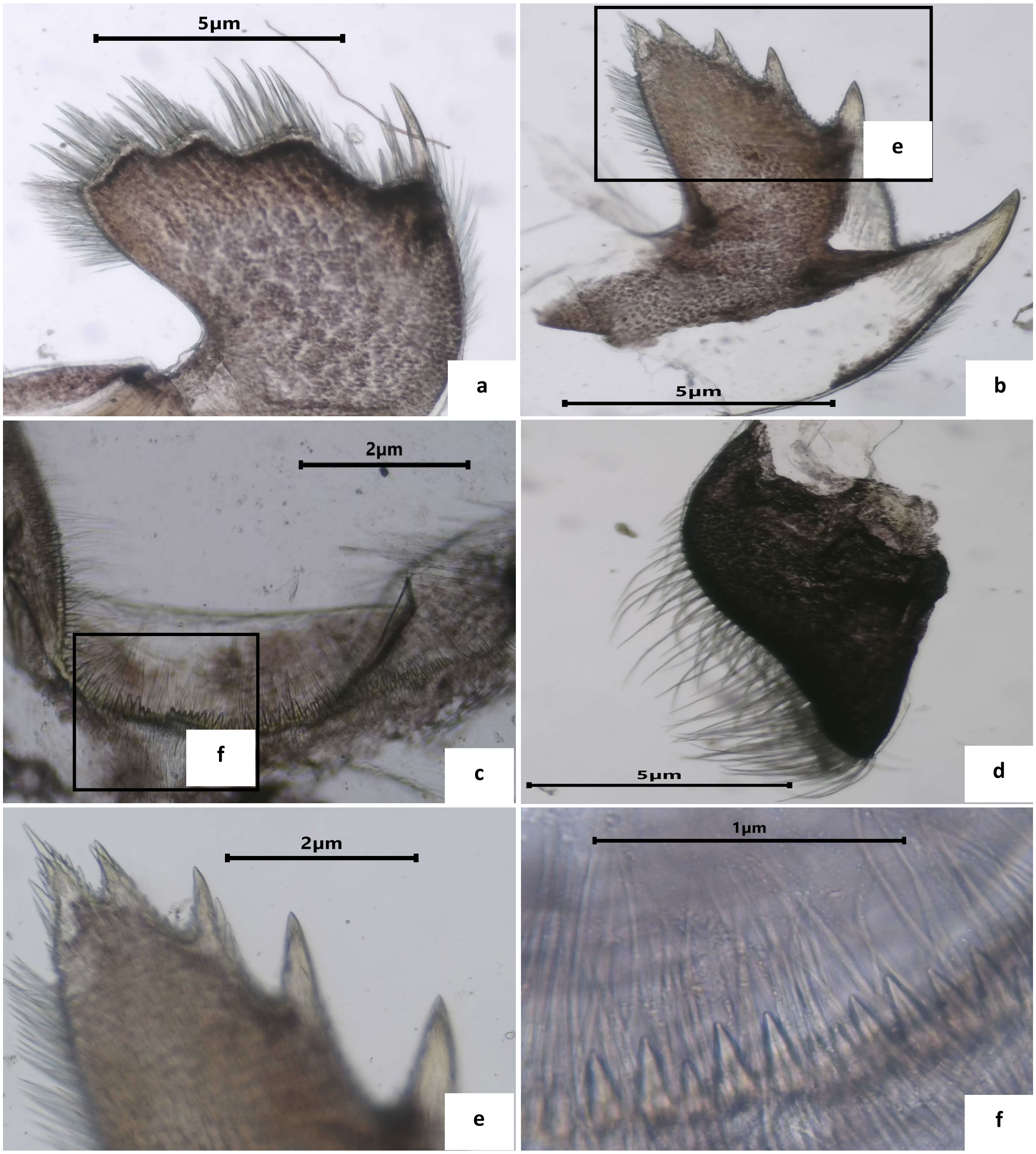

Plate 4.1.3: Mouthparts of *Lepas (Lepas) anatifera;* a) Maxillule b) Mandible c) Labrum d) Mandibulary Palp e) Zoom image of inferior angle of mandible f) Image showing teeth on labrum

Gilimanuk Ports (Sulistiono, et al., 2017), Gulf of Thailand, Gulf of Mexico (Spivey, 1981) and Madagascar (Ren, 1989).

Order Balanomorpha Pilsbry, 1916

Sperfamily Chthamaloidea Darwin, 1854

Family Chthamalidae Darwin, 1854

Genus *Chthamalus* Ranzani, 1817

Chthamalus malayensis Pilsbry, 1916

Chthamalus malayensis Pilsbry, 1916: Pilsbry 1916: 310, fig, 5; Karande & Palekar 1963: 231; Chan et al. 2009: 162, fig, 137, 139; Jones & Hosie 2016: 265; Pochai et al. 2017: 15, fig, 2

Fig. 4.1.1b, 4.1.4, 4.1.5

Material Examined: Two specimens, 23 September 2023, Siridao (15º26′48.0804″N, 73º49′48.9866″E); Two specimens, 28 October 2023, Japanese Garden (15º24′23.3316″N, 73º49′48.9868″E); Two specimens, 28 October 2023, Anjuna (15º35′4.0956″N, 73º44′12.9912″E); One specimen, 5 January 2024, Reis Magos Beach (15º29′47.6556″N, 73º48′0.162″E); Two specimens, 21 January 2024, Vagator (15º35′36.9852″N, 73º44′5.8128″E); One specimen, 22 January 2024, Galgibag (14º57′43.4376″N, 73º49′48.9871″E); One specimen, 22 January 2024, Talpona (14º58′57.0972″N, 73º49′48.9870″E) and One specimen, 7 March 2024, Vainguinim (15º27′15.9768″N, 73º48′51.5736″E), Goa, India, Coll. Navita Gaude.

