Litterfall production and decomposition in the fringing mangroves of Divar Island, 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

CRISTOPHER FERNANDES

Seat Number: 22P0400005

ABC ID: 818-573-915-681

PRN: 20184882

Under the Supervision of

DR. SHERYL O. FERNANDES

School of Earth, Ocean, and Atmospheric Sciences

Marine Sciences

GOA UNIVERSITY

APRIL 2024

Examined by:

Seal of the School

DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Litterfall production and decomposition in the fringing mangroves of Divar Island, 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 O. 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.

Cristopher Fernandes

Seat Number: 22P0400005

Date: 02|05|2024

Place: Goa University, Taleigao, Goa

COMPLETION CERTIFICATE

This is to certify that the dissertation report "**Litterfall production and decomposition in the fringing mangroves of Divar Island, Goa**" is a bonafide work carried out by **Cristopher Fernandes** 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 O. Fernandes
Assistant Professor
Dept. of Marine Sciences
Goa University
Goa- 403206

Date: 02/05/2024

GOA UNIVERSITY
TALEIGAO PLATEAU
GOA

School Stamp

Ghadi 6/5/24

Sr. Prof. Sanjeev C. Ghadi
Dean
Marine Sciences
School of Earth, Ocean and Atmospheric Sciences
Date:
Place: Goa University, Taleigao, Goa

CONTENTS

Preface

Studying the litterfall, decomposition and organic carbon in the mangroves of Divar Island, will help to understand health of the ecosystem, identifying the key species and also identifying human influence on the ecosystem. High litter fall, efficient decomposition and organic carbon storage all indicate a well-functioning mangrove ecosystem. However, variations in decomposition rates due to anthropogenic activities raise concerns about efficient C-cycling in these habitats. This study will provide a valuable baseline data for future monitoring and conservation of the pristine mangroves at Divar Island, Goa.

Acknowledgements

I am highly grateful to Dr. Sheryl O. 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 Mayuresh Pednekar, K.M. Dharani, Krutika Devashetti, Abhay Patil and Sumedha Kamble for accompanying me on the field sampling visits and 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.

Cristopher Fernandes

TABLE

FIGURES

ABBREVIATIONS USED

Entity	Abbreviation
HT	High Tide
MT	Mid Tide
LT	Low Tide
D1	Divar 1
D2	Divar 2
D3	Divar 3
D4	Divar 4
^oC	Degree Celsius
m	meters
TOC	Total Organic Carbon
$K_2Cr_2O_7$	Potassium dichromate
H_2SO_4	Sulphuric Acid
H_3PO_4	Orthophosphoric Acid
NaF	Sodium Fluoride
FAS	Ferrous ammonium sulphate
Wt.	Weight
Mo.	Month
%	Percentage
g	grams

Abstract

This study investigated the distribution and ecological roles of various mangrove species on Divar Island, India. *Acanthus ilicifolius* was abundant at D1 (78.2 %), while *Rhizophora spp.* was dominant at all the studied sites. Litterfall data revealed that the highest leaf litter at the high tide zones of studied sites. Decomposition rates varied across zones, likely due to a combination of factors including leaf traits, temperature and microbial activity. Analysis of total organic carbon (TOC) content in the sediment cores indicated spatial variability. These findings provide valuable insights into the zonation patterns, ecological functions, and biogeochemical processes of the mangrove ecosystem on Divar Island. However, the study acknowledges limitations in data collection and suggests the need for longer-term monitoring to gain a more comprehensive understanding of the mangrove dynamics.

Keywords: Divar, Mangroves, High tide, Mid tide, Low tide Relative abundance, Litter fall, Litter decomposition, TOC.

CHAPTER 1
INTRODUCTION

Background

Mangroves are a 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, and 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 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 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 et al., 2022). Mangrove litter production exhibits significant spatial and seasonal variations globally. Typically, peak litterfall occurs in the 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).

Litter decomposition is a process in which organic matter produced by mangrove forests is transferred to the sediment (Polidoro et al., 2010). Generally, four basic steps occurs during decomposition of litter when transferred to their habitat: (1) removal of leaves material compound by water, (2) microorganisms colonization, (3) consumption by herbivores, and (4) action of physical environmental factors (Kathiresan and Bingham, 2001; Dewiyanti, 2010). 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 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). Measuring primary productivity in mangrove ecosystems are intricate but litter production and litter decomposition has been widely used as a measure of productivity to predict contribution of nutrients to the estuarine ecosystem (Morrisey et al., 2007).

Scope of study

The interplay between litterfall, its decomposition, and biodiversity within mangrove ecosystems is crucial for maintaining the overall function of the ecosystem. It is also used for determining the productivity of the habitat. The 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. Thus, 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.

Aim of the study

This study evaluates the mangrove litter production and litter decomposition rate which results in the formation of organic matter in the mangrove ecosystem of Divar Island, Goa.

Objectives of the study

- To determine the abundance of mangroves and litterfall in the fringing mangroves of Divar Island, Goa.
- To determine the rate of decomposition of mangrove litter within a 30 day period.
- To determine the down core variation of total organic carbon and it’s link to litter fall and its decomposition.

CHAPTER 2
LITERATURE REVIEW

2. LITERATURE REVIEW

Importance of mangrove ecosystem

Kathiresan (2021) suggests that mangroves are ecologically significant in protecting the coast from solar UV−B radiation, ‘greenhouse’ gases, cyclones, floods, sea level rise, wave action, coastal soil erosion, provide feeding, breeding, and nursery grounds for many food fishes and wildlife animals. They act as nutrient sinks, sediment traps, and nutrient source to support the food web in other coastal ecosystems. They protect other marine systems such as islands, coral reefs, seaweeds, and seagrass meadows. The mangroves are the most efficient in carbon sequestration and climate change mitigation. Mangroves are economically valuable in supplying the forestry and fishery products and also in serving as sites for developing a burgeoning eco-tourism. In a review by Wang and Gu (2021) suggest that global climate change on mangroves in terms of global warming, sea-level rising, atmospheric CO_2 concentration increasing and extreme weather will have an impact on them. It also touches onto the importance of microbial geochemical processes that are linked to climate change. They say that Archaea are given attention due to the recent findings on their ubiquity in mangrove and their potential ecological function. The global climate change will bring great number of challenges and opportunities to research, maintain and development of mangroves in the future.

