HEWERS OF WOOD, DRUDGES OF WAVES: INTEGRATING DISTURBANCE IMPACTS, SOCIO-CULTURAL VALUES, AND GENDER TOWARDS MANGROVE BLUE CARBON CONSERVATION

by

DINA NETHISA RASQUINHA

(Under the Direction of Deepak Mishra)

ABSTRACT

In this dissertation, I argue how blue carbon narratives associated with mangrove ecosystems intersect with local communities' realities, values, and priorities. I examine the trade-offs associated with the climate change mitigation potential of mangrove habitats and their vulnerability to climate change impacts using Bhitarkanika Wildlife Sanctuary as a case study. Each of the chapters look at different themes associated with blue carbon—forest degradation, ecosystems services and values, and resource access/exclusion to understand the trade-offs associated with blue carbon policies.

First, I use an ecological lens to understand how mangrove ecosystems respond to large and small-scale disturbances like tropical storms and fuelwood harvesting. Second, I use the concept of reciprocity to understand how conservation values and priorities are impacted by the lack of access/exclusion from protected areas using Q-methodology. I also compare this value discourse using sentiment analyses and content analysis of Twitter data to understand the disconnect between global and local values towards mangrove conservation. Similarly, using the theory of access, I elaborate on the different mechanisms that perpetuate forest dependence. Finally, I use an agent-based model to determine how mangrove-human interactions, intersect with the interactive impact of disturbances on mangrove blue carbon.

The findings reveal an overall increase in mangrove productivity from storm induced freshwater and nutrient inputs while harvesting decreases mangrove forest biomass. However, local communities prefer smaller diameter species as fuelwood, sparing and thus conserving larger diameter mangrove trees. Similarly, local and extra-local actors' priorities converge on storm protection services whereas protected area exclusion has resulted in the dwindling acknowledgement towards provisioning services, implying the slow disconnect between mangrove-human relationships. Similarly, lack of access has also resulted in the increased feminization of forest relations.

Through this dissertation, using an interdisciplinary and plural worldview towards blue carbon sustainability and the conservation value nexus, I question the many assumptions surrounding blue carbon conservation schemes. I argue that effective and just conservation outcomes in mangrove ecosystems necessitate understanding systems holistically, particularly by incorporating voices and lived realities of marginalized communities, embedding socio-economic empowerment in plans, and investing in long term ethnoecological research for managing future uncertainties.

INDEX WORDS: mangroves, blue carbon, Bhitarkanika, India, fuelwood, tropical cyclones, fragmentation, theory of access, conservation values, reciprocity, intersectional feminism, political ecology, gender, social media, sentiment analyses, Q-methodology, gradient boosting, agent-based model.

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CHAPTER 1
INTRODUCTION

This dissertation titled, "Hewers of wood, drudges of waves" highlights the paradoxical nature of firewood extraction and carbon conservation in mangrove ecosystems. Firewood and carbon are both common pool resources whose extraction and conservation needs, motivations, and benefits are closely intertwined. The title is essentially a metaphor for the drudgery associated with forest dependence, whether material, cultural or ecological. It symbolizes the sequestration of woody biomass by maritime trees that sway with the ebb and flow of tides, day in and day out, as gatekeepers of dynamic shorelines. The carbon sequestration provides them the amplitude to withstand sea-level rise. It also symbolizes the drudgery associated with the removal of wood from forests by marginalized communities, especially women bound by the material and cultural needs of societies. While highlighting the drudgery of people and trees, and associated dependence, the title also emphasizes the irony associated with processes of labor, conservation, preservation, and development, implying that the same resource dependent communities can also act as resource conservation stewards.

1.1. Background

Mangroves are a type of tropical forest, found at the edge of land and sea and flooded regularly by tidal water. They are among the most carbon-rich forests in the tropics and are found to sequester carbon at rates 2 or 4 times greater than their terrestrial counterparts (Hutchison et al .2013, Alongi 2014). Although they occupy only 0.5 % of the global coastal area, they have high biomass or carbon levels (Alongi .2014). The carbon they and other coastal ecosystems like tidal marshes, and seagrass sequester is termed as blue carbon. This makes them extremely important from a climate mitigation and adaptation point of view, which has brought these forests in the global radar and led to a series of market-based approaches to conserving these forests that ensure multiple benefits alongwith climate mitigation.

With the ongoing climate emergency and the need for solutions to mitigate carbon emissions, nations are looking to include carbon rich mangroves forests towards their nationally determined contributions (NDCs). India also pledged to create an additional carbon sink of 2.5-3 billion tons CO_2 equivalent by increasing its forest and tree cover by 2030 under the 2015 Paris Agreement (TERI, 2020). Towards this a number of think tanks have reiterated the importance of mangroves as potential sites for implementing carbon finance projects and trading for carbon in the voluntary market (TERI, 2020). The Sundarbans Mangrove Restoration project, initiated in 2015, is currently the only blue carbon credit project operational in the country. The United Nations Framework Convention on Climate Change (UNFCCC) provides emission reduction credits to the Livelihoods Carbon Fund for this project. While most of the financing is distributed to communities as payment for work, the remaining finances cover the technical survey and scientific monitoring required for carbon offset certification. The India Sundarbans Mangrove Restoration project seeks to plant 6000 ha of mangroves over three years that will store a projected 700,000 t of carbon over 20 years in their biomass and soil (Wylie et al 2016). As part of this initiative, local women are trained for the mangrove planting process, and paid for planting work which lasts 4 hours a day during low tide and make roughly $2.54 USD a day, or around $50-56 USD per month (Wylie et al 2016).

At the same time, plans on integrating existing forestry projects to UNFCC protocols of carbon accounting and emissions reductions are also underway. One of the many ways in which this is being conducted are through loan assisted projects such as those with the Japan International Cooperation Agency (JICA). These loan-assisted projects collaborate with state governments to support ongoing Joint Forest Management Committees (JFMC) and Self-Help Groups (SHGs) to undertake plantation programs across the country (JICA, 2016). Although these JICA-led projects have been operational for a long time and contributed to the forestry sector extensively, with the growing push for more carbon offsetting forestry projects around the world, JICA-assisted projects are slowly looking to incorporate and link REDD plus conceptual framing.

While carbon mitigation is the need of the hour, protecting mangrove forests for their carbon mitigation benefits can have several trade-offs, especially with the overlapping regulations that define the fuzzy boundaries of these forests. In India, protected areas such as national parks or wildlife sanctuaries are special zones set aside for biodiversity conservation. Apart from providing a habitat for threatened and endangered species, they are also home to numerous human habitations. Therefore, frictional relationships between officials and local people because of illegal extraction or human-wildlife conflicts is often observed in such areas. Importantly, rights and privileges of local people differ in each protected zone. In a National Park, human interference from timber harvesting, fuelwood collection or minor forest products as well as private ownership rights is prohibited whereas these restrictions are waived off in sanctuaries as long as they do not interfere with the well-being of wildlife.

India possesses about 3% of the world's mangrove forests which are shaped by a number of disturbances such as sea-level rise, coastal developments, and frequent tropical cyclones that impact the coasts annually. These forests are distributed all along the west and east coasts of the country and its islands, and much of the remaining large expanses of mangrove forests within the country are found in protected zones (Figure 1.1). It thus becomes imperative to understand how these multiple zones of protection accommodate multiple zones of interaction and how that might play out with this new wave of blue carbon conservation.

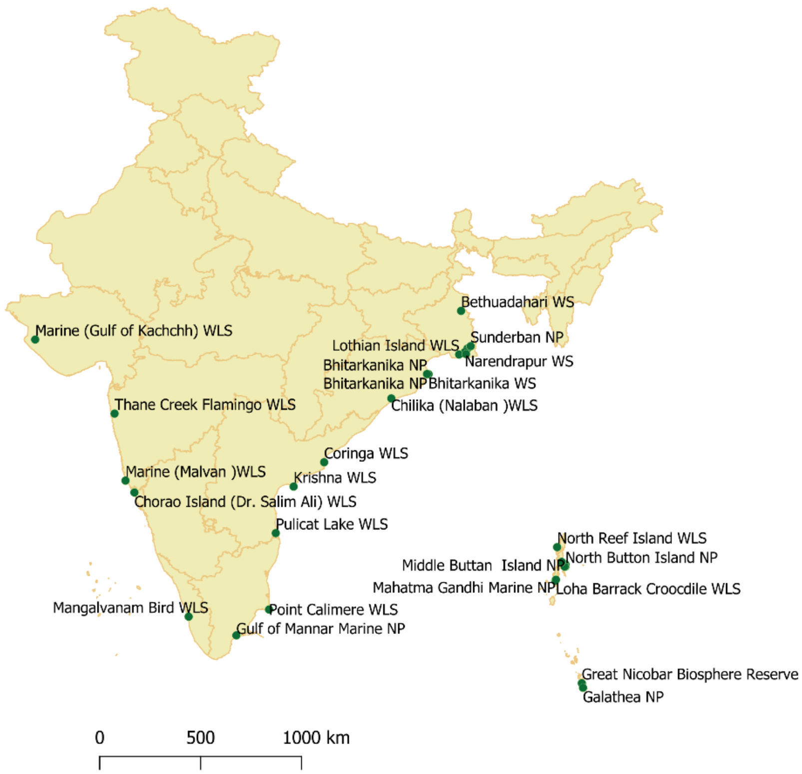

Figure 1.1 Protected mangrove habitats in the country

Research questions and objectives

In this dissertation, I examine mangrove forest conservation narratives at a global scale and intersections of mangrove productivity with small scale disturbances, like firewood use at a local scale (Bhitarkanika Wildlife Sanctuary, a protected forest on the east coast of India). This work builds on ecological resource foraging and disturbance theory, as well as draws from an intersectional ecofeminist and political ecology framework on resource use and access. More specifically, I ask **how do mangrove vegetation dynamics, gender relations, and historical legacies of use interact and influence politics of conservation in protected areas?** I answer this question using three different guiding questions and objectives, detailed below:

1. How disturbances interact and impact mangrove ecosystems, including small-scale disturbances like firewood extraction (primarily collected by women) and more devasting tropical storms that have biomass altering potential?
2. How do mangrove conservation values vary across the study area and across the world?
   a. To dissect themes from global media narratives on blue carbon conservation,
   b. To investigate different stakeholders' values, priorities, and knowledge towards mangrove forest conservation.
3. How does gender and resource access/exclusion influence mangrove forest conservation?
4. How does the interacting impacts of disturbances, and social dynamics impact mangrove biomass in this region?

1.2. Structure of the dissertation

This dissertation is organized into three major themes—forest degradation, ecosystem services and values, and gender and access in tropical forest systems with supplementary chapters that discuss and link these major themes together. Chapter 2 provides a comprehensive overview of the study area by discussing the historical legacies of colonial and imperial rule in this region and connecting it to present day ethnography. Chapters 3 & 4 investigate the role of disturbances in changing forest structure, composition, and biomass by using satellite imagery and field vegetation data. Chapters 5 & 6 engage with values literature connecting the place-based study to global themes of blue carbon conservation. Chapter 7 introduces the relevance of gender narratives in mangrove research and discusses it by engaging with questions of forest dependence, conservation values and resource access. Chapter 8 extends on forest degradation, and disturbances by modeling biomass change and social dynamics in the region. Chapter 9 provides the dissertation conclusion.

1.3. Methods overview

This chapter presents the research design and the methodological approach adopted to answer the main research and sub-guiding questions of this dissertation. In order to develop a holistic understanding of "how the intersections between mangrove vegetation dynamics, gender relations, and historical legacies of use influence politics of conservation in protected areas", I employed a mixed methods approach comprising of both quantitative and qualitative methods.

1.3.1. Selection of study area & sampling strategies

A flexible research design was adopted to accommodate diverse methods during data collection. The flexible approach allowed the research process to adapt to local factors, power dynamics and logistical constraints while conducting fieldwork. Quantitative methods were used to collect comprehensive ecological and socio-cultural data on community characteristics while qualitative methods through in-depth interviews provided insights on the various values, priorities and outcomes of community characteristics and dynamics. Similarly, a nested approach of looking at global, national, and local issues through the different themes of forest degradation, conservation values, and rights and access issues allowed to represent mangrove conservation decision making and impacts at varying scales providing a multi-scalar approach to theorizing socio-ecological dynamics. The data collection process for the study took eight months and took place between September 2018 and March 2019. The data collection period was divided into two phases — a pilot phase and an actual data collection phase. The pilot phase was carried out in September 2018 with multiple day or two-day visits to the sanctuary followed by the actual data collection over the next seven months covering the period October 2018-March 2019. During the pilot phase, informal discussions were conducted with different government and non-government organizations working on mangrove conservation or rural development. These discussions helped in selecting the villages for sampling and arranging logistical requirements for the field stay. This time was also utilized to arrange forest permits needed for the ecological data collection component of the study.

1.3.2. Research location selection

The research location selected was Bhitarkanika Wildlife Sanctuary situated on the east coast of India. The sanctuary was selected for several reasons. The area is part of a multiple protection criteria (national park, marine, and wildlife sanctuary) as well as an internationally recognized eco-sensitive zone (Ramsar site). The state is also considered at the bottom on the poverty level according to the national index on poverty by the planning commission of India (Government of India Planning Commission, 2014). Moreover, the region is vulnerable to extreme events, as it experiences frequent cyclones which directly impact the fishery and agriculture-based economy.

The intersections between multiple zones of protection of the sanctuary and the surrounding natural resource-based economy of the town allowed focusing on the links between place-based materialities, lived realities and experiences of people living at the edge of forest-land-sea. Each chapter contains a study area section which provides further information on how the questions asked demonstrated the selection of the study site.

1.3.3. Sampling strategies

I used a multi-scalar approach comprising of mixed methods to understand mangrove conservation decision making, and its intersection with conservation values and priorities. These different methods warranted different sampling strategies for both ecological and socio-economic and cultural data collection and analyses.

Global level

At the global level, social media references were used to understand how narratives and values impact policy decisions at regional and local scales. Social media tweets between 2019-2021 were extracted and analyzed, including a subset specific to various occasions of importance such as World Environment Day, International Mangrove Day, etc.

Regional/National level

For ecological analyses, we looked at how disturbances like tropical storms impact carbon assimilation rates of seven different mangrove sites with varying levels of species diversity, proximity to urban centers, and protection statuses across the west and east coast of India, including Bhitarkanika Wildlife Sanctuary.

Local level

At the local level, specific coastal communities were chosen as representative samples to carry out the community-focused part of the study to understand socio-political factors that enable and influence community values and priorities towards mangrove conservation. The impact of local small-scale disturbances (firewood harvesting) on mangrove species structure, composition and carbon were also studied by comparing harvested and non-harvested vegetation plots. The sampling strategies adopted for both community level ecological and sociological data collection studies are explained in detail in the following paragraphs as well as in individual chapters in the dissertation. However, the process adopted and the reasoning for each is explained as follows.

Ecological data sampling: We hoped to use a stratified random sampling technique to sample mangrove vegetation in harvested and non-harvested areas. However, due to logistical constraints and permit restrictions, we altered our sampling criteria to that described in Chapter 4 and further supplemented field data provided to us from collaborators. Our site and plot selection did start out randomly (following random point locations stratified by harvesting pressures based on interview results) but logistical constraints prevented it from being entirely random. However, site selection used a stratified random approach. Therefore, we adopted a purposive sampling approach based on our interview results, forest access restrictions, and logistical constraints. Further, the reason for unequal sample sizes between harvested (11) and non-harvested (15) forest site categories was also because of the sensitive nature of the issue. As the area is a protected forest, harvesting is technically illegal. The plots where forests were harvested were selected based on people's responses and field observations. We found it hard to enroll participants to disclose their preferred harvesting locations because previous studies neglected people's consent and resulted in stringent controls. Similarly, for sampling in non-harvested sites, we had to rely on forest department boats to take us around our random sampling locations. These locations were not always ideal for sampling and some areas were also restricted for entry. For instance, a major reason for sampling only one plot in Site VI was the absence of boats, and the high density of crocodiles in the region due to which we were not allowed additional sampling. Site differences are summarized in Chapter 4, to highlight some of the spatial variation in our study site, but all other results are direct comparisons between groups (harvested and non-harvested). Additionally, the results are not substantially impacted by the sampling framework because species observed in the sites were representative of the species complexes found in each site (explained further in Chapter 4). Overall, we collated information from twenty-six mangrove vegetation plots on species composition, structure, and biomass, as well as thirty-five mangrove soil samples to test for carbon and nitrogen levels.

Socio-economic and cultural data: The research site, Bhitarkanika Wildlife Sanctuary is situated within the Kendrapara district which is further divided into different community development blocks. The sanctuary falls in the Rajnagar block comprising of 18-gram panchayats which are rural governing bodies. The hierarchical structure of administrative units and villages selected for sampling as well as the sampling criteria are shown in Figure 1.2. In each village, we conducted focus groups consisting of 6-8 people, both men and women, to understand local priorities and values towards mangrove conservation. We also conducted surveys on different mangrove species used for cooking, amount of wood used by households on average, and information on land use practices to gather more data on people's relation with mangroves.

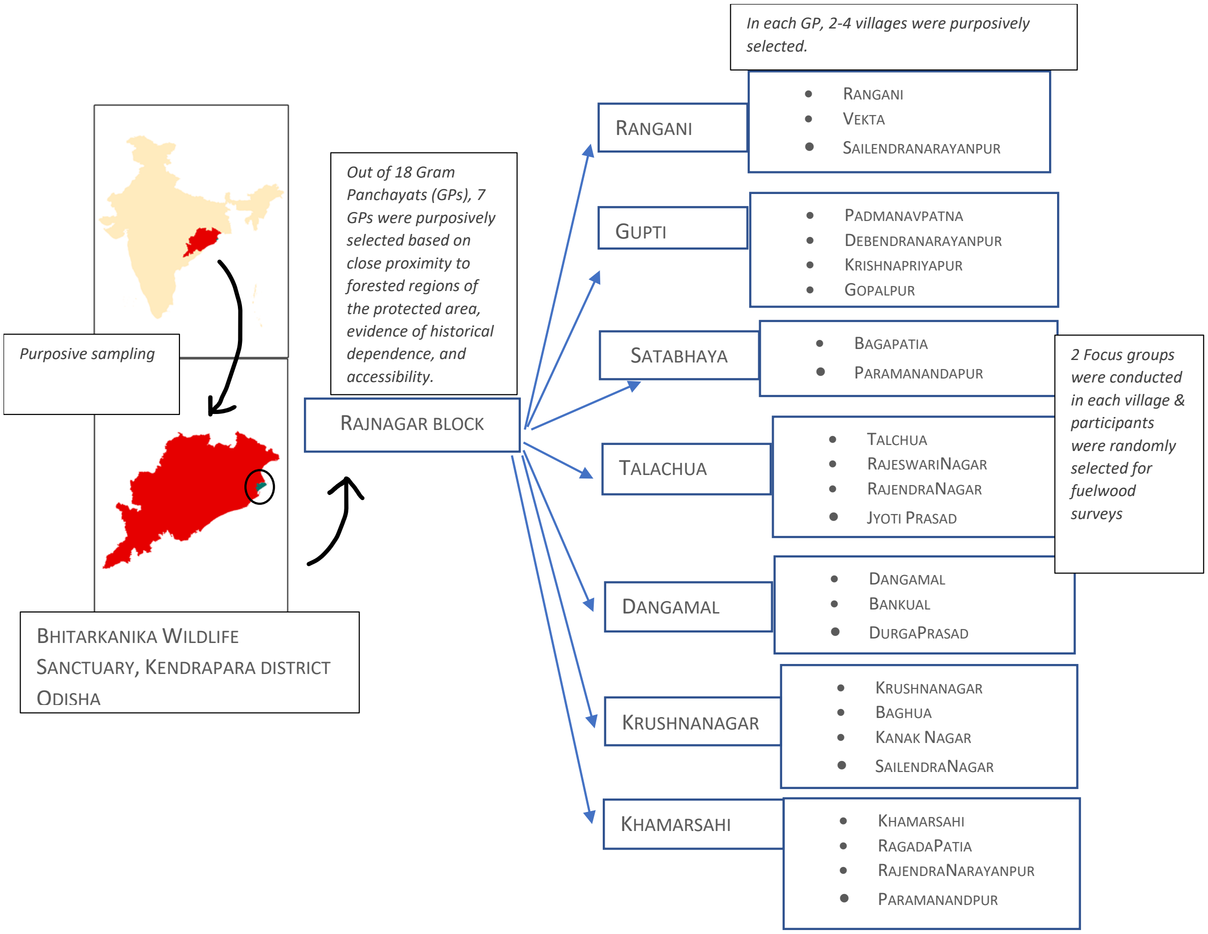

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Figure 1.2 Sampling strategy adopted for social interviews and surveys

1.3.4. **Research Methods, Data collection & Analyses**

In the following paragraphs I elaborate my choice of methods and their role in answering the several guiding research questions in this dissertation. I break the dissertation into three major themes comprising of three different, but interconnected facets related to mangrove forest conservation. **The overriding question of this dissertation asked, how do mangrove vegetation dynamics, gender relations, and historical legacies of use interact and influence politics of conservation in protected areas?** This question seemed pertinent in the light of the ongoing emphasis on blue carbon systems across the world because of their role in climate mitigation. To further understand how place-based drivers of change, power dynamics, and policies relate to global narratives of blue carbon, I used both ecological and social data collection and analyses techniques. The primary methods employed in this dissertation stemmed from different disciplines, from a combined spatial analyses of ecological data using both plot level and satellite imagery, focus group discussions and traditional surveys as well as the Q-methodology which combines priority ranking with in-depth interviews to understand similarities and differences among groups of individuals, social media analyses and agent-based modeling to develop a holistic understanding of the complexity in my field site.

1.3.4.1.Theme 1: Forest degradation

The first guiding research question of this dissertation was based on the role of disturbances in influencing the integrity of mangrove forest systems in my field site with implications for mangrove systems across the world. **The question asked was: how disturbances interact and impact mangrove ecosystems, including small-scale disturbances like firewood extraction (primarily collected by women) and more devasting tropical storms that have biomass altering potential?**

After spending several weeks seeking to obtain the necessary permits from the Forest Department in Bhubaneshwar, I set out to Bhitarkanika Wildlife Sanctuary to begin the proposed research for my dissertation**.** In some cases, either I or a hired local field assistant mapped different land uses (aquaculture, mangrove forest, paddy fields, fishponds, creeks, and rivers) in the area using a GPS receiver. Much of the forested landscape was near-impossible to traverse given the presence of crocodiles and the general lack of accessibility through boats or foot. Some of these unforeseeable logistical constraints warranted a change from the initial stratified random sampling strategy of measuring mangrove species composition, structure, and biomass. To overcome these challenges, I followed a purposive sampling strategy based on interview responses by local participants, especially for areas used for firewood and areas not utilized for firewood collection. The comparison provided insights on plot-level vegetation dynamics at a finer resolution, especially while comparing with modeled outputs from satellite imagery. Chapter 4 provides an in-depth overview of the field protocols adopted for measuring mangrove trees in harvested and non-harvested areas. To understand forest degradation in the light of large-scale disturbances like tropical storms, I used remote sensing techniques to analyze a series of historical satellite imagery. I used MODIS Gross Primary Productivity (GPP) product at 500 m resolution from 2000 to 2020 to understand how GPP changed over time at different sites, and Planet satellite imagery (Rapideye ortho radiance and surface reflectance products) at 5 m resolution from 2011 to 2020 to obtain streamlined changes at a finer resolution for my site. The modeling process is outlined in Chapters 3 and 8. The field data collection, including obtaining data from satellite imagery was possible due to collaborations with external partners like P Raghavan, who shared data from sites in the Andaman Islands, which helped in developing the modeling process for biomass estimation and prediction. The plot level measurements, and forest biomass change derived using satellite imagery helped me link local actors' characteristics to forest cover changes.

1.3.4.2.Theme 2: Conservation Values

The second guiding question was: **how do mangrove conservation values vary across the study area and across the world?** This question was intentionally vague as it necessitated comparing local participants values with those of external actors as well as global values towards mangrove conservation. It also necessitated asking how these values varied or changed locally especially with protection policies in place. For example, how conservation values interact with the impact of overlapping national park, or sanctuary boundaries and the current emphasis on setting aside areas for the conservation of blue carbon systems with the expectation that local communities forfeit their livelihood needs. The first part of this chapter looked at value outcomes at the local scale and asked, **"how exclusion impacts mangrove conservation values, priorities, and motivation?** I chose the Q-methodology to look at how people value mangrove forests at the local scale and a content and sentiment analyses of tweets to compare the value spectrum globally and its interaction with regional/local mangrove discourse. I also define the elusive concept of value in Chapter 5, and highlight the diverse ways in which it is expressed across the social sciences which also justifies the need for engaging with mixed methods to understand the human-mangrove relationships and how people value mangrove ecosystem services.

1.3.4.2.1. Q-methodology

The Q methodology (Q) is a common technique in psychology that allows the identification of diverging and converging values and perspectives among participants. Several social and environmental studies have applied QM in identifying a range of perspectives in natural resources management and conservation discourse (Zabala et al., 2018). Moreover, it provides the benefits of using both quantitative and qualitative data. The Q is a mixed method that combines quantitative surveys and qualitative interviews of stakeholders to determine distinct perspectives embedded in the sampled population. In this study, the Q was used to understand the subjectivities in opinions or viewpoints on mangrove forest conservation discourse.

The standard Q protocol generally follows a sequence of activities—collation of Q-statements, sorting of statements, factor analysis, and interpretation. A set of statements or discourses are collated from stakeholder groups, usually from literature (including visuals), pilot interviews, discussions, consultation with experts, or popular media. A curated set that is representative of the topics and ideas pertinent to the group is further selected to develop the Q-sample, usually between 20-60 statements. Each statement is sorted by participants on an ordinal scale, after which participants are interviewed to understand their worldviews on the topics presented and gather additional qualitative information relevant to their sorting approach. Each participants' sorts are compared using a multivariate data analysis approach, called the factor analysis and results analysed for trends in the discourse. Q identifies multiple subjectivities among social viewpoints and the knowledge structures that underlie those viewpoints using correlation rank scores.

The process of delineating subjectivities of peoples' perception of reality provides a basis for the method within a constructivist epistemological framework (Watts and Stenner, 2012) . Social constructionism looks at the social processes that influence those perceptions, choices, and trade-offs. As such, Q not only sorts different opinions as factors that relay similarities and differences among worldviews but also looks deeper into how such differences or similarities are created or come to be, further adopting a social constructivist approach. Additionally, the inclusion of a diversity of stakeholders to determine similar and disjoint perspectives provides an opportunity to understand the representation of marginal populations in policy discourse. Evidently, the method accommodates feminist epistemology by incorporating a diversity of stakeholders' worldviews which provides an opportunity to highlight operational power structures (Robbins and Krueger, 2000).

1.3.4.2.2. Social media analyses

Social media provides a rich and informative repository of data on global audiences that have access to the internet. By analyzing tweets relating to environmental or conservation themes, provided a unique lens to compare conservation values towards mangroves globally and locally at my field site using the Q-methodology. About 1,40,004 tweets were analyzed for the most frequently occurring words, the spatial location of the tweets were documented for comparison and a sentiment analysis of these tweets further provided insights on the spectrum of values evident in the content.

1.3.4.3.Rights and access

The third and last research question looked at two connected aspects related to forest degradation and conservation values and looked at the concept of gender and access. The guiding question asked: **how does gender and resource access/exclusion influence mangrove forest conservation?** This question combined the results of the above methods with participant observation, social interviews, historical document analyses, additional surveys on firewood extraction, and immersion in the study area over an 8-month period. A combination of ethnography and semi-structured interviews helped identify an anthropological conceptualization of local values which complimented the Q methodology, and the results from the social media analyses. It also helped in contextualizing how values, gender, forest access/exclusion, and degradation are connected and influence each other.

Because of the open-ended nature of semi-structured interviews, these questions only provided a loose outline of interview content. Participant observation also was a key element of ethnography. When possible, I toured farms and the mangrove forest with communities to learn more about their specific land use practices. I accompanied women to forest patches where they collected firewood, observed their daily activities like cooking dishes prepared for specific festivals, and their role in the paddy cycle—harvesting and parboiling rice. Participant observation extended beyond these specific activities into daily life activities while I was immersed in the region: visiting local schools, traveling on local buses across town, taking local boat rides to cross creeks, buying produce from local vendors, and conversing with residents in towns throughout the region, informally interviewing business owners, conservation practitioners. This plethora of contextual experience informed continual data collection and analysis.

1.3.4.4. Integration of themes: Agent based modeling

Lastly to understand how ecology and society work together in this landscape. I used an agent-based modelling framework to interpret the changes in mangrove forest productivity in the presence of different disturbances. The modelling outputs provide a visual spatial representation of biomass change with firewood collection patterns and incoming cyclonic storms. The rules governing the firewood collection pattern were adopted from the survey and interview responses and the biomass change profile obtained from the remote sensing analyses of satellite imagery. The detailed process is outlined in Chapter 8.

1.4. Researcher Bias, Reflexivity and Positionality

My social position, religion, and gender were subject to a number of beneficial and challenging situations which have been detailed below as and when they arose during fieldwork and the ways in which I tried to work around them, to the best of my capabilities. I acknowledge that data collection, observation, and interpretation are shaped by social perspectives and lived experiences of an individual. In this sense, it would be fair to note that research is equally shaped by the researcher's worldview, research skills, and the knowledge and biases one holds. Therefore, being cognizant of one's own inherent biases and privileges and recognizing them as crucial factors of the research process helps provide context while interpreting data. In the following paras, I reflect on some key points that, while influencing the research process, also helped me develop a holistic understanding of researcher-community relationships.

1.4.1 Nativeness versus non-nativeness

I was in my late twenties when I started fieldwork for this project. Although, shared identities were limited to our nationalities, cultural similarities through food (rice, coconut, and fish) helped me gel with the local community in my field site. My field assistant and I experienced otherness, exclusion, and belonging in varied forms, which may have influenced the research outcomes. After a few days of interaction with our local hosts and the surrounding community, a few things became very prominent. The first was the interest in knowing your caste, and second, the subtle regional rivalry between eastern and west Odisha cultures. I constantly struggled to balance nativeness in a non-native state, especially when participants could not decipher my caste. Social stratification and identity are important components in this society that influenced how people interacted with each other. It was not an extremely comfortable position for my field assistant (West Odiya habitant) either as she navigated being the mediator while being native but still an outsider. These social dynamics changed drastically when I was assisted by another student volunteer for the second half of my fieldwork season. Coming from an upper-caste background and sharing the same regional identity (East Odisha), her segue into the community was much more organic. Similarly, other conundrums of navigating spaces that may not completely fit into the native/non-native debate included having a meal with Bengali Odiyas or interacting with Muslim communities in the region. Although these communities are native residents here, we faced backlash in accessing these spaces by some community members. Social interviews with ‘native’ but othered Muslim communities especially was always not possible because of differences in food habits. My field assistant was not comfortable entering these households and at times communicated with the auto driver without my knowledge to skip them.

1.4.2 Privilege

I was privileged in terms of the opportunities I have had to be able to visit this new place, talk to people and experience their culture and hospitality. One of my overriding privileges were access to higher education because of an urban upbringing which also provided access to the most basic necessities like clean drinking water, public transport, and hospitals in terms of emergencies. I mostly interviewed farmers, and the highest educational attainment in this area was high school. One can reasonably assume that this statistic was very much limited to males in this region as the women barely attended school or left midway because of family commitments. I remember talking with an upper-caste community member who was rather sad one day. She was missing her 10-year-old son. He was living with her sister-in-law in another town (about 100 km away) because of the lack of good schools in this area. She had the opportunity to send her son to a relatively better school because of a good family network which most other people in this region probably did not have.

In contrast, my educational background did not give me the privilege to gather a solid footing with some community members because of my gender and marital status. Being an unmarried woman in her late twenties was surprising and unusual to the people I interacted with. It was challenging to be seen or heard at times as living in the place warranted dealing with native expectations while also being treated as an outsider while negotiating fair prices or treatment on daily interactions.

1.5. Caveats

The main caveats of this study included the temporal boundedness of data collection adopted because of institutional, financial, and logistical difficulties. The data gaps resulting from missing seasonal information on vegetation dynamics were accommodated through collaborative research with other scientists, referring to published government reports and archival documents to learn more about the place. At the same time, respondent fatigue was another aspect that prevented ready access and insights to community issues and experiences. It was challenging to recruit local participants at times, while at other times, respondents showed disinterest in answering questions midway through the interview process. The fatigue was generally from the ongoing surveys on storm impacts on communities by multiple institutions and agencies including government officials, forest staff, NGOs, and academic investigators. At all times, I made efforts to explain my research and its objectives to engage the respondents in the interview process and in cases where respondents expressed their disinterest, recruited other willing respondents, or scheduled meetings for other times. Both these factors might have influenced gathering rich data on diverse perspectives which may have impacted the overall study.

1.6. Conclusions

This chapter described the overall research design and methodology which was used to undertake the research including the different tools and methods adopted for each guiding research question and the overall sampling strategy used to implement them. By providing insights on researcher bias and positionality, the chapter also tries to engage more with the research process. The process highlights the stronger and richer aspects of the research and outlines areas for improvement which future studies can build on.

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CHAPTER 2
STUDY AREA

Through this chapter, drawing from field work conducted between September 2018 and March 2019, I attempt to connect the everyday rhythms of life with the seasonal rhythm of tropical storms and the monsoon to provide a place-based, situated narrative of Bhitarkanika, my field site. By thinking through literature from ecology, politics, and geography, I explore place-making through the activity of walking. I first situate the concept of rhythm in place-making, and then walk through my field site presenting stories of entanglements, relationality, reciprocation, displacement, belonging/otherness to explore temporal sense-making in this landscape. I then close the chapter by drawing attention on how boundary-making is manifested through a narrative of assorted histories, folklore and realities using the concept of "dwelling".

2.1. Tracing roots, tangled histories, and present realities through human and more than human worlds of Bhitarkanika, India

"in a world of incessant movement and becoming, one that is never complete but continually under construction, woven from the countless lifelines of its manifold human and non-human constituents as they thread their ways through the tangle of relationships in which they are comprehensively enmeshed" (Ingold, 2011: 141).

These continually evolving movements observed from the paths furrowed by individuals, develop, and transform like the path taken by meandering rivers that flow into tidal ecosystems. Ingold's ideas offer a way to understand the enmeshed network of human and non-human worlds and how they create continuous, changing, and evolving rhythms.

During fieldwork I learned how the past and present-day realities intersect and shape the enmeshed channels of relationships between humans and more-than human worlds in Bhitarkanika. I arrived in Bhitarkanika during the post-monsoon season (September) of 2018. After multiple cancellations and rescheduled taxi rides owing to two storm warnings that season, I reached Dangamal to be greeted by welcoming faces. The ride to my place of stay was nothing out of the ordinary, being a native researcher, I was accustomed to the life in a typical Indian city which included the usual hustle bustle of traffic on concrete bumpy roads because of potholes from yesteryears and the everyday rhythms of city streets. We passed through several roadside stalls selling tea and snacks, vegetable and fish markets and crowded bus stops before the distinctions between a city, town and village became apparent. Soon concrete *pakka* roads changed to muddy *kaccha* roads, and a concretized landscape changed to mosaic of green fields, fish farms and water bodies. The villages were composed of mud houses whose walls were intricately hand painted using rice paste (Figure 2.1) while a smattering of cement and brick houses were seen, here and there.

Figure 2.1 Mud houses painted using a mixture of rice paste

Bhitarkanika Wildlife Sanctuary, a tide-locked protected area extends from N 20° 29' 40” to 20° 58' 30" latitude and E 86° 41' 40” to 87° 03' 30" longitudes on the eastern coast of India. Historically, this region known plainly as Bhitarkanika, the largest single estate on the Cuttack Revenue roll with a total extent of 440 sq.miles, out of which 275 sq.miles were in the district of Cuttack and the rest 165 sq.miles in the adjoining Balasore district.

In the north, this region extended by the Parganas of Ankura and Bhera in the Balasore district; on the south and east by the Bay of Bengal and the kilia of Kujang; and on the west by the Parganas of Utikan, Damarpur and the kilia of Aul. Today, the Parganas and the Kilias, both historic princely kingdoms, have faded into district boundaries of democratically elected officials as shown in

Figure 2.2. The estates were referred to as 'Garh' by Hindus and 'Killa' or castles by Muslims (ref). For the purposes of administration, it was further divided into four division or *elakas,* namely Panchamuka (which covers present day Chandabali Tihidi and Basudevpur regions), Chhamuka (present day Rajkanika), Kerara and Kaladwip (present day Rajnagar block). The first elaka was in the Balasore district covering 240 villages and the remaining three elakas comprising of 481 villages were in the Kendrapara subdivision in the Cuttack district.

Today, this protected area also a Ramsar wetland site, is part of the Kendrapara district which used to be the trade hub of the ancient Kalinga kingdom as well as the first municipality of Odisha during British rule. The climate here is moderate with maximum mean temperature of the region can go up to 37° Celsius in summer whereas in winter it can drop to 13° Celsius. The average normal rainfall measured in the district is about 1510 mm. The Sanctuary is part of the Rajnagar community development block which has 18-gram panchayats (GP) or rural governance units and 309 villages (2011 census). For this study, I focused on 7 GPs (24 villages) which specifically surrounded the core area of the Sanctuary also legally regarded as a National Park. (See Methods for sampling locations and choice of GPs).

Figure 2.2 Present Day Bhitarkanika Wildlife Sanctuary as shown by the green box. Source: Odisha census 2011.

2.2. Placemaking through footprints

After a long day of sampling, we returned to our lodging late evening. Soon after a nice warm shower and change of clothes, the housekeeper came knocking at our room door for chai and pakoras. Chai time was all about long chats and sharing our experiences with Bhabhi, the lodge owner's wife, and the caretaker of the homestay. The lack of transport options meant most of our days were spent walking—walking to villages for interviews, walking to accessible forest patches for vegetation sampling, walking to observe how people spend their daily lives from 6 am to 4 pm every alternate day.

Late evenings, I set aside time for note-making and reflected the many interactions with people, places, and routes taken. That morning, on one of our sampling surveys, we walked a good stretch of more than 10 kms. We took a slight detour from the forest guard's usual path when he shared how he walked more than 20 kms inside the forest reserve every day. His day would start early in the morning at 4 am and continue till dusk. Planned amphibian surveys meant accompanying professors from renowned universities from Bhubaneshwar as late as midnight for trapping and netting surveys. When asked what he enjoyed about his work especially when it meant walking such long hours; striding through mud-soaked regions in his favorite casual blue and white rubber flip flops, he would say,

> *"I enjoy my job. It lets me roam for long hours in the jungle where I can observe the river, crabs, crocodiles, and the forest. I can work through the mud to plant mangroves that protect my home."*

Apart from accompanying high-profile tourists for nature trails around the forest, and assisting scientists out of sheer interest, he also looked after the mangrove nursery as part of the Department's mangrove restoration initiative in the region.

While the forest guard walked everyday along the same path, he traced his footprints, furrowed a track with places to pause, wander, dream, be remembered and astonished by the unexpected. They also helped me furrow paths, which traced narrow alleys where access was only possible by walking. While some paths were carefully chosen through conversations with local experts (or gatekeepers), some stories and interactions were chance meetings encountered on planned and unplanned routes.

Walking is an ordinary activity in our everyday lives, an unquestioned form of movement. Although, it is not regarded as a particularly insightful experience, yet it is through walking we immerse ourselves in the lived world. In a world of incessant movement, walking also provides avenues to slow down, observe and experience enmeshed relationships. One can experience the temporal embeddedness and cross-border connectedness of place by tracing everyday rhythmic movements by foot.

2.3. Of connected routes: The walk through the villages in Bhitarkanika

A walk around the villages in Bhitarkanika is filled with surprises and interesting experiences. We see men setting to work on their motorcycles to fish processing units or getting ready to work the paddy field or prawn ponds, women making a fire by burning wood, rice straws or dung cakes to prepare a fresh batch of *bhaat* (cooked rice) for their families, the hustle-bustle near community borewells, and the giggles of school children passing by (Figure 2.3).

Figure 2.3 A typical day in Bhitarkanika. Pictures depicting ordinary interactions observed and experienced during daily village walks.

Cullen (2021) theorizes that 'intra-actions' (pp 151) between storms, and everyday activities of living are intertwined with people's lives, recurringly changing the landscape through processes of "weathering" (Vannini et al. 2012, pp 361). The rhythmic cycle of the monsoon, the tidal rhythm of the sea or the incoming storms that unleash a cycle of impacts year after year are all embedded in the lived and representation lives of this place and its people. So do the fluctuating atmospheric patterns or changes resulting from progressing climate change continue to be enmeshed in peoples' lives, materialities and bodies through food, disease, and sensory perception. We walk through these entangled, sometimes diverging, sometimes converging routes to experience and understand places and place-making.

2.4. Traversing village paddy fields

Figure 2.4 Photograph of swaying rice fields. Picture credits: Dina Rasquinha

Rice and rice-based dishes form an integral part of people's lives, ingrained in their everyday rhythms of labour, leisure, and spiritual/religious significance. Paddy cultivation was, however, not the predominant land use in this area, a villager claims,

> *"When I came here, this place was a jungle. I took this place from Kanika King in just fifty-five rupees per acre and cut the jungle and build my home and rice field here."*

The fields (Figure 2.4) also provided the revenue needed for land rents that the King and the subsequent rulers demanded. The zamindari system was introduced during the Mughal rule in the region which continued during the British colonial rule (Table 2.1). Although the number of rulers took over the princely kingdoms, the inaccessibility of the region ensured that the submission of the Kanika rulers was only nominal in nature. The estates, and their chiefs stayed as *Rajas* and enjoyed a semi-independent status throughout the different rules in the state. During the Mughal rule, these chiefs also known as Garhjats or Killajats agreed to pay a fixed annual peshkush (rent) to the Mughals. The Mughals created more intermediaries as they remained busy in war, which were termed as zamindars. Kanika was placed under Aul zamindari. The Marathas followed suit and maintained the status quo to avoid conflict with the chiefs.

Table 2.1 The different rulers that governed this region at different points in time

Period (AD)	Ruler
1200 to 1803	Bhanj dynasty
1568-1576	Afghan rule
1576-1751	Mughal rulers
1751-1803	Marathas
1803-1947	British rule

Rice was a form of revenue, a source of income and the fodder that helped peasants survive. With time, rice has become an essential and integral part of people's lives and livelihoods. As the Odiya saying goes, "handi re pakhal nahin" which loosely translates to the emptiness of character, wealth, or prosperity by referring to empty dish of fermented rice. Pakhal is refers to the fermented rice dish, pakhala bhat, relished by the people all over the state.

As with many other states across India, the local variation of kanji rice (rice porridge) or pakhala bhat serves as a good rehydrating solution to paddy field workers to help them survive the intense heat during the day. A typical Odiya rice farmer or gherry (shrimp farm) worker will start their day with a large pot of *pakhala bhat,* accompanied with sides of dried fish, mixed vegetables, pickles, or curd, as an energy booster to help them through the day.

The term Pakhala (Figure 2.5) comes from the Sanskrit word '*prakhyalana'* which means to wash with water. The rice is soaked in an earthen pot with water, and a pinch of curd/lime for longer preservation times. The fermentation process usually takes about 7–8 hours. The fermented rice is known as *pakhala*. This rice preparation satiates and provides strength to the rice farmers, fisherfolks, daily wagers, every household here. Typically eaten as a summer cooler in most parts of Odisha, people here eat it all year for breakfast/brunch. There are many variants of this dish. The rice is cooked, cooled, and mixed with cold water and served with a side dish of dried fish or some vegetable preparation (bhaja) like potato or brinjal (eggplant). In other instances, it's seasoned with cumin, onions, and other spices and sometimes mixed with seasoned curd. It's something that connects the people of this region to their land and to each other.

Figure 2.5.Photograph of a. pakhala bhat with dried fish, b. Ranu tablets, the starter used for Handia fermentation. Picture credits: Dina Rasquinha

The labor associated with rice cultivation is equally ingrained in peoples lived realities and forms a crucial part of their identity. The growing cycle follows two rhythms to match the seasonal cycle of the monsoon. These two seasons are also named according to the season of harvest of the crop. The summer cropping pattern termed as the Kharif rice and the winter, Rabi rice. The sowing of Kharif rice or winter rice (Locally called *Sarad, Bada-Sarad* or *Laghu Sarad*) which is completely rainfed is usually taken up during June-July and harvested between November-December (Figure 2.6). About 84% of the country's rice crop is grown in this season (Das 2012, Moharaj & Rout 2020). Following the winters harvest, irrigated farming is taken up to produce the summer rice or Rabi rice (also known as *Dalua*, locally). The cropping cycle ranges from November-February with early maturing varieties grown in this season, to be harvested between March-June.

Figure 2.6 Top left a woman villager neatly arranges rice husks after harvest season in December while on the top right, a mound of rice grains can be found on the streets occasionally while walking through the villages. The movement of vehicles and pedestrians over the grains naturally separates the husk from the grain which is then collected for consumption or further processing as required. Bottom right and left pictures display the process of parboiling rice for consumption

Similarly, social customs and festivals have strong relevance to different phases of the rice cultivation process: Akhyatrutiya in May-June and Rajasankranti in mid-June marks the seeding and completion of the sowing process whereas, the ritual of Garbhanasankranti in October symbolizes the reproductive phase of rice, and Nuakhaee and Laxmipuja coincide with the harvesting of rice, respectively. Further, around mid-January, the Hindu festival of Makarsankranti is celebrated as Chaitra Parab by tribal and Adivasi communities to mark the end of the rice cycle, as by this time rice is threshed and brought to the granary (Das, 2012).

About 69 varieties of paddy adapted to the agro-climatic conditions of the place have been identified (Panda et al 2013). Several varieties of rice could withstand submergence during flood and some other varieties could also grow under moisture stress during drought conditions with higher tolerance for soil and water salinity allowing the co-existence of mangrove-paddy farms with tidal flow and annual flooding caused by the incoming cyclones augmenting the production of rice. Majority of cultivars suitable for lowland cultivation were also disease and pest resistant. However, with the adoption of modern rice cultivars, existence of many invaluable traits of traditional varieties are slowly being lost. Studies have shown that loss of traditional varieties and an increase in monocultures can decrease the resilience of cropping systems owing to changes in weather patterns or pest outbreaks (Altieri et al., 2015). As different species respond differently to change and diversity allows multiple species to co-exist, it enhances the system's functional capacity especially from when there is an incomplete understanding of the effects of environmental change (Elmqvist et al., 2003; Yachi and Loreau, 1999).

2.5. Caste, rice, beef, and beer

Rice itself doesn't discriminate, it satiates all: irrespective of caste, religion, or economic status. But processes of labor, land where rice grows and what you eat as an accompaniment with your rice can result in varied forms of othering. During the annual worship of Goddess Lakshmi, women recite the Puranas for a successful harvest and to invoke the blessing of the divine, which provides moments to pause and reflect on the intricacies of labor, caste, and human relationships in farming rural communities in India.

Although the story values women's work in the production of rice and challenges caste discrimination, the mythological tale doesn't reflect the realities as what you eat determines who remains in your social networks. As we walk from one home to the other, a Hindu household to a Muslim household, a Brahmin household to a Dalit household to an Adivasi household, we listen and learn the different ways in which rice is consumed and how different communities find beef in each other's ways of being and surviving, which may lead to different kinds of oppression. Religion doesn't change the way people interact or share information or even resources, but it does create subtle material demarcation (cutlery is not shared or exchanged) and sometimes segregation (where similar communities live). Similarly, rice beer (*Handia,* Figure 2.5) is consumed in small quantities as local beverage by the Adivasi communities providing even medicinal benefits (Joseph, 2021) but for many others a recreational and cheap source of intoxication changing the way an ordinary product of rice with spiritual and cultural significance is visualized, ultimately leading to conversations about how people perceive communities and their ways of being.

2.6. The fishy accompaniments

Although paddy cultivation forms the backbone of this place, each household has a pond in which they rear fish for subsistence. As we observed and were also informed by many villagers that shrimp farming has increased in the region. According to the Coastal Regulation Zone and rulings of Supreme court, all shrimp farms around the park are illegal but as one villager explains, *"Yes, some illegal, some legal. Before this place was so undeveloped but now you see development in people's living, this is all because of the prawn gheries. People are riding autos here, have their own boats, a house full of amenities—this is all because of prawn cultivation. People, who studied well but have no jobs, they engage in this business more."*

While walking through the paddy fields we see men hauling craters of prawns into trucks (Figure 2.7). A passer-by tells us these prawns are for export and nobody here gets to eat them. They will be transported to Kolkata from Dharma Port and some to Cuttack or Bhubaneshwar, beyond which the workers have no idea about its destination.

Figure 2.7 Local fisherfolk filling crates of shrimp for export to the Dhamra port. Picture credits: Dina Rasquinha

We walk a little further to encounter three Bengali Odiya women who insist we visit their home for lunch. They wanted to cook for us and lure us with the opportunity of tasting fresh harvested prawns and fish from their ponds. We comply. The scrumptious meal and conversations fill our stomachs and hearts. The women are not native to this region but were married into the family. They each come from different villages in West Bengal. Their husband's family however has been living here from generations and they identify themselves as Bengali Odiyas, like many of the families in this village.

According to 2011 census, the demographic profile of Rajnagar can be described to be predominantly, Hindu (98.12%) followed by Muslims (1.7%), both native Odiyas and Bengali Odiyas (Bengali population settled here from West Bengal and/ Bangladesh) especially in some of the sampled villages. Similarly, people belonging to the Schedule Caste (SC) constitute 12.6% while Schedule Tribe (ST) 1.4% of the total population. The demographics creates intriguing dynamics in the region. Among the sampled villages, three villages were predominantly composed of Bengali Odiya families with all villages showing further spatial segregation between Muslims and Hindu families. The labor profile however did not vary with religion or caste. They were either involved in agricultural or fishing activities, ran household industries or worked as daily wage laborers.

