Impact of litter fall on generation of organic matter at Vaidongor in Chapora Estuary, Goa.

A Dissertation for

Course code and Course Title: MSC 617 Discipline Specific Dissertation

Credits: 16

Submitted in partial fulfilment of Master's Degree

(M.Sc.) In Marine Sciences

by

MAYURESH SANJAY PEDNEKAR

Seat Number: 22P0400017

ABC ID: 534888574087

PRN: 202200077

Under the Supervision of

Dr. SHERYL OLIVEIRA FERNANDES

School of Earth, Ocean, and Atmospheric Sciences

Marine Sciences

GOA UNIVERSITY

APRIL 2024

Examined by:

Seal of the School

To My Parents

DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Impact of litter fall on generation of organic matter at Vaidongor in Chapora Estuary, Goa." is based on the results of investigations carried out by me in the discipline of Marine Sciences at the School of Earth, Ocean, and Atmospheric Sciences, Goa University under the Supervision of Dr. Sheryl Oliveira Fernandes and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given in the dissertation.

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

Mayuresh Sanjay Pednekar

Seat Number: 22P0400017

Date: 02/05/2024

Place: Goa University, Taleigao, Goa

COMPLETION CERTIFICATE

This is to certify that the dissertation report "**Impact of litter fall on generation of organic matter at Vaidongor in Chapora Estuary, Goa.**" is a bonafide work carried out by **Mayuresh Sanjay Pednekar** under my supervision in partial fulfilment of the requirements for the award of the degree of **Master of Sciences** in the Discipline of Marine Sciences at the School of Earth, Ocean, and Atmospheric Sciences, Goa University.

Dr. Sheryl Oliveira Fernandes

Assistant Professor

Dept. of Marine Sciences

Goa University

Goa- 403206

Date: 02/05/2024

SEOAS, GOA UNIVERSITY TALEIGAO PLATEAU GOA

School Stamp

Sr. Prof. Sanjeev C. Ghadi

Dean

Marine Sciences

School of Earth, Ocean and Atmospheric Sciences

Date:

Place: Goa University, Taleigao, Goa

CONTENTS

PREFACE

Studying litterfall, decomposition, and organic carbon in the Chapora Estuary's Vaidongor mangroves will help understand the health of the ecosystem, identifying key species and identifying human influence on ecosystem. Higher litterfall, efficient decomposition, and good organic carbon storage all indicate a well-functioning mangrove system. However, variations in decomposition rates due to anthropogenic activities raise concerns about efficient carbon cycling in these habitats. Nevertheless, this study provides valuable baseline data for future monitoring and conservation of the pristine Chapora mangrove habitats. Due to the fact that there are no studies available on the topic, it motivated me to undertake the study on litter fall in Vaidongor along Chapora Estuary.

ACKNOWLEDGEMENT

I am highly grateful to Dr. Sheryl Oliveira Fernandes, Assistant Professor, Department of Marine Sciences, School of Earth, Ocean, and Atmospheric Sciences, Goa University, Goa for her guidance and valuable suggestions for the successful completion of the dissertation. I would like to extend my sincere thanks to the Dean, Sr. Prof. S. C. Ghadi, the Former Dean, Dr. C. U. Rivonker and the Programme Director, Dr. M. R. Nasnodkar, Department of Marine Sciences, School of Earth, Ocean, and Atmospheric Sciences, Goa University, Goa for providing me with the opportunity and facility of working on this research topic.

I am thankful to my friends, Chetan Puntambekar and Cristopher Fernandes for accompanying me on the field sampling visits, Krutika Devashetti, K.M. Dharani, Varsha K., Sumedha Kamble and Chelsea Fernandes. for helping me during the various stages of the dissertation. I would like to thank the laboratory assistants for their help with the instruments and equipment during the laboratory work.

Last but not the least, I would like to take this opportunity to express my gratitude and love to my family for their constant moral support and encouragement.

Mayuresh Sanjay Pednekar

TABLES

FIGURES

ABBREVIATIONS USED

Entity	Abbreviation
Total Organic Carbon	TOC
High tide	HT
Mid tide	MT
Low tide	LT
Vaidongor	VD
Degree Celsius	° C
Year	yr
Hours	h
Hectare	ha
Month	mo
Day	d
Grams	g
Indian Remote Sensing Satellite	IRS
Geographic Information Systems	GIS

LIST OF EQUATIONS

1. TOC (%) = 10 (1-T/S) x F
2. Relative abundance (%) = $\frac{\text{No.of individuals of a species}}{\text{Total no.of individuals of all species}} \times 100$

ABSTRACT

This study investigated litterfall, litter decomposition, and downcore variation in total organic carbon (TOC) content within the Vaidongor mangrove ecosystem located along the Chapora Estuary, Goa, India. Samples were collected from high tide zones, revealing the highest production at VD-1- HT (186.19 g m^{-2} mo^{-1}) and the lowest at VD-2 -MT (57.17 g m^{-2} mo^{-1}). *Sonneratia alba* was the primary contributor to litterfall. Leaf litter decomposition was studied using litter bags for 30 days. The highest decomposition rate occurred at the high tide zone of VD-4, while the lowest occurred at the mid-tide zone of VD-3. Decomposition trends suggest a possible influence of benthic organisms such as polychaete worms and microbial activity moreso at VD-4. The TOC content varied across stations and depths. VD-4 (high tide) exhibited the highest TOC (> 6%), while VD-3 displayed the lowest. Generally, TOC concentration increased with depth, except for VD-4 (mid-tide), which showed a peak at mid-depth. The variations in TOC corresponded with litterfall and decomposition patterns. This study suggests that litterfall is the major source of organic carbon in the Vaidongor mangrove ecosystem, subsequently fuelling decomposition and influencing TOC content. Further research is recommended to explore the influence of infauna on decomposition rates and the long-term impacts of anthropogenic waste on the ecosystem.

Key words: Chapora Estuary, Mangroves, Relative abundance, Litter fall, Litter Decomposition, Total Organic Carbon.

CHAPTER 1

INTRODUCTION

1.1 Background

Mangroves are taxonomically diverse group of salt-tolerant, mainly arboreal, flowering plants that grow primarily in tropical and subtropical regions (Ellison and Stoddart, 1991). Dominant within tropical and subtropical intertidal zones, mangrove ecosystems thrive along coastlines, fulfilling a multitude of ecological and socioeconomic roles. These roles include nutrient filtration at the land-sea interface (Robertson and Phillips, 1995), coastline stabilization (Vermatt and Thampany, 2006), provision of commercially valuable fisheries resources (Constanza et al., 1997), and the function of nursery grounds for coastal fish and crustacean populations. Mangrove distribution is primarily determined by a suite of abiotic factors, including topography, tidal inundation, substrate characteristics, and salinity. Salinity exerts a strong influence on zonation patterns within mangrove forests, with the highest species diversity typically observed in the mesohaline and polyhaline zones having salinity 30-60. These zones represent a balance between freshwater and saltwater influence, providing suitable conditions for a wider range of mangrove plant tolerance. In contrast, upstream areas with lower salinity (0.05-5) support a more limited flora, with species such as *Kandelia candel, Sonneratia caseolaris*, and *Heretiera spp*. exhibiting adaptations for survival in these less saline environments (Jagtap et al., 1993).

Mangrove ecosystems sustain adjacent aquatic and intertidal mudflat food webs through the process of litterfall (Mitra and Mitra, 2017). Litterfall refers to the shedding of plant materials, including leaves, reproductive structures, and branches. Senescence, withering, death, along with environmental stressors such as wind and precipitation, are key drivers of litterfall production in mangrove ecosystems (Mitra and Mitra, 2017). In mangrove ecosystems, litterfall stands as a fundamental ecological process, driving numerous ecosystem services. These critical services include nutrient cycling and carbon storage (da Silva Rocha et al., 2022). As the foundation of detritus food webs, litterfall provides a vital source of organic matter for decomposition and sustains diverse detritivore communities across mangrove forests, intertidal mudflats, and adjacent coastal waters (Hemati et al., 2017; Monitoring and Sampling Manual, 2018; Dewiyanti et al., 2019). Furthermore, it serves as the primary source of organic carbon for various marine invertebrates and detritivores, facilitating energy transfer within the ecosystem (Bouillon et al., 2008; Mulya and Arlen, 2018).

Mangrove litter also plays a crucial role in both carbon storage and exchange with other connected coastal ecosystems (Rani et al., 2016; Dewiyanti et al., 2019; Azad et al., 2021). Studies have shown the substantial contribution of mangrove litter, including fallen reproductive structures and leaves, to organic carbon fluxes in estuaries, highlighting their importance as carbon sources (Mohit and Appadoo, 2009). Therefore, litterfall emerges as the primary driver influencing mangrove ecosystems' ability to store and cycle carbon and nutrients within the coastal zone (Kamruzzaman et al., 2019; da Silva Rocha et al., 2022).

Multiple factors govern mangrove litter production, encompassing natural processes, environmental conditions, and biological characteristics. Natural factors include senescence, growth cycles, and mortality driven by age. Environmental factors such as rainfall, wind, and temperature also play a role (Monitoring and Sampling

Manual, 2018; An et al., 2020; Cejudo et al., 2022). Studies have shown a correlation between mangrove density and litter production (Ntyam et al., 2014; Mulya and Arlen, 2018; da Silva Rocha et al., 2022).