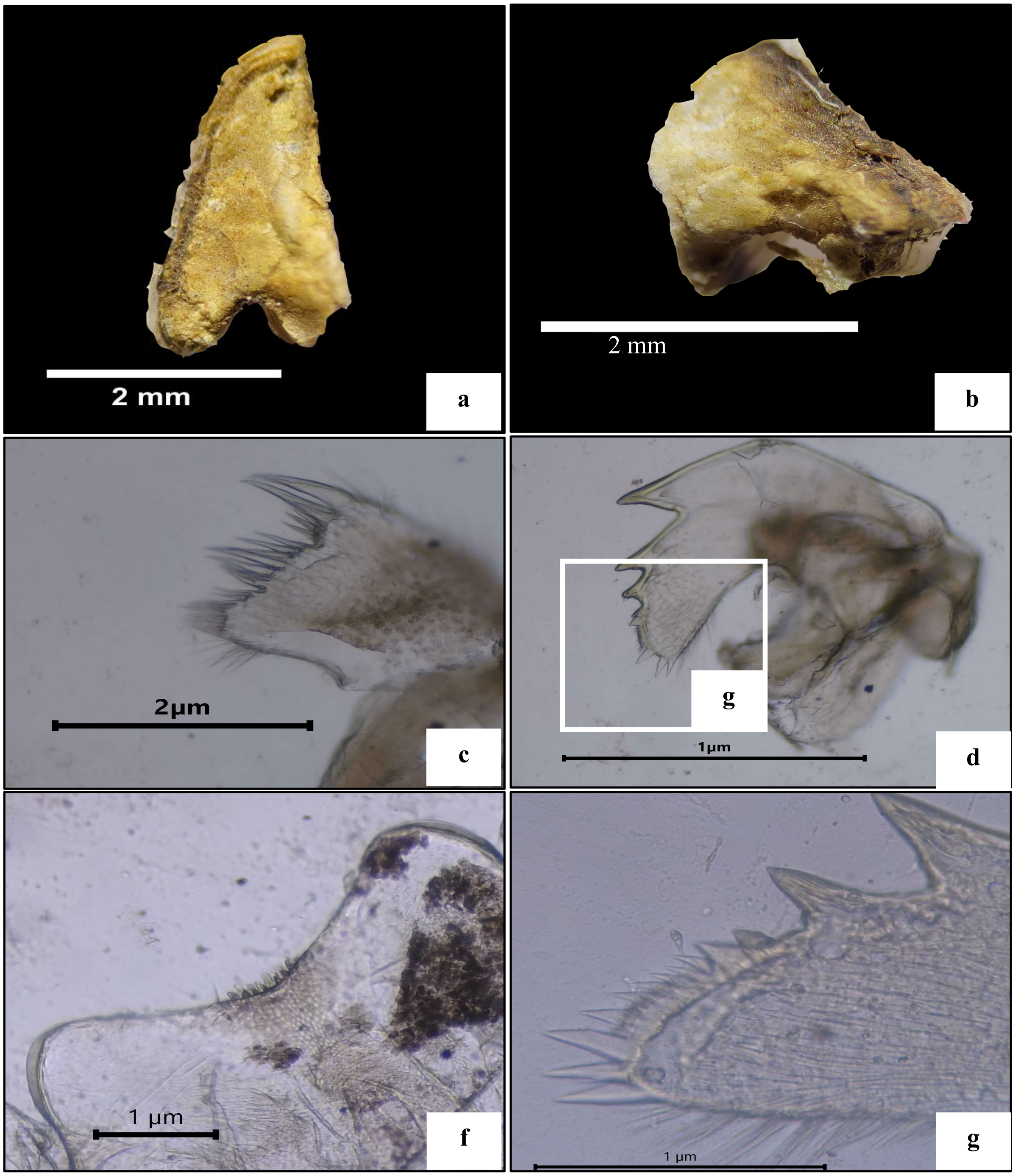

Fig. 4.1.4: Mouthparts of *Chthamalus malayensis*; a) Scutum, b) Tergum, c) Maxillule, d) Mandible, e) Labrum, f) Mandible showing inferior angle teeth.

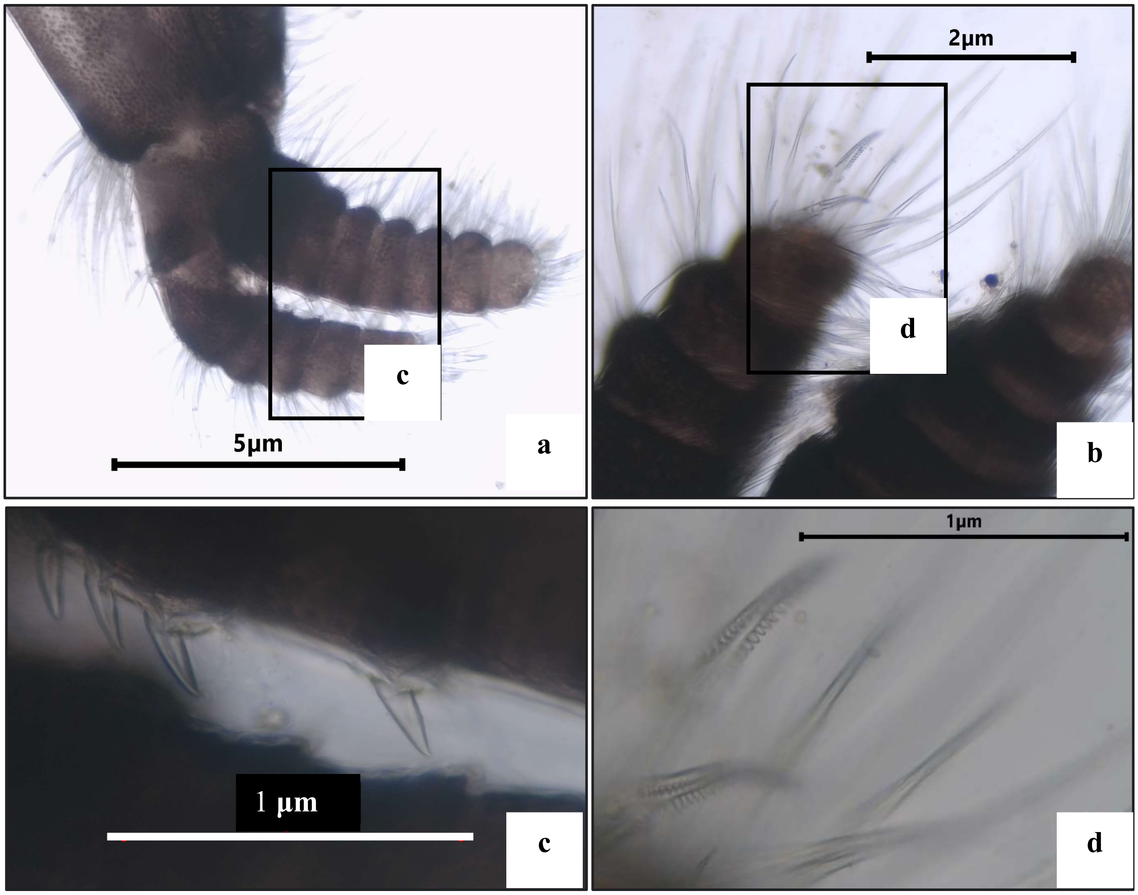

Fig. 4.1.5: Cirri of *Chthamalus malayensis*; a) Cirrus I. b) Cirrus II, c) Cirrus I showing conical spines and d) mutlticuspidate setae on Cirrus II

Description: Shell without peduncle, **s**hell surface is typically ridged and with 6 parietal plates. Scutum is triangular and elongated. Tergum without spur and short. Mandible with 4 teeth (excluding inferior angle) and inferior angle is pectinated with three setae at the end. Maxillule is notched. Labrum is concave with hairy margin and has fine teeth on cutting edge. Anterior side of cirrus I bears conical spines and Cirrus II with multi-cuspidate setae.

Remarks: The species examines resembles that of other Chthamalids. It is distinguished from others by having conical spines on the Cirrus I and multicuspidate setae on cirrus II, thus making it *Chthamalus malayensis* (Karande & Palekar, 1963; Chan et al., 2009; Pochai et al., 2017). *Euraphia depressa* (Poli,1795) resembles that of *Chthamalus malayensis* but, mandible of former species has 3 teeth while later species has 4 teeth (Pochai et al., 2017)

Distribution in India: This is the first report of *Chthamalus malayensis* from Goa. This species has previously been reported from Mumbai, Maharashtra (Karande & Palekar, 1963), Tamil Nadu (Daniel & Chakrabarathi, 1967) and Andaman and Nicobar Islands (Namboothri & Fernando, 2006; Pochai et al., 2017).

Elsewhere: The specimen is widely distributed in Indo-West Pacific region (Southward & Newman, 2003; Tsang et al., 2012; Pochai et al., 2018). This species has been reported from Taiwan (Chan et al., 2009), Moluccas (Pitriana et al., 2020), South China, Thailand and Vietnam (Tsang et al., 2012), Persian Gulf and Gulf of Oman (Shahdadi & Sari, 2011), Indian Ocean, India, Indonesia (Sulistiono et al., 2017; Jones & Hosie, 2016; Karande & Palekar, 1963; Daniel & Chakrabarathi, 1967).

Superfamily Balanoidea Leach, 1817

Family Balanidae Leach. 1817

Subfamily Amphibalaninae Pitombo, 2004

Genus *Amphibalanus* Pitombo, 2004

Amphibalanus amphitrite (Darwin, 1854)

Synonym: *Balanus amphitrite* Darwin, 1854

Balanus amphitrite Darwin 1854: 240; Pilsbry 1916: 89

Amphibalanus amphitrite (Darwin, 1854): Chan et al. 2009: 241, fig, 208; Jones & Hosie 2016: 284; Pochai et al. 2017: 26, fig, 9; Sulistiono et al. 2017: 10, fig, 4; Pitriana et al. 2020: 57, fig, 21; Trivedi et al. 2021: 149, fig, 2F, 5

Fig. 4.1.1c, 4.1.6

Material Examined: Four specimens, 23 September 2023, St. Jacinto Island (15º24′15.0336″N, 73º49′48.9867″E); Two specimens, 23 September 2023, Siridao Beach (15º26′48.0804″N, 73º49′48.9866″E); One specimen, 28 September 2023, Hollant Beach (15º22′11.6436″N, 73º49′48.9869″E); One specimen, 5 January 2024, Reis Magos Beach (15º29′47.6556″N, 73º48′0.162″E); One specimen, 30 September 2023, Odxel (15º27′13.284″N, 73º49′48.9864″E); Two specimens, 28 October 2024, Anjuna (15º35′4.0956″N, 73º44′12.9912″E); Two specimens, 21 January 2024, Vagatore (15º35′36.9852″N, 73º44′5.8128″E); One specimen, 22 January 2024, Galgibaga(14º57′43.4376″N, 73º49′48.9871″E); One specimen, 22 January 2024 Talpona (14º58′57.0972″N, 73º49′48.9870″E) and Two specimens, 7 March 2024, Vainguinim (15º27′15.9768″N, 73º48′51.5736″E), Goa, India; Coll. Navita Gaude.