Crab farming, like shrimp farming is also slowly catching up in this region. It makes for more sustainable farming techniques since mud crabs are free from diseases with a high survival rate and grow a sizeable chunk in just a few months. About 1500 kg of crabs can be cultivated in a pond of one hectare. Tourists can order crabs or shrimps ranging between 150 INR to 500 INR per plate from local vendors depending on the variety. A steep (almost 50%) increase from the market rate. The local varieties of shrimp cultivated for sale include *Penaeus monodon* locally called Bagada or black tiger, *Penaeus indicus* also known as Kantala or white prawn, Marandi or brown shrimp whose scientific name is *Melapenacus menecerus* and the exotic *Penaeus vannamei* or whiteleg shrimp. All are large or giant shrimp varieties. Similarly, the local varieties of crab cultivated for sale include *Scylla serrata* and *Scylla tranquebarica.*

On our way back from our afternoon meal, we cross paths with three kids running around with basket nets. They grasp for breath while running and call us to look at their catch from the mangroves. They generously offer us dinner, their fresh haul of crabs for 150 INR, at half the price they usually sell during the peak tourist season. I noticed two interesting aspects about both crab and shrimp production in this region. The produce was solely catered towards export or tourists whereas a different variety of crab not produced on a large scale, much tinier in size, much juicy but with almost negligible meat and more crunch, cooked with onions and tomatoes was consumed with rice occasionally by villagers. Mud crab farming hasn't taken flight like shrimp culture but shows promise. In contrast, shrimp cultivation receives both favoritism as well as caution. Some exclaim that Bagada prawns are not what they enjoy, they prefer tiny prawns. Paddy cultivators warn that their fields are getting contaminated by the chemicals released from the *gheries*, which is destroying their produce and land. Some other villagers including the Forest Department warn the released chemicals are destroying the mangroves.

2.7. Walking the change

The housekeeper comes knocking at our door once again. This time to bid farewell with a plate full of pakoras and chai. He informs us that he has quit his job and is planning to leave for Kerala next week for work. A little surprised as he was still in the early years of his education, I ask why he does not continue working here until he finishes his education as landing a job with a degree would be easier than leaving school midway. He replies that he will turn 18 next month and he knows many villagers who have gone to work outside and are earning over 10,000 INR (~130$) per month. Being the sole breadwinner, and with an ailing father he had to stop his schooling for a couple of years to support the family. Now he doesn't seem to be interested in completing his education as he wants to make big bucks by travelling to a big city like everyone else in the village.

His case raises many questions about the lack of opportunities but also how social conditions perpetuate a cycle of choices for the people (outmigration for work) in this region.

As we continued the next day on foot, I realized that the everyday rhythms are slowly changing with the changing climate, politics, and demography of the place. We observed more women, and older men in the villages and young male adults leaving for cities in search of jobs. Migration is closely timed with the presence and absence of labor activities associated with paddy cultivation and fishing bans, respectively. The Olive Ridleys feature in the Red List of Threatened Species by the International Union for Conservation of Nature (IUCN). They surface on Odisha's beaches especially near the mouths of Dhamra, Devi and Rushikulya rivers as well Gahirmatha beach in large numbers to lay eggs. To protect the mass nesting sites (arribada) of the turtles, motorized vessels/trawlers within 20 kilometers of the state's shoreline remain off-limits to fishers from November to May every year. The ban is imposed for 120 kilometers of the 480-km coastal stretch of the state's shoreline. The move while protecting the iconic turtle species, also impacts thousands of traditional fishermen, including persons involved in fishing, selling and boat mechanics. The government provided Rs 7,500 per family as a one-time livelihood support to about 14000 families in the region in the year 2018. This meagre compensation doesn't help solve the lack of opportunities available to people in this region nor does it help cover living or schooling expenses for families.

While the ban stays operational, fisherfolk travel to other states where fishing is supported during this period to supplement their incomes. These may include nearby states of Andhra Pradesh, or Tamil Nadu but also further south to Kerala or towards the west coast of Maharashtra and Gujarat. A typical annual calendar of livelihood activities (Table 2.2) provides insight on changing place-based temporalities resulting from conservation policies but also how place-based relationships continue through familiar labor practices.

Table 2.2 Annual calendar of livelihood options. 5th April 15-June 15 offshore and open sea banned by trawlers & motorized boats whereas from November 1 – May 31 offshore fishing remains banned for breeding and recovery of the Olive Ridley turtles

Month	Fishing ban	Schedule #1	Schedule #2	Schedule #3
January		Rice farming	Rice farming	Rice farming
February		Rice farming	Rice farming	Rice farming
March		Rice farming	Crab farming /Pond fishing/ Prawn aquaculture	Rice farming
April		Crab farming /Pond fishing/ other daily wage jobs including prawn aquaculture	Crab farming /Pond fishing/ Prawn aquaculture	Outmigration to other cities
May		Crab farming /Pond fishing/ other daily wage jobs including prawn aquaculture	Crab farming /Pond fishing/ Prawn aquaculture	Outmigration to other cities
June		Rice farming	Crab farming /Pond fishing/ Prawn aquaculture	Outmigration to other cities
		Rice farming	Open sea or, and offshore fishing	Outmigration to other cities

July		Rice farming	Open sea or, and offshore fishing	Outmigration to other cities
August		Crab farming/Pond fishing/ other daily wage jobs including prawn aquaculture	Open sea or, and offshore fishing	Outmigration to other cities
September		Crab farming/Pond fishing/ other daily wage jobs including prawn aquaculture	Open sea or, and offshore fishing	Outmigration to other cities
October		Crab farming/ Pond fishing/ other daily wage jobs including prawn aquaculture	Open sea or, and offshore fishing	Outmigration to other cities
November		Rice farming	Rice farming	Rice farming
December		Rice farming	Rice farming	Rice farming

2.8. The path through the Walking trees

When we think of mangrove vegetation, we think of the Rhizophora mangrove or the red mangrove, also known as the 'walking tree' because of its numerous prop roots. But mangrove vegetation here shows a range of adaptations, root types and zonation patterns. The park's core area can be divided into roughly three distinct zones--Dangamal, Khola and Gupti Forest division. Khola which forms one of the entry points to Bhitarkanika, comprises of a series of artificial waterways, dug out by the then King of Kanika to facilitate navigation and connection to the Brahmani River. A boat ride through the creeks from Khola to Dangamala provides a glimpse into the non-human world in this region. While perusing through the waterway, the sight of the slinking mud-soaked kumbhiras (crocodiles) basking in the sun will distract you from the branches of the mangrove trees rustling in the muddy stream water, almost blocking the channel. Occasionally, a brown winged kingfisher (Figure 2.8) will fly across the stream and perch on the rustling branch to rest for few moments before diving into the muddy water for a quick fishy snack.

While perusing on the boat, the boundaries we traverse while walking become blurry. The water seeps into the mud and disappears, the roots of the mangroves cover the mudflats like a fishnet, while propagules float on the wavy turbid water. The boundaries between the rice fields and mangroves are demarcated with barbed wires and the *kaccha* road that lines the clingy trees waiting to perch over to other side. I catch a glimpse of a sneaky monitor lizard (Figure 2.8) running across to the fields to pick up some grub, while it briefly pauses before disappearing into the mangroves possibly sensing the presence of a pair of glued eyes watching it slither away.

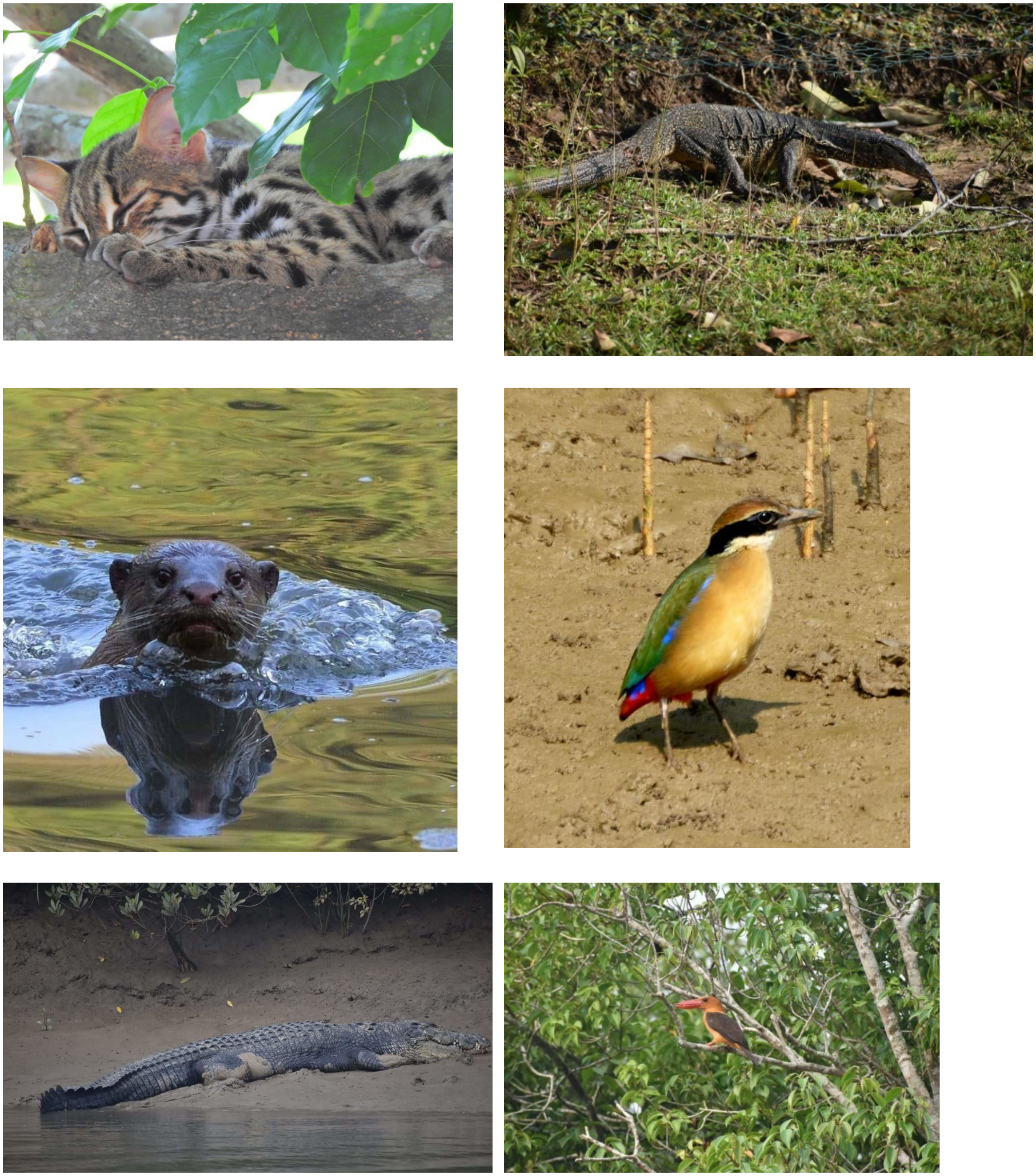

Figure 2.8 Faunal Diversity of Bhitarkanika. From top left, Blackcapped Kingfisher, King cobra, Fishing cat, Monitor lizard, Otter, Mangrove pitta, crocodile, Bown-Winged Kingfisher. Photo credits: Dina Rasquinha and Nirraker Behera

The mudflats provide many more non-human beings a haven to bask in the sun and nourish themselves. The crocodiles and otters, especially. The transition of the latter to live alongside human habitation has been much smoother than many other creatures. You can find them nestled in the mangroves or covered in a mud puddle along creeks or riverbeds. The crocodile, however, shares a love-hate relationship with the forest dwellers. The proximity to habitation and the fluidity of the landscape increases the chances of crocodile-human encounters, sometimes resulting in life-threatening situations. Then, occasionally if one is lucky, one may also spot a fishing cat curled up among mangrove branches.

Our boat was now moving inside Khola creek, into the narrow water channels surrounded by thick *Avicennia* trees (Bani in local language). The *Avicennia* is a very loved species in this region—frequently used as a source of firewood but also voracious colonizer occurring in newly formed muddy islands especially after a disturbance like a cyclone because of the presence of epicormic roots that aid post-storm recovery. The soft, muddy banks of these waterways support a range of low salinity loving mangrove species. Among these, *Sonneratia* species (*Keruan*) and the *Lata Sundari* or *Brownlowia tersa* dominant this area with grasses like *Myriostachia wightiana*, known as *Nalia* grass, locally. The local artisans use this grass for basket, toy and rope making. However, a ban on the grass collection within the park to prevent grass collectors from getting attacked by the estuarine crocodiles has impacted this ancient artform and the people dependent on it for their livelihood. When the ban was reinforced in 2010, about 300 craftsmen were left jobless. This artform has completely vanished since and only a handful artisans (a majority belonging to the scheduled caste group) remain that continue practicing it to keep it alive and as side income.

Mangrove associates like the *Pandanus fascicularis,* known as *Luni Kia,* also form dense patches along the Khola creek just like in many other parts of the park especially the Gahirmatha coast.

We change our mode of transport and hop on a boat to traverse the giant walking trees in Gupti measuring each prop root for our vegetation sampling surveys. Crossing over, the mangroves closer to Dangamal are largely composed of the *Sundari* trees, belonging to the Heriteria genus as well as abundantly covered by *Exoecaria* species.

The dependence on mangrove firewood is slowly changing due to several reasons ranging from local values towards these forests but also through policy initiatives that discourage dependence. Wood is not harvested in the monsoon and during other times of the year supplemented with rice husks or straws, alternate wood from woodlots and cow dung cakes. On an average, women collect about 30kgs (ranges from 25 to 300 kgs at times) of fuelwood per trip using forest permits or are fined when entering the forest without permits, which are valid for at least 6 months. The monthly requirement for fuelwood ranges from 25 to 300 kgs depending on the presence of alternative fuel sources like LPG cylinders.

The aftermath of the 1999 super cyclone changed peoples' perception towards mangrove forest. After witnessing the wrath that killed 10,000 people and left thousands homeless, people also witnessed the shielding protection of mangrove vegetation (Das and Vincent, 2009). Studies document that the villages lined by mangroves suffered minimum losses from the impacts of the cyclone (Das and Vincent, 2009) . Almost every villager that was encountered acknowledged the importance of mangroves in keeping villages safe from devasting storms year after year reinforcing the strong links between mangrove-human relations especially in light of tropical storms.

2.9. Walking down memory lane: Navigating the land and sea of the pirates

We make a quick pitstop for snacks and chat with the local boatmen parked here. They stall around in the hope of fetching some income by renting their boats to tourists for sightseeing. One of them tells us, *Dangamala means the congregation of boats."* It once possessed a large fleet of pirate boats, that looted, fought, and won battles against many royal and colonial rulers—the Marathas, Nawabs and the British East India company.

The pirates of the east Indian coast often traversed hidden beneath the dense foliage of the mangrove forest and the narrow meandering creeks of Bhitarkanika. The pirates with their skills, tools and technology that was catered to the local land-seascape had an advantage because of their familiarity with the region. The Marathas, for example used wide and flat-bottomed battle boats which were heavy and unsuitable for the wavy-sea front whereas the King of Kanika in alliance with the pirates of the region depended on long narrow boats equipped with barricades and nearly 100 paddles or oars, designed specially to navigate the regional waters. Likewise, sea-merchants rarely went away with all their treasures intact. Kanika remained a princely ruled state, free from the political ingress of external princely or colonial powers because of the pirates of this land, creeks, and the sea. The accessibility to the creeks and knowledge of the area worked in favor for the princes in this region against many invaders. The Marathas and Nawabs did not interfere with the politics of chiefs or zamindars or tried to overrule the Kanika Rajas.

For example, Hamilton in his work "The Hindostan (pp 46-47)" describes the advantage of inaccessibility that helped the Raja of Kanika in battles against the Marathas and strategy of the Kanika fleets –

"KUNKA. – A town in the province of Orissa, district of Cuttack, 80 miles N.E. from the town of Cuttack. This is the capital of one of the tributary estates in Cuttack subject to the British regulations, the exact limits of which have never been ascertained, but which have been roughly estimated at 75 miles from north to south, by 50 from east to west. Prior to the acquisition of Cuttack by the British, the Raja of Kunka, who possessed this inundated and unhealthy tract of country, had long baffled the Maharatta generals in all their attempts to subdue to him. The Maharattas had been accustomed to embark troops and artillery on large unwieldly flat bottom boats, unmanageable in large streams or near the sea, in consequence of which, their ill-constructed fleets always fell a prey to the Raja's light armed vessels, which were long, narrow, with barricades to cover the men, and some of them having 100 paddles or oars. When these squadrons met, the Ooria boats moved quickly round the heavy Maharatta armada, and picked off their men with their matchlocks, until the remainder were compelled to surrender, when they carried into a captivity from whence they seldom returned, the pernicious atmosphere of these morasses permitting none to live but the aborigines.

On this account the Kunka chief and his country were viewed with vast horror by the Maharatta, and when Cuttack devolved to the British government, its subjugation presented a task of difficulty as square rigged vessels could navigate but few of the shallow rivers at ebb tide, and the Ooreas were very expert at stockading both their country and streams. The perseverance and determination, however, of the British commander overcame every obstacle, and having, by a well concerted enterprise, in March 1805, captured some of the Kanuka Raja's boats, a detachment made their way in them to Kunkagur, which so staggered the chieftain's fortitude that he came out and surrendered, and with this operation, and not before, the conquest of Cuttack may be said to have terminated. At present the annual tribute paid to the British government is 19, 132 rupees, and the estimated revenue enjoyed by the proprietor, one lack. This territory produces rice and salt in large quantities, also some sugarcane, cotton, honey, and wax."

The same mangrove estuarine system that in many parts of the country because of colonial legacies was considered inhabitable, inaccessible and a mere wasteland was indeed a treasure for the princes here, that helped them maintain nominal rule but still enjoy the perks of monarchy.

Today, Dangamala connects the remaining villages of this region with the other small and large cities through a single road network and through the strong presence of the Forest Department in the region. The village is part of the larger gram panchayat which contains several smaller villages or blocks. Many of the villages in this Panchayat are not legally recognized owing to the discrepancies between forest-land boundaries. However, the largest influx of tourists rush here during the winter months. The only concretized road in this region runs through every village of this GP, connecting the far lands of Vetka, Rangani, and Talachua villages. An inch closer to the sea.

2.10. The path leading to uncharted routes: Conversing with the sea-merchants

As the year closes on us, the tides and the forests dance to the rhythm of the astral deities, rising and falling with the push and pull of gravity. The tide, the forests, and the moon bid farewell to the sea-traders or the *Sadhabas* that once set out during the month of Kartika to places like Bali and Indonesia during the reign of the Kalinga empire. This ancient tradition is commemorated through the festival of Boita Bandana which celebrates the maritime heritage of this region. The festival is organized every year from the day of Kartika Purnima which corresponds to a full moon day in the month of Kartika (Odia calendar) which is around the end of October and early November. People set afloat boats called biotas into nearby water bodies. Traditionally, these biotas used gigantic cotton fabric sails called Ajhala or Pala to utilize the favorable trade winds during the month of Kartika. The miniature floating boats are made of banana stem and carry earthen lamps, flowers, betel leaves, and coins, to mark the legacy of the maritime trade in this region. The women sing folk songs, which go by:

"Aa ka Ma Boi,
Pana Gua Thoi
Pana Gua Tora,
Masaka Dharama Mora"

which symbolizes three Odia months- Aa for Ashwina, Kaa for Kartika, Maa for Marghasira. and Boi for Baisakha. The song refers to the time spent by the merchants during their voyage to the Southeast Island countries of Bali, Java, Sumatra, Borneo, and Sri Lanka during the Asweena and Kartika months and their return journey during the Marghasira to Baisakha months.

The sea faring village of Satbhaya also derives its name from these sea merchants and their wives, viz. Sadhaba and SadhabaBohu. The SadhabaBohu is represented as a soft and lovely red velvet mite which surfaces during the moonsoon. The women of the *Sadhabas* were considered to be gentle soft beings, just like the soft and shiny *Sadhababohu* worm and living luxurious lives owing to all the wealth accumulated through trade routes. Their riches were talk of the town. Satbhaya village is located right at the edge of the mangrove forest that touches the Bay of Bengal. The legend goes that this place is named after the story of Ta'poi, the daughter of Tanayabant, the richest sea merchant of Righgarh, a town adjacent to the Bhitarkanika forest. The youngest of seven brothers, Ta'poi lost her parents at a young age and was abused by her sisters-in-law on the behest of a Brahmin widow when her brothers were out sailing. Her sisters-in-law except the youngest of the seven made sure her life was miserable. She survived by eating broken rice or Khuda and prayed to the goddess Mangala who resided in the mangrove forests. She offered husks and the same broken rice as offering for the safe return of her brothers so she could be freed of her misery. And also pledged to fast every Sunday. The Goddess soon heard her prayers and her brothers returned. Ta'poi then avenged her sufferings by cutting off the nose of their wives except for the youngest. Since then, Goddess Mangala is worshipped by the young girls for the wellbeing, prosperity of their brother and celebrated as the *Bhalukuni* (the name derived from the appearance of the girl – Ta'poi who resembled a bear) or *Khudurukuni*, the broken rice festival all over the state. The *Khudurukuni* festival is not celebrated by Brahmins considering Ta'poi went through all those hardships because of the Brahmin widow.

Today, Satbhaya is a memory and a feeling. The village was heavily impacted during the supercylone of 1999. Since then, most of the villagers have been rehabilitated to the inner reaches of the Sanctuary. Some relocated and rehabilitated households have found solace in a nearby village called Bagapatia which is about 10 km away. The village of Satbhaya is in fact considered the village of Ta'poi and her seven brothers. The name Satabhaya describes a cluster of seven villages namely 1-Kahnupur, 2-Balarampur, 3-Hariharapur, 4-Laxminararayanapur, 5-Gobindapur, 6-Gopalpur and 7-Banabiharipur. However, only a few hamlets remain with many of the inhabitants scattered in different villages after continuous annual storms and surging sea-waves have increased shoreline erosion, destroyed property, drastically increasing vulnerability of this region to disasters.

Satbhaya, situated at the edge of the sea, is often battered by incessant rain during the monsoons, and the crushing tropical cyclones and tidal waves. However, underneath this labyrinth of inaccessibility owing to extreme weather, dwells a rich past filled with stories.

Figure 2.9 a. Panchubarahi temple at Satbhaya. b. The newly built Panchubarahi temple at Bagapatia where most of the previous residents have relocated. c. A woman offers worship to the deities. At present four Dalit priestesses take turns to perform the temple rituals. Picture credits a and b: Nirraker Behera and c Ashis Senapati, courtesy: Gaon connection

The rich history of the centuries old Panchubarahi temple (Figure 2.9) is one of the many mythology legends that also make this region unique. The legend goes that a male Brahmin priest saw the deities unclothed and was cursed to become a stone. Thereafter, only women were allowed to conduct daily rituals and look after the welfare of the temple. Even today, all daily rituals are conducted by Dalit women priestesses from the adjoining fishing community, from the Sabar caste, who head this seaside temple and no man is allowed to touch the idols. The descendants of the Bhanj dynasty maintain control as the chief trustees of the temple. However, the future of this colorful and historically important location is threatened from the changes resulting from progressing climate change. In Aug 2021, a giant wave washed off much of this temple architecture and the idols were shifted to the nearest town.

2.11. Concluding remarks: Intersecting routes

This visual essay is a gathering of fragments assorted through movement around the landscape bringing insights that combine and build a rich, but partial understanding of how the human and more-than human world is entangled within a complex "dwelling". In his essays on *The Temporality of the Landscape* (1993) and *Building, Dwelling, living* (1995), Ingold builds on the concept of dwelling by highlighting that dwelling is the shared form of existence of all—human and more than human worlds. Thereafter, studies have utilized this concept to describe landscapes in a variety of ways (Cloke and Jones, 2001; Lounela et al., 2019). This essay of fragments also centers on the concept of dwelling by highlighting traces from the past, everyday life, culture, and the [uncertain] future that cultivates a relationship with place.

As Buttimer (as quoted by Vannini et al., 2012:363) suggests that dwelling is simply living "in a manner which is attuned to the rhythms of nature, to see one's life as anchored in human history and directed towards a future, to build a home which is the everyday symbol of a dialogue with one's ecological and social milieu".

In this context, I use dwelling as a place-making process especially while looking at how people in Bhitarkanika associate with their environment and are "emplaced" within the seasonal rhythms of the physical, astral, and social environment. The monsoon, the tropical storms, the tides shape how people dwell in their landscape which manifests in their food, culture, and movement patterns. It also draws us to the constant tension (processes of access/exclusion) and movement of both human and more than human worlds (shoreline erosion, human movement for refuge, livelihoods) which molds their sense of place.

By contrast, the mangrove forests, remain emplaced within the core areas of the national park, bounded by fences, accessible by boats to a few. In some other areas, they are disengaged from human habitation through rapid sedimentation processes occurring due to the flow of water. From some others, they have disappeared. However, historical ties maintain engagement through memories, social interactions, and movement of waterflow in the landscape. Fences do not entirely prevent people from accessing these forests, but policies (fines), social status, politics (who has access) influence the level of interaction. In the same way, policies and politics also dominate how people experience the landscape—through their farming practices, or fishing activities or where they choose to live.

In the past, access was merely nominal for non-native rulers while native rulers controlled the meandering and dense forests to their advantage. The pirates build alliances maintaining control of inaccessible forested areas while the sea-merchants enjoyed the riches of their trade. The past remains imprinted in the present where people still navigate the changing rhythm of control from princely rulers to elected government officials and the associated benefits and sanctions. These are manifested through regulating process of access (forest or open sea) but also through the changing weather patterns that influence their daily lives.

Processes of how change is produced, or how it manifests is inseparable from how it is experienced. According to Ingold (2000), dwelling is an emergent and fluid process constantly shaping nature-culture over time. Following, human livelihood patterns, histories, non-human counterparts, and their associated socio-cultural entanglements, provides an indirect way of engaging with a complex phenomenon of boundaries and how those change in time and space. By focusing on multiple stories across time, and space it becomes difficult to separate one from the other, from seeing the mangroves as a disconnected entity from the surrounding villages or from understanding the present realities of the people without digging into the past or the policies that govern the region. By tracing various lines of association with the human, the non-human and the more-than-human acknowledges these different spaces, are nothing but entanglements of each.

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CHAPTER 3

RIDING THE CREST OF WAVES: TROPICAL CYCLONES SHAPE MANGROVE PRODUCTIVITY GRADIENTS IN THE INDIAN SUBCONTINENT[1]

[1] Rasquinha, D. N., & Mishra, D. R. (2021). Tropical cyclones shape mangrove productivity gradients in the Indian subcontinent. *Scientific Reports*, *11*(1), 1-12. Reprinted here with permission of publisher.

Abstract

Recent literature on the impact of cyclones on mangrove forest productivity indicates that nutrient fertilizations aided by tropical cyclones enhance the productivity of mangrove forests. We probe the implications of these predictions in the context of Indian mangroves to propose potential future directions for mangrove research in the subcontinent. First, we look at the time series trend (2000-2020) in satellite-derived gross primary productivity (GPP) datasets for seven mangrove forests across the country's coastline. Second, we compare seasonal changes in soil nutrient levels for a specific site to further the arguments proposed in the literature and investigate the role of potential drivers of mangrove productivity. We find overall increasing trends for GPP over the past two decades for all seven mangrove sites with seasonal fluctuations closely connected to the tropical storm activities for three sites (Bhitarkanika, Pichavaram, and Charao). Additionally, organic carbon and nitrogen levels showed no significant trend, but phosphorus levels were higher during the post-monsoon-winter period for Bhitarkanika. Our findings expand the predictions of previous studies that emphasized the role of storm-induced nutrient fluxes and freshwater supply as primary drivers of productivity gradients in mangroves. Our study provides insights on how mangrove productivity may change with fluctuating frequency and magnitude of cyclones under a changing climate, implying the need for more mechanistic studies in understanding the long-term impact on mangrove productivity in the region.

Keywords: GPP, mangroves, Indian subcontinent, nutrient supply, tropical cyclonic storms

3.1. Introduction

The last few decades have witnessed a surge (~ 15% increase) in high-intensity tropical cyclones across the globe(Kossin et al., 2020). The increase in the proportion of high-intensity cyclones has significant implications for associated coastal systems through substantial socio-economic impacts. These increasingly frequent and intense cyclones can also have significant environmental consequences, including structural damages to ecologically sensitive coastal habitats such as mangrove forests, which provide many critical ecosystem services. In addition to their role in carbon sequestration and reducing water pollution, mangrove forests are well-known for their protective role against the dissipation of coastal storm surges (Alongi 2008). Mangroves and other coastal wetlands are considered as the first lines of defense against incoming cyclones. They help reduce the storm surge, wind shear, and the overall intensity of the cyclone and, in the process, also endure varying degrees of structural degradation such as defoliation and uprooting. The damages mostly result from strong winds, flooding, and the onslaught of runoff and sediment influx.

The Everglades, for example, have witnessed multiple significant hurricane events causing severe damage to the mangrove forests in the Everglades National Park. Hurricane Wilma damaged about 1250 ha of the Everglade mangroves in 2005, resulting in widespread stem mortality, basal area loss, and damage to the forest canopy, setting back the recovery that started following hurricane Andrew in 1992 (Smith et al., 2009). Similarly, in the Indian subcontinent, several recent tropical cyclones, namely Phailin (Category-5), Hudhud (Category-4), Fani (Category-5), Titli (Category-3), and Amphan (Category-4) are only a few notable examples of intense cyclones to make landfall on the east coast, since the great 'Super Cyclonic Storm' of 1999 (Kumar et al., 2020). The latter devasted vegetation, human life, and property when it made landfall on October 19, 1999, in the state of Odisha on the eastern coast of the country. It killed around 9,000-10,000 people, blew off structures, natural and man-made, with strong winds of 155 mph and a storm surge of about 8 meters. Much recently, the country has witnessed several super cyclones on the east coast bringing back memories of 1999. According to an initial survey by the forest department of West Bengal, the super cyclone Amphan that hit the east Indian coast in May 2020 ravaged about 1600 sq. km of mangrove forests (Jayanta Basu, 2020).

The damages resulting from such annual cyclonic events are visually discernible through the physical destruction of habitats, trees, and property but the long-term ecological trends remain relatively less understood. For instance, a study by Castañeda-Moya et al. (2020)(Castañeda-Moya et al., 2020) observed the positive aspects of hurricane impacts on the Florida Everglades mangrove ecosystem. They found that hurricanes help improve mangrove productivity, carbon assimilation, and resiliency due to vertical accretion from soil and nutrient deposition resulting from the land surface runoff. Mangrove ecosystems have high rates of carbon sequestration, which is reflected in their high aboveground biomass, soil carbon content, and belowground to aboveground biomass ratios (Alongi, 2008; Donato et al., 2011; Lovelock, 2008). Despite such high gradients of productivity, these systems are found to be nutrient deficient (Lovelock et al., 2011). However, nutrient fertilization aided by tropical cyclones can enhance the productivity and growth of this typically nutrient-limited ecosystem. A single hurricane, Irma, in 2017 resulted in soil deposition 6.7-14.4 times greater than the past 100 years accretion rate (Castañeda-Moya et al., 2020). Similarly, phosphorous (P) deposition contributed 49-98% to the total annual soil nutrient pool. The long-term interactions between mangrove forest productivity, tropical cyclone intensity, and resulting nutrient deposition, as well as its implications for coastal resiliency, remain uncertain. More so in developing nations like India, where mangrove ecology research is largely underrepresented.

India possesses about 3% of the world's mangrove forests which are shaped by press and pulse disturbances such as sea-level rise, coastal developments, and frequent tropical cyclones that impact the coasts annually (Figure 1). These forests are distributed all along the west and east coast of the country, and along the low energy tidal fringes, estuaries, and lagoons of the Andaman and Nicobar Islands. The mangrove area extent, species diversity, and land use dynamics vary along the west and east coast. Along the east, the mighty Sundarbans in West Bengal (2112 km^2) form the largest mangrove extent in the country followed by the island mangroves of the Andaman & Nicobar islands (616 km^2) (FSI, 2019). Other mangrove areas along the east coast include the river-fed mangroves of the Godavari and Krishna delta in Andhra Pradesh (404 km^2), the high species diversity of Bhitarkanika and Mahanadi delta in Odisha (251 km^2) and the estuaries of Pichavaram and Muthpet in Tamil Nadu (45 km^2). In comparison, the mangrove area is much smaller and dispersed along the west coast, with the Gulf of Khambat and Kachchh covering the largest extent in Gujarat (1171 km^2), followed by the urban mangroves of Mumbai and surrounding rural coastal belts in Maharashtra (320 km^2), the bird haven of Charao in Goa (26 km^2), the estuaries and backwaters in Kerala (9 km^2) and the fringing mangroves of the Aghanashini and Kali rivers in Karnataka (10 km^2)(FSI, 2019) .

Mangrove forest area, extent, floristic composition, and community diversity are vastly different between the east and west coast of India(Mandal and Naskar, 2008; Ragavan et al., 2016). Similarly, the impact from cyclonic storms is also found to vary greatly, with the east coast experiencing more frequent and damaging storm events than the west coast (Figure 1, Table 1). The differences in mangrove extent, species diversity, and productivity between the west and east coast can be attributed to the large estuarine environments shaped by the meandering deltas of the Ganga, Brahmaputra, Mahanadi, Krishna, Godavari, and Cauvery Rivers. The nutrient-rich alluvial soil and sedimentation from upstream discharge provide a conducive intertidal environment for mangrove colonization and growth. However, nutrient supply from upstream river flows can also be supplemented by nutrients through incoming stormwater pulses, which flood these regions more frequently than the west coast, annually (Figure 3.1).

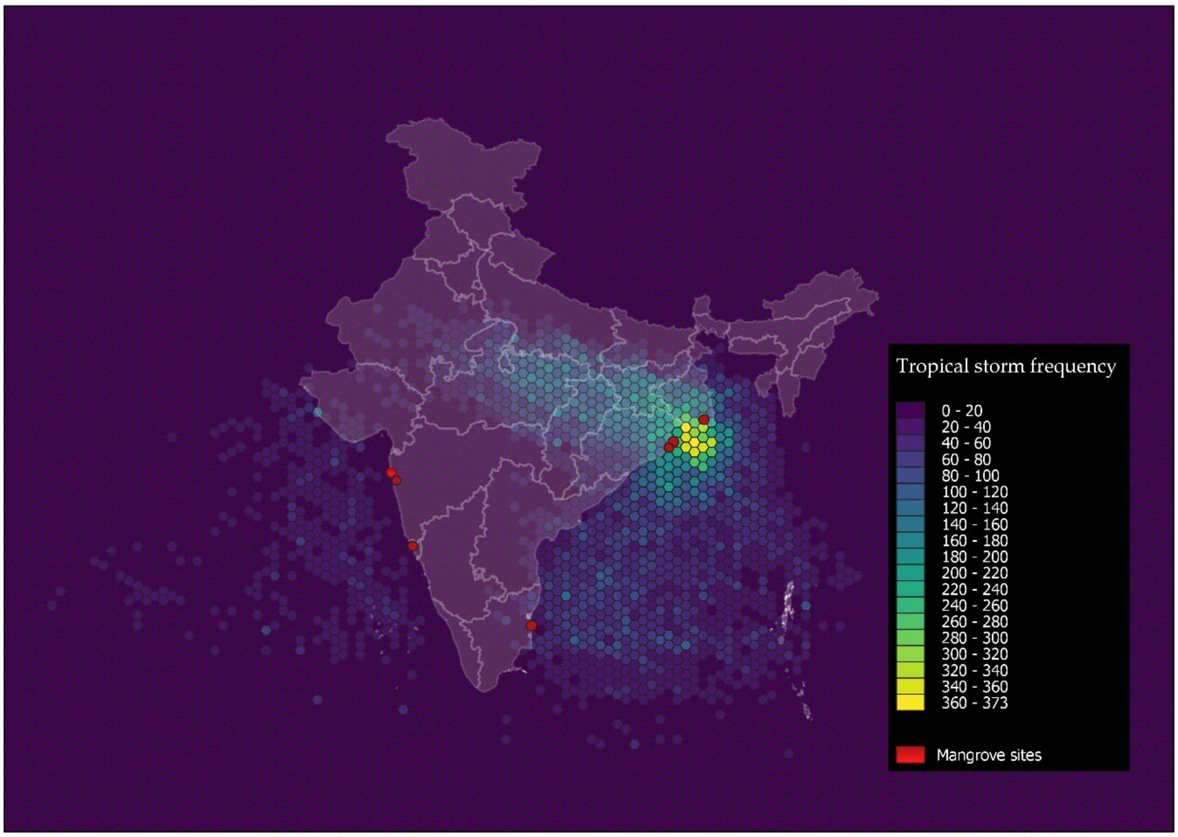


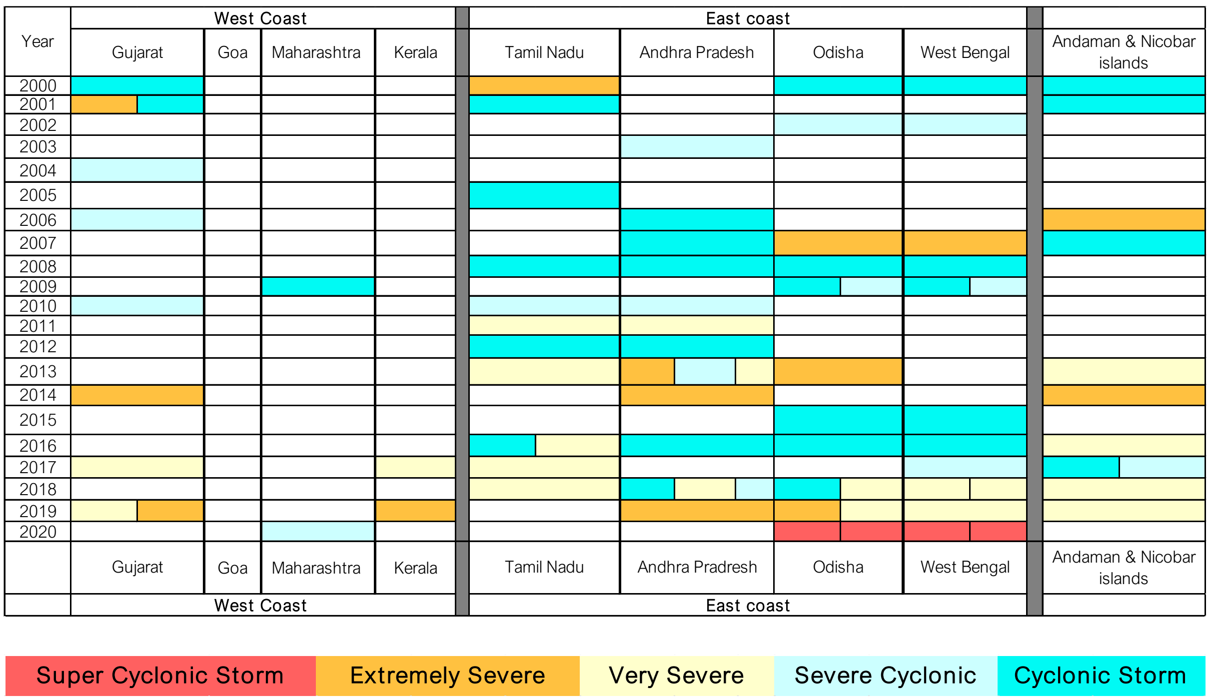
Figure 3.1Cyclone frequency from 1890 to 2020 along the Indian coast. The numbers indicate the frequency of storms overlapping on a 0.5 by 0.5 deg hexagon grid. The darker purple shades represent low frequency, whereas green to yellow shades indicate higher frequency. Red circles show the location of mangrove forests explored in this study.

3.1.1. Cyclone Frequency and Intensity along the Indian Coast

Between 1891 and 1970, a stream of about 98 tropical cyclones, including 55 severe ones, swirled the Arabian seawaters, whereas the Bay of Bengal absorbed and stood ground to nearly 346 cyclones, including 133 severe ones, in that same time period (Blasco et al., 1994; Kathiresan and Rajendran, 2005) . Studies have found that the losses occurring from cyclone events and even tsunamis were much less to areas protected by mangrove forest cover compared to other areas (Kathiresan and Bingham, 2001; Suresh HS, 2015). These relatively large numbers of cyclones swarming the Bay's tidal and intertidal areas have only increased in the past few decades, as presented in Table 3.1.

The devasting super cyclone of 1999 that created havoc with several thousand deaths and destruction to property remains a distasteful memory following which studies investigated the role of mangrove vegetation in protecting coastlines against such fiery storm surges. One such study found that mangroves lining villages, especially those surrounded by large swaths of mangroves, experienced fewer deaths than those that were located directly in the tropical storm's path(Das and Vincent, 2009). Although the frequency and intensity of these extreme disturbance events that rile up the coast every year have been increasing over the past decades, the damages caused to human life and property have reduced drastically. That is because of the increased awareness, preparedness, and disaster management initiatives by local governments (Rathore et al., 2016). However, studies posit that the intensities of the disturbances shape the resilience of vegetation structure and function(Alongi, 2008; Imbert, 2018). Studies also indicate an overall positive relationship between vegetation productivity and disturbance regimes, albeit at moderate levels(Capdeville et al., 2019; Galeano et al., 2017; Matayaya et al., 2017; Silva Pedro et al., 2016).

Table 3.1 Time series of tropical storms across the east and west coast of India, including the Andaman Islands, compiled from data available through the Indian Metrological Department (IMD). The colours represent the intensities of the cyclones in a given year. It does not, however, provide insight on the frequency of storms for any given year. Super Cyclonic Storm = Category 5; Extremely Severe = Category 4; Very Severe = Category 3; Severe Cyclonic = Category 2; and Cyclonic Storm = Category 1.



3.1.2. Mangrove productivity gradients in the Indian subcontinent

Studies evaluating the biomass and carbon stock spatiotemporal dynamics of Indian mangroves remain few and far between, but that trend is slowly changing with greater value placed on the carbon storage potential of these forests. The Sundarbans, the largest mangrove area (approx. 2000 km^2) in the country occupying more than 40% of India's total mangrove cover and a swooping floral diversity, both true and mangrove associate species, absorbs over 41.5 million tons of carbon dioxide daily, making it one of the most important blue carbon sinks in the world(Suresh HS, 2015) (Sahu et al. 2015). Similarly, mangrove forests in the Andaman Islands in the Bay of Bengal have shown to possess about 118.3 tC/ha of carbon stocks in biomass, followed by Tamil Nadu (62.81 tC/ha), Karnataka (50.40 tC/ha), and Gujarat (24.57 tC/ha) as documented by a series of studies compiled by Sahu et al. (2015). A much more recent study for Bhitarkanika and Mahanadi (Odisha) mangroves estimated a mean total of 124.11 ± 30.1 tC/ha(Banerjee et al., 2020).

Consolidating these findings, we explored the gross primary productivity (GPP) trends across different mangrove sites in the country to understand the different drivers of change. Our central hypothesis for this study was inspired by Castañeda-Moya *et* al.(Castañeda-Moya et al., 2020). We hypothesized that the cyclones and storm events have a net positive effect in the long-term on the mangroves' carbon assimilation abilities across the Indian subcontinent. We put forward two questions to test the hypothesis with publicly available data and model outputs.

1. *Do these intense pulses of storm surges that bring in nutrients, sediments, and other debris, shape the long-term allocation of carbon in mangrove vegetation?*
2. *Are the differences in carbons stocks related to growth and productivity across India's west and east coast a function of mangrove extent and diversity, or do frequency and intensity of storm events influence mangrove vegetation growth and productivity gradients?*

The goal of this study was to examine the long-term trends in GPP of Indian mangroves in reference to cyclone frequency and magnitude. We limited our investigation to seven different sites spanning five states across the west and east coast of India. These sites represent diverse protection regimes, species diversity, varying proximity to urban and agricultural centers, and a varying frequency of cyclonic storms.

3.2. Data and Methods

We used a combination of satellite derived datasets to understand the trends in GPP across seven mangrove sites along the east and west coast of India. The satellite derived trends were then further analyzed to understand linkages with environmental and nutrient fluxes from recorded field observations from previous studies as described below.

3.2.1. Cyclone frequency and Intensity

Data for cyclone frequency and intensity was extracted from the International Best Track Archive for Climate Stewardship (IBTrACS), a global historical archive on tropical cyclones worldwide. IBTsACS provides data by collating cyclone track information from multiple regional sources(Knapp et al., 2010). We also referred to the Indian Meteorological Department (IMD) to understand the intensity of cyclones that have impacted the Indian coastline during the last 20 years.

3.2.2. Long terms GPP trends across seven mangroves sites

We used MOD17A2H Version 6 500-m 8-day GPP products from MODIS (MOD17A2H, 500 m SIN Grid V006), which are developed using light use efficiency model and frequently used to monitor terrestrial and wetland carbon cycle processes (Tao et al., 2018) to analyze time-series trends in mangrove forest GPP. The images were processed using the Google Earth Engine (GEE) platform and analyzed with R+RStudio. For each mangrove site, area-averaged GPP values were extracted from MOD17A2H 500-m pixels to understand trends with time. MODIS GPP products have been extensively used across the world in different forest types, including mangrove forests to monitor vegetation productivity patterns, including estimating changes in carbon sequestration over time, to understand how biophysical variables such as temperature or rainfall correlate with forest productivity, and to develop models to predict future productivity trends (Hutley et al., 2013; Sannigrahi et al., 2016). The high temporal frequency of the product makes it a reliable and feasible option while analyzing current and predicting future trends. Using MODIS GPP time-series plots

(Figure 2), we demonstrated the spatiotemporal trends in mangrove GPP for the seven Indian sites along the west and east coast, which are under a varying degree of cyclone disturbance regime.

3.2.3. Seasonal GPP trends for three mangrove sites

While satellite derived GPP trends helped us understand long term GPP trends across the coastline, individual site analyses highlighted the seasonal dynamics of GPP with possible implications of the role of nutrients in influencing observed GPP trend. We collated data from published scientific reports on seasonal photosynthetic rates, fPARChl, and LUE values in Bhitarkanika, Odisha, Pichavaram, Tamil Nadu, and Charao, Goa for the year 2015 to investigate links between tropical storm activities and seasonal GPP trends(TVR Murthy, 2019).

3.2.4. Role of environmental variables and nutrients in influencing GPP trends

Further, to test if nutrient levels were higher post monsoon-winter seasons for the same time period (2015), and to understand the relationship between soil nutrient levels and changes in GPP, we analyzed soil carbon, nitrogen, and phosphorus data for Bhitarkanika forest mangrove site for the year 2015. Finally, we also looked at possible relations between various meteorological variables and GPP. Specifically, land-surface temperature (LST), storm runoff, evapotranspiration (EVAP), and rainfall patterns in influencing GPP gradients for a small mangrove region in Bhitarkanika (86.9014E, 20.6029N, 87.0511E, 20.8007N) using data from NASA's Giovanni (MEERA-2 simulations) portal for the years 2014-2016 as shown in Figure 3.5.

3.3. Results

3.3.1. Long term GPP trends of Indian mangrove sites

Our findings revealed the usual phenological cycle of GPP seasonally within any given year, but with a varying degree of an increasing trend over 20 years (Jan 2000 to July 2020) for all sites. Some sites, especially Pichavaram in Tamil Nadu, showed a remarkable increasing trend in GPP over the past two decades. Although no sharp trends were noticeable for the remaining sites, none showed a decrease despite the frequent and intense storms that have crossed paths with these forested areas, as shown in Figure 3.2. Frequencies of cyclones on the east coast (n=39) were relatively greater than those on the west coast (n=12).

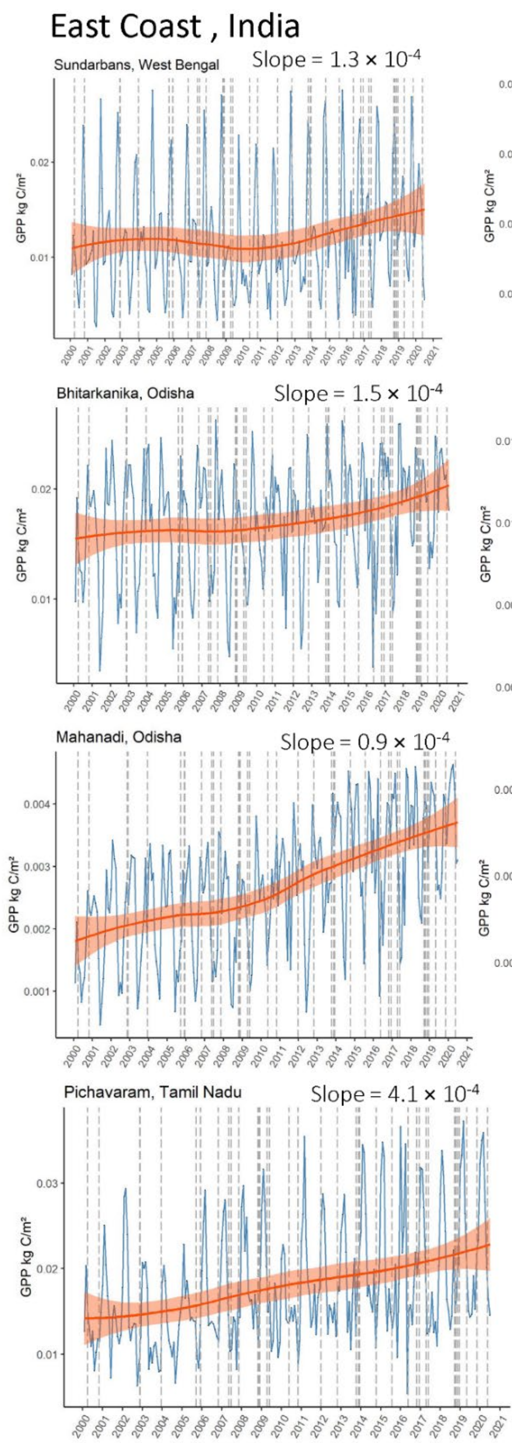


Figure 3.2 Time series of GPP for seven mangrove sites from Jan 2000 to July 2020. Dotted vertical lines indicate cyclone activity along the coast (number of tropical cyclones on the East coast, n=39 and West coast, n=12). Blue lines indicate the seasonal trend of GPP in a given year.

3.3.2. Inter-site seasonal changes in GPP

Seasonal changes in photosynthetic rates of mangroves have also been noted in Bhitarkanka, Pichavaram, and Charao (Table 2). Of importance here is that post-monsoon and winter rates were found to be higher for east coast mangroves (Bhitarkanika and Pichavaram), whereas summer rates high for west coast mangroves (Charao).

Table 3.2 Seasonal photosynthetic rates, fPARChl, and LUE values for mangroves in Bhitarkanika (Area extent=144.25 km2), Picharavaram (Areal extent=7.86 km2), and Charo (Areal extent=6 km2) for 2015(TVR Murthy, 2019). LUE values are noted as mean values for dominant mangrove species on all sites. Values in parentheses represent the total overall GPP (carbon fixed per day) for each site.