Mangrove litter production exhibits significant spatial and seasonal variations globally. Typically, peak litterfall occurs in summer months, with the lowest production observed in winter (Cunha et al., 2006; Sharma et al., 2010; Rani et al., 2016). Estimates of litter production vary considerably across the globe, ranging from a minimum of 0.8 t ha^{-1} yr^{-1} to a maximum of 28.1 t ha^{-1} yr^{-1}. Species composition, tree height, and anthropogenic activities are key factors contributing to this variation (Shunula and Whittick, 1999; Rafael and Calumpong, 2018). Geographical location, forest type, nutrient availability, and freshwater drainage patterns further influence litter production (Liu et al., 2014; Zhang et al., 2014).

Seasonal litterfall patterns exhibit variations within different mangrove forest types (Zhang et al., 2014; An et al., 2020). Subtropical mangrove forests experience peak litterfall during autumn, with the minimum occurring in winter (Mfilinge et al., 2005). In contrast, tropical mangrove forests may exhibit continuous litterfall throughout the year with two peak periods (bimodal) (Wang'ondu et al., 2014). In mangrove areas of Cameroon and Ghana it has been reported that litterfall was maximum during the dry season and a minimum during the wet season (Ntyam et al., 2014). Similar results were observed in India Wafar et al. (1997) in Goa. Thus, it is evident that environmental factors like seasonal changes in precipitation affects litter production patterns in mangroves.

Leaf breakdown is defined as weight loss due to physical fragmentation (caused by abiotic factors), animal feeding, microbial activity and leaching (Stewart and Davies, 1989). Leaf litter decomposition serves as a key source of organic matter and nutrients for both the mangrove sediments and surrounding coastal environments (Mamidala et al., 2022). The decomposition process releases essential nutrients back into the sediments and water column, fuelling further ecosystem functions (Manzoni et al., 2008). Microorganisms play a key role in this process by producing extracellular enzymes that break down complex organic matter into simpler, readily usable forms like glucose, amino acids, and phosphate (Keuskamp et al., 2015). Additionally, non-biotic forces such as fragmentation can also significantly contribute to leaf litter breakdown (Ashton et al., 1999). Leaf litter entering streams undergoes a rapid initial leaching phase upon immersion (Fell et al., 1975; Robertson, 1988). This leaching process results in a variable percentage loss of leaf mass, depending on the specific leaf species and its location within the stream environment (Robertson et al., 1992). After the initial leaching phase, the remaining organic material, known as particulate organic matter (POM), decomposes at a slower rate. This slower decomposition relies heavily on the activity of bacterial and fungal communities that quickly establish themselves on leaf surfaces (Schleyer, 1986; Steinke et al., 1990; Robertson et al., 1992). Tidal range also plays a significant role in litter fate. In areas with a large tidal range, a substantial portion of the litter may be exported from the mangrove system by tidal flushing. Conversely, in areas with a smaller tidal range, a greater proportion of the litter remains on the substrate (*in situ*) where it decomposes. However, tidal flushing may not completely remove all deposited litter (Boto and Bunt, 1981).

Decomposition of mangrove litter exhibits a pivotal role in nutrient cycling within the ecosystem, supplying essential organic matter that fuels estuarine food webs. These also function as significant exporters of organic matter, fuelling detrital-based food webs in coastal environments. This export of organic material has long been recognized as crucial for sustaining diverse coastal fisheries. Several factors influence the rate of decomposition, including oxygen availability, the properties of the underlying substrate, and the activity of decomposing animals and microorganisms (Lugo and Snedaker, 1974; Odum and Heald, 1975).

1.2 Scope of study

The interplay between litterfall, its decomposition, and biodiversity within mangrove ecosystems is crucial for maintaining their overall function of the ecosystem. It is also used for determining the productivity of the habitat. Species richness of the leaf litter itself may significantly influence the complex relationships between biodiversity and ecosystem properties. Consequently, a comprehensive understanding of how biodiversity within mangrove ecosystems shapes their functioning and stability is essential (Wardle et al., 1997; Ashton et al., 1999). The rate of decomposition will also give insights on the nutrient dynamics and remineralization of the region. This study will also provide a literature base for future studies as currently there is a lack of information on the contribution of mangrove litter to organic carbon pool in the mangroves of Goa. It will also help in strategic management and effective conservation of these habitats.

1.3 Aim of the study

This study evaluates the mangrove litter production and litter decomposition rate which contributes to the formation of organic matter at Vaidongor mangrove habitat in Chapora Estuary.

1.4 Objectives of the study

- To determine the abundance of mangroves and litterfall at Vaidongor mangrove habitat.
- To determine the rate of decomposition of mangrove litter within a 30-day period.
- To determine the downcore variation of total organic carbon and its link to litterfall and its decomposition.

CHAPTER 2

LITERATURE REVIEW

2.1 Extent of Mangroves

Goa lies on the west coast of India, bordering the Arabian Sea. Its coastline stretches approximately 105 km, situated between latitudes 15° 48' N and 14° 53' N and longitudes 74° 20' E and 73° 40' E. This region boasts seven estuaries fringed with mangrove forests, forming a complex network of creeks and backwaters. Lush mangrove growth and associated swamp ecosystems are a prominent feature along these estuarine reaches. Records indicate the presence of approximately 16 mangrove species and a few associated plant species along the Goa coast. The Mandovi-Zuari estuarine complex exhibits the greatest species richness. The composition of the mangrove communities varies across different locations. The size of propagules (seedlings) of various species plays a crucial role in their establishment within different zones, ranging from high tide to low tide levels. These forests exhibit distinct vertical and horizontal strata, forming a dense canopy cover. Visual cues like variations in canopy color from pale green to dark green along the estuary can aid in identifying dominant species. Some of the most prevalent species include *Rhizophora mucronata, Sonneratia alba,* and *Avicennia officinalis.* Additionally, other widely distributed species include *Rhizophora apiculata, Sonneratia caseolaris, Kandelia candel, Bruguiera gymnorhiza,* and *Aegiceras corniculatum* (Dhargalkar et al., 2014).

Nagi et al. (2014) tracked changes in mangrove cover along the banks of Goa's major rivers and minor creeks using Remote sensing and Geographic Information Systems (GIS). Satellite images from the Indian Remote Sensing satellites (IRS) taken in January/February of 1997, 2001, and 2006 with a resolution of 23.5 meters were used. Additionally, topographic maps of Goa from 1962 - 1979 were used to identify ground features and ensure accurate positioning of the satellite images. A computer program analyzed the satellite image colours and patterns to classify land cover types (like forest and water). GIS techniques applied to create maps showed mangrove locations across the three selected years. The area of mangroves in each location was calculated and expressed in hectares (ha). The study revealed mixed results. For example, the Chapora estuary showed a small decrease in mangrove area (0.74%) between 1997 and 2006. In contrast, the Terekhol estuary saw a significant increase (10.60%) in mangrove cover, with a total gain of 2.89 ha. Unfortunately, the Mandrem and Baga creeks experienced a substantial loss (32.36%) of mangroves during the same period. However, there were positive trends in other areas, with the Mandovi and Zuari estuaries, along with the Cumbarjua canal, exhibiting increases of 36.50%, 5.95%, and 52.68% respectively from 1997 to 2006.

2.2 Mangrove bio-diversity

Silva and Bhat (2011) determined the diversity of mangroves and their associates in 7 major and 3 minor estuaries of Goa, using well established diagnostic identification keys in Ecology and Biodiversity of Indian Mangroves. Quantative studies were performed using quadrat method whereas hydrological parameters and sediment analysis was done using standard methods. In Chapora Estuary they found a relative mangrove diversity of about 84.37% consisting of species *Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorrhiza, Bruguiera cylindrica, Kandelia candel, Aegiceras corniculatum, Avicennia alba, Avicennia marina, Avicennia officinalis, Sonneratia alba, Sonneratia caseolaris, Acanthus illicifolius* and *Excoecaria agallocha*.

Jagtap et al. (1993) stated that mangrove distribution is primarily determined by salinity. Areas with mixed salinity (polyhaline) and moderate salinity (mesohaline) have the highest species richness. In areas farther inland and with low salinity (0.05-5%), only a few plant species thrive, such as *Kandelia candel, Sonneratia caseolaris,* and *Heretiera* species.

Similarly, Untawale and Jagtap (1992) also observed a strong link between salinity and mangrove distribution. The majority of mangrove species flourish in areas with mixed (polyhaline) and moderate (mesohaline) salinity, ranging from 18 to 30. However, several species exhibit remarkable adaptability to a wider salinity range. This includes *Avicennia marina, Rhizophora spp., Bruguiera spp., Sonneratia apetala, Excoecaria agallocha, Aegiceras spp., Ceriops spp.* and *Luminitzera racemosa*. These versatile plants can even tolerate the harsh conditions of highly saline supralittoral zones. Here, stunted *Avicennia* share the habitat with salt-tolerant plants like *Salicornia* and *Suaeda*. In contrast, species like *Xylocarpus, Heritiera, Kandelia,* and *Nypa* thrive in areas with a stronger influence of freshwater and weaker tidal action. Moving further inland from the mangroves, distinct plant communities emerge in the marsh lands, often referred to as "back mangroves". These areas are home to species like *Aeluropus lagopoides*, *Cressa cretica*, *Heliotropium currasavicum*, *Fimbristylis cymosa*, and *Clerodendrum inerme*.