Litterfall

Assessment of litterfall production is essential to find out the status of nutrient cycling, forest health, potential carbon export to coastal marine ecosystems, and a valuable indicator of mangrove productivity (Clough, 1992; Twilley et al., 1997; Mohammed et al., 2015). Despite covering only <0.1% of the continent, it has been suggested that mangroves provide about 10% of the DOC (Dissolved Organic Carbon) that is transferred to the ocean from terrestrial sources (Dittmar et al., 2006). Global estimates indicate that a significant fraction of net primary productivity is exported to coastal waters in the form of dissolved organic matter (DOM; Dittmar et al., 2006). Saenger and Snedaker (1993) stated that litter fall recorded from several 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 falling beneath them than short mangrove trees (< 4 m). Studies by (Mackey and Smail, 1996; Wafar et al., 1997; Ochieng and Erftemeijer, 2002; Castillo et al., 2006; Dewiyanti et al., 2019) suggest that mangrove leaf litter is the most important component of the total litter material. It accounts for the greatest percentage of total annual litter production (70%), followed by flower litter (15%), twigs (10%) and propagules (5%). Twilley et al. (1997) estimated that newly fallen leaves lose 20−40% of organic carbon within 10–14 days due to leaching when submerged in seawater. Study by Wafar et al. (1997), in the mangrove system along the Mandovi-Zuari estuarine complex, revealed a seasonal pattern of leaf litterfall in the mangroves. Results showed that litter yield for four mangrove species viz., *Rhizophora apiculata*, *R. mucronata*, *Sonneratia alba* and *Avicennia officinalis* varied from 2.79–4.65 g m^{-2} d^{-1}.

Decomposition of mangrove leaves

Mamidala et al. (2022) stated that decomposition of leaf litter particularly is a key ecological process in tidally-influenced forest ecosystems, where the breakdown products act as an important input of organic matter and nutrients to mangrove sediments and adjacent coastal ecosystems. Stewart and Davies (1989) defined leaf breakdown as weight loss due to physical fragmentation (caused by abiotic factors), animal feeding, microbial activity and leaching. Manzoni et al. (2008) stated that leaf litter decomposition releases nutrients in sediments and water columns also playing a key role in nutrient cycling and global carbon. Several studies have identified that decomposition rates are highest in subtidal zones where there is more frequent flooding (Twilley et al., 1986). However, Feller et al. (2002) discovered that decomposition rates varied across the different zones in the mangrove ecosystem. They found that decomposition rates were lower in the permanently flooded subtidal zone but the decomposition rate was higher in the upper intertidal zone. Middleton & McKee (2001) theorized that tidal flushing creates optimal physico−chemical conditions for decomposition. Wardle et al. (1997), found that mixing the different types of litter can significantly impact decomposition rates and the quantity of nitrogen it loses. Thus, results from the study suggest that the composition of litterfall can play a key role in the functioning of the mangrove ecosystem.

2.3 Factors affecting the decomposition of organic matter

Mfilinge and Tsuchiya (2008) stated that climate plays an important role in the decomposition rate of organic matter hence an increase in the temperature and humidity causes the decomposition process quickly, on the other side low temperatures may impair the decomposer communities. A study by Arnaud et al. (2020) suggests that climate warming is likely to increase sediment organic matter decay rates, but the impact of the rising temperatures may be lower than previously suspected, especially in mangrove sediments that become inundated by rising relative sea levels. Drought conditions are likely to increase sediment organic matter mineralization of mangroves and global warming might exaggerate this effect. Also, wind speed enhances the percentage fraction of the twigs, buds and fruits in total litter production. There is a significant positive correlation between litter production and wind speed (Mflinge et al., 2005; Mchenga and Ali, 2017). Kida and Fujitake (2020) stated that the low decomposition rate in mangrove sediments is due to suboxic conditions. Studies by Middleton and McKee (2001) found that the mass loss of leaves essentially came to a standstill after an initial phase. However, Twilley et al. (1986) found higher decomposition rates after 117 days. Suriani et al. (2013) stated that the abundance of microorganisms, bacteria and invertebrates enormously accelerates the decomposition process of the organic matter produced by the mangrove forest. Microorganisms play an important role in the degradation of leaf litter through the production of extracellular enzymes that break down complex organic matter into simple compounds such as glucose, amino acids and phosphate (Keuskamp et al., 2015). Degradation of litter occurs as soon as fungi and bacteria that reside in the sediment/water have colonized (Holguin et al., 2001). However, (Cundell et al., 1979) suggest that tannin content in mangrove leaves can delay microbial colonization and may contribute to differences in leaf decomposition rates.

Middleton and McKee (2001) suggest that the presence of detritivores such as crabs and amphipods can accelerate the decay rate. In some tropical Australian mangroves, 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 little chance of this organic matter being transported towards adjacent habitats by these organisms. Ravichandran et al. (2006) have shown that the leaf-eating mangrove crab *Neosarmartum smithi* stores leaves in their burrows. Using a stable ($\delta^{13}C$) isotope, Guest et al. (2004), showed the signature of crabs as an indicator of carbon source. Carbon movement between 2 adjacent habitats (mangroves and salt marshes) in a subtropical estuary has been reported to be spatially restricted to a scale of several metres (30 m).

CHAPTER 3
METHODOLGY

Study area

Divar Island (15°31′31.6″N 73°53′59.9″E) is a remarkable estuarine island in the Mandovi Estuary in Goa, India. With an area of 0.57 hectares, it is the second−largest island among the other seven islands in the river. The island is bordered by mangroves throughout its length, with the dominant species being *Avicennia marina* and *Sonneratia alba*. Besides this, *Avecennia officinalis*, *Acanthus illicifolius*, *Sonneratia caseolaris*, *Rhizophora mucronata*, *Rhizophora apiculate*, *Kandelia candel*, and *Exocoecaria agallocha* have also been observed. Beds of *Crassotrea edulis* and *Meretrix casta* have been recorded. The island is a favoured spot among local as well as migratory birds and is known for its ecological significance (Kumar, 2000).

Sampling

Sampling was conducted during January-February 2024, at the inter-tidal zones of the mangrove ecosystem located at Divar Island, Goa. The inter-tidal zones included high tide, mid tide, and low tide. Four stations were selected: D1 (15°30'18"N 73°53'22" E), D2 (15°30'18"N 73°52'48"E), D3 (15°30'20"N 73°52'33"E), D4 (15°31'16"N 73°53'21" E)., Sediment core samples were obtained in duplicates during low tide using a PVC corer with a diameter of 7.5 cm. The core was then capped at both ends and labelled. The core samples were placed in an icebox and transported to the laboratory. The core was sectioned at 2 cm intervals using a knife. The sectioned sub-samples were labelled, transferred to petri plates, and kept in a hot air oven at 60 °C for 48 hours. The oven-dried samples were then homogenized into a fine powder using an agate mortar and pestle and transferred to zip-lock bags.