	Bhitarkanika (East Coast)			Pichavaram (East Coast)			Charao (West Coast)		
	Photosynthetic rate (g C m^{-2} day^{-1})	fPARChl	LUE (g C MJ^{-1})	Photosynthetic rate (g C m^{-2} day^{-1})	fPARChl	LUE	Photosynthetic rate (g C m^{-2} day^{-1})	fPARChl	LUE
Summer	1.2 (166831)	0.049	3.93	2.6 (20275)	0.15	2.20	7.7 (46376)	0.064	5.24
Post-Monsoon	1.7 (248762)	0.085	7.82	3.7 (29255)	0.11	4.34	1.2 (10658)	0.037	3.03
Winter	5.9 (844486)	0.153	11.61	2.7 (21560)	0.12	3.80	1.8 (7430)	0.049	1.77

Post-monsoon (7.82 g C MJ^{-1}) and winter (11.61 g C MJ^{-1}) LUE exhibited by dominant mangrove species (*Avicennia alba, Avicennia marina, Avicennia officinalis, Aegiceras corniculatum, Bruguiera cylindrical, Ceriops decandra, Excoecaria agallocha, Heritiera fomes, Lumnitzera racemosa, Rhizophora mucronata and Sonneratia apetala)* in Bhitarkanika were also found to be higher than in the summer (3.93 g C MJ^{-1}). Among these species, the highest values were noted for *Avicennia marina,* which recorded a peak with 12.52 g C MJ^{-1} in winter, followed by *Sonneratia alba* (7.28 g C MJ^{-1}) in post-monsoon and *Excoecaria agallocha* (6.17 g C MJ^{-1}) in summer (Figure 3.3). As LUE is directly proportional to GPP, we also see significant differences in GPP values between the summer and winter. For example, for the same recorded dominant species, GPP values for the summer (42.29 g C m^{-2} day^{-1}) and post-monsoon season (41.00 g C m^{-2} day^{-1}) were significantly lower than what was observed for the winter season (58.03 g C m-2 day^{-1}). Graphical outputs for Pichavaram and Charao are presented in Appendix A.1.

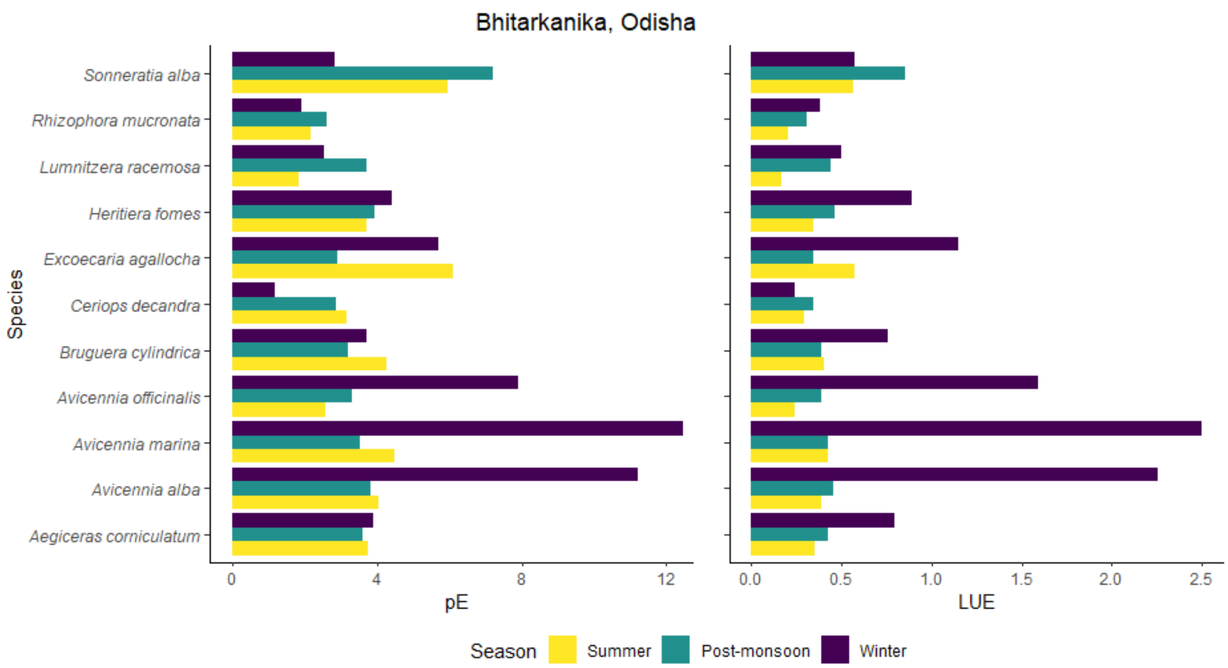


Figure 3.3 Seasonal variation in daily carbon fixation in terms of photosynthetic rate (pE in g C m^{-2} day^{-1}) and Light use efficiency (LUE or ε in g C MJ^{-1}) in dominant mangrove species in Bhitarkanika adapted from a published Government of India report(TVR Murthy, 2019). See Appendix A.1 for Charao and Pichavaram.

3.3.3. Role of Disturbance Induced Nutrient Fluxes

Apart from the physical damage caused by hurricanes and cyclones to mangrove stands, long term successional impacts through a regular supply of allochthonous sediments can also play a significant role in increasing surface elevation levels of these wetlands but at the same time also improve productivity and growth through timely nutrient pulses(Castañeda-Moya et al., 2020; Lovelock et al., 2011; Smith et al., 2009; Smoak et al., 2013; Whelan et al., 2009). Although the data provided are limited, we find that seasonal changes in organic carbon and phosphorus levels, which is also a limiting nutrient for Indian mangrove wetlands(Bala Krishna Prasad, 2012; Reddy et al., 2021), tend to slightly increase in post-monsoon season (Figure 3.4). However, nitrogen levels were lower in post-monsoon winter period as shown in Figure 4, implying that more data would be needed to establish the seasonal dynamics of nutrient fluxes and their role in influencing GPP gradients.

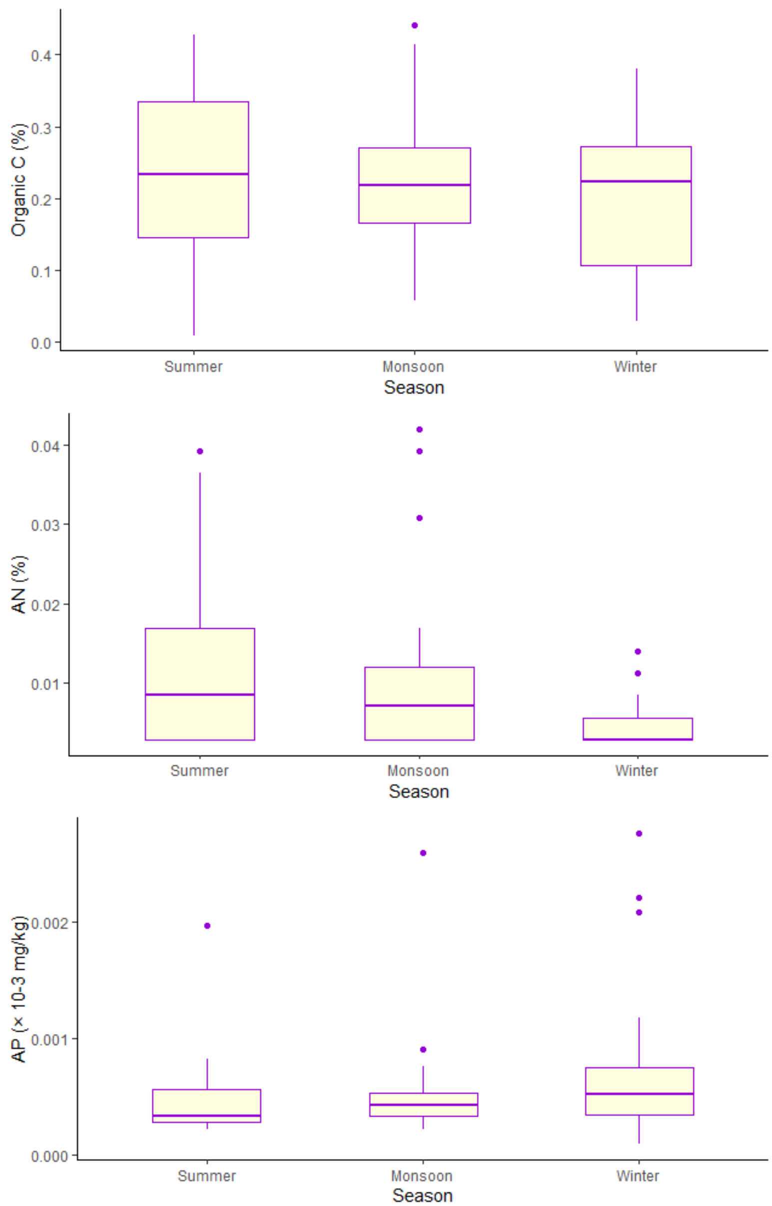


Figure 3.4 Soil carbon, available nitrogen, and phosphorus levels for the year 2015 for Bhitarkanika.

Therefore, our initial question about, do GPP values increase because of nutrient fertilization caused by frequent tropical storms along the Indian coast, seems plausible but needs more investigation. Although the 20-year GPP time-series graphs do not show sharp patterns of increase for all sites, none of the sites showed a decline even though there was a clear indication of increasing frequency for storms in the past two decades. The seasonal differences are manifested in all sites, implying sudden spike of freshwater supply and/or nutrient availability post storm events in enhancing LUE and GPP trends (Bhitarkanika, Picharavarm, and Charao) which warrants the need for more such studies. Evidently, inter-site species differences also play a role in influencing GPP trends, as manifested in Figure 3.3 and SFigure 1. Dominant species for each site can change the trajectory of recovery post-cyclone events, through differential competitive regeneration and growth processes.

3.3.4. Drivers of productivity of Indian mangroves

Focusing again on the data-rich site of Bhitarkanika, and to better understand the drivers that influence mangrove GPP, we looked at possible relations between various meteorological variables and GPP. We find that GPP recovers slowly but steadily between 2015 and 2016 after previous storm events peaking in the first quarter of 2016 (Figure 3.5). The spike in GPP is closely correlated with low evapotranspiration and LST values for the same period. Although, surface runoff and rainfall values dip during peak GPP, higher values are associated with storm events throughout. Also, worth noting is that during summer and pre-monsoon months(Bala Krishna Prasad et al., 2006), ocean water inputs are found to be greater relative to river flow, leading to lower dissolved nutrient concentrations which can explain why GPP is influenced by storm surges. This also proves the trend in Figure 5 for low evapotranspiration levels when GPP is high, implying low evapotranspiration levels maintain a steady flow of freshwater supply, keeping salinity in check, allowing GPP to recover post storms. However, recovery time is something that needs further investigation.

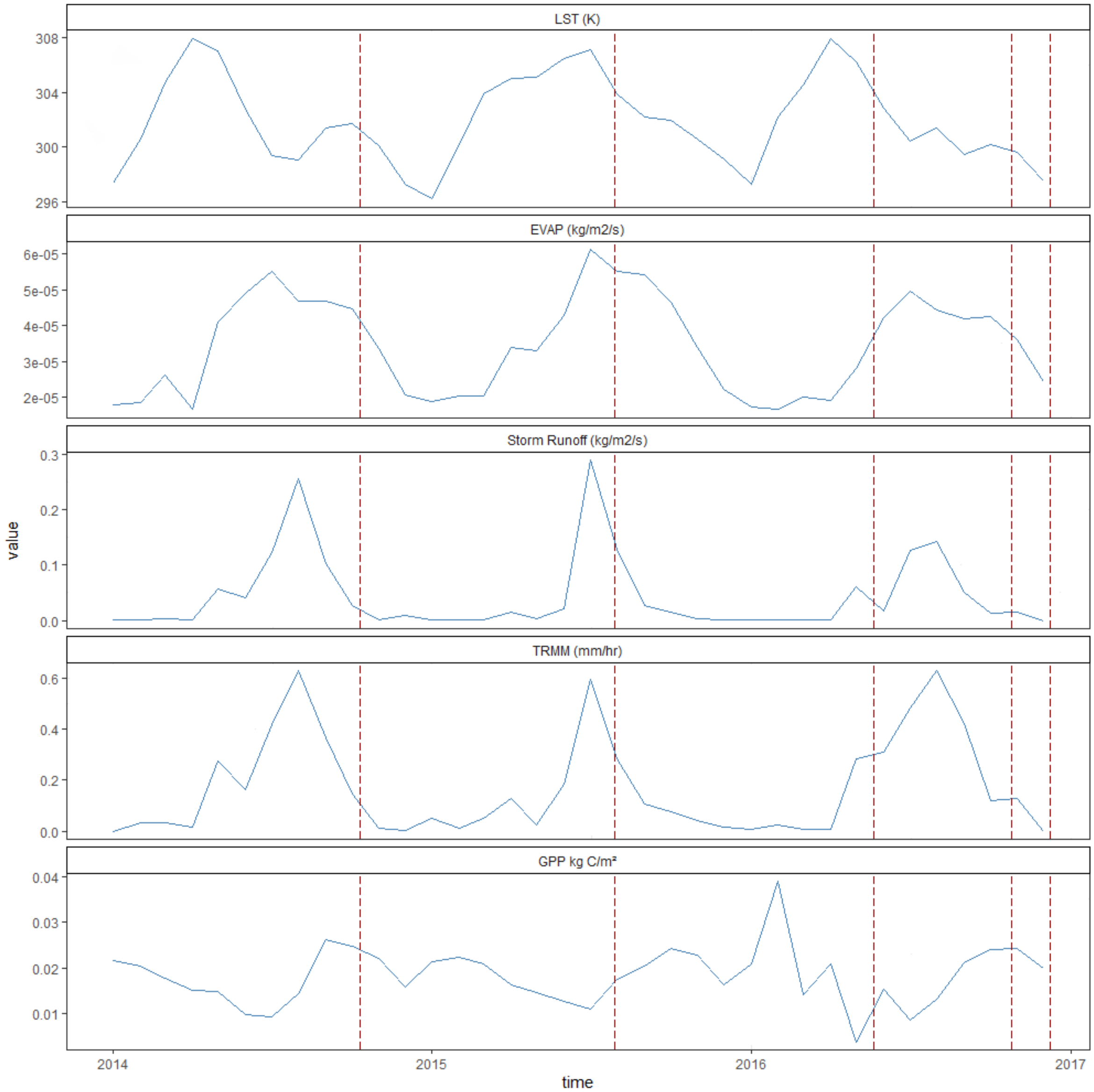


Figure 3.5 Time series, area-averaged monthly values for Land surface temperature (LST), Evapotranspiration (EVAP), Storm surface runoff, Precipitation Rate (TRMM), and Enhanced vegetation index (EVI) for pixels between Region 86.9014E, 20.6029N, 87.0511E, 20.8007N. LST data were obtained from MODIS-Terra MOD11C3 at 0.05 deg, EVAP data and Storm surface runoff values are model outputs of GLDAS-NOAH025 at 0.25 deg, precipitation rate data are from TRMM at 0.25 deg, and EVI values at 0.05 deg from MODIS-terra MOD13C2 satellite imagery.

3.4. Discussions

Productivity (GPP) of both terrestrial and coastal ecosystems is commonly estimated using the light use efficiency (LUE) model, which predicts that productivity is directly proportional to the amount of the incident photosynthetically active radiation (PAR). PAR is a function of seasons, latitude, and time of the day. This is particularly important as cloud cover in coastal areas can be variable, especially on the east coast, where it is found to be transient. In fact, coastal areas frequently experience overcast days, especially during cyclones and tropical depressions, which can influence light availability, and in turn, plant photosynthesis. Seasonal changes can also influence light availability and intensities, directly impacting photosynthetic rates of vegetation. Seasonal fluctuations in photosynthesis rates among other physiological parameters such as transpiration, PAR, and stomatal conductance were prominent in 16 true mangroves species in the Sundarbans(Nandy (Datta) and Ghose, 2001). For some mangrove species (*Aegiceras corniculatum, Avicennia officinalis, B. gymnorrhiza, and Xylocarpus mekongensis*), photosynthesis rates were considerably higher when measured in the winter than summertime despite lower levels of PAR (0.65 to 0.99 mmol m^{-2} s^{-1})(Nandy (Datta) and Ghose, 2001). According to several studies that found similar values(Ball and Critchley, 1982; Cheeseman et al., 1991), it can be concluded that optimum PAR for mangroves is low, about 25-50% of full sunlight is sufficient to saturate photosynthetic rates in mangroves. Seasonality can thus play a crucial role in determining growth rates and productivity in mangroves by influencing photosynthetic rates, which are more prominent and species-specific during the winter season(Nandy (Datta) and Ghose, 2001).

Following this logic, the high post-monsoon and winter photosynthetic rates for the east coast mangroves can be attributed to the steady supply of freshwater from river discharge and monsoon rainfall which also varies between the northern and southern mangrove wetlands. For example, the southwesterly winds bring rains to Bhitarkanika in the monsoon season from June to September, as well as light showers during the northeast monsoon season running from October and December. This is also when Pichavaram experiences its monsoon season. Both regions experience a prolonged dry season which is longer for Pichavaram area extending from February to September. The number of extreme drought events have also increased considerably in this region over the years(Lakshmi et al., 2021; Rajkumar et al., 2020). This has implications for the salinity gradients of the mangrove wetlands. For example, these gradients are found to be as high as 35 to 45 for Pichavaram. These prolonged dry spells are also found to be longer for southern mangroves than northern mangrove wetlands on the east coast, implying the role of tropical cyclones and depressions in influencing the flora, fauna, and fisheries of these mangrove wetlands. Evidently, mangrove species diversity is recorded to be higher on the east coast (about 40 mangrove species belonging to 14 families and 22 genera) than on the west coast (27 species belonging to 11 families and 16 genera)(Mandal and Naskar, 2008; Ragavan et al., 2016). Species-level differences can also be attributed to the differential ability of species to absorb and utilize available atmospheric CO_2 as well as other macro and micro-essential nutrients necessary for growth. Some species (e.g., *Excoecaria agallocha* or *Sonneratia alba*) can use a high level of PAR effectively, whereas some species (e.g., *Avicennia marina or Avicennia alba*) have evolved in shady conditions and can thrive well only in a relatively small amount of PAR before photosynthetic rate levels off. Studies have shown that some species exhibit traits that increase resiliency to storm damage through large nutrient reserves, and plant tolerance to high salinity levels(Alongi, 2008; Aung et al., 2013; Capdeville et al., 2019). Some others, such as *Avicennia* sp. can easily re-sprout from epicormic shoots(Alongi, 2008; Aung et al., 2013) (Alongi 2008, Aung et al. 2013). A recent study conducted in China reports an overall positive impact of diversity on mangrove vegetation productivity and soil carbon storage levels(Bai et al., 2021) (Bai et al. 2021). But disturbances through processes of gap-light dynamics can impact which species recover faster and contribute to the carbon pool. Disturbances can also enhance cryptic ecological degradation, compensating for the lost mangrove contributed biomass through mangrove associates that may have higher carbon storage levels(Rasquinha and Mishra, 2021).

Frequent nutrient enrichment is the most plausible explanation behind the observed increasing trend of GPP in Indian mangroves, especially on the east coast. Though studies on Indian mangroves focus on dissolved nutrients, similar seasonal and annual trends in nutrient load post monsoon or tsunami induced events further our argument on nutrient induced fertilization changes in GPP(Prasad et al., 2006, 2016; Ranjan et al., 2011). Changes in organic phosphorus were found to increase by almost twofold following the tsunamic in 2004 in the Pichavaram mangrove ecosystem(Ranjan et al., 2011). However, Alongi (2009 and 2014) reported that approximately 65% of GPP by the mangrove forest itself is respired, and the rest is partitioned into net primary productivity (NPP) allocated nearly equally to roots (36%), branches (32%), and foliage (32%). With an estimated carbon use efficiency (CUE) of only roughly 33%, a relatively small proportion of GPP is utilized in the aboveground biomass, and that could be why occasional physical damage such as defoliations due to cyclones and storms does not significantly impact the mangrove GPP. On the contrary, the negative impact of cyclones on canopy structure and canopy portion of the GPP, carbon assimilation by the mangrove forest as a whole is most likely being overcompensated by the increased pulse nutrient enrichment aftermath of the cyclones. That is because all other physical and meteorological variables, such as light, temperature, salinity, and tide level, that regulate GPP in mangrove ecosystems may have a seasonal (monsoonal) or intra-annual trend but do not reveal any interannual trend, unlike GPP in the past 20 years. Their relationships with mangrove light use efficiency (LUE) and GPP are complex and non-linear and do not have the compounding effect similar to nutrient deposition by increased cyclone frequency. In addition, Lovelock et al. (2015)(Lovelock et al., 2015) have found that the proportion of GPP buried as C in the soil is higher for the fringing mangroves than fertilized mangroves because higher nutrient flow may speed up the decomposition of soil C hence decrease the C burial rates. That finding supports our observed 20-year GPP trend, which shows a net increase in GPP for all mangrove sites, and more interestingly, a slightly higher positive slope for east coast mangroves (See Pichavaram, Tamil Nadu), which are more frequently hit by cyclones compared to the west coast (Figure 2). Based on these observations, we can theorize that the cyclones may be having a net positive effect on mangrove GPP by intermittent, excessive nutrient supply but could have an opposite effect by negatively affecting C burial rate and a declining soil organic carbon (SOC). We do not have data to examine the SOC trend for the same time period, but that could form a part of future research.

In summary, tropical cyclones interact with a range of biophysical drivers to influence productivity gradients of maritime forests, however, nutrient fertilization from frequent cyclonic storms and freshwater supply remain two critical primary indicators of observed GPP trends for all sites analyzed in this study. The secondary drivers such as PAR, LUE, and other biophysical variables such as surface temperature, salinity gradients, rainfall, and evapotranspiration rates interact closely with each other to further influence GPP trends. In fact, mangrove sites in Asia are predominantly minerogenic, and sediment supply is essential for the long-term resilience of Asia's mangroves (Ward et al., 2016). This supply is strongly influenced by unpredictable rainfall regimes (or drought conditions), changes in hydrology (input of freshwater), flooding, and storm surge events which can further influence the growth and productivity of the forests by altering mangrove forest salinity gradients. For example, both higher salinity and greater seawater-sulfate concentrations have been found to decrease mangrove production(Ward et al., 2016). Salinity levels also strongly influence competitive interactions among species (Kathiresan and Bingham, 2001). For example, at Pichavaram, South India, mangroves are largely dying because of a combination of factors owing to hypersalinity, increasing temperature, low precipitation, and reduced tidal flushing(Kathiresan and Bingham, 2001). Similarly, in Sundarbans, the reduction in freshwater inputs has resulted in a decrease in some species such as *Heritiera fomes* and *Nypa fruticans* (Banerjee et al., 2017).

Although these drivers are inter-related and spatially variable through processes including sea level rise, changing ocean currents, precipitation, and temperature changes which influence evaporation rates, their synergistic impact can influence both mangrove growth and productivity levels. For example, studies show increases in precipitation values effect the increase in riverine discharge levels impacting a range of variables including sediment input levels, surface elevation and landward mangrove expansion rates ultimately leading to an overall increase in mangrove productivity(Eslami-Andargoli et al., 2009; Gilman et al., 2007; Ranasinghe et al., 2013). In contrast, low precipitation and high temperatures increase evapotranspiration which can lead to increases in soil salinity and aridity, ultimately impacting seedling survival, species diversity, mangrove growth, and productivity over long time scales(DUKE et al., 1998; Eslami-Andargoli et al., 2009; Field, 1995; Smith and Duke, 1987). The complex interaction between environmental drivers is further influenced by tropical storms which is possibly the reason for the spike in GPP values post-cyclonic events. Tropical storms can temporarily decrease aridity-induced salinity changes, allowing nutrient fertilization to improve mangrove productivity levels. Equally noteworthy is how these drivers might interact with progressing climate change or increased nutrient load from land use change. The temporary spike in productivity levels might reach a break-off point and decline steadily or adapt to the changing climate to do better.

The exchange of CO_2 between forests and the atmosphere has gained impetus in the last few years as forests can act as sink repositories to offset the steady growth of emissions. Although mangrove forests are increasingly seen as carbon-rich ecosystems because of their climate change mitigation potential(Mcleod et al., 2011; Siikamäki et al., n.d.; Van Lavieren, Hanneke, Spalding, Mark, Alongi, Daniel M., Kainuma, Mami, Clüsener-Godt, Miguel, Adeel, 2012), knowledge and understanding of how mangroves in India may be influenced or changed because of climate change such as frequent intense cyclonic events is still insufficient. Over the past years, considerable efforts have been made in the field to understand the land-use change ecology of mangroves, ecosystem services evaluation, and natural history traits through a series of scientific studies. The studies have translated on-ground efforts into preservation, restoration, and afforestation efforts as coastal adaptation strategies. However, there remains much debate and contrasting views on the relationships between mangrove species diversity, composition, and productivity. Similarly, the trends in biophysical characteristics, dispersal ecology of these forests, and response to small-scale pulsed stressors such as grazing, insect herbivory, or extraction of forest products, also needs probing. More so the synergistic role of biophysical drivers on plant physiological traits and their future trajectory in the light of varied disturbances, need deeper examination for Indian mangroves.

3.5. Conclusions

Our synthesis of present knowledge on tropical cyclones impact on mangrove forests along the Indian coast highlights key conclusions which can direct future mangrove ecology research and provide a better understanding of potential future changes in mangrove productivity gradients with respect to change in frequency and intensity of cyclones. We conclude that (1) seasonal changes in GPP are influenced by tropical storms; (2) a change in nutrient levels can plausibly increase GPP levels post-tropical cyclones; (3) environmental drivers of mangrove productivity such as precipitation and evapotranspiration are heavily impacted by tropical cyclones on the Indian east coast influencing GPP gradients, whereas what drives productivity along the west coast needs further introspection and exploration.

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CHAPTER 4

IMPACT OF WOOD HARVESTING ON MANGROVE FOREST STRUCTURE, COMPOSITION, AND BIOMASS DYNAMICS IN INDIA[2]

[2] Rasquinha, D. N., & Mishra, D. R. (2021). Impact of wood harvesting on mangrove forest structure, composition, and biomass dynamics in India. *Estuarine, Coastal and Shelf Science*, *248*, 106974. Reprinted here with permission of publisher.

Abstract

Mangrove forest are used widely for meeting fuelwood needs of local communities in the tropics. However, the implications of fuelwood extraction on mangrove ecology has received very little attention. In this study, we investigated the impact of such small-scale fuelwood harvesting practices on mangrove forest structure, composition, regeneration, and biomass and carbon stocks in a protected area on the east coast of India. We sampled vegetation plots in areas where harvesting was practised and where no harvesting was observed. We found that species composition differed across forest categories with *Exoecaria aggalocha* and *Heriteria fomes* dominating non-harvested forest types and *Sonneratia apetela, Sonneratia caseolaris, Avicennia officinalis* alongwith mangrove associates comprising a large proportion of harvested mangrove forests. Similarly, tree, sapling and seedling densities, basal area, and biomass and carbon stocks were also found to vary across forest categories, with overall lower values observed in harvested areas. Lastly, total aboveground (11%) and belowground (18%) biomass and carbon stocks were also lower in harvested forests than non-harvested forests. However, large DBH size-class trees were found in harvested areas implying selective cutting practices that conserved old-growth trees and contributed to larger mean carbon pools. As harvesting is selective, mainly for cooking fuel needs, integrated management plans are needed that accommodate local cultural and economic needs of the communities in this region.

Keywords: Fuelwood harvesting, carbon storage, mangroves, anthropogenic disturbance, composition, India

4.1. Introduction

Mangroves provide a wealth of services that support and maintain human communities around the world. These include protection from storm surges and floods; nurseries and breeding habitats for a variety of terrestrial, estuarine and marine fauna; and livelihood needs of local communities (Aheto et al., 2016; Beitl, 2012; Feka, 2015; Thornton and Scheer, 2012; Uddin et al., 2013; Walters et al., 2008).

Despite these benefits and services, these forests have experienced widespread deforestation and degradation (Polidoro et al., 2010; Thomas et al,2017). Their global annual loss since the 1980s was estimated to be as high as 2%-8%, surpassing that of terrestrial tropical forests (Alongi, 2011; Polidoro et al., 2010; Valiela et al., 2001; Spalding et al., 2010). A much more recent study by Thomas et al. (2017) exposed the extent of mangrove loss due to anthropogenic activities between 1996-2010 using satellite radar imagery data. They found nearly 38% of the (1168) tiles analysed to exhibit losses in mangrove area due to anthropogenic degradation. By far, Asia has suffered the largest loss of mangrove area since the 1980s (Giri et al., 2015; Thomas et al., 2017). Although, mangrove deforestation rates in Asia (including South Asia, Southeast Asia and Asia-Pacific) are slowly improving, large swaths of forests still get converted to oil-palm plantations, agriculture and aquaculture farms (Richards and Friess, 2015; Giri et al., 2015; Thomas et al., 2017).

Consequently, deforestation from logging, timber harvest, and over-extraction of forest products not only reduces mangrove area (Dahdouh-Guebas et al., 2006; Walters et al., 2008) but also alters forest structure and composition subsequently impacting the myriad ecosystem services provided by these forests (Walters, 2005a; Walters, 2005b; Gillis et al., 2017; Scales and Friess, 2019; Kihia et al., 2010). In fact, a plethora of studies have investigated the implications of mangrove loss due to large scale deforestation in the tropics (e.g., Valiela et al., 2001; Hamilton, 2013; Richards and Friess, 2015; Thomas et al., 2018; Gandhi and Jones, 2019).

However, only a handful have looked at the impacts of small-scale harvesting on mangrove forest structure and function (Walters, 2005a; Walters, 2005b; Richards and Friess, 2015). Ironically, informal markets for mangrove products, especially fuelwood, form a significant portion of some rural populations' livelihoods (Walters, 2005a; Walters, 2005b). Many coastal communities across the tropics widely use mangrove wood as poles and planks for construction of houses, fencing and boats, to make furniture and utensils, as firewood and in charcoal production, as fish traps and for timber (Bandaranayake, 1998; Ribot and Peluso, 2009; Blanco et al., 2012; Dayarathne and Kumara, 2015). The mangrove ''nipa'' palm (*Nypa fruticans*) is used as roof thatching material and for floor mats in Southeast Asia (Walters et al., 2008). Further, in some regions they form sources of fodder for livestock, are consumed as food and traditional medicines, honey and waxes (Bandaranayake, 1998; Walters et al., 2008; Atheull et al., 2009). Additionally, the wood from *Rhizophora*, as *banda* for smoking fish, is unique to Cameroon (Atheull et al., 2009). In India, human-mangrove subsistence is only thoroughly documented for the Sundarbans, whereas Dahdouh-Guebas et al. (2006) highlight people's mangrove utilization patterns in the Coringa Wildlife Sanctuary in Andhra Pradesh. They report the frequent use of *Avicennia marina,* a dominant species of the region, for firewood and construction activities.

Although the ecological impacts of small-scale harvesting are not as pervasive as large-scale forest conversion which alter landscape level processes that can impact biogeochemical cycles, biodiversity and climate regulation, it could lead to permanent forest degradation (Alongi and Carvalho, 2008). Studies reveal that small-scale harvesting practices result in cumulative effects on mangrove forest structure, composition and regeneration (Blanco et al., 2012; Longonje, 2012;

Scales and Friess, 2019; Walters, 2005b; Sillanpää et al., 2017). For instance, Walters (2005b) found smaller tree sizes and basal area, and abundant canopy gaps in areas where mangrove cutting was prevalent in the Philippines. Similarly, Kihia et al. (2010), argue that litter production in mangroves disturbed by human influences such as digging, trampling and cutting was lower than those found in comparatively undisturbed sites in Kenya. Further, Scales and Friess (2019) also report changing mangrove forest composition in the Bay of Assassins in southwest Madagascar due to small-scale harvesting by local human communities.

Studies also reveal that changes to mangrove forest composition and structure can cause disturbances to soil layers that release substantial amount of greenhouse gases such as CO_2, CH_4 and N_2O (Chauhan et al., 2008; Donato et al., 2011; Lovelock et al. 2011). Similarly, a study conducted by Gillis et al. (2017) shows that deforestation may impact carbon outwelling processes from mangrove forests. Their findings imply important linkages between forest characteristics and sediment processes and the role of forest structure and compositional elements such as species richness, basal area, or density of trees have on soil characteristics. Deforestation exposes top soil layers to extreme weathering processes, leading to greater decomposition (Lovelock et al., 2011). Further, carbon sequestration is also affected due to loss in aboveground biomass (Furukawa and Wolanski, 1996; MacKenzie et al., 2016; Shrestha et al., 2016). However, other studies have shown that biomass and carbon storage differences due to harvesting may get compensated by species showing different adaptation strategies. For example, a study by Blanco et al. (2012) in the Urab´a Gulf in Colombia, showed that selective logging for poles and planks resulted in skewed diameter distributions because of overexploitation in some species like *Rhizophora*, but biomass and carbon storage differences were offset by the spread of other light tolerant species such as *Langucularia*.

This study examines the impact of such small-scale forest use on the structure, composition and regeneration pattern in a tropical mangrove forest in Bhitarkanika Wildlife Sanctuary, located on the east coast of India. Specifically, we investigate the differences in tree densities, basal area, aboveground biomass and carbon stocks in areas where harvesting occurred frequently (harvested) and in those where harvesting for firewood was uncommon (non-harvested). We hypothesize that the variations in biomass and carbon stocks will differ with disturbance levels, i.e., with increasing disturbances, biomass and carbon stocks will show decreasing trends. However, we also predict a strong association between species diversity and biomass and carbon stocks, irrespective of disturbance status.

4.2. Methods

4.2.1 Study site description

This study was conducted in the Bhitarkanika Wildlife Sanctuary (BWS) on the east coast of India (86°45′Eand 87°50′E and 20°40′N and 20°48′N). The entire Sanctuary covers about 672 sq. km and is located in the Rajnagar block of the Kendrapada district, in the state of Odisha. It is the largest mangrove ecosystem after the Sundarbans in the country, comprising 145 sq.km of pristine forests which also forms the core area of the Sanctuary (Odisha Forest Department). This core zone was designated as a National Park in 1975 (Figure 4.1). The area is known for the highest diversity of true mangrove species in the country, endangered estuarine crocodile species, the largest nesting area of the *olive ridley* turtle, the king cobra and for numerous migratory and resident bird assemblages (Naskar and Mandal, 1999; Mandal and Naskar, 2008). This lush and vibrant mangrove ecosystem is fed by the rich estuarine deposits from the Brahmani and Baitarani rivers and their tributaries. The rivers form an extensive network of meandering streams and creeks, which empty into the Bay of Bengal. The searing heat and humidity of the summers

(March- June) can be daunting with mercury crossing 35 °C, followed by a long and refreshing monsoon season that runs from July to September and mild pleasant winters where temperatures are as low as 4°C. The region also occasionally receives light showers during the months of October and November due to low pressure events in the Bay of Bengal. Although the coastal region is heavily impacted by frequent cyclones every year, the villages located inside the Sanctuary have largely been unaffected from major flooding events and related loss of assets or human life since the super cyclone of 1999 because of the expansive protective mangrove cover (field interviews). Although rich in biodiversity, and a Ramsar wetland site, this region is also heavily human impacted. There are about 410 villages in and around the Sanctuary. The mangrove forests are abundant in wood, fodder and fishery resources which sustain the livelihood needs of the locals. About 40 villages in the BWS depend on mangroves for their firewood needs. Studies have estimated that about 85% of the daily firewood needs are extracted from mangroves and about 20% of the village population is engaged in firewood collection (Chadha and Kar, 1999). Studies have also reported that barricade fishing was widely practiced in the area and the wood used for the poles (about 150-200 poles) was obtained from the mangrove forest (Ravishankar et al., 2004). Similarly, our field observations suggest that small-scale artisanal fishing gear like individual fish traps and barrier traps are also constructed using mangrove wood, especially when bamboo is not available. Similarly, small-scale harvesting for firewood is usually conducted to supplement cooking fuel needs of households, with monthly extraction ranging from 25 to 300 kgs depending on the presence of alternate sources of fuel such as LPG cylinders (field interviews, data not provided). People harvest all-year round excluding the monsoon season. Generally, dried fallen logs and small diameter branches (5-10 cm) are selectively harvested (field observations and interviews, data not provided). There is no large-scale logging or clearing practices for timber prevalent in the region but mangrove patches closer to the Gupti Forest Division are witnessing deforestation for aquaculture ponds (field observations, data not provided).

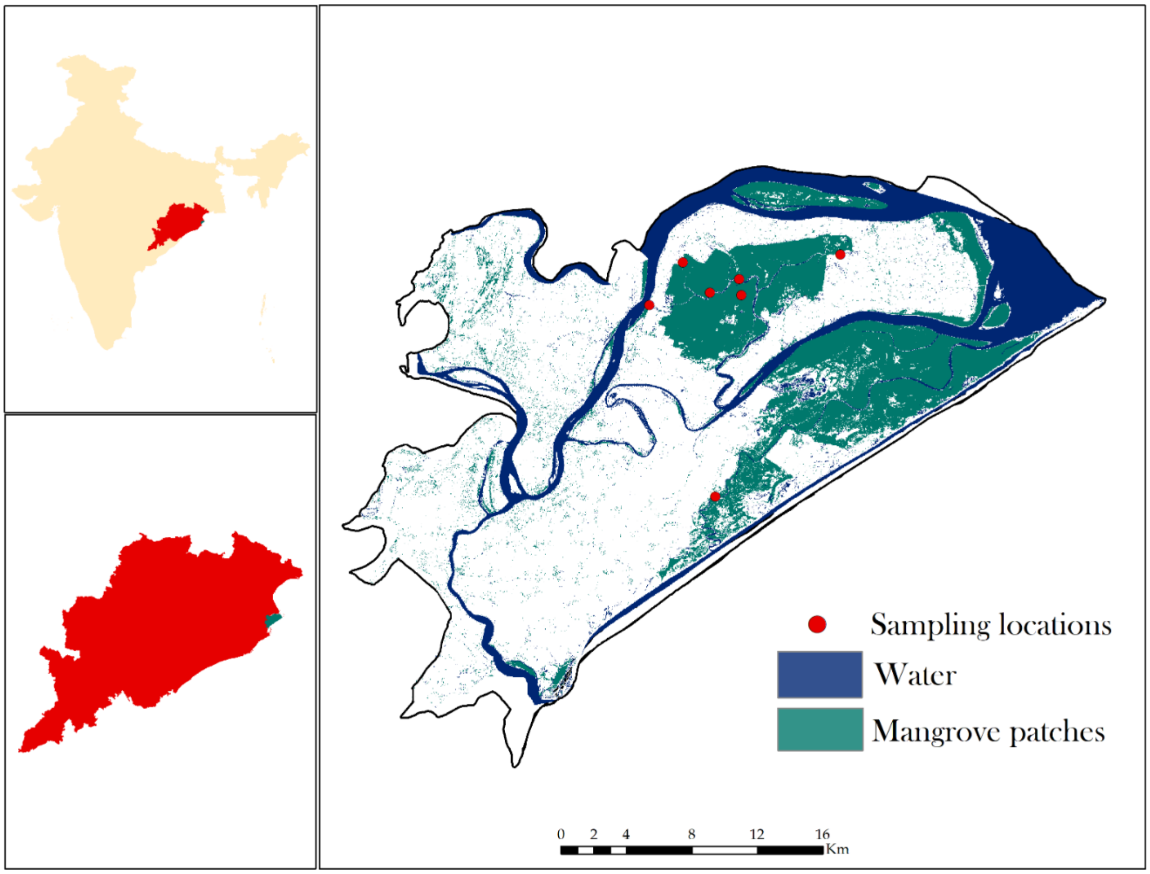


Figure 4.1 Map showing the mangrove vegetation and sampling sites in Bhitarkanika Wildlife Sanctuary, India.

4.2.2. Data collection and Analyses

4.2.2.1. Field measurements for forest composition, structure, and diversity

We sampled a total of 26 plots, each measuring about 10 by 10 m (covering a total area of 2600 sq. m) within 7 sites across the Sanctuary that represented varying degrees of human access and use (Table 1, Fig 1). Harvesting status was assessed by interviews with local communities and presence of logging in plots. We adopted a purposive plot sampling approach based on our interview results, forest access restrictions, and logistical constraints. Plots were categorised as harvested if clear signs of harvesting were visible such as the presence of lopping and coppicing (Table 4.1). At each site, we established 10 by 10 m quadrats, in a perpendicular direction from the land-water interface. Sampling across sites was uneven because of access and other logistical issues but our sampling covered species representative of each individual site.

We followed the general protocol outlined by *Kauffman* and *Donato* (2012), with a few modifications, as outlined in Scales and Friess, 2019. The geographic location of each plot was recorded using a handheld Global Positioning System (GPS). At each plot, we measured the girths of all trees more than 2 cm in diameter at 1.3 m height (diameter at breast height, DBH). All vegetation, greater than 5 cm DBH were defined as trees whereas DBH less than 5 cm but greater than 1 cm, as saplings. We also counted all seedlings in the plot. All vegetation was identified to genus or species level and heights of trees were estimated using a laser ranger.

4.2.2.2. Aboveground and belowground live biomass and carbon stocks

Aboveground and belowground live biomass was calculated using species-specific allometric equations (See Table B.1, for allometric equations used in this study). If a species-specific equation was unavailable, we substituted it for a similar species within the same genus. For instance, we used the allometric equation of *Xylocarpus granatum* for *Xylocarpus mekongensis*. Similarly, *Avicennia marina* was substituted for *Avicennia officinalis*. Specifically, we used species-specific equations for *Aegiceras corniculatum, Rhizophora sp., Avicennia officinalis, Bruguiera sexangular* and *Xylocarpus mekongensis*. For all other species, the general allometric equation by Komiyama et al. (2005, 2008) for aboveground and belowground biomass was used. The allometric equations provided by Komiyama et al. (2005, 2008) have been extensively used for determining both aboveground and belowground biomass stocks in studies across the globe as well as in Asia (Camacho et al., 2011, Kauffman and Donato, 2012; Sitoe et al., 2014; Tue et al., 2014; Rojas-García et al., 2015; Rahman et al., 2015).

4.2.2.3. Soil characteristics and carbon stocks

At each site, we also collected topsoil cores (10 cm depth, n=26) to determine soil physical parameters such as bulk density and moisture content as well to estimate soil carbon stocks (soil organic carbon- SOC) and nutrient content (nitrogen (N) concentration). Topsoil samples were collected as this region is the most dynamic soil layer which also makes it more vulnerable to any environmental changes. We followed the guidelines by Harris et al. (2001) for sample preparation and analysis. The soil samples were air dried and further oven dried at 60°C till constant weight. The samples were then ground and homogenized in a mortar and pestle before undergoing acid fumigation for the removal of carbonates. These carbonate-free samples were then analyzed for SOC content using the Leco Analyser (LECO, St. Joseph, MI).

4.2.3. Data analyses

We calculated basal area ($BA = \mu[\frac{DBH}{2}]^2$), tree density (trees per hectare), and biomass for each plot. We collated total soil C pools (Mg C/ha) using soil C concentration (%), bulk density (g/cm3), and soil depth (cm). Subsequently, plot-level basal area, tree densities, biomass, and carbon stock values were extrapolated to site and disturbance categories. For each species, an importance value (IVI) was estimated by summing their relative frequency, relative density and relative cover values in harvested and non-harvested forest sites (Delaune et al., 2020). We also estimated diversity indices such as the Shannon diversity (H'), Simpson dominance (Cd) and Pielou's evenness (J') index to understand the differences in community composition. A larger value of H' implies greater diversity. Similarly, lower values for Cd indicate dominance by a handful of species and lower diversity. Further, a value closer to 1 for J' signifies complete evenness. All analyses were performed in R + RStudio.

4.3. Results

4.3.1 Floristic Composition, Diversity and Richness

A total of 19 mangrove species including mangrove associates belonging to 12 families and 15 genera were recorded in this study. Out of the 19 tree species recorded, 14 tree species were found in the non-harvested and 10 tree species in the harvested forest categories (Table 2). Two mangrove species, which are categorized as threatened species according to the IUCN red list, *Brownlowia tersa* (Near Threatened), and *Heritiera fomes* (Endangered) were also observed in this study. Sites II was found to have the highest number of tree species (7 species) while only 2 species were found in Site V (Table 2). Although, our plot numbers were variable across sites, overall species abundance values were lower in harvested than non-harvested sites. Similarly, in the harvested forest site, Site VII was less populous than all other non-harvested sites based on species abundance values (Table 4.1).

Table 4.1 Forest structural attributes for sampled mangrove sites. (Shannon diversity (H'), Simpson dominance (Cd) and Pielou's evenness (J') index)

Sites	Distance to villages (km)	Forest category	No. of plots	Mean Tree Density (trees/ha)	Mean Basal Area (m^2/ha)	Species Richness	Species Abundance	H'	Cd	J'
Site I	1.5	Non-harvested	5	2740	55.3	5	137	0.97	0.56	0.35
Site II	3	Non-harvested	3	4566.67	47.57	7	137	0.91	0.52	0.27
Site III	2.8	Non-harvested	6	2550	37.1	4	153	0.72	0.40	0.29
Site IV	0.25	Harvested	5	2000	29.5	5	100	1.1	0.56	0.35
Site V	0.5	Harvested	3	1700	35.68	2	51	0.66	0.47	0.67
Site VI	0.25	Non-harvested	1	5200	32.97	6	52	1.50	0.72	0.4
Site VII	0.8	Harvested	3	866.67	68.34	6	26	1.47	0.72	0.40

Overall, harvested forests (H'=1.88, Cd=0.81) were found to have lower species diversity and higher dominance of a handful of species than non-harvested areas (H'=1.50, Cd=0.68). However, community evenness was found to be greater in harvested (J'=0.35) than non-harvested forests (J'=0.26). Further, IVI values ranged from 5.2 (*Aglaia cucullata*) to 106.58 (*E. agallocha)* for forest areas where harvesting was observed, and 2.33 (*Cerbera odallum*) to 114.19 (*Heritiera fomes*) in comparatively non-harvested forest zones (Table 2). Of importance was the presence of *E. agallocha* with high IVI values in both harvested and non-harvested areas indicating a wide distribution in the area. Consequently, the genera *Exoecaria* and *Sonneratia* dominated harvested areas, whereas *Heriteria* and *Exoecaria* dominated the non-harvested areas. Interestingly, the IVI contribution of the threatened species, *Heriteria fomes* (35%) was high in non-harvested forest areas, while *Brownlowia tersa* was as low as 0.7% implying its rarity in this area.

Table 4.2 Tree species recorded and their importance values (IVI) across harvested and non-harvested forest types.

Species	Importance values	
	Harvested (n=11)	Non-harvested (n=15)
Aegiceras corniculatum	----	3.83
Aglaia cucullata	5.21	4.59
Avicennia officinalis	58.94	26.92
Brownlowia tersa	----	2.36
Bruguiera sexangula	10.5	----
Cerbera odallum	----	2.33
Cynometra ramiflora	----	14.69
Dolichandrone spathacea	----	2.37
Exoecaria agallocha	106.58	96.64
Heriteria littoralis	0	7.89
Heritiera fomes	15.22	114.19
Pongamia pinnnata	16.48	----
Rhizophora stylosa	16.34	----
Rizophora apiculata	----	4.4
Rizophora mucuronata	----	4.95
Sapium indicum	15.69	----
Sonneratia apetela	29.82	2.42
Sonneratia caseolaris	25.22	----
Xylocarpus mekongensis	----	12.41

4.3.2 Structural composition

In both harvested and non-harvested forests, frequency of trees sampled decreased with increased DBH classes. The distribution of trees sampled in different DBH classes when plotted as a frequency histogram revealed an almost reverse J-shaped curve for both harvested and non-harvested areas. This distribution was found to be skewed towards lower DBH classes for both forest categories, indicating unequal mortality rates among equal size DBH classes (Figure 4.2.a). The DBH classes between 1 cm and 15 cm dominated the tree size distribution in both harvested and non-harvested forests. The distribution also showed that large DBH classes (>20 cm) were sparsely present in both forest types. However, a large number of trees with similar DBH sizes were found in non-harvested areas, whereas the variability in DBH sizes was larger for harvested areas.

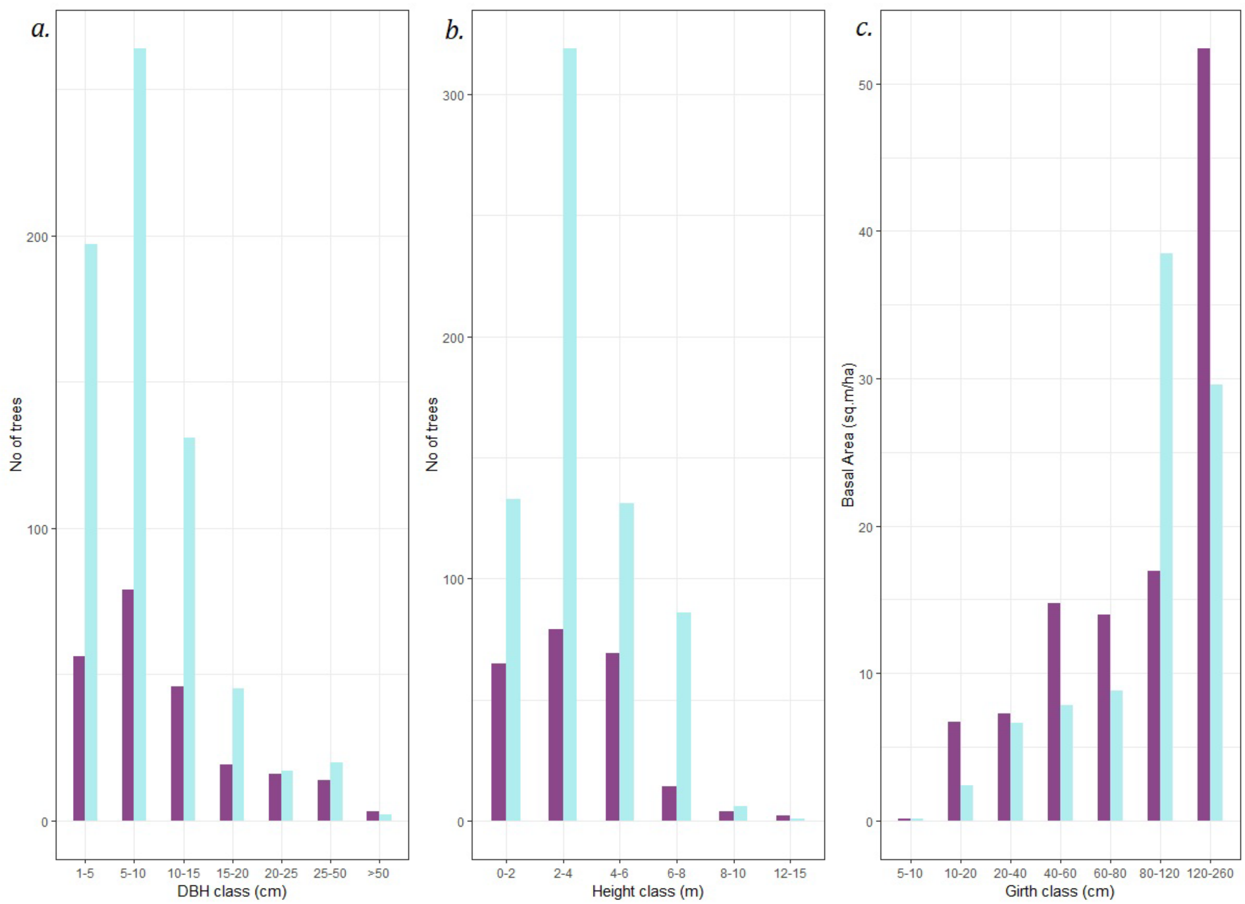


Figure 4.2 Distribution of (a) DBH classes and (b) height classes with total number of individuals, and (c) tree basal area in different girth classes in harvested and non-harvested forests.