Description: Shell without peduncle. Conical shell with 6 plates and longitudinal purple lines while horizontal striations are absent. Tergum is triangular and larger than scutum. Scutum with short spur. Maxillule without notch and has setae on upper and lower margins. Mandible

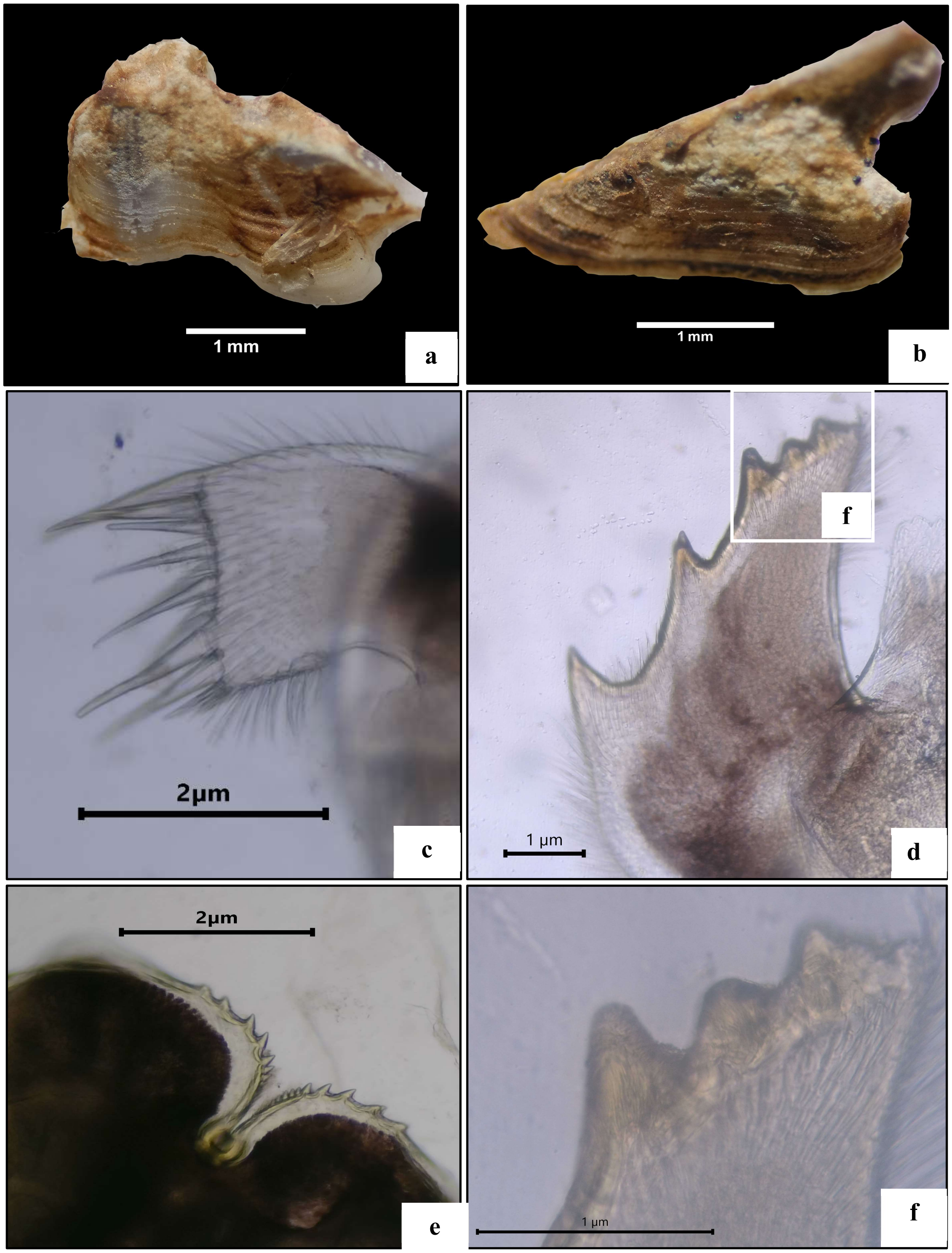

Fig. 4.1.6: Mouthparts of *Amphibalanus amphitrite;* a) Tergum, b) Scutum, c) Maxilllule, d) Mandible, e) Labrum f) Mandible showing inferior angle teeth

with 5 teeth, upper 3 teeth are sharp and large and lower 2 teeth are little blunt. Labrum with deep cleft and bears many teeth on crest and also in cleft.

Remarks: The specimen described herein is similar to the species described by Chan et al. (2009); Trivedi et al. (2021) and Pochai et al. (2017). This species is difficult to distinguish from *Amphibalanus reticulatus* as both are similar in appearance but the shell of *Amphibalanus amphitrite* lack horizontal striations whereas *Amphibalanus reticulatus* has longitudinal and vertical striations. Thus, making this species *Amphibalanus amphitrite*.

Distribution in India: This species has been reported from Gujarat (Parmar et al., 2018; Trivedi et al., 2018), Maharashtra (Bhatt & Bal, 1960), Goa (Nandankumar, 1990; Desai & Anil, 2005; Gaonkar & Anil, 2013) and Andaman and Nicobar (Mishra et al., 2010; Pochai et al., 2017).

Elsewhere: This species is cosmopolitan in distribution.

Amphibalanus reticulatus (Utinomi, 1967)

Synonym: *Balanus reticulatus* Utinomi, 1967

Amphibalanus reticulatus (Utinomi, 1967): Chan et al. 2009: 234, Fig, 200-203: Jones & Hosie, 2016: 286; Pochai et al. 2017: 26, fig, 10; Pitriana et al. 2020: 59, fig, 22; Trivedi et al. 2021: 150, fig, 2g, 6

Fig. 4.1.1d, 4.1.7

Material Examined: Five specimens, 5 January 2024, Reis Magos Beach (15º29′47.6556″N, 73º48′0.162″E); Two specimens, 28 October 2023, Anjuna (15º35′4.0956″N, 73º44′12.9912″E), Goa, India, Coll. Navita Gaude.