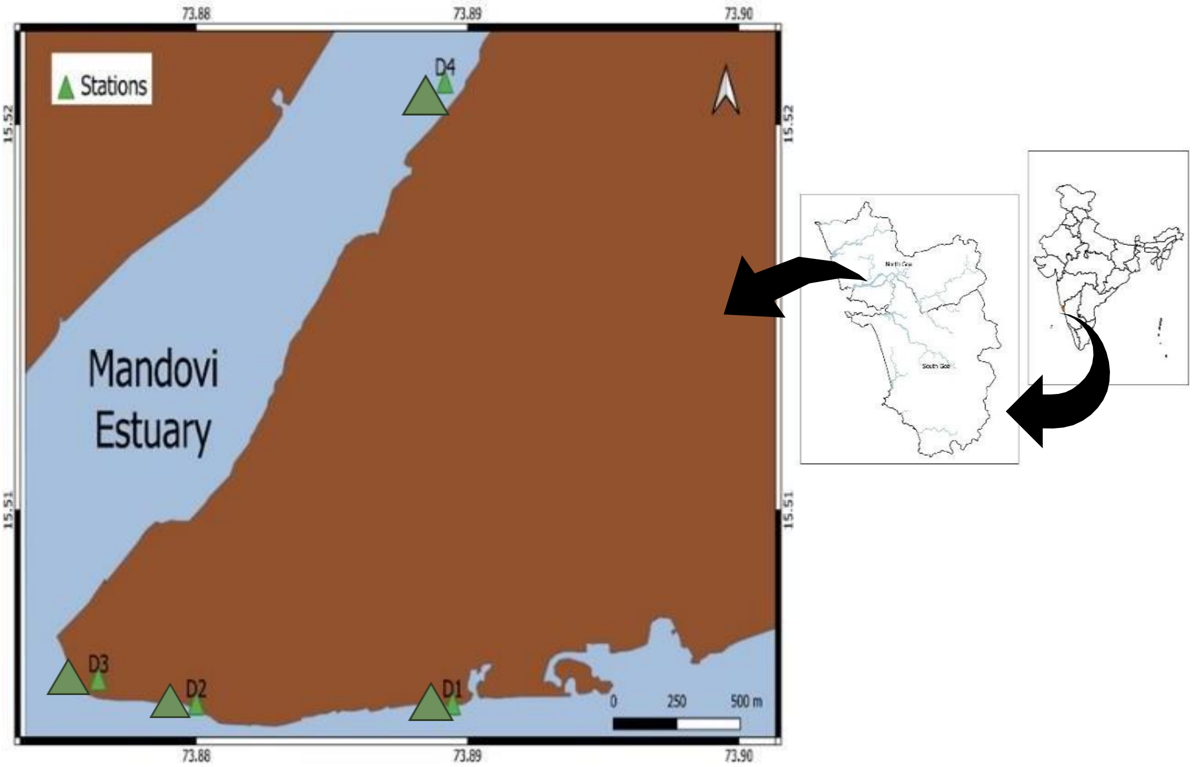

Fig. 1. Study area located at The Divar Island, Mandovi Estuary, Goa

Measurement of physical parameters

Representative cores from each site were sectioned at 0−2, 2−4, 4−6, 6−8, and 8−10 cm upon arrival at the laboratory. The hydrogen ion (pH) concentration of each section was measured using a pH meter (EUTECH pH 700) after calibration with standard buffers (pH 4, 7, and 10). The temperature of each section of the core was noted using a mercury thermometer during the sampling process.

Mangrove community composition

Studies on the distribution and composition of the mangroves were carried out according to Jagtap (1985). Four study locations were demarcated which extended perpendicularly from the landward to the estuarine side. Quadrat (50 m × 16.75 m) was laid out at D1. However, the number of quadrats at each location varied depending on the extent of the intertidal expanse (∼16.75−27.8 m). Based on the width of each location (land to estuary), they were further sub-divided as mid tide and high tide zones to enable grouping of each mangrove species as per their zonation pattern. Saplings smaller than 30 cm in height were not recorded as they were difficult to identify. The relative abundance of mangrove trees was calculated as:

Relative abundance = (No. of individual specie / Total individuals of all species) ×100

Litterfall production and quantification

The litter production was quantified using litter trap. A square frame measuring 1m x 1m was used. The trap was made into a conical shape towards the center to accumulate litter at the center. Seven traps were hung at high tide and mid tide at all study sites under the canopy of the mangrove trees. The traps were placed at a height of approximately 1.8 m to avoid tidal inundation and washing away of litter material. The litter trap was not hung at mid tide of station D3, as the mangrove plant height was not sufficient enough to record to the litterfall data. Litter samples were collected in two sets at 15−day intervals. The litter materials were dried in a hot air oven at 60 °C for 24 hours and then litter material is sorted into leaves, twigs, flowers, and fruit. The weight of each litter component was recorded in dry wt. m^{-2} mo^{-1} after being weighed individually on an analytical balance.

Decomposition studies

The litter bag method (Tam et al. 1990) was used to evaluate the rate of in−situ decomposition of leaf litter for 30 days. The litter bags were made of synthetic shade net with pore size 2 mm and dimensions 20 cm × 30 cm. The green and yellow leaves that had fallen in the mangrove forest were collected. After weighing and filling the litter bags with 7g of mixed leaf litter, each station's litter was buried. After a 30-day incubation period i.e. from 17 March 2024 to 16 April 2024, the litter bags were retrieved and then the decomposed leaves were washed thoroughly to remove any sediments. Next, the decomposed leaves were transferred onto petri plates and allowed to dry for 24 hours. Finally, the dried decomposed leaves, were weighed on an analytical balance (Scale -Tec) in g (dry wt.).

Total organic carbon (TOC) of sediments.

A modified Walkley-Black method (Gaudette et al. 1974) was followed to estimate the percentage of TOC in sediments. It involves exothermic heating and oxidation of organic carbon in the sediment with $K_2Cr_2O_7$ and concentrated H_2SO_4 respectively. The excess of $K_2Cr_2O_7$ which does not participate in the reaction is titrated against 0.5 N solution to a sharp one-drop brilliant green endpoint.

A 0.5 g powdered sediment sample was transferred to the conical flask. 20 mL of H_2SO_4 and Ag_2SO_4 mixture was added to the conical flask. Ten mL of 1N $K_2Cr_2O_7$ was transferred slowly through the burette and the conical flask was kept in an ice bath. The conical flask was kept aside for 30 minutes. After 30 minutes 200 mL of distilled water, 10mL of 85% H_3PO_4 and 0.2g NaF were added. A few drops of indicator were added to the conical flask. The contents in the conical flask were titrated against the 0.5 N Ferrous ammonium sulphate solution till brilliant green was observed. For blank, the same steps were followed excluding sediment samples.