As shown in Figure 4.2.b, it is evident that the canopy of both harvested and non-harvested forest categories was predominantly composed of trees, ranging between 0-8 m in height. In fact, trees belonging to the first four height classes (≤ 8 m) accounted for approximately 70% of all trees measured. The tallest tree (*E. agallocha)* was measured at 15 m. Additionally, we also found a gradual decrease in tree numbers with increasing height class with only a handful of trees reaching heights of more than 10 m (Figure 4.2.b).

The distribution of basal area in different girth classes is shown in Figure 4.2.c. In both forest categories, basal area showed an increasing trend with increase in girth class. However, patterns were not clearly defined because of the low number of trees found in larger girth classes. In non-harvested forests, the contribution of basal area was less variable and dominated by low to moderate size girth classes. In contrast, for harvested forests, the major contribution of basal area was dominated by fewer but larger girth class trees.

The tree density and basal area in this study across sites ranged from 867 to 5200 trees ha^{-1} and 32.97 to 68.34 m^2 ha^{-1}, respectively (Table 4.1, Figure 4.3). The total tree density was found to be higher in non-harvested forests (3764 ± 1320 trees ha^{-1}) compared to the harvested forests (1522 ±587 trees ha^{-1}). The highest tree density (5200 trees ha^{-1}) was recorded for the non-harvested forest, Site VI (n=1), followed by the non-harvested forest, Site II (n=3), and the lowest of 1700 trees ha^{-1} for the harvested forest, Site VII (n=3) (Table 4.1). Similarly, basal area of trees was lower in the harvested forest sites than the non-harvested forest sites except for Site VII (68.34 m^2ha^{-1}) which was largely dominated by mangrove associate species.

Overall, sapling density was found to be substantially lower in harvested forest sites (509 saplings/ha) compared to non-harvested forest sites (1791 seedlings/ha) (Figure 4.3). However, the density of young trees (seedlings and saplings) was almost 79% higher than the density of mature mangrove trees in forests where harvesting was prevalent, whereas, about 60% in relatively non-harvested forests (Figure 4.3). Among the tree species observed, the seedling and sapling density was the highest for *E. agallocha*, followed by, *Heriteria*, *Avicennia* and *Rhizophora* in both forest types.

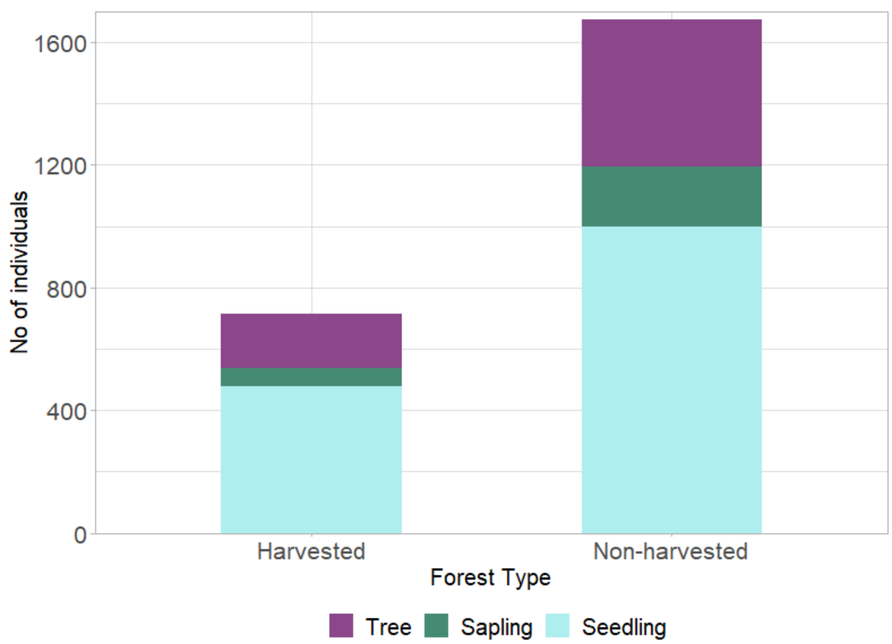
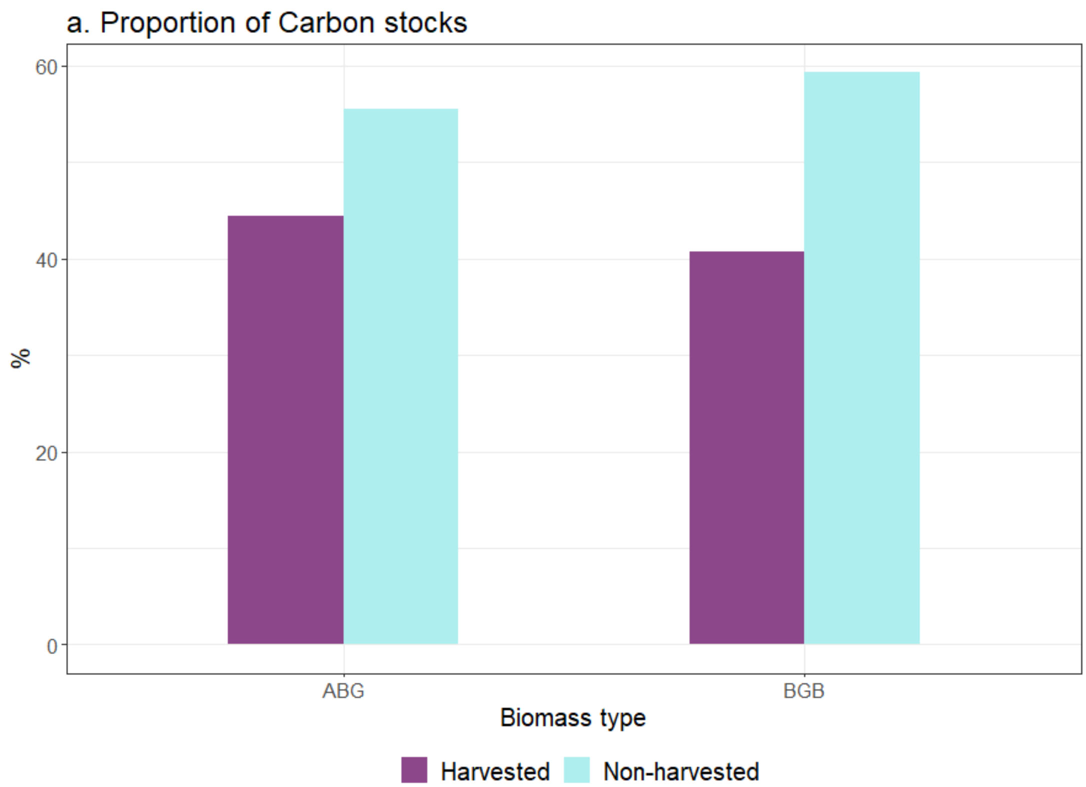


Figure 4.3 Sapling, seedling and tree densities across harvested and non-harvested forest types.

4.3.3. Aboveground and belowground live biomass and carbon stocks

Overall, mean aboveground carbon pools ranged from 55 Mg C/ha to 720 Mg C/ha and belowground pools from 23 Mg C/ha to 220 Mg C/ha across disturbance categories. Further, the proportion of total carbon stocks was lower in harvested than non-harvested forest sites (Figure 4.4.a). Non-harvested forest sites had 11% more C, stored in the form of aboveground vegetation biomass compared to harvested mangroves (Figure 4.4.a). Similarly, belowground vegetation C in harvested sites was 18% lower than that of non-harvested mangroves (Figure 4.4.a). However, mean aboveground carbon pools for harvested sites (ABG= 196.11 ± 182.07 Mg C/ha), were slightly larger than non-harvested sites (ABG = 179.72 ± 66.98 Mg C/ha) when large DBH trees (> 50 cm) were included but lower when excluded from the mean estimation for both the forest categories (Harvested: ABG = 141.65 ± 54.27 Mg C/ha; Non-harvested: ABG = 166.16 ± 49.93 Mg C/ha). Higher aboveground biomass owing to mangrove associates like *Pongamia pinnnata* and *Sapium indicum* (combined mean ABG= 27.67 MgC/ha and C stock = 13.28 MgC /ha), and large DBH trees such as *Sonneratia caseolaris and Sonneratia apetela* (combined mean ABG=236.1 MgC/ha and C stock =113.33 MgC/ha) in Site VII led to the higher amount of mean carbon stock values in the harvested forest category (Figure 4.4.b). In contrast, mean belowground pools displayed large variance but were overall lower in harvested (including large DBH trees: BGB= 63.95 ± 55.03 Mg C/ha; excluding large DBH trees = 47.84 ± 18.25 Mg C/ha) than non-harvested areas (including large DBH trees: BGB = 68.34 ± 17.12 Mg C/ha; excluding large DBH trees = 67.25 ± 18.13 Mg C/ha).


a. Proportion of Carbon stocks
60
40
20
0
%
ABG
BGB
Biomass type
Harvested
Non-harvested

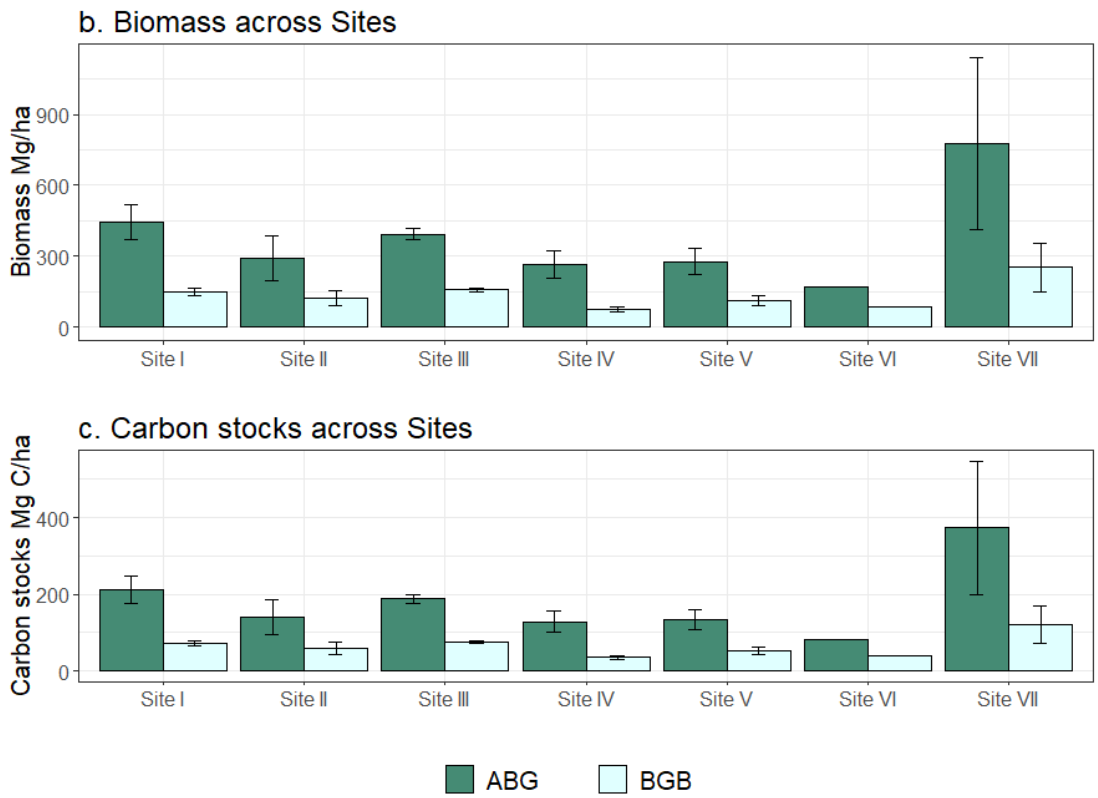


Figure 4.4 Summary of biomass and carbon stocks across forest types (a) and sites (b and c). ABG and BGB represent aboveground and belowground vegetative biomass and carbon stocks.

However, mean vegetation C stocks were found to be highly variable for harvested sites relative to non-harvested sites (Figure 4.4.b and 4.4.c). Biomass and carbon stocks were largely influenced by tree diameter, basal area and species differences. Although, average tree densities were lowest for Site VII (866.67 trees/ha), the average DBH (22 cm) of trees was higher than all other sites, recording the highest mean total biomass (777.20 Mg C/ha) and carbon (373.06 Mg C/ha) values among all sites. Additionally, *Heriteria fomes* (64%) and *Exoecaria agallocha* (19%) were the major contributors to total carbon storage in the non-harvested and *Sonneratia caseolaris* (27%) to the harvested forest areas (Figure 4.5).

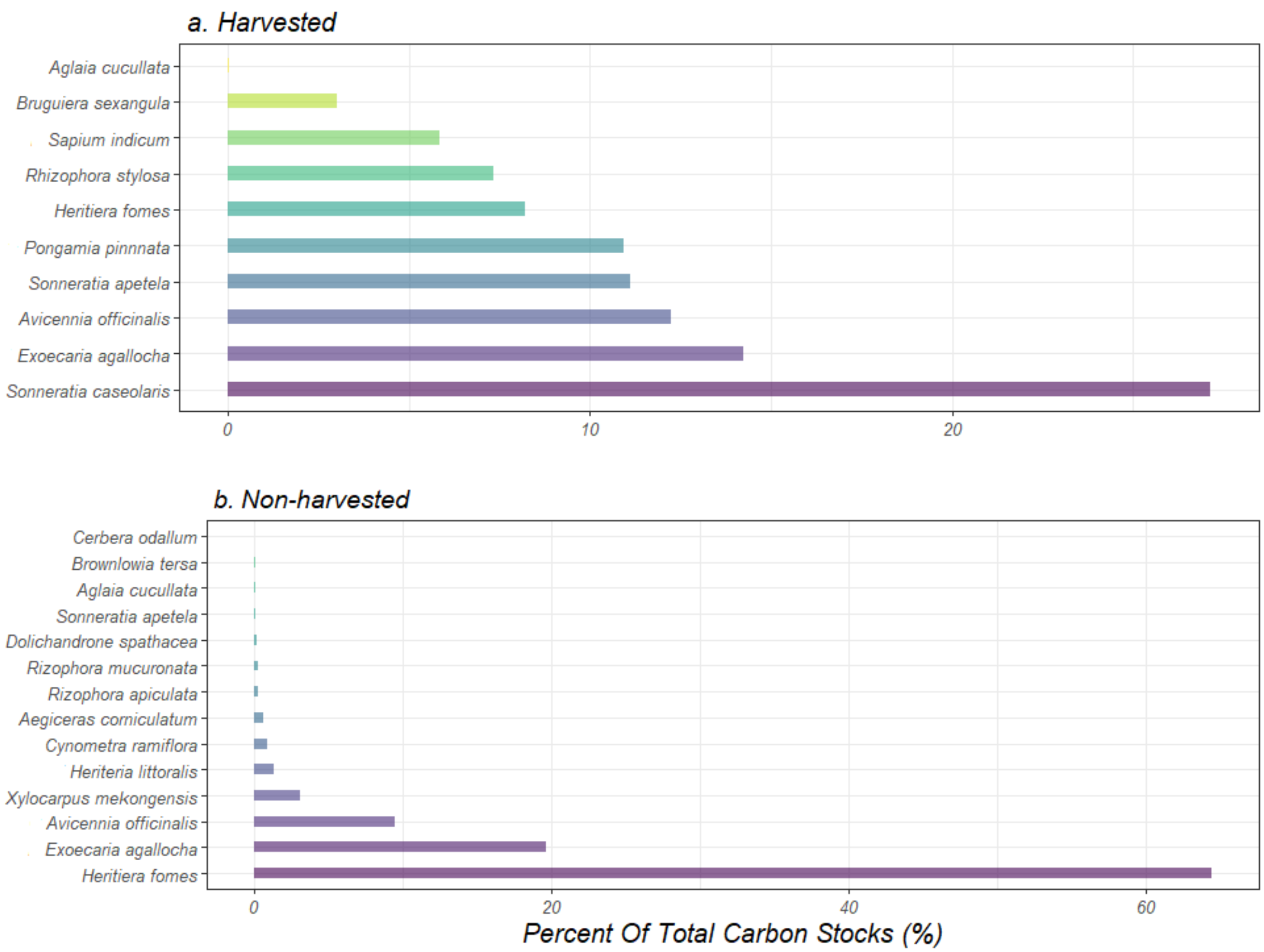


Figure 4.5 Species-wise biomass contribution for mangrove forest types.

4.3.4. *Soil characteristics and carbon stocks*

Mangrove soil moisture and bulk density values ranged from 11.18 to 84.6 % and 0.32 to 0.93 g/cm^3, respectively. The soil texture in the sampled locations was primarily composed of clay to clayey loam type. We found considerable variation in soil C and N concentration across all sites, with overall lower values in harvested than non-harvested categories for both mean soil carbon and nitrogen levels (Figure 4.6). The total soil carbon for harvested and non-harvested mangroves was 15.63±7.22 and 16.49±6.59 Mg C/ha, respectively. Similarly, the nitrogen values ranged from 0.68±0.33 Mg/ha for harvested to 0.81±0.34 Mg/ha for non-harvested forest sites, respectively.

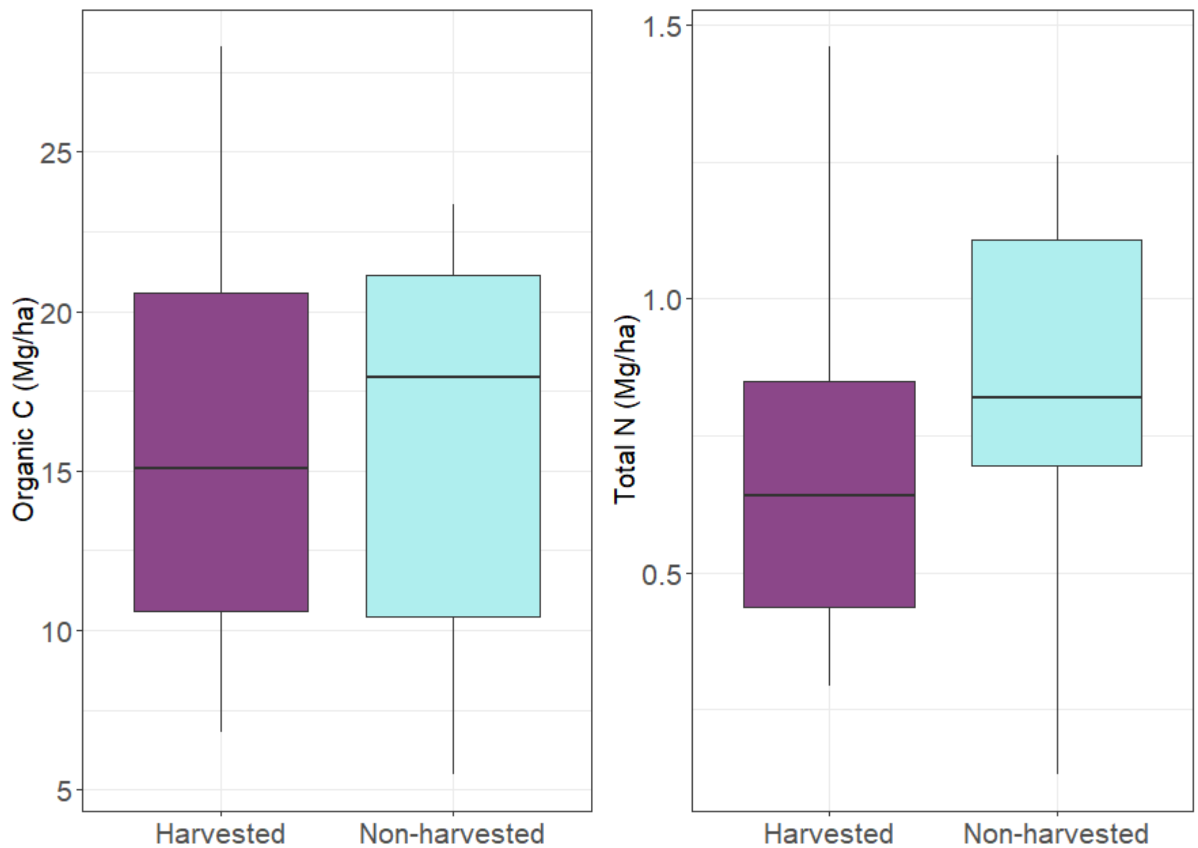


Figure 4.6 Soil carbon and nitrogen levels for harvested and non-harvested mangrove forest types.

4.4. Discussion

In this study, we compared forest characteristics such as tree densities, species richness, basal area, regeneration patterns, aboveground and belowground biomass, and carbon stocks in harvested and non-harvested categories in a tropical mangrove forest in Odisha, India. Forest structural and compositional elements were found to be impacted by harvesting practices prevalent in the region. A large variation in biomass and carbon stocks was found in harvested areas which provides insight on how species level changes may influence disturbance gradients in human dominated mangrove landscapes**.** In the section below, we elaborate on the observed changes in forest characteristics and discuss natural and anthropogenic factors driving the change.

A plethora of studies have investigated the loss in mangrove area, extent and distribution in India using field and remote sensing techniques (Ambastha et al., 2010; Pattanaik and Prasad, 2011;Vyas and Sengupta, 2012; Ponnambalam et al., 2012). However, accurate countrywide information on the ecological impacts in terms of mangrove species loss due to natural and anthropogenic disturbances such as illegal logging, tourism, cyclone storm surge, excessive land surface runoff, and sea-level rise in India are scarce. Some studies have attempted to fill this gap by looking at how large-scale felling for agriculture and aquaculture impacts mangrove species (Upadhyay et al., 2002; Polidoro et al., 2010; Pattanaik and Prasad, 2011, Ponnambalam et al., 2012), some others have assessed the impacts of polluted river discharge on mangrove health (Remani et al., 2010, Bala Krishna Prasad, 2012). For instance, Mandal and Naskar (2008) posit that regeneration rates of *Sonneratia caseolaris* have declined drastically due to the highly polluted lower-saline zones in Indian Sundarbans causing the species to almost go extinct in the region. Further, some studies report that infrequent and unpredictable periodicity and quantity of freshwater supply are the major reasons for the reduction in population densities of mangrove species such as *Heritiera fomes* and *Nypa fruticans* in the Sundarbans, *Xylocarpus granatum, Sonneratia apetala, Kandelia candel and Bruguiera gymnorrhiza* in Pichavaram and *Avicennia officinalis, Excoecaria agallocha and Luminitzera racemosa* in the Godavari wetlands (Selvam, 2003; Banerjee et al., 2017).

However, very rarely studies have looked at the impact of small-scale harvesting practices on mangrove vegetation in India. The combined effect of large-scale clearing and small-scale harvesting pressures can have detrimental effects on the status and distribution of mangrove forests in the country despite ongoing afforestation efforts. For instance, despite mangrove expansion statistics which have been reported in the Sundarbans and other areas in southeast Asia, studies note an implicit loss in mangrove species diversity at those sites (Giri et al., 2015, 2008; Hamilton and Casey, 2016). Several species are on the verge of becoming rare because of over-exploitation. For example, species of *Xylocarpus* and *Nypa fruticans* in Sundarbans and Odisha (Naskar and Mandal, 1999; Pattanaik et al., 2008). Similarly, *Sonneratia griffithii* has declined drastically in areas where more than 80% loss in mangrove extent was reported (Polidoro et al., 2010).

Indian mangroves exhibit considerable variation in species diversity. The extensive deltaic mangrove forest complex along the east coast is floristically diverse, compared to the fringing mangroves of the west coast (Kathiresan, 2018). A mix of species complexes is very typical of the mangrove forests found along the east coast. In context, the Sundarbans houses the highest species diversity in the country comprising of 69 species spread across 49 genera and 35 families (Mandal and Naskar, 2008). While the Bhitarkanika mangrove community comes second in species richness, it harbours the highest diversity of true mangroves species in the country (Ragavan et al., 2016)

4.4.1. Forest species composition and diversity

We recorded only 17 true mangrove species in our sampled plots, out of the total 35 known to be present in the region (Ragavan et al., 2016). The dominant species assemblages found at the site included *H. fomes, E. agallocha, C. ramiflora*, *A. officinalis, Sonneratia, C. decandra, Phoenix paludosa* and *L. racemose* (Upadhyay and Mishra, 2014). However, we found that sites where harvesting was common, were largely composed of a mix of species types, dominated by the presence of *Avicennia officinalis* and *Sonneratia* sp., whereas non-harvested areas exhibited a strong presence of *Heriteria fomes* and *E. agallocha* at all sites. In fact, both *H. fomes* and *E.*

agallocha accounted for 58% of all the trees sampled. The ubiquitous presence of *Excoecaria agallocha* and *Heriteria fomes*, locally known as *Guan* and *Sundari* can be attributed to the geomorphological settings in the past, which maintained dispersal mechanisms across the Sundarbans, Bhitarkanika and the Andaman and Nicobar Islands (Ragavan et al., 2016). Both these species provide a rich source of timber and fuelwood to the local people and were further propagated as plantations during the princely rule (field interviews, *data not reported*).

People living in Bhitarkanika mainly cut mangrove trees for fuelwood and poles. They also use firewood for warmth and heat during the chilly winters. Past practices of cutting for boats and house construction have been replaced by imported materials from nearby city markets. The species preferred for fuelwood include *Aegiceras corniculatum (*locally known as *Kharsi*), *Sonneratia* sp. (*Kheruva*), *Avicennia* (*Bani*), *Heriteria species or Sundari*, *Excoecaria agallocha* or *Guan* and *Hibiscus tiliaceus* or *Bania* (field interviews, data not shown). Ironically, the densities of each of these species were quite low in forests where harvesting was documented. Additionally, local people also regularly use *Phoenix paludosa* (or *Hental* in local parlance) as house thatching material, and for basket or mat weaving. Although, none of our plots documented the presence of *Phoenix paludosa,* we observed large swaths of this species near Site VI around river creeks outside of our plots. The mangrove patches were bushy and scrubby with abundant coppicing owing to frequent cutting, which made sampling difficult, specifically to measure diameter and other vegetation structural characteristics. Field interviews (n=10) on species loss perception also revealed an almost 75% reduction in the presence of *Heriteria sp.* and *Avicennia sp.* since the 1970. The *Heritiera* species is especially known for the durability and strength of its wood, as opposed to *Avicennia* which is sought for its fodder quality. However, several people (n=40) were of the opinion that in many places around the Park, *Phoenix paludosa* as well as other species have substantially increased in extent (25-50%) because of frequent plantation efforts as well as restriction in firewood extraction. Interestingly, young scrubby *Phoenix paludosa* also serves as a nesting site for the estuarine crocodile*, Crocodylus porosus* which explains the popularity of this species around the park. Our sampling efforts did not cover large swaths of the park to capture finer scale differences in the abundances of other species found in the Park to make any conclusive statements on changes in forest composition due to harvesting. However, our sampling did capture the species commonly harvested in the area. Therefore, cutting for fuelwood and other uses, was partly species-specific but was limited to dried stems and branches keeping larger diameter trees untouched.

4.4.2. Forest structure

Studies which investigated the ecological impacts of selective cutting on mangrove trees argue that continuous pressures can alter reproductive capacity of mature trees (Dayarathne and Kumara, 2015) and tree mortality rates (Walters, 2005a, 2005b), perpetuate monospecific stands leading to lower ecosystem complexity (Simon and Raffaelli, 2012) as well as further cryptic ecologic degradation (Blanco et al., 2012). Cryptic ecologic degradation can also be attributed to the increase in mangrove associates in areas subject to harvesting pressures. For instance, Site VII was largely dominated by mangrove associates *Pongamia* and *sapium* species, covering almost all life stages from small to large DBH classes (9.5 to 46.5 cm and 4.9 to 43.3 cm, respectively). Although, fuelwood extraction was not completely species-specific, abundance of species such as *Avicennia*, *Exoecaria* and *Sonneratia* were relatively very low, with a complete absence of seedlings and trees in lower DBH classes. In contrast, small-scale cutting of preferred species like *Avicennia*, *Heriteria* and *Sonneratia* may possibly be the reason for the reduction in larger sized mangrove trees in harvested Sites IV and V. Similar results have been documented in the Caribbean Islands by Smith and Berkes (1993), who also document a decline in large trees in the region and a greater abundance of smaller trees due to small-scale cutting practices.

Additionally, tree height, basal area and densities can influence the ability of a system to recover from disturbances (Krauss and Osland, 2019; Samson and Rollon, 2008; Sherman et al., 2000). The tree densities, basal area and height values observed in this study were similar to those reported by Upadhyay and Mishra (2014) and Bhomia et al. (2016) for Bhitarkanika. Moreover, basal area effectively integrates both size and number of trees, predicting the ability of the system to store biomass and carbon and hence, withstand stressors (Twilley, 1998). Similarly, previous studies have used basal area as a proxy to determine the disturbance status of forest stands (Ellison, 2015; Komiyama et al., 2008). A low to no disturbance, pristine mangrove forest was found to have a basal area of 25 m^2 ha^{-1}, secondary forests had a basal area of 15 m^2 $ha^{-1}$and harvested forests with values around 10 m^2 ha^{-1} (Komiyama et al., 2008). The basal area for all our sites were well above these designated value ranges, indicating good structural development and reinstating the fact that local communities sustainably harvest these forests. Additionally, a large proportion of basal area (52 %) in the harvested forests were dominated by *Avicennia* and *Sonneratia* species and *Heriteria* and *Exoecaria* species in (74 %) non-harvested sites.

Importantly, observed diameter distribution of trees (Fig 2a) further emphasize the dependence on smaller sized-DBH trees for harvesting. Although, tree size distributions are determined by a complex interplay of disturbance regimes and forest regeneration rates, our results do not support the inverse *j*-shaped tree diameter distribution (Smith 1986) for either forest types implying poor structural development. Previous studies have shown that in areas devoid of large-scale cutting practices, plotting the diameter distribution of trees results in a nearly perfect *j*-shaped curve (Allen et al., 2001). However, forests subject to frequent harvesting show a reduction in smaller size class trees (Allen et al., 2001).

People generally sought tree stems <10 cm in diameter and selectively harvested short and thin stems from forest patches. Smaller diameter branches are easier to carry and burn quickly. There were no signs of clear cutting in our plots. However, a few areas did show signs of clear cutting in nearby forest patches. Any signs of harvesting were mainly observed along forest edges and pre-marked trails near villages. This emphasises that harvesting pressures are largely dependent on distance and feasibility of access to resource availability, in contrast to other studies which emphasise resource availability alone as the driving factor for harvesting pressures (Dahdouh-Guebas et al., 2000; Scales and Friess, 2019). In this region, villagers did not have to travel too far to harvest except when forest boundaries were fenced and flooded. The maximum distance travelled was about 3km if the access to boats was considered (field interviews and observations). Overall, our results do not show any significant differences in size classes between harvested and non-harvested forests. In fact, large diameter classes of tree species were found in harvested rather than non-harvested forest areas especially in Site VII. These differences can be attributed to the selective process of harvesting practised by the local communities that prefer thinner and even-sized stems as fuelwood for cooking, sparing and hence, conserving larger diameter trees.

4.4.3. Forest Regeneration

Small-scale disturbances are common in mangrove forests around the world (Simon and Raffaelli, 2012; López-Angarita et al., 2016; Sherman et al., 2000; Walters, 2005). These small disturbances affect mangrove forest dynamics at different scales, intensities, and frequencies. Studies emphasise that disturbances play a crucial role in determining the spatial distribution of canopy gaps which ultimately influence establishment, recruitment as well as growth of mangrove trees (Sherman et al., 2000). Canopy gaps can facilitate suitable environmental conditions such as light availability for shade-intolerant mangrove species, enhancing recruitment and contributing to the maintenance of existing tree species (Smith, 1987; Smith 1992). Similarly, canopy gaps created by small-scale cutting practices also facilitate seedling regeneration (Sherman et al., 2000; Smith, 1987; Smith 1992; Ewel et al., 1998; Imai et al., 2006).

According to Smith (1987), regeneration of mangrove seedlings takes places rapidly in canopy openings. In this study, the overall density of saplings and seedlings combined was greater than the density of mature mangrove trees in both forest types (Fig 3), implying a good regeneration potential (Gan, 1995). We also observed that harvested areas did substantially better in seedling and sapling density (79% as opposed to 60% in non-harvested areas) which could partially be due to the presence of several small gaps in forest canopy owing to harvesting practices (Clarke and Kerrigan, 2006; Amir, 2012). As harvesting for fuelwood is done selectively and does not involve large-scale forest clearing, the canopy gaps created are usually smaller in size and dispersed in spatial distribution (Allen et al., 2001). Some studies have found a strong correlation between canopy gaps and seedling abundance (Clarke and Kerrigan, 2006; Amir, 2012).

Additionally, we also found some peculiar species level differences. For instance, *Heriteria* performed much better in non-harvested areas, whereas did poorly in harvested areas. In contrast, regeneration of *Exoecaria* was not affected by harvesting. The species was adequately represented in all life stages from seedling to mature adults in both forest types, implying its strong resilience to disturbances. However, its low wood density (0.390 g cm^{-3}), poor wood quality and poisonous latex may not make it a very popular choice among the masses for firewood. Similarly, saplings and mature adults, of the locally preferred species, *Phoenix paludosa* were completely absent in sampled harvested forest areas. Subsequently, saplings (between 2-5 cm DBH) of *Avicennia* were frequently harvested for firewood in this region, explaining the absence of this size-class from harvested forest sites. One of the many ecological implications of regeneration success or the dominance of a particular size-class in these forest communities is the effect on water residence times. Mazda et al. (1997) posit that smaller thinner trees such as saplings which do not possess aboveground root biomass can negatively impact the hydrodynamics of the region. A forest site with higher density of saplings can thus potentially increase the draining of organic matter from the mangrove forest.

4.4.3. Aboveground and belowground carbon stocks

A number of factors influence biomass and carbon storage potential in mangrove forests such as wood density of trees (Komiyama et al., 2005; Ray et al., 2011), forest cover, structural characteristics and life history stages of forest development (Fromard et al., 1998; Walcker et al., 2018) as well as environmental stressors that influence growth and dispersal of propagules such as rainfall, sunlight, temperature, sediment flux and salinity levels (Clough, 1992). Studies also emphasize the importance of forest cover for carbon sequestration (Achat et al., 2015; Pendleton et al., 2012). A large aboveground biomass repository can facilitate sedimentation by reducing water velocity, thus maintaining a positive feedback loop for increasing carbon storage (MacKenzie et al., 2016). Similarly, high species diversity, richness as well as tree densities also influence the carbon sequestration potential of mangrove forests by maintaining complex root structures (Clough, 2013; MacKenzie et al., 2016).

Aboveground biomass and carbon stocks in Bhitarkanika were estimated to be comparatively higher than those reported by other studies subjected to harvesting or deforestation pressures. For example, Singh et al. (1987) report about 15.08 Mg/ha to 149.46 Mg/ha as aboveground biomass in mangrove forests of the Andaman Islands. Similarly, Jones et al. (2014) estimated about 146.8

Mg/ha in the Ambanja and Ambaro Bays of Madagascar, whereas, Goessens et al. (2014) report ~372 Mg/ha in mangroves subjected to felling after 30 years of growth in the Matang Mangrove Forest Reserve in Malaysia. In mixed species mangrove plantations of Bohol in Philippines, Camacho et al. (2011) estimate similar high values ranging from 370.7 Mg/ha to 823.7 Mg/ha as aboveground biomass. The mangrove forests were primarily composed of *Rhizophora stylosa, Avicennia marina* and *Sonneratia alba* forests.

Our results, however, compare well with those reported by Bhomia et al. (2016) for the same region. They estimated mean carbon values ranging from ~ 100 to 240 MgC/ha for planted and scrub/dense mangroves. Similarly, their soil carbon estimates (up to 15 cm depth) ranged between 18.5 ± 2.4 MgC/ha and 19.1 ± 1.8 MgC/ha. However, unlike Bhomia et al. (2016) who compare difference among land use types, we did not find significant differences in SOC storage between harvested and non-harvested forest sites. Overall total SOC storage was lower in harvested than non-harvested sites. The small difference in SOC values between both forest types may be attributed to the discharge of organic wastes from adjoining fish and rice farms. Further, the differences in soil storage values also do not reflect the seasonal or annual variations in this region. Paradoxically, mangrove soils known to harbor large carbon pools, are poor in nutrients. We measured only nitrogen content values in our plots, which were found to be lower in harvested sites than non-harvested areas. But our study did not examine how variability in phosphorus content might impact forest characteristics, which is also a limiting nutrient. Studies suggest that nutrient enrichment can enhance shoot biomass storage but also result in higher mortality rates in mangroves (Lovelock et al., 2009). As nutrient addition favors shoot over root allocation, it affects the ability of the plant to deal with fluctuations in salinity and humidity levels in the environment.

Mangroves in Site VII where harvesting was observed represented a significantly high reservoir of carbon stock (373.06 Mg C/ha) compared to other non-harvested sites. Most of the carbon reservoir in Site VII was contributed by large DBH trees belonging to *Sonneratia* (mean ABG=236.1 MgC/ha and C stock =113.33 MgC/ha) and mangrove associates like *Pongamia pinnata* and *Sapium indicum* (combined mean ABG= 27.67 MgC/ha and C stock = 13.28 MgC /ha). Thus, implying that large DBH and hence high basal areas contribute to higher carbon allocation. Similarly, Bruguiera *sexangula* contributed about 51% of carbon in harvested forests of Site IV. In this site, *Avicennia* and *Sonneratia* were the preferred species for harvesting firewood, and together constituted about 25% of total site carbon with poor regeneration rates. This implies that any imbalance that harvesting may cause in terms of carbon allocation among species is compensated by other species, averting a net loss in the total reservoir.

4.5. Conclusions

The implications of small-scale harvesting pressures on mangrove forests have not received much attention, despite the continued dependence of local communities for their livelihood needs. In India alone, about 67% of rural households are still dependent on firewood for their cooking and heating needs (Chakraborty et al., 2014). The continued dependence on forests, including mangroves can have tremendous impact on forest composition, structure, and biomass levels. Although, much more research is needed across spatial and temporal scales, our study provides insights on how such small-scale resource use can impact forest structure, composition, regeneration, and carbon storage potential of mangrove forests. Further, this study also provides avenues for future research on mangrove forestry practices including silviculture management for timber production zones, sustainable yield and forest thinning practices across the globe.

This study using mangrove vegetation surveys, including areas used by the local communities for their firewood needs shows that harvesting pressures may have important implications for mangrove forest conservation. Harvesting is mainly carried out by women who are bound by cultural needs, which demand cooking with firewood on traditional cookstoves like the *chullah*. It is also largely species as well as size specific, with substantial ecological impacts on associated forest characteristics. The study showed that tree densities, basal area, aboveground and belowground biomass, and carbon storage was lower in areas harvested for fuelwood with species-specific differences across both forest types. Harvesting also resulted in cryptic ecological degradation by facilitating the growth of mangrove associates as opposed to true mangrove species. In contrast, since harvesting is species and size-specific, forests comprising of large sized trees are conserved to an extent. However, continual harvesting can also drive rare species to local extinction. Therefore, further research on long-term impacts of such practices, especially on forest regeneration becomes essential.

A landscape-based approach to manage this area is necessary which involves keeping local communities involved with the plans. For instance, shrimp aquaculture is rapidly increasing in this region. The lack of steady job opportunities and large profit margins compel local communities to invest in shrimp cultivation ventures. The clearing of forest patches to accommodate aquaculture ponds is another pressing concern for this area, combined with continued dependence on necessities like fuelwood on forest resources. Further, disturbances from frequent cyclone events can exacerbate the vulnerability of this extensive forest landscape, which has been sustaining a rich and diverse ecosystem for decades. A fortress approach that does not acknowledge local customary rights or excludes local people from the decision making and forest governance process may exacerbate forest conversion leading to unsustainable forestry practices (Siurua, 2006).

Therefore, management plans should accommodate for socio-cultural needs of the local people, as there is significant potential for community management initiatives in this region.

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CHAPTER 5

SEEING THE FOREST THROUGH FOREST COMMUNITIES: INCLUSION OF VALUES, PRIORITIES, AND MOTIVATIONS IN ECOSYSTEM-SERVICES FRAMING FOR PROTECTED MANGROVE FOREST ECOSYSTEMS[3]

[3] Rasquinha, D.N., Mukherjee, N. & Mishra,D.R. Submitted to the Journal of Ocean and Coastal Management.

Abstract

The discourse on mangrove conservation has typically used the ecosystem services narrative--forest as the service provider, to develop management regimes across the globe. In contrast, the emphasis on the reciprocal nature of human relationships with forests, that is, how local human communities relate with, perceive, and maintain these seascapes, has received little attention. This study distinguishes the value-preference paradigm in a protected mangrove forest region, Bhitarkanika Wildlife Sanctuary, on the east coast of India. We ask how exclusion impacts local values, motivations, and priorities towards mangrove forest conservation in Bhitarkanika Wildlife Sanctuary. Using the Q-methodology, a mixed method approach, we identify the narratives that dominate the human-mangrove reciprocal sphere. Our findings reveal three distinct narratives: *livelihood security* that calls for both current and perceived focus on quality-of-life attributes in the region closely related to the livelihoods of the local people, *conservation value through management* which drives the management regime of this region, and *sense of place* that reinforces the importance of recognizing social and cultural norms. These narratives are also influenced by gender, accentuating the need for more gender sensitive approaches in value-preference literature and conservation policies. A value centered approach that looks at how people perceive, value, and prioritize mangrove conservation narratives illuminates the assumptions of conventional approaches to conservation. It helps in identifying differences and similarities in people's value systems that shape their understanding, interests, and interactions with their environment.

Keywords: mangrove ecosystem, Q-methodology, conservation values, ecosystem services, human-nature relations, reciprocal values, India

5.1. Introduction

A key aspect of the valuation literature focuses on categorization, specifically how humans assign values to nature. These values can be categorized as intrinsic values, which are independent of human valuation; instrumental value, which provides a sense of satisfaction; and relational values, which are how people understand and translate multiple values of nature (Chan et al. 2016). In line with this approach, conservationists and economists have attempted to translate and amalgamate different valuation categories with the ecosystem services concept for both a cost–benefit analysis of conservation interventions and the development of economic instruments (Kumar, 2010). The concept of ecosystem services extends to include not only *provisioning services* such as food, water, timber, and fiber, but also *regulating services* such as the regulation of climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment 2005). The assessment and valuation of these categories provide a useful tool for decision-makers to understand what communities are willing to forfeit in exchange for that ecosystem service (Kumar 2010). Similarly, by providing insight on the service beneficiaries and how that might change in the future under different management decisions (Pendleton et al. 2016), economic assessments are increasingly considered essential for environmental decision-making (Vo et al., 2015). Mangrove ecosystems serve as an excellent case study to study these interactions given their presence in 123 countries and close proximity to dense human habitation (Lee et al. 2014).

Mangrove forests are some of the most productive coastal ecosystems on the planet. They are found to sequester more carbon than their territorial counterparts and can reduce erosion and flooding risks during storms (Alongi 2011; Rasquinha and Mishra 2021). Apart from these important climate regulating services, they are also valued for their provisioning (fish, fuelwood, materials), supporting (nutrient cycling, photosynthesis, and carbon assimilation, and refugia functions), and cultural services (recreational, religious, spiritual, aesthetic, educational and sense of place) across the globe (Walters et al. 2008; Lee et al. 2014). Despite these services, they are lost at an alarming rate to accommodate a variety of developmental needs (Thomas et al. 2017). To combat this change, studies have sought economic instruments to estimate the myriad services obtained from these forests to build a case for their conservation status (Millennium Ecosystem Assessment 2005, Barbier et al., 2011). Towards this, in recent years, a number of studies have focused on delineating distribution and valuation criteria of mangrove ecosystem services and their relevance for mangrove conservation (Barbier et al., 2011; Costanza et al., 1997; Emerton and Kekulandala, 2003; Himes-Cornell et al., 2018; Jerath et al., 2016; Brander et al., 2012; Mukherjee et al., 2014; Uddin et al., 2013; Hussain and Badola 2010). Examples include Reduced Emissions from Deforestation and Degradation (REDD+) programs, Payment for Ecosystem Services (PES) schemes, blue carbon bonds, nature-based solutions, and carbon-biodiversity offsetting where communities are compensated for preserving prioritized forest ecosystem services (Sian 2006; Milne and Adams 2012; Lele et al. 2013; Lakerveld et al. 2015; Rahim 2020; Dunlap and Sullivan 2020; The Nature Conservancy 2021).

A consistent shortcoming of past approaches is the lack of valuation of relational values of mangroves (Sian 2006; Lele et al. 2013; Himes-Cornell et al. 2018). Other challenges include differences in value prioritization between scientists and local human communities, the difficulty in capturing cultural and aesthetic services such as ‘sense of place’ in valuation approaches, and placing monetary values on ecosystems (Sian 2006; Mukherjee et al. 2014b; Lakerveld et al. 2015; Lele 2016). Despite these shortcomings, the ecosystem services model has been rigorously applied to mangrove ecosystems to prioritize areas for conservation at all scales (Camacho-Valdez et al. 2014; Mashayekhi et al. 2016; Atkinson et al. 2016). The outcome or main strategy arising of such efforts is to evaluate trade-offs between services, sometimes advocating for maintenance or establishment of special demarcated areas or nature reserves to conserve prioritized ecosystem service benefits (Vázquez-González et al. 2015; Buchhorn et al. 2016; Mashayekhi et al. 2016; Atkinson et al. 2016; Palomo et al. 2019). For example, Webber et al. (2014) argue that since conservation is a more economical choice over restoration, the establishment of protected areas remains a preferred policy tool to prevent mangrove loss, conserve ecosystem services, and obtain benefits from these forests. However, we argue that embedding values into the more rigid ecosystems services framework serves multiple facets which can facilitate mangrove conservation goals.

5.1.1. Conceptual framework: Situating value preferences with mangrove forest management priorities

Several theoretical value typologies about nature and forests have been presented, and empirically tested to understand forest ownership patterns or motivations for forest management. Two of these include those of Rokeach (1973) and Schwartz (1992). While Roakeach's value theory includes aspects related to aesthetic beauty derived from nature to describe human-nature value typologies, Schwatz (1992) goes one step further to develop a comprehensive list of values that are interconnected and those that portray both conflict and compatibilities between humans and more-than-human worlds. Other social scientists, such as Pietarinen (1991, 1987) distinguish four value dimensions towards forests and nature, which include: materialism, humanism, mysticism, and primitivism (Karppinen 1998). These four value dimensions can be described as exploitative, harmonious, or subjugated forms of human forest relationships (Kluckhohn 1951, Karppinen

1998). Materialism denotes value orientations linked with increasing the standard of living of humans, whereas humanism involves a rather nuanced relationship involving a variety of dependencies and ties-economic, intellectual, cultural, or aesthetic benefits derived from more than human worlds. Mysticism draws on the spiritual connections between humans and their environment, and primitivism takes a preservationist stance, which seeks to conserve more than the human worlds in its most pristine state.

While neoliberal conservation approaches, including REDD +, and PES schemes advocate compensating local communities by preserving pockets of biodiversity, it fails to recognize different relational sociocultural values (Tadaki et al. 2017; Mould et al. 2020). More so, mutual obligations of care, protection, and restoration of land and resources between people and more than human worlds like forests, rivers, or wildlife (Gurven 2004; Vaughan and Vitousek 2013; Comberti et al. 2015; Tadaki et al. 2017; Lyver et al. 2017). Glossing a simplified view of land-use practices and resource rights or assuming communities' willingness to participate in such schemes (Milne and Adams 2012). Further, we also argue that the ecosystem services model, which categorises natureculture is embedded in colonial conservation narratives which do not address how environmental governance is impacted by the binary categorization of human-environmental relations (Chan et al. 2016). We use the term natureculture instead of nature to dissolve the boundaries between nature and culture. Natureculture, introduced by feminist scholar Donna Haraway is a concept that highlights the dissociation between humans and more than human worlds by addressing entangled multispecies histories and relationships. It also provides a framework to understand issues about power differences, agency, or sociality.

Similar to the concept of relational values identified by the ecosystem services model, in indigenous cosmology and worldviews, reciprocal values constituting mutual caretaking between people and places are concepts that exist as intertwining entities (Vaughan and Vitousek 2013; Whyte et al. 2015; Lyver et al. 2017). These reciprocal values are part of everyday local practices of labor, and culture which western knowledge systems fail to acknowledge and, in the process, legitimize separation and power differences between humans, non-humans, and more-than-human worlds (Swyngedouw and Heynen 2003).

Reciprocity in social processes and natureculture relations motivate collective action and lend a unique lens to investigate the value-preference-prioritization paradigm operational in socio-ecological systems like mangroves. More importantly, in mangrove cultural ecology, how value preferences are made and how social priorities align with social values in the presence of different management regimes remain understudied. Similarly, forest exploitation can also occur when materialistic, humanistic, and mystic values are denuded through direct or indirect processes of exclusion.

We ask how exclusion through boundary management of tidal wetlands such as mangrove forests influence local values, motivations, and priorities towards mangrove conservation. We define exclusion as the inability to access a protected area identified based on the fortress model of conservation which assumes that "local people use natural resources in irrational and destructive ways, and as a result cause biodiversity loss and environmental degradation". (Robbins 2007). In such protected areas, local people are excluded from using natural resources especially timber and non-timber forest-based products and enforcement is ensured through patrolling officers like park rangers or forest guards which use the classic "fines and fences" approach (Robbins 2007).The acceptable forms of access and use comprise tourism-based activities such as boat or park safari, and scientific research based on applied permits (Robbins 2007).