2.3 Litter fall in mangroves.

Wafar et al. (1997) studied the rate of litter fall, litter decomposition and nutrient content in the Mandovi - Zuari estuarine complex. The study revealed a seasonal pattern of leaf litter fall in these mangroves. The calculated annual litter yields were 11·7, 11·8, 17 and 10·2 tonnes ha^{-1} $year^{-1}$, respectively for *R. apiculata, R. mucronata, S. alba* and *A. officinalis*. Two *Rhizophora* species (*R. apiculata* and *R. mucronata*) shed roughly the same amount of leaves each year (1017 tons per hectare). During the dry pre-monsoon period, high salinity and hot conditions may trigger canopy thinning through increased leaf shedding. This could be further accelerated by stronger winds before the monsoon rains, leading to the observed pre-monsoon peak in litterfall. The low litterfall during the monsoon itself might be due to reduced leaf drop and a focus on new growth fuelled by the influx of freshwater and nutrients.

Castillo et al. (2006) investigated the litter production and decomposition in *Rhizophora mangle* trees, a dominant mangrove species, within a lagoon on Mexico's Gulf Coast. The majority (70%) of the annual litterfall consisted of leaves, highlighting their crucial role in the ecosystem's organic matter input. Flowers, twigs, and propagules contributed the remaining 30%. Litterfall exhibited a distinct seasonal pattern with two peaks - one during the dry season and another during the rainy season. However, the peak for leaf litter specifically occurred in the dry season, even though total litterfall (including flowers, twigs, and propagules) was highest during the rains. This suggests potential variations in shedding strategies for different litter components. The study revealed a high annual litterfall rate (1116 g m^{-2} y^{-1}) for *R.*

mangle trees compared to similar studies in other regions. This abundance of litter production might be linked to the possibility of taller trees in this specific lagoon.

A study by Ntyam et al. (2014) also confirms this pattern, demonstrating year-round litterfall with a maximum during the dry season and a minimum during the wet season. Thus, environmental factors like seasonal changes in precipitation affects litter production patterns in mangroves.

Saenger and Snedaker (1993) stated that litter fall recorded from a number of mangroves varies widely but, as a general rule, appears to be related to tree height and latitude. According to the study by Woodroffe (1985) large mangrove trees (> 10 m) have more litter fall beneath them than short mangrove trees (< 4 m).

2.4 Litter decomposition

Wafar et al. (1997) found surprisingly rapid decomposition in mangrove ecosystems. For three species (*Rhizophora apiculata, Rhizophora mucronata,* and *Sonneratia alba*), most litter weight, decomposed within just 15 weeks. This highlighted the efficient litter breakdown processes in these environments. Interestingly, *Avicennia officinalis* leaves decomposed much faster than the others, disappearing entirely in just 8 weeks. This suggested unique properties in these leaves that are preferred by decomposers to accelerate decomposition.

In Castillo et al. (2006) decomposition rates weren't uniform throughout the year. The study found that leaves decomposed fastest during the rainy season and slowest during strong northerly winds. During the initial 60 days of decomposition, the primary mechanisms involved leaching (dissolving of materials) and microbial activity. Notably, these processes didn't exhibit significant seasonal variations. After 60 days, the way leaves decomposed became more dependent on the season. Water movement or presence of aquatic invertebrates, like specific types of snails e.g. *Neritina reclivata* played a more prominent role in degrading leaves during some seasons compared to others. This suggested a potential shift towards mechanical breakdown and animal consumption as the decomposition process progressed.

Dhaou et al. (2022) investigated how leaves from a mangrove tree (*Avicennia germinans*) decompose in different parts of 3 rivers (Mahury, Kourou, Sinnamary) in French Guiana using litter bag method. Leaves at the shore (fringe stands) decomposed faster than those further inland (riverine stands) during first 30 days. Moving leaves from one location to another (transplant) didn't significantly impact their overall decomposition rate after 45 days. The type of microbes on the leaves themselves wasn't the main factor affecting how quickly they broke down in the first 30 days. Instead, the location of placement (fringe vs. riverine) seemed to be more important. They suggest that stronger tidal forces near the shore might be why leaves decomposed faster there. This stronger water movement could potentially wash away and expose the leaves to more decomposing organisms. The study highlighted the importance of location and physical factors like water movement in influencing how quickly mangrove leaves decompose in the early stages.

Ashton et al. (1999) found that litter decomposition rates in mangroves may be influenced by the specific species composition. Leaves of *Sonneratia sp*. with their high initial nitrogen concentrations, may decompose more rapidly. Conversely, *Rhizophora* leaves, containing higher levels of decomposition inhibitors like tannins, may decompose slower. They further stated that the lack of a clear overall mixing effect might be due to the counteracting influences of these species. The enhancing effect of *Sonneratia* litter decomposition might be offset by the retarding effect of *Rhizophora* litter in the specific combinations used.

Wardle et al. (1997) found that on mixing litter from different species, in combinations of more than two species, litter breakdown rates differed. They found that mixing different types of litter can significantly impact how quickly they decompose and how much nitrogen they lose. This effect is particularly pronounced when leaves from trees are mixed with leaves from broadleaf herbs. These results suggest that the composition of litterfall can play a significant role in the functioning of mangrove ecosystems.

Studies have shown that decomposition rates are generally higher in subtidal zones due to more frequent tidal inundation (Twilley et al., 1986). However, Feller et al. (2002) observed a contrasting pattern, with lower decomposition rates in permanently flooded subtidal zones compared to the upper intertidal zone. This suggested the interplay of multiple factors influencing decomposition rates within mangrove forests.

Within the mangrove forests in some tropical Australian regions, it has been shown that a large proportion of the leaf-litter is not exported but recycled by resident crabs (Robertson and Daniel, 1989; Robertson et al., 1992) with a little chance of this organic matter being transported towards adjacent habitats through these organisms. Ravichandran et al. (2006) have shown that the leaf-eating mangrove crab *Neosarmartum smithi* stores leaves in their burrows.

Kida and Fujitake (2020) stated that low decomposition rate in mangrove soil is due to suboxic conditions. Studies by Middleton and McKee (2001) found that mass loss of leaves essentially came to a standstill after an initial phase. But Twilley et al. (1986) found higher decomposition rates after 117 days.

Hernandez and Park (2024) reviewed various old as well as new studies on mangrove litter fall. They found that most research on mangrove litter fall and decomposition (57%) focused on biological factors, like microbes, decomposers, and leaf health. This highlights the importance of mangroves in how much litter they produce and how quickly it breaks down. The second most common area of study (41%) explored physical and chemical factors, like temperature, rain, and wind. These factors influence how much litter falls and how quickly it decomposes. Surprisingly, there wasn't much research (2%) on human activities like pollution and deforestation. These activities too can affect how much litter mangroves produce and how quickly it breaks down. Therefore, more study is needed in this area.

CHAPTER 3

METHODOLOGY

3.1 Study Area

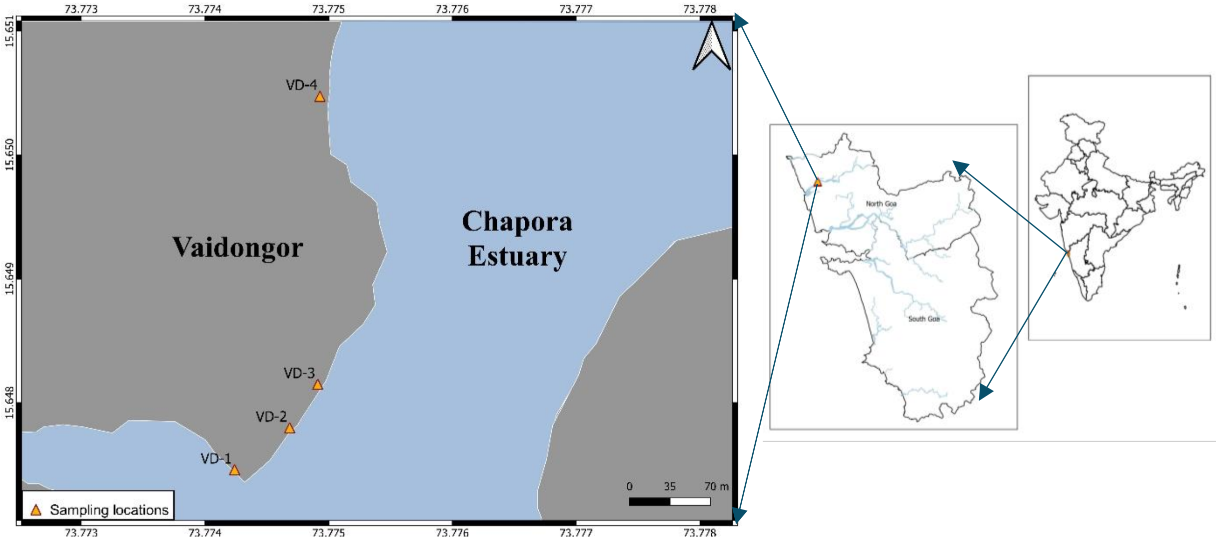

Fig. 3.1. Study area

The study was conducted at the Vaidongor mangrove habitat along the Chapora Estuary, Goa. Four stations were selected as shown in **Fig**. 3.1. (VD-1: 15°38'50"N 73°46'27"E, VD-2: 15°38'52"N 73°46'28"E, VD-3: 15°38'53"N 73°46'30"E, and VD-4: 15°39'01"N 73°46'29"E). All stations were spaced approximately 50-55 m apart, except for VD-4 which was 250 m apart due to a rocky patch between it and VD-3.