Calculations:

$$\text{TOC (\%)} = 10\left(1 - \frac{T}{S}\right) \text{ x F}$$

where,

S = Standardisation blank titration

T = Sample reading

F = Normality of $K_2Cr_2O_7$ x milliequivalent weight of carbon x $\frac{100}{sample\ weight}$

Statistics

Graphs for data were generated using Microsoft Excel 2021.

CHAPTER 4 ANALYSIS AND CONCLUSIONS

4. Results

Variation in physical parameters at Divar.

The mangrove sediments at Divar Island had acidic to neutral to slightly alkaline pH varying from 5.87 to 7.54 (Table 1). There was not much variation in the pH and temperature values in the downcore from station D1 – D4 in the downcore. These slight variations observed in physical parameters is due to the differences in canopy cover, water levels etc.

Table 1. Variation in physical parameters at the study sites.

	Stations	D1					D2					D3					D4				
High tide	Depth (cm)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
	pH	6.2	6.46	6.72	6.86	6.53	6.94	6.71	7	6.96	7.02	6.39	6.47	6.73	6.77	6.66	6.87	6.6	6.73	6.7	6.66
	Temperature (° C)	28.9	28.9	28.6	28	28	29.9	29.5	29.5	29.5	29.5	26.1	26.1	26.1	26.1	26.1	32	30.1	30	30	29.5
Mid tide																					
	Depth (cm)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
	pH	6.42	6.61	6.89	6.75	6.53	6.63	5.87	6.3	5.92	6.1	6.86	6.76	6.71	6.65	6.59	6.77	6.45	6.39	6.52	6.4
	Temperature (° C)	29.9	29.5	29.5	29.5	29.5	26	26	25.9	26	26	30	30	29.6	29	28	30	29.5	29.5	29.3	29.2
Low tide																					
	Depth (cm)	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10	2	4	6	8	10
	pH	6.4	6.88	6.97	6.86	6.74	6.4	6.88	6.97	6.86	6.74	6.82	6.56	6.33	6.4	6.58	7.5	7.54	7	7.23	7.12
	Temperature (° C)	30.1	30.1	30	30	30	29.8	29	29	29	29	32	32	33	31	31	29.9	29.5	29.5	29.5	29.5

Relative abundance (%) of mangroves

Acanthus ilicifolius was found to be growing abundantly only in HT zone of D1 (78.2 %) and MT (57.6 %) respectively. *Acanthus ilicifolius* is a shrub and it may grow up 2.5 m tall. Positive selection of genes promotes *Acanthus ilicifolius* growth in the intertidal zones of the mangrove ecosystem (Ma et al. 2022). *Rhizophora apiculata* was found to be growing at all the studied sites. While *Avicennia marina* and *Avicennia officinalis* are also overall found growing at all the studied sites except in MT zone of station D4. At D2-MT this site was dominated by older trees of *Rhizophora mucronata* and *Rhizophora apiculata*. Most of the trees had height of >10 m.

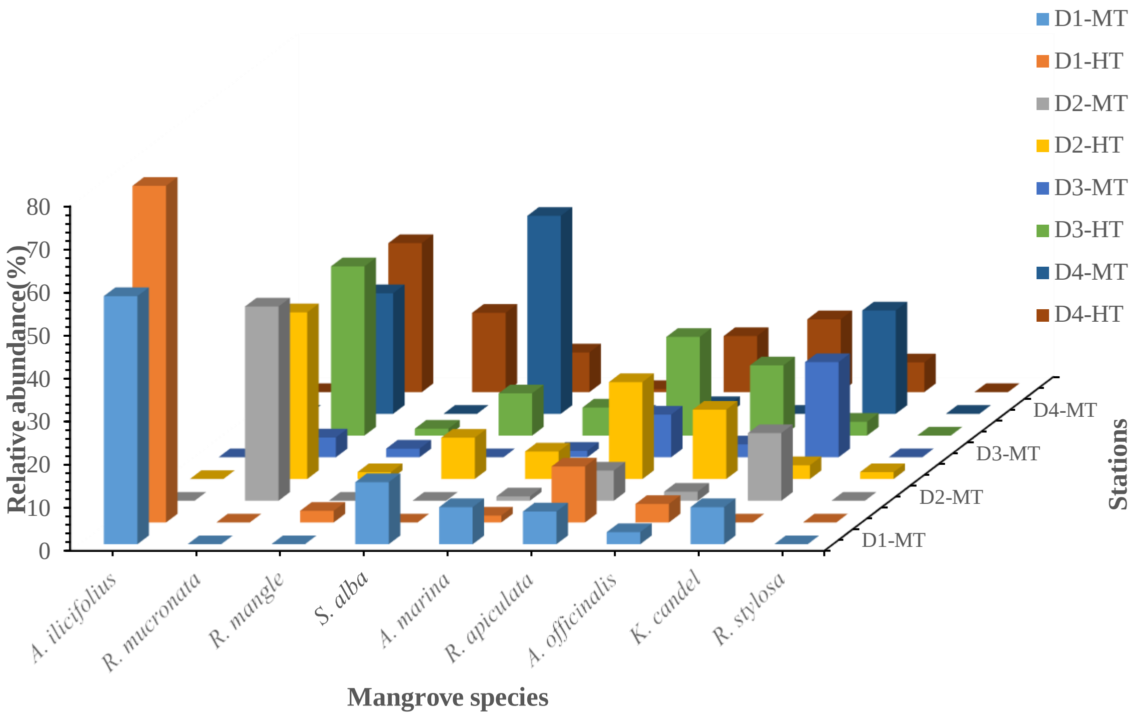

Fig. 4.1. Relative abundance (%) of mangrove species at studied sites

They have stilt root that anchors the tree into the sediments. They primarily function to stabilize the trees in the soft, unstable substrate of the mangrove swamp, water conduction, nutrient uptake, storage and gas exchange vis lenticels (Tomlinson, 1986). It was observed during survey that, numerous stilt roots of the older trees take up lot of area around them as result it makes harder for other mangroves to grow through the stilt roots. Basyuni et al., (2018) confirmed that *Rhizophora mucronata* is an inland plant with a growth rate of 96 %. *Kandelia candel* species are observed growing at HT zone as well as MT zones of the study area except at station D1-MT. This could be because it is one of the few salt excluders of the mangrove community with an excluding capacity of 90% in the estuarine system. *Kadelia candel* leaves have specialized salt excreting glands helps in the maintenance of a NaCl level (Popp et al., 1993). Station D4 was dominated by *Rhizophora mangle* (18.4 %) followed by *Avicennia officinalis* (16.9 %) at the HT zone. *Sonneratia alba* was also observed at D4. *Sonneratia alba* do well in the low intertidal zones of estuaries, making it a widespread and highly salt-tolerant mangrove species. It can thrive in environments with 5 to 50% seawater, showcasing its exceptional tolerance for high salinity and low oxygen (hypoxia) conditions (Ball and Pidsley, 1995). The tree employs two key strategies to survive in these challenging conditions. Firstly, it adjusting the osmotic potential to synthesize organic solutes it can regulate its internal pressure thus balancing the high salt concentration outside the cells and by combating oxidative stress. Secondly, it can produce an antioxidant enzyme to neutralize harmful reactive oxygen species (ROS) generated by high salinity (Yang et al. 2015).

