Eco- ethological studies of *Austruca annulipes* (H. Milne Edwards, 1837) in Calangute, Goa

Dissertation Submitted By

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Eco- ethological studies on *Austruca annulipes* (H. Milne Edwards, 1837) in Calangute, Goa" is based on the results of investigations carried out by me in the Zoology Discipline at the School of biological sciences and biotechnology, Goa University under the Supervision of Dr. Nitin Sawant and the same has not been submitted elsewhere for the award of a degree or diploma by me.

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Name of Student: Vaishnavi Bharti

Seat no: 22P0440035

Signature of Student:

Date: April 2024

Place: Goa University

COMPLETION CERTIFICATE

This is to certify that the dissertation report "Eco- ethological studies on *Austruca annulipes* (H. Milne Edwards, 1837) in Calangute, Goa" is a bonafide work carried out by Ms. Vaishnavi Bharti under my supervision in partial fulfilment of the requirements for the award of the degree of Masters in Science in the Zoology Discipline at the School of biological sciences and biotechnology, Goa University.

Name of Supervising Teacher: Dr. Nitin Sawant

Signature of Supervising Teacher:

Date:

Dr. Bernard F. Rodrigues
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Date: 8-4-24
Place: Goa University

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CONTENT

PREFACE

School textbooks have taught me Science as lab experiments, diagrams, cyclic processes and Latin terminologies. Lately a field called Animal behavior was introduced in M.Sc. which exposed me to the natural world and its magic. Works by Jane Goodall, Dian Fossey, and Reena Mathur have impressed me to the core of my heart. Their work has been an inspiration to me. It truly made me believe Science is not just about experimenting and expensive parades of chemicals but it is a cost effective, simple, spiritual way to connect to nature and discover its wonders.

This dissertation is an effort towards understanding the behavior of Fiddler crab specie in the mangroves and its importance to the ecosystem in these changing environment. This work is very simple, based on observations and basic statistics, without any high level mathematics and understandings. The dissertation is an inductive research aiming to explore more in future.

This work unveils how a tiny crab has a complex life and aims to sow a seed of interest in the readers mind to look into the natural world, discover the secrets of animal life and learn the most valuable lessons from mother earth.

I hope you have a delightful time reading this work, and try to understand what the crab has to say to us.

"Sand is a canvas, and the animal writes on it."

- Dr. Anish Andheria

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I would like to express my gratitude to the program director of Zoology discipline and my supervisor Dr. Nitin Sawant for his constant guidance, help and his willingness to share his knowledge in the field of ethology. His valuable guidance helped us in understanding the study in all its dimensions. I am grateful to him for always encouraging the field visits throughout the study.

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Last but not the least we would like to appreciate myself for being motivated and working efficiently throughout the project in every possible aspect.

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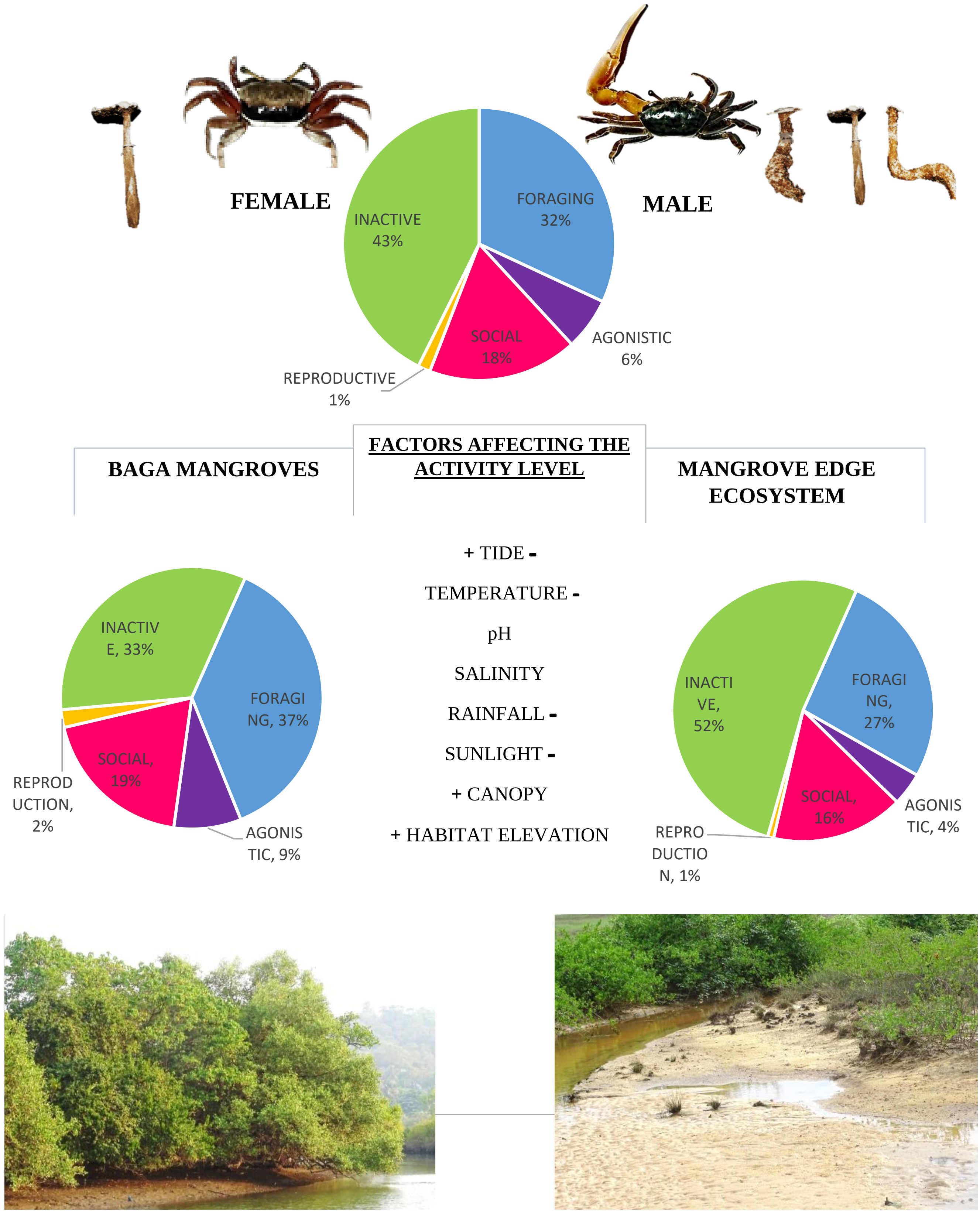
ABSTRACT

A.annulipes is a widely distributed fiddler crab specie in the Indian coast yet it is not studied much. This 9 month (July 2023- March 2024) study provides preliminary information on the activity pattern of the crab and the impact of ecological factors on it. The behaviors observed were resting, foraging (mobile, defensive static, non-defensive static and intermittent), agonistic (attack and defense), reproductive and social movements. The crabs are partially diurnal and inactive during day high tides, while in the remaining day time they spend forging and excavating burrow. Reproductive and social interactions account a small proportion of their activity cycle in non-breeding seasons too. The study recorded crab activity in two habitats- mangrove edge ecosystem and Baga mangroves. The crab's activity was affected by rainfall pattern, tide level and the difference in habitat elevation and canopy level at both sites. Hence, the fiddlers were more active at Site II compared to site I. Additional information on Bioturbation by *A.annulipes* is also provided. The fiddler crab *A.annulipes* is a polymorphic specie and forms an essential component in mangroves ecosystems and showcase's a very complex Activity rhythm. The descriptive data obtained via this study serves a door to many experimental studies to understand the activity pattern of fiddler crab in depth at higher levels.

KEYWORDS: Burrow, Ecology, Ethogram, Fiddler crab, Mangrove.

GRAPHICAL ABSTRACT



+ Influence of factor enhances the activity level

-Influence of factor reduces the activity

*Pie charts depict the % of time spent in different activities in a day.

CHAPTER I: INTRODUCTION

"The universe is a mine of jewels,
Filled with deep dwellers and many sky crewels,
The sensational crabs are an art in it,
Rooting cultures, myths and science."

1.1.BACKGROUND

Invertebrates are immensely diverse and challenge the mind providing limitless opportunities for discoveries and research. They are characteristics of not having a notochord (also called backbone) hence invertebrates. They comprise of 90 percent of known animals. They are very diverse in terms of their habitat, morphology, physiology, anatomy, behavior and distinct classification.

The invertebrates are divided and classified based on two factors – the number of species ad individuals; and their participation in local communities (Jordan & Verma, 2017).

The largest group of invertebrates as well as of the entire animal kingdom is the phylum Arthropod. It is highly diversified in terms of number of species and their ecological distribution by adapting and evolving into all niches, right from aerial, aquatic, terrestrial to parasitic environment. Roughly they make up 80 per cent of the animal kingdom.

"Arthropod's are bilaterally symmetrical, triploblastic, metamerically segmented animals with coelom which is reduced and modified. Their body is covered externally in a chitinous exoskeleton which moults periodically and their appendages are jointed." (Jordan & Verma, 2017).

They are classified in various groups. As per Vandel (1949), Snodgrass (1960) and Storer (1979) it consist of 3 subphylums.

The subphylum Mandibulata (has mandibles) consist of many classes, one of the most fascinating is the Crustacea consisting of shrimps, water fleas, fish lice, barnacles, prawn, crabs, etc.

The crabs are very diverse in habitat and classification, right from freshwater, marine to brackish water crabs. They are not only found in waters but also in rocky shores, mudflats, rocky plateaus, etc. and also vary in size. The smallest crab is the pea crab (few millimeters in size) and the largest is Japanese spider crab (14 feet) in size (Wolfe et al., 2019).

Many groups of crustacean's have converged to develop a crab like body plan by process of carcinisation, and are not rue groups, some examples include king crab, mole crabs, etc. (Wolfe et al., 2019)

Crabs are noted by their hard carapace, exoskeleton body covering and distinct sexual dimorphism. The shape of the abdomen (narrow, triangular in males; wide, oval in females) is the primary differentiator. While groups like fiddler crabs show characteristic asymmetric enlarged chelae in males, which is not seen in females. They are known to exist since the Jurassic times. The crabs belong to infraorder Brachyura, which is a sister clad Anomura consisting squat lobsters, hermit crabs and other relatives (Wolfe et al., 2019).

The infraorder Brachyura contains approximately 7,000 species in 98 families. It comprises of all true crabs ,that include a complex classification with many groups, some are sponge crabs, carrier crabs, frog crabs, fresh water crabs, coral gall crabs, ghost crabs, fiddler crabs, sentinel crabs, talon crabs, land crabs, etc (Ng et al., 2008).

The fiddler crabs are semi terrestrial group of crabs found in mangroves, salt marshes, coastal mudflats in topics and subtropics. They are regarded as mangrove flagship species (Peer et al., 2015).The fiddlers (Ocypodidae) consist of 97 species globally, of which many are researched for their ecology, systematics and behavior (Mangale & Kulkarni, 2013).

The study organism chosen for this study is the fiddler crab species *Austruca annulipes.*

1.1.1. TAXONOMIC CLASSIFICATION OF STUDY ORGANISM:

Phylum: Arthropoda (jointed appendages)

Subphylum: Mandibulata (having mandibles)

Class: Crustacea (hard exoskeleton)

Subclass: Malacostraca (Branched appendages)

Series: Eumalacostraca (true soft shells)

Superorder: Eucarida (large carapace fused to cover the entire thorax)

Order: Decapoda (ten legs)

Infraorder: Brachyura (has reduced abdomen folded against the ventral surface)

Family: Oxypoididae

Genus: Austruca

Species: *A.annulipes*

A.annulipes is a very abundant, widely distributed fiddler crab species found across the coast of tropics and subtropics. It is widely known for its bright coloration, high density and inability to survive in aquariums. Till now it is widely studied for its genetic diversity, behavioral ecology, and burrow morphology, ability to regenerate its claw and population biology. It is commonly called as the porcelain fiddler crab (Mangale & Kulkarni, 2013).

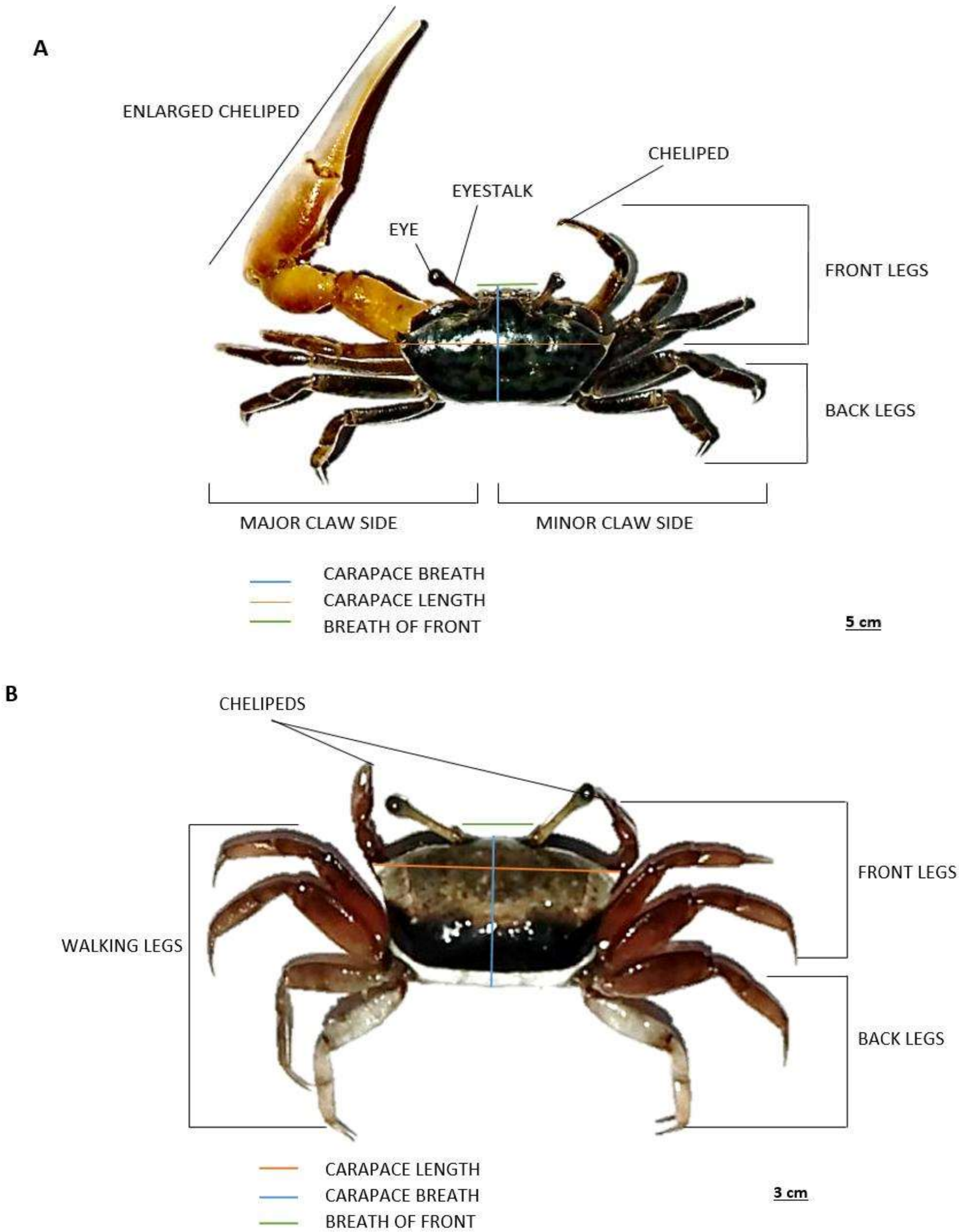


Figure 1.1. Morphology of male (A) and female (B) fiddler crab A.annulipes

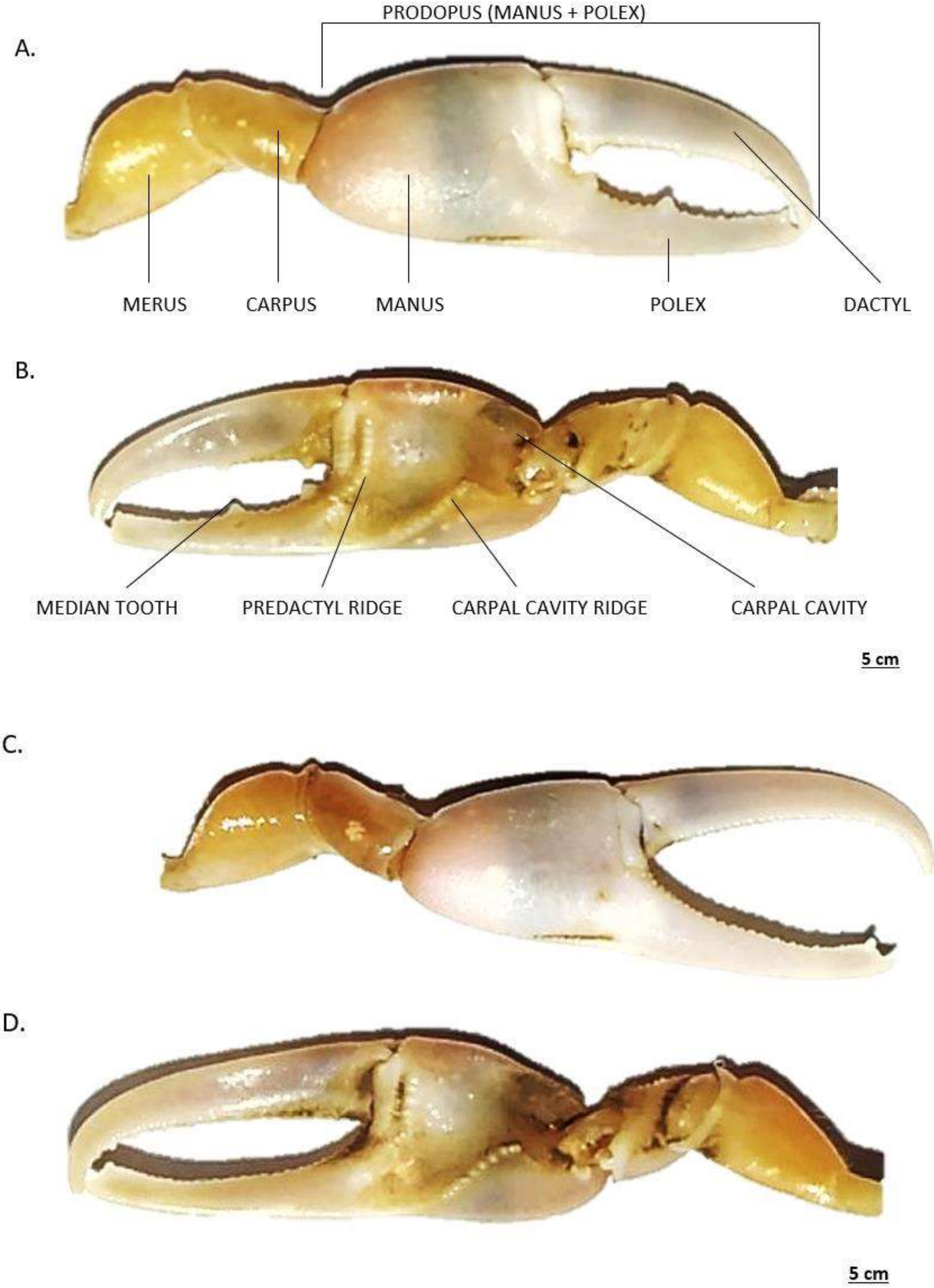


Figure 1.2. Enlarged Chelae of Male (Variation 1(A-B) and 2 (C-D)).