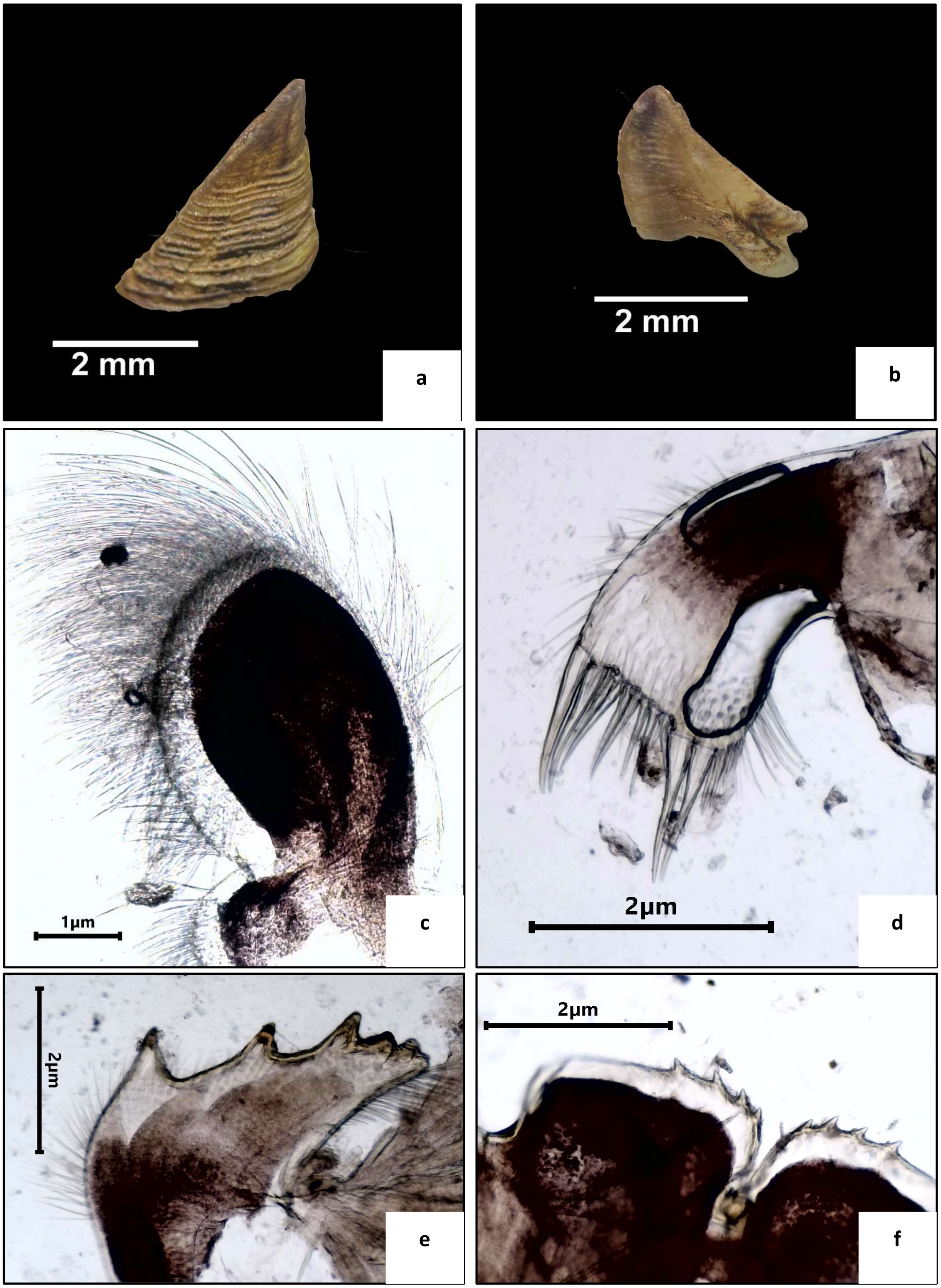

Fig. 4.1.7: Mouthparts of *Amphibalanus reticulatus*; a) Scutum, b) Tergum, c) Maxilla, d) Maxillule, e) Mandible, f) Labrum

Description: Shell conical without peduncle; Shell with six plates and prominent longitudinal and horizontal lines. Toothed orifice. Scutum is triangular with a prominent articular ridge and has straight scutal margin. Tergum flat with short spur. Maxilla bilobed and external margin covered with dense setae. Maxillule without notch and bears setae on lower and upper margin. Mandible with four teeth; upper three teeth are sharp. Labrum is notched, bears four teeth on each cutting edge, the gap between forth and third teeth is large on each side as compared others.

Remarks: The examined specimen follows the description provided by Chan et al. (2009); Pritiana et al. (2020); Trivedi et al. (2021). This specimen resembles that of *Amphibalanus amphitrite*. The difference between this two is *Amphibalanus reticulatus* has longitudinal and horizontal striations on shell whereas *Amphibalanus amphitrite* has only longitudinal lines.

Distribution in India: The species is reported for the first time from Goa. This species has been reported from Gujarat (Trivedi et al., 2021).

Elsewhere: This species has been reported from Singapore (Jones & Hosie, 2016), Moluccas (Pitriana et al., 2020), Pakistan (Rizvi & Moazzam, 2006), Taiwan (Chan et al., 2009), Belgium, Caribbean Sea, Coral Sea, Gulf of California, Gulf of Mexico, Mediterranean Sea, South Pacific Ocean (WoRMS, 2024).

Amphibalanus variegatus (Darwin, 1854)

Synonym: *Balanus variegatus* Darwin, 1854

Amphibalanus variegatus (Darwin, 1854): Jones & Hosie, 2016: 286; Pitriana et al. 2020: 62, Fig, 23a-p.

Fig. 4.1.1e, 4.1.8

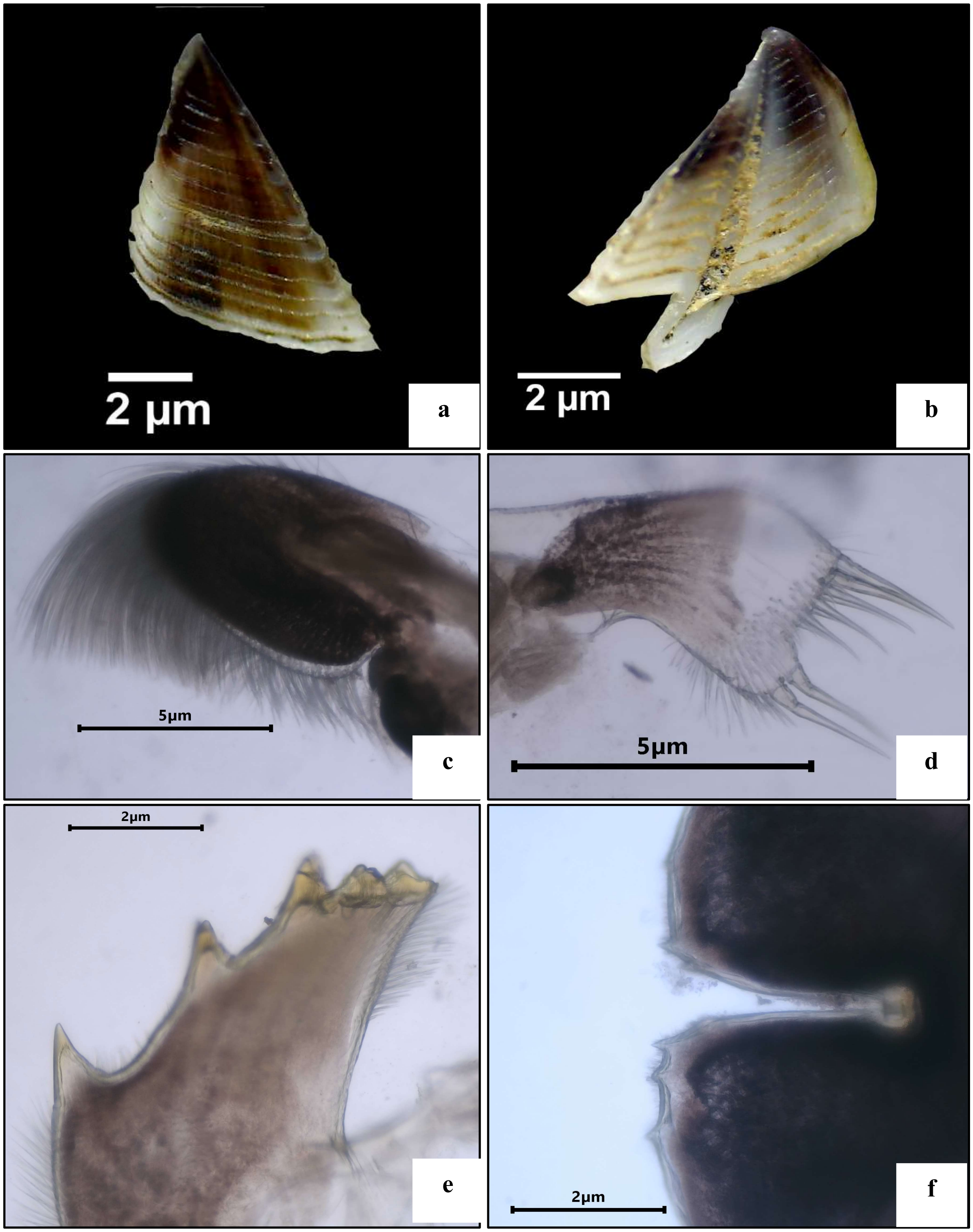

Fig. 4.1.8: Mouthparts of *Amphibalanus variegatus*; a) Scutum, b) Tergum, c) Maxilla, d) Maxillule, e) Mandible, f) Labrum

Material Examined: Five specimens, 28 January 2024, Caranzalem (15º24′10.8144″N, 73º49′48.9865″E), Goa, India, Coll. Tanaya Naik Chopdenkar.