Litterfall assessment

The results shows that mangrove leaf litter contributed the largest, compared to other litter components such as twigs, flowers, propagules, and fruits (Mackey and Smail, 1996; Wafar et al., 1997; Ochieng and Erftemeijer, 2002; Castillo et al., 2006; Dewiyanti et al., 2019). Highest litterfall was observed at D4-HT (149.5 g dry wt.) and D4-MT (133.5 g dry wt.) followed by flower litter at D4-HT (1.94 g dry wt.) and D4-LT (0.82 g dry wt.). This leaves and flower litter was generated by *Sonneratia alba* (Fig 4.1.). The flower litter consisted of stamens that had fallen off, as flower started to mature into a fruit. Overall, Twigs, propagules and fruits contributed very less to litter component.

The average litter fall per day at all stations was found to be 2.6 g m^{-2} d^{-1}. Wafar et al. (1997) reported 4.66 g m^{-2} d^{-1} litter fall in Mandovi and Zuari estuaries. 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). It may be noted that these observations in this study were recorded for a period of 30 days. Therefore, there is a need of data covering for 12 to 24 months to gain clear understanding about the litter in the mangrove ecosystem of Divar Island on a seasonal scale. Also, other parameters needs to be accounted such as redox potential, wind speed data, pollution from metals, hydrocarbons etc.

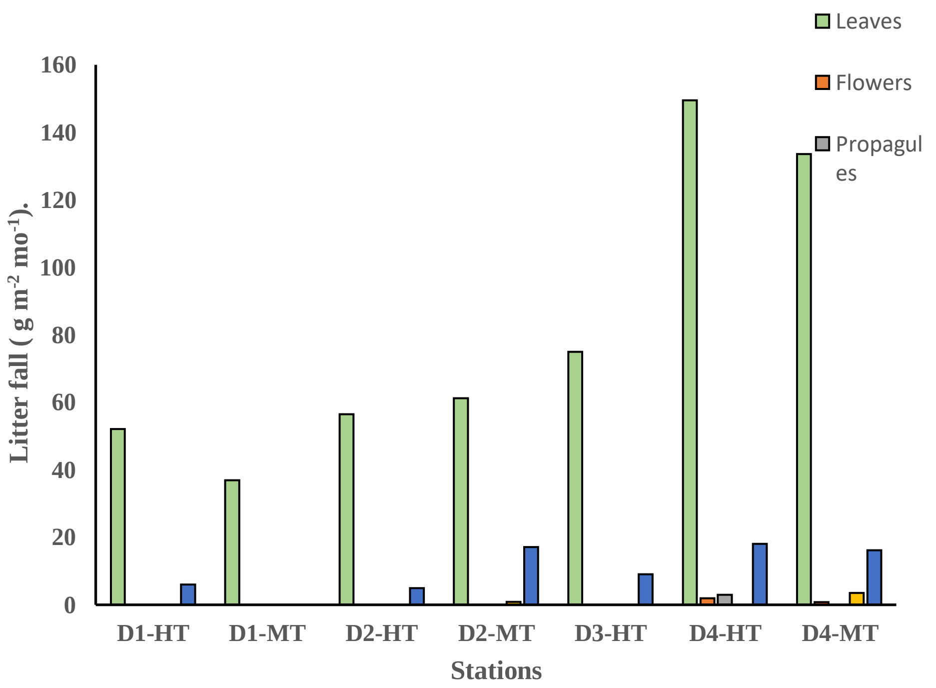

Fig. 4.2. Litter fall at the study sites.

Decomposition of mangrove leaves

The HT, MT, LT zones at all the stations of the study areas shows different values of percentage decomposition rate of mangrove leaves over 30 days. The HT zones of stations D1 and D2 shows a slow rate of decomposition while D2 and D3 shows a faster rate of decomposition. Also, the MT zones of D2 and D3 shows a slower rate of decomposition compared to D1 and D2. The litter bags at station D1-HT and D3-HT contained leaves of *Rhizophora apiculata* in mixed leaf litter along with leaves of *Avicennia marina* and *Avicennia officinalis*. Because *Rhizophora apiculata* leaves have a larger surface area, it makes them more difficult for microorganisms to decompose whole leaves. Nutritional quality in decomposing leaves is often assessed by the C:N ratio. A lower ratio indicates higher nitrogen concentration and faster decomposition rates (Wieder & Lang, 1982). *Avicennia marina* exhibits a significantly lower initial C:N ratio compared to *Rhizophora mucronata* (Rao et al., 1994; Wafer et al., 1997), suggesting higher nutritional quality and potentially faster decomposition.

Litter bag experiment excludes the fragmentation of the leaves by crabs and amphipod which help to accelerate the decomposition process (Bokhorst and Wardle, 2013). Also, D1-HT zone is dominated by *A. ilicifolius* (Fig 4.1.). According to the studies by Mohamad et al., (2019) suggest that *A. ilicifolius* leaves biosynthesizes Silver nanoparticles (AgNP) which have antimicrobial properties. This could be one of the reasons why decomposition rate is slow (proper studies needs to be conducted for better understanding on this topic). However, Osono, and Takeda, (2006) states that compounds contained in the leaf litter also affects the ability of a microbe to decompose complex compounds contained in the litter. Higher decomposition rates of leaf litter were observed at D1-MT and D4-MT, potentially driven by elevated temperatures (Table 1). Higher temperatures are known to accelerate decomposition processes and may also enhance the rate of chemical weathering of leaf litter components. Climate could be one of the key factors in enhancing decomposition in mangrove ecosystem (Dewiyanti et al. 2019). The decomposition bags only had leaves of *Sonneratia alba* at D1-MT and D4-MT.