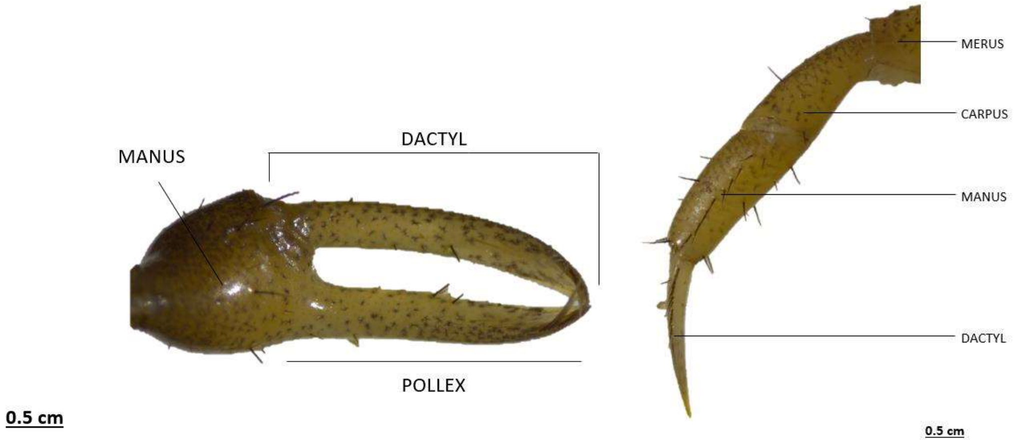


Figure 1.3. The feeding chelae and walking leg of A.annulipes.

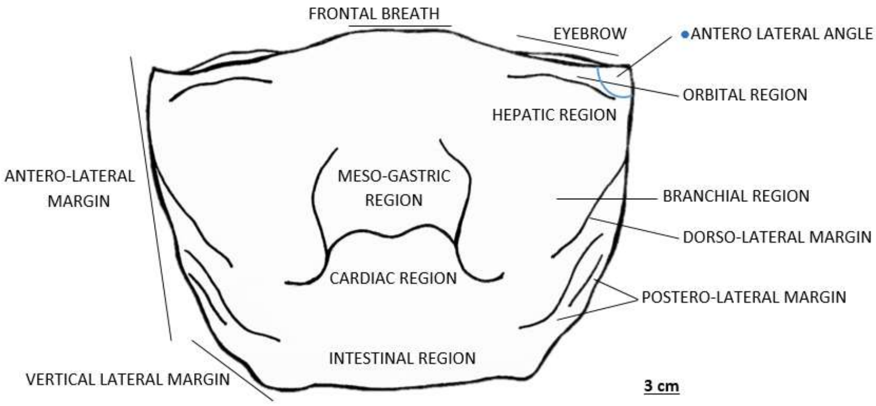


Figure 1.2. The carapace morphology of A.annulipes.

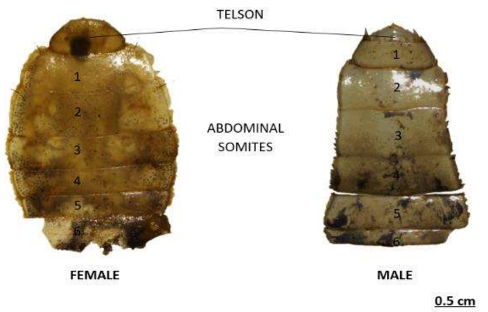


Figure 1.3. The distinction between the male and female abdomen of A.annulipes.

1.1.2. INTRODUCTION TO ECO ETHOLOGY:

Since olden times behavior of animals has been studied out of curiosity but as time passed the curiosity turned into a link between humans and animals. In 18th century the French academy of sciences publishes the term Ethology from the Greek word Ethos meaning habit, convention. The scientific study of animal behavior is known as Ethology. Which expresses the lifestyle of animals. Studies say behavior is important for an animal to survive. A species shows different forms of behavior right from taking care of young ones, catching prey, building nest, or simply changing colors to sleeping. The reason behind such striking behaviors are unknown. Let's take an example of a domestic's cat, the kitty in the house behaves different always and we understand our pet, its daily chores and mood. We know that it cries for food. But why does she need food the simple answer would be to satisfy its hunger but the other way round we can say it had to eat to survive so that it doesn't die and stay healthy to reproduce. Hence behavior has many different aspects to understand (Mathur, 2014).

The complexity of animal behavior studies does not depend on elaborate mathematical chemicals, giant instruments, chemicals that people associate with science. An experienced researcher in ethology is equipped with binoculars, camera, stopwatch, hidden in environment and can gather facts about his subject in few days to him pondering for a year (Mathur, 2014).

Science uses numbers, facts and equations primarily to describe nature but when it comes about animal behavior writing, we humans have the tendency to express our emotions and attribute the characters to animals, for example we would use the word happy or excited to describe our pet's mood. This is an anthropomorphic way of describing animal's behavior and is not considered as a proper scientific writing. Due to exploratory human minds and detailed research has expanded ethology to various branches like ethoneurobiologists, ethogeneticists, ethophysiologists, ecoethologist, Sociobiologist, etc. (Mathur, 2014). With time ethology is getting more importance and is the key component to understand animal's adaptations and evolution. The change in behavior of animals directly impacts the changes in its environment. It ultimately affect their population and ecological balance. Such studies help conserve species and their habitat, and are known to improved captive breeding enhancing animal welfare.

Behavioral studies can be conducted in two ways. It can be a laboratory set up environment to observe the animals behavior, or it can be a case where the organism is exposed certain substances or fluctuating environment and noted for its change in activity or reaction. The other aspect of behavior includes studying the animal in its natural space by least disturbing it and its environment. This can be done in many ways depending on the demand of the research and the researcher's flexibility. The methods range from group to individual monitoring for continuous period to cyclic schedules.

The term Eco ethology is one of the branches in ethology, where the animal is studied in complete natural environment. It is a two way relation where the impact of animal on the environment and the environments impact on the animal is studied, to know the animal's activity and importance. It does not deal with probability or statistical predictions and is often confused with behavioral and ecological studies. In essence, ecoethology is a short term behavioral response to environment more focused on the immediate ecological factors affecting behavior, while behavioral ecology delves into the evolutionary explanations for behavior persisted cross generations, shaping fitness and reproductive fitness of individual and populations over time (Danchin et al., 2008; Krebs & Davies, 2009). The ecoethological studies employ variety of observational and experimental techniques in natural setting, termed as descriptive research, while the behavioral studies use a combination of field observations, lab set ups and theoretical modellings to investigate (Krebs & Davies, 2009; Alcock 2009; Dawkins 1982).

1.2.STATEMENT OF PROBLEM

Mangroves are among the most dynamic and fascinating ecosystems on earth. They are known to provide the highest ecosystem services to the environment. The ecosystem services by mangroves are categorized as provisioning ecosystem service that account for fuel wood; supporting ecosystem services count the dense network of mangrove roots that act as breeding ground for fishes; regulating ecosystem services which include control of soil erosion, protection from floods, acts as barrier between land and sea, regulate carbon and nutrient recycling. The most important function of mangrove is its dynamic nature to balance the tidal fluctuations and maintain the changing water levels, temperature which act as a hotspot of biodiversity in estuaries and shorelines (Getzner & Islam, 2020).

Such an important Eco tone of earth is degrading rapidly. Globally, mangroves are highly threatened and disappearing at an alarming rate due to intense human pressure resulting from population growth, eco-tourism, land use change, and anthropogenic sources of pollution. At an estimate every year 7 million hectares of mangroves are lost which are equivalent to 2 years of loss for all types of forests covers. As per studies since last 50 years, 20-35% of mangroves have vanished due to deforestation and degradation of land (Nunoo & Agyekumhene ,2022).

The temperature of earth has been rising at average of 2°C and more every few years, indicating high degree of Climate change. Hence the growing nation have come up with conservation efforts to control the global temperature rise lesser then 2°C. This effort directly impacts the mangroves and their health due to their distribution in tropics and subtropics, highly impacted by the changing environment (Friess et al., 2022).

Similar state in observed in Goa, the mangroves are alarming the mankind. Goa has ~2000 hectares of fringed mangroves occurring densely at estuarine banks. It contributes 0.5% to mangroves of India. In a GIS time lapse study from 1997 to 2006, the mangrove cover of goa has increased by 22% due to invasion of mangrove in agricultural farms and poor maintained river bunds. Majorly the state has nine major rivers and 2 minor creeks. The Baga creek runs 5.4 Km along river Baga. Studies show that mangrove cover in Baga has drastically come down from 6.6 hectares in 1997 to 4.48 hectares in 2006. (Nagi et al., 2014)

For effective conservation of the Eco tones it is important to understand each of its species, its requirements, role and distribution in the mangrove ecosystem. The Indian Ocean and the west Pacific Ocean are highly rich in mangrove crabs, and they make up a very important component of the mangrove forests. So it is important to understand their role in mangroves (Yousefi & Naderloo, 2022).

1.3. OBJECTIVES

1. To understand the ecoethology of *A. annulipes*
2. To analyze the ecological significance of *A. annulipes* in a mangroves edge ecosystem

1.4. FUTURE SCOPE

The ecoethological studies contribute to the multi-beneficial researches. As it helps to understand the species, the environment and also projects the interaction between both (species and environment) highlighting the current status of the entire ecosystem (eco-web) of the chosen study area.

- The obtained data from this study will/may contribute towards conservation of mangroves.
- Study results will generate a baseline data for further researches.
- The model organism selected for the study is being first time observed for an eco-behavioral study globally.
- The study will contribute to a data deficient species (IUCN, 2023).

CHAPTER II: LITERATURE REVIEW

The field of ecological studies came into light in the 18th century when Sir Ernst Haeckel coined the term ecology. Later the publication of Carl Linnaeus *Oeconomia naturae* meaning "the economy of nature" brought fame to ecologists.

Ethology being the science of studying the totality of visible movements in an animal brought up by stimulus and response came up as an emerging field due to the collective contributions of Nikolaas Tinbergen, Konrad Lorenz and Karl von Frisch in 1973.

The concept of studying animals and its environment dates back to the prehistoric era when hunters lived with wild. Their stories and living styles are carved and painted on the walls of many ancient caves found globally. Later in 372 BC Aristotle was the first to describe animal behavior in his book – Historia Animalium meaning "the history of animals" (Mathur, 2019).

Eco-ethology is a comparative new branch of ethology in which the relationship between the behavior of a species and other living and non-living components of the environment are investigated (Mathur, 2019).

Due to similar terminologies the field of ecology , ethology, behavioral ecology and eco ethology are being studies in an overlapping way but the specialty of ecoethology distinguishing it from other fields is being justified by the given definition - "*Eco-ethology is the science of the effects of animal behaviour on animal environment and the effects of animal environment on animal behaviour, with the purpose to find out how natural selection within this control loop has formed and molded animals*."(Krebs and Davies, 1981).

There is not much research in the field of ecoethology but a handful of short studies are done globally.

In 1988 a study was published in United States to understand adaptations in intertidal life throwing some light on mangrove dwelling species like barnacles, fiddler crabs and others like hermit crabs, land crabs, shrimps and others (Hartnoll, 1988).

Attention is given by entomologists to understand the ecoethology of insects (Hemiptera, hymenoptera, orthoptera) which act as pests and vectors to human and plant diseases. Such studies have helped control invasive insect population and safeguard crops. It has aided to formulate pesticides, insecticides (Schaffner et al., 1994; Maatouf and Lumaret, 2012; Giordanengo, 1993).

Two precise works on eco ethology of Brachytrupes megacephalus (Orthoptera, Gryllidae) in UE (Conti et al., 2012) and on Parallelomorphus laevigatus (Coleoptera, Carabidae) in Italy (Conti et al., 2012) Are a piece of art explaining all aspects of the topic. These papers target the importance and conservation of the species as well as their habitat.

Lately an report on ecoethology of queen conch (*Strombus gigas*) aimed to aid conservation, restoration and well managed aquaculture programs without over exploitation of the species in Caribbean (Noguez and Aldana, 2014).

An Eco-ethology study of paedomorphic populations of the Alpine newt (Amphibia: Caudata) gives a insight on their special morphological adaptation's for efficient habitat use and risks to the population due to introduced fish in Europe (Denoël, 2003) a recent research on similar aspects of gilled newts was also reviewed (Denoël, 2019) .

To understand the impact of degrading forests on red collared lemur a comparative ecoethological study on troops of lemurs was done in Madagascar (Campera, 2012; Donati, 2011).

The endangered Bonobo's endemic to democratic republic of congo (DRC) are well adapted to their habitat, an ecoethological study was done to help in formulation of specific management plans, recommendations for conservation programme to save the bonobo's (Serckx, 2011).

Ecoethology of *Aythya nyroca* (Ferruginous Duck) has revealed the role of wetlands in diurnal activity of this species (Belhamra and Houhamdi, 2014) and one similar study on Mallard (*Anas plathyrhynchos)* in Algeria (Dziri et al., 2014).

A study on ecoethology of common langur (*Semnopithecus entellus)* was also done in Bangladesh (Ahsan and Khan, 2007).

The relation between ecoethological requirements and traits in two congeneric species of *Acanthoplus (Orthoptera: Tettigoniidae)* was analysed (Conti et al., 2019).

A study on eco ethology of predation in the ant species is also recorded *(*Dejean, 1985*).*

A short note on ecoethology, distribution and status of *Glutophrissa punctifera* (Peridae) is published (Racheli et al., 2020).

An Eco ethological case study was done on European beavers (*Castor fiber)* to know the impact of fluctuations in water level on their ecology (Pasca et al., 2014).

Karoo bustard (*Korhaan Eupodotis Vigorsii*) was studied to understand its ecoethology and prepare its conservation and management plan accordingly (Boobyer, 1989).

A thesis in Lake Tanganyika on eco ethology of shell dwelling chichlids along with a comment on their phylogenetic relationship behind their shell dwelling behaviour is repoted (Bills, 1996).

An ecoethological study reports the coexistence of five corvid species showed that they follow dominance hierarchy in land and resource use pattern (Rolando, 1988).

Studies on burrow morphology of sea organisms and behaviour of burrow occupants provide an insight on their ecoethology of marine life (Atkinson et al., 2000).

Each species having a significant role in ecosystem the aye aye *(Daubentonia madagascariensis*) were also monitored for their ecoethology (Andriamasimanana, 1994).

Reports on how each species (each sex) has different strategies and methods for reproduction based on their varying reproductive and social environment so does reflect in their behavioral flexibility has been observed throughout the animal kingdom providing a brief review on ecoethology of sexual strategies in animals(Ciani, 2003).

The ecoethological studies on bats (*Myotis bechsteinii*) have helped to review and describe the various parasites on them and comment on their host parasite interaction (Deunff et al., 2004).

A little more complex studies are done to understand the endocrine control and components of the brain involved in animals (bats, hedgehog, cichlids and birds: Tinamidae) adaptations to specific niches which make up a unique ecoethology for them (Simmons, 1996; Stephan et al., 1991; Stark, 1985; Bee and Carezzano, 1993).

The concept of ecoethology has also been applied in non-sciences fields of humanities, political science which emphasis the human ecoethology with global development (Ruiz, 1999; Bergan and Laiti, 2023).

As national contribution, India has only one research where ecoethology of butterflies is studies in an urban garden in Kolkata (Thakur and Chaudhuri, 2017).

It was evident for larger vertebrate species to grab attention of ethologists and to track their behavior and understand its significance, but a little less attention is given to the invertebrates. Thou they form a very crucial part of ecosystem and contribute to more than 50% to the species diversity of animals. The invertebrate behavior is essentially and fundamentally distinct from the vertebrate behavior (Savory, 2013). One of the fascinating invertebrate are the fiddle crab, grabbing researches eyes since nineteenth century. The crabs are well known for their distinct sexual dimorphism i.e. the large unsymmetrical front chelae in males. Since 19 century the fiddler crabs are used as model organism globally for research right from field studies to lab based molecular and developmental biology studies.

The fiddlers are one among the most misidentified species due to their similar size, colorations, carapace pattern, habitat and general behavior. Which has motivated scientist to sequence the genome of species throughout world and create keys for their accurate identification and new taxonomic rankings too (Hsi-Te Shih et al. 2016).

Recent data suggests there are 104 fiddler crab species worldwide distributed along intertidal zones of tropical and subtropical coasts, muddy beaches and mangroves (Hsi-Te Shih et al. 2016; Crane. 2015). Fiddler crabs being highly social animals are found in large colonies hence it is important to have a clear idea about their identification and diversity. Fiddler crabs are mostly studied for their eco system engineering activity specially feeding. The rate of feeding and its ecological significance among the male and female fiddler crab varies. Which inquisited biologists to study the male’s large chelae, its pattern and varied waving pattern in different species.

There are various records on their population, abundance and distribution, studied across the globe, like in Africa, Myanmar, Indonesia, Brazil,Florida, Vietnam (Peer et al., 2015; Teal, 1958 ;Fadilah et al., 2023; Mokhtari et al., 2015; Thurman et al., 2015; Salmon, 1967; Shih et al., 2022).

Where else no much studies are done in India except a few like the study on morphological analysis of fiddler crabs found on the coast of Mumbai includes detailed identification key for three fiddler crab species – *Uca annulipes, U. vocans* and *U. dussumieri (*Mangale and Kulkarni, 2013).
Uca annulipes and *U. perplexa* from southwest coast of India are DNA barcoded to confirm their identification due to their similar morphological appearance *(*Apreshgi et al., 2016).

A report on meiofauna interaction in mangroves at Chorao Island in goa talks about the important role of fiddler crabs *(Uca spp.)* in bioturbulation of the sediments and aerating the mangrove roots to increase the meiofaunal diversity and abundance (Sahoo et al., 2013).
A paper on formal education to primary students about importance and conservation of mangroves in goa also highlights the important of *Uca* crabs in the mangrove ecosystem (Antao, 2015).
The studies on population biology of crabs on west coast of Goa and intertidal shore crabs mentions the presence of few *Uca spp*. along with *Austruca annulipes* in Goa (Vijaylaxmi et al., 2020; Vijaylaxmi, 2020).

Interestingly a lot of attention is given to the ecology of fiddlers across the world. Its speculative behaviour has proposed numerous papers on the morphological and behavioral ecology of Genus *Uca,* of which some are dedicated to selected species and comparative ecologies between *Uca* species (Knopf, 1966; Aspey, 1978; Salmon and Zucker, 1988; Wolfrath, 1993; Nobbs, 1999; Takeda and Murai, 2003).
Apart from this works on individual aspects of fiddler behaviour are also documented. Studies on thermal ecology, visual ecology, mating preferences, claw waving display, circadian rhythm of carapace pigmentation are explored through genus *Uca (*Powers and cole, 1976; Nakasone, 1982; Thurman, 1985 ;Thurman et al.,2010).

Many such researches are done globally pointing towards fiddler's behavior, ecology, distribution and identification. But there is no evidence of pure eco ethology of *Austruca annulipes.*

A new field of animal architecture is coming up. Here researches are trying to reveal the burrow architecture, structure, morphology and to understand the significance behind the burrows created by various animals and how they vary among species in terms of shape, size and function. Along with it such information can be a lead in field of biomimetic too (Pardo et al., 2020).

The fiddler crabs are extensively studied for their burrow structure throughout the world. The burrow structures are classified based on their size and shape in varied ways. Additionally, they are analyzed for their role as Bioturbation agents in mangroves and their impact on sediments of mangroves (Gusmão-Junior et al., 2012; Sen & Homechaudhuri, 2018).

The fiddler crabs are responsible for altering the soil profile in mangroves by creating burrows and also altering the soil topography by continually feeding in the soil (Holdredge et al., 2010; Hoffman et al., 1984; Natálio et al.,2017).

Vice versa the effect of mangrove vegetation and micro habitat on the burrow morphologies is also studied (Lim & Hang, 2007).