The study area is bordered by riverine mangroves dominated by species of *Sonneratia*, *Kandelia*, and *Rhizophora*. The tidal range varies from 0.2 m to 2.0 m, and the salinity of the estuarine water was 17. The region experiences low garbage input through local communities. The area is a prominent fishing spot, and the sediments are abundant with crustaceans and oysters such as *Saccostrea cucullata* (Bhatkhande and Nasnodkar, 2022). A few shrimp farms and agricultural fields are present upstream of the estuary. The main source of organic matter in the ecosystem as mainly from the decomposition of mangrove litter.

Fig.3.2. Images of all four study locations at Vaidongor: (a) VD-1; (b) VD-2; (c) VD-3; (d) VD-4.

3.2 Sediment sampling

In January 2024, duplicate sediment samples were collected from the intertidal zones (high tide, mid tide, and low tide) at each station. PVC cores with a diameter of 7.5 cm and length of 10 cm were used for sample collection. Sediment temperature was recorded using a thermometer. The core samples were then transferred to zip-lock bags and stored in an icebox. Upon reaching the lab, the pH of the cores was noted at 2 cm intervals till 10 cm and then carefully sub sampled. Samples were dried in a hot air oven at 60 °C for 48 h and then stored in zip-lock bags for further analysis.

Temperature, salinity and pH of the ambient water was also determined. Temperature was measured using a mercury thermometer. For pH and salinity determination, the water sample was collected in 250 mL HDPE bottle and stored in ice box. Upon reaching the lab, salinity and pH was measured by using a hand-held refractometer (ATAGO, MASTER-S/Millα) and pH meter (Eutech, Singapore; pH 700).

3.3 Litter fall

To estimate litterfall, 1 m² litter traps were constructed using locally available wood. One-meter-long branches were tied with rope to form a square frame. A PVC shade net with a 2 mm pore size was then secured to the frame using rope. The traps were suspended below the canopy above the high tide level, at breast height, by tying them to the branches of mangrove trees as shown in **Fig**.3.3.

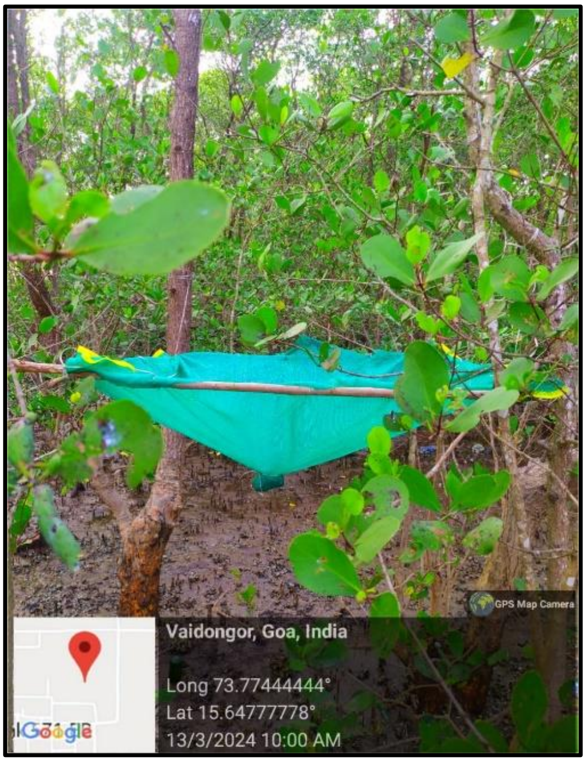

Fig. 3.3. Litter trap installed at VD-3 at the mid tide zone.

Due to the lack of canopy at low tide zones and insufficient tree height at VD-1, traps were not placed in these areas. Additionally, dense vegetation at the mid-tide zone of VD-1 hindered trap placement. Traps were installed on 13th March 2024 and collected on 11th April 2024.

3.4 Litter decomposition

Litter decomposition was estimated using the litter bag technique reported by Tam et al. (1990). Briefly, leaf litter (consisting of green leaves and senescent yellow leaves) collected from the intertidal zones was dried in a hot air oven at 60 °C for 48 h. As shown in **Fig**. 3.4, leaf samples of 10 g dry weight were then placed in nylon bags of 2 mm mesh size (Lima and Colpo, 2013) and buried in the sediments at the study area for 30 days. The litter bags were buried in the same intertidal zone and station from where the leaves were picked up. After retrieval, the bags were carefully washed with tap water to remove sediments. The contents of the bag were transferred to a clean petri plate and dried in an oven at 60°C for 48 h. Finally, the dry weight of the samples was measured.

Fig. 3.4. Litter bags made for litter decomposition study.

3.5 Mangrove species abundance and composition

At each station, 50 m×50 m plots were demarcated for vegetation composition analysis. However, due to area constraints at VD-4, a 50 m × 30 m plot was used. Ecological sensitivity and accessibility were some factors considered during plot demarcation. All individual trees of identified species within the plots were counted. Newly formed plants less than 50 cm long were excluded due to their lack of significant features for identification. Relative abundance was then calculated from the data using the formula:

$$\text{Relative abundance (\%)} = \frac{\text{No.of individuals of a species}}{\text{Total no.of individuals of all species}} \times 100$$

3.6 Total Organic Carbon (TOC) analysis

Total organic carbon was estimated using the modified Walkley-Black (1974) method by Gaudette et al. (1974). This method involves exothermic heating using potassium dichromate ($K_2Cr_2O_7$) and oxidation with concentrated sulphuric acid (H_2SO_4).

0.5 g sample of powdered sediment was weighed and placed in a 500 mL conical flask. To this, 10 mL of 1 N standard potassium dichromate solution and 20 mL of the sulphuric acid and silver sulphate mixture were added. The conical flask was gently swirled and allowed to stand for 30 minutes. Thereafter, 200 mL of distilled water was added, followed by 10 mL of 85% orthophosphoric acid and 0.2 g of sodium fluoride. The conical flask was gently swirled again to thoroughly mix the reagents with the sediment sample. A few drops of diphenylamine indicator were then added to the flask. The solution was titrated with 0.5 N ferrous ammonium sulphate until an endpoint (one-drop endpoint) showing brilliant green was attained. The addition of silver sulphate prevented the oxidation of chlorine ions. A standardization blank was performed using the same procedure without the sediment sample. The percentage of TOC was calculated using the following formula:

$$TOC (\%) = 10 (1-T/S) \times F$$

where,

S = Standardization blank titration, ml of ferrous solution.

T = Sample titration, mL of ferrous solution.

F = (1.0 N) x 12/4000 x 100/sample weight 0.6, when sample weight is exactly 0.5 g.

where, 12/4000 m. eq. wt. carbon.

CHAPTER 4

ANALYSIS AND CONCLUSION

4.1 Results and discussions

4. 1.1 Physical parameters

Table 4.1. Downcore variation in sediment temperature and pH at all the stations.

	Stations	VD-1					VD-2					VD-3					VD-4				
Low tide	Depth (cms)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
	Temperature (° C)	29	29	29	29	29	30	30	29	29	29	31	30	31	31	30	28	28	29	29	29
	pH	7.2	7.5	7.4	7.4	7.5	6.9	7.1	7.2	7.2	7.3	7.6	7.4	7.4	7.2	7.24	7.6	7.8	7.6	7.8	7.5
Mid tide	Temperature (° C)	31	31	31	30	30	28	28	28	28	28	29	29	29	29	28	29	28	28	28	28
	pH	6.2	6.1	6	6	6	6.3	6.3	6.5	6.3	6.5	6.4	6.4	6.4	6.4	6.49	6.6	6.5	6.5	6.5	6.5
High tide	Temperature (° C)	29	28	28	28	28	29	29	29	29	28	29	29	29	28	28	28	28	28	28	28
	pH	6.6	6.5	6.5	6.3	6.3	6.5	6.4	6.3	6.3	6.3	6.5	6.7	6.8	6.9	6.84	6.5	6.7	6.8	6.8	6.9

Temperature, salinity and pH of the ambient estuarine water measured was 29.0 °C, 17 and 7.65 respectively. The temperature and pH of the sediments at all 4 stations and their intertidal zones are shown in **Table** 4.1. There was not much variation in the downcore values of pH and temperature. Slight variations in physical parameters might be due to the differences in canopy cover, water level, etc.