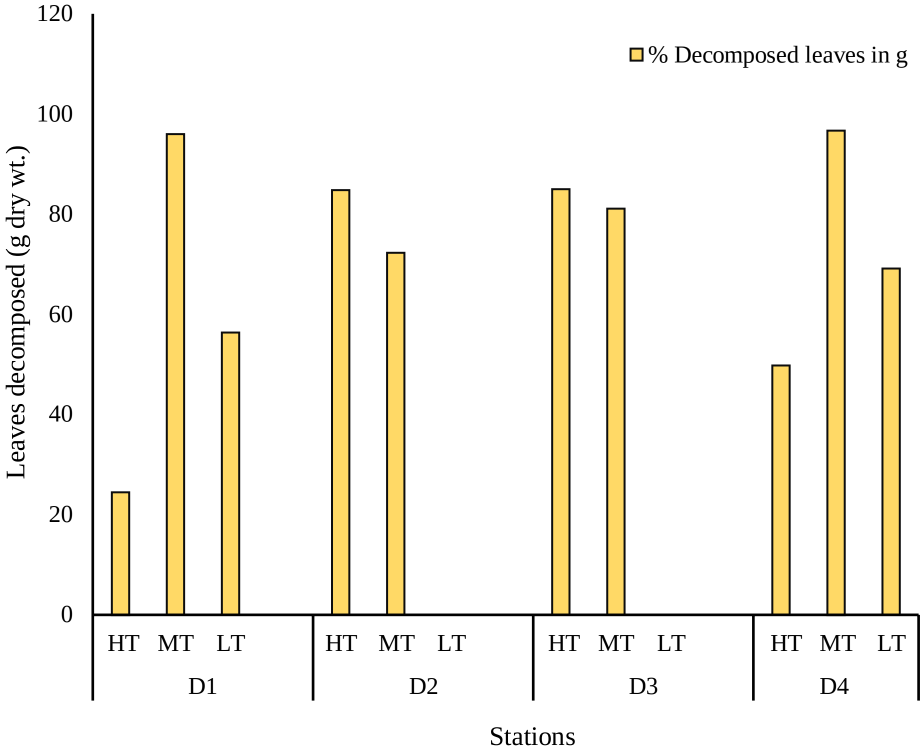

Fig. 4.3. Leaves decomposed within 30 days.

4.5.1 Downcore variation in TOC in the sediments of Divar.

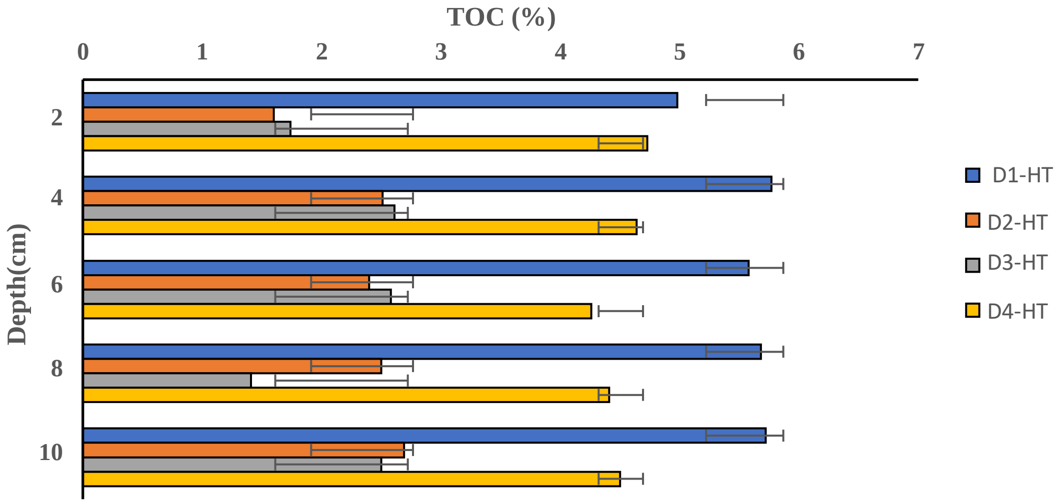

Fig. 4.4. Downcore variation of TOC at HT zones of Divar

At D1 and D4, no significant change in the down core TOC content was observed (Fig 4.4). In contrast, at D2 and D3, a slight decrease in TOC content was observed at 2 cm. At D3 a minimum in the TOC content was observed at 8 cm. At D4, no significant changes was observed in TOC content within the core.

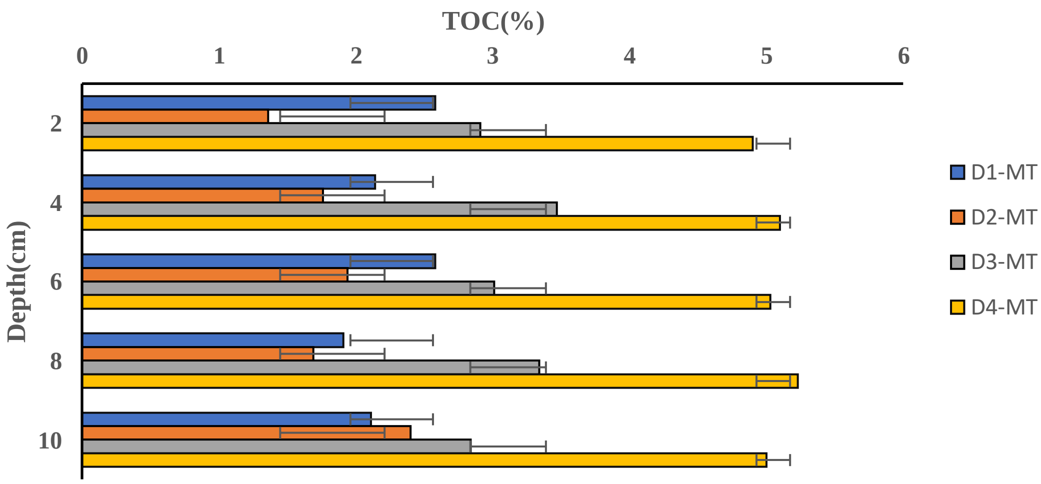

Fig. 4.5. Downcore variation of TOC at MT zones of Divar

TOC content exhibited varied patterns across different depths. At D1, a significant downcore variation in TOC content was observed (Fig. 4.5). At D2, TOC content increased with depth, although a minimum was observed at 8 cm. D3 exhibited minimal variation in TOC content. Finally, at D4 no significant change in TOC content was observed, implying a relatively uniform distribution.