A.annulipes is the selected model for this study found across the globe in abundance still is not being studied in depth. Only comparative behavioral study of between *Uca annulipes* and *Uca sindensis* was done in Iran .thou the results of this study doesn't match to our study .the possible reason for this could be the geography of the habitat (Mokhlesi, 2011).

The species *A.annulipes* was known by many synonymized names like *Gelasimus annulipes*, *Gelasimus porcellanus* ,*Uca (Austruca) annulipes*, *Uca (Paraleptuca) annulipes* ,*Uca (Paraleptuca) lactea annulipes*, *Uca annulipes*, *Uca consobrinus* prior to its taxonomic revisions (DecaNet WORMS, 2023) and is commonly known as Porcelain fiddler crab (Mangale and Kulkarni, 2013).

Literature for *Uca annulipes* and/or *A.annulipes* suggest that, the behavioral studies done this species are insufficient, but many experimental studies have provided informative keynotes to science.

An experimental study on change in behavior in *Uca annulipes* and *U.inversa* in response to sewage effluents in water makes the fiddler an important biological indicator of eutrophication and health of mangrove ecosystem. The crabs were seen to reduce their foraging time which ultimately affected the rate of bioturbation if sediments (Bartolini, 2009).

The species is well habituated and proves to be social. Experiments suggest that within minimum of 10 attempts the *U.annulipes* is known to habituate to change and disturbances in its environment (Walker, 1972).

CHAPTER III: METHODOLOGY

3.1. STUDY AREA

Baga mangroves is the part of the Baga creek and is very popularly known for its beaches, crowded tourist and nigh parties. Lying in the village Calangute, it is a prime tourist hotspot in goa. In spite of that the area has managed to maintain its biodiversity till date. The hindered areas include the fields, tiny forest patches and mangroves harboring rich flora and fauna. The mangroves in Baga have 5 mangrove flora species present, which include – *Rhizophora mucronata, Avicennia marina, Exoecaria agallocha, Aegiceras corniculatum* and *Acanthus illicifolius.*

The adjoining fields to the mangrove have seen a lot of construction since past few years. Also the sewage plant in the area is set up such that its effluents will be released in the river once it starts to function. There are many salt pans surrounding the mangroves which are not being operated since a decade now.

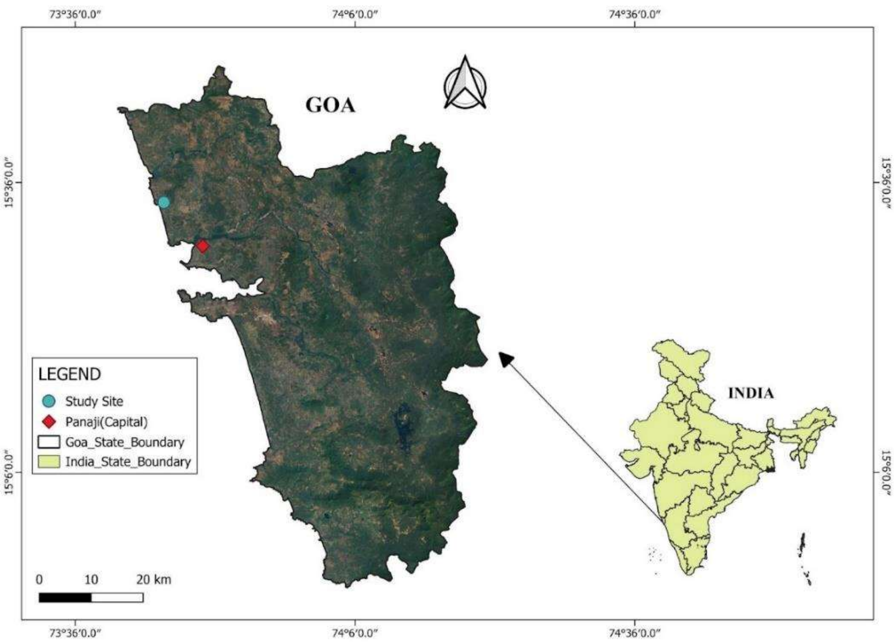


Figure 3.1. Study area map depicting study site of Baga creek, Goa

For this study, two study points were selected in Sauta Vaddo (Baga). As per requirements the first spot was located in the natural mangrove creek (15.566121, 73.75818), and the second study spot was located in the adjoining fields, where the mangroves have invaded due to certain anthropogenic reasons. Such invaded mangroves are known as “Mangrove edge ecosystem” (15.561503, 73.759013).

Figure 3.2. Images of Study site II (Baga Mangroves).

Figure 3.3. Images of Study site I (Mangrove edge ecosystem in Baga).

The mangrove ecosystem in Baga has a two sided story to tell. The outskirts of mangrove which meet the Arabian Sea (Baga beach) towards the west, is a very chaotic area affected by human disturbance like fishing activities and water sports like boat ride, kayaking, parasailing, etc. While the inner regions of Baga mangroves are silent, undisturbed and culturally protected due to the presence of small temples of the local deities in it. Which towards the east side merges in the fields parallel to salt pans. The mangroves in this part have started to exploit the fields impacting the agricultural activities.

The study organism *A.annulipes* was identified using taxonomic keys given by (White A., 1847) and WORMS (World register of marine species) database.

3.2. DATA COLLECTION

3.2.1. ECOETHOLOGICAL DATA COLLECTION

The eco- ethology involves two components – ecology i.e. the biotic and abiotic components around and the ethology which is the behavior of the animal. The abiotic factors considered for the study were –

Temperature of water, surface soil, air and burrow, pH of soil and water, rainfall, salinity of river water and reference tide chart. All these factors were recorded using standard instruments respectively.

The data was recorded on behavioral sheets, along with that additional field information was taken in form of notes, videos and photos using smart phone (Oppo A7), DSLR camera (Nikon Coolpix P1000, Sony DSLR HV-400) and tripod stand.

The field visits were scheduled as three visits per month to each site, for the study period of July 2023 to march 2024(9 months). Recording data for 30 minutes by Ab libitum (Andriamasimanana, 1994), all occurrence sampling after every 2.3 hours. A total of 6 scans were made per day which were evenly categorized as morning, afternoon and evening from 7 am to 7 pm.

The recording time scheduled were as followed:

Morning (7:00 am to 7:30 am; 9:00 am to 9:30 am), Afternoon (11:00 am to 11:30 am; 1:00 pm to 1:30 pm) and Evenings (3:00 pm to 3:30 pm; 6:00 pm to 6:30 pm).

Apart from the scheduled slots, often random visits were done to the field sites for extraneous observations.

The data sheet was formulated based on preliminary study carried out on the species during May to June 2023.

Sample of Data Sheet:

Table 3.1. Data collection sheet for A.annulipes

DATE:
SITE: Start Time: ______________ End Time: ______________

TEMP:	WATER TEMP:	SOIL TEMP:
BURROW TEMP:	WATER pH:	SOIL pH:
RAINFALL:	WATER SALINITY:	

POSSIBLE BEHAVIOURS	FIELD NOTES	DURATION	PERCENTAGE
FORAGING			
AGONISTIC			
SOCIAL			
REPRODUCTIVE			
INACTIVE			
OTHERS			
TOTAL BEHAVIOUR			100%

- The organism's visual behavioral movements will be observed as followed:

TYPE OF BEHAVIOUR		OBSERVATIONS
Foraging	Acquiring and utilizing sources of energy and nutrients. Location and consumption retrieval and storage of resources.	When the species fiddled with food and took it close to its mouth.
Agonistic	defense, attack, territorial	Movement of large chelae towards other individuals; male combat, female combat
Social/Communication	Inter (with other species) and intra (within the species) interaction. Grooming, prey –predator relationship	Except inter species combat; waving of claw in air; activity with other species, or self; burrow construction
Reproductive	Pre and post behavior ,courtship	Male and female interaction, courtship sequence.
Inactive	No movement detected	In burrow for very long periods
Others	Investigative/ suspicious / exploratory activities	Behavior not mentioned specifically

The observed behaviors and other ecological factors were analyzed in three different ways. Firstly the activity rhythm of *A.annulipes* was classified as active and inactive period.

Secondly, the activities done by fiddler crab were represented monthly. Lastly, the collected data was graphically represented for the study sites.

This representation of activity rhythm in the crabs in form of graphs and charts is a direct observational, descriptive type of statistical analysis.

The entire observations done throughout the study period were used to construct the Ethogram for the selected study organism, *A.annulipes.*

3.2.2. BIOTURBATION IMPACT

BURROW SAMPLING

The aim behind this method was to understand the burrow structure of *A.annulipes* and see the difference between the male and female burrow design due to the asymmetric body morphology.

On a completely low tide afternoon on 22 January 2024 (full moon) and 10 February 2024 (no moon) lunar cycle. The burrows of 10 male and 10 female *A.annulipes* were observed and marked by random sampling method. The cast were made with POP (Plaster of Paris) (Saher & Qureshi, 2011).

A mixture of water and pop in 2:3 ratio was freshly prepared for every burrow and poured slowly down the burrow, and was left for 45 to 60 minutes to dry. After drying the cast was slowly dug up and removed safely, transferred in a labelled container and carried to lab. In case , If a crab was found trapped in the cast it was slowly removed , washed with water in a utensil to remove any particles of POP on it using a soft brush, to minimize the impact of POP on environment and was released back in the field. The cast was allowed to dry for another 3-4 days to completely harden in lab. Later, using brush and sandpaper the excess soil particles were removed from the cast to reveal its precise shape and size.

For further analysis, the burrow cast were labelled in a systematic format of species, sex, date, month, year, place of burrow cast followed by cast number (e.g. *A.annulipes*,M,220124SV01, *A.annulipes*,F,100124SV01, …).

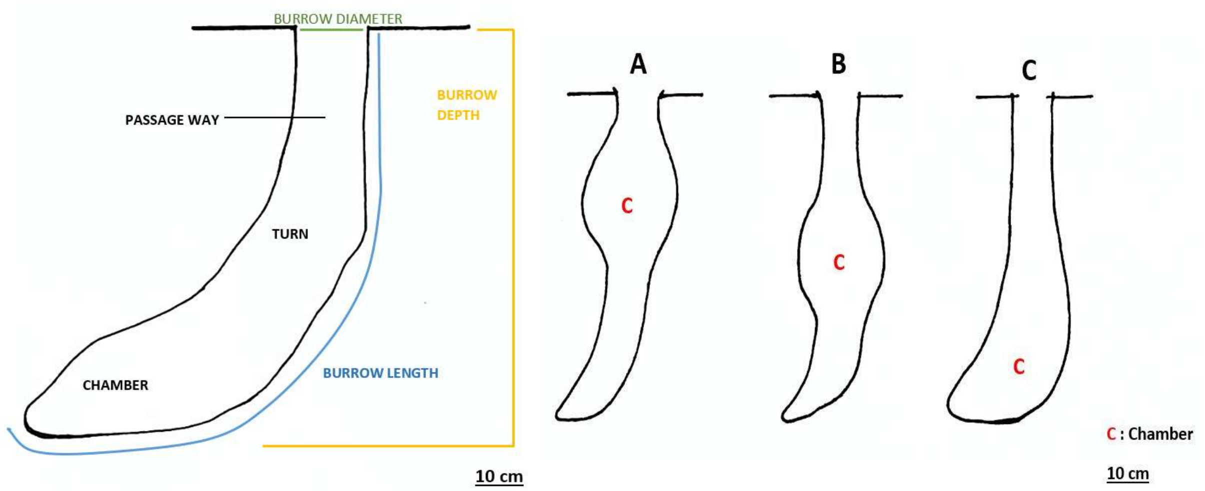


Figure 3.4. Burrow morphology of A.annulipes; Figure A-C showing the position of chamber in burrow of A.annulipes (A-top; B-middle; C-bottom). (Adapted from Tina et al., 2018; Saher & Quereshi, 2011).

The following measurements were taken using thread, scale and vernier calliper for each cast and statistics were applied. The morphometric units measured were– Burrow diameter(BD), Burrow length(BL), Burrow depth (BD), Number of chambers(NC), Diameter of chamber(DC) (Saher & Quereshi, 2011).Additionally the burrow shapes were classified based on the visual shape of burrow as J, S,I and L (Saher & Quereshi, 2011).

The burrow sampling was performed in the mangrove edge ecosystem only. Due to cultural significance it was unable to procure casts from the natural mangroves.

To understand the morphometric of the burrows, the data was collected and analyzed in Microsoft excel to find the average burrow diameter, depth and length for the A.annulipes burrows (Appendix).

The burrows were observed for their shape and size and classified primarily as I, J, L and S type as given in table 1 (Saher & Quereshi, 2011).

Table 3.1. Representatives of classified burrow shape in A.annulipes

I	J	L	S
			

The difference in male and female burrows was confirmed by performing PCA (Principle component analysis) using R studio software.

CARBON CONTENT ANALYSIS

With reference to a tide chart the time was decided when the high tides lowers down and low tide starts. The soil samples were collected in labelled bags from more than 25 burrows at random from the mangrove edge ecosystem. Three soil samples were collected as followed- the feeding pellets, burrow pellets and fresh surface soil washed by tide and undisturbed by crabs.

The soil was collected and brought to lab. It was evenly spread in trays and left to sundry for 4 days to remove all the moisture (water content) from the soil. Once completely dry, the soil was weighed to take 20g of each sample. The sample were placed in preweighed crucibles and heated in a muffle furnace for 3 hours at 450° C, so that all the organic matter from the soil gets burned off. This technique is known as loss of ignition method. After the heating it was allowed to cool in the furnace and weighed again. The loss in weight indicated the amount of organic matter in the soil that is correlated with the sediment size (Neely, 2023). The soil sediment samples of the dried soil were placed under the stereomicroscope Zeiss Stemi 508 with Axiocam camera and visually observed for the difference in grain sizes.

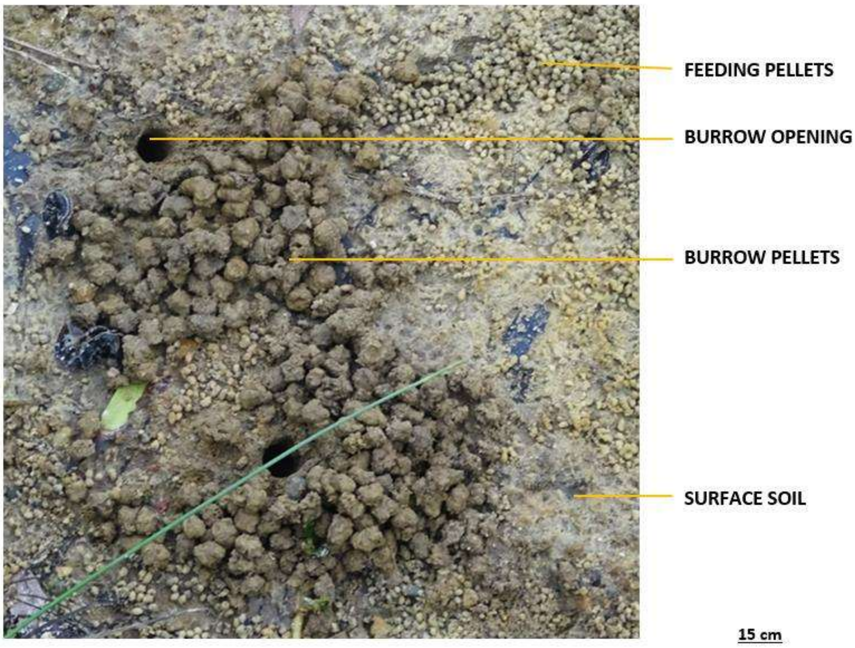


Figure 3.5. Image showing the difference between feeding and burrow pellets in field.

CHAPTER IV: ANALYSIS & DISSCUSSION

4.1. ACTIVITY RHYTHM

The *A.annulipes* were observed to be inactive at nigh throughout the study period. It is a diurnal specie following the tidal rhythm.

The sunrise marks the crab's activity and it remains active until its starts to get dark. The days are warm and cool with a temperature varying from 25°C to 33°C. The species is most of the time inactive due to influence of high tide, and is observed resting in its burrow. During monsoons the burrows are disrupted due to rains. In such conditions the crabs remain in pairs or individually in water, partially submerged in soil.

During favorable weathers, the crab's activity starts by foraging. The females are observed to forage faster and more efficiently than the males. The males and females are sometimes seen indulged in fights with same sexes. They are very social species. They are observed to co-exist with other fiddler crab species. As the tide goes lower both the sexes explore the exposed area and begin to excavate their burrows. Throughout the study period the species showed reproductive behavior, where the male and female co-occupied a burrow for short period. Such mating rituals were observed mostly in morning and evenings. A rhythmic claw moment in air is seen in small groups of male fiddlers every morning and late evening.

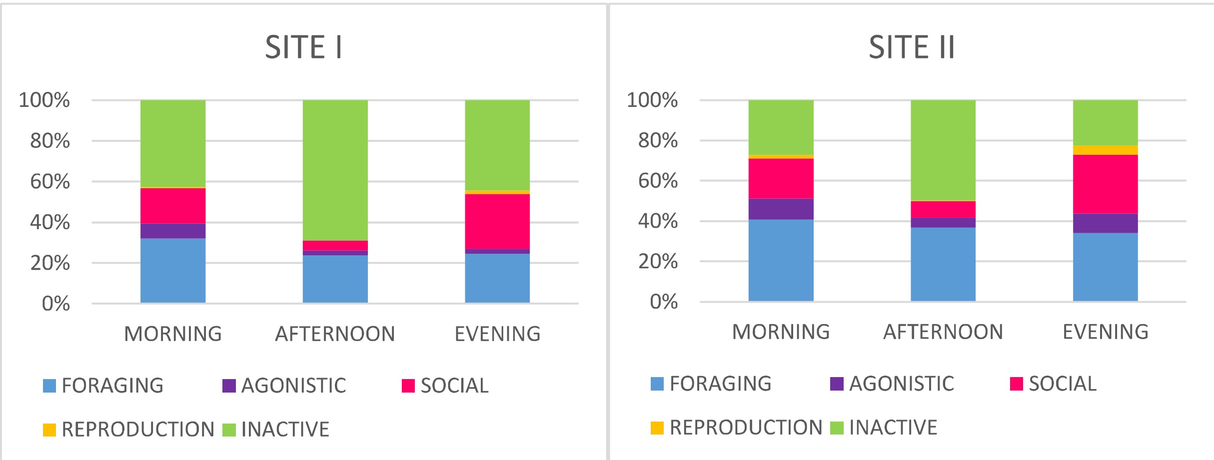
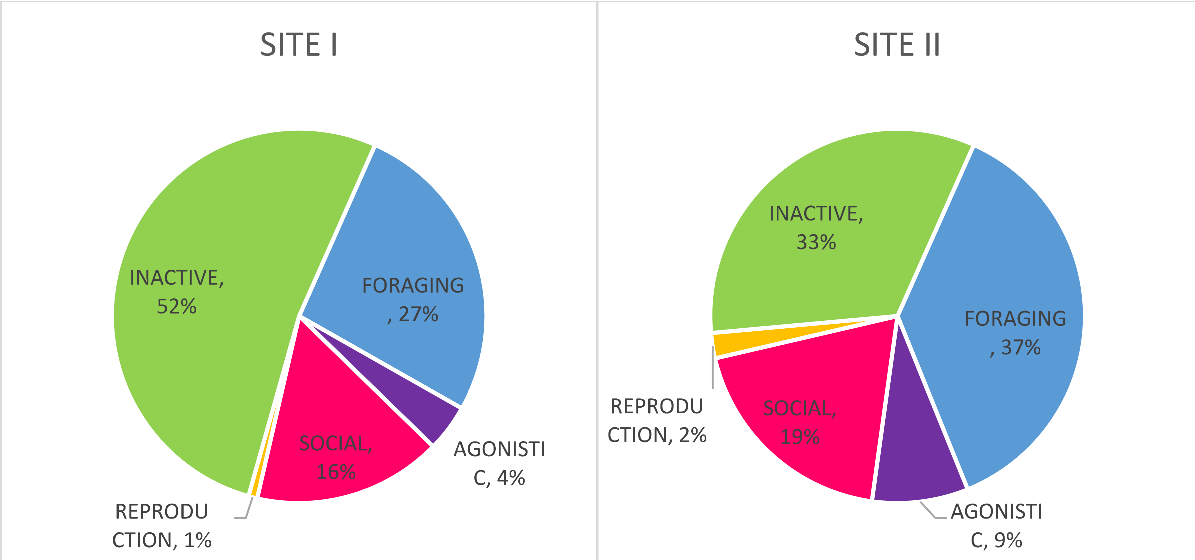


Figure 4.1. Graph depicting the time spent by the crabs A.annulipes in one day over the entire study period at both study sites.