Description: Shell without peduncle; shell with six parietal plates; tergum and scutum approximately of same size; scutum triangular with a raised articular ridge and externally growth lines are prominent; tergum with a spur. Maxilla is bilobed with dense setae. Maxillule without notch but inferior angle is raised. Mandible with three sharp teeth on upper margin and two blunt on lower margin; upper margin covered with setae. Labrum with deep cleft and denticulate; has three teeth on one side of cutting edge and two on other.

Remarks: This specimen resembles the description provided by Pitriana et al. (2020).

Distribution in India: This species has been recorded from Maharashtra, Goa and Tamil Nadu (Bhatt & Bal, 1960; Nelsson-Cantell, 1938, Krishnamoorthy et al., 2007).

Elsewhere: Indo-west Pacific, Singapore (Jones & Hosie, 2016), Moluccas (Pitriana et al., 2020).

Subfamily Megabalaninae Leach, 1817

Genus *Megabalanus* Hoek, 1913

Megabalanus tintinnabulum (Linnaeus, 1758)

Synonyms: *Balanus tintinnabulum* (Linnaeus, 1758); *Lepas tintinnabulum* Linnaeus, 1758

Megabalanus tintinnabulum (Linnaeus, 1758): Chan et al. 2009: 259, Fig, 224; Pochai et al. 2017: 28, fig, 11; Pitriana et al. 2020: 69, Fig, 26; Trivedi et al. 2021: 150, Fig, 2D,E,7.

Fig. 4.1.1f, 4.1.9

Material Examined: Three specimens; Hollant (Vasco) (15º22′11.6436″N, 73º49′48.9869″E) 28 October 2023, Goa, India; Coll. Navita Gaude.

Description: Shell without peduncle; six parietal plates and cylindrical to conical; shell with longitudinal patterns. Scutum triangular and has strong striations externally, internally has prominent articular ridge. Tergum with deep medial furrows and has long spur with blunt end. Maxillule without notch but has raised inferior angle; lower and upper margin bears setae. Mandible with four teeth; first two are sharp and distance between first two teeth is large. Labrum with a deep cleft and cutting edge has three underdeveloped teeth and hairy margin.

Remarks: The specimens examined follows the description provided by Chan et al. (2009); Trivedi et al. (2021). *Megabalanus* has larger parietes plates than that of *Amphibalanus.* Most of balanides have prominent spur on tergum and striations on external plates. However, this species shows irregular striations, thus making it *Megabalanus tintinnabulum.*

Distribution in India: This species has previously been reported in Gujarat, Maharashtra, Goa and Tamil Nadu. (Trivedi et al., 2021; Parmar et al., 2018; Karande & Palekar, 1966; Nandankuamr, 1990; Krishnamoorthy et al., 2007) Andaman Sea (Pochai et al., 2017)

Elsewhere: This species is widely distributed worldwide; including Singapore (Jones & Hosie, 2016), Moluccas (Pitriana et al., 2020), Taiwan (Chan et al., 2009), Madagascar, and Japan (WoRMS, 2024).

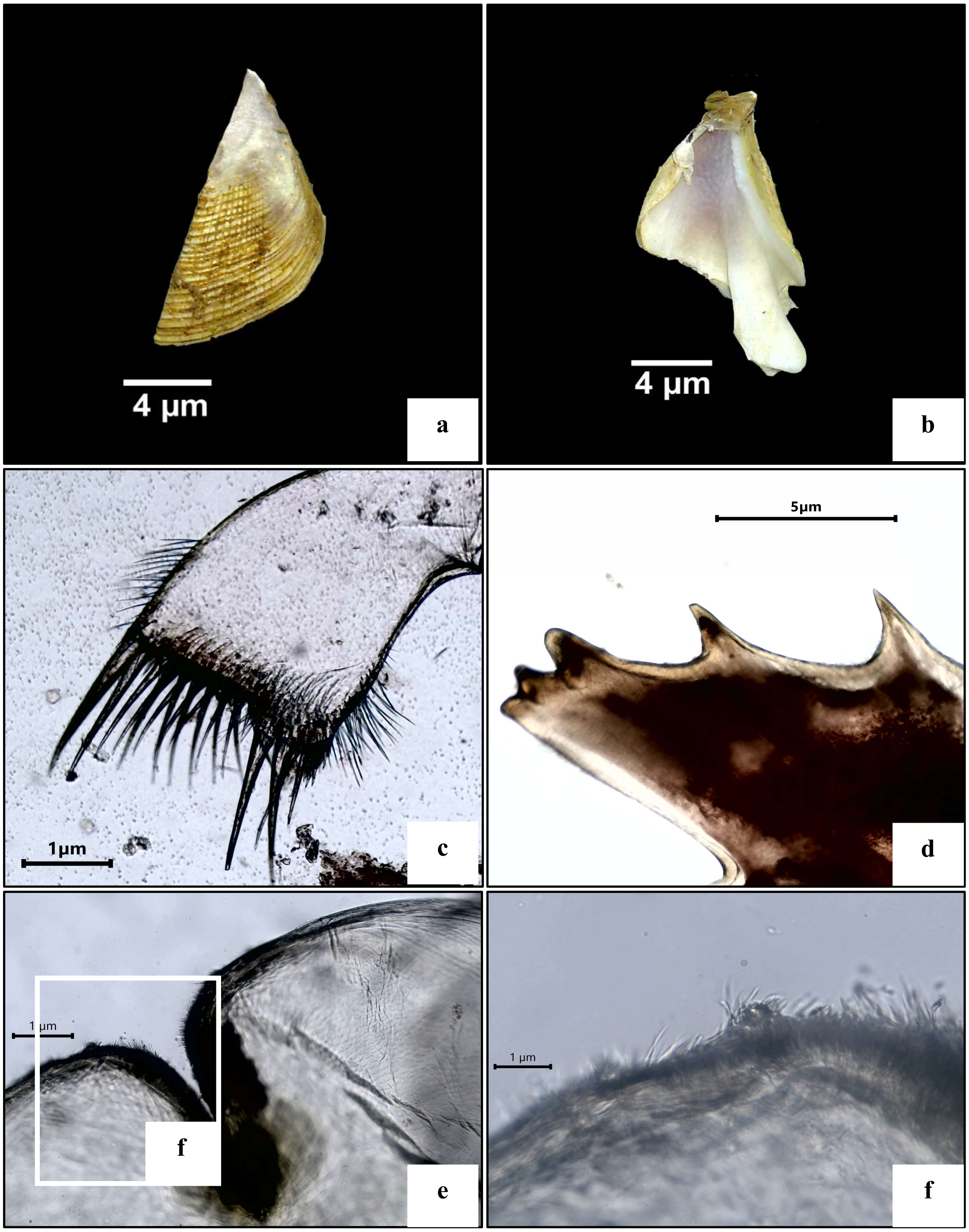

Fig. 4.1.9: Mouthparts of *Megabalanus tintinnabulum*; a) Scutum, b) Tergum, c) Maxillule, d) Mandible, e) Labrum, f) underdeveloped teeth on labrum

Recruitment and settlement

The ability to settle and recruit of any benthic organism demonstrates sustainability of particular population in specific habitat. Observations were carried out to study the substrate preference of barnacles. The recruitment and settlement patterns were studied in mangrove region at two different tide levels (low tide; 0m – 0.2m and high tide; 0.4m – 0.8m) during August 2023 to March 2024. Salinity was monitored monthly and once recruited basal diameter of live barnacles were taken on weekly basis. No recruits were observed from August 2023 to January 2024. High density of recruits was observed in the month of February. Barnacle recruitment was found at high tide levels (0.4 – 0.8) but not at low tide.