4.1.2 Composition and abundance of mangrove

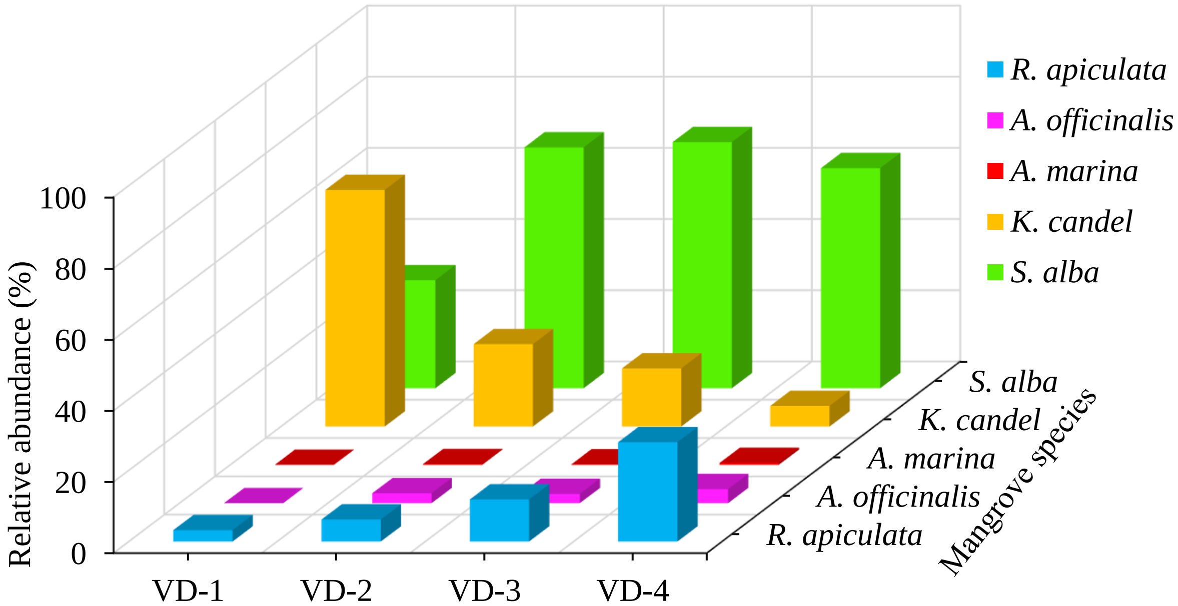

Fig. 4.1. Relative abundance of the species at the study locations.

The mangrove community at Vaidongor comprised mainly of 5 types of species as shown in **Fig**.4.1. *Sonneratia alba* was the dominant species at all locations in the mid-tide and high-tide zones, except for VD-1, where numerous small *Kandelia candel* shrubs were observed in dense patches. The relative abundance of *S. alba* varied from 30.34% at VD-1, to 69.15% at VD-3. It dominated the mid-tide zones of VD-2, VD-3, and VD-4. The mid-tide zone of VD-1 was dominated by *K. candel*. Their small stature (<1 m) and dense clustering contributed to their high abundance at VD-1. The relative abundance of *K. candel* decreased, while that of *R. apiculata* increased, from VD-1 to VD-4. VD-4 had the lowest abundance of *K. candel* and the highest abundance of *R. apiculata*. Scattered individuals of *A. officinalis* and *A. marina* were observed in high-tide zone (landward) at the locations. *R. apiculata* abundance was highest at VD-4. It was also observed at the landward high-tide zones of VD-1, VD-2, and dominated this region at VD-3.

4.1.3 Litter fall

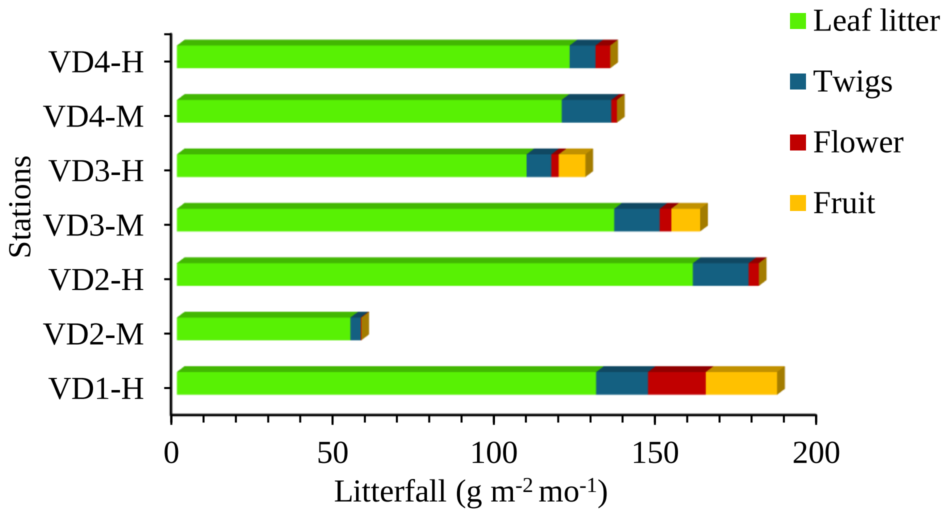

Fig. 4.2. Variation in litterfall at the study locations.

As observed in **Fig**. 4.2., leaf litter comprised the majority of litter collected. Several studies (Wafar et al., 1997; Castillo et al., 2006; Ntyam et al., 2014; Saenger and Snedaker, 1993; Woodroffe, 1985) have reported similar findings on mangrove litter fall. Twigs, fruits, and flower litter were also present, but in much smaller quantities. Therefore, leaf litter from mangrove trees was the major source of organic matter at Vaidongor.

Litter production was highest at the high tide zone of VD-1 (186.19 g m^{-2} mo^{-1}) and lowest at the mid-tide zone of VD-2 (57.17 g m^{-2} mo^{-1}). The second-highest litter fall was recorded at the high tide zone of VD-2 (180.52 g m^{-2} mo^{-1}), followed by the mid-tide zone of VD-3 (162.3 g m^{-2} mo^{-1}). Flower and fruit litter was only observed at a few locations viz. VD-1 and VD-3. Since the traps were installed at breast height above the tide level, only *Sonneratia alba* contributed to the litter collected. Other mangrove species were shorter and below trap height.

The average litter fall per day at all stations for *S. alba* was found to be 4.68 g m^{-2} d^{-1}. Similar findings were reported by Wafar et al. (1997) in Mandovi and Zuari estuaries for *S. alba* (4.66 g m^{-2} d^{-1}). The observed variations in litter production were mainly attributed to the irregularities in the canopy cover of *S. alba* trees at different stations. Wind speed, climatic conditions, seasonal variations, tree height, and nutrient availability are other factors known to influence litter fall rates (Wafar et al., 1997; Mfilinge et al., 2005; Ntyam et al., 2014; Mchenga and Ali, 2017; Mitra and Mitra, 2017).

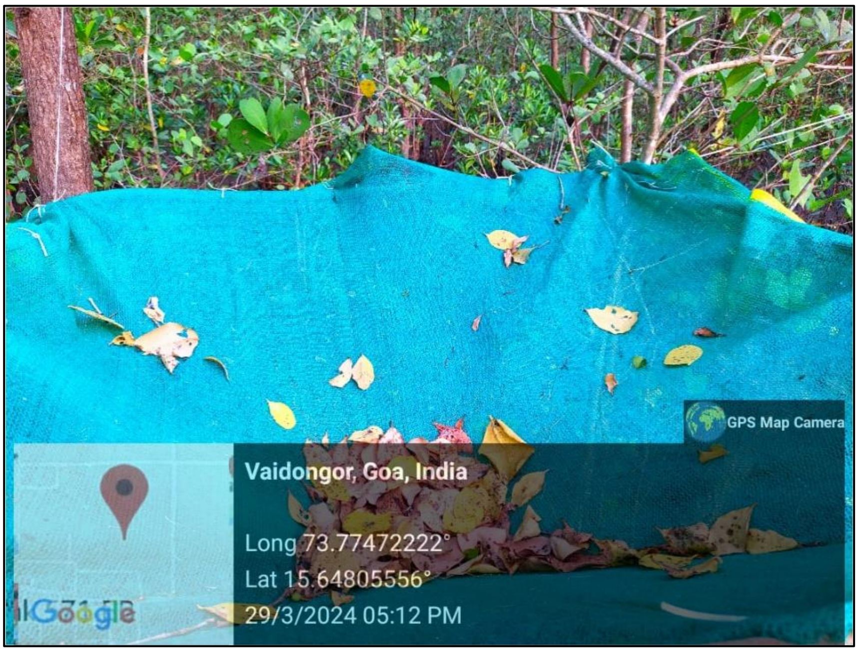

Fig. 4.3. Leaf litter collected in litter traps.

4.1.4 Litter decomposition

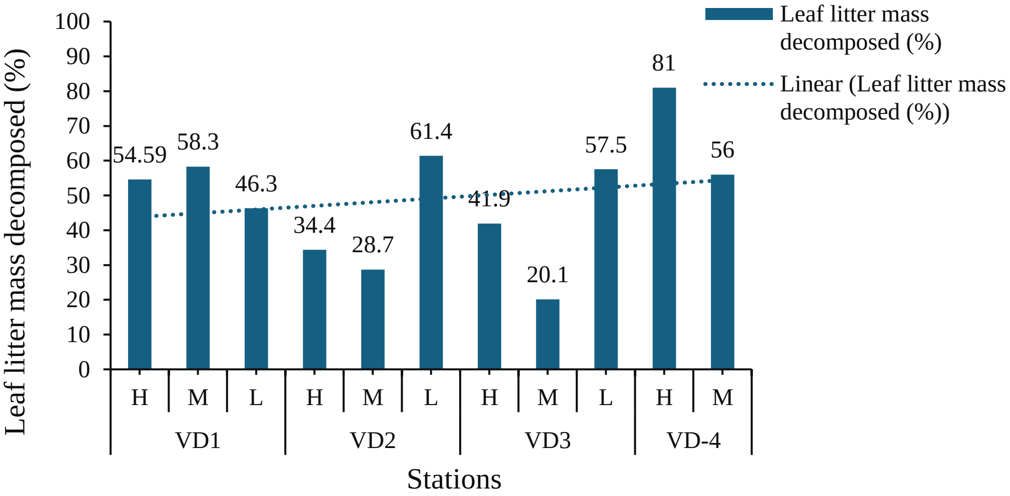

Fig. 4.4. Decomposition of Leaf litter across all stations in a month.