N= 1620 MINUTES

Figure 4.2. Graphs showing the time spent by A.annulipes in a day over the entire study period at site 1(Mangrove edge ecosystem) and II (Baga mangroves).

Figure 4.3. Males and polymorphic females of A.annulipes in the Baga mangroves.

4.2. ECOETHOLOGY OF *A.annulipes*

The *A.annulipes* is observed to have a very unique activity period to adjust with the dynamic environment in the mangroves. The study conducted from July 2023 to March 2024 (9 months), was influenced by 3 types of basic weather conditions i.e. the monsoons, winters and beginnings of summers. The ecological factors varied throughout the study period.

The average amount of rain received at both sites varied during the data collection period. The site I received maximum rainfall in July (32.3 mm), 6.3 mm in august and 11.7 mm in September. The site II received 30.7 mm of rainfall in July, 3.85 mm in august and 5.9 mm in September. The site I received little more rain then site II, due to canopy difference at both sites. The site I is an open edge of mangroves while the site II is a shaded forest patch of Baga mangrove.

The backwaters of mangroves show a varied range of salinity from 0 % ppt in monsoon to 40 % ppt in summers. The salinity level of site I (mangrove edge ecosystem) was always slightly higher compared to its salinity at site II (mangrove ecosystem).

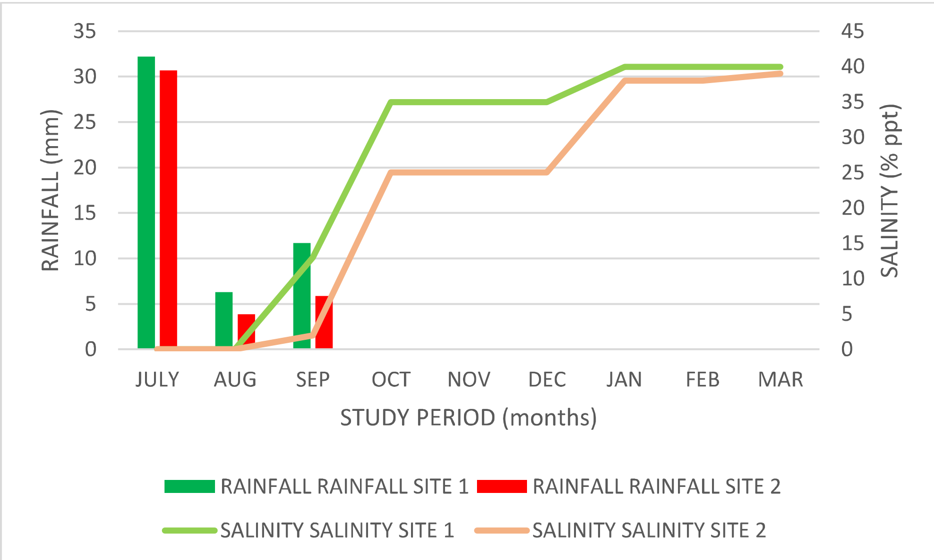


Figure 4.5. Graph showing variation in salinity and rainfall pattern at study sites (data set in appendix)

The pH (of water and soil) was 7.7. It was constant throughout at both the sites indicating slightly above neutral, making the mangrove water mildly basic. While mangrove ecosystems can tolerate a range of pH levels, a slightly basic pH (around 7.5-8.5) is generally considered ideal for their health.

The pH of the soil and water were same possibly due to the type of habitat. The accumulation of detritus (leaf litter, dead remains of organisms, etc.) in the mangroves make its soil slightly acidic, but in situations when river water flushes the soil the salts in the water neutralizes the soil's acidity making it alkaline in nature. The study points are present at the bunds of the river which are always flushed with river water twice a day, not allowing any detritus to accumulate which makes the soil alkaline in nature.

The temperature at site II was recorded 1 – 1.5 °C lower then site I due to the presence of canopy cover. Over all at both sites the temperature of water and soil differ from that of air and burrow temperature. The warmest temperature was in air followed by surface soil, water and coolest inside the burrow compared to the outside environment.

The minimum and maximum temperature recorded at site I in air (26.3°C to 33°C), water (26.6°C to 32.9°C), soil (26.6°C to 32.9°C) and burrow (26.6°C to 31.3°C).

The minimum and maximum temperature recorded at site II in air (26°C to 31.6°C), water (25°C to 30.9°C), soil (25°C to 30.9°C) and burrow (25°C to 30.9°C).

It is so because the burrow acts as refuges for the crab from not just predators but also shades from the scorching continuous heat.

The *A.annulipes* has adapted well to adjust to these ecological changes and dynamic ecosystems in the Baga mangroves. The ethology of the crab observed at both sides is as followed:

The activity level at both sites during the study is visualized in figure 4.9. The activity at site II is more compared to site I. It is so because the mangroves in Baga are on the edge of river bunds, slightly elevated, so even during the high tide suitable land area is available for crabs to be active. The site I is the edge of mangroves, where poor maintenance of bunds have caused salinity to rise into the fields and expand the area for mangroves to grow. The activity percentage of crabs is highly influenced by rainfall pattern in initial 3 months of study, followed by tide level for the remaining study period.

Figure 4.6. Graphs showing temperature pattern at study site during the study period (July 2023- march 2024).

The tide varies each day, with respect to the lunar cycle. The full moon and new moon (no moon) days provide extreme low tide and extreme high tide, showing highest activeness in crabs during lows and least activity during extreme highs while the waxing and waning phases show limited activity of crabs.

The activity of fiddler crab *A.annulipes* is less in months of July, August and September due to rainfall. The crabs remain inactive in burrows during night and also inactive in their burrow during high tide most of their time. The remaining active phase primarily includes extensive foraging. The later months from October to march the crabs are active and seen building burrows, interacting with other crabs in addition to feeding.

With respect to the tide, the afternoons are mostly inactive for the crabs due to the high tide level, but morning and evenings are active. The crabs indulge in reproductive, social, foraging and agonistic behavior across the active time. As mentioned earlier the crabs are more active at site II compared to I due to the canopy cover there, which is responsible for cooler climate and excess free surface for crabs to be active and move around.

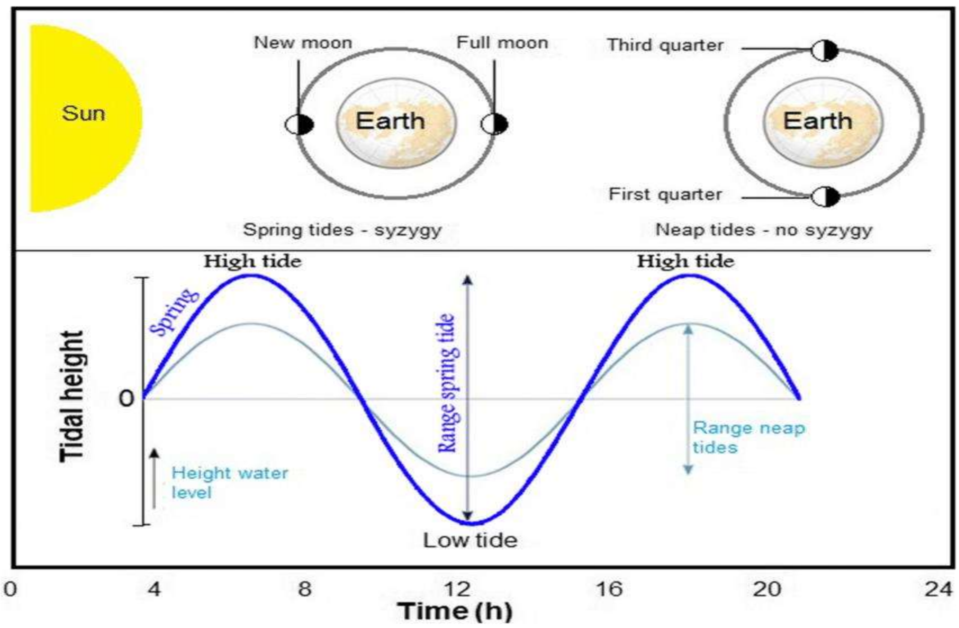
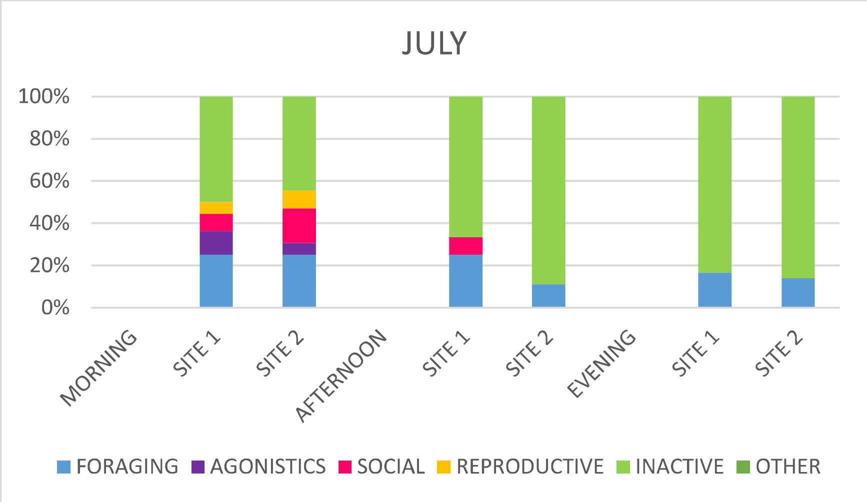


Figure 4.7. Semidiurnal tidal cycle showing water height at spring and neap tides versus the time in two high and low tides. Tidal levels in the spring and neap are 20% higher or lower around the average. From Awadh, S. M. (2021). Solar system planetary alignment triggers tides and earthquakes. Journal of Coastal Conservation, 25(2), 30.

The biotic component includes all the living organisms that interact with each other and their environment. These organisms can be broadly classified into three functional groups based on how they obtain their nutrition: producers, consumers and decomposers. In the mangrove ecosystem of Baga, the fiddler crab *A.annulipes* functions as a decomposer. It continuously feeds on the soil of the mangroves which controls the microorganisms in soil and breakdowns the larger particles of detritus (plant matter, animal feces, dead remains, crustacean carapace, etc.) to smaller particles. The fiddler crabs are preyed by shore birds primarily. Black headed ibis and mangrove crab was observed feeding on *A.annulipes*.

A B

Figure 4.8. Photographs clicked at Baga mangroves: A. Males of A.annulipes feeding in Baga mangrove; B. Group of A.annulipes near water during low tide.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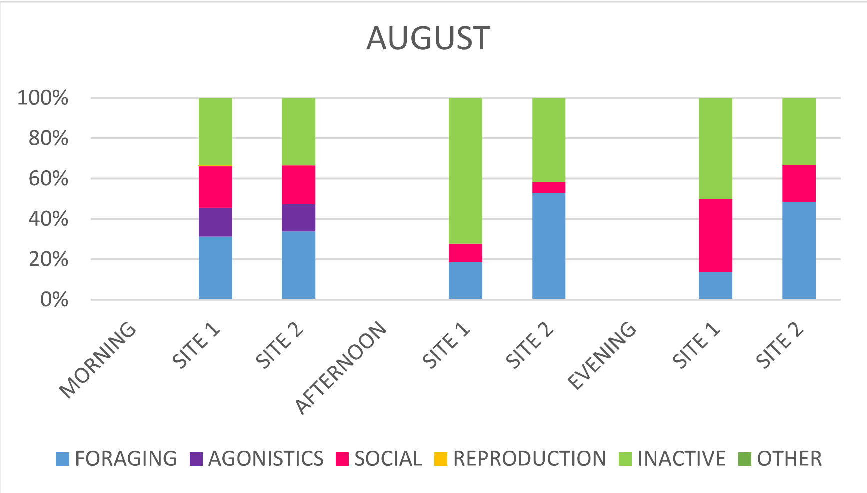
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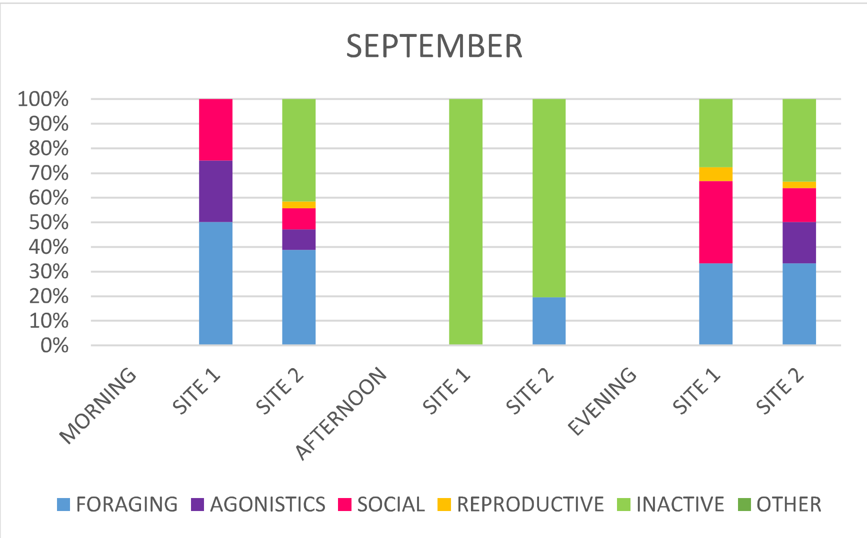
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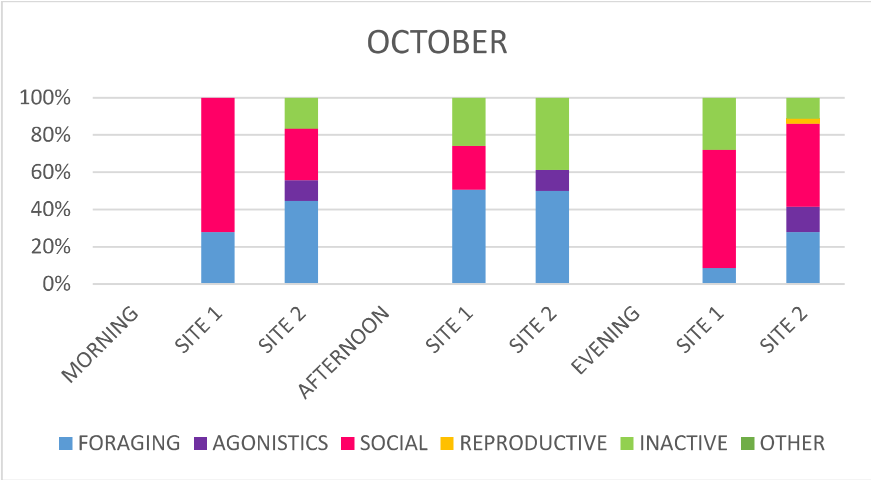
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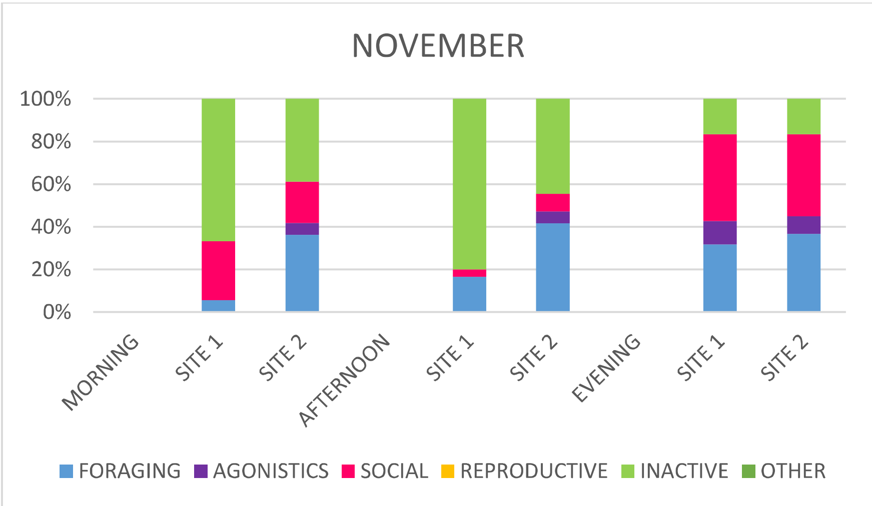
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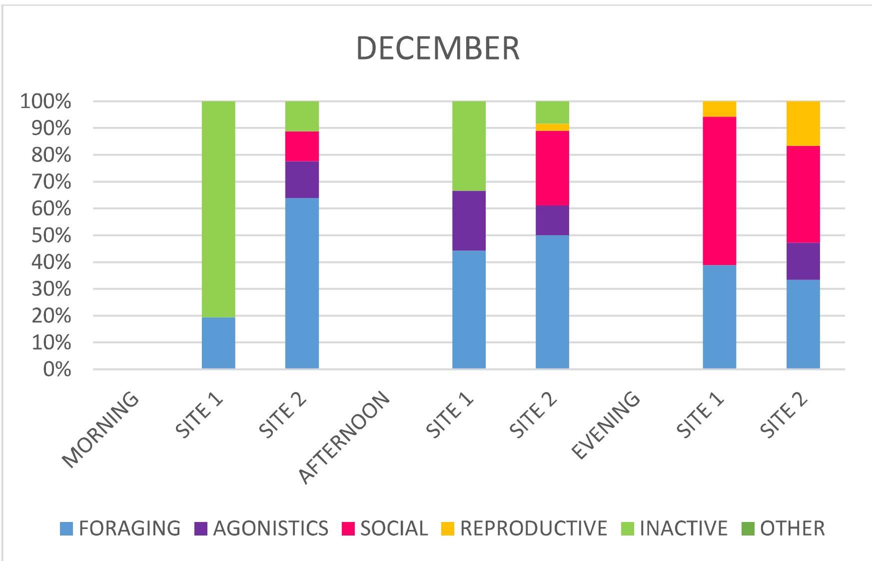
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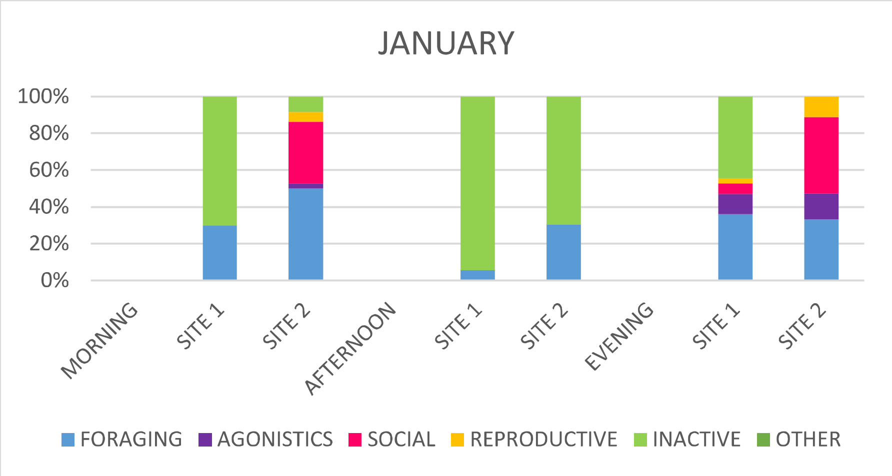