A look into how value-preference trends align and differ can provide insights into how social priorities are assigned by human communities (Zube 1987; Jepson and Canney 2003; Bryan et al. 2011). By determining and accommodating the multiple and complex ways humans perceive, understand, and value mangrove landscapes, social acceptance of conservation plans can be increased (Cash et al. 2003; Berkes 2009).

In order to understand how these values, diverge or converge between local residents living in proximity to protected mangrove forests and other stakeholders, we used Q methodology supplemented by community discussions in our study site on the east coast of India, Bhitarkanika Wildlife Sanctuary. The mangrove forests situated within the boundaries of the Sanctuary are layered with multiple levels of management regimes (hosting a Marine Sanctuary, a National Park, and recognized as a Ramsar wetland site). Although no explicit carbon offsetting projects are planned for this area, pilot surveys for a loan assisted project with Japan International Cooperation Agency (JICA) was initiated for this region. The loan assisted projects collaborate with state governments to support Joint Forest Management Committees (JFMC) and Self-Help Groups (SHGs) to undertake plantation programs across the country (JICA, 2016). JICA-led projects have been operational since 1991, substantially contributing to the forestry sector of India (JICA, 2016). As of 2015, the program has achieved about 2 million ha of plantation and forest regeneration across 13 states, and more than 16,000 JFMCs and 24,000 SHGs have been supported through their sustainable forest management and livelihood enhancement schemes (JICA, 2016). With the growing push for more carbon offsetting forestry projects around the world, JICA-assisted projects are slowly looking to incorporate and link REDD+ conceptual framing into the ongoing JICA loan assisted projects. Bhitarkanika is one of the may prioritized regions where JICA assisted REDD + projects are being implemented (JICA 2017).

Considering these realties, we look at how protected area exclusion downplays human-mangrove relationships or influences peoples' values, motivations, and priorities towards mangrove forest conservation. We argue that landscape relations are complex behaviors, which are further influenced by social and political forces that limit people's freedom to experience and hence prioritize.

5.2. Study Area

Bhitarkanika Wildlife Sanctuary is about 672 km^2 in area with a core zone of about 145 km^2, designated as a national park. This area has had a diverse land tenure system. It was under the Zamindari system (aristocratic system of collecting land revenue in the form of land taxes) until about 1951. It was then declared as a Wildlife Sanctuary in 1975, a National Park in 1998, and later recognized as a Ramsar Wetland Site because of the high diversity of mangrove flora (about 66 species including a few endemic species), and charismatic fauna like endangered crocodile species, olive ridley turtles or the king cobra (Mandal and Naskar 2008).

Though rich in wildlife, the rural-forest landscape also supports a substantial human population. The forest is surrounded by people belonging to different social classes, castes, religions, and out-of-state residents that settled here historically from West Bengal and Bangladesh (Chadha and Kar, 1998). The mangrove forest area, which forms the National Park (green shaded region in Figure 5.1), is surrounded by about 55 villages, comprising of fisherfolk, farmers, and daily wagers (Census of India, 2011) (Hussain and Badola 2010). An agriculture and fishing reliant economy sustain the livelihoods of the people living in this region. Shrimp farming is also growing rapidly in the region. Forest dependence is mainly through the use of firewood for cooking purposes by some (about 44 out of the 55 villages) village communities (pilot interviews, data not reported) (Ambastha et al. 2010; Hussain and Badola 2010). We conducted our interviews between

September 2018 to February 2019 and limited our sampling to 18 villages, as shown on the map. Bhitarkanika falls under the Rajnagar district, which comprises 29 Gram panchayats (GP), local governing bodies in rural areas. Out of the 29 GPs, 7 GPs with close proximity to forested regions of the protected area and historical dependence were selected for this study. Participants for this study were purposely selected from this subset of GPs for the sorting and interview process. The demographic characteristic of the selected villages is diverse, but the average population is about 900 residents (2011 census).

Tourism is slowly catching up in this region attracting an increasing flux of tourists every year looking for spaces to immerse in nature-based activities. This has created several small-scale boating ventures and lodges around the Sanctuary (See, Figure 5.1 for tourist spots) that offer varying levels of facilities and services. Small ventures that provide most basic facilities attract low number of tourists, from Forest Department guesthouses, and other privately owned resorts with better services and capital.

This region also experiences frequent annual tropical storms making it disaster-prone, and destructive aftereffects of past storm events are still etched in the memories and lived experiences of the local communities. The remoteness, while maintaining minimal influence from polluting industries, has also ensured the dearth of infrastructure facilities and opportunities to make a decent living. Only a small percent of the population has access to treated tap water connections or live-in permanent structures. A large percentage of the population is still reliant on tubewells and live-in mud, unburnt bricks, or bamboo houses (Census of India, 2011).

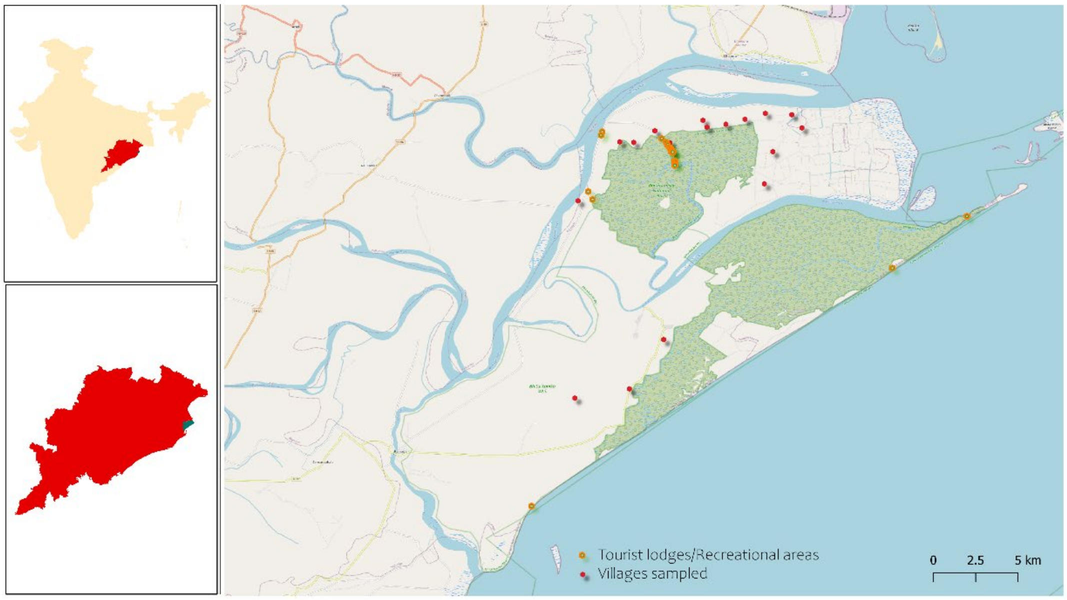


Figure 5.1 Map of study area showing different villages sampled and location of tourist lodges or recreational areas such as boat ride entry points, camping sites, or food joints catering to tourists.

5.3. Methodology

5.3.1. Data Collection and Analyses

Q-methodology was employed to understand the values and perspectives of diverse stakeholders towards mangrove forest conservation. This was supported by open-ended community discussions in villages shown in Figure 5.1 with the same Q-sample, which allowed us to develop further insights on the prevailing mangrove forest conservation discourse. Interview participants were selected using a combined purposive and snowball sampling approach. Local interviewees were representatives of forest communities, women self-help group leaders, Adivasi groups in the region, religious head leaders, and common village folks; whereas extra-local interviewees included members of academia, non-profits, and government staff who have previously worked in this region specifically on mangrove conservation.

5.3.2. Q-methodology

Q-methodology identifies multiple subjectivities among social viewpoints and the knowledge structures that underlie those viewpoints using correlation rank scores. The standard Q protocol generally follows a sequence of activities—collation of Q-statements, sorting of statements, factor analysis, and interpretation (Table 5.1).

Table 5.1 A flow diagram of the methodology followed, including sample size and analyses conducted.

Q- sample

[30 statements, generated from published and unpublished articles, and pilot interviews]

↓

P-set

[41 participants: Local villagers (29), Government officials (4), Academia (5) and staff from non-profits (3)]

↓

Q-sorts

↓

Factor Analysis & Interpretation

[PQ method, R+ RStudio]

5.3.2.1. Q-statements

We formulated a list of statements drawn from ethnographic observations, pilot interviews, and relevant regional and global mangrove ecology peer-reviewed literature (Hugé et al. 2016), including popular media articles on mangrove conservation issues and initiatives in our study site. The final selected list of 30 statements captured a variety of themes such as ecosystem services and benefits, social conflict or co-operation, livelihood needs, and perception towards reward-based schemes or community conservation initiatives. Table 5.2 provides an overview of the statements used in this study. Some statements (S1-S4, S11, S26) were adapted from Hugé et al. (2016), which looks at mangrove conservation discourse in Matang, Malaysia. Incorporating similar statements helped us compare value perspectives on mangrove ecosystem services in different regions experiencing similar pressures.

Table 5.2 List of statements used in this study. Factors F1, F2, and F3 represent the three different narratives: Livelihood Security, Sense of Place, and Conservation Value, identified in this study. The numbers depict the Q-sample values for each factor array, with different levels of agreement (4 to 1), and disagreement (-4 to -1).

ID	STATEMENTS	F1	F2	F3
S1.	Mangroves are important because they provide medicines, honey, wood, charcoal, timber, and fish.	3	2	3
S2.	Mangroves are important because they protect from cyclones and storms.	4	4	4
S3.	Mangroves are important because they provide spawning grounds and nurseries for fish, prawn, and shrimp.	0	3	0
S4.	Mangroves are also important because they store lots of carbon, act as sinks and mitigate climate change.	1	4	1
S5.	The wages earned from mangrove products is higher than other menial labour-intensive jobs.	-4	-4	-4
S6.	The quality and quantity of firewood has declined over the years	-3	-2	4
S7.	Mangroves attract ecotourism and other recreation opportunities	1	3	-1
S8.	Mangroves keep the air, water, and land clean and healthy and support biodiversity (crocodiles, turtle, birds, mammals, fish)	2	3	2
S9.	Biodiversity (animal life) helps to promote livelihood opportunities like tourism.	0	2	0

S10.	Mangroves are an important source of income for all the villages in Bhitarkanika.	-4	-2	-2
S11.	Parts of the forest should be restricted from human use	0	1	3
S12.	Parts of the forest should be restricted from use by villages outside the Park	-2	1	0
S13.	Forest Dept. provides assistance to get in touch with contractors/ merchants/traders for mangrove products like baskets, honey, etc.	-3	0	-1
S14.	The process for accessing compensation schemes through the Forest/Revenue Dept. is not complex.	-1	0	-3
S15.	The Forest/Revenue Dept. staff are approachable to access compensation/reward programs or schemes	0	-1	-3
S16.	Illegal extraction of forest products is a big issue here	-1	-3	0
S17.	Illegal extraction is mostly carried out by informal settlements	-1	-3	0
S18.	Informal settlements have increased over the years, as well as their demand on mangrove resources	-2	0	1
S19.	Rehabilitation and relocation packages are more feasible for long term mangrove conservation than living in the Park.	-2	-2	-3
S20.	Food made using firewood is more nutritious/tastier than food cooked on stoves/LPG cylinders	4	-4	3
S21.	Pressures on Mangrove forests may be reduced if provided with alternate forms of cooking stoves	2	-1	-1
S22.	Pressures on Mangrove forests may be reduced if provided with alternate raw material for boat and house construction	0	-1	-1
S23.	Monetary compensation or alternate forms of technology/equipment is more appropriate in exchange for firewood/timber/honey extraction.	3	-1	1
S24.	Mangrove ecotourism enhances livelihood opportunities	-1	2	0
S25.	Most villages have access to toilets, clean drinking water facilities, and transport options like roads.	-3	-3	-4

S26.	There has been an increase in the number of people (especially men) migrating to cities for work opportunities	3	1	2
S27.	Mangrove tourism may be enhanced if there are better roads, toilets, and clean drinking water facilities in all the villages	0	1	2
S28.	Prawn and shrimp farming are spreading rapidly across the region	1	0	1
S29.	Shrimp farming provides livelihood opportunities and is a good source of income for households	2	0	-2
S30.	Villagers are actively involved in protecting parts of the reserve through community forestry programs	1	0	-2

5.3.2.2. Participant selection

The data collection for this study took place between September 2018 to February 2019. We purposively selected participants from 18 out of the 44 identified villages (Figure 5.1) dependent on forest firewood for cooking purposes, and other stakeholders based on their willingness to participate, knowledge of the topics at hand, and relevance to the operational social networks in the region. The 18 villages were identified based on pilot interviews which shed light on the proximity to forest boundaries, land tenure issues, and continued forest dependence. The selection of our participant list included local villagers (n=29) including members at leadership positions such as heading local governing bodies, forest communities, or women self-help groups, state forest officials and other participants that identified themselves as government officials (n=4), non-profit workers (n=3), and academics (n=5) who have previously worked in the area. We tried to capture a diverse range of stakeholder groups to also draw insights on how local values map out in relation to extra-local stakeholders with greater power in decision making.

5.3.2.3. Pile sorting

We allowed the ranking to follow a fixed normal distribution pattern. Each statement was transcribed in the local Odiya language and randomly presented on index cards to villagers and some extra-local interviewees. We also used QSortWare, a virtual platform to complete the sorting process to accommodate participants who could not be interviewed in person. Participants were instructed to rank statements from -4 (most disagree), 0 (neutral/no opinion) to +4 (most agree) (Van Exel and De Graaf 2005). The quantitative sorting process helped highlight sensitive issues like illegal firewood harvesting, compensation schemes, and social conflict, which may seem difficult to initiate in conventional interviews.

5.3.2.4. Analyses and Interpretation

We used the PQMethod software (Schmolck, 2014), a dedicated software for Q studies, to perform a centroid factor analysis with varimax rotation to analyze our data. The method produces distinct factors or groupings of statement rankings that reflect participants' shared values or views. To further dissect themes that dominate each factor, we followed the crib sheet method described by (Watts and Stenner 2012) for developing brief descriptions of each factor's viewpoint. We also conducted post-sorting qualitative interviews to gain a deeper understanding of participant values and priorities.

5.4. Results

Our findings highlight a diversity of worldviews emphasizing key value preference patterns and priority regimes towards mangrove forest conservation and management. The results of Q-methodology revealed three distinct narratives (livelihood security, recognition of mangrove conservation value, and sense of place), prioritized by different stakeholder groups as discussed in the following sections.

5.4.1. Factors analyses revealed three different perspectives

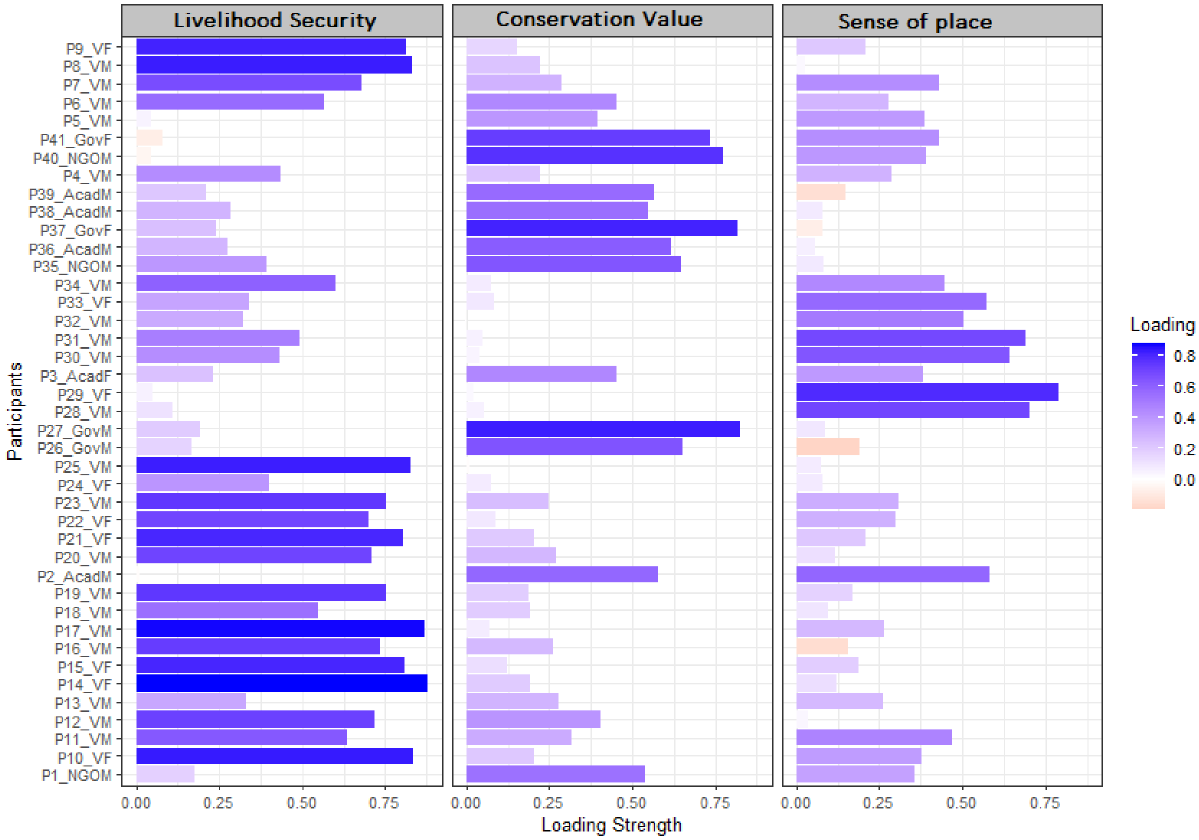
The Factor analyses generated three distinct factors, each representing three distinct narratives related to mangrove conservation in this region. The first factor highlighted aspects of "Livelihood security", the second emphasized "Conservation value of mangrove forests", and the third, a "Strong sense of place". In Table 5.3, the list of some statements that loaded significantly ($P < 0.05$) on each factor and corresponding interview quotes are presented. We focus on key themes which occurred as recurring topics of discussion throughout our interactions with interviewees. The first factor represented local villagers' conflicted views on shrimp farming, seen both as a lucrative and risky business opportunity. It also covered the growing migration of village folk to cities in search of jobs. The second described the immense storm protection potential of the mangroves as well as other ecosystem services. The third factor covered aspects of self-identity, which emphasized that the Sanctuary was their home and did not see rehabilitation and relocation packages as an option.

Table 5.3 Example representative statements and corresponding village participant views for each factor perspective

Factor Perspectives (Mangrove conservation discourses)	Some representative statements	Key quotes from local villagers
Factor1: Livelihood Security	S29: Shrimp farming provides livelihood opportunities and is a good source of income for households	*"Gherries* can be very profitable, but equally risky. So, the losses can be huge. But having the option, has prevented many people from going to cities in search of jobs"
	S26: There has been an increase in the number of people (especially men) migrating to cities for work opportunities	"Do you see any man in this village? Everybody has left the village in search of work. They go to Gujarat, Kerala, Bangalore because there are no jobs here."
Factor 2: Conservation value	S2: Mangroves are important because they protect from cyclones and storms.	"We are here because of the jungle. Due to cyclones and floods from sea, so many places got washed away, so many people died. But we wouldn't be here without the jungle. "

Factor 3: Strong sense of place	S19: Rehabilitation and relocation packages are more feasible for long term mangrove conservation than living in the Park	"This is where I was born, why will I leave? I will stay here only."

Similarly, Figure 5.3 shows how each participant dominated the narrative that shaped each factor. The horizontal axis indicates the strength of each factor loading for all the 41 participants, which are shown on the left-hand vertical axis. The correlation of each variable (rankings by each participant) and the factor is called 'factor loading'. Participants associated with higher loadings for a factor are the representatives of the factor. One of the key takeaways from the loadings was that interviewees such as researchers, NGO workers, and government officials, dominated factor 2 whereas the other two factors were dominated by villagers, indicating two different perspectives (See Figure 5.3.b. for factor loadings of participant groups).



Livelihood Security
Conservation Value
Sense of place
Participants
P9_VF
P8_VM
P7_VM
P6_VM
P5_VM
P41_GovF
P40_NGOM
P4_VM
P39_AcadM
P38_AcadM
P37_GovF
P36_AcadM
P35_NGOM
P34_VM
P33_VF
P32_VM
P31_VM
P30_VM
P3_AcadF
P29_VF
P28_VM
P27_GovM
P26_GovM
P25_VM
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P15_VF
P14_VF
P13_VM
P12_VM
P11_VM
P10_VF
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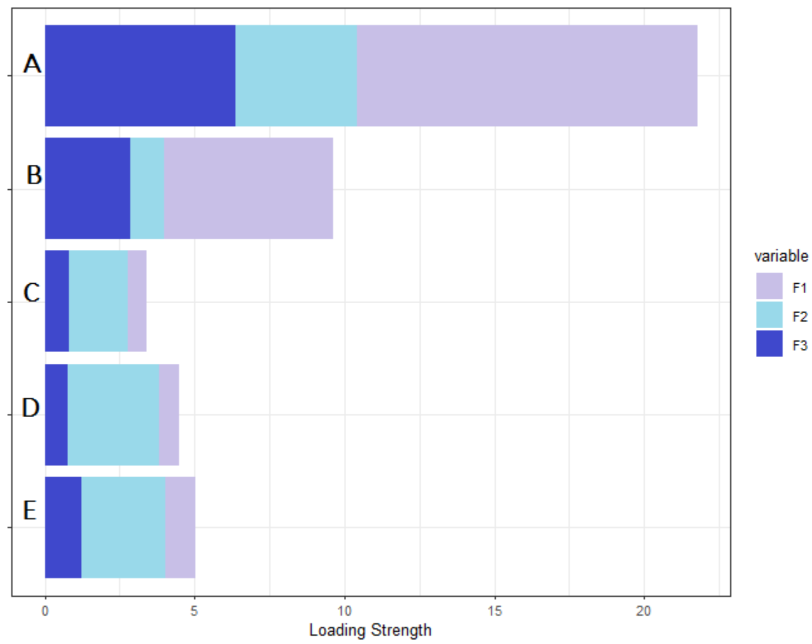


Figure 5.2 Individual Factor loadings of each participant (V: Village, Gov: Government official, Acad: Academic, M: Male, F: Female, for example: P1_NGOM indicates a male NGO participant and P10_VF indicates a female village resident) b. Factor loadings of participant groups A: Male village residents, B: Female village residents, C: NGO staff, D: Government officials E: Academics.

Although each factor denoted a specific theme, the interviews shed light on how these themes connected to the posed statements. A common link between the protective role of mangroves against cyclones as well as the invisibility of provisioning services in the day-to-day lives of the local people was evident across all three factors and the interviews. Furthermore, we also compared the interview responses for the statements that dominated each factor, to explore each factor's significance in defining the highlighted narratives which are described for each factor below.

5.4.1.1. Factor 1: Livelihood security

Based on the factor analysis, factor 1 explained about 30% of the total variance. The participants that loaded significantly constituted mainly villagers (both men and women) as shown in the factor loadings graphic by the darker blue bars (Figure 5.3). This factor emphasized the need for a better standard of living (strong disagreement on S5, S10, S13, S25 and agreement with S2, S20, and S26) while also agreeing with potential conservation measures (S23) directed towards improving the overall well-being and quality of life of local communities. It also emphasized the conflicting views concerning the growth of shrimp farming avenues (S28 and S29) in the region.

The dearth of employment opportunities has created a vicious cycle of migration to towns and metro cities in other parts of the country. Migration can further place a burden on families left behind, especially women who are bound by patriarchal structures that perpetuate marginalization as well as forest dependence. A female participant shared her grievances on the lack of job opportunities in the region,

"Do you see any man in this village? Everybody has left the village in search of work. They go to Gujarat, Kerala, Bangalore because there are no jobs here."

Other participants share similar ideas as well as the need for greater diversification of job opportunities and more income-generating jobs in the region, as stated by a male participant on the growth of shrimp farms over the years:

"The government says forests are important for us. I also understand that it is important for me and my children's future, but we don't have enough food to eat, so we need to utilize the forest."

According to him, prawn farming benefits are far greater than the daily wage earned through MNREGA (government sponsored scheme for daily wage laborers). Through MNREGA, the fixed daily wage allowance ranges between 350-500INR per day (~4-7$), whereas if he spends around 1.5 lakhs INR (~2000$) on the initial set-up and running of a *gherry* or shrimp farm, he can earn a profit of another 1.5 lakhs INR (~2000$). When asked about losses, he exclaims that for about 50,000 INR (~600$) hatchlings, a loss of 10,000 INR (~130$) is inevitable, but still, profits are guaranteed.

On the one hand, participants justified the growth of aquaculture in the area, at the same time, they also felt that the growth was out of need rather than preference. Some also felt that the growth of the farms destroyed the aesthetics of the place. One participant recalls an episode of rampant disease that swept the region and the incurring losses that burdened many, which completely changed their outlook towards shrimp farming. They elaborate,

"if one person gets to profit from prawn farming, 50 people face losses. The place stinks because of the disease. It's not a safe option but a risky business."

Although the dominating statements did not include perspectives on tourism, participants had mixed but positive opinions about the possibility of tourism as a potential income generating opportunity. They also believed tourism and forest dependence were more correlated and intertwined than their reliance on firewood or other non-timber products from the forest. A female participant warns:

"If tourism increases, if all villages are given equal opportunities and resources for the expansion of tourism, then we can say that these forests are providing us with income; otherwise, they're not."

5.4.1.2. Factor 2: Conservation value of mangrove forests

According to the factor analysis, factor 2 explained about 16% of the total variance. The participants supporting this factor's narrative mainly comprised of researchers, NGO, and government officials, including Forest Dept. staff, as evident by the factor loadings graphic (Figure 5.3). This factor was dominated by themes surrounding the preservation and conservation potential of the mangrove forest. Although this narrative was also emphasized in other factors, the current emphasis was purely from an ecosystem services perspective, compared to the material and cultural relationships manifested in factor 1 and factor 2. The focus on the mangrove's protective role against storms (S2), a carbon sink (S4), and other regulating services like nutrient cycling, water filtration (S8) were emphasized by the participants. Similarly, participants dominating this factor also recognized the role mangroves play in fisheries by serving as fish spawning and nursery areas (S3) in addition to their potential as ecotourism hotspots (S7). Surprisingly, these viewpoints were not explicitly shared by villagers except in those cases where they directly supported livelihood opportunities such as ecotourism and regulating services like storm protection which were ingrained in their memory and through their lived experiences of witnessing the benefits and role of the forest in protecting against damaging storm events.

5.4.1.3. Factor 3: Strong sense of place

According to the factor analysis, factor 3 explained about 13% of the total variance. The participants that loaded significantly constituted mainly villagers (both men and women) represented by the darker blue and purple bars as shown in Figure 5.3. The villagers dominating this narrative were part of a different pool from factor 1 and 3. This factor's narrative included a strong sense of community and belonging reflected in high disagreement levels to relocation or rehabilitation (S19) measures in exchange for preserving and expanding forest areas in the region. There is also a strong sense of place among most communities and neighborhoods in Bhitarkanika. A sense of place denotes close attachment or emotional ties between people and places because of their lived experiences. Many people living in Bhitarkanka had families located there for generations. Others have found solace through familiarity, residents that moved from West Bengal, the neighboring state, or Bangladesh. The familiarity of culture (food, language, and religion), and labor processes of working in rice fields, culturing fish, and other crustaceans made it easier for migrants to settle and prosper in this region.

Moreover, studies suggest that reconstruction skills and abilities (social, educational, and health services) are intricately linked with a sense of place and the safety of conditions (Zakour 2018). However, reconstruction and revitalization post disasters are better achieved in areas with higher social capital (Zakour 2018). The frequent destruction caused by recurring tropical storms in this region required communities to reconstruct lives and properties periodically. Despite lacking social infrastructure, individual social networks maintain place attachment and upkeep. The interviews also reflect a sense of belonging, a participant insisted,

"This is where I was born, why will I leave? I will stay here only. We only get firewood from the forests and nothing else. The forest is my home."

A close relationship with the forest also stems from the material relationship shared by the villagers through the use of forest timber as fuelwood (manifested through S1, S6, and S20).

Another participant, while addressing past relocation schemes in the vicinity, was of the opinion;

"Government has relocated people in the past because of sea-level erosion. We know about the example of Satbhaya, but we don't have any interest in relocating now. If in the future sea-level

rise causes intense flooding in this region, and I suppose that might happen if the forest disappears because of development, say in the next 20 years or so, then we don't mind relocating but not now."

Another interview participant, a recipient of the relocation benefits, reminiscing his time in the village, "tigers and leopards (fishing cats are sometimes confused for leopards but several villagers mentioned the presence of tigers in the past) are less now, but we still have lots of deer and boars that often came near our house in Satbhaya (See purple marker on Fig 1 for historic spatial location of the village). That place is rich in wildlife, if you visit my house, you won't feel like coming back. It is beautiful there."

5.4.2. Diverging and converging views

Further, correlation values, as shown in Figure 5.4 compare the views of each participant with the other. The blue shades reflect a positive correlation indicating similar views, whereas the red to yellow shades, a negative correlation indicating dissimilar views. The correlation values indicate a strong positive correlation between women, whereas villagers showed a low positive or negative correlation with government officials.

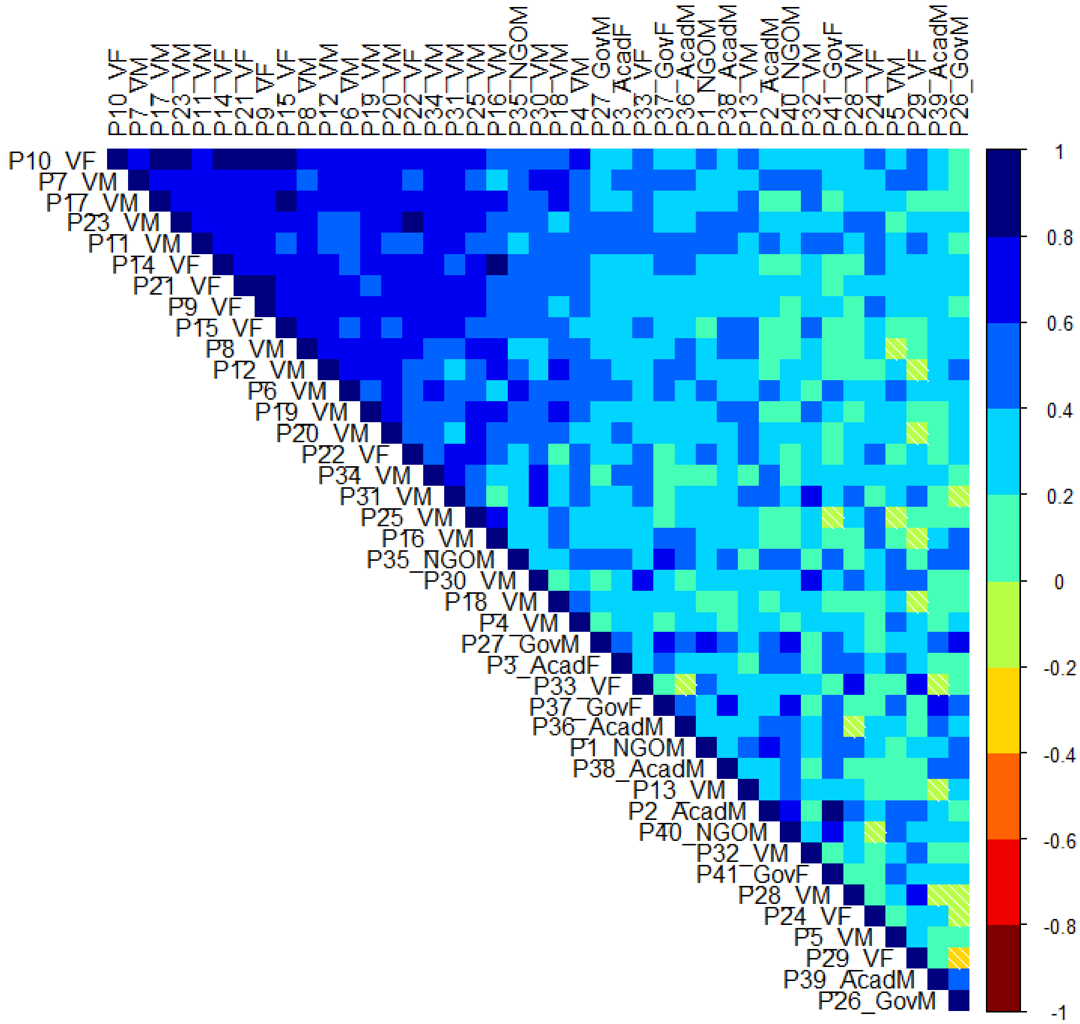


Figure 5.3 Correlation plot of participant factor scores

The two major points of discussion were firewood use and the tourism potential of the region. When women were interviewed and asked to explain their reasons and preference for cooking with firewood over other alternatives, their responses reflected a sense of helplessness arising from low economic backgrounds but also a strong cultural significance. As quoted by one respondent, "*We must put food on the table. An LPG cylinder costs about 1000 INR. That is awfully expensive as it does not last long for a large family. We are poor people; from where we can get 2000-3000 INR every month just to cook rice?"*

Consequently, government officials, including many academics, denied firewood extraction as an ongoing reality. They often emphasized that,

"Firewood was used a very long time ago, now people use only gas stoves."

Many others confirmed that since it is a protected area, firewood collection is not practiced anymore. When we compared the responses from the interviewees for their views on provisioning services of mangroves & reward-based schemes for mangrove conservation, we found some contrasting viewpoints. The complexity of these viewpoints was not captured through the sorting exercise, but the interviews provided further context. For example, towards the statement on mangrove provisioning services (S1), we found comparing levels of agreement among all interviewees. However, local villagers believed these services were not readily accessible to them. Many strongly felt that, in reality, the forests did not provide these services to them. Similarly, when presented with the statement (S21) about alternatives for firewood extraction, some interviewees were skeptical if people would change their habits of using firewood even when alternate options were provided. However, villagers showed interest but lacked adequate resources.

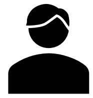
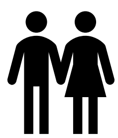
Similarly, since tourism is conducted by the Forest Dept. and concentrated in a few pockets of the Sanctuary, the Forest officials felt that tourism is helping this region immensely. In contrast, several women believed tourism has a long way to go till it develops as a regular stable income source for all the villages in the region. It has benefits, but those benefits are limited to a few pockets in the Sanctuary. As quoted by one women respondent, "People come to see the diverse animals, plants, and beauty of this place but the benefits of tourism are restricted only to villages of Dangmal and Bankual (Figure 5.1). Nobody comes to this side; we do not benefit from tourism."

5.4.3. Gendered differences in values and labor

Women mainly collected firewood and were involved in activities that did not contribute directly to household income, whereas men were considered the sole breadwinners of the family. The differences in responsibilities contributed to certain subtle differences in how men and women perceive and value the forests differently. For instance, when asked about significant changes in firewood quality or quantity since stringent forest access restrictions were imposed, men often denied the use and insisted that forest quality has improved over the years owing to low extraction activities. In contrast, women often provided reasons to justify that their forest use did not impact forest health significantly (Table 5.4).

Further, some of the responses indicate an embedded cultural significance of cooking food, especially rice using firewood. When presented with compensation schemes in exchange for firewood collection, men were more open to adopting these schemes. However, women often paused to explain that rice has always been cooked on traditional stoves, and they were bound by family obligations to continue this practice. Interestingly, both genders strongly preferred food cooked on wood-fired cookstoves (Table 5.4).

Table 5.4 Gendered differences in value and labor practices

S6: The quantity & quality of firewood has declined over the years		"We use cylinders and not firewood so it's actually improving"
		"We don't cut trees; we only use dry wood, so our use has nothing to do with quantity or quality of the forests"
S23: Monetary compensation or alternate forms of technology/equipment is more appropriate in exchange for firewood/timber/honey extraction		"Yes, we're open to accepting compensation"
		"Yes, but everyone prefers eating rice cooked on traditional *chullahs*"
S20: Food made using firewood is more nutritious/tastier than food cooked on stoves/LPG cylinders		"Without doubt, food cooked with firewood"

5.5. Discussion

Our results indicate three distinct narratives that are influenced by a range of factors, including a history of limited access to forest resources, a dearth of livelihood opportunities, and the narrative of preservation which shape local and extra-local interviewees' values and priorities. Summarizing, narrowing conservation goals to a single worldview might seem futile in the long run. We elaborate these patterns below to highlight how forest access can impact and influence interviewees' worldviews using three distinct points of discussion, namely the value preferences and priorities surrounding mangrove ecosystem services, quality of life, and specific conservation or management options related to mangrove forests.

5.5.1. Ecosystem services

The value preference patterns between local and extra-local interviewees revealed common patterns for regulating and recreational services, irrespective of social and economic differences. This aligns with the study conducted in Matang, where the authors elaborated on the diversity of perspectives held by different stakeholders towards mangrove management regimes using Q. Their findings also highlight a need for more participatory management regimes and a focus on ecotourism initiatives (Hugé et al. 2016).

Similarly, their findings also stress the need for investment in biodiversity initiatives and storm protection services of mangroves. Both these viewpoints were shared by our participants. They recognized and felt strongly about the storm protection services provided by mangrove forests. At the same time, they valued the forest's diversity and unique flora and fauna for their potential in attracting tourists to the region.

In contrast, recreational services were valued for their potential in contributing to livelihood opportunities. Large contiguous forest patches inhabiting unique biodiversity are increasingly valued for their potential to contribute to the local economy through tourism facilities, alongside the conservation of natural resources. Similarly, the paradox of preserving a natural space while still accommodating the growing needs of the population creates an attractive avenue to develop income generating opportunities using the biodiversity narrative. Our results indicated a similar value preference pattern among both local and extra-local interviewees.

The concentration of revenue in a few localized areas has upsurged the need for more spaces with modern facilities and opportunities, making it possible for only a small fraction of the upper social class to invest in such ventures. The recognition of tourism as an income generating opportunity has also changed the outlook of the local stakeholders towards the supporting services provided by these forests. Local stakeholders recognized the value of the forests for supporting iconic wildlife and for maintaining a healthy ecosystem that is valued by non-residents for recreation and its aesthetic appeal more than for supporting their own well-being.

The ecosystem service model paints a romanticized view of how local habitants are directly and indirectly reliant on forest provisioning services for food, timber, and fuelwood. However, our interview results revealed a denial of such dependency among residents. Confirming that legal exclusion prevents the dependent population from readily acknowledging provisioning services. This acknowledgment was not only stemming from the need for escaping repercussions but also the failure to visualize and connect these provisions that were once a crucial part of local village life and forest values.

5.5.2. Quality of life

The quality-of-life narrative was predominantly limited to the lack of employment opportunities in this region. Local interviewees valued the multiple use landscape, which provided them the opportunity to cultivate land to produce rice which was an important livelihood option for a large proportion of the population in this region; maintain ponds for raising fish and investing in fish, shrimp, and crab production and other allied industries while living alongside a rich forested landscape.

Most often, anticipation for better infrastructure facilities and stable job opportunities was prevalent in all the conducted interviews and surveys. Among possible options, villagers felt strongly that paddy cultivation produced the most stable annual benefits, whereas shrimp farming was a risker but the most profitable venture. However, a majority hoped for a future where service industry jobs were plentiful as they provided stable monthly wages with benefits.

At the same time, local stakeholders also imbibed a strong sense of place, which was reflected through their sense of community, tight social networks, and pride in local cultural heritage. The forest was considered an essential component of the daily lives of the villagers, irrespective of its exclusionary status. The two value patterns reflect two contrasting perspectives that have shaped the priorities of stakeholders towards rural development in this region. The stakeholders seek economic growth, which is based upon attributes that contribute to a holistic quality of life. A life that embodies both economic, social, and aesthetic qualities of human well-being (Papageorgiou et al. 2005).

5.5.3. Conservation and management options

The third value preference perspective provides insight on the trade-offs in conservation choices and priorities based on the perceived potential of forest ecosystems in providing beneficial services. These environmental services are not just limited at the local scale but also at the regional and global scale by improving quality of life attributes, maintaining a culturally rich ecosystem, and contributing to the mitigation of climate change impacts.

Our results indicate that low economic stability and conflicts with wildlife are a lived reality of the local people in this region. Many respondents felt the need for clearly defined boundaries such as barbed wired fences to reduce human-wildlife conflicts (S11). These realities greatly influence the value preferences of the local stakeholders, especially when compared with outsiders without a stake in the region. The majority of the respondents preferred the maintenance of boundaries between the core area and the surrounding farmland. The tight protection status was not perceived as a hindrance to their development needs but rather a necessity.

The frequent wildlife raids caused tremendous losses to the local people's livelihoods, and a clear demarcation between tightly protected forest core areas was observed as a need to prevent further damage. Similarly, since local stakeholders were expected to change their cultural dependencies on forest resources (extraction of firewood for cooking and heating needs) a strong focus on provisioning services would not change the status quo. In fact, studies focusing on the diffusion of cleaner cookstoves in remote rural areas have highlighted that forest fuelwood dependence is driven by several factors, including the availability of fuelwood, lack of infrastructure, as well as cultural preferences such as the taste of food (Jeuland and Pattanayak 2012). Similarly, the cost of stoves plays a significant role in influencing choices (Wallmo and Jacobson 1998).

The two diverging value perspectives help in understanding the need for more community-based forestry options where provisioning services are met while still maintaining other beneficial services, such as regulating and supporting services, intact. This is only possible when local interviewees are provided opportunities to maintain small forest patches for meeting their livelihood needs rather than restrict their entry completely.

Furthermore, Mashayekhi et al. (2016) also show similar results from their study on the Hara (or mangrove) forests in the southern coasts of Iran. The authors used a choice modelling approach to understand people's preferences towards different protection measures for the conservation of the mangrove forests in the biosphere. These options included reduced fishing and cutting of the forests and a ban on tourist boat trips. In exchange for these reduced activities, the local people were promised adequate compensation. The study found that respondents belonging to high-income classes (including fishers) showed low interest in increasing protection regimes for mangroves forests for fear of losing access to these forests, whereas lower income respondents like anglers and hunters preferred the current status quo. They also found that respondents were willing to accept lower compensation for cutting and fishing activities relative to a ban on tourist operations.

We found several parallels with this study. Our respondents were also apprehensive of reporting their dependency on the forests or reporting their actual use to avoid being classified as encroachers involved in illegal extraction activities. On the contrary, our results also portray the willingness and recognition for the preservation of mangrove forests to improve human well-being.

In fact, these conflicting values are also highlighted in an IUCN report published in 2013 on the status of mangroves in Can Gio, Vietnam (Quoc Vo and Kuenzer 2013). The report provides insight on the limited understanding of the role of mangroves in providing services crucial to local stakeholders. They conducted household surveys in Can Gio where they found that a large percentage of the households (80%) valued mangroves in the role they play in protecting the area from storms, whereas only 20% understood their nutrient filtering services. Similarly, only a small fraction of the surveyed respondents (less than 50%) recognized the importance of mangroves for biodiversity or regulation of the local climate.

5.5.4. Incorporating gender differences in conservation plans

Our interviews revealed that respondents showed interest in accepting alternatives to firewood use and adapting to newer technologies for the management of the forests. The majority were also accepting of incentive-based programs such as alternate cookstoves or monetary compensation towards alternate fuel choices. However, these views were mostly represented by men who were not involved in household chores. In a nutshell, participants showed interest in accepting compensation or willingness towards reward-based schemes but had contrasting gendered views on provisioning services provided by the mangrove forest they depended on for their firewood needs.

On the surface, exclusion assumes a reduction in people-forest interactions, when use continues, which explains why people are reluctant to recognize, and even value provisioning services of these forests as exclusion does not legally give them rights. The use of reward-based schemes (e.g., subsidies for cookstoves or LPG cylinders) or alternative forms of technology (biogas stoves, etc.) may again backfire as people prefer food cooked on wood-fired cookstoves as well as traditionally have been cooking rice on wood-fired stoves. The onus of conservation ultimately falls on women who do the collection, cooking, and other household chores.

5.5.5. Exclusion, reciprocity, and values

About 36% of world's mangroves lie within protected areas (Friess et al. 2019). These restricted spaces have been shown to reduce mangrove loss at local scales in many developing countries. However, protected area designation does not guarantee a reduction in mangrove degradation from small scale disturbances like cutting practices for fuelwood and timber or extraction of non-timber forest products. In such cases, community management can provide a better alternative than total exclusion because it helps involve people in the functioning and decision-making process.

About a third of India's forests are managed by forest dependent communities run under the community-based forest management or the Joint Forest Management initiative (Dasgupta & Burivalova 2017). Such community environmental initiatives inculcate home-grown stewardship. In fact, many such initiatives are already in practice in some regions of the Sanctuary and other regions of the state, which can be supported better with state recognition.

This narrative is also supported by studies that claim that resource dependent communities, which especially experience outmigration but show strong social relationships and a sense of place, have better chances of a successful outcome at community-based management programs (Chan et al. 2016). For example, mangrove forest conservation because of its storm protection value or sense of place linked to cultural ties can serve as guides while designing forest management decisions to accommodate both economic, ecological, and cultural needs of communities.

Importantly with exclusionary processes of management in place, the introduction of neoliberal conservation mechanisms will then be largely implemented through top-down processes benefitting the larger global community as well as state government agencies while side-lining local socio-cultural values and concerns of livelihood security and tenure. While forests outside boundaries change to accommodate other land-uses, exclusion maintains and shifts forest dependence further on core areas. In line with this thought, extending the traditional ecosystem services framing to accommodate values and priorities into decision making (Figure 5), it is argued that reciprocity enables the different constitutes of well-being (social security, health, material for a good life, good social relations and freedom of choice and action). The conceptual framing (Figure 5) also emphasizes two-way interactions between ecosystem services, which are impacted by human values and motivations, which in turn are influenced by access or exclusion to resources rather than one-way interaction between services and human welfare.

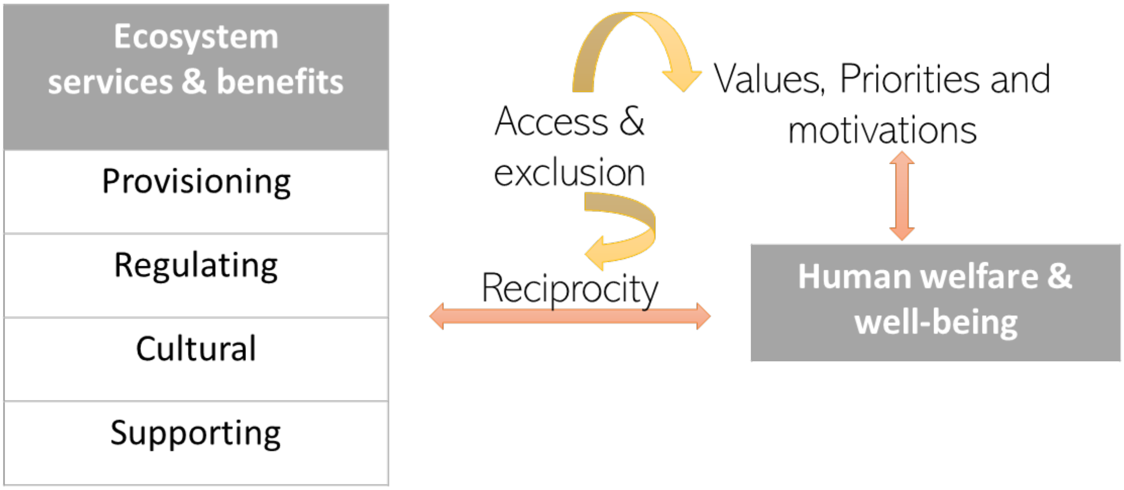


Figure 5.4 Conceptual framework linking ecosystem services framing with values and priorities in mangrove conservation

5.6. Conclusions

The goal of this study was to explore how exclusion interacts with stakeholder values to influence mangrove-human relationships, as well as how those values align with mangrove conservation narratives. Through the Q-method survey and in-depth interviews, we highlight three different value preferences: livelihood security, a sense of place, and ecosystem services that enhance the conservation value of mangrove forests across the globe. The study also tried to establish possible links between the diverse values of stakeholders and derive value-preference patterns, which can further draw light on forest management priorities that are most likely preferred by local inhabitants. Villagers valued their cultural and material ties with the landscape, while academics, government, and non-profit officials emphasized the value of preserving mangrove fragments for the myriad ecosystem services derived from them. If conservation decisions are expected to be successful, it is imperative to capture a broad spectrum of stakeholder preferences and values to be representative of society. The present study provided a comprehensive insight into how and where local values converge and differ from those with different lived experiences and worldlings. An understanding of the value preference patterns can be used as a guide to incorporate socially just, culturally sensitive, and equitable decision making.

Although the intrinsic values of non-human worlds are immutable, society might value natureculture for different reasons. Pascual et al. (2017), elaborates on the multiple connotations surrounding the concept of ‘value’ where the term takes a holistic view ranging from a culturally defined principle, a preferred attribute or condition, and a mere tool for measurement. In this context, ecological services provided by mangrove forests such as climate regulation, nutrient cycling, and suitable habitats for wildlife is only one measure for the forest’s significance which forms the basis of value preferences by scientists and environmentalists. In the same way, livelihood subsistence provided by provisioning services of mangroves through the supply of firewood forms another measure of ‘nature’s contribution to people’ (Pascual et al. 2017), albeit an unrecognised value. A value that is prioritised by women over men and reinforced by cultural connections as well as economic feasibility.

In a place layered with such multiple interests and priorities, these values need to be understood and acknowledged in its complexity to have successful conservation outcomes. Based on this study, we can conclude that some level of dissonance between current practices of mangrove conservation and local values and priorities exist, which need further investigation. The discussion on management choices should be drafted on the different trade-offs in stakeholder values and priorities. As indicated by the findings, integrated forest management is needed, which accommodates provisions for both plural services provided by mangrove forests and the plural values-biophysical, economic, and socio-cultural, derived by the people.