The rate of leaf litter decomposition was studied using litter bag method (Tam et al., 1990) for a period of 30 days (1 month). The highest decomposition was observed at high tide zone of the VD-4 and lowest was at mid tide zone of VD-3 as described in **Fig**. 4.4. Decomposition of leaf litter occurred in the following order: High tide > Mid tide > Low tide. Among the stations, VD-4 showed highest decomposition rate and VD-3 showed the lowest. Benthic organisms such as bivalves (*Saccostrea cucullata)* were observed at low tide zones of VD-1, VD-2, VD-3 and VD-4. Crabs were observed at VD-1, VD-2 and VD-3. Polychaete worms were found in decomposition

Fig. 4.5. Large number of benthic snails and crab burrows at VD-1 high tide zone bags stationed at VD-4 and VD-2. Benthic snails and crab burrows were observed were observed in surface sediments at VD-1 (Fig.4.5). The trendline (**Fig.** 4.4) showed an increase in decomposition from VD-1 to VD-4. Field observations also revealed that high tide zone of station VD-4 contained garbage (plastic waste, e-waste, clothes, etc.) dumped by the locals living in the vicinity. The decomposition at the low tide zones might be attributed to stronger tidal forces and bioturbative / feeding activity of crabs (Robertson and Daniel, 1989; Alongi et al., 1989; Dhaou et al., 2022). Since the decomposition study used fresh leaf litter collected directly from the sediments. Thus, there was variation in the composition of the leaf litter within the litterbags. The leaf decomposition rate varies among plant species and depends mainly on the structure and chemical composition of the leaf, especially the lignin and nutrient concentrations (Wardle et al., 1997; Tam et al., 1998; Ashton et al.,1999) stated that on mixing litter from different species, in combinations of more than two species, litter breakdown rates differed. The enhancing effect of *Sonneratia* litter decomposition might be offset by the retarding effect of *Rhizophora* litter in the specific combinations used. They found that mixing different types of leaf litter can significantly impact how quickly they decompose and how much nitrogen they lose. The percentage of mass loss also depends on species of the leaf litter (Robertson et al., 1992). Thus, the lower decomposition rates at VD-2 and VD-3 mid tide zones might be attributed to the litter content in the bags. Other factors affecting litter decomposition are microbial activity, dissolve oxygen concentration, nutrient availability, climatic conditions (Twilley, 1985; Boto et al., 1989; Hossain and Hoque, 2008).

4.1.5 Variations of TOC in the sediments at Vaidongor

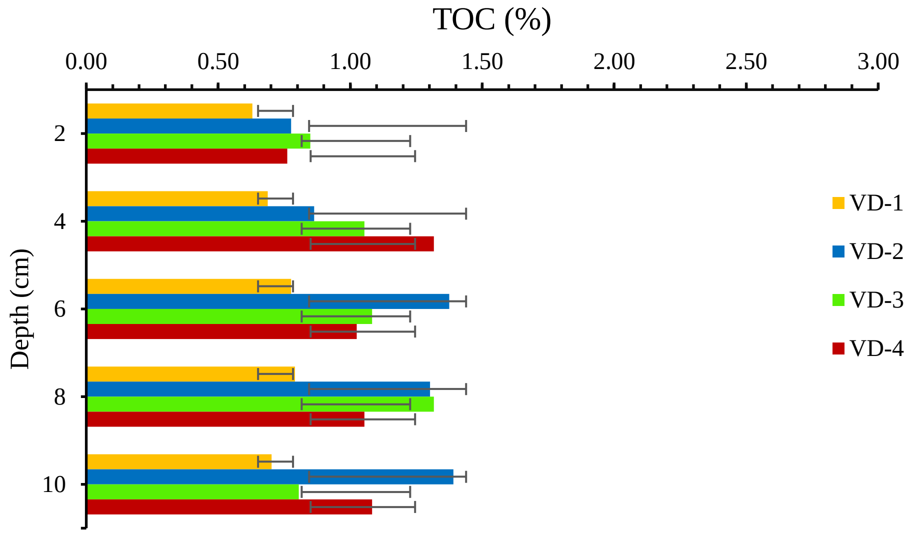

Fig. 4.6. Downcore variation of TOC at low tide zones

The concentration of total organic carbon (TOC) varied across the stations. VD-2 station in the low tide zone had the highest TOC content, while VD-1 station had the lowest (**Fig**. 4.6). The TOC content was generally lower at the surface and increased with depth. Interestingly, VD-4 exhibited a peak in TOC concentration at mid-depth, while VD-1 showed minimal variation throughout the core. At VD-3, highest TOC content was found at a depth of 8 cm.

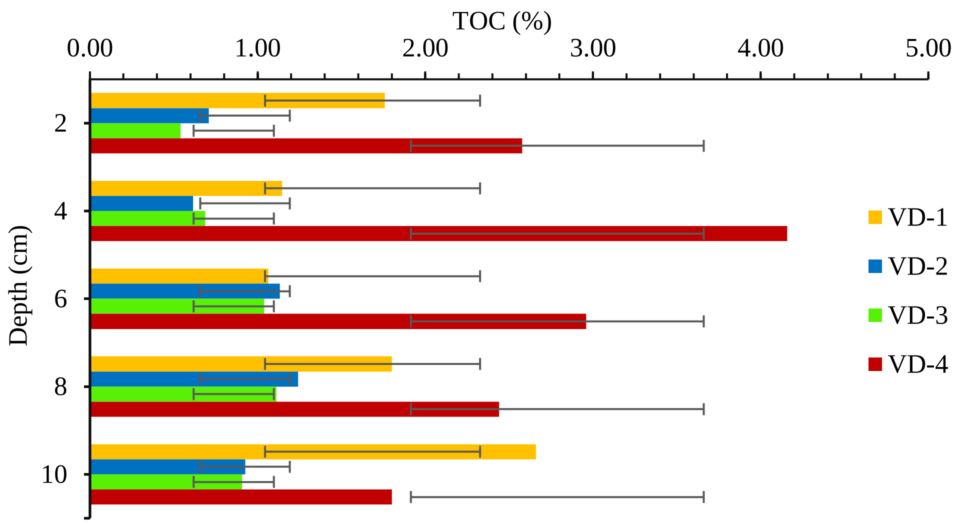

Fig. 4.7. Downcore variation of TOC at mid tide zones at Vaidongor.

Contrasting patterns in TOC concentration down the core between VD-1 and VD-4 at the mid-tide zone were observed (Fig.4.7). At VD-1, the TOC percentage initially decreases with depth until 6 cm. However, it increased again, reaching 2.66% at 10 cm depth. In contrast, VD-4 exhibited high TOC levels at the surface, which further increase until 4 cm depth before decreasing further with depth. VD-2 and VD-3, on the other hand, display a similar trend to that observed in the low tide zone, with low TOC content at the surface that increased with depth.

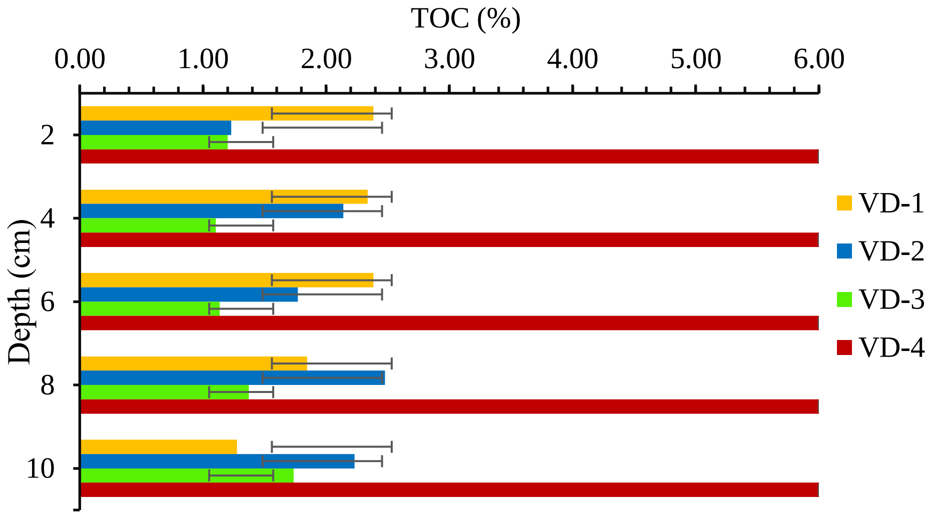

Fig. 4.8. Downcore variation of TOC at high tide zones at Vaidongor.