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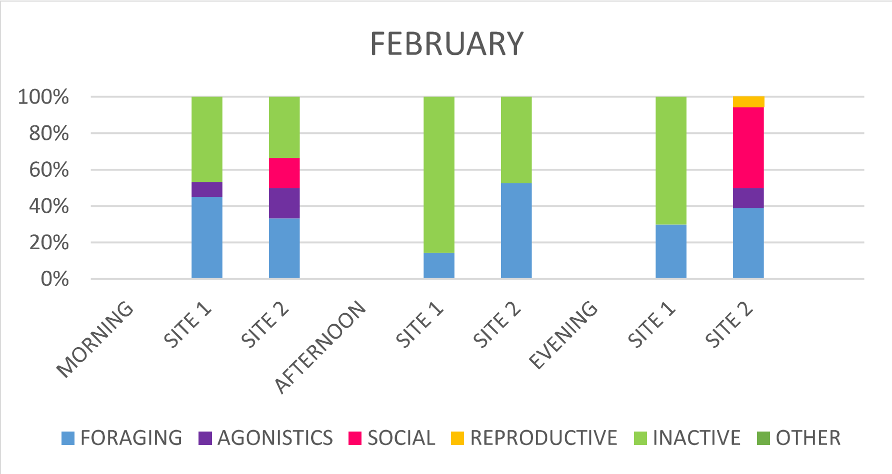

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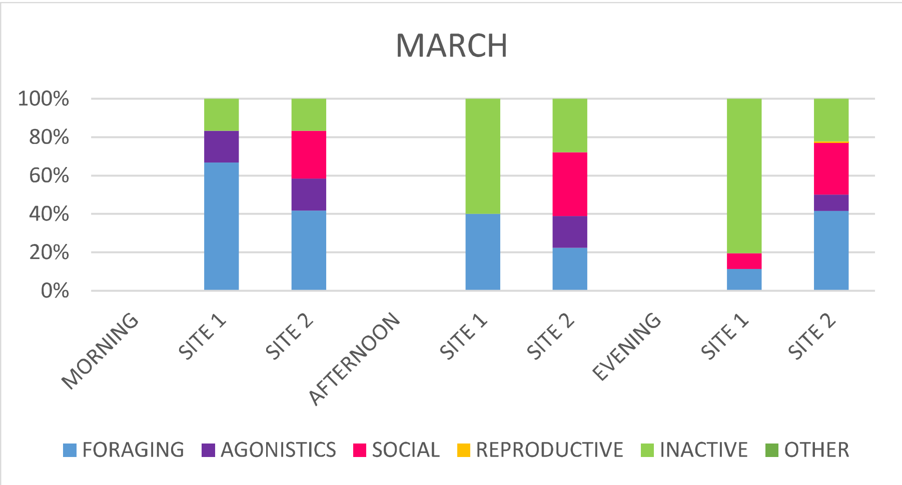

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Figure 4.9. Graph A-I represents month wise ethology (% of time spent) of A.annulipes at both study site.

DETRITUS FOOD CHAIN

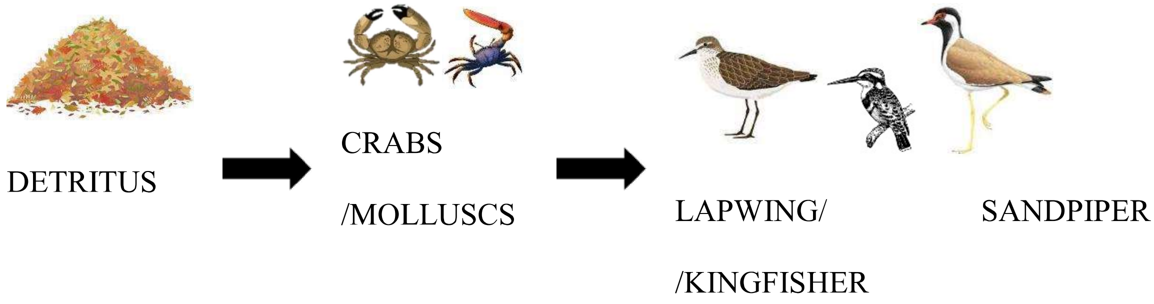


Figure 4.10. Food chain showing position of fiddler crabs in the detritus food chain as a decomposer in Baga mangroves.

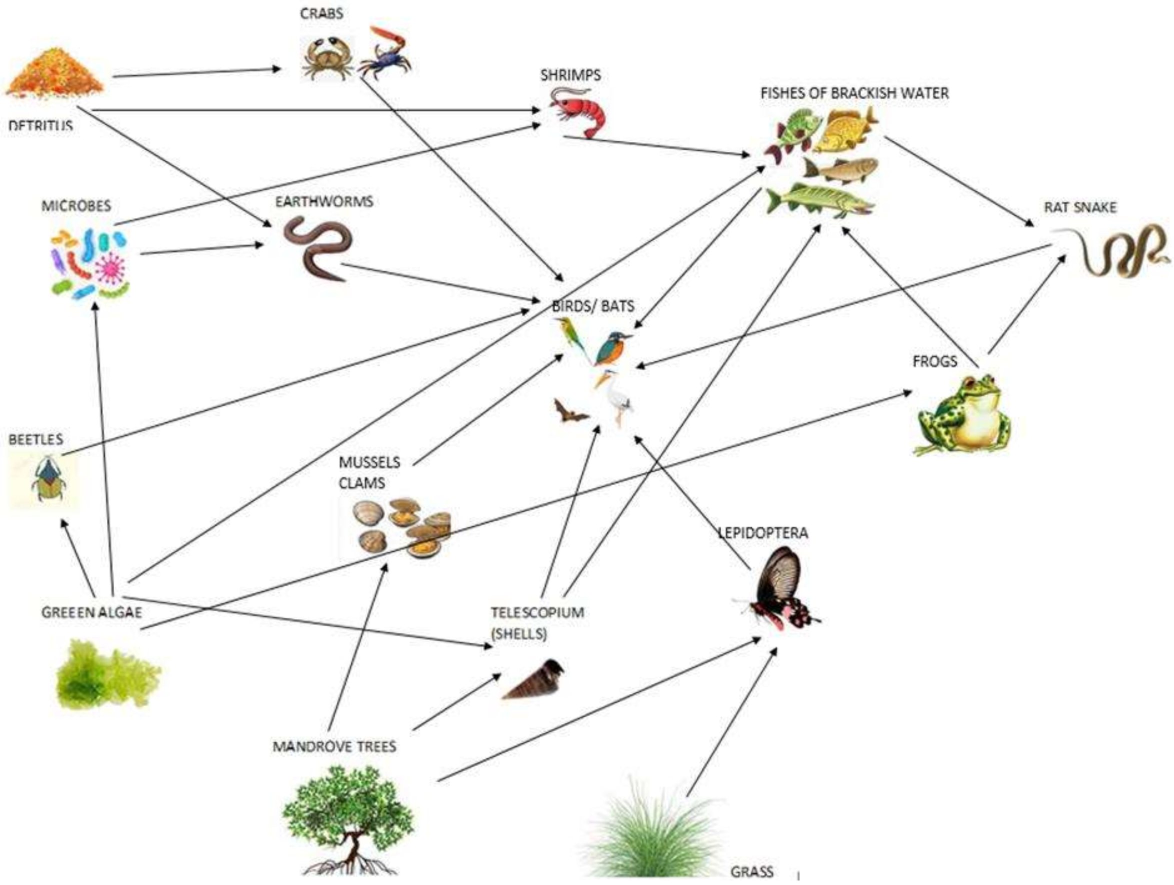


Figure 4.11. Food web in Baga mangroves

The species *A.annulipes* co- habits with many other species. It shows neutral interaction with other fiddler crab species. The commonly found species were – *Tubuca alcocki, Perisesarma bidens* (Red claw crab).

A.  B. 

Figure 4.12. Photographs of contemporary species in Baga mangroves: A. Male and female of Tubuca alcocki; B. Perisesarma biden.

The mangrove crabs were observed to prey on the *A.annulipes.* The observed predators were *Metopograpsus thukuhar,* bandicoot rat and black headed ibis. The red clawed crab and ibis stuck the crab, broke its enlarged chelae and fed on its body, while the rat came after sunset at low tides, dug the burrows in search of crabs, defecated near the burrows and escaped.

Figure 4.13. M. thukuhar, Black headed ibis, Bandicoot rat feeding on A.annulipes in mangrove edge ecosystem.

DETAILED DESCRIPTION OF EACH ACTIVITY OBSERVED:

- FORAGING ACTIVITY

The species forages all day long when active. The speed and efficiency of feeding is higher in females compared to males. The males feed with only one cheliped because their other cheliped is enlarged. The females have pair of symmetrical chelae hence she feeds faster than the male. In one attempt the male takes at average 5 -7 scoops of substrate and produces one feeding pellet, while the female takes in 10-13 scoops of substrate and produces one feeding pellet.

The feeding can be static, exploratory and intermittent type. In static foraging the species forages on its burrow entrance only. The male is observed to feed static in two ways. It sometimes just feeds (non defensive static feeding) and sometimes guards its burrow entrance by feeding and simultaneously waving its large cheliped in air (defensive static foraging).

Static foraging is observed immediately after a high tide when the crabs emerge on exposed surface after a long break to feed. As the tide approaches low, more area of surface soil is exposed, with that the crabs explore around and extend their foraging range by indulging in mobile feeding.

Exploratory feeding is when the species wanders around the area and feeds randomly. Intermittent foraging deals with feeding accompanied by burrow construction. It is observed the species brings one burrow pellet out and feeds for a minute then again goes inside to bring another burrow pellet, as if it replenishes its energy to construct the burrow. The crabs often go in their burrow and stay for few seconds and come out, it can be assumed the crab’s takes shelter in the burrow from the continuous heat outside. As the burrow temperature is slightly cooler then the temperature outside.

Among all the activities performed by the crab, after the inactive phase, the crab spends most of its time in foraging, which involves gaining energy, controlling micro fauna in the soil and bioturbating the mangrove soil.

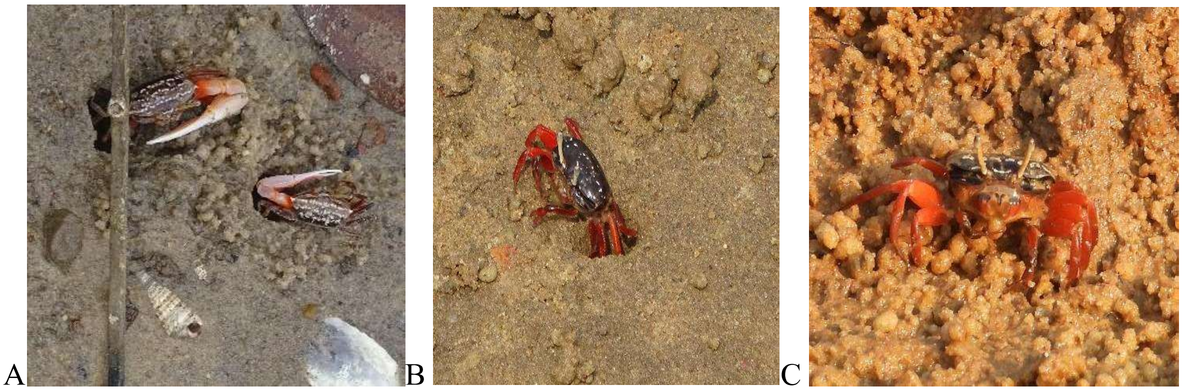


Figure 4.15. A.annulipes (A. Males; B. & C. Females) feeding on its burrow entrance in Baga mangroves.

- AGONISTIC BEHAVIOUR

It deals with behavior of attack, defense and escape. The species is known to show intra species claw fights regularly. It could be for defense, guard its territory, mate selection or for pleasure.

The fights can be short for 4-5 seconds to as long as 1 minute in duration. Mostly the fights are seen among equal sized males. Females also indulge in combat, but the reason for this phenomena remains a mystery.

The fiddlers get engaged in burrow fights when a wandering individual attacks on a suitable burrow. The males threaten each other by displaying their enlarged chelae to each other. If this doesn't drive away the opponent, the territorial male will snap the opponent's large chelae with its own large chelae and a combat takes place. Both the males try to push each other, until one gives up or gets defeated after the weaker male loses its enlarged chelae. The females simply push each other until one gives up.

As defense the individuals escape the predators by taking refuge in their respective burrows. In an instance if the crab is not close to its burrow opening it tries to construct a burrow and hide immediately, but doesn't enter other individuals burrow, showing high degree of territoriality.

The species is highly vigilant and active. They have a powerful sensory system. During its active phase, it was observed even if a bird flies over the crabs they immediately run back in their burrows to escape the predator.

They are observed to be non-territorial during rains/ high tide periods but highly territorial otherwise. The crabs, males as well as females are often seen engaged in fights. In times males also damage or loose their major chelae in fights for burrows. In times of attack of predators the crab is seen losing its life but it shall not refuge in other individuals burrow at any cost. This could be due to the individual investment in construction cost, maintenance cost of each crab towards its burrow.

Figure 4.16. Photograph showing male- male combat of A.annulipes in Baga mangroves.

- SOCIAL BEHAVIOUR

The fiddler crabs are highly social organisms. They show a wide range of social activities. They explore the surface as tide starts to go down. A systematic pattern is observed where fiddlers in group one behind the other move ahead as the tide level goes down. As they move they come in contact with other species inhabiting the habitat. But there is no sign of aggression observed, once encountered they smoothly part away their ways, indicating resource partitioning among themselves. Every early morning as tide goes down and late evening as tide comes up, the male fiddlers in large groups of 10-15 individuals wave their large chela in air in a synchronized pattern continuously. Each wave repeats at an interval of 7 seconds. It acts as a signal to either start the activity or end the activity for the day respectively, additionally it could also be an anatomical- physiological adaptation in them to provide relaxation or exercise to their large chelae after along inactive night and before a start of inactive phase respectively.

Burrows are a social symbol for crabs, the size of burrow entrance marks their dominance and act as a territorial signal. After a high tide, the crabs forage for a while to replenish energy and then commence to construct a burrow. Approximately 7 to 12 seconds are required to bring one burrow pellet to the surface, depending on the depth and complexity of burrow built.

Fiddler crabs build a complex burrow network underground but some species also create above- ground sedimentary structures at their burrow entrance. Most common structures observed are chimneys, hoods, pillars, semi domes, mud balls, and rims (Pardo et al., 2020).

The *A.annulipes* displays deposition of mud balls outside its burrow opening. The burrow pellets (mud balls) are used to mark their territory. Some studies suggest the size and number of mud balls determine the burrow's fitness for breeding and attracts the females during the courtship season (Pardo et al., 2020).


A


B


C


D

Figure 4.17. Photographs (A-D) of A.annulipes in groups with inter and intra species individuals at low tide in Baga mangroves.

- REPRODUCTIVE BEHAVIOUR

The reproductive term indicates the close association of male and female. Very rare observations of male coming close to a female burrow and approaching her to enter in a burrow was seen. They remained in for few seconds (5-10 seconds) and after coming out and immediately parted away. But it was not always seen that the female followed the male in burrow, sometimes rejection by female was also observed.

Some instances of forcefully mating attempts done by female were also seen, and as a spontaneous reaction the female's disagreement was seen.

As per literature, the reproductive period of *A.annulipes* is from April to June, which is not part of this study, still 1 -2% of reproductive behavior was observed during this study, which indicates the adapting life style of this species.

Throughout the study male and females juveniles were observed among the adults at the study site.

The well-known mating ritual among the fiddler crabs is the claw waving display by males to impress the females. But no such phenomena was observed in his study, as this study has no account of the breeding period of the species. Still the crabs were observed having opposite sex interactions. This interaction was- the male sensing the female presence and trying to court her and vice versa. Some random sights of females entering a male burrow and moving out in 2-3 seconds were also seen, the possible reason could be burrow inspection by females before courting the males.

Additionally, polymorphism in this species could also be an important factor. The females of this species appear in 14 different polymorphs, showcasing bright colorations and patterns. It could be an exceptional case where the female ornamentation acts as mate attraction strategies in this species. As per observations, the two morphs were more seen more in contact with males compared to the others.

A B

Figure 4.18. Photographs (A & B) of male and female (polymorphic individuals) of A.annulipes in Baga mangroves.

- INACTIVE PHASE

The fiddler species remains inactive in dark time (full night) following a circadian rhythm, but additionally they are also affected by circa tidal clocks during the day. They remain inactive during high tides of day time. It appears that they have a powerful sensory system and show inclination towards rheotaxis (behavioral response towards water). As the tides go down or start to move up, the crabs can sense the water currents and reduce/increase their activity close /far from water.

Thou they remain inactive but during night time at low tides, they are highly susceptible to predators.

A B C

D  E 

Figure 4.19. Photographs (A-E) of A.annulipes resting in burrow during night time and high tides at Baga mangroves.

4.2.1. ETHOGRAM FOR *A.annulipes*

Based on cumulative observations at both study points, the species is partially diurnal.

The fiddler crabs were observed spending 43% (1393 minutes) of their day time resting in its burrow. In their remaining active time, 32% (1036 minutes) of time was for foraging, 18% (584 minutes) in social activities, 6% (194) in agonistic behavior and 1% (33 minutes) reproductive activity.

During day its activity is influenced by tide, hence 43% of the day time it remains inactive. In the remaining time it forages around. The foraging could be of many types. The social activities observed was mainly of 4 types, which includes moving around the space exploring, interacting with other species, constructing its burrow and waving of large claw in air by males. The agonistic or fight behavior is observed in both male and females. The reproductive behavior included the close interaction of male female above surface followed by moving in burrow together.

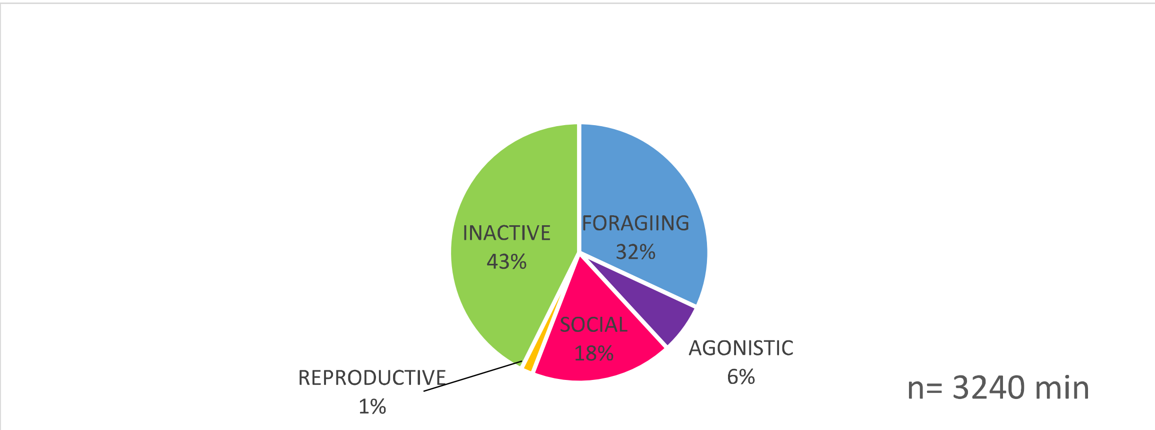


Figure 4.20. Graph showing Activity budget for A.annulipes.