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CHAPTER 6

BLUE IS THE NEW GREEN: WHOSE NARRATIVES SHAPE MANGROVE POLICIES?[4]

[4] Rasquinha, D.N. & Mishra D.R. Submitted to the Annals of the American Association of Geographers

Abstract

The last two decades have witnessed an increase in market-related approaches to conservation in both territorial and coastal habitats. We review the implications of this increasing trend in coastal habitats, specifically mangrove forests and highlight the role social media plays in influencing public perceptions towards coastal habitats. To this end, we analyzed a summary of social media tweets about mangrove ecosystems between 2019-2021 and found a growing trend in narratives, dominated especially by developed nation entities. The implications of blue carbon narratives by influential entities in geographically apart and culturally distinct locations, at times without a stake in the social welfare of resource-rich nations, may result in conflicts and displace local livelihoods while advocating for conserving mangrove vegetation. Instead, a place-based approach that includes local values and cultural consensus within the larger framework of carbon conservation is needed which can provide more effective conservation outcomes.

Keywords: blue carbon, mangroves, coastal policy, social media, twitter

6.1. Introduction

Green economy as a solution to the ongoing global planetary crises was first introduced in Rio in 2012 during the United Nations Conference on Sustainable Development (UNEP, 2011). With time, the concept of green economy has evolved to include various schemes, from market-based approaches to technological solutions, each with its own varying outcomes across the globe (Scoones et al., 2015). While the Global North is moving towards green transitions through ecological modernization (Mol and Spaargaren, 2000), in post-colonial countries of the Global South, green measures have manifested largely in the natural resource sector (Brown et al., 2014; Buseth, 2017). Studies argue that the green economy agenda with roots in neoliberal approaches to conservation is a result of persistent, powerful narratives pushed across by organizations, governments, and entities in the Global North (Brockington and Ponte, 2015; Buseth, 2017; Corson et al., 2013) These agendas eventually shape and inform green economy discourses and policies in post-colonial resource-rich countries of the Global South. However, how such powerful narratives are being translated into ground realities or in the processes of how natural resources are utilized, controlled, and managed has received much less attention.

6.1.1. The growing legacy of blue carbon projects across the globe

As signatories to the Paris Agreement (2015), governments around the world are looking for strategies to meet their national commitments to reduce carbon emissions. The international push to protect blue carbon, or carbon stored in coastal habitats such as mangroves, marshes, and seagrasses, stole the spotlight when the United Nations published a report pointing out the crucial role of coastal ecosystems in capturing and storing carbon, far more efficiently than their terrestrial counterparts (Nellemann et al., 2009). The report also highlighted the need to incorporate an ocean's agenda into international climate change initiatives (Nellemann et al., 2009). A humble appeal and rightly so, considering over half of the biological carbon is captured by marine organisms, a focus on oceans and coastal ecosystems is important in the fight against climate change. However, increasingly the focus on protecting these critical ecosystems has shifted from their existence or relational value to their climate mitigation value especially with a strong focus on tree planting initiatives for carbon sequestration (Seddon et al., 2021).

In the past decade, the bulk of the proposed initiatives (REDD plus, PES, carbon credit trading) have shifted focus to market-based conservation strategies, especially on carbon offset schemes that involve large corporations investing dollars in buying emissions reductions from resource-rich nations. One such notable example includes mangrove restoration work undertaken by a group of European companies in Niodior, Senegal between 2008 and 2012 (Bird 2016). Similarly, Apple has growing philanthropic interest in blue carbon projects in collaboration with Conservation International (CI) in South American countries like Colombia (McVeigh, 2021; Jones 2021). Further, Gucci and Procter & Gamble have announced mangrove protection and restoration projects to offset their greenhouse gas emissions (Klein, 2021). Shipping and tourism-based corporations like the Geneva-based MSC Cruises are also keen to invest in preserving coastal landscapes, both as part of their corporate social responsibility philosophy but also as a way to offset their own emissions (Tracy, 2021).

Along with a number of increasing restoration projects underway, proposals dealing with integrating the idea of blue carbon into existing international frameworks and agreements have become the focus of conservation policies. Agreements such as the UN Framework on Conservation and Climate Change (UNFCCC) and the Convention on Biodiversity (CBD) with mangrove inhabiting nations have occupied the centre stage in the policy arena of climate change mitigation actions and agendas (see Table 6.1). Further, in its recent blue carbon report, UNESCO highlighted the financing potential through selling and claiming carbon credits of its 50 marine Heritage Sites, comprising 15 percent of the planet's blue carbon (Hutto et al., 2021). Similarly, negotiations over Article 6, which outlines how countries can use their carbon markets to reach their emission targets, and to boost and facilitate the smooth incorporation of voluntary carbon credit schemes into market-based programs was the focus of the 2021 United Nations Climate Change Conference (COP26). Article 6 also includes private sector participation in the Paris process.

Table 6.1 Policy working groups working on blue carbon initiatives across the world. Source: (Barbesgaard, 2016)

Policy initiative	Collaborative team
Blue Carbon Initiative	• Conservation International (CI) • International Union for Conservation of Nature (IUCN) UNESCO's International Oceanographic • Commission (IOC-UNESCO)
Eye on Oceans & Blue Carbon Special Initiative	• Environment Agency – Abu Dhabi • Global Environment Fund (GEF) • UNEP • UNEP Global Resource Information Database (GRID), • World Bank • Blue Ventures • Ecological Society of America • IUCN • CI
Ocean and Climate Platform	• Blue Fish • Global Ocean Trust • IUCN • IOC-UNESCO • Marine Stewardship Council • Mission Blue • The Nature Conservancy • The World Ocean Council
International Partnership for Blue Carbon	• Australian, Indonesian & Costa Rican government • Blue Carbon Initiative alliance

This relatively new and rapidly spreading approach to coastal conservation promises multiple benefits including climate mitigation, upkeep of sensitive coastal environments, and greater prosperity for the local communities who inhabit them (Phelps et al., 2012). The interest and growing trend of investing in blue carbon projects is not the crux of the problem. The issue lies in allocating a greater proportion of resources towards a one-size fits all approach to mangrove conservation and the lack of recognition and assessment of trade-offs between blue carbon services and local livelihoods (Phelps et al., 2012; Barbesgaard, 2016; Muradian et al., 2013; Seddon et al., 2021).

Voluntary carbon markets could also lead to company greenwashing and undermine the goals of the Paris Agreement (Streck, 2021). For example, active efforts to reduce or decarbonize operations especially Scope 3 emissions through relevant carbon measurement technology is a pressing need (Johnsson et al., 2020). These emissions form the bulk of a company's carbon impact (65-95%) and comprise of emissions resulting from activities not directly controlled by the organization along its value chain which makes it hard to measure or manage (Sullivan and Gouldson, 2012).

Similarly, not accounting credits against the host countries' Nationally Determined Contributions (NDCs) shifts focus from decarbonizing fossil fuel-based industries to increasing carbon sinks in growing economies and resource rich nations. The latter with a large community of local people dependent on blue carbon habitats for their livelihood needs. Thus, transferring the burden to curb emissions on marginalized communities whose lives are intricately intertwined with such habitats and whose contribution to the historical pool of carbon emissions has been almost negligible (Khan, 2017).

Although the concept of emissions trading is not new, the growing interest, scale, and push for blue carbon projects in developing nations, however, is something that has progressed rapidly in the last few years (Conniff, 2009). Many established non-profits have formed coalitions with corporations, and far more have sprung up in the last decade to keep carbon registries. Some notable examples include Washington, DC based Verified Carbon Standard, Verra or VCS (founded in 2005), Geneva-based Gold Standard (founded in 2003), Edinburgh-based Plan Vivo Foundation (founded in 2009), among others. There are more than 1,700 projects registered with Verra alone, which have issued nearly 740 million units of carbon credits, enough to counteract the emissions released from nearly 161 million passenger vehicles taken off the road for a year (Verra - Standards for a Sustainable Future). On the other spectrum and operating on a smaller scale, Plan Vivo (Plan Vivo Foundation – For Nature, Climate and Communities) has about 25 projects (both mangrove based and other terrestrial vegetation) under their belt which have committed to reducing 3.5 million tCO_2 emissions by planting trees in their project sites.

As with the growing demand, the extent of investments has also taken a turn from small localized projects to large scale projects such as the ambitious Indus-Delta reforestation plan which comprises of more than 200,000 acres of mangroves with the aim to absorb 2 million tCO_2-equivalent per year, at about 1 million credits in 2021 alone (Delta Blue Carbon). Other notable examples of upcoming and recently established projects include the Tahiry Honko project set-up in collaboration with the government of Madagascar and World Bank under their Forest Carbon Partnership Facility (FCPF). In this project, the country has agreed to reduce 10 million tons of carbon emissions in exchange for about $50 million between 2020 and 2024 (Vyawahare 2021). Similarly, the recent Philippines Palawan Protection Project, in partnership with P&G and Conservation International, aims to safeguard 31 species of mangroves comprising an area of

44,500 hectares on the Philippines' largest island. The Muskitia Blue Carbon REDD+ project is another recent addition (initiated in 2021) by Gucci to protect 12,350 acres of mangroves in Honduras, as is Apple's collaboration with CI to preserve a 27,000-acre mangrove forest in Colombia. Moreover, the trend shows that demand for more carbon credit-based projects will likely grow in the future by a factor of 15 by 2030 (Blaufelder et al., 2021).

6.1.1.2. Social media a translational actor in blue carbon policy discourse

Social media veils power by its ability to influence public sentiments by making information, knowledge, and narratives accessible to a worldwide audience. It has also changed the way individuals interact, share information, and relate to their environment (Casarin et al., 2021). Organisations furthering carbon credit programs and approaches using creative hashtags and specific messaging can influence people's perception towards market-based programs in mangrove conservation. It provides a ubiquitous platform for global policy narratives to penetrate national and local contexts. In this sense, it acts as a "policy entrepreneur" in the process of translating policy discourses and narratives (Huitema and Meijerink, 2010).

Green (and blue) economy agendas may emerge or fade away with the aid of policy actors that push for "nirvana concepts" in conservation (Molle, 2008). Molle's nirvana concepts can be extended to neoliberal approaches to conservation such as carbon payments, PES, REDD+ schemes, blue bonds, ecotourism, or biodiversity offset schemes which largely illustrate a large portion of the green economy in the Global South (Brockington and Ponte, 2016; Mukhtarov et al., 2013). The network of social media platforms generates a web of translational actors who assist in promoting a credulous appeal of green-blue economy narratives to scientists and policymakers that paint win-win solutions. Such narratives can have profound impacts on the conservation and management of natural resources in developing countries, especially on livelihood strategies, by ignoring underlying power structures in political processes or policy implications of green transformations (Scoones et al., 2015).

In this study, we hypothesize that social media can play a significant role in pushing for the promotion, adoption, and execution of blue projects in mangrove inhabiting nations (Blaufelder et al. 2021). To test this, we look at social media tweets from 2019-2021 to understand how public perception across the world varies with respect to mangroves and if these narratives have geographic hotspots.

6.2. Methods

We used the Twitter streaming API to collect tweets with the hashtag mangrove/s from 2019 to 2021 for assessing their geographical variation. We also extracted tweets posted during 2019-2020 for special observance days set aside for conservation and the environment, such as the International Mangrove Day or International Wetlands Day (See Table 2 for a list of all days considered). The tweets for each observance day were extracted using hashtags specific for that day (e.g., #worldhabitatday or #worldwetlandsday). All the tweet text was cleaned to remove stop words, hashtags, links, punctuation, and retweets before processing for any further analyses. The special observance day tweets were further processed to include only those tweets that contained the term mangrove/s and forest/s. This ensured that our analyses were limited to only mangrove forest ecosystems and to an extent to only coastal habitats for those special events. The total number of distinct tweets analyzed included about 1,40,004 for analyzing geographical variation among extracted tweets and 10,301 for the subset considered for sentiment analyses.

6.2.1. Analyses

For visualizing the geographical variation of tweets, the user location for non-geotagged tweets was used for geocoding addresses. This was done as the percentage of geotagged tweets comprised only about 2% of the total data. Tweet locations were geocoded using RStudio and mapped using QGIS. While public sentiment towards blue carbon policy discourse was deciphered using sentiment analyses based on the Bing and AFINN lexicon library. The top 32 most frequent unique words were also collated to understand the overriding narrative of mangrove conservation messaging on social media. All analyses, including text cleaning, was performed using various packages available in the RStudio + R environment (rtweet, tidyverse, ggplot2, tidytext, and textdata packages).

Table 6.2: Special observance days considered in these analyses.

#	Date	Significance
1	Oct 5, 2019	World Habitat Day
2	Oct 15, 2019	International Day of Rural Women
3	Nov 21, 2019	International Fisheries Day
4	Feb 2, 2020	World Wetlands Day
5	March 8, 2020	International Women Day
6	March 3, 2020	World Wildlife Day
7	March 21, 2020	International Day of Forests
8	April 22, 2020	World Earth Day
9	May 22, 2020	International Day for Biological Diversity (World Biodiversity Day)
10	May 9, 2020	World Migratory Bird Day
11	May 23, 2020	World Turtle Day
12	June 5, 2020	World Environment Day
13	June 8, 2020	World Oceans Day
14	June 16, 2020	World Sea Turtle Day
15	June 17, 2020	World Crocodile Day
16	June 22, 2020	World Rainforest Day
17	July 26, 2020	World Mangrove Day

6.3. Results

We highlight how the green shift, now prevalent in the blue domain or coastal and inter-tidal environments, has been promoted through social media platforms such as Twitter by showcasing global tweets on mangroves.

6.3.1. Geographical variation of tweets that included #mangrove/s

We looked at collated tweets that included 'mangrove/s' in their hashtags to decipher public sentiment towards blue carbon policy discourse and found that out of the 140,004 tweets extracted, 30% belonged to users from India, United States of America, United Kingdom, Canada and Australia. Among the top 50 countries that formed the largest user base of tweets posted from Jan 2019-Dec 2021, 30% came from handles of developed countries, while 27% were from developing nations (Figure 6.1).

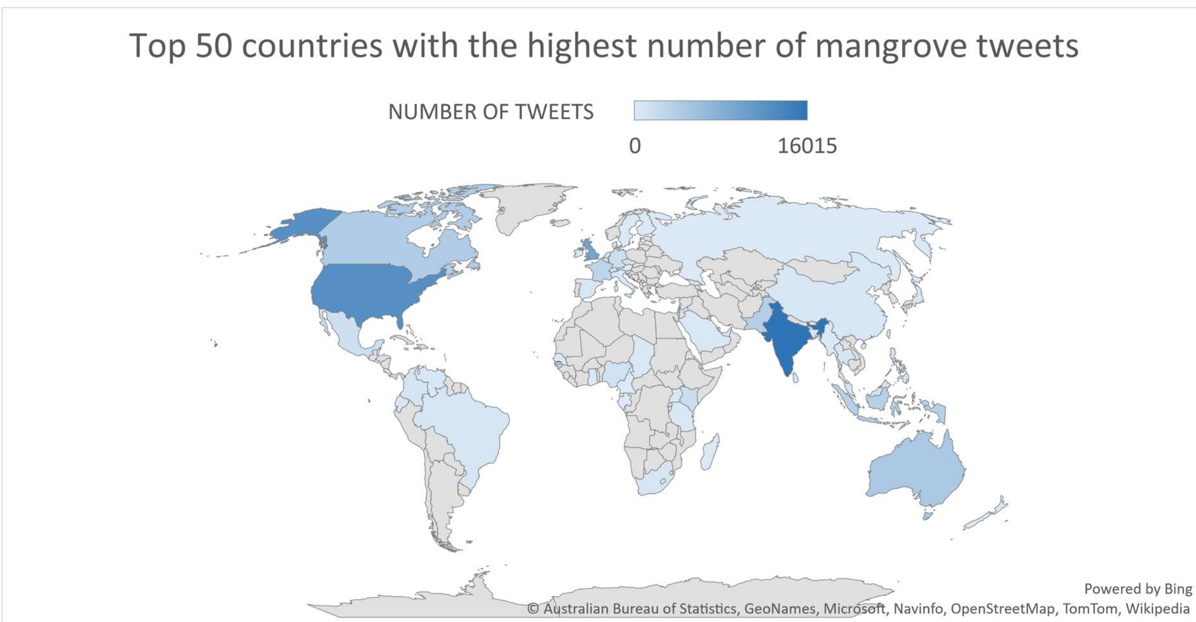
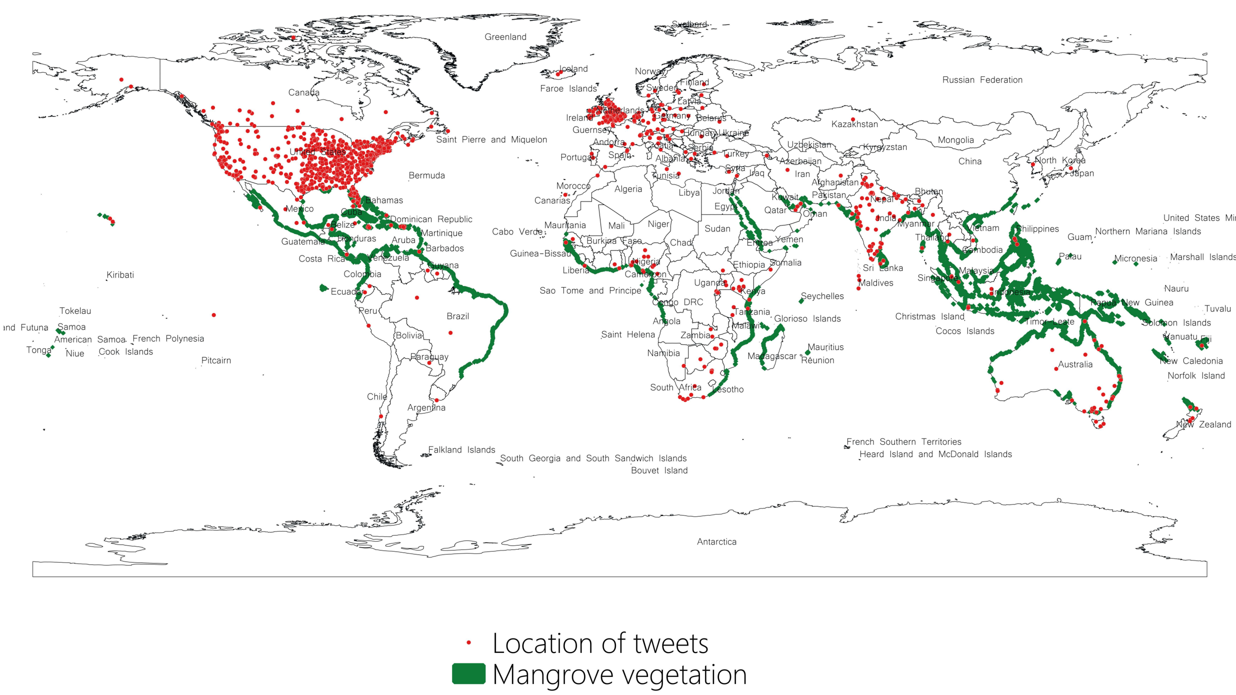


Figure 6.1 Geographical variation in tweets from Jan 2019-Dec 2021. The top 50 countries that posted Tweets on mangroves between Jan 2019- Dec 2021

Among the top 32 unique words frequently used by users between Oct 2019 to July 2020 on prominent observance days for the environment, carbon was the most frequently repeated word, with most tweets posted from handles located in developed nations without a significant presence of mangrove ecosystems (Figure 6.2). Interestingly, the largest extent and distribution of mangroves are found in countries with relatively low GDP rates, low literacy rates, and high poverty rates, excluding countries in the North American and Australian continent (Appendix C, Table C.1). Also, the historical emissions of these countries compared to the developed world are almost negligible (Khan, 2017). For example, the per capita emissions of Asmat communities an ethnic group of New Guinea, residing in the Papua province of Indonesia whose lives are intertwined with the surrounding mangrove ecosystems and live off the land, does not compare with that of an average American or European (Guinea, 2016; Wambrauw and Morgan, 2014).



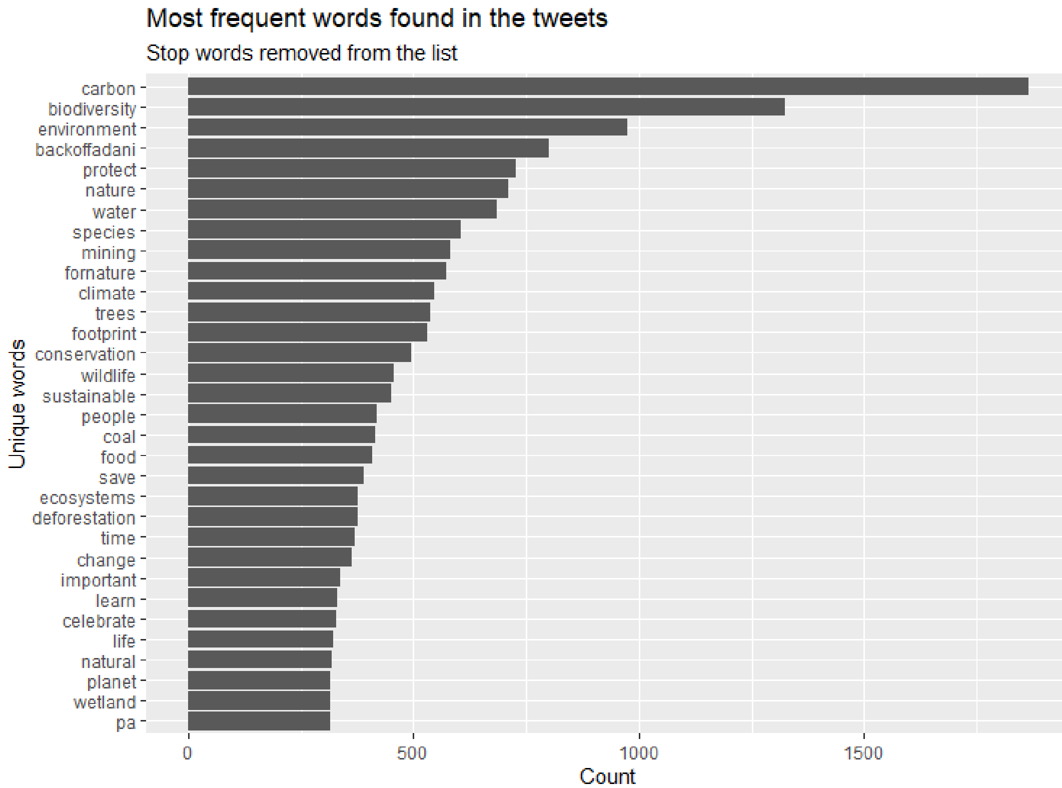


Figure 6.2 a. Importance Day tweets, including International Mangrove Day 2020, were dominated by entities in the Global North. b. Frequency of unique words compiled in the tweets from 2019-2020

6.3.2. Sentiment analyses of tweets

We performed sentiment analyses on mangrove day (2019) tweets to determine connotations of sentiments expressed on social media platforms as well as to understand how social media messaging on Twitter (general public, civil society organisations, non-profits, and government verified handles) towards mangroves varied. The sentiment analysis results show that about 60-66% of the words in the collected tweets expressed positive emotions towards different aspects of the mangrove ecosystem based on the Bing and AFINN lexicon library. Sentiment scores help us understand which sentiment provides more insight into the overall content of social media tweets. As observed in Figure 6.3, words invoking positive sentiments and trust dominated the social space, whereas words providing insights on (words like income) or the lack-thereof (e.g., harvest, livelihood) about human dependence on mangrove habitats were either concerned with the sentiment of sadness or missing from the discourse altogether respectively. This helps us understand the limitations of the approach (lexicons missing certain words) in deciphering meaning associated with content we are analyzing as well as provides clues on how social media either fails to recognize ground realities of local communities directly dependent on mangrove habitats or views reciprocal relationships as extractive actions. For example, a disproportionate number of tweets were posted from handles far removed from mangrove locations (greater than 90%).

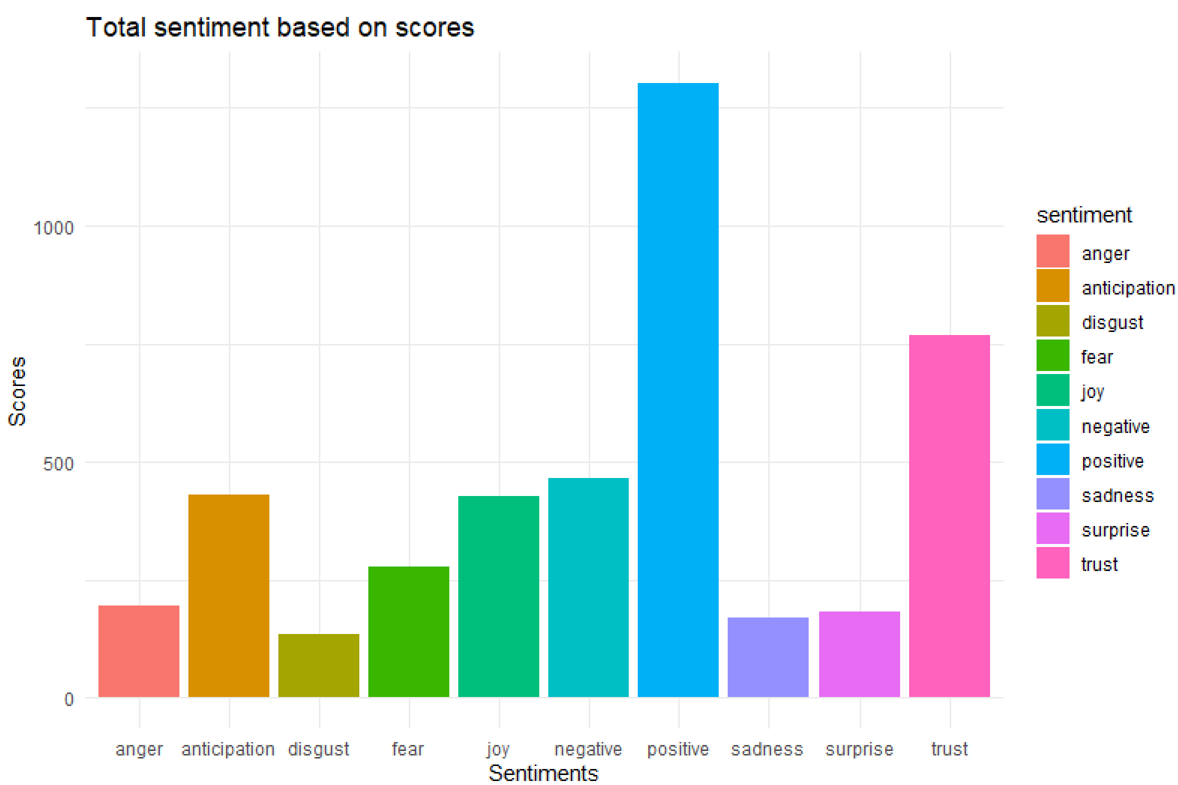


Figure 6.3 Sentiment and emotion scores of tweets extracted from Mangrove Day 2020. The nrc word lexicon library was used to extract scores for this graphic

Overall, our analysis revealed that positive sentiments largely comprised attributes related to mangrove ecosystem services and benefits (words like food, provide, land) or sense of place (words like unique, land or vital), whereas negative sentiments were concerned with habitat destruction and impact of disturbances (storms, erosion, and pollution) on the health and extent of mangrove cover in the region.

We also looked at word trigrams (triplets of words) or a group of consecutive words to further gain insights into the content, especially about the co-allocation of words in the tweets. By looking at how often a word follows another, we can build a model of relationships between them. The resultant output sheds light on the frequency of co-allocated words and the network of their relationships, as shown in Figure 6.4. The most frequent trigrams were linked to the attribute related to storm occurrences or sea-level rise. The groups of connecting words/phrases presented in the network diagram also provide insights on how often words with specific meanings represent the content corpus which helps us understand interactions between these phrases. For instance, in Figure 6.4, we can visualize some details of the text structure. We see a wide range in the narrative, from trigrams focusing on livelihood related attributes ("timber", "well-being"), activism ("savenigerianmangroves"), as well as climate mitigation and threats facing mangroves ("tsunamis"). Mangrove and related words were filtered out as much as possible to highlight supplementary words that are often used to describe these systems. The absence of indigenous community relationships or cultural attributes portrays the lack of reciprocation of ecosystem services and benefits in the text corpus, while storms or other threats stemming from climate change were highlighted more often than other trigrams.

Figure 6.4 Common trigrams extracted from tweets on Mangrove Day 2020, showing those that occurred more than 2 times and where neither word was a stop word. The level of transparency of the arrows indicates how common or rare the trigram is, and the directionality highlights the most common words that follow the preceding word

6.4. Discussion

A number of studies have looked at how social media messaging can be used to identify public opinions on social and environmental issues by categorising recurring words in tweets or websites and deciphering feelings (positive, neutral, or negative) associated with such words (Pak and Paroubek, 2010; Palomino et al., 2016). We used the geographical distribution of tweets to understand the spatiality as well as the type of content posted to understand global narratives related to mangrove ecosystems.

The type of recurring content (‘carbon’) emphasizes that the value placed on mangrove vegetation for their carbon services is widely recognised throughout the world. A number of studies have looked at how social media messaging can be used to identify public opinions on social and environmental issues by categorising recurring words in tweets or websites and deciphering feelings (positive, neutral, or negative) associated with such words (Pak and Paroubek, 2010; Palomino et al., 2016). Corroborating, that public sentiments towards mangroves may strongly be associated as well as grow in this direction.

Further, the sentiment analyses demonstrated the range in feelings across users towards mangroves. Although this approach has been widely used to identify and correlate public opinion to environmental health and well-being attributes or people's views, relationships, and impact on the natural environment, the approach has its limitations (Palomino et al., 2016; Taj & Girisha 2021). The analyses is limited by the dictionary of words (and language of communication) used to extract sentiment scores which can simplify meanings of words or emotions attributed to certain phrases. Similarly, our data may not completely reflect all global users considering restrictive use of Twitter in countries like China. However, it can also serve as a repository to obtain information on the issues that mostly disturb the community, and to communicate about environmental risks (Ekenga et al., 2018; Pak and Paroubek, 2010). The studies demonstrate the potential of social media platforms in gauging public sentiments and, in some way, paving the path for public participation in decision-making processes, especially in the case of large or risky projects with several regulations and the need for participatory mechanisms to facilitate approval and execution (Chen 2008).

6.4.1. Spatiality of social media messaging on mangroves

Literature on social media messaging further draws light on the geography of twitter networks. Studies highlight how messaging is linked to the share of ties within the same metropolitan region and how posts are retweeted between users especially belonging to similar regional clusters (Takhteyev et al., 2012). This brings us to the question who is present on twitter and how their social networks are connected with each other. We do see a high influx of tweets from users in countries that have a strong research presence in mangroves with or without the presence of the ecosystem within their boundaries (see Appendix C, Table C.2 for top 50 countries with mangrove/s in their tweet hashtags). It's also not surprising to note that the top two countries are India and United States, considering both regions have a strong social media presence, especially for political engagement (O'Boyle, 2019). It then becomes more important to highlight the influence social media may have on mangrove conservation and policy framing and why global narratives need further attention while discussing local context specific policy framing.

6.4.2. Why does blue carbon need to follow a "think global act local" paradigm?

In the last few years, mangrove based blue carbon projects have increased rapidly. Most aim to reduce emissions by thousands to hundreds of thousands of tons of CO_2 equivalents per year. From the pioneering Mikoko Pamoja project in Kenya, and other places in the African continent, including the Livelihoods project in Senegal, Sumatra, Tahiry Honko in Madagascar; to the Delta Blue carbon project focusing on mangroves in the Indus Delta in Pakistan, the Sundarbans Mangrove Restoration project in the Asian continent and countries like Panama, Costa Rica, (Muskitia Blue Carbon Project), El Salvador, Colombia in Central and South America. Although the carbon mitigation potential of these projects is immense, a stronger focus on the unequal distribution of power between project developers, state interventions, and local communities needs scrutiny not only for better adoption of such conservation measures but also for environmentally just outcomes (Myers et al., 2018). For example, the outcomes of payments in the case of market approaches such as PES schemes or REDD+ projects largely depend on the interplay of political forces (Myers et al., 2018; Vatn, 2010). Many PES schemes hold a low degree of 'environmental additionality' which means they target areas with low deforestation risk and opportunity costs (Porras, 2010; Sánchez-Azofeifa et al., 2007; Sierra and Russman, 2006), including large farms, privately or government controlled parks often comprising de facto or de jure community rights (Porras, 2010). The framing of co-benefits such as compensation to community members for losses arising from restricted access to forested areas, cash benefits for changing actions that prevent deforestation, or even capacity building initiatives are often anti-political (Myers et al., 2018). However, studies document a range of challenges, often political arising from benefit sharing mechanisms. These include conflicts among actors over land claims, historical rivalries, and fairness of the distribution of cash payments (Loft et al., 2017; Sanders et al., 2017). We elaborate further on some other issues which need attention while discussing blue carbon approaches to mangrove conservation.

6.4.2.1. Resource accumulations and rights

Another major implication of such policy narrative campaigning is the increase in tree planting campaigns to rewild landscapes and stringent controls through resource accumulations in protected mangrove areas of the Global South. One example is the concept of blue bond, which is slowly catching on in countries of the Asia-Pacific. Blue bonds are supported by some international non-profits and backed by international funding bodies like the World Bank (World Bank press release 2018). An example is the proposed blue bond initiative in Seychelles where the diversion of government debts into ocean conservation initiatives, such as the creation of marine protected areas and nature reserves is underway. Similarly, blue carbon initiatives in Mexico, in partnership with the Mexico's Ministry for the Environment (SEMARNAT) seek to establish federal conservation concessions for mangrove areas, known as "acuerdos de destino". Such concessions are granted to the National Commission for Protected Areas (CONANP), through applications that range detailed mapping, and photographic archives of ecological information to assess the ecological value of the selected areas. In short, to be set aside as protected areas for voluntary carbon accreditation and offset programs. A major critique of such initiatives is the loss of land-sea rights and tenure of local communities and claim in the functioning economy of a previously colonised nation (Cormier-Salem and Panfili, 2016). UNESCO, for example, noted in its blue carbon report that its 50 marine Heritage Sites, which together account for 15 percent of the planet's blue carbon assets, could finance at least part of their conservation work by claiming and selling carbon credits (UNESCO, 2020). The downside of an emerging and trending blue economy discourse may work against existing local access to mangroves, in the process displacing coastal livelihoods (Satizábal et al., 2020; Thomas, 2014).

6.4.2.2. Simplification of complex ecosystem interactions

Similarly, rapid tree planting programs in unsuitable habitats can not only result in low success rates of plantation activities but also displace other coastal flora and fauna where mangrove trees are usually not found, such as mudflats or marshes (Hiraldo, 2015; Lewis, 2001). Such conversions may lead to a loss of the significant services provided by these ecosystems. It may also result in more displacement of livelihoods, as a large proportion of local shellfish collectors rely on these spaces. In short, reforestation leads to spatial competition in mudflats or shoals, usually utilised by birds, as feeding and resting sites, as well as by shellfish harvesters which also serve as picking or gathering areas for women when covered by trees after reforestation (Cormier-Salem, 2017; Hiraldo, 2015).

Moreover, carbon credit projects are expensive to set up considering the costs of developing a carbon storage baseline or continued measurements, not ignoring the uncertainty resulting in the face of increasingly intense storms, or prolonged droughts. That is how this carbon might fluctuate with increasing climate change impacts. The uncertainty involving the response of plantations in influencing biodiversity or soil conditions is also a point of concern. Besides, mangrove species are adapted to varying levels of salinity, freshwater flows, and nutrient dynamics resulting in unique zonation patterns along coastlines and estuaries(Mitra et al., 2021; Upadhyay et al., 2007). In several cases, plantations comprise of a single species which are more susceptible to risk from diseases or any drastic environmental changes over the long term (Das, 2020; Lewis, 2001). For example, about 20% of planted mangrove trees have failed to survive in Oceanium's mangrove reforestation program in Senegal (Bird 2016). Similarly, planted mangroves may not be able to entirely compensate for the loss of ecosystem functions such as erosion or sediment accretion processes provided by natural mangrove forests (Das, 2020). For example, using remote sensing techniques, (Besset et al., 2019) observed no significant relation between erosion reduction and mangrove plantations in the Mekong Delta in Vietnam. Further, Das (2020) demonstrated insignificant effects of planted mangroves on coastal erosion across the entire coast of Gujarat in west India where thousands of hectares of mangroves have been planted over the years. They attribute the rising sea current activity as the driving mechanism for this trend.

6.4.2.3. Markets, pricing of carbon credits and marginalised communities

Market-based conservation approaches assign economic values to natural resources to develop and enhance markets where they can be either be sold or traded. In this case, for blue carbon to achieve certain emissions targets by corporations or countries. Their flexibility and cost-effectiveness when compared to standard command and control approaches and the incentives provided by such approaches make conservation a lucrative and viable option (Berck and Helfand, 2005; Coria et al., 2019; Gómez-Baggethun and Muradian, 2015). However, market-based programs require caution because of their focus on economic efficiency and their simplified assumptions about the nature of rights, access, state control and interventions, religion, caste and race issues, and monitoring costs of such programs. In the case of blue carbon programs, the success of carbon offset programs also depends on how carbon credits are priced across the world. The price of carbon varies from nation to nation, from less than $1 a ton in Mexico to $137 a ton in Sweden (World Bank, 2021). Apart from pricing, the volatile market and double counting further raise questions of the legitimacy of such initiatives. Other concerns include diverting revenues towards the state which may or may not accrue to communities at the forefront of this exchange. Of note is the Tahiry Honko Project where under FCPF the state is expected to keep more than 20% of the revenues.

As the number of blue carbon projects across the world increases, it becomes crucial to apply a critical lens in discussing the benefits promised and received by local communities in exchange for forfeiting their rights of access and use of mangrove forests. According to project partners in different regions around the world, blue carbon projects are expected to be a win-win strategy for both climate mitigation targets and local community welfare (Macreadie et al., 2021; Phelps et al., 2012; Sutton-Grier and Moore, 2016). Community benefits range from greater harvests of fish and protection from storm surges but also monetary compensation and other income generating opportunities, especially for women by including them in plantation work. However, money transfer to local communities lacks transparency and equity. For instance, women were paid meagre salaries for plantation work, and in many cases, communities were unaware of the carbon offsetting mechanism between project partners or governments at the cost of losing access to harvesting wood, gathering of cockles, rice cultivation, or other allied fishing activities (Cormier-Salem, 2017; Hiraldo, 2015)

On the one hand, the increased focus on the vital importance of coastal ecosystems is a positive, however, the commodification of these areas with the emphasis on the idea that conservation is only possible and effective when market-based approaches are implemented needs caution. This perspective ignores the historical relations of people reliant on coastal resources for their well-being and livelihoods. In a way, blue carbon projects emphasize that market tools are good strategies for initiating and organising conservation interventions, but they provide a 'false solution' by undermining unequal social relations, access, land rights, and other power dynamics at play, hence ignoring environmental justice issues which should be at the forefront of conservation initiatives.

6.4.2.4 Misplacement of values, a case for place-based research

Recent studies highlight how mangrove conservation discourse in the Philippines has changed over time from "conservation", to blue "carbon", harbouring less focus towards local access and use patterns (Song et al., 2021). Similarly, comparison of values among local and extra-local actors divulges contrasting views towards mangrove ecosystems around the world (Rasquinha et al. 2022; Quoc Vo and Kuenzer, 2013). To illustrate, Rasquinha et al. (2022) highlight three distinct narratives shaping stakeholders concerned with a mangrove protected area on the east coast of India. The narratives are shaped by different actors, with local actors concerned more with issues of livelihood security which focuses on well-being and quality of life attributes, whereas scientists and government officials dominate the conservation rhetoric of protecting mangrove forests for their ecosystem services. A comparison between the global narratives from this study and local perspectives using the case of the protected mangrove area in India, also reveals an absence of recognition or value towards provisioning services because of the lack of access to mangrove forests. Other studies also show that economic benefits allocated towards forest management are reported to be lower than conversion to other forms of land uses such as oil palm plantations or aquaculture practices (Butler et al., 2009). These contrasting views further highlight a need for more localised policy framing to tackle socio-environmental challenges.

6.5. Concluding remarks

In conclusion, blue economy discourses and narratives which ensure that environmental services are guaranteed through payments deflect from underlying on-ground systemic causes of ecological and associated socio-economic crisis. This is important as what is prioritized as a key conservation solution may conflict with local processes. For example, small-scale fishers play an important role in conserving fisheries and natural resources through local knowledge and traditional management practices. Relocation of access through carbon offsetting schemes can change land tenure rights and increase state or industrial control of resources resulting in the expansion of waterfront development activities through coastal reclamation. Such initiatives are already underway in many coastal cities in Asia. The solving of the climate crisis should also insist on decarbonising of nations and companies before turning to offsets for their remaining emissions. Similarly, place-based engagement with local people's worldviews, values, and motivations through co-government regimes, provides not only a morally and environmentally just but also more effective conservation and socio-economic outcomes (Dawson et al., 2018; Hutton et al., 2005; Oldekop et al., 2016). Right to access and control of coastal land for fisher families, decent work, access to fair markets, and also mobilising state resources to support adaptation to climate change based on the communities' own knowledge and solutions must be prioritised over narrow profit-interests. Instead, more context-specific policy framing, along with payment approaches, should be considered as one among the diverse set of potential solutions towards mangrove conservation rather than the only or best solution, as "track record of the use of panaceas is one of repeated failures" (Ostrom et al., 2007).

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CHAPTER 7

MANNING THE MANGROVES: GENDER, REGIONAL IDENTITIES AND SOCIAL HISTORY SHAPE MANGROVE FOREST DEPENDENCE AND GOVERNANCE[5]

[5] Rasquinha, D.N. To be submitted to Society & Natural Resources

Abstract

Fuelwood, a forest resource, is used to satisfy local energy demands in many parts of the world. However, wood harvesting for subsistence or livelihood dependence is challenged with conservation narratives of forest degradation and loss in many parts of the Global South. Despite a vast network of protected areas that regulate access to resource extraction, forest dependence continues. At the same time, wood fuel continues to be used as a renewable source of energy in many developed countries. Energy transitions and adoption of cleaner or low carbon fuels are deeply socio-political and embedded in gender and social inequalities. In fact, fuelwood dependence and adoption of alternate low-carbon technologies impact gender and social equity in intersectional ways. In this paper, I investigate the drivers of forest dependence for fuelwood and how that relates to broader narratives of forest degradation and conservation in Bhitarkanika National Park, a protected mangrove forest along the east coast of India. Drawing from the theory of access, surveys and semi- structured interviews within focus groups were used to ask what are the socio-cultural beliefs and factors that influence firewood dependence. I find that fuelwood was mainly collected by women, who were reluctant to change traditional ways of cooking and heating because of social responsibilities and preferences. While men supported alternatives to fuelwood use. This implied a gendered differentiation in labor and values, and an invisible burden of conservation on women. While forest dependence was largely for fuelwood, I also found that these dependencies stemmed from both social and cultural preferences. This study used the theory of access to understand how access plays a central role in limiting or exacerbating dependence and interacts with intersectionality to maintain social conditions. Confirming that alternate technology or subsidized fuel solutions need an amalgamation of cultural preferences and values that shape mangrove forest dependent communities for pragmatic conservation solutions.

7.1. Introduction

Mangrove forest dependent communities rely on timber and other non-timber forest products (NTFPs) for subsistence and livelihood needs throughout the world (Nordlund 2012). Wood from mangrove forests which are contiguous with human settlements along the coast also serve as a common pool resource which satisfies local energy demands, construction material for building houses and boats, poles for fish enclosures, and a variety of other uses (Walters 2005a; Dahdouh-Guebas et al. 2006; Walters et al. 2008; Badola et al. 2012; Sathya and Sekar 2012). Mangrove forest use, dependence, and degradation are intricately connected through socio-economic and cultural processes. However, studies largely focus on forest loss such as complete canopy removal, but only a handful on forest-socio-cultural relations such as firewood extraction (Glaser 2003; Walters 2005b; López-Hoffman et al. 2006; Feka et al. 2011; Cormier-Salem 2017; Queiroz et al. 2017; Thomas et al. 2018). This is important as wood is still a crucial biofuel for many households in Asia, which use firewood on a daily basis (Stoner et al. 2021).

In India, a significant proportion of households still continue to rely on biomass for some, if not all, of their cooking needs (Kim et al. 2011; Amegah et al. 2014). Although, the adoption of cleaner fuels has substantially increased across the country, about 800 million Indians still use traditional biomass cookstoves or mud chullahs for their cooking needs (Access 2017). There is still a dearth of statistics pertaining to the role of mangrove forests in supplementing this pool, with only a handful of studies that describe the implications of this reliance on forest degradation and potential socio-economic impacts (Ambastha et al. 2010; Badola et al. 2012; Sathya and Sekar 2012). Much less on the heavily gendered differences in mangrove resource use, both marine and forest resource foraging activities, and its implications for mangrove conservation.

However, mangrove wood rarely forms the main source of income for poor forest dependent families, rather a resource for household subsistence needs (Walters et al. 2008; Atheull et al. 2009). Although exchange for revenue in local markets can supplement income (Bandaranayake 1998; Scales and Friess 2019), forest protection laws criminalize such exchanges in many parts of the tropics (Roy 2014). In India, much of these forests exist within protected area boundaries where harvesting mangrove wood is illegal, but high poverty rates and the absence of affordable fuel choices perpetuate reliance on forest products. Several factors determine forest exploitation levels, from proximity to access, but socio-economic factors remain strong determinants for perpetuating dependence (Hauff et al. 2006). The continued reliance may have unintended environmental consequences (accelerated forest degradation, cryptic damage, depletion of local resources), but also have socio-economic implications (Kowsari and Zerriffi 2011; Scales and Friess 2019; Bošković et al. 2021; Rasquinha and Mishra 2021).

The drudgery associated with fuelwood collection is usually borne by women increasing higher physical burdens and opportunity costs in relation to the time spent collecting firewood. On average, women dedicate about 20 hours per week towards collection of wood-based fuels for household cooking needs (Rehfuess et al. 2006; Mohapatra et al. 2017). These social practices and responsibilities can reinforce social norms but also limit women and children from diverting time to education or other income generating activities (OECD/IEA, 2006). In fact, women and children are found to be most vulnerable to the effects of indoor air pollution due to wood burning for cooking and heating purposes (Lim et al., 2013). Apart from being a global health hazard, indoor wood burning is also a global warming threat as the emissions from burning solid fuel release carbon monoxide (CO) and plain soot, also known as black carbon, a short-lived but highly potent climate pollutant (Jeuland and Pattanayak 2012). Thus, both fuelwood extraction from mangrove forests, and its use indoors for cooking can potentially contribute to climate change as well as exacerbate socio-economic impacts.

In this study, we focus on how intersecting relations of gender and social identities influence issues of access in forest landscapes of Bhitarkanika National Park, India. We extend Ribot and Peluso's (2003) theory of access to include intersectionality of social structures like gender, tribal affiliations, and regional identities to demonstrate how enmeshing relations of places, people, and environmental histories mediate mangrove forest governance in this region. According to Ribot and Peluso (2003), access is "the ability to benefit from things —including material objects, persons, institutions, and symbols". They also theorize access as an *ability* to benefit rather a *right* to benefit, which is to say neither de facto nor de jure rights determine a community's ability to access natural resources (Ribot and Peluso 2003, 153). In turn, access is influenced by the intersectionality of identities—gender, caste, religion, statehood, knowledge, authority, markets, labor, capital, or technology (Ribot and Peluso 2003, 160). A theory of access embedded in intersectional feminist narratives offers important insights into the factors that shape mangrove forest extraction, dependence, and governance. We identify dominating structures within our study in the context of those mechanisms to describe the web of power relations operating in Bhitarkanika to further our discussion on gender, access, and resource dependence while also highlighting inequity issues and power differences dominating current blue carbon discourse.

7.2. Study Area: Bhitarkanika National Park, India

The Bhitarkanika mangrove-human landscape accommodates about 309 villages located within Rajnagar community development block (CD), in the Kendrapara district in Odisha (Figure 7.1). It represents India's second-most important mangrove forest area after the Sundarbans on the east coast. The landscape holds multiple protected areas, each exhibiting varying levels of protection. These include a national park, a wildlife sanctuary, a marine protected area and a Ramsar wetland site.

This study covers 21 villages comprising of a mix of ethnicities, caste, and religion identities (Figure 7.1). Villages are spatially segregated based on ethnicity and religion, while (Hindu and Muslims) Odiyas form the larger proportion among all social classes, followed by Bengali Odiyas and Adivasi Santhali communities in the sampled villages (Census 2011). While both Hindu and Muslim communities in this region share amicable relationships, they maintain social boundaries (field observations). For example, neither visit each other's houses, nor do they perform exchanges, even with food which is rather common within communities sharing the same religion in this region (field observations).

People in this region earn their livelihoods by wage labor, which includes both public employment and government-funded social employment plans (such as the Mahatma Gandhi National Rural Employment Guarantee (MNREGA) schemes). Public employment is dominated by the agricultural and aquaculture sector where farms are leased out on a yearly basis for labor and profit sharing, tourism allied jobs, working on sea trawlers and fish processing and storage facilities. The annual income of the villagers varies across the landscape with fisherfolk working on trawlers and investing in aquaculture farming earning large substantial profits (1 lakh to 10 lakh INR, equivalent to ~ 1200 to 12000 USD). However, daily wagers, that form the bulk of the population, including those involved in small-scale fishing activities, migrant labor and rice farming earn an annual income ranging between 20,000-1,00,000 INR (~250 to 1200 USD).

Figure 7.1 Bhitarkanika landscape with the location of sampled villages

7.3. Approach

I conducted research in the 21 villages (Figure 7.1) over 6 months. The villages were purposively selected based on prior knowledge of firewood use, land tenure issues and proximity to forest core area. All research was approved by the University of Georgia's institutional review board and conducted with permits from the Forest Department.

7.3.1. Questionnaire Survey

I conducted a structured questionnaire survey (Table 7.1) with 170 adult community members, (108 women and 62 men), from the 21 villages (Figure 7.1). We conducted random individual surveys to capture firewood dependency in the region. The questionnaire was designed to capture gender differences in firewood collection and usage for cooking purposes. Monthly consumption patterns, alternate fuelwood sources, preferred mangrove tree species and capacity to switch to other sources was also collated. The questionnaire asked about fuelwood consumption patterns, alternate fuelwood sources, preferred mangrove tree species and capacity to switch to other sources and was designed to capture gender differences in processes of resource access struggles. The data was collated and summarized using descriptive statistics.