A variety of substrates were laid out at the study site, wood, plastic, roof tile, granite, glass and cement boulder. Of all the substrates, only two substrates were occupied by barnacles, *viz.,* roof tile and granite. The highest number of recruits were observed on roof tiles than on granite. It means recruitment number varied among substrate type. No recruit deaths were recorded in week 2 on both the surfaces. But after week 3 high degree of mortality was observed on granite. Subsequently, no new recruits were observed on granite surface. On the other hand, the mortality on roof tile was lower than recruitment in week 4 of the study, as new recruits were recorded. The number of recruits continued to increase on roof tiles (Fig. 4.1.10)

Salinity was recorded on monthly basis, August to December i.e. till post monsoon, salinity ranged from 5-15 ppt whereas from January salinity recorded was more than 20 ppt.

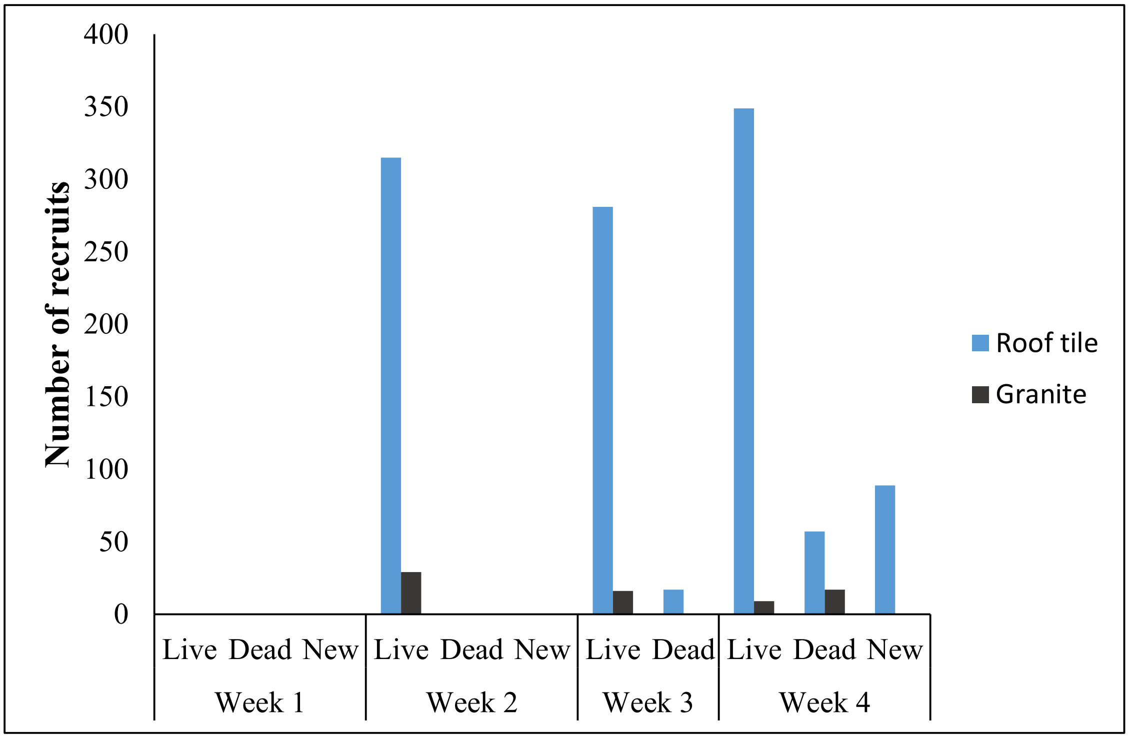

Fig. 4.1.10: Showing number of recruits on weekly basis on roof tile and granite

4.2 DISCUSSION

This study documented the presence of six intertidal barnacle species from Goan coast, of which three has been recorded for the first time in Goa; *Lepas anatifera*, *Chthamalus malayensis* and *Amphibalanus reticulatus*. All the recorded species have been verified using WoRMs, (2024). Reports from Indian waters include Gujarat (Pochai et al., 2017; Trivedi et al., 2021), Maharashtra (Karande & Palekar, 1963; Bhatt & Bal, 1960), Goa (Nandankumar, 1990; Gaonkar & Anil, 2013; Desai & Anil, 2005), from the west coast and Tamil Nadu (Krishnamoorthy et al., 2007), Andaman and Nicobar (Namboothri & Fernando, 2012) from the east coast.

Cirripedes of Goa have not been the focus of much interest. The present study is attempted to provide a detailed taxonomical account of cirripedes of Goa and their distribution along the coast of Goa. A total of six species have been identified and classified into 4 genera and 3 families (Lepadidae, Chthamalidae and Balanidae). The species reported herein have been identified based on their shell morphology, *viz.,* include basal shell pattern, parietes pattern, opercular plates and arthropodal characters by referring published literature (Chan et al., 2009; Jones & Hosie, 2016; Pitriana et al., 2020; Trivedi et al., 2021).

This study shows that *Amphibalanus amphitrite* and *Chthamalus malayensis* are dominant species along the Goan coast, as these species reported from most of the sampling sites. The only goose barnacle reported i.e. *Lepas anatifera* found to be attached on floating debris at a sandy shore, however rest all acorn barnacles are reported from rocky intertidal region. Though some acorn barnacles were found to be attached to plastic, these substrates were stuck in the rock crevices, allowing for settlement of barnacles.

A large number of recruits were observed on roof tile than on granite. Though in preliminary surveys of the same study site, barnacles were observed on granites and cement boulders in large number (Personal observation). From the months of August to January no recruitment was observed at the study site, which could probably be attributed to the variation in salinity due to monsoon (Desai & Anil, 2005; Zega et al., 2007). The roughness and corrugations on the substrate are also a factor that could impact recruitment rate (Skinner & Coutinho, 2005). Roof tile showed higher degree of settlement than granite due to the roughness and corrugations which provides an adequate surface for new recruit. However, due to the bias in sampling efforts and the short duration of the study, the observations may be skewed. As per the pilot study, barnacles were present on granite and cement boulders which showed a natural ecological succession.

Continuous monitoring of different survey sites revealed that a large number of barnacles found to be attached on plastics, wood and glass. Although, not a single recruit was present on alternative substrates provided at the study site which could be attributed to the duration of observations. With a longer exposure of the substrates to the wave action and tidal influence, a large number of recruitments would have settled on all the substrates provided. It is noted that most of the acorn barnacles were attached to plastics, which were stuck in rocks crevices and not on floating plastic debris but goose barnacles were able to settle on floating debris, as their larval life span is much longer than acorn barnacles, which has been observed by Whitehead et al. (2011).

4.3 CONCLUSION

This study has provided a detailed taxonomic account for intertidal cirripedes of Goan coast. A total of six cirripedes has been reported in this study. The present study also aims to study the recruitment and settlement of barnacles, through this it was concluded that recruitment number vary among substrate type. As high density of recruits was observed on roof tile than on granite. The further investigation of this study can be done by analyzing the molecular data of reported species, so as to provide good taxonomical evidence. Also, recruitment and settlement can be studied for much longer period so as to get proper results.

REFERENCES

Achituv, Y. (1980). A New *Chthamalus* (Crustacea: Cirripedia) from intertidal rocks of the Red Sea. *Israel Journal of Zoology*, 29(1-3), 99-109.

Anil, A. C., & Kurian, J. (1996). Influence of food concentration, temperature and salinity on the larval development of *Balanus amphitrite*. *Marine Biology,* 127, 115–124.

Anil, A. C., Desai, D. V., Khandeparkar, L. & Gaonkar, C. A. (2012). Barnacles and their Significance in biofouling. In: Rajagopal, S., Jenner, H. & Venugopalan, V. (eds) Operational and Environmental Consequences of large Industrial Cooling Water Systems. *Springer, Boston, MA*. pp. 65-93.

Barbosa, A. C. C., Gomes, C. C., Pereira, G. C., Bueno, M. & Flores, A. A. V. (2016). Local biological drives, not remote forcing, predict settlement rate to a subtropical barnacle population. *Marine Ecology Progress Series,* (543), 201-208.

Bhatt, Y. M., and Bal, D. V. (1960). New records of barnacles from Bombay shores. Curr. Sci. 29, 439–440.

Brickner, I. & Hoeg, J. T. (2010). Antennular specialization in cyprids of coral-associated barnacles. *Journal of Experimental Marine Biology and Ecology*, 392, 115-124.