Based on this study the following Ethogram in proposed for the fiddler crab species *Austruca annulipes*:

BEHAVIOURAL STATE			DESCRIPTION
RESTING			
	DIURNAL REST		During high tide the animal rests in its burrow.
	NOCTURNAL REST		From dusk to dawn the animal remains inactive in its burrow.
FORAGING			
	STATIC FORAGING	NON- DEFENSIVE	Continuously feeding at one spot, mostly around its burrow opening.
		DEFENSIVE	Continuously feeding at one spot and simultaneously waving its enlarged cheliped in air.
	MOBILE FORAGING		Continuous feeding by moving around the habitat randomly.
	INTERMITTENT FORAGING		Feeding alternately while constructing its burrow.
AGONISTIC			
	ATTACK		Intra species combat: The males fight using their enlarged chelae while females use their pair of feeding chelae.
	ESCAPE		In defense the animal runs and hides in its burrow.
SOCIAL			
	EXPLORATORY		Randomly moving around in the habitat away from its burrow.
	PERIODIC CLAW PARADE		In large groups the animal waves its large cheliped in a cyclic pattern continuously.
	NEUTRAL INTERACTION		Inter species encounters: the animals come close and immediately part away.
	BURROW EXCAVATION		Exclusively forming burrow pellets by digging deeper in soil.
REPRODUCTIVE			
	ENCOUNTER		Male and female approach each other and part away immediately.
	BURROW CO-OCCUPANCY		Male and female enter a burrow and come out after few seconds.
	COERCIVE MATING		The male forcefully attacks the female by trying to push her in the burrow.

To discuss the above findings with available literature, there were lack of eco-ethological studies on fiddler crab species. However, some studies on individual aspects of *A.annulipes* behavior, taxonomy, distribution, claw regeneration are studied. As per Lim et al (2022) feeding is preferred over other activities and the crabs are active only during low tides. Additionally the females are more efficient feeders compared to the males, as observed in this study too. But no evidence on types of foraging and other detailed activities are available. Such minute behavioral details were contributed via this study.

Litulo in 2004 stated that the *A.annulipes* reproduces throughout the year with peaks of spawning during summers. Throughout this study courtship patterns were observed very often. Also juvenile crabs were encountered regularly. No details about summer spawning was observed due to restricted study period.

Thou this study didn’t focus on the population dynamics, a population study in Thailand showed that crab density was high and the sex ratio was more male biased (Chumsri et al., 2023).

Hence, there is a large scope for numerous studies to be carried out focusing on ecology and ethology of *A.annulipes.*

4.3. BIOTURBATION BY A.annulipes

Bioturbation in simple terms means disturbing the physical and chemical characteristics of soil particles.

The mangroves are blessed with unique properties to its soil. They are very different in their physical, morphological and chemical properties compared to other soil types. The mangrove sediments express hydromorphism associated with the accumulation of organic and sulphidric material. The soil here is saturated with moisture due to lack of water movements in mangroves which favors (creates an anaerobic environment) this soil to be classified as Moisture regime aquic type. The large amount of biomass and the soil moisture regime favor the intense accumulation of organic material (Staff, 2014).

The neutral colors indicate the process of reduction of $Fe3+$ to $Fe2+$ in suboxic environments by the microorganisms, the darker regions include higher proportions of OM. Intensification of the greyish colors with depth and the presence of orange mottling at the surface is due the reoxidation of Fe (Otero & Macías, 2010).

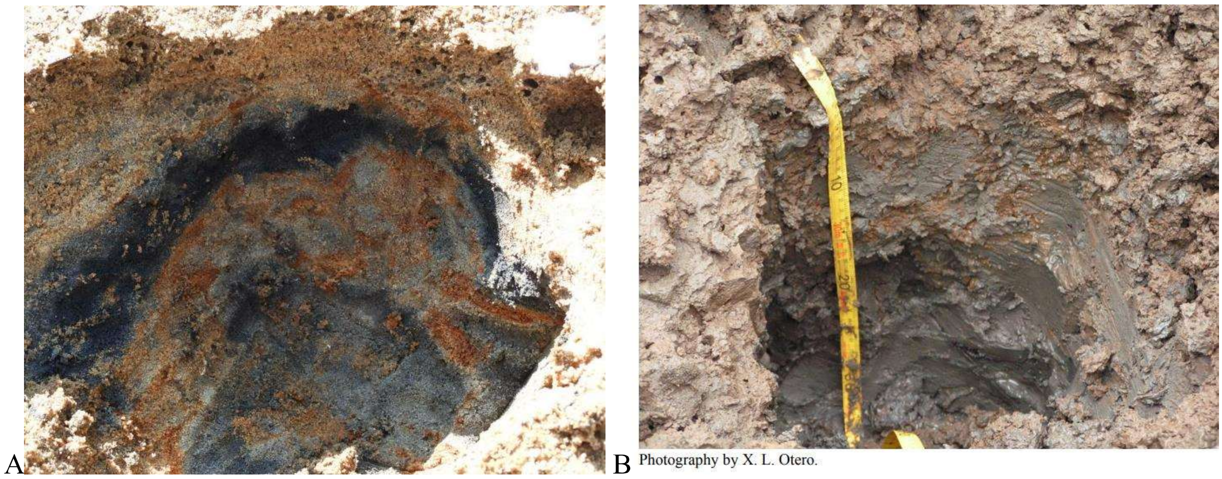


Figure 4.21. A. Soil profile in the mangrove edge ecosystem (the different colored soil layers indicate the gleization of soil); B. Morphological evidence of the gleization process in mangroves of São Paulo(Otero & Macias, 2010).

The gleization of soil in the mangrove edge ecosystem indicates the transformation of the soil. It changes the soil profile such that mangroves can expand and invade in the area. With time the soil will become more compact and clay based (refer to fig. 4.21 B).

The continuous process of soil gleization leads to gleyed soil. The gleyed soil is blue- black- grey in color formed in the lower part of the soil profile above the parent material due to poor drainage condition (lack of oxygen) and where waterlogged conditions prevail. Such soil material is hard when dry and sticky when wet. It has a sandy clay subsur- face layer over permanently anaerobic subsoil. –oxides. (Chandran, 2012).

Hence the sticky, clay, anaerobic conditions in the mangrove soil are improved and nurtured by the fiddler crab species.

The fiddler crabs are known to bioturbate the soil of mangroves by two ways- first by forming burrows and second by feeding extensively and continually on the soil, altering the sediments/ organic matter particulate size.

The fiddler crabs are known to shuffle the soil particles by building burrows. The crabs dig a burrow and bring the deeper sediments to the surface causing them to circulate. The burrow pellets brought up are washed by the tide. Simultaneously, the tidal influx to the deeper soil via burrow openings ultimately causes flow of nutrients in the soil.

Table 4.1. Data of number of casts procured in different types of burrow shapes in Baga mangroves.

BURROW SHAPE	NO. OF BURROW IN MALES	NO. OF BURROWS IN FEMALES	TOTAL NO. OF BURROWS CAST
I	2	8	10
J	1	0	1
L	4	1	5
S	3	1	4

The burrows procured were of different sizes and shapes. Over all, for a sample size of 20 burrows (10 males; 10 females) the average burrow diameter is 13.0465±4.6 mm, burrow depth is 109.876±34.9 mm and burrow length is 128.5±44.8 mm.

The small burrow opening is due to the small size of the crab, making it sufficient for the crab to move in and out. Due to the small size of the *A.annulipes* they can go around 10-12 cm deep in the soil. The possible reason restricting the burrow length could be the tidal cycle, which disrupts the burrow structure at regular intervals, not allowing the crabs to penetrate deeper in the soil bed.

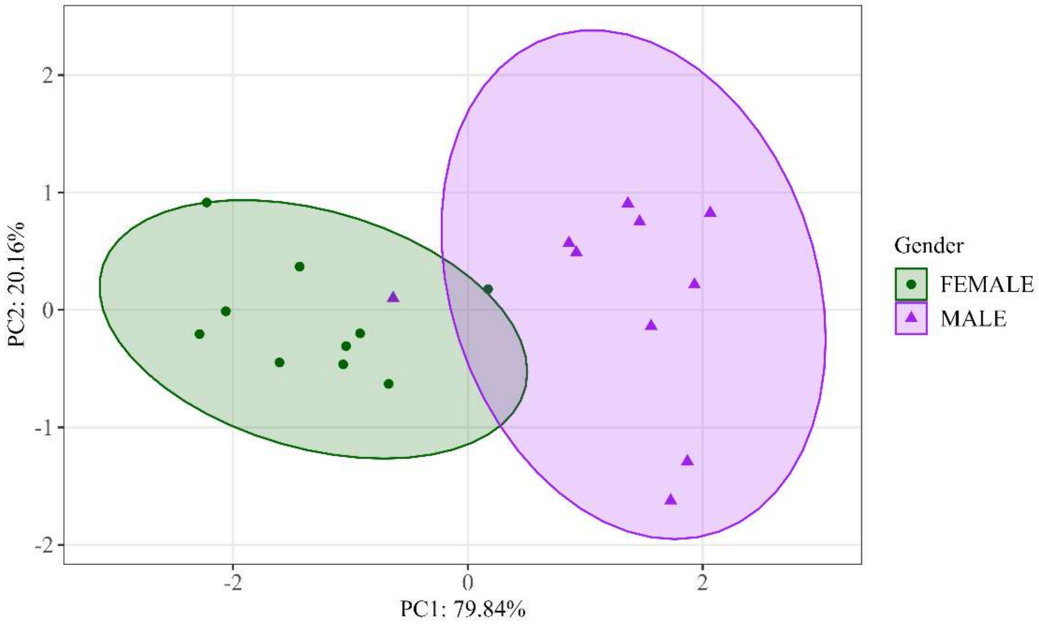


Figure 4.22. PCA graph depicting the difference in burrow structure of male and female A.annulipes.

The male burrows are larger, bigger and deeper compared to the female burrow due to their larger size specially due to their enlarged chelae, which require extra space to move in and out of the burrow, also the male burrow are used for mating hence requires larger surface area. The complex structure of the burrow accounts as an animal architecture build by male fiddler crab to impress the female crab to increase mating success.

The examined female burrows were simple, straight mostly 'I' shaped due to the symmetrical body shape and is used only for defense and protection from predators. While the male burrows are found in varied shapes due to different reasons. One important factor that could affect the burrow shape are the mangrove roots and larger rocks at the river bank in mangroves.

While the male burrows were not only in different shapes but also had bulges in it. The bulge in the burrow is termed as a chamber. The position of the chamber could be at the top, middle or bottom of the burrow. The males showed a chambers in the bottom in most cases and a few in the middle of borrow structure. The reason behind this is mysterious, as some burrows showed absence of a characteristic chamber. The possible reason could be the burrow was not yet complete as it could be of a young/juvenile fiddler crab who has not yet skilled the art of burrow construction.

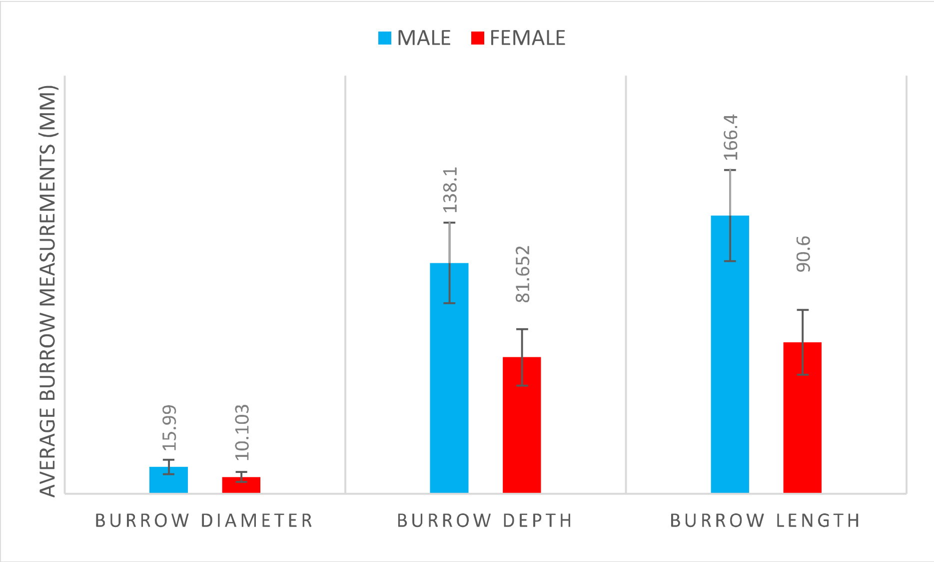


Figure 4.23. Graph representing the average size comparison between male and female burrows on A.annulipes.

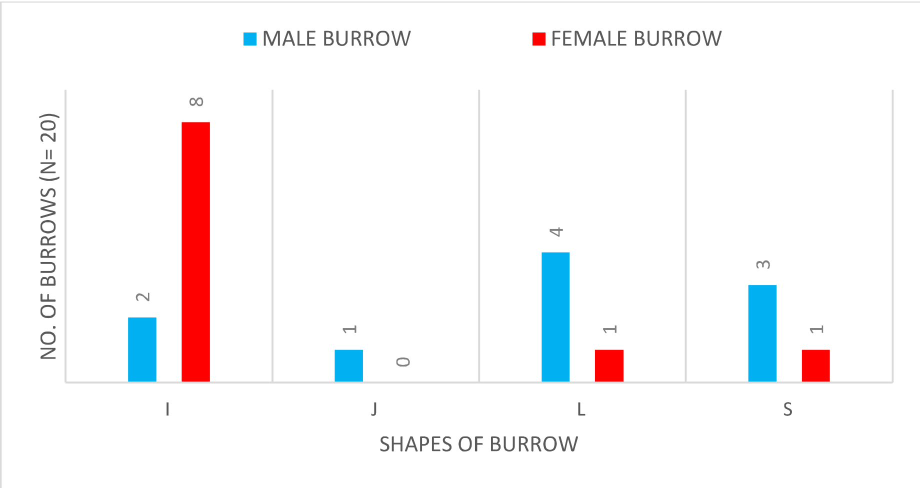


Figure 4.24. Graph showing the number of different burrow shape procured from male and female burrow of A.annulipes.

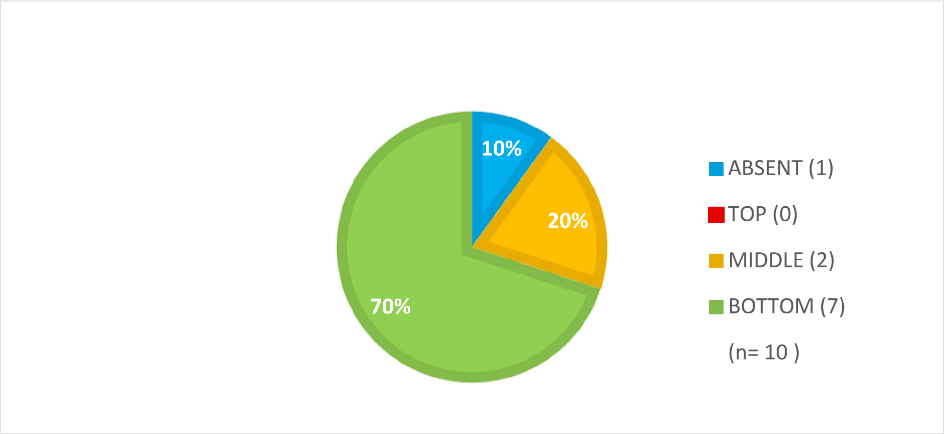


Figure 4.25. Chart showing the no. of burrows having different position of chambers in A.annulipes male burrows.

Also, Fiddler crabs' burrows expose underground soil to air, which fuels the decay of trapped organic matter and releases carbon dioxide (CO2) into the atmosphere and increase's soil respiration in salt marshes (Agusto et al., 2022).

Primarily the tidal fluxes and vegetation for an area are responsible for the organic matter (OM) present in the tidal marshes and adjoining areas. But these factors are not sufficient for determining the change in OM. The organisms living there, mainly fiddler crabs are responsible for this purpose. The sediments deposited on surface are timely shuffled with sediments buried underneath, casing a balance in carbon (OM) in the tidal areas. the fiddler crabs transport OM through excavation by carrying sediment from bottom to surface, hence an increase in OM content on the top layer is seen (Natalio et al., 2017).

Table 4.2. The observations for loss of ignition methods in the mangrove edge ecosystem.

	BURROW PELLETS	FEEDING PELLETS	SURFACE SOIL
Weight of Crucible (g)	27.411	31.293	18.477
Weight of Crucible + 20g Soil sample	47.411	51.293	38.477
Heating in a muffle furnace for 3 hours at 450° C			
Weight after heating	47.154	50.931	38.323
Difference in Organic matter	0.257	0.362	0.154

The soil particles are not just aerated and mineralized due to the crab's behavior but the fiddler crabs are also responsible for circulating and breaking down the organic matter in soil.

The fresh washed off soil after a high tide consist of nutrients, salts, minerals and organic debris. The fiddler crab *A.annulipes* feeds on the surface soil and produces feeding pellets. These feeding pellets are rich in organic matter, as the crab masticates the surface soil in its mouth absorbing the nutrients and producing out dry feeding pellets. The feeding pellets are made of finer grain size compared to surface soil because they are broken down while chewing.

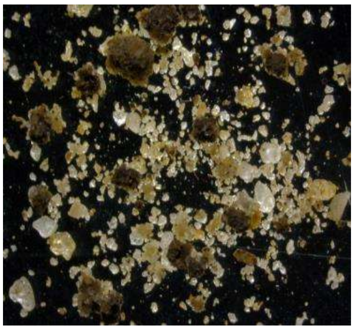
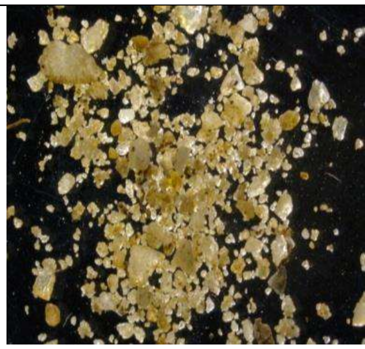
Table 4.3. Amount of OM (Organic matter) present in the soil samples.

SOIL SAMPLE (20 g)	AMOUNT OF OM
Burrow pellets	0.257 g/20 g
Feeding pellets	0.362 g/20 g
Surface soil	0.154 g/20 g

While the soil of burrow pellets is very granular, large in size compared to feeding pellets and surface soil, as it is brought from the lower strata of soil and is rich in organic matter.

Table 4.4. Visual Sedimentation analysis at edge ecosystem.

	Image clicked in field (Scale: 4 cm)	Image under Stereo-microscope (Scale: 1 mm)
BURROW PELLETS		

FEEDING PELLETS		
SURFACE SOIL		

The difference in size and amount of carbon matter in different layers of soil sample indicate that the crabs activity in the soil is responsible to alter (i.e. bioturbate) the soil bed in mangroves, making it efficient enough for other animals to survive underground.

To summarize, both of the Bioturbation studies on crabs have proved their role in aerating the mangrove soil as per as important role in disturbing and the soil particles in different layers of soil bed. The burrows built by the crabs also contribute to the same. Most burrow studies have used POP as the median to procure the casts, but some papers show alternative methods like resin, aluminum, silicon, polyester resins, wax, etc. the changing environment now alarms the usage of pop as a pollutant to the environment.

But still this research was conducted sing POP (Plaster of Paris). It is so because the POP is relatively non-toxic, decomposes naturally into gypsum (calcium sulfate) which is a common mineral in aquatic environments. While on the other end the setting process can increase water turbidity temporarily, potentially affecting filter feeders. High amounts of sulfate released during setting can disrupt sensitive aquatic ecosystems. But on contrary the other materials used are more dangerous compared to POP.

Aluminum is toxic to aquatic life even at low concentrations. It disrupts fish gills and reproduction and persists in the environment.

The cons of resin depends on the type of resin used and the VOCs present in them. Primarily it is a sticky substance and can kill the crabs trapped in while casting and all types of resins are readily non-biodegradable.