7.3.2. Semi-Structured Interviews

We also conducted semi-structured interviews within focus groups (5-8 participants) to provide context and depth to issues of access and the factors that contribute to forest dependence in this region (Table 7.1). Interviews were audio recorded if permission was granted, and transcribed. We conducted 42 interviews, out of which 32 were audio recorded. Interviews that were not recorded were supplemented with observations and extensive field notes. Interview responses were analyzed and coded for themes using grounded theory in MaxQDA (VERBI Software, 2022). Themes are concepts that emerge from qualitative data that help explain relationships. These themes were identified by the presence of repetitive concepts, word frequency, word co-occurrence, and key words in context (Opler 1945, Ryan and Bernard 2000). Finally, I coded relevant interview segments connected with the identified themes to analyze issues of access and forest dependence (Ryan and Bernard 2003).

Table 7.1 General survey & semi-structured interview questions

QID	**Survey questions**
1.	Do you go to the forest to collect firewood? How much and how many times in a year?
2	What sources of fuels other than firewood you use for cooking?
3.	Which tree species you prefer for collection?
	Semi-Structured interview questions
4.	Do you think firewood quality and quantity has decreased over the years?
5.	What issues you face while accessing firewood?
6.	Do you use the LPG subsidies to purchase the cylinders and if not, why?
7.	What prevents you from using gas stoves?
8.	Do you think boundaries between villages and the forests need to be maintained?
9.	Given a choice what are your preferences for land use options for the future. What drives these choices?

7.3.3. Mapping firewood dependence hotspots

During data collection, spatial information on firwood use/extraction was also noted. If the interviews, surveys, or field observations recorded forest extraction, we marked those areas as a potential hot zone, with degrees of influence dependent on the number of times extraction was reported for the same region. Based on this criterion, villages that recorded less than 20 responses were marked as Low, between 20-50 as Moderate and greater than 50 as High. The map, however, doesn't provide information on the villages but the general location of the observations.

7.4. Observations & Findings

7.4.1. Gendered roles in firewood collection

From the interviews and survey results it was evident that firewood extraction is primarily carried out by women. Villagers pay a lump sum amount to obtain passes to collect firewood to the Forest Department. These passes, which are not officially documented, have a life span of about six months and cost them a maximum of 2000 INR. In some villages, fines of 1000 to 2000 INR are imposed if caught trespassing forest boundaries for firewood collection. At such times, these fines also serve as passes for a period of 6 months permitting collection for that time frame.

Similarly, there was also a gendered response by residents to firewood use as a fuel source for cooking (Figure 7.2). Among the total individuals surveyed, 61% agreed versus 39% denied that they used firewood for cooking. The bar graph (Figure 7.2) summarizes the number of people characterized by gender who affirmed that firewood was used as a fuel source for cooking. Among those that agreed, 89% suggested that women were primarily involved in the collection of firewood. The process of fuelwood harvesting was never a solitary venture but conducted in groups (2-6), comprising of women from the same household or from different households. They usually coordinated their timings for fuelwood collection with essential household chores (such as cooking and other farming or livestock maintenance activities), and tidal fluctuations.

The amount of firewood collected varied from household to household and was influenced by a variety of factors. Approximately, 20-300 kgs (~ 25kgs being the average amount conveyed by majority) were extracted monthly depending on household size, access to alternative cooking fuels like dung cakes, rice straws or LPG cook stoves. On an average, a majority of the households used about 25-30 kgs per month with a few exceptions (<5 residents) stating between 100-300 kgs.

These one-off cases of high usage reflected households which didn't supplement their fuelwood consumption with alternate sources.

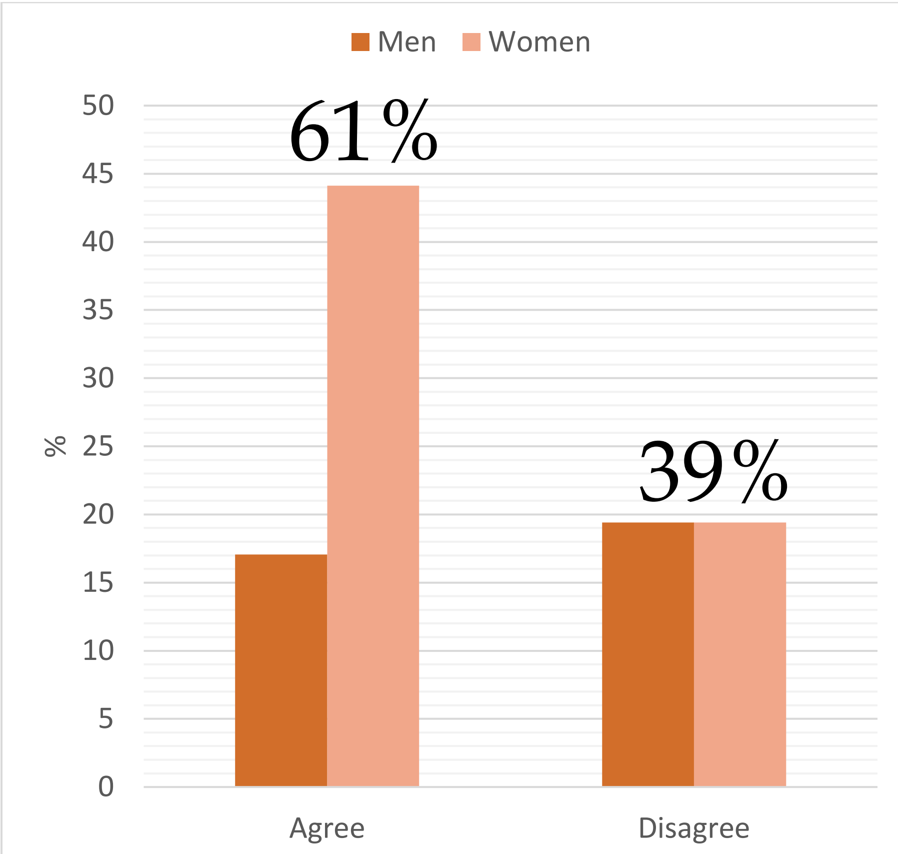

Figure 7.2 Responses by gender on fuelwood collection practices in Bhitarkanika

Accessing firewood

Throughout the region multiple types of cooking fuel are used: firewood, rice husks, dried coconut palms, dung cakes, and gas cylinders (Figure 7.3). Residents said that the two most common uses of firewood collection were for cooking and heating.

A majority of the households interviewed (80%) also owned Liquified petroleum gas (LPG) cylinders but preferred other sources of fuel because of their inability to afford or access a regular supply of gas cylinders for their needs. Residents also confirmed that the subsided cost of cylinders was insufficient to cater to the needs of larger families which required at least two refills every month. Similarly, a continuous supply of cylinders was equally difficult to obtain due to the absence of relevant paperwork and remoteness of the area.

Figure 7.3 Photographs of firewood collected at different locations on the field and alternate forms of fuel used for cooking, such as rice husks, and cow dung cakes kept for air drying for future use

We summarized found forest dependence for firewood as hotspots of dependence (Figure 7.4). Our focus group discussions and field observations provided information which helped us map areas within the protected region where firewood extraction/use is practiced. This is however not the only areas where extraction is conducted as depending on tidal fluctuations and the presence of fences, extraction trails may change. These trails were areas within the forest with ready access and clear paths for fuelwood collection.

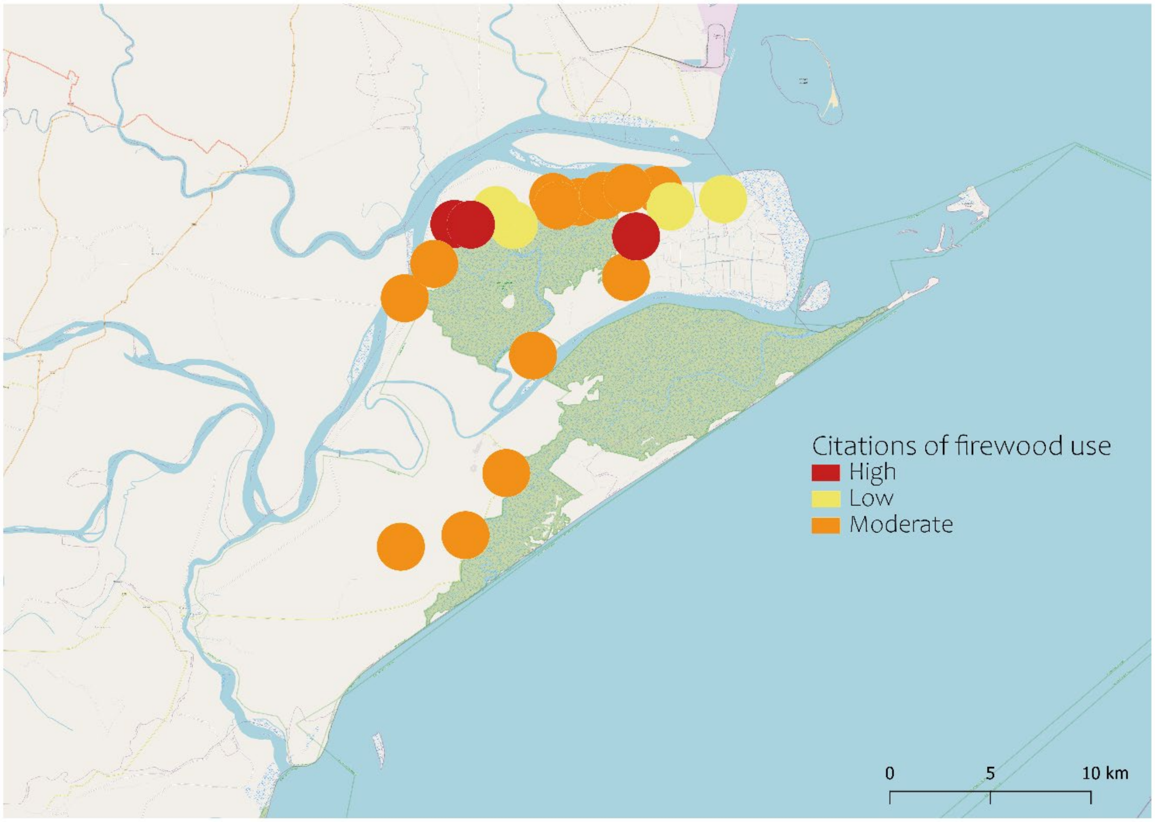

Figure 7.4 Hotspots of forest dependence. Resident reports of areas used for fuelwood collection. Areas with >50 responses indicate high use, areas with 20-50 moderate and less than 20, low use

7.4.2. Species preference, and consumption patterns

Participants named a number of species used for fuelwood but did not name non-timber forest product (NTFP) use (Table 7.2). Table 7.2 provides a list of mangrove timber and NFTPs reported from previous studies (Hussain and Badola; Pattanaik et al. 2008; Ambastha et al. 2010) in the area and those that are currently used today (based on information collated from our interviews). Participants (90%) confirmed that dependence on mangrove species for fuelwood has drastically declined, and therefore often supplemented with alternative biomass sources. Such alternative fuel use was especially important during the monsoon season, when access to forest was limited or impossible due to continuous flooding but also due to absence of reliable storage or other infrastructure to keep wood dry and usable. The gradual decline of fuelwood dependence is also closely connected with improved forest quality. Surveys also revealed the preference of some species over others as fuelwood, because of better calorific value or the presence of thinner stems that made it easier to harvest and burn the wood. The complete absence of previously reported uses for NTFPs was also prevalent across responses. We were surprised that no one reported on NTFP use, even though earlier studies had reported in this area (Hussain and Badola; Pattanaik et al. 2008; Ambastha et al. 2010).

Differences in responses based on gender were also noted, with women acknowledging that firewood extraction was not synonymous with timber cutting practices. The former accommodates for growth and recovery of forests over complete destruction of the ecosystem. The former accommodates for growth and recovery of forests over complete destruction of the ecosystem. As one of the participants highlights,

"*We collect dried stems usually. If no dried stems are available, we collect small stems from two out of four trees. Next time we cut from the other two trees*"

Responses highlighted the cognizance of forest regeneration and recovery processes. Another striking difference among men and women was based on forest quality issues where men acknowledged that forest quality has improved over the years because of less dependence. While women repeatedly highlighted how the quality of fuelwood of specific mangrove species to be better in the past.

6.4.3. Past and current uses of mangroves

Table 7.2 provides a list of mangrove timber and NFTPs reported from previous studies (Hussain and Badola; Pattanaik et al. 2008; Ambastha et al. 2010) in the area and those that are currently used today (based on information collated from our interviews). Several mangrove products are not in use today. These also include those used in the past for medicinal purposes. A decline in past uses was clearly evident across a range of products, with the only predominant use being fuelwood. This decline signals a change in the traditional knowledge systems of villagers as well as change in mangrove-human relationships. It is most likely the result of the restrictive legislation on mangroves which is based on prohibitions rather than regulated use. Some studies demonstrate a similar loss of perceived mangrove values with subsequent legal restrictions on resources, indicating how access plays a crucial role in forest-people relationships (Moreira dos Santos and Lana 2017, Rasquinha 2022 in press).

Table 7.2 Mangrove tree species used for fuelwood and as NTFPs.

Scientific name	Family	Common name	Calorific value (cal/kg)	Firewood usage		Other uses (*Past use)
				Past use	Current use	
True Mangrove species						
Ceriops decandra	Rhizophoraceae	Garani/Barani	5,150	+	+	Honey
Excoecaria agallocha	Euphorbiaceae	Guan/Guna	4,767	+		
Aegiceras Corniculatum	Primulaceae	Kharsi		+	+	Fish poison

Heritiera sp.	Malvaceae	Sundari	5,028	+	+	Wood for boats*, timber*
Avicennia alba	Acanthaceae	Kala bani		+	+	Fodder
Avicennia marina	Acanthaceae	Singala bani		+	+	Honey
Avicennia officinalis	Acanthaceae	Dhala bani		+	+	
Cerbera odollam	Apocynaceae			+		Charcoal*
Rhizophora apiculata.	Rhizophoraceae	Rai		+	+	
Rhizophora mucronata	Rhizophoraceae	Rai	4,888	+	+	
Kandelia candel	Rhizophoraceae	Sinduka		+		Charcoal*, dye for fishing nets*
Bruguiera sp.	Rhizophoraceae	Dot/Bandari		+		Timber*, poles*, and fishing traps, Hypocotyls eaten as vegetable
Aegialitis rotundifolia	Plumbaginaceae	Banarua				Honey
Aglaia cucullata	Meliaceae	Ooanra				Timber *
Sonneratia alba	Sonneratiaceae	Orua		+	+	Fodder, vegetable, timber*

Sonneratia apetala	Sonneratiaceae	Keruan	4,901	+	+	Fodder, Fruits are edible, timber*
Sonneratia caseolaris	Sonneratiaceae	Orua		+	+	Fodder, vegetable, timber*
Xylocarpus granatum	Meliaceae	Sisumar		+		Timber *
Xylocarpus mekongensis	Meliaceae	Pitamari				Furniture*
Xylocarpus moluccensis	Meliaceae	Pitakorua		+		Timber *
Mangrove associates						
Hibiscus tiliaceous	Malvaceae	Bania		+	+	Furniture
Myriostachya wightiana	Poaceae	Nalia ghasa				Fodder
Phoenix paludosa	Arecaceae	Hentala				Ropes, mats, roof thatching material
Phragmites karka	Poaceae	Nala				Fodder, mats, fish baskets, thatching material
Pongamia pinnata	Papilionaceae	Karanja				Fodder
Suaeda maritima	Chenopodiaceae	Giria saga				Eaten as vegetable
Senna Occidentalis	Fabaceae	Chakunda tree			+	

Bombax ceiba	Malvaceae	Simli tree		+		
Bambusa sp.	Poaceae	Bamboo			+	House construction, poles, fishing traps
Pandnaus fascicularis	Pandanaceae	Keda/Kevda				Used in perfumes, making mats & baskets

6.4.3.1. Mechanisms of access

Social identities, relation, and history

According to the theory of access, right to benefit (from use, production, extraction, or consumption of a resource) and the ability to benefit are not the same thing. Although people have de jure rights to access forests, all do not possess the ability to benefit equally which may stem from social conflicts arising due to caste, regional identity or, and religion. One interviewee share's,

"*There are Bengali, Muslim, Odia, Christian, Adivasis here. Not everyone likes each other. Everyone keeps an eye on what the other is doing and that's why people get fined easily or get in trouble with the forest department*".

Conversations between forest committee members of different villages also revealed the lack of information or knowledge on accessing subsidies to clean energy fuels and discrepancies between the ability to continue using clean energy source for firewood even after securing the connection. They emphasized how unsteady income flow prevented them from continuing a steady LPG supply. Similarly, climate induced changes in shorelines (coastal erosion that has wiped out villages) have resulted in many villages to be relocated to other villages. Resettling and finding a grounding in a new village doesn't always work smoothly. A relocated interviewee highlights the changing people-forest connections, reminiscing old times and emphasizing that extraction may or may not stem from care anymore, "We are still waiting for papers for the relocation. They have not given us papers. We depend on the forest for fish, crabs, and wood but if we go to the jungle, we will be fined or jailed, so people go secretly. Nobody knows who is bringing how much wood anymore".

7.4.3. Policies seeking to increase access to alternate forms of cleaner energy for cooking

Our interviewees demonstrated mediocre to low levels of awareness towards the presence of government policies and schemes for accessing cleaner sources of fuel for cooking. About 10% of interviewees were not aware of different policies (eg: Pradhan Mantri Ujwala Yojana (PMUY) scheme) or its benefits. Those that were knowledgeable reiterated that one-time connections don't help in the continued supply of such services. Many had cylinders but did not use them regularly because the cost of continued access was not feasible. Instead, they adopted a pragmatic approach of relying on a combination of fuels and stove options that helped them navigate the shortage or unavailability of alternative sources. An example of mud stove is shown in Figure 7.5.

Figure 7.5 Different kinds of mud stoves used for cooking. Traditional mud stove on the left fired using mangrove wood whereas a village participant uses rice husks on an improved mud stove on the right.

A closer look at the evolution of policies subsidizing cleaner fuel access and adoption in India highlights a stronger focus on economic factors rather than regional or social-cultural factors (Gould and Urpelainen 2018). Since 2009, the government has issued a number of policies towards domestic cooking energy choices for poorer rural sections of the country (Table 4).

The introduction of subsidies for LPG (and kerosene) for residential consumers goes back to the 1960s, along with continued efforts to maintain subsidized prices and prevent market fluctuations. These price and income-based policy approaches are administered in conjunction with oil-based companies. One of which includes a direct benefit transfer (DBT) scheme called PAHAL which ensures that fuel subsidies can be directly linked to individual bank accounts to prevent the unlawful use of fuel outside of non-household sectors. Similarly, the use of LPG has largely been limited to the middle and upper classes in urban areas. With the ready infrastructure for natural gas availability in urban areas, LPG subsidies remain underutilized. The Give it Up scheme helps transfer these excess LPG subsidies of middle-class households to poor households (Gould and Urpelainen 2018).

Lastly, the Pradhan Mantri Ujjwala Yojana (Ujjwala) launched in May 2016 provides deposit free new connections in the name of woman beneficiaries to households which below the poverty line (BPL). According to the reports, about 80 million poor households were supposed to benefit from this scheme (Gould and Urpelainen 2018). These price and income-based approaches have been successful at many levels, especially considering about 10 million households participated in the "Give it Up" program and 20 million households benefitted through Ujjwala (Manjula and Gopi 2017; Gould and Urpelainen 2018), a wide disparity exists still exists in the extent of adoption of clean cooking fuel across different states within the country, and various social categories within these states.

Table 7.3 Different policies introduced to enable the adoption and use of cleaner fuel among rural households

Year	Policy	Policy focus
2009	Rajiv Gandhi Gramin LPG Vitrak Yojana (RGGLVY)	To increase rural access of LPG through decentralisation of dealership agencies. Increasing capacity of local small size agencies to distirbute atleast 600 cylinders a month.
2011-2012	Pahal or Direct Benefit Transfer of Subsidy for domestic LPG	The domestic LPG connection is linked to the bank accounts using the Aadhar number, (Unique Identification Number) and the consumer receives the subsidy amount in their personal bank account. The consumer pays the full market price of the LPG cylinder during delivery.
2015	GiveItUp Campaign	The campaign is aimed 'to encourage ''well off'' consumers to voluntarily surrender their LPG subsidy'. The campaign promises one security deposit-free connection to a BPL family for every voluntary surrender of LPG subsidy
2016	Pradhan Mantri Ujwala Yojana (PMUY) scheme	The scheme aims to spread the reach of LPG to poor rural households. The scheme provides deposit free connections in the name of woman beneficiaries in BPL households, thus reducing initial startup costs incurred in new LPG connections. The stove and refill costs are proposed to be covered through EMI facility. The total financial support extended through the scheme to a BPL household amounts to Rs. 1600

A large proportion of rural households (about 80% in 2011) in Odisha depend on solid fuel sources, mainly firewood and chips, for cooking and other lighting purposes (Manjula and Gopi 2017). In fact, studies document an increase in the proportion depending on solid fuel over the period 1991-2011, implying persistence of energy poverty in the region (Manjula and Gopi 2017). An even higher proportion of Scheduled Caste (SC) and Scheduled Tribe (ST) households rely on such fuel sources than other social categories. Only about 2% of the rural population uses non-solid fuel sources, and less than 1% have adopted LPG sources for use. Similarly, female headed households, especially those belonging to the SC and ST show a larger proportion of households using solid fuel like biomass, coal, lignite, and charcoal for cooking across both rural, and urban areas (Manjula and Gopi 2017).

7.5. Discussions and Conclusions

The use patterns of mangroves, especially mangrove wood for cooking and heating needs, largely coincide with previous documented studies from this region as well as other countries. In fact, previous studies highlight greater dependence on mangrove wood in the Indo-Pacific region because of their structural complexity and diversity (Bandaranayake 1998). From the responses gathered, it was evident that current dependence stems from economic but also cultural conditions, concentrated more among marginalized communities. A number of studies document similar findings that reiterate how poor and vulnerable coastal communities are submerged in a web of social conditions that prevent them from adopting mechanisms that change reliance on forests for subsistence (Glaser 2003; Moreira dos Santos and Lana 2017). Similarly, this study also found a disconnect between past and current uses of mangrove forests with a stark decline in small scale mangrove exploitation practices such as firewood extraction. This can be attributed to change in social conditions through adoption of profit generating practices like aquaculture, or positive values towards regulating services such as protection from storms and conservation policies that have discouraged the extraction and use of natural resources. Similarly, studies conducted in other parts of the world (Moreira dos Santos and Lana 2017) also highlight how historical dependence is dwindling among mangrove local communities. For example, Moreira dos Santos and Lana (2017) show non-existence of firewood and tannin extraction, use and sale of Brazilian mangroves because of the introduction of technological innovations. Mangrove as an insect repellant is practically invisible today, and bamboo poles have replaced the need for cutting down mangrove wood for house construction purposes.

Although, mangrove forest dependence has declined over the years, a large proportion of the interviewees documented the use of mangrove wood for cooking and heating needs. This draws light on how mangrove wood continues to remain a source of subsistence which that complements other fuel sources. This is to say that almost all interviewees used multiple fuels for their needs, suggesting fuel stacking (use of multiple fuel sources for cooking combinations within the same household) to be prevalent in all households. A strong reliance on traditional fuels like mangrove wood for certain activities in addition to adopting fuel choices was the observed norm. Overall, these choices are influenced by a variety of factors, the lack of energy access being a crucial component, but also who is able to access the benefits of a complete switch to non-traditional biomass fuels for cooking or heating. The latter brings us to the discussion on 'mechanisms of access' (Rebot and Peluso, 2003: 155) and what conditions perpetuate the continued reliance on forest resources.

7.5.1. The ability to access: Social conditions, choices, and norms

Ribot and Peluso (2003) theorize various structural and relational mechanisms which facilitate rights-based or, and illicit mechanisms of access. They shape how benefits are gained, controlled, maintained, or even excluded. To illustrate, the right to extract wood from mangrove forests can be determined through both rights-based or illicit modes by controlling who or how access to mangrove wood is obtained, or access to cleaner energy fuels or the lack of thereof, could be governed by income disparities, poverty, or and knowledge about policies that influence clean energy adoption and access. Similarly, conditions that prevent the adoption and continued use of cleaner energy sources can also be embedded in structural or relational mechanisms. They include technology, capital, markets, labor, knowledge, authority, identities, and social relations as some of the structure and relational mechanisms that influence access.

The responses illuminate both illicit and rights-based mechanisms wherein access to the protected mangrove forest and access to clean energy adoption is controlled. People’s access to forests are controlled by de jure rights which makes it illegal to extract timber or non-timber forest products. So, their means of access is governed largely through de facto mechanisms which are both illicit and de jure in nature. They obtain permits to extract firewood but also use their fines for trespassing, as passes to enter the forests. Those who are able to obtain permits are members of village committees with active relations to people in positions of power or part of social networks that enhance the ready availability of these permits. However, households from marginalized communities depend on their social networks to escape fines (go in groups or avoid going during patrols) or pay the fine if caught considering the costs are still lower than completing switching to LPG.

Similarly, although LPG is widely preferred to solid fuels for its cleanliness, and ease of handling (Patra 2015), in many cases, high fuel costs, the lack of paperwork to access subsidies and lack of supply at times especially during monsoons or storms can limit use. Households may also be hesitant to cook fuel-intensive meals like rice or thick curries to ration gas (Wang 2014) as well as owing from tradition or preference for wood cooked meals. Fuel stacking becomes part of social conditions in rural India.

Social conditions also determine choices which are more often dealt by women rather than men. Women play a crucial role within decentralized energy systems, as part of various tasks, including fetching fuel, fodder, and water for homes, preparing food for their families as well as engaging in micro-enterprises like basket making or selling dried fish. The choice to enter the forest, or substitute with alternate sources of readily available fuel (rice husks, cow dung cakes etc.) to compensate for the lack of capital to switch to LPG is ultimately determined by women. Gender roles and inequalities impose differential costs on family members. For example, collecting traditional fuels is a physically draining task that may take anywhere from 2 to 20 or more hours per week, which could alternatively be spent on childcare, self-care, education and other self-improvement activities, or income-generating activities. Thus, being the sole bearers of the majority of negative effects owing to fuel collection, transport and indoor air pollution resulting from the use of solid fuels (Clancy, Skutsch, and Batchelor 2002). Moreover, continuous migration of male members to cities for jobs has resulted in greater responsibilities on women in terms of managing finances while also tending to farm labor, cattle care and limited agency in household decision making. The concept of decision-making highlights how 'feminization of forest-relations' (Figure 7.6) may be a double-edged sword and was an ongoing premise in this study which influenced access to forest resources, as well as alternatives to forest resources. Figure 7.6 provides a summary of each mechanism that highlights how forest-relations become feminized, whether it was about understanding forest regeneration processes or questions pertaining to forest access or alternatives to reduce dependence.

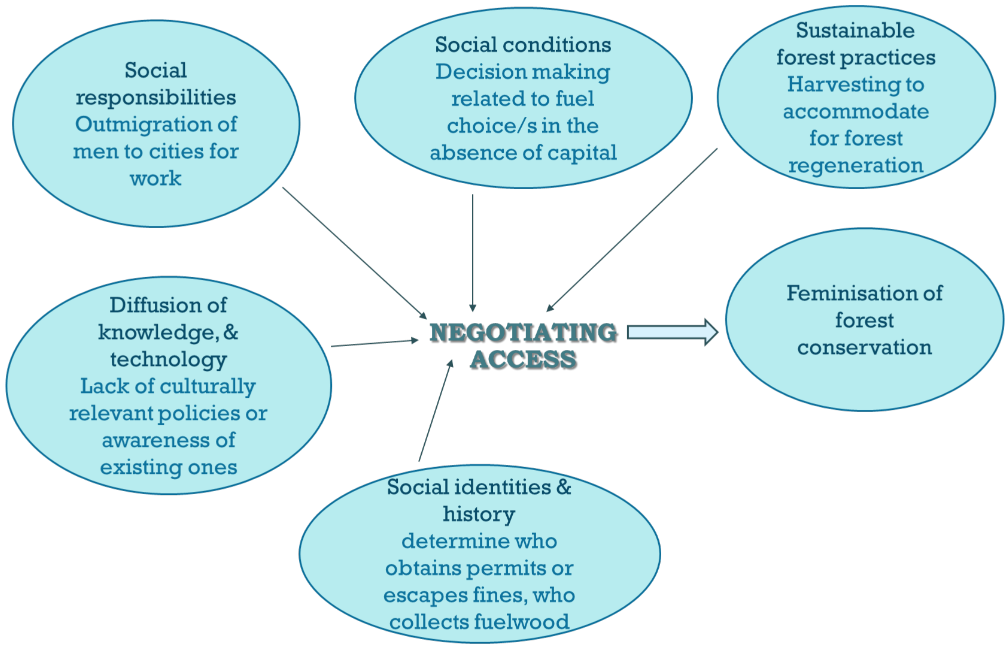

Figure 7.6 Feminization of forest relations

Consolidating, with increasing income and prosperity, people gradually advance the energy ladder (Kowsari and Zerriffi 2011). The energy ladder represents the relationship between poverty reduction and energy with traditional fuels (woodfuels, dung, and crop residues) at the bottom rung, whereas more advanced or modern fuels like gas and electricity are at the top. The switch to more modern fuel sources comes with positive health effects, reduced atmospheric emissions, and improved forest cover (Yevich and Logan 2003). However, the switch is not only determined by income and price of fuels but also by tradition, social expectation, and availability (Barnes et al. 2004).

Roy (2014) highlights how ill-defined property right regimes in the Sundarban mangrove forests create social conflicts which further marginalize mangrove dependent communities. They argue that top-down allocation of permits that provide access to forest resources has increased the incidence of overharvesting. In order to achieve better conservation measures, both local human communities as well as state forest departments should share responsibilities, control, and benefits over forest management decisions. In contrast, but on a similar note, Beitl (2012) demonstrates how demarcation of clear rights can also marginalize communities (independent cockle collectors). In this study, she critically examines the impact of changing policies in Ecuador which result in concomitant issues of access. As a community-based conservation strategy, a number of custodias –ten-year community managed areas were established and granted to 'traditional user groups' after several years of social conflicts with shrimp farmers. Consequently, the establishment of custodias led to further marginalization of independent cockle collectors, which also depended on mangrove resources but lacked any relevant legal backing. Both these studies illuminate how power manifests through institutional mechanisms and de jure policies which can influence sustainable resource use (Ribot 1998; Ribot and Peluso 2003; Beitl 2012; Roy 2014). They also demonstrate how these power dynamics further marginalize forest dependent communities.

7.5.2. Channels of access and blue carbon

A series of variables involved at different scales dominating the channels of access are described in Figure 7.7. Of relevance to this study are the costs of forfeiting environmental benefits such as firewood dependence and the resulting gain to the blue carbon pool, and climate mitigation protection or, loss to livelihood subsistence. But also, who benefits, and at which scale and who has access to these benefits?

Policies imposing exclusion at local community level are drafted, and regulated at global, national, and regional (state and local) levels. These may include conserving blue carbon stocks to contribute to climate mitigation goals of states, countries, and global corporations. It may also include fortress measures of governing forested areas through demarcation of national parks, reserves, or private parks. All these policies at higher scales operate with the assumption that exclusion empowers communities through compensation mechanisms. However, at lower scales, exclusion becomes the norm and compensation mechanisms are governed by rules which are controlled through different mechanisms (mechanisms of access like gender, social class, regional identity, history) or diverted to maintenance costs.

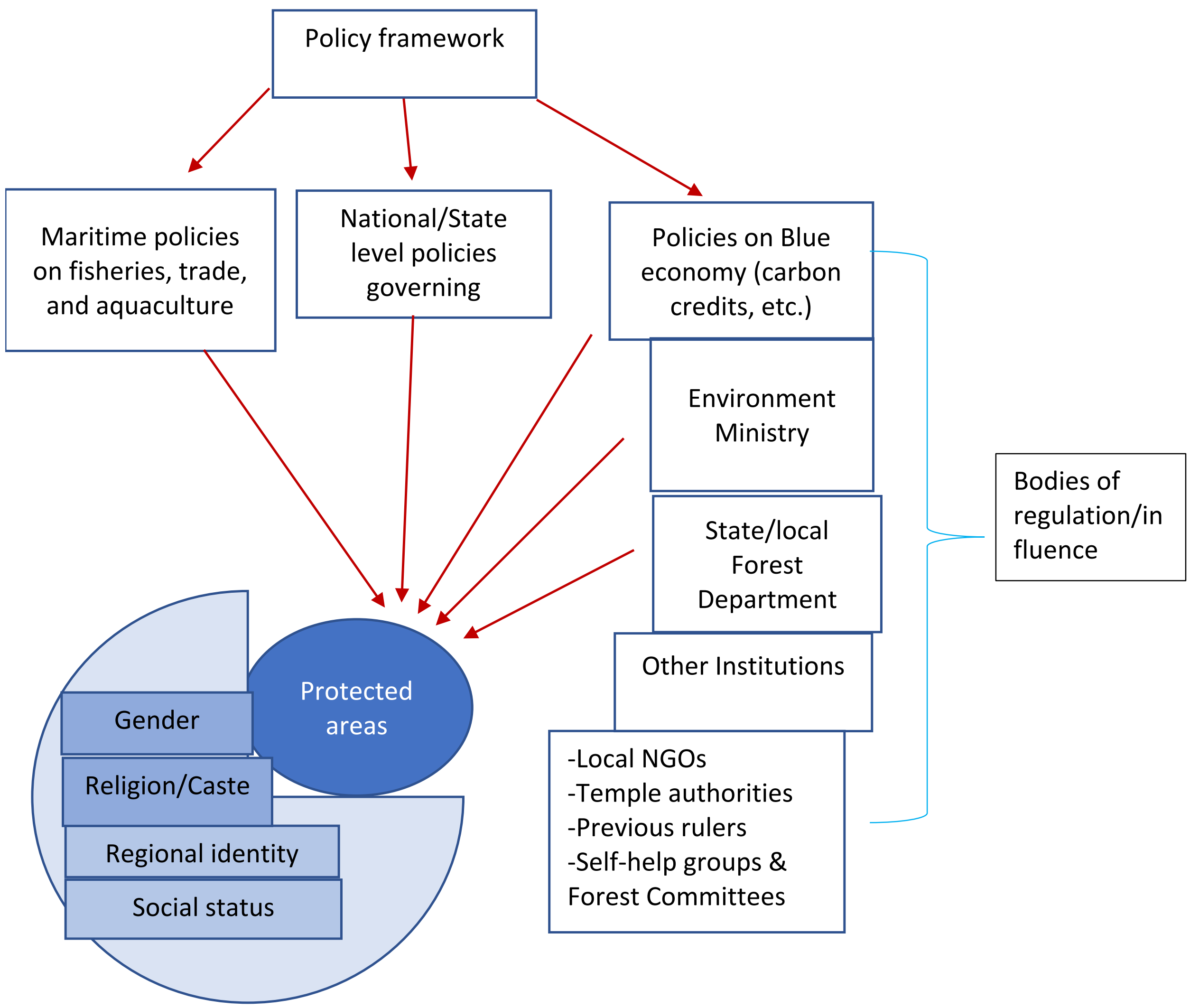

Figure 7.7 Channels of access controlled by different entities operating through protected areas, and the resulting impact on environmental benefits & blue carbon

Similarly, benefits are not always straightforward. For example, fuelwood has large opportunity costs in terms of collection time, effort or labor devoted by women which ultimately varies with distance, density of fuelwood/forest patches and accessibility to forest resources. Therefore, switching to improved cooking technologies or renewable sources which also come with substantial financial and opportunity costs, may seem like the intuitive choice or switch but unless provided with continuous access to subsidies may end up being confined to the relatively wealthy. Alternative fuel sources like dung cakes or producing fuelwood in woodlots on farms, also requires access to land (and land rights) and cattle. Similarly, dung also forms an important source of manure, using it as fuelwood may result in reduced soil fertility.

In conclusion, using access to understand people-forest relations provides new insights on the how intersectional identities influence resource access as well as highlights the disconnect between well-meaning conservation and socio-economic policies and ground realities. This study shows that although clean cooking fuels have positive impacts and are well-acknowledged and even used regularly in forest surrounding households, solid fuels remain a crucial aspect of local choices. The benefits depend on place-based policies but also extend to space heating needs, especially in areas where electricity is scarce, the ability to provide low-cost meals for large families, and saving for rainy days, especially during fuel shortages (example, the recent pandemic induced lockdown and supply shortages to rural areas). Fuel stacking (by women) is an outcome of rational decision-making given ground realities. It also highlights that the design and implementation of mangrove conservation policies need to run hand in hand with socio-economic empowerment acknowledging the differential impact on marginalized social classes.

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CHAPTER 8
LIVING ON THE EDGE: SPATIO-TEMPORAL CHANGES IN MANGROVE FOREST BIOMASS LEVELS OF BHITARKANIKA WILDLIFE SANCTUARY[6]

[6] Rasquinha, D.N., Mishra D.R., McEntire, K., Ragavan, P, Murthy T.V.R, Nikhil V. Lele , Kripa M.K. To be submitted to Remote Sensing

Abstract

Mangroves line highly dynamic environments and, in the process, are exposed to frequent tropical cyclones, along with other environmental interactions that shape the trajectory of this ecosystem. A range of environmental drivers (climate, physical or social) work in tandem with both large-scale and small-scale events that alter mangrove vegetation structure which ultimately influences aboveground biomass (ABG). This study focuses on the cumulative impacts of such events on mangrove biomass by quantifying the changes in biomass over the last seven years using high resolution satellite imagery, and by modeling this change using an agent-based model (ABM). The ABM results suggest that firewood extraction impacts on ABG occur at highly localized forest edges with almost negligible impact on the overall ABG estimates of the forest. In contrast, tropical storm impacts on ABG were found to significantly correlate with the storm path and wind speeds associated with the incoming storm. When compared with the overall change in forest ABG over the past seven years, greater decreasing changes were observed along edges while forest interiors showed signs of biomass accumulation. The clear pattern in ABG loss and gain along fragmented parcels of the forest indicates the plausible role of salinity fluctuations and subsequent changing species composition in this region in influencing the overall accumulation or loss of ABG. Through this comprehensive theoretical and empirical synthesis, this study highlights the significance of spatial variability in ABG change as an important factor to consider while planning restoration activities in this region considering the differential impact of environmental drivers on forest loss, growth, and health.

8.1. Introduction

Across the world, mangrove anthromes are found along estuaries lining river creeks and shorelines. Due to close proximity with such highly dynamic environments, these anthromes are considered to be in a constant flux with a variety of environmental and human natural and anthropogenic interactions. In a recent review, 45 % of reported changes to mangrove areas in the global literature were attributed to tropical cyclones (Sippo et al. 2018). However, fragmentation arising from land use land cover changes (LULCC) to changes in environmental variables such as salinity fluctuations due to inadequate freshwater supply or sea-level rise and storm surges (FAO 2007) can also change mangrove vegetation composition and biophysical status. At finer scales, it could also result from logging or extraction practices for subsistence or livelihood needs as reiterated by several studies in different parts of the world (Walters 2005; Feka et al. 2011; Scales and Friess 2019a)

Although, mangroves are adapted to dynamic environments because of their spatial location (along riverine edges and at the interface of land and sea boundaries) (Krauss and Osland 2019), studies provide contrasting evidence on how different events change and may influence mangrove biomass. Following Hurricane Irma, Lagomasino et al. (2021) documented the largest canopy damage and dieback among 62% of mangroves in southwest Florida in tall forests (> 10m) and poorly-drained inland sites, respectively. In Myanmar, about 70 % of larger adult mangrove trees suffered broken stems and were uprooted during Cyclone Nargis (Aung et al. 2013).

However, some studies posit that nutrient fluxes and sediment accretion processes from storm surges provide fodder for the growth and recovery of lost biomass (Lovelock et al. 2009; Castañeda-Moya et al. 2020; Rasquinha and Mishra 2021b). Castañeda-Moya et al. (2020) observed positive aspects of hurricane impacts on the Florida Everglades mangrove ecosystem.

They found that hurricanes help improve mangrove productivity, carbon assimilation, and resiliency due to vertical accretion from soil and nutrient deposition resulting from land surface runoff. In dry regions, this effect is more pronounced, as shown by a similar study by Lovelock et al. (2009) for the Australian mangroves. Similarly, an overall increasing trend in gross primary productivity (GPP) was found for multiple sites in India over the last 20 years by Rasquinha and Mishra (2021b). The trend was also seasonal and evident among dominant mangrove species, with higher values coinciding with the timing of incoming storms in the selected areas (Rasquinha and Mishra 2021b).

While the impacts from storms have varied consequences, pressures from harvesting forest resources like fuelwood can also alter vegetation characteristics and biomass levels. Studies show that sites, where harvesting was common were dominated by larger gaps, shorter tree statures/smaller tree diameters, multiple stems (higher coppicing), presence of more mangrove associates or non-native species, and lower biomass/carbon levels. However, the interactive impacts of these changes are challenging to tease apart because of the scale and frequency at which they influence these forests and the logistical constraints in accessing these forests readily due to the dynamic spatial environments they occupy. Peters et al. (2011) (as cited by (Krauss and Osland 2019)) outlines a general conceptual framework to understand how such interactions influence ecosystems.

8.1.1. Conceptual framework: Effects of tropical storms & harvesting pressures on mangrove biomass levels

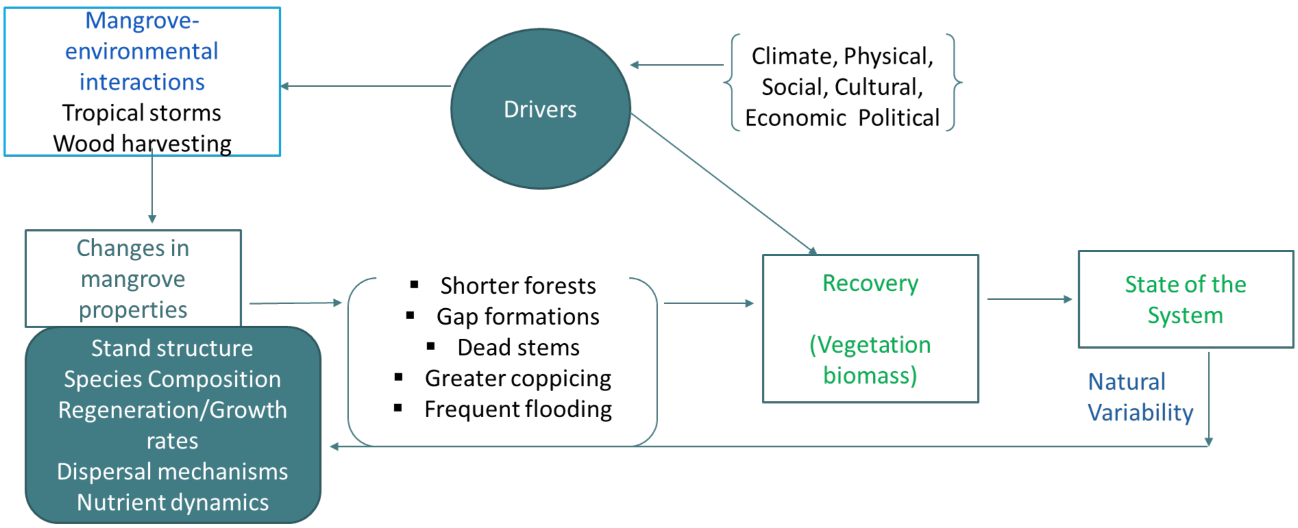


Figure 8.1 Conceptual framework on how the interacting influence of firewood extraction and tropical storms may impact mangrove biomass recovery

The conceptual framework highlights (Figure 8.1) how either a single devastating event or interacting impacts from small- or large-scale events can influence mangrove vegetation in a variety of ways through different environmental drivers (climate, physical, social, cultural, economic, or political). For example, climatic drivers could be wind speeds, temperature, or rainfall changes; physical drivers could relate to changes in sedimentation processes, whereas social/cultural drivers could arise from value differences or economic or political policies that reinforce inequity. These environmental drivers could change specific ecosystem properties of the vegetation, which may include structural changes or changing species composition patterns. For example, an increase in more salt tolerant species or changes in growth rates, or investment in small stems versus larger diameter trees. These changes can ultimately influence the trajectory of the system to recovery (recovery of lost biomass) post a disturbance event.

With this background, in this study, we investigate the spatio-temporal changes in biomass levels of a mangrove forest in eastern India. Considering about 20% of the remaining tropical forests lie less than 100m from an edge, the implications on the carbon budget of these remnant tropical forest fragments are significant (Haddad et al. 2015; Ordway and Asner 2020). By looking at how two different environmental regimes at different scales impact mangrove vegetation, specifically biomass levels in the study area, we can understand their interactive impacts better. We look at this change both theoretically and empirically. We model the theoretical implications of biomass change at the landscape level with firewood extraction and storm impacts using an agent-based model (ABM). We then empirically test these predictions using biomass change maps for the area and investigate (a) how biomass has changed over the considered 7-year period? (b) if biomass changes are impacted by species differences, and (c) if there is a pattern in biomass change values along riverine edges, forest edges, and shorelines in order for us to correlate impacts with plausible biotic or abiotic changes. While looking at this from an ecological perspective, we also discuss how biomass changes interact with social dynamics in this region by discussing the relationship between local community dependence on fuelwood in the region, its impact on biomass changes of the forests, and the implications of exclusionary policies in determining the sustainability of the forests.

8.2. Methods

8.2.1. Study site

The study area is a protected mangrove region of the Bhitarkanika Wildlife Sanctuary (BWS), Odisha, situated on the eastern coast of India. The sanctuary is spread between 20° 40′ N and 20° 48′ N latitude and 86° 45′ E and 87° 50′ E longitude (Figure 8.2) and has an area of about 672 sq. km with its core area measuring about 145 sq. km. A tropical warm and humid climate dominates this region, with tropical cyclones passing through its shoreline annually. In the last two decades, this region has witnessed about 40 tropical cyclones, including two supercyclones (> 250 km/hr). This does not include the countless low-level depressions that bring rain to this region annually.

The site provides a perfect case study to understand how different drivers help alter or maintain mangrove vegetation biomass. From a socio-cultural-political point of view, this area has had a diverse land tenure system which has interfered with how mangrove vegetation is managed in this region. For example, the core area where human activities are prohibited is a designated national park, while the surrounding region is a wildlife sanctuary where certain human activities are allowed. It also ranks second in the number of true mangrove species found in the country, with about 35 species of true mangroves and several mangrove associates (Ragavan et al. 2016). The dominant species found in this region are shown in Figure 1. Some of these include *Heritiera fomes, Excoecaria agallocha, Avicennia officinalis, Cynometra ramiflora, Sonneratia apetala, Rhizophora mucronata, Aegicera corniculatum, Phoenix paludosa, L. racemose and Ceriops decandra* (Rasquinha & Mishra, 2020). Further, mangroves in this region are fed by a meandering network of rivers and creeks. A number of upcoming upstream industrial (steel processing units) extraction processes are projected in the near future, which could potentially impact the salinity levels of this region, influencing species composition and biomass levels.

8.2.2. Mangrove biomass estimation and modeling

A gradient boosting model was used to develop spatio-temporal mangrove aboveground biomass (ABM) estimations for Bhitarkanika mangroves using plot level ABM data and satellite derived reflectance values as predictor variables. The boosting model was chosen after comparing model accuracy results with a random forest model and several iterations of predictor variables (data not reported).

8.2.3. Field data collection

We followed sampling protocols outlined by Rasquinha and Mishra, 2020. The sampling criteria followed represented different species types and harvesting patterns. Plot level (n= 25) mangrove vegetation data on species composition and structural characteristics were measured within 10 by 10 m plots using purposive sampling techniques. Structural data like diameter at breast height and tree height were then used to estimate biomass values for the plots using both general and species-specific allometric equations. These data were further supplemented with plot data (n=20) on mangrove biomass values from Murthy et al.2019 for the same region, and with mangrove plot data (n=173) from the Andamans and Nicobar Islands. Overall, a total of 45 vegetation plots for Bhitarkanika and an additional 173 plots for the Andamans & Nicobar Islands (see Appendix D, Figure D.1 for plot locations) were combined to build the training set for the gradient boosting model. Field data from each dataset is summarized in Appendix D Table D.1 and Figure D.2. The addition of sampling points from the same and structurally and compositionally similar sites helped increase model accuracy and provided a platform to test models for cross-site comparative studies in the future.

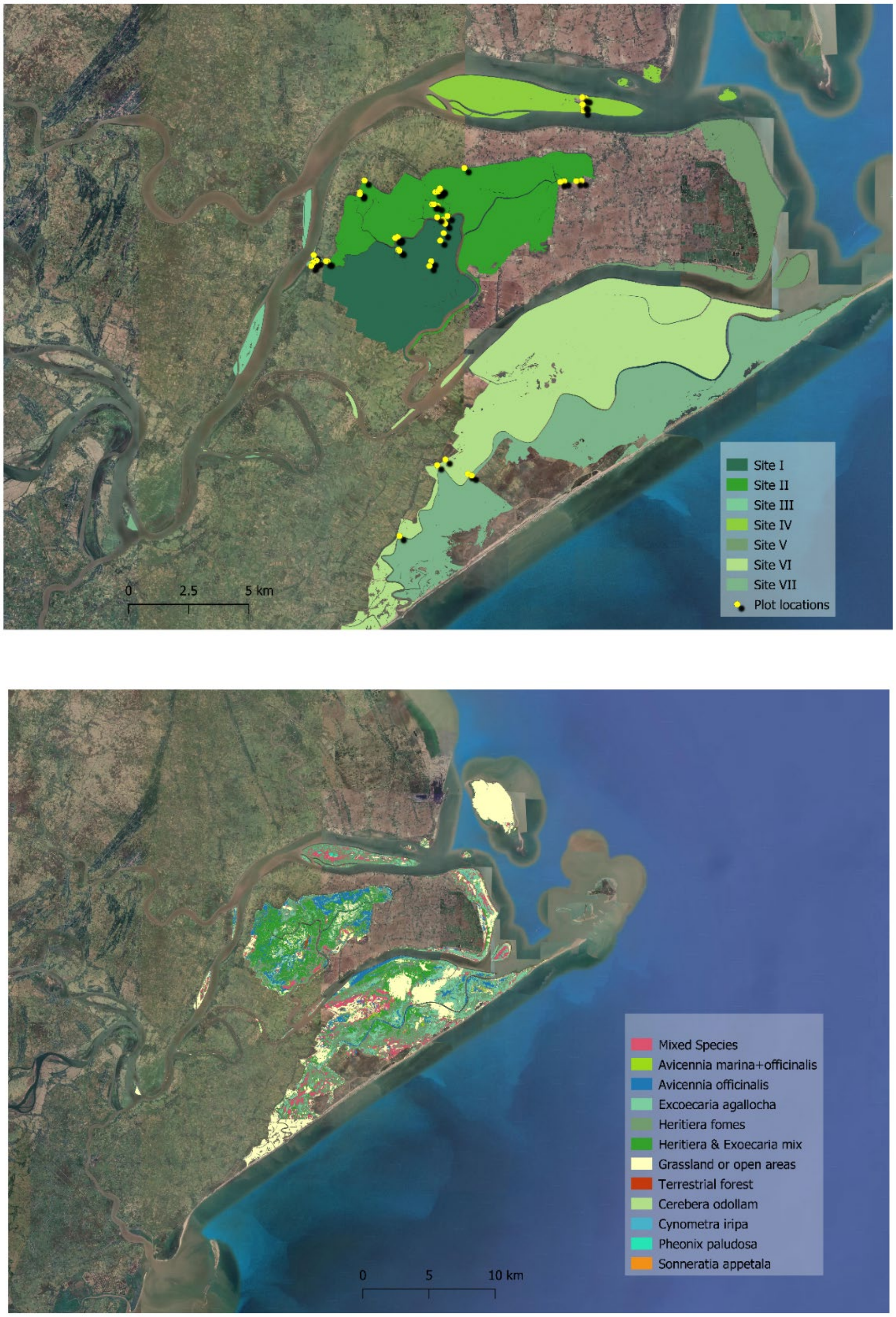


Figure 8.2 a. Map of mangrove distribution blocks and sampling sites in Bhitarkanika, b. Species map of Bhitarkanika collated using field data and data from Murthy et al 2019.