As observed in **Fig**. 4.8, TOC concentrations in the high tide zone were highest at VD-4. Notably, TOC content at VD-4 exceeded the detectable limits (> 6%) of the modified Walkley-Black method by Gaudette et al. (1974) at all depths. At VD-1, TOC levels remained relatively constant until 6 cm depth, followed by a decrease with increasing depth. VD-2 displayed the opposite trend, with TOC percentage increasing with depth. VD-3 exhibited minimal variation until 8 cm, with a slight increase observed thereafter.

Overall, the variation of TOC in the intertidal zones was as follows: HT (3.01 %) > MT (1.38 %) > LT (1.01 %). Between stations TOC variations followed: VD-4 > VD-1 > VD-2 > VD-3. The variations in TOC results corresponds with the variations in litter fall and decomposition. In low tide zones, the litter fall varied depending on the tide intensity as the leaves are transported from the habitat to the nearby areas and vice-versa (Alongi et al., 1989; Slim et al., 1996). More the bacterial abundance more will be organic matter generated, through decomposition (Boto and Bunt, 1981; Twilley, 1985; Alongi et al., 1989; Boto et al., 1989). Recent study by Bhatkande and Nasnodkar, (2022) on the Chapora estuary observed a non-significant correlation of TOC with sediment grain size. Thus, it can be stated that the major contributor to organic carbon generation in the Vaidongor mangrove habitat is litter fall and its subsequent decomposition.

4.2 Conclusion

The present study aimed to assess various aspects of the Vaidongor mangrove ecosystem, including the plant community composition, litter production, decomposition and downcore variation in sediment TOC percentage. The findings revealed several key points such as *Sonneratia alba* was the dominant mangrove species and found with its abundance varying across all intertidal zones. *Kandelia candel* was dominant in the mid-tide zone mainly at VD-1. Leaves comprised majority of the litter originating from Sonneratia alba. Litter production also showed spatial variations likely due to differences in canopy cover. The rate of leaf litter decomposition varied across stations and tidal zones. VD-4 exhibited the highest decomposition rate, potentially influenced by the presence of anthropogenic waste. The TOC concentration displayed a positive increasing trend with litter fall and decomposition rates. VD-4 had the highest TOC content, likely due to a combination of factors like litter input, its decomposition, and anthropogenic influence.

These findings suggest that litter fall and subsequent decomposition play a crucial role in organic matter cycling within the Vaidongor mangrove ecosystem. Future studies could explore the specific contributions of different mangrove species, windspeed and seasonal variation to litter production and the influence of environmental factors such as climate, microbial abundance, benthic fauna, rainfall, sediment grain size, sediment dissolve oxygen, redox potential, nutrient availability, seasonal variation etc on decomposition rates in the Chapora Estuary. Additionally, investigating the impact of anthropogenic activities like waste dumping on decomposition processes would provide valuable insights for sustainable mangrove management.

CHAPTER 5

REFERENCES

1. Alongi, D. M., Boto, K. G., Tirendi, F., 1989. Effect of exported mangrove litter on bacterial productivity and dissolved organic carbon fluxes in adjacent tropical nearshore sediments. Marine ecology progress series. Oldendorf, 56(1), 133-144.
2. An, J. Y., Han, S. H., Youn, W. B., Lee, S. I., Rahman, A., Dao, H. T. T., Seo, J.M., Aung, A., Choi, H., Hyun H. J., Park, B. B., 2020. Comparison of litterfall production in three forest types in Jeju Island, South Korean Journal of forestry research, 31(3), 945-952.
3. Ashton, E. C., Hogarth, P. J., Ormond, R., 1999. Breakdown of mangrove leaf litter in a managed mangrove forest in Peninsular Malaysia. Hydrobiologia, 413, 77-88.
4. Azad, M. S., Kamruzzaman, M., Ahmed, S., Kanzaki, M., 2021. Litterfall assessment and reproductive phenology observation in the Sundarbans, Bangladesh: A comparative study among three mangrove species. Trees, Forests and People, 4, 100068.
5. Bhatkhande, A. D., Nasnodkar, M. R., 2022. Metal enrichment in sediments and bioaccumulation in edible bivalve *Saccostrea cucullata* from mudflats of a tropical estuary, India: a study to investigate toxicity and consumption suitability. Environmental Science and Pollution Research, 29(39), 59885-59902.
6. Boto, K. G., Alongi, D. M., Nott, A. L., 1989. Dissolved organic carbon-bacteria interactions at sediment-water interface in a tropical mangrove system. Marine ecology progress series. Oldendorf, 51(3), 243-251.

7. Boto, K. G., Bunt, J. S., 1981. Tidal export of paniculate organic matter from a northern Australian mangrove system. Estuarine coastal and shelf science, 13, 247-255.

8. Bouillon, S., Borges, A. V., Castañeda-Moya, E., Diele, K., Dittmar, T., Duke, N. C., Kristensen, E., Lee, S. Y., Marchand, C., Middelburg, J. J., Rivera-Monroy, V. H., Smith III, T. J., Twilley, R. R., 2008. Mangrove production and carbon sinks: a revision of global budget estimates. Global biogeochemical cycles, 22(2).

9. Castillo, J. A., Vázquez, G., López-Portillo, J., 2006. Litterfall and decomposition of *Rhizophora mangle L.* in a coastal lagoon in the Southern Gulf of Mexico. Hydrobiologia, 559, 101-111.

10. Cejudo, E., Hernández, M. E., Campos, A., Infante-Mata, D., Moreno-Casasola, P., 2022. Leaf litter production and soil carbon storage in forested freshwater wetlands and mangrove swamps in Veracruz, Gulf of Mexico. Mires and Peat, 28.

11. Costanza, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., Van Den Belt, M., 1998. The value of the world's ecosystem services and natural capital. Ecological economics, 25(1), 3-15.

12. Cunha, S. R. D., Tognella-De-Rosa, M. M. P., Costa, C. S. B., 2006. Structure and litter production of mangrove forests under different tidal influences in Babitonga Bay, Santa Catarina, southern Brazil. Journal of Coastal Research, 1169-1174.

13. da Silva Rocha, J. I., Magnago, L. F. S., Piotto, D., 2022. Litter production in successional forests of southern Bahia, Brazil. Journal of Tropical Ecology, 38(6), 377-385.

14. Dali, G. L. A., 2023. Litter production in two mangrove forests along the coast of Ghana. Heliyon, 9(6).

15. Dewiyanti, I., Nurfadillah, N., Setiawati, T., Yanti, F., Elrahimi, S. A., 2019. Litter production and decomposition of mangrove in the Northern Coast of Aceh Besar district, Aceh province. In IOP Conference Series: Materials Science and Engineering, 567(1), 012025.

16. Dhaou, D., Gros, R., Baldy, V., Adotévi, A., Gaboriau, M., Estevez, Y., Lecareux, C., Dupouyet, S., Fernandez, C. and Bousquet-Mélou, A., 2022. Comparison of leaf litter decomposition and microbial decomposer communities in fringe and riverine mangroves in French Guiana. Regional Environmental Change, 22, 102.

17. Dhargalkar, V. K., D'Souza, R., Kavlekar, D. P., Untawale, A. G., 2014. Mangroves of Goa. Government of Goa, Forest Department.

18. Fell, J. W., 1975. Microbial activities in the mangrove (*Rhizophora mangle*) leaf detrital system. The biology and management of mangroves, 2, 661-679.

19. Feller, I. C., McKee, K. L., Whigham, D. F., O'Neill, J. P., 2002. Nitrogen vs phosphorous limitation across an ecotonal gradient in a mangrove forest. Biogeochemistry, 62,145-175.

20. Gaudette H. E., Flight W. R., Toner L., 1974. An inexpensive titration method for the determination of organic carbon in recent sediment. Journal of Sediment Petrology, 44(1), 249-253.

21. Hemati, Z., Hossain, M., Rozainah, M. Z., 2017. Determination of carbon and nitrogen in litter fall of mangrove ecosystem in Peninsular Malaysia. Pakistan Journal of Botany, 49(4), 1381-1386.
22. Hernandez, J. O., Park, B. B., 2024. Litterfall Production and Decomposition in Tropical and Subtropical Mangroves: Research Trends and Interacting Effects of Biophysical, Chemical, and Anthropogenic Factors. Wetlands, 44(2), 23.
23. Hossain, M., Hoque, A. F., 2008. Litter production and decomposition in mangroves-a review. Indian Journal of Forestry, 31(2), 227-238.
24. Jagtap, T. G., Chavan, V. S., Untawale, A. G., 1993. Mangrove ecosystems of India: a need for protection. Ambio, 252-254.
25. Kamruzzaman, M. D., Basak, K., Paul, S. K., Ahmed, S., Osawa, A., 2019. Litterfall production, decomposition and nutrient accumulation in Sundarbans mangrove forests, Bangladesh. Forest Science and Technology, 15(1), 24-32.
26. Keuskamp, J. A., Feller, I. C., Laanbroek, H. J., Verhoeven, J. T. A., Hefting, M. M., 2015. Short- and long-term effects of nutrient enrichment on microbial exoenzyme activity in mangrove peat. Soil Biology and Biogeochemistry, 81, 38-47.
27. Kida, M., and Fujitake, N., 2020. Organic carbon stabilization mechanisms in mangrove soils: A review. Forests, 11(9), 981.
28. Kothari, M. J., Rao, K. M., 2002. Mangroves of Goa. Botanical Survey of India.
29. Lima, R. G., and Colpo, K. D., 2013. Leaf-litter decomposition of the mangrove species *Avicennia schaueriana, Laguncularia racemosa* and

Rhizophora mangle. Journal of the Marine Biological Association of the United Kingdom, 94(02), 233-239.