Thou some waxes are biodegradable, they may block sunlight from penetrating in water and the hot wax when poured may boil and kill the crabs immediately and also its sticky nature will trap and kill the crabs

(Shukla et al., 2014).

The Burrow characteristics are similar in researches from Thailand, Tamil Nadu. These publications documented 6 different burrow shapes (I, J, L/LL,S,V,Y), However in this study only 4 shapes were seen. The difference could be due to the different vegetation cover at study sites (Tina et al., 2018 ;Min et al., 2023).

Investigating the burrow architecture of Austruca annulipes offers a valuable opportunity to delve deeper into their lives and ecological roles. The findings can improve our understanding of these fascinating crabs and contribute to conservation efforts.

CHAPTER V: CONCLUSION

The earth carries many unique and dynamic ecosystems in it, and one among them are the coastal mangrove ecosystems. Also called as the "Guardians of the sea", they are very dynamic in nature and possess a unique flora and fauna. But with changing climatic conditions the mangroves are at threat and require immediate conservatory actions.

The fiddler crab *A.annulipes* is one of the exclusive fauna found in the mangroves. This inductive research generates an overview of the activity pattern of *A.annulipes* and how its activity is influenced by the environmental factors like temperature, rainfall, tide level, etc. A cumulative data from both the study sites shows the crab remains inactive at high tides and during low tides it spends most of the time feeding and constructing its burrow. The species was seen reproductively active throughout the study period. The comparative study at two sites shows the time spend in different activities is more at site II (mangrove ecosystem) than at site I (mangrove edge ecosystem). It is due to the elevation and canopy cover at site II, which allows the crabs to access the open surface even during high tide. Additionally, provides a better cooler environment and cover from direct predators due to the canopy cover.

This direct observational study collected a time budget for the crab, which gave rise to a robust Ethogram for the species. The sub types of behaviors shown by the species are categorized in detail.

The activity rhythm of the crab shows that the species has incorporated feeding as part of its every other activity, followed by burrow excavation. Which signifies its primary role in mangroves is to be a bioturbating agents. Hence, they are extremely important for the mangrove ecosystem to remain healthy.

It opens scope for experiments to use these species to restore the mangroves and contribute towards conservation and nature wellbeing.

This opens door for many more qualitative and deductive studies to be performed for the species to understand its ecology in more detail.

Such simple studies which see nature in its original form are the call of the hour. Humans since ages have fiddled with nature and are facing the consequences to it. As said by Jane Goodall – "it's appalling to me to see Science with a big capital S… it is turning people into machines." It's time to reflect and understand the purpose of human life, and see carefully. We can find solution to our problems from nature itself, we just need to be patient and observe it.

"Nature has it all: nourisher, teacher, and punisher"

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WORKSHOP ATTENDED

- State level workshop on "Animal Behaviour and Cognition" organized be Ganpat Parsekar College of Education in collaboration with Directorate of Higher education, State of Goa and School of Biological Sciences & Biotechnology, Goa University.

INTERNSHIP

- Worked for two weeks with Goa State Biodiversity Board and submitted a report on "A short study on ecology of Baga mangrove: current status and prospects".

APPENDICES

APPENDIX I: ECOLOGICAL DATA FOR STUDY SITES

							TEMPERATURE			
		SITE	pH WATER	pH SOIL	SALINITY % ppt	RAINFALL mm	AIR °C	BURROW °C	SOIL SURFACE °C	WATER °C
JULY	MORNING	1	7.7	7.7	0	32.15667	25.83333	26.66667	26.66667	26.66667
		2	7.7	7.7	0	30.72667	25.66667	25	25	25
	AFTERNOON	1	7.7	7.7	0	32.15667	26.89	27	27.33333	27.33333
		2	7.7	7.7	0	30.72667	26.33333	25	25	25
	EVENING	1	7.7	7.7	0	32.15667	26.60667	27	27.33333	27.33333
		2	7.7	7.7	0	30.72667	26.33333	25	25	25
AUG	MORNING	1	7.7	7.7	0	6.243333	26.33333	29.36667	29.5	29.5
		2	7.7	7.7	0	3.85	26.33333	25.86667	25.86667	25.86667
	AFTERNOON	1	7.7	7.7	0	6.243333	26.33333	29.26667	29.8	30.46667
		2	7.7	7.7	0	3.85	27.1	26.33333	25.66667	25.66667
	EVEING	1	7.7	7.7	0	6.243333	26.33333	29.26667	29.26667	30.46667
		2	7.7	7.7	0	3.85	26.33333	26	25.66667	25.66667
SEP	MORNING	1	7.7	7.7	13	11.70667	25.83333	25.66667	25.66667	25.66667
		2	7.7	7.7	2	5.963333	26.9	26.33333	27	27
	AFTERNOON	1	7.7	7.7	13	11.70667	27.1	27.5	27.5	27.5
		2	7.7	7.7	2	5.963333	27	26.66667	27.33333	27.33333
	EVEING	1	7.7	7.7	13	11.70667	26.33333	26.66667	26.66667	26.66667
		2	7.7	7.7	2	5.963333	28.66667	26.33333	27.33333	27.33333
OCT	MORNING	1	7.7	7.7	35	0	32.33333	28.66667	29.66667	30.33333
		2	7.7	7.7	25	0	28.66667	26.33333	27.66667	27.66667
	AFTERNOON	1	7.7	7.7	35	0	34	29.66667	31.66667	32
		2	7.7	7.7	25	0	31	28.33333	29.33333	29.33333
	EVENING	1	7.7	7.7	35	0	32.66667	29.3	30.2	30.73333
		2	7.7	7.7	25	0	29.66667	27.66667	29	29
NOV	MORNING	1	7.7	7.7	35	0	31	27.96667	30.33333	29.66667
		2	7.7	7.7	25	0	28.83333	26.66667	27.33333	27.33333
	AFTERNOON	1	7.7	7.7	35	0	32.33333	29.33333	31.66667	31
		2	7.7	7.7	25	0	33.33333	28.66667	30	30
	EVENING	1	7.7	7.7	35	0	31.83333	28.63333	29.95	30.75

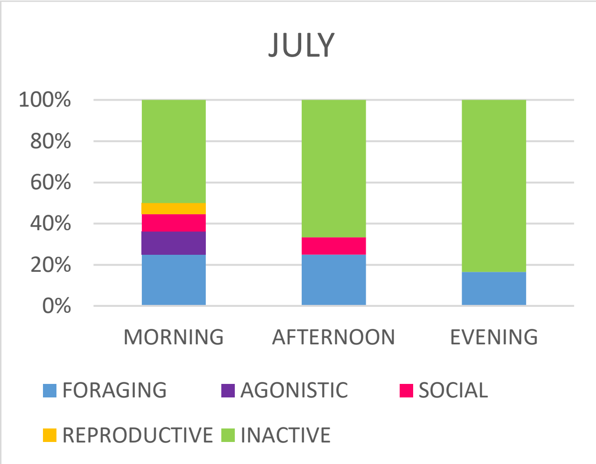
		2	7.7	7.7	25	0	31.66667	28	29.66667	29.66667
DEC	MORNING	1	7.7	7.7	35	0	30	28.66667	28.9	28.9
		2	7.7	7.7	25	0	29	26.66667	27.33333	27.33333
	AFTERNOON	1	7.7	7.7	35	0	32	28.66667	29.66667	29.66667
		2	7.7	7.7	25	0	32.33333	28.66667	30	30
	EVENING	1	7.7	7.7	35	0	31.33333	28.66667	29.33333	29.33333
		2	7.7	7.7	25	0	29.66667	28	29	29
JAN	MORNING	1	7.7	7.7	40	0	29.3	29.33333	29.33333	29.33333
		2	7.7	7.7	38	0	29.33333	27.5	28	28
	AFTERNOON	1	7.7	7.7	40	0	33.83333	30.5	32.33333	32.33333
		2	7.7	7.7	38	0	26.25	28.66667	30.16667	30.16667
	EVENING	1	7.7	7.7	40	0	32.66667	30	32.16667	32.16667
		2	7.7	7.7	38	0	32	28.83333	30	30
FEB	MORNING	1	7.7	7.7	40	0	32.66667	30.63333	32.66667	32.66667
		2	7.7	7.7	38	0	29.33333	27.5	28.6	29.1
	AFTERNOON	1	7.7	7.7	40	0	33.33333	33.16667	33.33333	33.33333
		2	7.7	7.7	38	0	33	30.2	32.6	32.4
	EVENING	1	7.7	7.7	40	0	32.66667	30.33333	32.83333	32.83333
		2	7.7	7.7	38	0	32	29.63333	31.63333	31.2
MAR	MORNING	1	7.7	7.7	40	0	29	28	28	28
		2	7.7	7.7	39	0	29.33333	28	28.33333	28.5
	AFTERNOON	1	7.7	7.7	40	0	33	30	30	30
		2	7.7	7.7	39	0	33.33333	95.66667	32.5	32.33333
	EVENING	1	7.7	7.7	40	0	31	28	29	29
		2	7.7	7.7	39	0	32.16667	29	30	31

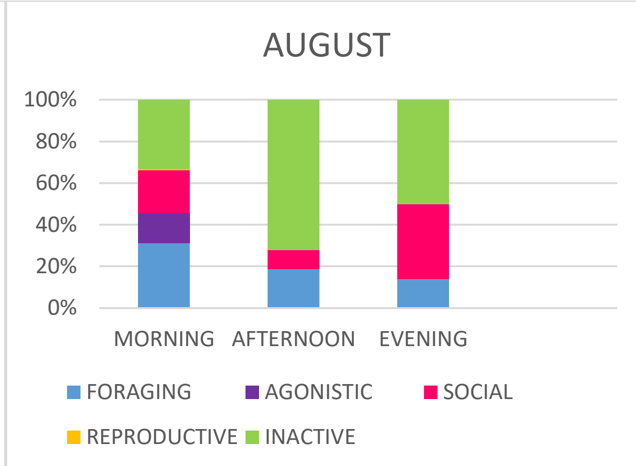
APPENDIX II: ETHOLOGICAL DATA OF *A.annulipes* FOR SITE I

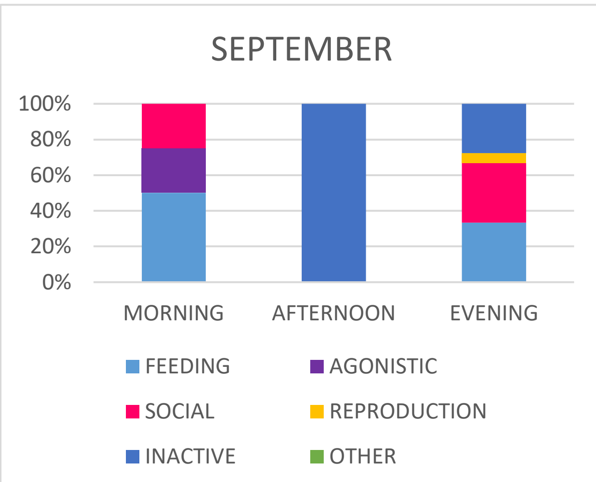
		FEEDING	AGONISTIC	SOCIAL	REPRODUCTVE	INACTIVE	OTHER
MORNING	JUL	25	11.2	8.3	5.5	50	0
	AUG	31.1	14.4	20.5	0.5	33.3	0
	SEP	33.4	16.6	16.6	0	0	0
	OCT	27.8	0	72.2	0	0	0
	NOV	5.5	0	27.8	0	66.6	0
	DEC	19.4	0	0	0	80.6	0
	JAN	30	0	0	0	70	0
	FEB	45	8.4	0	0	46.6	0
	MAR	53.4	13.3	0	0	13.3	0
SUM		270.6	63.9	145.4	6	360.4	0
AFTERNOON	JUL	25	0	8.3	0	66.7	0
	AUG	22.2	0	11.1	0	86.6	0
	SEP	0	0	0	0	100	0
	OCT	48.8	0	22.8	0	25	0
	NOV	16.6	0	3.4	0	80	0
	DEC	44.4	22.3	0	0	33.4	0
	JAN	5.5	0	0	0	94.5	0
	FEB	14.4	0	0	0	85.5	0
	MAR	40	0	0	0	60	0
SUM		216.9	22.3	45.6	0	631.7	0
EVENING	JUL	16.6	0	0	0	83.4	0
	AUG	13.8	0	36.1	0	50	0
	SEP	33.4	0	33.4	5.5	27.7	0
	OCT	8.4	0	63.4	0	27.8	0
	NOV	31.6	11.2	40.5	0	16.6	0
	DEC	38.8	0	55.5	5.6	0	0
	JAN	36	11	5.6	2.8	44.4	0
	FEB	30	0	0	0	70	0
	MAR	11.2	0	8.4	0	80.5	0
SUM		219.8	22.2	242.9	13.9	400.4	0

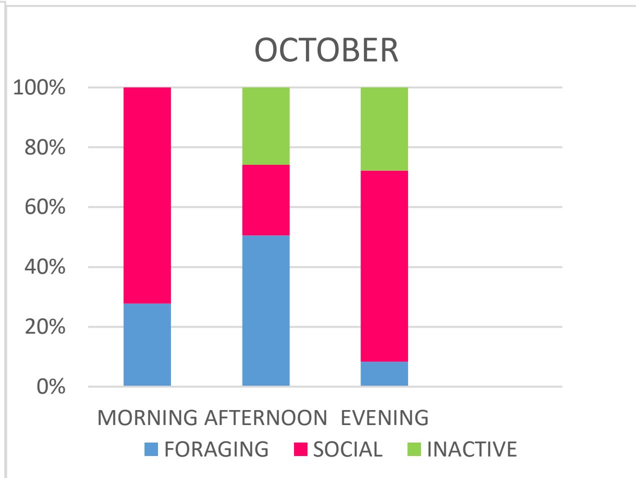
APPENDIX III: GRAPHS DEPICTING MONTH WISE ACTIVITY OF *A.annulipes* AT SITE I

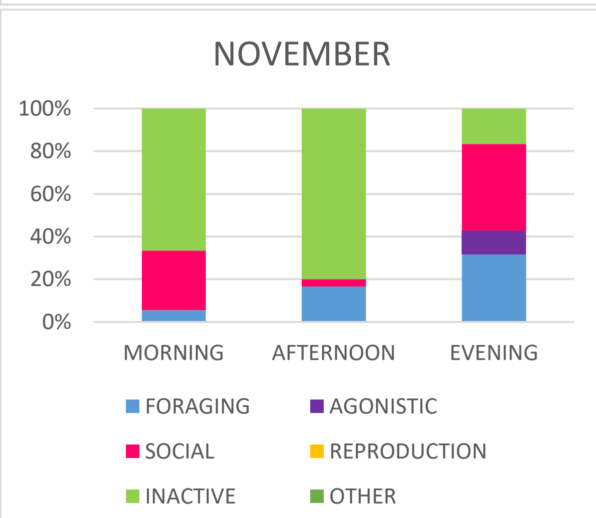
X AXIS: (horizontal) ACTIVITY TIME Y AXIS: (vertical) TIME SPENT IN ACTIVITY (PERCENTAGE)

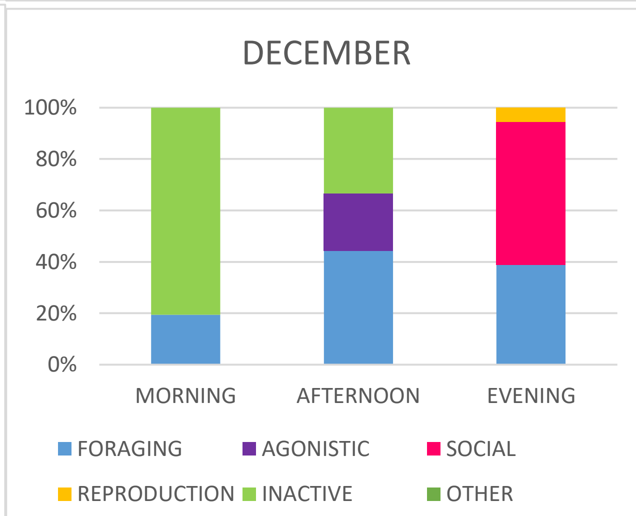


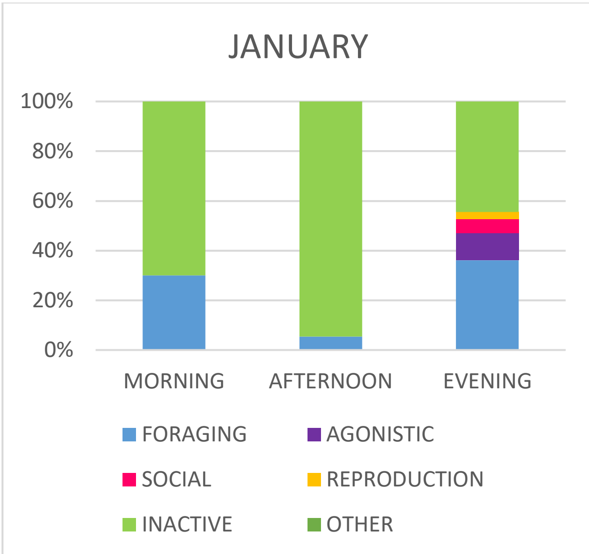








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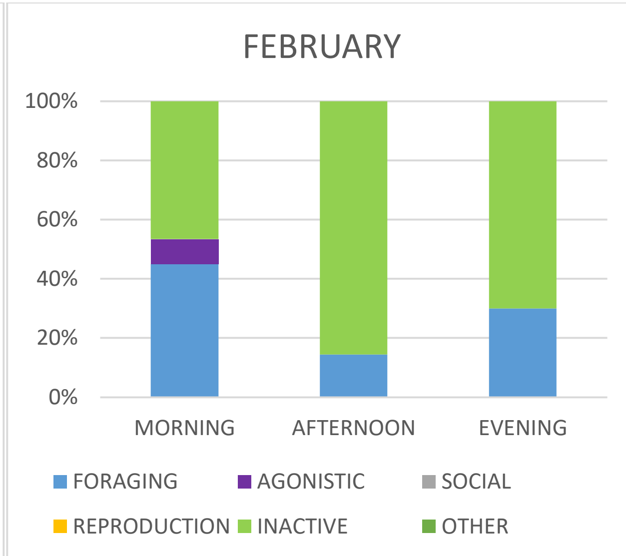
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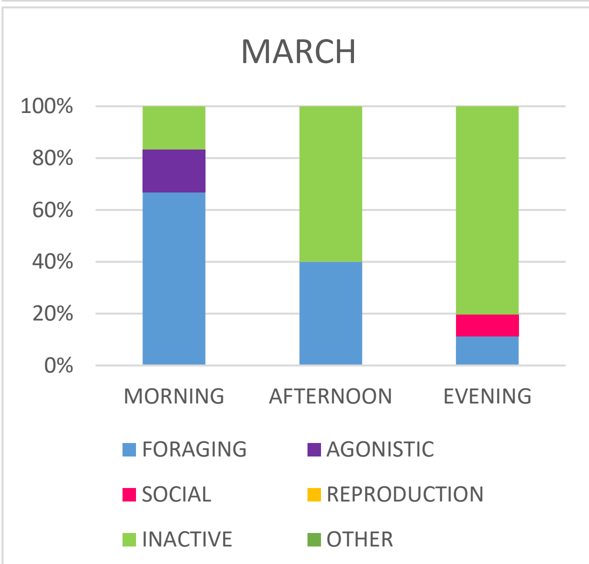
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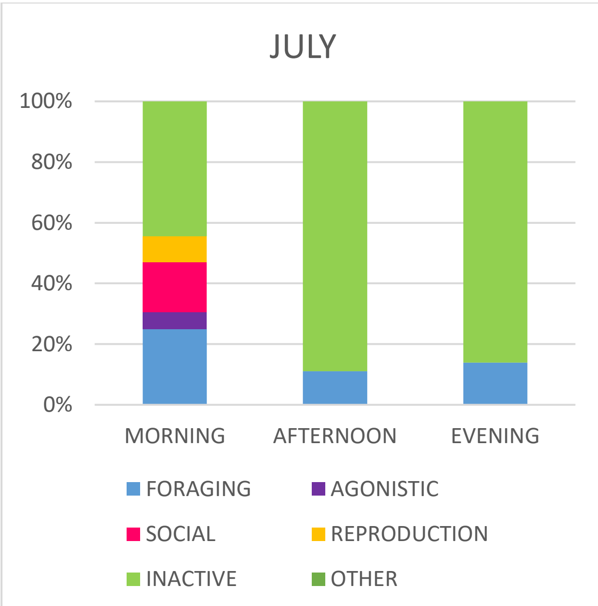
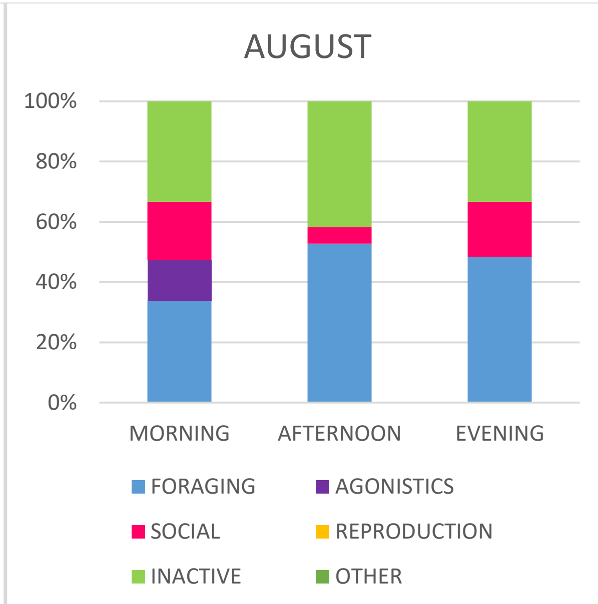
APPENDIX IV: ETHOLOGICAL DATA OF *A.annulipes* FOR SITE II