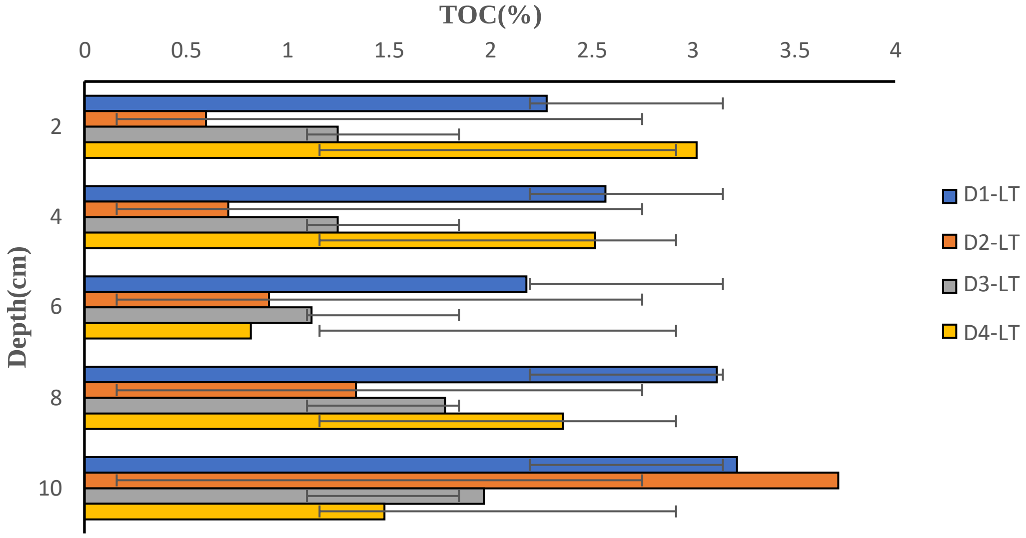

Fig. 4.6. Downcore variation of TOC at LT zones.

At D1, a sudden increase in TOC content was observed at 8 cm (Fig. 4.6). At D2, gradual increase in TOC content was observed as the depth increased. At D3, decrease in TOC content was observed till 6 cm, followed by an increase in TOC content from 8 cm. At D4, a minimum was observed in TOC content at 6 cm, suggesting potential decomposition or transport of organic matter.

The subsequent variation in TOC content at deeper layers suggests, a combination of certain factors such organic matter composition, parameters such as salinity and dissolved oxygen at that depths and sediment characteristics.

4.2 Conclusions

This study revealed variations in plant zonation, litterfall, and decomposition rates across different intertidal zones (HT, MT, LT) and stations (D1, D2, D3, D4) within the Divar Island mangrove ecosystem. *Acanthus ilicifolius* was abundant at station D1 (HT-78.2 % and MT-57.6 % resp.), while *Rhizophora spp.* was dominant and found growing at all studied stations. *Sonneratia alba* was primarily observed in the at MT zone at station D4. The highest litterfall was recorded at D4-HT, consisting mainly of *Sonneratia alba* leaves (149.5 g dry wt.) and flowers (1.9 g dry wt.). Decomposition rates varied between zones and stations, likely influenced by factors like leaf surface area, C:N ratio and temperature. These factors might play a role in decomposition dynamics. TOC content also displayed diverse patterns across depths, suggesting complex interactions between organic matter deposition, decomposition and transport processes.

These findings suggests that litter fall and subsequent decomposition play a crucial role in supplying organic matter to Divar mangrove ecosystem. Future studies will include additional parameters such microbial abundance, sediment grain size, nutrient availability, redox potential, wind speed data of the study area, monitoring litter fall over a longer period (example over the course of 12 to 24 months) in order to observe seasonal variations etc.

References

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.

Arnaud, M., Baird, A.J., Morris, P.J., Dang, T.H., Nguyen, T.T., 2020. Sensitivity of mangrove soil organic matter decay to warming and sea level change. Global Change Biology, 26(3), 1899−1907.

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.

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.

Ball, M.C., Pidsley, S.M. 1995. Growth responses to salinity in relation to distribution of two mangrove species, *Sonneratia alba* and *S. lanceolata*, in northern Australia. Functional Ecology, 77-85.

Basyuni M., et al., 2018. Evaluation of *Rhizophora Mucronata* Growth at first-year Mangrove Restoration at Abandoned Ponds, Langkat, North Sumatra. IOP Conference Series: Earth and Environmental Science, 126, 012118

Bokhorst S., Wardle D.A., (2013). Microclimate within litter bags of different mesh size: Implications for the ‘arthropod effect’ on litter decomposition. Soil Biology and Biochemistry, 58, 147-152.

Bosire, J.O., Dahdouh−Guebas, F., Kario, J.G., Kazungu, J., Dehairs, F., Koedam, N., 2005. Litter degradation and CN dynamics in reforested mangrove plantations at Gazi Bay, Kenya. Biological Conservation, 126, 287–295.

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.

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).

Castillo, J.A., Gabriela, V., Jorge, L.P., 2006. Litterfall and Decomposition of Rhizophora mangle L. in a Coastal Lagoon in the Southern Gulf of Mexico. Hydrobiologia, 559, 101−111.

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.

Clough, B.F., 1992. Primary productivity and growth of mangrove forests. Tropical mangrove ecosystems, 41, 225−249.

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.

Cundell, A.M., Brown, M.S., Stanford, R., Mitchell, R., 1979. Microbial degradation of Rhizophora mangle leaves immersed in the sea. Estuarine and Coastal Marine Science, 9(3), 281−286.

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.

Da Silva, R.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.

Das, S., Manna, R.K., Gogoi, P., Roshith, C.M., Sajina, A.M., Das, B.K., 2021. Quantification of litter fall and estimation of nutrient release through in−situ decomposition of leaf litter from some important mangrove species of Indian Sundarbans.

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

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

Dittmar, T., Hertkorn, N., Kattner, G., Lara, R.J., 2006. Mangroves, are a major source of dissolved matter sources to the oceans. Global Biogeochemical Cycles, 20(1).

Dewiyanti, I., 2010. Litter decomposition of Rhizophora stylosa in Sabang−Weh Island, Aceh, Indonesia; evidence from mass loss and nutrients. Jurnal Biodiversitas, 11(3), 139−144.

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. IOP Conference Series: Materials Science and Engineering, 567.

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

Ma, D., Song, S., Wei, L., Ding, Q., Zheng, H.L., 2022. Comparative transcriptome analysis on the mangrove *Acanthus ilicifolius* and its twoterrestrial relatives provides insights into adaptation to intertidal habitats. Gene, 839.

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.

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

Gaudette, H.E., Flight, W.R., Toner, L., Folger D.W., 1974. An inexpensive titration method for the determination of organic carbon in recent sediments. Journal of Sedimentary Research, 44(1), 249−253.