30. Liu, L., Li, F., Yang, Q., Tam, N. F., Liao, W., Zan, Q., 2014. Long-term differences in annual litter production between alien (*Sonneratia apetala*) and native (*Kandelia obovata*) mangrove species in Futian, Shenzhen, China. Marine pollution bulletin, 85(2), 747-753.
31. Lugo, A. E., Snedaker, S. C., 1974. The ecology of mangroves. Annual review of ecology and systematics, 5, 39-64.
32. Mamidala, H. P., Ganguly, D., Purvaja, R., Reddy, Y., Paneer Selvam, A., Singh, G., Banerjee, K., Robin, R. S., Ramesh, R., 2022. Distribution and dynamics of particulate organic matter in Indian mangroves during dry period. Environmental Science and Pollution Research, 29(42), 64150-64161.
33. Manzoni, S., Jackson, R. B., Trofymow, J. A., Porporato, A., 2008. The global stoichiometry of litter nitrogen mineralization. Science, 321(5889), 684-686.
34. Mchenga, I., Ali, A. I., 2017. Mangrove litter production and seasonality of dominant species in Zanzibar, Tanzania. Journal of East African National History, 106(1), 5-18.
35. Mfilinge, P. L., Meziane, T., Bachok, Z., Tsuchiya, M., 2005. Litter dynamics and particulate organic matter outwelling from a subtropical mangrove in Okinawa Island, South Japan. Estuarine, Coastal and Shelf Science, 63(1-2), 301-313.
36. Middleton, B. A., McKee, K. L., 2001. Degradation of mangrove tissues and implications for peat formation in Belizean Island forests. Journal of Ecology, 89, 818-828.

37. Mitra, A., Mitra, A., 2017. Mangrove litter production: A process of immense ecological value. Recent Developments in Mangrove Research, 261-272.

38. Mohit, V. N. D., Appadoo, C., 2009. Characterization of forest structure and an assessment of litter production, accumulation and litter-associated invertebrates in two naturally occurring *Rhizophora mucronata* stands in Mauritius (Indian Ocean). University Of Mauritius Research Journal, 15(1), 244-267.

39. Mulya, M. B., Arlen, H. J., 2018. Production of litter and detritus related to the density of mangrove. In IOP Conference Series: Earth and Environmental Science, 130(1), 012033.

40. Nagi, H., Rodrigues, R., Murali, M., Jagtap, T., 2014. Using remote sensing and GIS techniques for detecting land cover changes of mangrove habitats in Goa, India. 26, 21-33.

41. Ntyam, S. C. O., Kojo Armah, A., Ajonina, G. N., George, W., Adomako, J. K., Elvis, N., Obiang, B. O., 2014. Importance of mangrove litter production in the protection of Atlantic coastal forest of Cameroon and Ghana. The Land/Ocean Interactions in the Coastal Zone of West and Central Africa, 123-137.

42. Odum, W. E., Heald, E. J., 1975. The detritus-based food web of an estuarine mangrove community. Estuarine Research, Chemistry Biology and the Estuarine System, 1, 265.

43. Queensland Government, Monitoring and Sampling Manual: background to monitoring mangrove forest health. Environmental Protection (Water) Policy 2009. Monitoring and Sampling Manual, 2018, 1-15.

44. Rafael, A., Calumpong, H. P., 2018. Comparison of litter production between natural and reforested mangrove areas in Central Philippines, Aquaculture, Aquarium, Conservation and Legislation Bioflux,11(4), 1399-1414.

45. Rani, V., Sreelekshmi, S., Preethy, C. M., BijoyNandan, S., 2016. Phenology and litterfall dynamics structuring ecosystem productivity in a tropical mangrove stand on South West coast of India. Regional Studies in Marine Science, 8, 400-407.

46. Ravichandran, S., Kannupandi, T., Kathiresan, K., 2006. Mangrove leaf litter processing by sesarmid crabs. Ceylon Journal of Science (Biological Sciences), 35 (2), 107-114.

47. Robertson, A. I., 1988. Decomposition of mangrove leaf litter in tropical Australia. Journal of Experimental Marine Biology and Ecology, 116, 235-247.

48. Robertson, A. I., Alongi, D. M., Boto, K. G., 1992. Food chains and carbon fluxes. Tropical mangrove ecosystems, 41, 293-326.

49. Robertson, A. I., Phillips, M. J., 1995. Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. Hydrobiologia, 295, 311-321.

50. Robertson, A. I., Daniel, P. A., 1989. The influence of crabs on leaf litter processing in high intertidal mangrove forests of tropical Australia. Oecologia, 78, 191-198.

51. Saenger, P., Snedaker, S. C., 1993. Pantropical trends in mangrove above-ground biomass and annual litterfall. Oecologia, 96, 293-299.

52. Schleyer, M. H., 1986. Decomposition in estuarine ecosystems. Journal of the Limnological Society of Southern Africa, 12, 90-98.

53. Sharma, S., Rafiqul Hoque, A. T. M., Analuddin, K., Hagihara, A., 2010. Phenology and litterfall production of mangrove *Rhizophora stylosa Griff*. in the subtropical region, Okinawa Island, Japan. In Proceedings of International Conference on Environmental Aspects of Bangladesh, 87-90.

54. Shunula, J. P., Whittick, A., 1999. Aspects of litter production in mangroves from Unguja Island, Zanzibar, Tanzania. Estuarine, Coastal and Shelf Science, 49, 51-54.

55. Silva, C., Bhat, U. G., 2011. Diversity status of mangrove species in estuarine regions of Goa, central west coast, India. Nature Environment and Pollution Technology, 10, 651-654.

56. Slim, F. J., Hemminga, M. A., De La Morinière, E. C., and Van der Velde, G., 1996. Tidal exchange of macrolitter between a mangrove forest and adjacent seagrass beds (Gazi Bay, Kenya). Netherland Journal of Aquatic Ecology, 30, 119-128.

57. Steinke, T. D., Barnabas, A. D., Samuru, R., 1990. Structural changes and associated microbial activity accompanying decomposition of mangrove leaves in Mgeni Estuary. South African Journal of Botany, 56, 39-48.

58. Stewart, B. A., and Davies, B. R., 1989. The influence of different litterbag designs on the breakdown of leaf material in a small mountain stream. Hydrobiologia, 183, 173-177.

59. Tam, N. F. Y., Vrijmoed, L., Wong, Y. S., 1990. Nutrient dynamics associated with leaf decomposition in a small subtropical mangrove community in Hong Kong. Bulletin of Marine Science, 47, 68-78.

60. Twilley, R. R., 1985. The exchange of organic carbon in basin mangrove forests in a southwestern Florida estuary. Estuarine, Coastal and Shelf Science, 20, 543-557.

61. Twilley, R.W., Lugo, A. E., Patterson-Zucca, C.,1986. Litter Production and Turnover in Basin Mangrove Forests in Southwest Florida. Ecology, 67(3), 670-683.

62. Twilley, R. R., Pozo, M., Garcia, V. H., Rivera-Monroy, V. H., Zambrano, R., Bodero, A., 1997. Litter dynamics in riverine mangrove forests in the Guayas River estuary, Ecuador. Oecologia, 111, 109-122.

63. Untawale, A. G., Jagtap, T. G., 1992. Floristic composition of the deltaic regions of India. Memoirs of the Geological Society of India. 22, 243-263.

64. Vermatt, J. E., Thampanya U., 2006. Mangroves mitigate tsunami damage: A further response. Estuarine, Coastal and Shelf Science, 69, 1-3.

65. Wafar, S., Untawale, A. G., Wafar, M., 1997. Litter Fall and Energy Flux in a Mangrove Ecosystem. Estuarine, Coastal and Shelf Science. 44(1), 111-124.

66. Wang'ondu, V. W., Bosire, J. O., Kairo, J. G., Kinyamario, J. I., Mwaura, F. B., Dahdouh-Guebas, F., Koedam, N., 2014. Litter fall dynamics of restored mangroves (*Rhizophora mucronata Lamk*. and *Sonneratia alba Sm*.) in Kenya. Restoration ecology, 22(6), 824-831.

67. Wardle, D. A., Bonner, K. I., Nicholson, K. S., 1997. Biodiversity and plant litter: experimental evidence which does not support the view that enhanced species richness improves ecosystem function. Oikos, 79, 247-258.

68. Woodroffe, C. D., 1985. Studies of a Mangrove Basin, Tuff Crater, New Zealand: I. Mangrove biomass and production of detritus. Estuarine, Coastal and Shelf Science, 20, 265-280.

69. Zhang, H., Yuan, W., Dong, W., Liu, S., 2014. Seasonal patterns of litterfall in forest ecosystem worldwide. Ecological Complexity, 20, 240-247.