Burmeister, H. (1834). Beitrage Zur Naturgeschichte Der Rankenfusser, Cirripedia. Gedruckt Und Verlegt Bei G. Reimer, Berlin, 74 pp.

Burns, T. E., Gohad, N. V., Orihuela, B., Mount, A. S., Spillmann, C. C., Wahl, K. J. & Rittschof, D. (2017). Barnacle biology before, during and after settlement and metamorphosis: a study of the interface. *Journal of Experimental Biology*, 20, 194-207.

Buschbaum, C. (2001). Selective Settlement of the barnacle *Semibalanus balanoides* (L.) facilitates Its Growth and Reproduction on Mussel Beds in the Wadden Sea. *Helgoland Marine Research,* (55), 128-34.

Caffey, H. M. (1985). Spatial and Temporal variation in settlement and recruitment of Intertidal Barnacles. *Ecological Monographs*, 55(3), 313-332.

Carlton, J. T., Newman, W. A., Pitombo, F. B. (2011). Barnacles Invasions: Introduced, Cryptogenic and Range Expanding Cirripedia of North and South America. In: Galil, B., Clark, P., Carlton, J. (eds), In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts. *Invading Nature – SpringerSeries in Invasive Ecology*, 6, 159-213.

Carlton, J. T., Munizaga, M. & Thiel, M. (2021). The rediscovery of the only introduced barnacle in Chile: *Amphibalanus amphitrite* (Darwin, 1854) (Crustacean: Cirripedia) in Estero Tongoy, Northern-Central Chile. *BioInvasions Records*, 10(4), 869-874.

Chan, B. K. K. & Hung, O. S. (2005). Cirral length of the acorn barnacle *Tetraclita japonica* (Cirripedia: balanomorpha) in Hong Kong: Effect of wave exposure and tidal height. *Journal of Crustacean Biology*, 25(3), 329-332.

Chan, B. K. K. (2006). Ecology and Biodiversity of Rocky Intertidal Barnacles Along a Latitudinal Gradient; Japan, Taiwan and Hong Kong. *The Nagisa World Congress*, 1-10.

Chan, B. K. K., Tsang, L. M. & Chu, K. H. (2007). Morphological and genetic differentiation of the acorn barnacle *Tetraclita squamosa* (Crustacea, Cirripedia) in East Asia and description of a new species of *Tetraclita*. Zoologica *Scripta*, 36, 79-91.

Chan, B. K. K., Garm, A. & Høeg, J. T. (2008). Setal morphology and cirral setation of thoracican barnacle cirri: adaptations and implications for thoracican evolution. *Journal of Zoology,* 275(3), 294-306.

Chan, B. K. K., Prabowo, R. E. & Lee, K. S. (2009). Crustacean Fauna of Taiwan: Barnacles, Volume I – Cirripedia: Thoracica Excluding the Pyrgomatidae and Acastinae. National Taiwan Ocean University, Keelung, 1-297.

Chan, B. K. K. & Hoeg, J. T. (2015). Diversity of lifestyles, sexual systems, and larval development patterns in sessile crustaceans, in Lifestyles and Feeding Biology. *The Natural History of the Crustacea,* (2), eds M. Thiel & L. Watling (Oxford: Oxford University Press), 14–34.

Chan, B. K. K. & Cheang, C. C. (2015). A new *Chthamalus* (Crustacea: Cirripedia) from the *challengeri* subgroup Taiwan rocky intertidal shores. Zootaxa, (5), 547-558.

Chan, B. K. K., Dreyer, N., Gale, A. S., Glenner, H., Ewers-Saucedo, C., Perez-Losada, M., Kolbaso, G.A., Crandall, K.A. & Hoeg, J.T. (2021). The evolutionary diversity of barnacles, with an updated classification of fossil and living forms. *Zoological Journal of the Linnean Society*, 193(3), 789-846.

Chen, H. N., Tsang, L. M., Chong, V. C. & Chan B. K. K. (2014). Worldwide genetic differentiation in the common fouling barnacle, *Amphibalanus amphitrite*. *Biofouling*, 30(9), 1067-1078.

Connell, J. H. (1985). The consequences of variation in initial settlement vs. post-settlement mortality in rocky intertidal communities. *Journal of Experimental Marine Biology and Ecology*, 93, 11-45.

Darwin, C. (1852) A Monograph on the Sub-class Cirripedia with Figures of all Species. The Lepadidae, or, pedunculated barnacles. *Ray Society, London,* 400 pp.

De Gregoris, T. B., Khandeparker, L., Anil, A. C., Mesbahi, E., Burgess, J. G. & Clare, A. S. (2012). Characterisation of the bacteria associated with barnacle, *Balanus amphitrite,* shell and their role in gregarious settlement of cypris larvae. *Journal of Experimental Marine Biology and Ecology*, 413, 7-12.

Daniel, A., and Chakrabarathi, P. K. (1967). Notes on a collection of barnacles from east coast of India. *Journal of the Bombay Natural History Society,* 63, 772–777.

Dessai, D. V. & Anil, A. C. (2005). Recruitment of the barnacle *Balanus amphitrite* in a tropical estuary: implications of environmental perturbation, reproduction and larval ecology. *Journal of the Marine Biological Association of the United Kingdom*, 85, 909-20.

Fernando, S. A. (2006). Monograph on Indian barnacles. Cochin University of Science & Technology, Kochi, Kerala, 199 pp.

Gaonkar, C. A. & Anil, A. C. (2013). Settlement and Recruitment of the barnacle *Balanus amphitrite* from a tropical environment influenced by monsoons. *Journal of the Marine Biological Association of the United Kingdom,* 93(5), 1335-1349.

Hawkins, S.J. & Hartnoll, R.G. (1982). Settlement patterns of *Semibalanus balanoides* (L.) in the Isle of Man (1977-1981). *Journal of Experimental Marine Biology and Ecology*, 66, 271-283.

Henry, D. P, & McLaughlin, P. A. (1975). The barnacles of the *Balanus amphitrite* complex (Cirripedia, Thoracica). *Zoologische verhandelingen*, 141(1), 1–254.

Innocenti, G. (2006). Collections of the Natural History Museum, zoological section “La Specola” of the University of Florence. XXIII. Crustacea, Class Maxillopoda, Subclass Thecostraca, Infraclass Cirripedia. Atti. Della. Soc. Tosc. Sci. Nat, (113), 1–11.

Jeffery, C.J. (2003). Determination of abundance and distribution of an intertidal barnacle: settlement or post settlement mortality? Marine *Ecology Progress Series*, 246, 291-305.

Jones, D.S. & Hosie, A.M. (2016). A checklist of the barnacles (Cirripedia: Thoracica) of Singapore and neighbouring waters. Raffles Bulletin of Zoology, 34, 241-311.

Karande, A. A. & Palekar, V. C. (1963). On a shore barnacle Chthamalus malayensis Pilsbry from Bombay, (India). *Annals and Magazine of Natural History*, 6(64), 231-234.

Krishnamoorthy, V. (2007). Fauna of Chennai Coast. *Marine Ecosystem Series*, 1, 57-60.

Lagos, N. A., Navarrete, S. A., Veliz, F., Masuero, A. & Castilla, J. C. (2005). Meso-scale spatial variation in settlement and recruitment of intertidal barnacles along the coast of central Chile. *Marine Ecology Progress Series*, 290, 165-178.

Larsson, A. I., Granhag, L. M. & Jonsson, P. R. (2016). Instantaneous Flow Structures and Opportunities for Larval Settlement: barnacle Larvae Swim to Settle. PLoS ONE 11(7).

Mishra, J. K., Patro, S., Adhavan, D., and Mishra, A. (2010). Biodiversity of rock pool organisms and their adaptive zonation along the coast of port blair. *Journal of Coastal Environment*,1, 159–167

Moesges, Z., Brandis, D. & Ewers, C. (2023). Detailed integrative taxonomic analysis reveals large-scale species misidentification of barnacles based on DNA barcoding data. *Zoological Journal of the Linnean Society*, XX, 1-8.

Motro, U., Simon-Blecher, N., Bronstein, O., Frumin, S. & Achituv, Y. (2023). Brewed in the African pot: the phylogeography of the toothed barnacle *Chthamalus dentatus* (Chthamaloidea: Chthamalidae. *Marine Biology Research*, 19(6-7), 327-41.