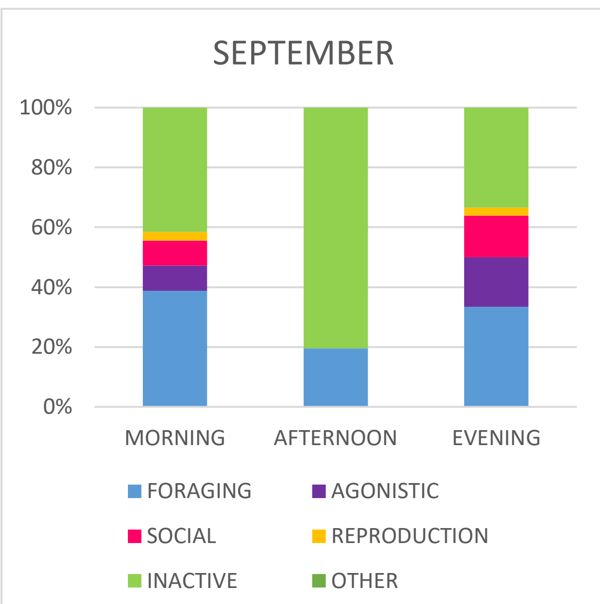
MORNING						
	FEEDING	AGONISTIC	SOCIAL	REPRODUCTIVE	INACTIVE	OTHER
JUL	25	5.5	16.6	8.4	44.4	0
AUG	33.8	13.4	19.4	0	33.3	0
SEP	38.8	8.4	8.4	2.8	41.6	0
OCT	44.5	11.1	27.8	0	16.6	0
NOV	36.2	5.5	19.4	0	38.8	0
DEC	63.9	13.8	11.1	0	11.2	0
JAN	50	2.8	33.4	5.5	8.4	0
FEB	33.4	16.6	16.6	0	33.4	0
MAR	41.6	16.6	25	0	16.6	0
SUM	367.2	93.7	177.7	16.7	244.3	0
AFTERNOON						
	FEEDING	AGONISTIC	SOCIAL	REPRODUCTIVE	INACTIVE	OTHER
JUL	11.1	0	0	0	88.9	0
AUG	52.8	0	5.5	0	41.7	0
SEP	19.5	0	0	0	80.5	0
OCT	50	11.2	0	0	38.8	0
NOV	41.6	5.5	8.4	0	44.4	0
DEC	50	11.2	27.8	2.7	8.3	0
JAN	30.5	0	0	0	69.5	0
FEB	52.7	0	0	0	47.3	0
MAR	22.2	16.6	33.4	0	27.8	0
SUM	330.4	44.5	75.1	2.7	447.2	0
EVENING						
	FEEDING	AGONISTIC	SOCIAL	REPRODUCTIVE	INACTIVE	OTHER
JUL	13.9	0	0	0	86.1	0
AUG	48.4	0	18.3	0	33.3	0
SEP	33.4	16.6	13.8	2.7	33.4	0
OCT	27.8	13.8	44.4	2.8	11.2	0
NOV	36.6	8.4	38.4	0	16.6	0
DEC	33.4	13.8	36.2	16.6	0	0
JAN	33.4	13.8	41.6	11.2	0	0
FEB	38.9	11.1	44.5	5.5	0	0
MAR	41.6	8.4	27.2	0.6	22.2	0
SUM	307.4	85.9	264.4	39.4	202.8	0

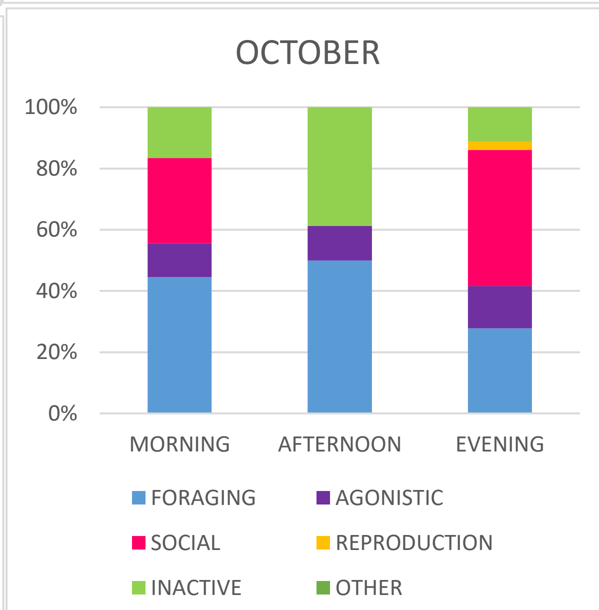
APPENDIX V: GRAPHS DEPICTING MONTH WISE ACTIVITY OF *A.annulipes* AT SITE II

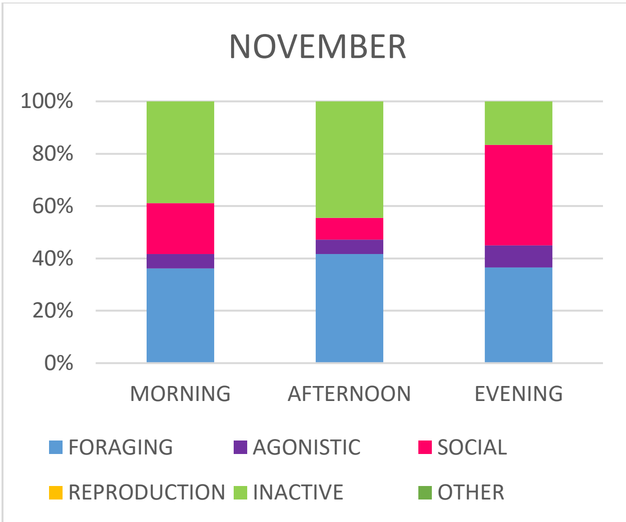
X AXIS: (horizontal) ACTIVITY TIME   Y AXIS: (vertical) TIME SPENT IN ACTIVITY (PERCENTAGE)







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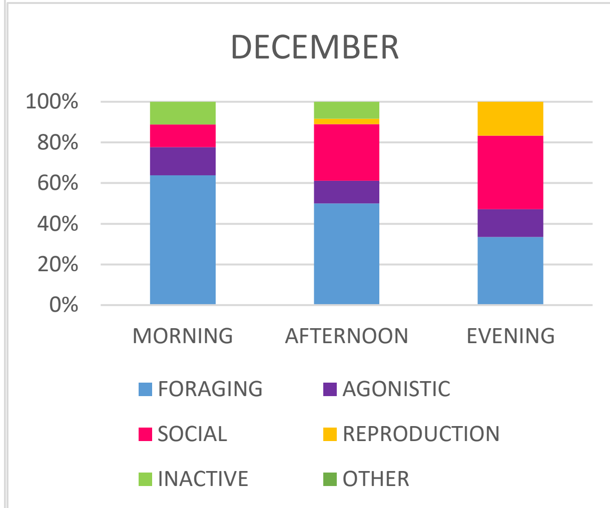
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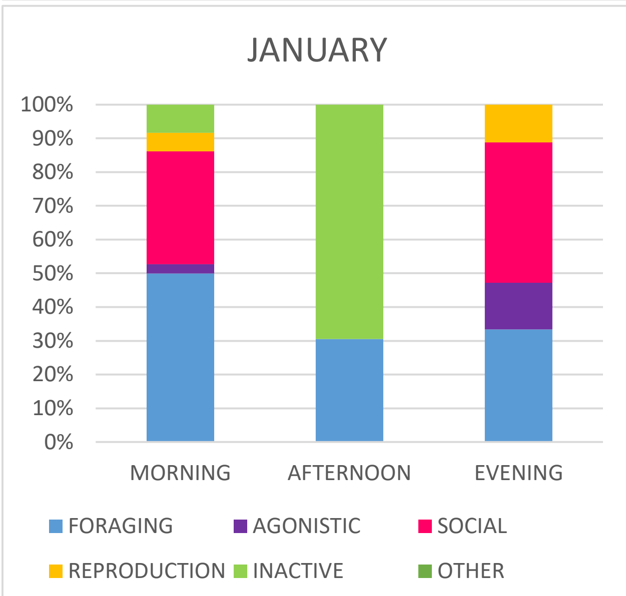
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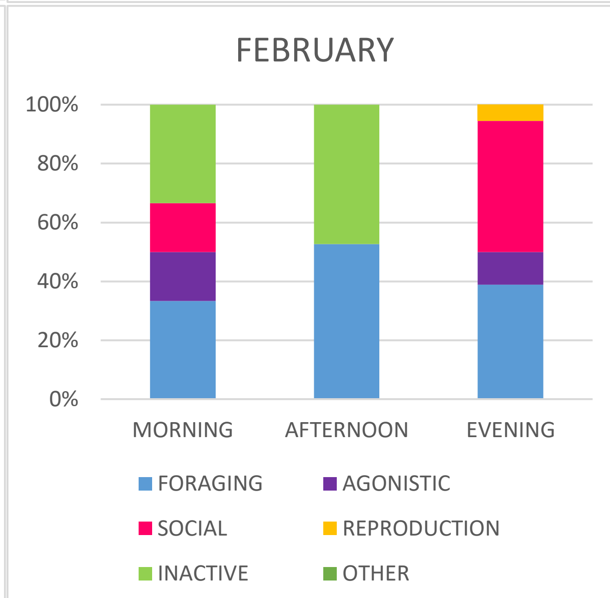
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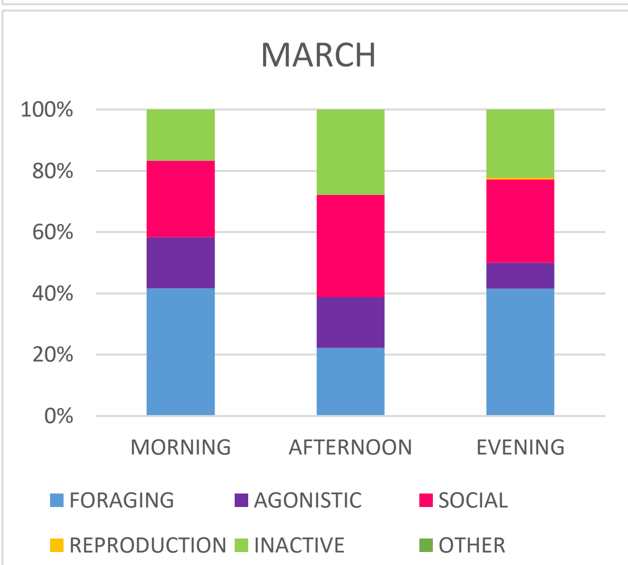
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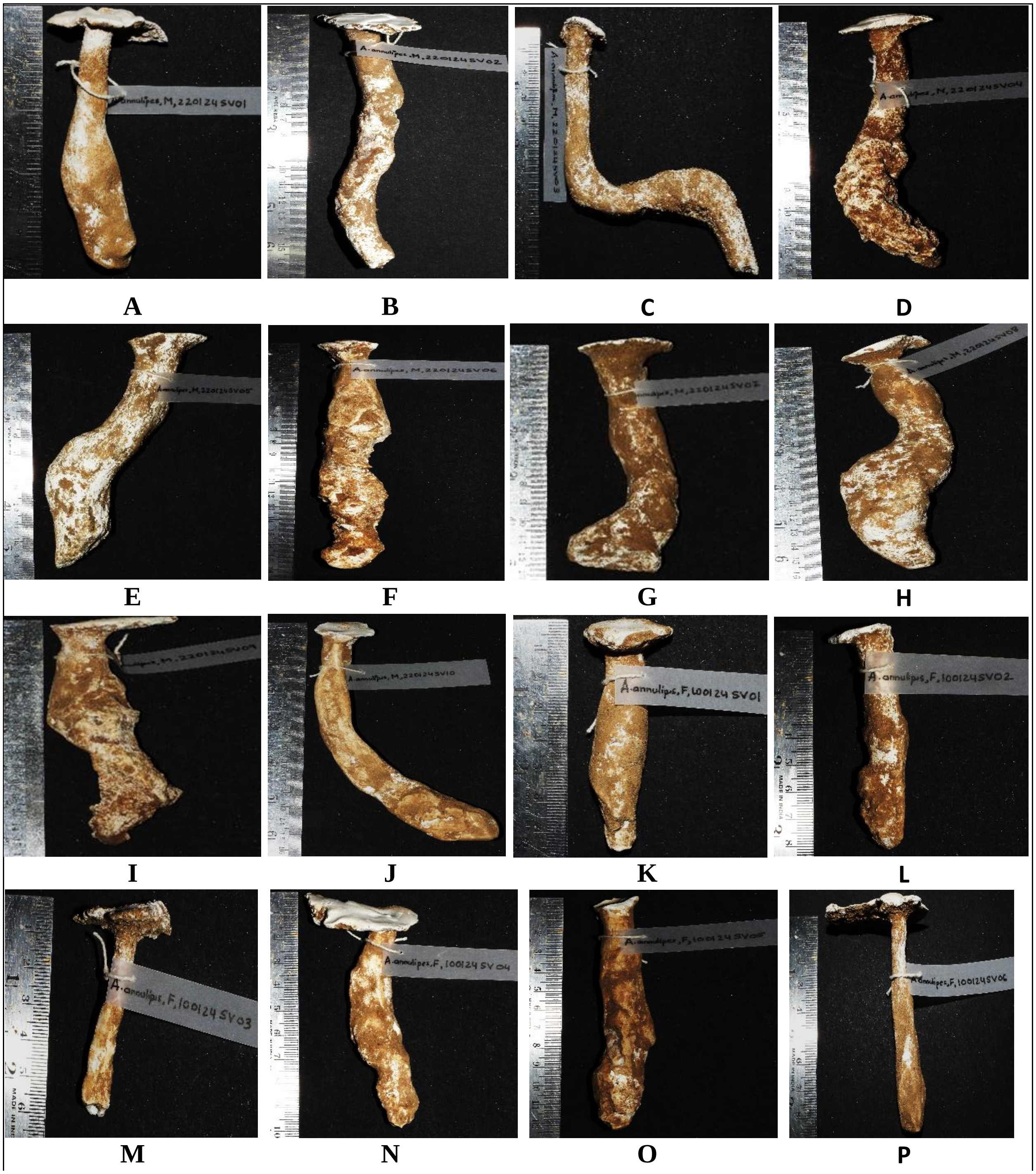
APPENDIX VI: BURROW CAST MALE (A -J) AND FEMALE (K-T) OF *A.annulipes*.




A.annulipes,F,100124SV07

Q


A.annulipes,F,100124SV08
MADE IN INDIA

R


A.annulipes,F,100124SV09

S


A.annulipes,F,100124SV10

T

APPENDIX VII: SEX SPECIFIC MORPHOMETRIC DATA FOR *A.annulipes* BURROW

BURROW	SEX	BD (Burrow diameter) mm	BDP (Burrow depth) mm	BL (Burrow length) mm	NC (No. of chambers)	PC (Position of chamber) *T(TOP), M(MIDDLE), B(BOTTOM)*
1	M	11.01	101	109	1	B
2	M	13.48	161	169	-	-
3	M	13.42	102	201	1	B
4	M	13.48	129	170	1	B
5	M	22.87	134	156	1	B
6	M	14.64	177	184	1	M
7	M	23.76	133	139	1	B
8	M	12.72	154	177	1	B
9	M	17.4	146	163	1	M
10	M	17.12	144	196	1	B
11	F	10.8	74.45	72	0	
12	F	3.91	69.91	89		
13	F	8.21	58.55	63		
14	F	11.56	88.73	99		
15	F	12.7	119.42	132		
16	F	7.94	88.36	91		
17	F	11.74	82.17	97		
18	F	12.34	77.64	96		
19	F	13.87	90.28	96		
20	F	7.96	67.01	71		
	Average					
	M+F	13.0465 ± 4.6	109.876 ± 34.9	128.5 ± 44.8		
	Male	15.99 ± 4.3	138.1 ± 24.1	166.4 ± 27.2		
	Female	10.103 ± 3.1	81.652 ± 16.8	90.6 ± 19.3		

APPENDIX VIII: INSTRUMENTS USED DURING THE STUDY


Muffle furnace *Refractometer* *Vernier caliper* *pH meter*

Sony HX 400V *Nikon coolpixP1000* *Wired Temperature sensor*

Tide chart app *NASA power data app*

APPENDIX IX: PICTURES DURING WORK

Pictures during field observations and burrow cast analysis.

Trying to take burrow casts at field during low tide.

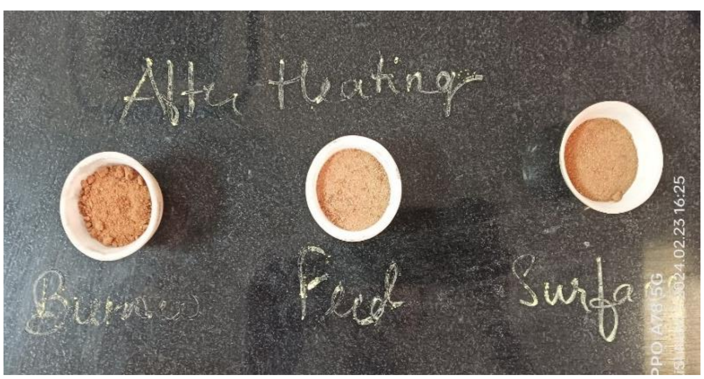
Burrow filled with POP and left for drying.

Trying to release the trapped crabs in field from POP casts.

After 4 days of burrow casts, the casts were analyzed in lab. 2 crabs were found alive trapped in the casts. They were carefully rescued, washed with distilled water to remove any excess POP on their body and later released back in the field.

Collection of soil samples from field followed by sun drying of samples and transporting the dried samples to lab.

Weighed samples in crucibles transferred in the muffle furnace to heat.



Samples after removing from the muffle furnace.

Field observations in late evenings.