Guest, M.A., Connolly, R.M., Loneragan, N.R., 2004. Carbon movement and assimilation by invertebrates in estuarine habitats at a scale of metres. Marine Ecology Progress Series, 278, 27−34.

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.

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.

Holguin, G., Vazquez, P., Bashan, Y., 2001. The role of sediment microorganisms in the productivity, conservation, and rehabilitation of mangrove ecosystems: an overview. Biology and Fertility of Soils, 33, 265−278.

Jagtap, T.G., 1985. Ecological studies in relation to the mangrove environment along the Goa coast, India. Ph. D. Thesis, Shivaji University, Kolhapur.

Jagtap, T.G., Chavan, V.S., Untawale, A.G., 1993. Mangrove ecosystems of India: a need for protection. Ambio, 252−254.

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.

Kathiresan, K., Bingham, B.L., 2001. Biology of mangroves and mangrove ecosystems Advances in Marine Biology, 40, 81–251.

Kathiresan, K., 2021. Mangroves: Types and Importance. In: Rastogi, R.P., Phulwaria, M., Gupta, D.K. (eds) Mangroves: Ecology, Biodiversity and Management. 1–31.

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 Biogeochemistry, 81, 38−47.

Kida, M., Fujitake, N., 2020. Organic carbon stabilization mechanisms in mangrove soils: A review. Forests, 11(9), 981.

Kothari, M.J., Rao, K.M., 2002. Mangroves of Goa. Botanical Survey of India.

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.

Lugo, A. E., Snedaker, S. C., 1974. The ecology of mangroves. Annual review of ecology and systematics, 5, 39−64.

Mackey, A., Smail, G., 1996. The decomposition of mangrove litter in a subtropical mangrove forest. Hydrobiologia, 332, 93−98.

Mamidala, H.P., Ganguly, D., Purvaja, R., Reddy, Y., Paneer Selvam, et al. 2022. Distribution and dynamics of particulate organic matter in Indian mangroves during dry period. Environmental Science Pollution, 29(42), 64150−64161.

Manzoni, S., Jackson, R.B., Trofymow, J.A., Porporato, A., 2008. The global stoichiometry of litter nitrogen mineralization. Science, 321, 684−686.

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.

Mflinge, P.L., Meziane, T., Bachok, Z., Tsuchiya, M., 2005. Litter dynamic and particulate organic matter outwelling from a subtropical mangrove in Okinawa Island, South Japan. Estuarine, Coastal and Shelf Science, 63, 301−313.

Mfilinge, P.L., Tsuchiya, M., 2008. Effect of temperature on leaf litter consumption by grapsid crabs in a subtropical mangrove (Okinawa, Japan). Journal of Sea Research, 59 (1), 94−102.

Mohammed, M.H., Abu, H.M.K., Mohd, H.I., Osumanu, H., Ahmed, A.T.M., Rafiqul, H. Masum, B.M, 2015. Litterfall production in a tropical mangrove of Sarawak, Malaysia. Zoology and Ecology, 25(2), 157−165.

Mohamad N.M., Razak S.R.A., Ahmed M.A., Kamal L.Z.M., et al. 2019. Characterization, Antimicrobial Activity of Silver Nanoparticles Biosynthesized by Acanthus ilicifolius. American Journal of Current & Applied Research in Microbiology, 1(1), 09−16.

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.

Morrisey, D., Beard, C., Morrison, M., Craggs, R., Lowe, M., 2007. The New Zealand mangrove: review of the current state of knowledge. Auckland Regional Council Technical Publication, 325.

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.

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.

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.

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.

Osono, T., Takeda, H., 2006. Fungal decomposition of *Abies* needle and *Betula* leaf litter. Mycologia, *98*(2), 172–179.

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A. M., Ellison, J.C., Farnsworth, E.J., Fernando, E.S., Kathiresan, K., Koedam, N.E., Livingstone, S.R., Miyagi, T., Moore, G.E., Nam, V. N., Ong J.E., Primavera, J.H., Salmo, S.G., Sanciangco, J.C., Sukardjo, S., Wang, Y., Yong, J.W.H., 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. PLoS ONE 5(4): e

Popp, M., Polania, J., Weiper, M. (1993). Physiological adaptations to different salinity levels in mangrove. Towards the rational use of high salinity tolerant plants: Vol. 1 Deliberations about High Salinity Tolerant Plants and Ecosystems, 217-224.10095.

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

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

Rajiv, K., 2000. Distribution of mangroves in Goa. Indian Journal of Forestry, 23(4), 360−365.

Rani, V., Sreelekshmi, S., Preethy, C.M., Bijoy N.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.

Rao, R.G., Woitchik, A.F., Goeyens, L., Vanriet, A., Kazungu, J., Dehairs, F., 1994. Carbon, nitrogen and stable carbon-isotope abundance in mangrove leaves from an East Africa coastal lagoon (Kenya). Aquatic Botany, 47, 175-183.

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

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

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

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

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

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

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.

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.

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, 651654.

Stewart, B.A., 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.

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.

Stewart, B.A., 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.

Suriani, M., Bengen, D.G., Prartono, T., 2013. The Production of Organic Matter From Rhizophora mucronata and Sonneratia alba at the Kajhu and Meunasah Mesjid Villages, Aceh Besar. Omni−Akuatika, 3(12), 132−146.

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.

Tietjen, J.H., Alongi, D.M., 1990. Population growth and effects of nematodes on nutrient regeneration and bacteria associated with mangrove detritus from northeastern Queensland (Australia). Marine Ecology Progress Series, 68,169−179.

Tomlinson P.B., 1986. The Botany of mangroves. Cambridge University Press.

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.

Twilley, R.R., Pozo, M., Garcia, V.H., 1997. Litter dynamics in riverine mangrove forests in the Guayas River estuary, Ecuador. Oecologia, 111, 109−122.

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.

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.

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

Wang, Y.S., Gu, J.D., 2021. Ecological responses, adaptation and mechanisms of mangrove wetland ecosystem to global climate change and anthropogenic activities, International Biodeterioration and Biodegradation, 162.

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.

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.

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.

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.

Wieder, R.K., Lang, G.E., 1982. A critique of the analytical methods used in examining decomposition data obtained from litterbags. Ecology 63, 1636-1642.

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.

Yang, E., Yi, S., Bai, F., Niu, D., Zhong, J., et al., 2015. Cloning, characterization and expression pattern analysis of a cytosolic copper/zinc superoxide dismutase (SaCSD1) in a highly salt tolerant mangrove (*Sonneratia alba*). International Journal of Molecular Sciences, 17(1), 4.

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