Namboothri, N., and Fernando, S. A. (2012). Intertidal distribution of the coral-boring barnacle *Lithotrya nicobarica* Reinhardt, 1850 in the Great Nicobar Island, in *Ecology of Faunal Communities on the Andaman and Nicobar Islands*, eds K. Venkataraman, C. Raghunathan, and C. Sivaperuman (Berlin: Springer), 49–57.

Nandankumar, K. (1990). Studies on Energy Content of Fouling Organisms with Special Reference to Sessile Barnacles. Ph.D. thesis. Goa: Goa University.

Nilsson-Cantell, C. A. (1938). Cirripedes from the Indian ocean in the collection of the Indian Museum, Calcutta. Mem. Ind. Mus. 14, 1–81.

Olivier, F., Tremblay, R., Bourget, E. & Rittschof, D. (2000). Barnacle settlement: field experiment on the influence of larval supply, tidal level, biofilm quality and age on *Balanus amphitrite* cyprids. *Marine Ecology Progress Series*, 199, 185-204.

Parmar, H. H., Joshi, D. M., Salvi, H. & Kamboj, R. D. (2018). Diversity and distribution of Cirripedia from Gujarat Coast, India. In*ternational Journal of Scientific Research in Biological Sciences*, 5(5), 25-29.

Pilsbry, H. A. (1916). The sessile barnacles (Cirripedia) contained in the United States National Museum; including a monograph of the American species. *Bull. U.S. Natl. Mus*, 93, 1–366.

Pitombo, F. B. (2020). Class Cirripedia. *Throp and Covich's Freshwater Invertebrates,* pp. 579-584.

Pitriana, P., Valente, L., Rintelen, T. V., Jones, D. S., Prabowo, R. E. & Rintelen, K. V. (2020). An annotated checklist and integrative biodiversity discovery of barnacles (Crustacea, Cirripedia) from the Moluccas, East Indonesia. *ZooKeys*, 945, 17-83.

Pochai, A., Kingtong, S., Sukparangsi, W. & Khachonpisitsak, S. (2017). The diversity of acorn barnacles (Cirripedia, Balanomorpha) across Thailand's coasts: The Andaman Sea and the Gulf of Thailand. *Zoosystematics and Evolution*, 93(1), 13-34.

Reis, P. A., Salgado, M. A. & Vasconcelos, V. (2011). Barnacles as biomonitors of metal contamination in coastal waters. *Estuarine, Coastal and Shelf Science*, 93, 269-278.

Ren, X. (1989). On a collection of Cirripediaa Thoracica from Madagascar and adjacent waters. *Bull. Mus. Natn. His. Nat.*, 4(2), 431-468.

Riani, S., Prabowo, R. E. & Nuryanto, A. (2021). Molecular characteristics and taxonomic status of morphologically similar barnacles (*Amphibalanus*) assessed using the cytochrome c oxidase 1 gene. *Biodiversitas Journal of Biological Diversity*, 22(3), 1456-1466.

Rizvi, S. H. N. & Moazzam, M. (2006). Sessile barnacles (Cirripedia) from the Pakistan coast. *Pakistan Journal of Marine Sciences*, 15(1), 91-118.

Sahoo, G. & Khandeparkar, L. (2016). Epibiotic community on the acorn barnacle (*Balanus Amphitrite*) from a monsoon influenced tropical estuary. Academy of Scientific and Innovative Research (AcSIR), CSIR-National Institute of Oceanography, Dona Paula, Goa, 37(3), 618-630.

Sahu, G., Mohanty, A. K., Achary, M. S., Prasad, M. V. R. & Satpathy, K. K. (2015). Recruitment of biofouling community in coastal waters of Kalpakkam, southwestern Bay of Bengal, India: a seasonal perspective. Indian Journal of Geo-Marine Sciences, 44(9), 1335-1351.

Satumanatpan, S., Keough, M. J. & Watson, G. F. (2001). Role of settlement in determining the distribution and abundance of barnacles in a temperate mangrove forest. *Journal of Experimental Marine Biology and Ecology*, 241, 45-66.

Scrosati, R. A. & Ellrich, J. A. (2016). A 12-year record of intertidal barnacle recruitment in Atlantic Canada (2005-2016): relationships with sea surface temperature and phytoplankton abundance. PeerJ 4.

Scrosati, R. A. & Holt, J. K. (2021). Recruitment and Post-recruitment Dynamics of the Barnacle *Semibalanus balanoides* on a Wave-Exposed Headland in Atlantic Canada. Front. *Mar. Sci.*, 8:799514.

Shahdadi, A. & Sari, A. (2010). Chthamalid barnacles (Cirripedia: Thoracica) of the Persian Gulf and Gulf of Oman, Iran. *Journal of the Marine Biological Association of the United Kingdom*, 91(3), 745-753.

Shahdadi, A., Sari, A. & Naderloo, R. (2014). A checklist of the barnacles (Crustacea: Cirripedia: Thoracica) of the Persian Gulf and Gulf of Oman with new records. *Zootaxa*, 3784(3), 201-223.

Southward, A. J. & Newman, W. A. (2003). A review of some Indo-Malayan and western Pacific species of *Chthamalus* barnacles (Crustacea: Cirripedia). *Journal of the Marine Biological Association of the United Kingdom,* (83) 797–812.

Spivey, H. R. (1981). Origins, distribution, and zoogeographic affinities of the Cirripedia (Crustacea) of the Gulf of Mexico. *Journal of Biogeography*, (8), 153-176.

Sulistiono, S., Setiarina, D. E. M. & Prabowo, R. D. (2017). Intertidal barnacle community of Ketapang and Gilimanuk ports that separated by the Indonesian throughflow of Bali Strait. *Scripta Biologica*. 4(4), 207-213.

Tomanek, L. & Helmuth, B. (2002). Physiological Ecology of Rocky Intertidal Organisms: A Synergy of concepts, 42, 771-775.

Trivedi, D. J., Trivedi, J. N., Soni, G. M., Purohit, B. D. & Vachhrajani, K. D. (2015). Crustacean fauna of Gujarat State of India: A Review. *Electronic Journal of Environmental Sciences*, 8, 23-31.

Trivedi, J. N., Doshi, M., Patel, K. J. & Chan, B. K. K. (2021). Diversity of Intertidal Epibiotic and Fouling Barnacles (Cirripedia, Thoracica) from Gujarat, Northwest India. *ZooKeys*, 1026, 143-78.

Tsang, L. M., Wu, T. H., Shih, H., Williams, G. A., Chu, K. H. & Chan, B. K. K. (2012). Genetic and Morphological Differentiation of the Indo-West Pacific Intertidal Barnacle *Chthamalus malayensis*. *Integrative and Comparative Biology*, 52(3), 388-409.

Tsang, L. M., Achituv, Y., Chu, K. H. & Chan, B. K. K. (2012). Zoogeography of Intertidal Communities in the West Indian Ocean as Determined by Ocean Circulation Systems: Patterns from the *Tetraclita* Barnacles. PLoS ONE, 7(9).

Trivedi, J., Patel, K., Chan, B. K. K., Doshi, M. & Padate, V. (2021). Diversity of Indian Barnacles in Marine Provinces and Ecoregions of the Indian Ocean. *Front. Mar. Sci*, (8).

Whitehead, T. O., Biccard, A. & Griffiths, C. L. (2011). South African Pelagic Goose Barnacles (Cirripedia, Thoracica): Substratum Preferences and Influence of Plastic Debris on Abundance and Distribution. *Crustaceana*, 84(5-6), 635-649.

Williamson, D. I. (2014). The Origin of Barnacles (Thecotraca, Cirripedia). *Crustaceana*, 87(6), 755-765.

World Register of Marine Species (WoRMS). (n.d.). Assessed April 25, 2024, from https://www.marinespecies.org/aphia.php?p=taxdetails&id=421137

Zega, G., Pennati, R., Dahlstrom, M., Berntsson, K., Sotgia, C. & De Bernardi, F. (2007). Settlement of the barnacle *Balanus improvises*: The roles of dopamine and serotonin. *Italian Journal of Zoology,* 74(4), 351-361.