8.2.4. Satellite data processing

8.2.4.1. Satellite imagery

Image data from RapidEye, a high spatial resolution spaceborne multispectral sensor, covering the study sites were obtained from the Planet data repository. The RapidEye image comprises five multispectral bands with a spatial resolution of 5 m. The spectral ranges of the five bands are 440–510 nm (Blue), 520–590 nm (Green), 630–685 nm (Red), 690–730 nm (Rededge), and 760–850 nm (NIR). The high spatial and temporal resolution allows for the rapid analyses of mangrove biomass changes at finer spatial and temporal scales. Most of the downloaded images were surface reflectance products and required no additional atmospheric correction. However, data from the earlier periods (2011-2014) were atmospherically corrected using the FLAASH algorithm within ENVI 4.7. The images were acquired on dates close to the field sample dates for both Bhitarkanika and the Andamans to cloud-free conditions (Table 8.1). For Bhitarkanika, images were downloaded for the months of February or March for each year from 2011 to 2020, and for the Andamans, we considered images from March 2019. A list of all the acquired dates for each site and year is provided in Table 1.

Table 8.1 Details of the RapidEye imagery used to estimate AGB. Field data collection for both Bhitarkanika and the Andamans was conducted between October 2018 and March 2019

Year	Acquisition dates for Bhitarkanika	Acquisition dates for Andaman & Nicobar Islands
2011	November 8, 2011	
2012	December 18, 2012	
2013	December 18, 2013	
2014	March 03, 2014	
2016	March 20, 2016	
2017	October 28, 2017	
2018	March 01, 2018	
2019		February 06, 2019 February 21, 2019
2020	January 18, 2020	

Along with the 5 bands reflectance data, a total of eleven vegetation indices (VIs), including normalized difference vegetation index (NDVI), green and red ratio Vegetation Index (GRVI) and red edge normalized difference index, and several others were generated from individual date images. The different VIs used as covariables in the boosting model is further elaborated in Table 8.2. A 20 m radius buffer around each field plot center was created using RStudio+R. The associated reflectance values for each satellite band and index were extracted within this buffer and the mean values were used as plot predictor variables.

Table 8.2 List of predictor variables including the vegetation indices selected for AGB estimation

	Satellite band indices	Formulae	References
Spectral bands (5)	Blue, Green, Red, Rededge, NIR	SR	(Stoll et al. 2012)
Conventional near infrared indices	Normalized Difference Vegetation Index (NDVI)	(NIR − R)/ (NIR + R)	(Tucker 1979)
	Near-infrared (NIR) reflectance of vegetation (NIRv)	NIR*NDVI	(Badgley et al.)
	Green and Red ratio Vegetation Index (GRVI)	Green- red/Green +red	(Gitelson et al. 2003)
	Green Chlorophyll Vegetation Index (GCl1)	(NIR/(Green-1)	(Gitelson et al. 2003)
	Difference vegetation index (DVI)	NIR-Red	(Tucker 1979)
Red edge indices	Rededge Normalized Difference Vegetation Index (NDRE)	(NIR − RE)/ (NIR + RE)	(Shoko and Mutanga 2017)
	Red-Edge Simple Ratio index (RESRI)	Rededge/Red	(Pu and Landry 2012)

8.2.4.2. Model training and Validation

To validate the performance of the boosting model, the field derived AGB datasets were combined and randomly split into 70% training dataset and 30% for a test (independent) dataset. The training dataset was used to optimize the regression model and to train the prediction models, whereas the test datasets were used to examine the performance of the prediction model.

The final boosting model was generated using a subset of the satellite band values after comparing performance with multiple iterations of predictor variables. The final subset of the remote sensing predictor variables included the 5 primal RapidEye band values as well as the 9 generated vegetation index values (Table 8.2). Moreover, the test data was further split into three validation sets by location to determine model performance. Different error measurements, namely, the correlation coefficient (r), the root mean square error (RMSE), and mean absolute error (MAE) were used to evaluate the performance of the gradient boosting model.

8.2.5. Agent-based modeling

The model is designed to explore and understand the impact of (1) changing intensities and frequencies of tropical storms and (2) forest extraction levels on the spatial and temporal patterns on mangrove ABG. It also seeks to understand the change in social dynamics of the local village community in Bhitarkanika, India, to understand if harvesting patterns (and ABG) are influenced by grouping behavior to link mangrove conservation with social policy. The model has the following entities: (1) fuelwood harvesters which are primarily women, (2) patches of different landcover types (mangrove forest and all other land covers/uses), (3) villages, and (4) tropical storms with different wind speeds.

Each patch has the following variables: (1) land cover types and (2) aboveground biomass (ABG) of each mangrove patch estimated in tons or Mg/ha. Each storm is characterized by its wind speed in km/hr (<100 km/hr, 100-150 km/hr, 150-200 km/hr, 200-250 km/hr, >250 km/hr). The non-mangrove forest areas house the different villages which are characterized by the number of households within the village. Based on social interviews and surveys, it was highlighted that harvesting occurs in groups comprising of harvesters from different households (sometimes women from the same households). Each harvester is then characterized by their group size, and their minimum monthly requirement of firewood which ranges from 25 to 300 kgs (0.025 to 0.3 Mg). Each model tick represents a month which is repeated daily until fuelwood needs are met. In each model run, harvesters from each household collect firewood to meet the household's monthly fuel requirement. Each collector belongs to a single household and village. Similarly, tropical storms impact mangrove forests depending on their distance from the storm's path. The patches within the storm's path exhibit higher levels of biomass loss than patches further away from the path. These losses are modeled based on previous studies that report damage due to tropical storms (Dutta et al. 2015; Krauss and Osland 2019). At the end of each model run, the numbers of mangrove patches harvested are recorded along with the mean biomass of the harvested patches. Similarly, we compare the mean biomass values of patches before and after the storm has passed this region to assess storm damage. We also document the change in biomass with different groups sizes, across different time periods, the number of storms, and the time required to collect biomass as a function of group size to understand how social dynamics play a role in influencing biomass changes

8.3. Results

8.3.1. Gradient boosting model performance

In general, a higher r or R^2 value and lower RMSE values indicate a better estimation performance of the model. The model performance measures are listed in Table 8.3.

Table 8.3 Error metrics for the biomass model, including mean absolute error (MAE) (Mg/ha), root mean squared error (RMSE) (Mg/ ha), normalized RMSE (nRMSE) (%), and correlation (r) for all the testing data combined ('all'), for testing data from each site ('Bhitarkanika', 'Andamans'). Data for both sites were collated between 2018-2019.

Model	Test-data	MAE	RMSE	Normalized RMSE (SD)	Normalized RMSE (Maxmin)	Correlation (r)
Gradient Boosting	all	109.15	201.82	24.2	6.3	0.98
	Andamans	76.5316	127.67	26.3	5.8	0.97
	Bhitarkanika	225.62	357.75	37.4	11.2	0.97

Similarly, the predicted and observed values for each independent test and validation datasets also show high accuracy levels, as shown in Figure 8.3.

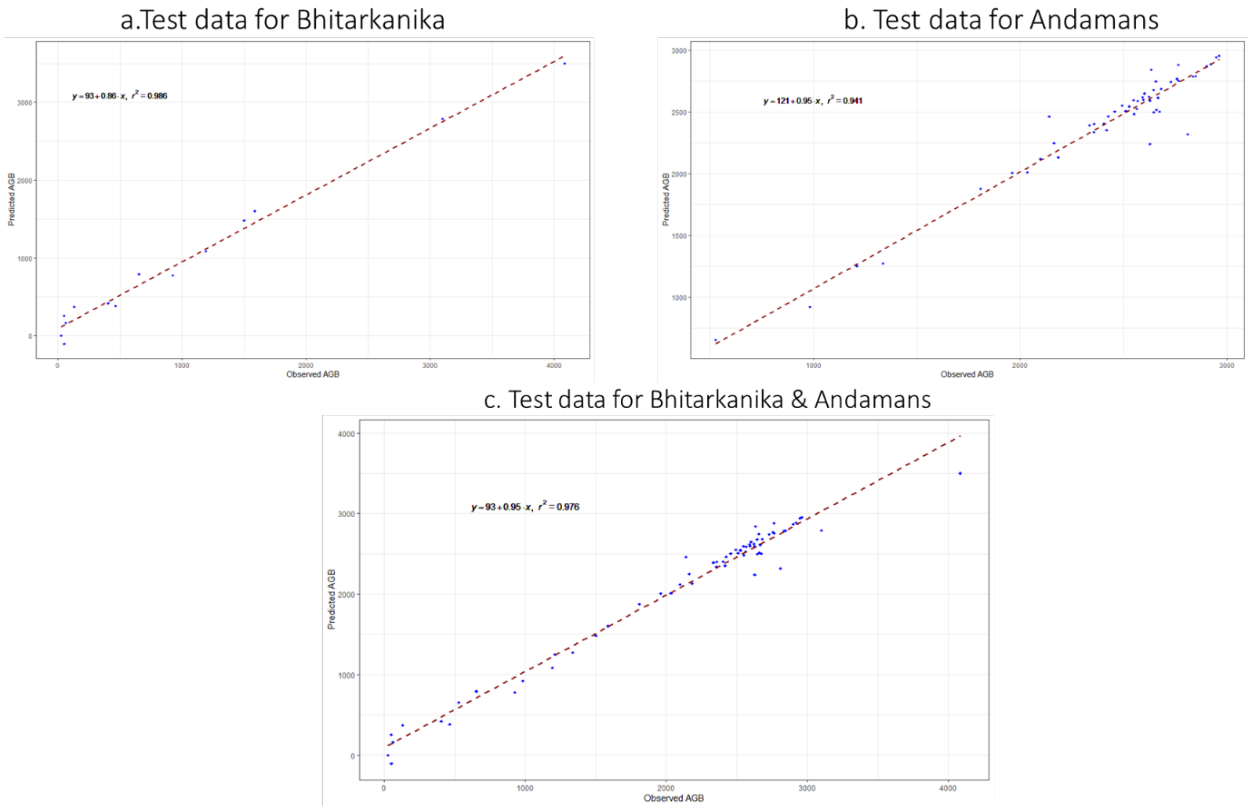


Figure 8.3 Relationship between predicted and observed AGB using gradient boosting field data

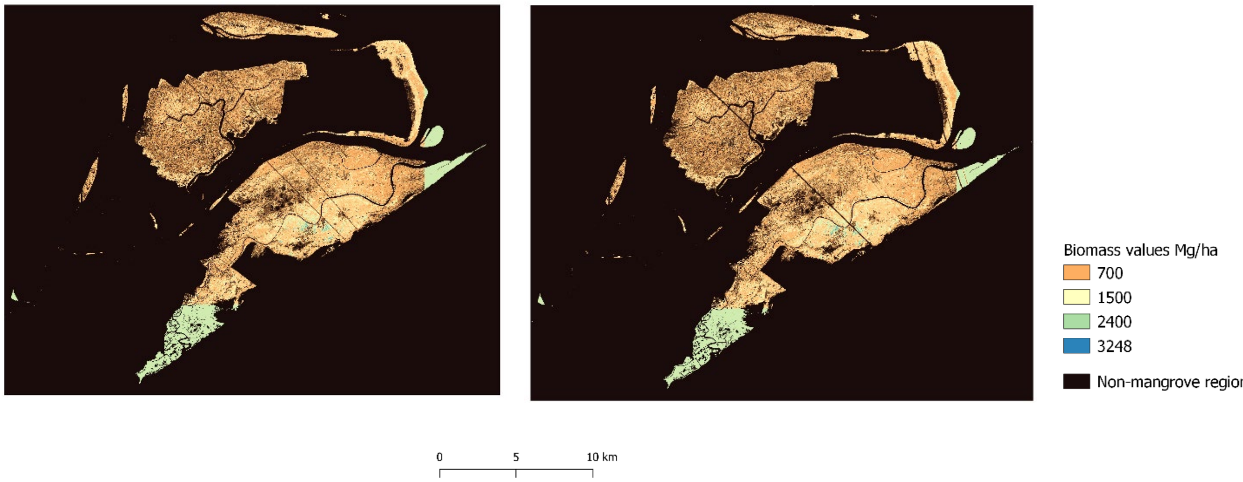
8.3.2. Theoretical predictions about biomass change using agent-based models

8.3.2.2. Firewood harvesting and social dynamics

Studies document that firewood dependence/collection is intricately linked with forest resource management (Walters 2005; Feka et al. 2011). This may include ecological degradation like loss of biodiversity, change in watershed functions, loss in carbon dioxide sequestration, and soil erosion (Walters 2005; Scales and Friess 2019b; Rasquinha and Mishra 2021a). But at the same time, forest degradation may exceed sustainable yield and result in fuelwood scarcity. Moreover, fuelwood collection also has a high opportunity cost in terms of collection labor and time. The ABM looked at two aspects to understand how these opportunity costs and biomass change are connected. We found that biomass loss due to firewood extraction ranged between 22 to 29% when harvesting was conducted solitary and when in groups of 5 (see Appendix D, Table D.3a). We also found that the time allocated to collect firewood does not change with group size (used as a state variable to understand the interaction between households). While the biomass of patches harvested decreased with group size indicating that larger groups extract more biomass, overall change in biomass (considering only the patches harvested by agents) due to harvesting ranged between 162 to 210 Mg/ha when group size was one and five, respectively. Similarly, agents harvested patches with biomass values ranging from 691 to 777 Mg/ha. Most of these patches were located near forest edges indicating that patches which are below the overall average (969 Mg/ha) are more likely to be harvested because of their spatial location.

8.3.2.3. Tropical storms

We modeled different storm intensities and frequencies to understand the change in biomass of the mangrove forest using an ABM. Our results show that with increasing storm intensities and frequencies overall change in mangrove biomass ranges between 15 to 34% depending on previous storm impacts (see Appendix D, Table 3b). Biomass alteration because of storm events is greatly influenced by storm speed especially if a high-speed storm (>200) had passed through the region previously. Similarly, overall biomass loss was similar when greater number of storms passed in a year or if only a few storms with greater speeds passed that same year. For example, when expected storms in a year were five (storm speeds ranged from 68 to 278km/hr), biomass change was about 24 Mg/ha, whereas when eleven storms (storm speeds ranged between 8 to 242 km/hr) passed that same year, biomass change was about 22 Mg/ha.



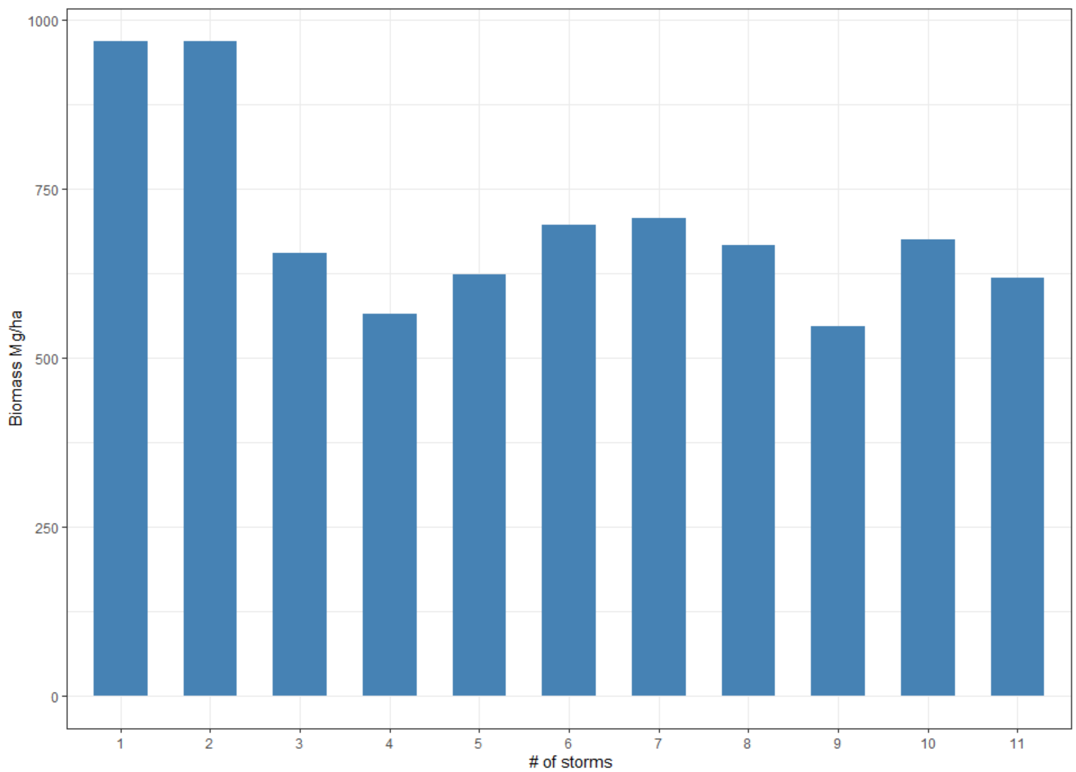


Figure 8.4 The maps are simulation outputs of tropical storms with different wind speeds (3 versus 10) passing through the mangrove forest in Bhitarkanika. The bottom graph depicts the change in mean biomass of the entire forest with increasing number of storms.

8.3.3. Quantification of biomass change using field and modeled biomass data

8.3.3.1. Spatio-temporal changes in biomass values

Based on the GBM results, AGB time series maps from 2011 to 2020 were derived (Figure 8.5). A rising trend of mean AGB occurred between 2011 and 2012 (~385 t/ha), while after 2012, there was a fluctuating decreasing change. The peak change in the value of mean AGB was ~3041 t/ha which occurred between 2017-2018. Overall, the time series of satellite derived ABM values over the 7-year period showed a fluctuating decreasing trend in mangrove AGB in all forest blocks considered. Overall, the greatest decline in mangrove forest biomass occurred between 2011 and 2012 (~460 Mg/ha) Mand between 2018 and 2017 (~330 Mg/ha), whereas the largest increase was between years 2012 and 2013 (~480 Mg/ha). Overall, the estimated mangrove ABG in forest block VI showed the largest decrease among all forest blocks (see Figure 8.1 for forest blocks), with about 61 t/ha decline between 2011 and 2020.

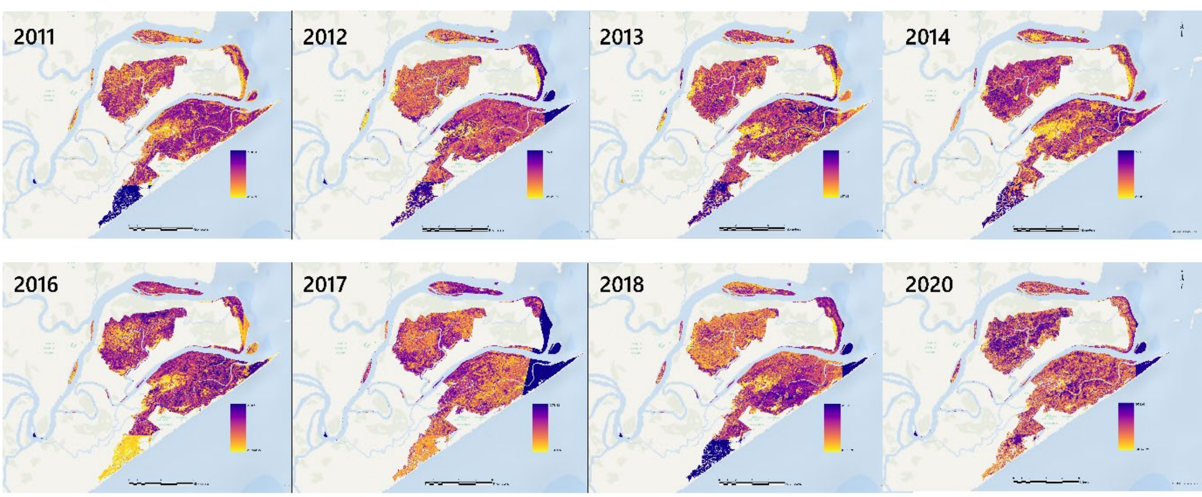


Figure 8.5 Modeled ABG values are shown for available years

Annual rates of mangrove ABG loss were on average highest during 2011–2012 and lowest during 2016–2014. Our analysis shows that the ABG change was variable for the entire 7-year period with a decrease at a mean rate of 73 t/ha per year over 78 % of the study site and an increase by 50 t/ha per year for the remaining 21% of the study region (remaining 1% area showed no change in biomass). We estimate that 46 t/ha of biomass was lost per year from the study site over the study period. While some regions showed a more vigorous decline, especially in forest blocks V and VI closer to the seaward edge, increases in biomass was noticeable in some fragmented parcels of the same block and interior forest parcels of other forest blocks, as shown by the green pixels in Figure 8.6.

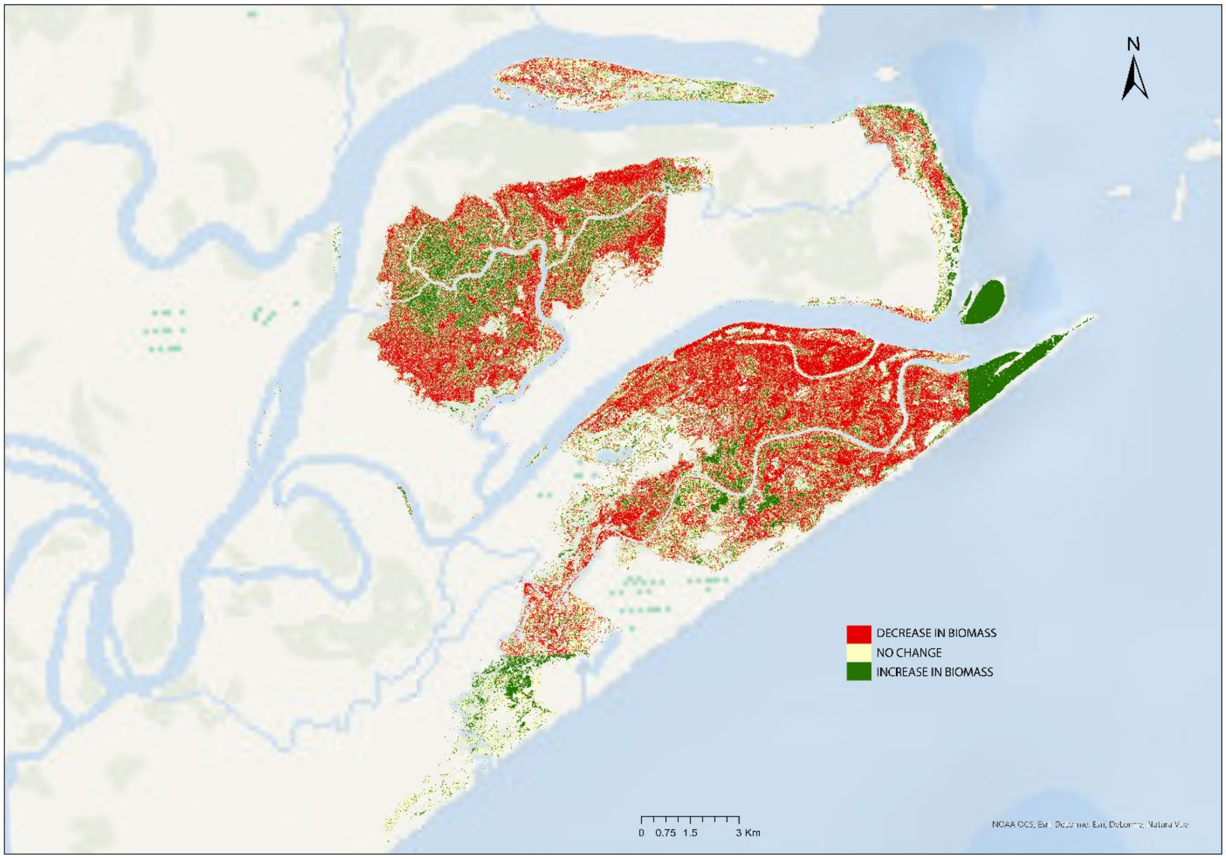


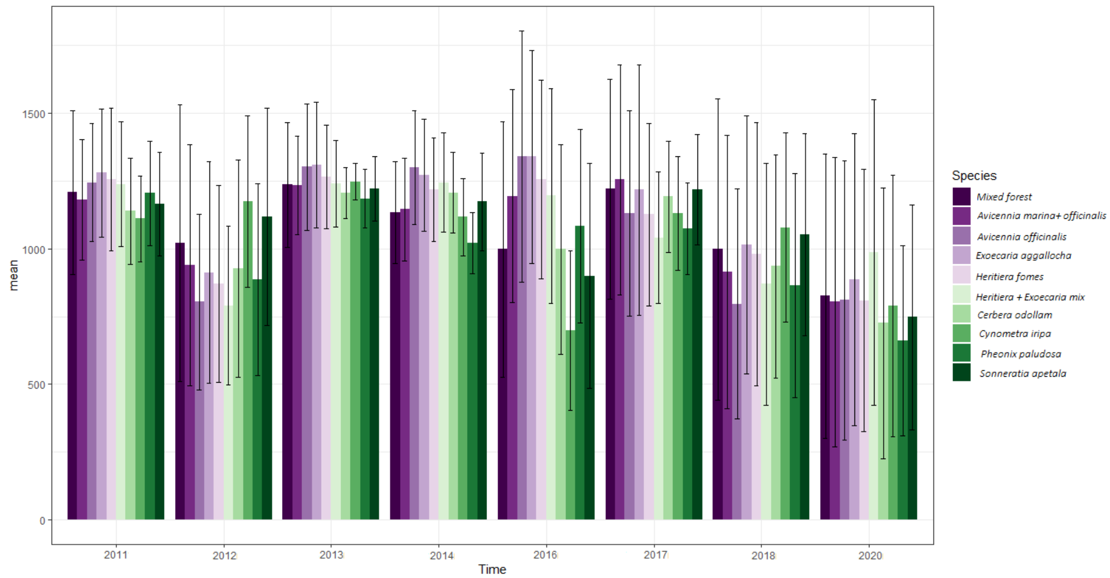
Figure 8.6 Biomass change over the observed 7-year period

The spatial variability in biomass levels highlights forest degradation in some forest parcels located closer to the shoreline, while forest parcels in the interior, near blocks I and II closer to the riverine edge, show an increase in biomass values. Similarly, biomass along the forest edges near block V adjacent to human settlements (see Figure 8.2a for locations of site blocks) show stark differences in overall biomass changes, with several pixels exhibiting no change over the 7-year period.

8.3.3.2. Species level biomass changes

Studies document strong links between species richness and ecosystem functioning, especially biomass production. However, the relationships between biomass production and loss of specific species or species traits remain still unclear. For instance, the replacement of apex predators with small predators (mesopredators) along the food chain that maintains similar ecosystem functions may help prevent the total collapse of the system to a large extent (Prugh et al., 2009). At the same time, removal of large predators can also impact overall ecosystem health drastically while ecosystem function is compensated by other species (Fraser 2011; Steneck 2012). Similarly, selective harvesting of mangrove species or loss of species susceptible to storm impacts due to low recovery rates may impact community productivity and have a larger than anticipated influence on ecosystem functioning than random species losses. In a nutshell, species identities, dominance and richness can operate simultaneously to influence community biomass.

In this study, we analyzed annual changes in biomass levels with respect to species identities to understand how biomass has changed over time and if the identified dominant species show pertinent trends which may seem to influence community biomass. The predicted AGB of all species showed a drastic declining trend for the years 2012, 2018, and 2020. Similarly, overall biomass was consistently low during 2012 for all species (Figure 8.7). Of all the years considered, *Cynometra* showed a stark decline during 2016 and *S. apetala* in 2020. Species biomass levels were also found to be consistently lower at the edges than core areas.



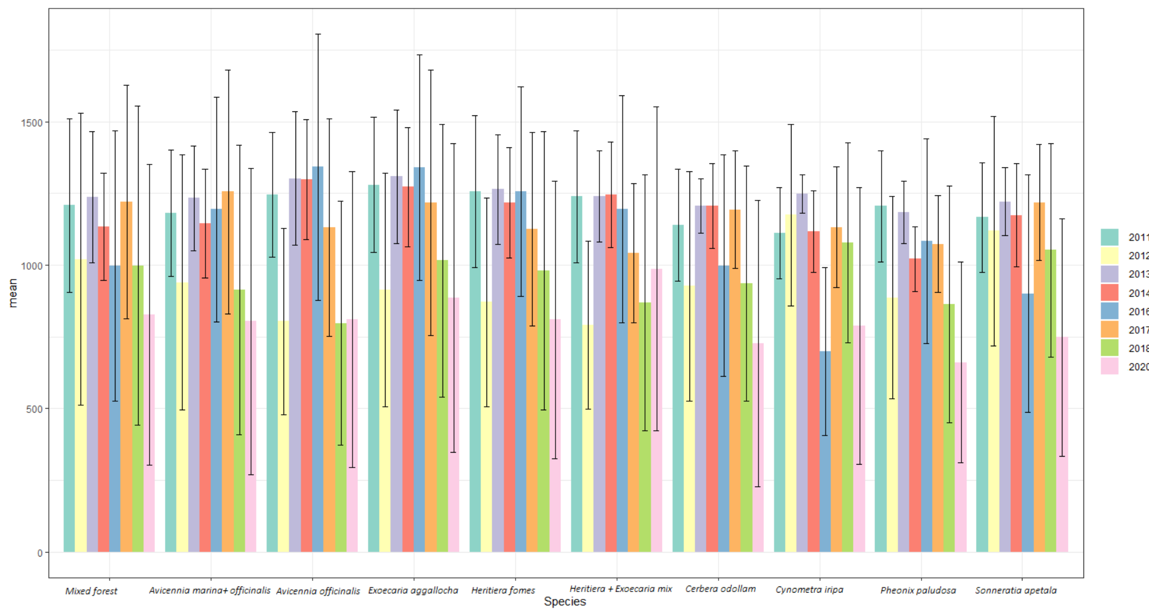


Figure 8.7 Relationship between predicted and observed AGB using and gradient boosting field data

8.3.3.3. Edge effects on biomass levels

Overall large patches of mangroves showed a negative trend in biomass change parallel to the shoreline (-82.6 MgC/ha), rivers edges (-65.61 Mg/ha), and forest edges (-71.9 Mg/ha) near human habitations, which corresponds to a low-productivity band that has moved inland over the past 7 years. Significantly positive trends (50 Mg/ha near shoreline, 52.18 Mg/ha near river edge, and 45.56 Mg/ha near forest edges) were also observed along the different edge categories at variable locations (Figure 8.8). We also summarized mean values of core area pixels (see Appendix D, Figure D.3) and found that 89% of the core area showed an increase in biomass values (54 t/ha) and 10% a decline (70t/ha). In comparison, 83% of edge pixels showed a decrease (78 t/ha) and 16% an increase in biomass (38 t/ha). Taken as a whole, the results suggest that increased saline intrusion associated with sea-level rise or degradation arising from the release of effluents from aquaculture ponds or forest extraction continues to reduce the photosynthetic biomass within mangrove marsh communities of this region.

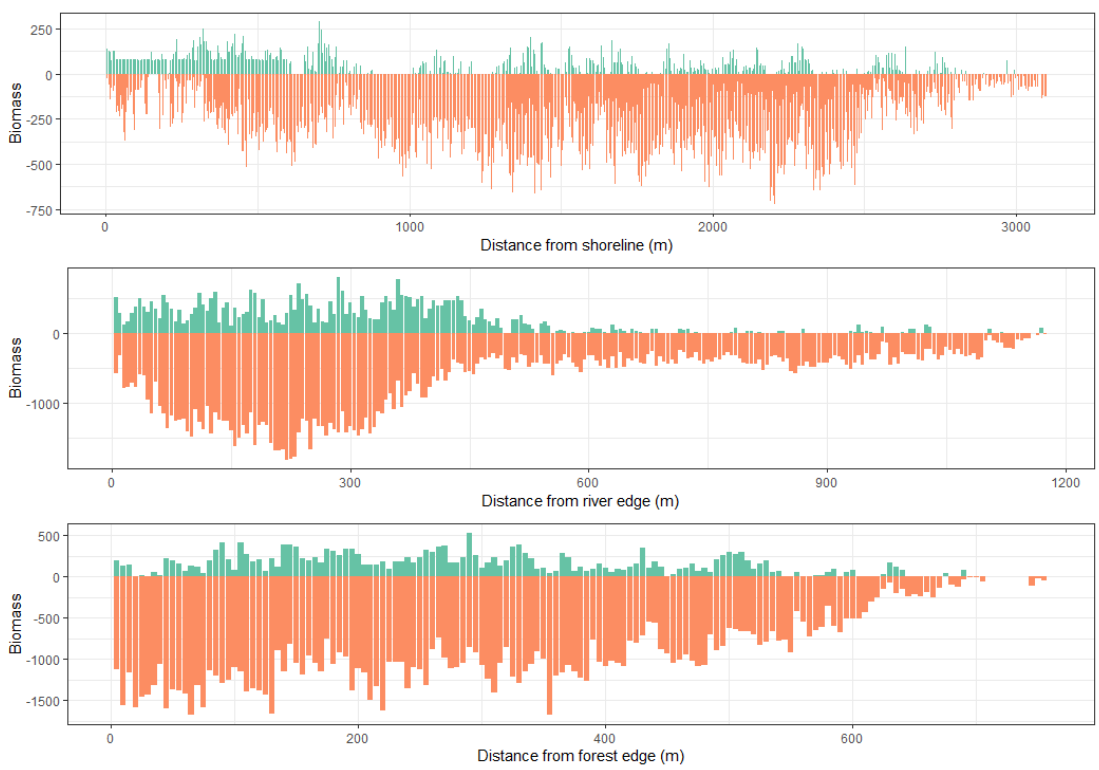


Figure 8.8 Biomass changes along different edge types

8.4. Discussion

8.4.1. Interacting drivers of change: Firewood harvesting and tropical storm impacts

Large scale tropical storms or small-scale harvesting practices can alter vegetation structure and composition to varying extents. But studies highlight that associated environmental drivers such as wind, rain, light availability, storm surge, and sedimentation processes are the stressors that determine the extent of damage to the ecosystem (Krauss and Oswald 2020). Moreover, historical accounts suggest site variability, tropical storm type (wind intensities), and species composition greatly influence outcomes during tropical cyclones, particularly species susceptibility to change and post-storm recovery. During Cyclone Nargis, a category 3 storm, mortality was much lower for some species such as *Excoecaria agallocha*, *Sonneratia caseolaris*, *Heritiera fomes* and *Avicennia officinalis which showed >85% survival,* while others like *Bruguiera sexangula* and *Rhizophora apiculate suffered >90% mortality* (Aung et al. 2013). Similarly, mangrove species in the family Rhizophoraceae (*Rhizophora* and *Bruguiera*) were found to be more susceptible to tropical cyclone effects than families such as Avicenniaceae, especially for old world mangroves (Woodroffe and Grime 1999). *Avicennia* is found to sprout readily because of their epicormic roots which may be the reason for its rapid recovery post storms. Similarly, Dutta et al. (2015) document that tropical cyclone impacts were more dependent on the cyclone trajectory and size of the incoming storm which determined the extent of damage to mangroves of Sundarbans in India and Bangladesh. Between 2007 and 2009, three Cyclones (Cyclones SIDR with wind speeds of 46–212 km h^{-1}, Reshmi with wind speeds of 46–83 km h^{-1} and Aila with wind speeds of 37–111 km h^{-1}) impacted <10% of the overall forest spatially with major structural changes in very small areas of the forest. Similarly, tidal flow plays a significant role in changing the amount of saline water influx during storm surges. In southwestern Florida, researchers observed that storm surge and trapped seawater not wind ultimately caused the trees to die post Hurricane Irma (Lagomasino et al. 2021). So, trees survived in places where salty ocean water brought in by the hurricane was able to drain.

Similarly, for the same study region, Rasquinha and Mishra (2021a) document that species dominance and variability differ between harvested and non-harvested sites. They found forest sites where harvesting was common, were largely composed of a mix of species types, dominated by the presence of large diameter trees of *A. officinalis* and *Sonneratia* sp., whereas non-harvested areas exhibited a strong presence of *H. fomes* and *E. agallocha* at all sites. They also document the presence of mangrove associates like *Pongamia pinnnata* and *Sapium indicum* were more in harvested than non-harvested sites. The ABM did not assess change in species composition to understand how harvesting might impact species-biomass allocations at localised scales, but the overall loss in biomass was negligible. This could be an artifact of regeneration rates used in the model, which may differ based on species type, further highlighting the role of species level differences in biomass change.

8.4.2. Changing social dynamics

The agent-based model also tried to capture how social interactions (group size) impacted foraging efficiency (time taken to forage) and biomass levels during firewood extraction. As the study region is part of a national park where extractive activities are prohibited/ regulated, social dynamics (reflected using group size) highlight how people relate to the forests through their social interactions with other households. People harvest in groups which helps them maintain social interactions or networks in the community but also provides them a safe space for conversations, and knowledge sharing. Although we do not find a change in time devoted to harvesting with increasing group size or much change in the amount of biomass extracted, our initial prediction that time and effort required to forage decreases with group size stands defeated. This indicates that although social cohesion is enhanced during these harvesting trips, it does not impact the forest biomass change to a great extent. Of note, however, is how firewood harvesting changes biomass values of mangrove vegetation. The model shows that overall, the change in biomass is minuscule along the edges, and it does not change forest biomass levels to an alarming extent.

8.4.3. Relation of salinity and species composition in influencing biomass levels

A number of studies document freshwater input and increasing salinity levels as an important driving factor influencing mangrove vegetation health (Mitra et al. 2021; Samanta et al. 2021). For the Sundarbans, Rahman (2020) documents the changing species composition levels with loss of some mangrove species (i.e*., Heritiera fomes, Nypa fruticans, Phoenix paludosa*), due to increasing salinity. Similarly, other studies show mangrove patches with regular intermittent freshwater input exhibit moderate deterioration in health despite high salinity levels (Mitra et al., 2021). High salt stress can result in stunted growth, reduced physiological functioning, and degradation of forest cover in several places. It can also change species-genus composition, especially towards more salt tolerant species (Chowdhury et al. 2019; Samanta et al. 2021). For example, freshwater-loving mangrove species such as *Heritiera fomes, Nypa fruiticans, Xylocarpus sp., and Sonneratia caseolaris* are documented to be widely diminishing and being replaced by more salt-tolerant species like *Ceriops sp., Avicennia sp., and Excoecaria agallocha*. The change in species composition can result in a net loss of species biodiversity which can ultimately impact biomass and carbon levels of the forest.

8.4.4. Impact of edge dynamics on species composition and biomass levels

The differential impact of edges on forest biomass has been documented by several studies across the world. For example, a study conducted in Tanzania demonstrated a negative correlation between mangrove soil carbon values with increasing seaward distance, while they found no significant relationship between aboveground carbon values (de Jong Cleyndert et al. 2020). While Son et al. (2019) document an increasing trend in biomass of *A. marina* with increasing distance from the coast, attributing the salinity gradient in determining biomass characteristics of this species.

These differences maybe because of the synergistic effect of biotic and abiotic drivers, which influence structural attributes of the vegetation but also the structural complexity of the forest patches. For instance, the structural heterogeneity arising from different patch shapes and sizes may also be responsible for the variable biomass values along rivers and creeks (Koontz et al. 2020). Complicated shapes mitigate tidal wave action better as curvilinear boundaries weaken wave energy more efficiently (Kamali and Hashim 2011). A complex structure also possesses a larger perimeter and narrow lobes. In the process, enhancing dispersal mechanisms by increasing interactions with adjacent patches and survival of mangrove seedlings (Forman 1995; Lester et al. 2007; Kamali and Hashim 2011).

While an array of ecosystem services and functions provided by these forests may be compromised with increasing fragmentation stemming from LULC transitions (Satyanarayana et al. 2013; Bosire et al. 2014), fragmentation can also change edge area dynamics in fringe mangroves. As fragmentation increases, the edge area also increases. As these forests serve as nurseries for a variety of terrestrial, marine, and estuarine fauna, a high edge-to-area ratio increases the risk from predation and increases potential for changes from environmental drivers like tropical storms (Skilleter 1996; Della et al. 2011). Further, with increasing fragmentation, studies have shown greater gaps in canopies of mangrove forests as well as short statured trees, skewed tree-diameter distributions, and spatial clustering of patches (Bosire et al. 2014; Blanco-Libreros and Estrada-Urrea 2015). Gaps caused by wind penetration and desiccation along forest edges may further result in increased mortality among large trees changing forest structure through canopy height changes, and ultimately impacting biomass levels (Briant et al. 2010; Laurance et al. 2011). The interacting effects of increased light availability in gap dominated edges may also impact species competitive ability by influencing seedling recruitment, ultimately influencing species composition (Yamamoto 2000; Meurant 2012).

Similarly, the establishment, dispersal, and abundance of exotic and invasive species may also be exacerbated in a fragmented landscape (Aguirre Acosta et al. 2013; Waddell et al. 2020) through both biotic and abiotic processes. These may include external pressures from grazing, logging but also diversity and distribution of native species, which may directly interact with the competitive ability of invasive species (Liu et al. 2018; van Kleunen et al. 2018). For example, Zhang et al. (2021) document that small mangrove patches with large edge proportions and regular boundary shapes are more susceptible to salt marsh invasion than mangrove forests with large sizes, small edges, and irregular boundary shapes in China. Similarly, the interacting impacts of edge effects and abiotic factors like tidal range, salinity levels, and local temperature changes may also enhance changes in species composition and structure, ultimately changing carbon dynamics in these forests.

8.5. Conclusion

We combined theoretical and empirical estimates of biomass change using field vegetation data, social interviews and surveys, and two different modelling techniques (agent-based and gradient boosting model) to understand mangrove vegetation dynamics in Bhitarkanika, India. Our agent-based modeling results convey interesting insights on how the interacting impacts of firewood harvesting and tropical storms can change mangrove vegetation biomass in the region and its impact on local community dynamics. Similarly, biomass changes for the last seven years (2011 to 2020) provide further insights on how spatial variability in biomass change is crucial for understanding mangrove vegetation composition and health. Further, species levels change in biomass also highlighted how interacting drivers like tropical storms and firewood harvesting can work at two different scales to influence ABG biomass of mangrove vegetation.

Although Bhitarkanika has a high human population density, it has not been transformed much in terms of the total areal extent of the mangrove forest. However, this study demonstrates a decline in vegetation biomass and carbon content along several parts of the forest. Interestingly, the declines in biomass values are spatially variable across different forest parcels showing high signs of forest fragmentation along the core as well as forest edges. The different stressors that may be responsible for this pattern may range from a number of abiotic and biotic drivers, including forest dependence in the form of harvesting but also salinity levels and freshwater input.

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CHAPTER 9
CONCLUSIONS

In this section, I will summarize the key takeaways from each chapter, providing recommendations for future research in this region, broader theoretical underpinnings of this work and the policy implications of my findings.

9.1. Mangrove forest degradation and its implications for blue carbon

This section analyzed the individual impacts of disturbances on mangrove vegetation dynamics and blue carbon across multiple sites in the Indian subcontinent. We focused on tropical storms and extraction for fuelwood as two driving disturbances operating at different scales on mangrove forests in the country. Our key findings suggest an overall increase in GPP over the last two decades across seven sites along the west and east coast of India. This increase was found to be intricately connected to tropical storm events through seasonal fluctuations in nutrient and freshwater inputs. While our results provide insights on how mangrove productivity may change with fluctuating frequency and magnitude of cyclones under a changing climate, it also highlights how different mangrove species may respond to this change. In Bhitarkanika, mangrove species like *Avicennia marina* (12.52 g C MJ^{-1}) and *Sonneratia alba* (7.28 g C MJ^{-1}) were found to have the highest values of photosynthetic rate and LUE (corresponding to high GPP values) during post-monsoon/winter periods whereas *Excoecaria agallocha* (6.17 g C MJ^{-1}) in summer. How species perform post storms can provide insights on their ability to recover after a storm event and help with restoration activities in the region.

Similarly, our findings on the impact of fuelwood harvesting on mangrove forest dynamics, and blue carbon stocks in Bhitarkanika further reinforce the role of species in determining the trajectory of mangrove forest stands post disturbances. Although, we found blue carbon stocks to be lower in harvested forests than non-harvested forests, fuelwood harvesting was both species-and size specific. We found species composition and structural characteristics of trees to vary between harvested and non-harvested sites. In non-harvested sites, *Exoecaria aggalocha* and *Heriteria fomes* dominated, whereas *Sonneratia apetela, Sonneratia caseolaris, Avicennia officinalis* and mangrove associates formed a large proportion of harvested mangrove forests. However, large DBH size-class trees were found in harvested areas implying selective cutting practices that conserved old-growth trees and contributed to larger mean carbon pools.

9.2. More than blue: Mangrove ecosystem services, values, and priorities

In this section we look at the concept of value in the context of blue carbon systems and investigate how these change across a range of local and extra-local actors. First, by adopting the Q-methodology we looked at how values, priorities, and motivations of local actors (community members living near protected mangrove forest areas) differed from extra-local actors like scientists, non-profit and state government officials towards mangrove forest conservation and management. Our results highlight three different narratives that describe the value-preference paradigm in Bhitarkanika Wildlife Sanctuary—livelihood security, conservation value and sense of place. These narratives highlight how different actors value and prioritize distinct aspects about mangrove ecosystems. To illustrate we found local communities to value the storm protection service of mangroves to a great extent, but their priorities were most aligned with both current and perceived quality of life attributes and with their sense of place, whereas other actors like non-profits or researchers placed a high importance on mangrove ecosystem services emphasizing their conservation value which also drives the management of these forests here and elsewhere. We also found each of these narratives to be influenced and divided between genders enforcing that management decisions need to be sensitive to the differential impact on marginalized genders and communities for effective and just outcomes. Our local case study also highlighted the dwindling role of mangroves in providing provisional services to local communities as popularly perceived in scientific literature and used as one of the primary factors for conserving these forests.

These discrepancies were further accentuated when looked at global perspectives on mangrove conservation narratives using social media data from Twitter between 2019-2021. Overall, we found users to express positive emotions towards several aspects of the mangrove ecosystem but a lack of engagement with reciprocal relations between local communities and mangrove forests. However, on further introspection we also found “carbon” to be the predominant narrative (most repeated word) among the analyzed tweets. The spatiality of the analysis also highlighted that the majority of these tweets came from countries in geographically apart and culturally distinct locations from mangrove habitats. Our results portray the nuances that differentiate conservation values which are influenced by mangrove policies between global and local actors and highlight the need for local, context specific policies towards the management and conservation of mangrove forests.

9.3. Blue communities: Gender and resource access in mangrove protected areas

In this chapter, we look at the socio-material transitions that impact marginalized communities or, and genders and its impact on blue carbon policy. We use the theory of access (Ribot and Peluso, 2003) to further the argument that forest dependence is related to cultural and social structures where intersectionality of several factors—gender, caste, history, social identity and status dominate how benefits are derived, which values are prioritized and how conservation motivation develops among local actors. The study also looks at how past and present uses of mangrove forest products have changed or continue to change with different policy interventions. By especially focusing on firewood use and dependence and understanding the role of access to forest products and [access to] interventions, it highlights how forest reliance determines blue carbon forest conservation. The results highlight the role of women as collectors and rational decision makers of continued fuelwood use. Their role is dependent on a number of factors, a. they are less bound to face severe repercussions from authorities when caught foraging for firewood, and b. they are bound by social and cultural preferences and responsibilities that determine the continued reliance on mangroves for fuelwood. While men seem supportive of alternative fuel choices, these choices do not necessarily determine ground realities, furthering the burden of conservation on women.

9.4. Coupled-human mangrove interactions

In this chapter, we looked at the cumulative impacts of tropical storm events and small-scale cutting practices on mangrove biomass by both modeling and quantifying this change spatially and temporally. We also looked at community social dynamics to understand how mangrove forest-social relations are intertwined with mangrove biomass. In this study we show that biomass changes occur largely along mangrove forest edges with biomass accumulation in forest interiors, indicating the role of salinity at the landscape scale in influencing species composition in the region. Species composition plays a significant role in understanding the losses and gains to biomass in fragmented forests especially when considering human-mangrove interactions. We found that certain species (*Avicennia, Sonneratia and to an extent Exoecaria*) do well in the light of disturbances, but that changes with spatial location. For example, *Exoecaria* does well where freshwater influx is steady. We also used an agent-based model to understand how communities make choices to harvest forest patches and if these choices were correlated with high/low biomass patches. We found that communities on an average, harvest patches with low to intermediate biomass levels in all our runs. Similarly, we found that group size (a proxy to understand if forest resource use is correlated with increased interactions between households) doesn't have an impact on time or biomass harvested. Finally, the results also provide insights on mangrove forest restoration especially the significance of spatial variability in AGB change which is important while considering where afforestation can be directed, and which species may perform and recover better in the targeted areas.

9.5. Way forward for blue carbon in the Indian subcontinent

The blue carbon wave is fresh and thriving but directing it into the right channels can enhance conservation outcomes. A series of mangrove plantation drives across the country's coastline has ensured a steady increase in mangrove plant cover (Das, 2020). However, many studies have reported that this new growth is not able to survive or perform the same ecological functions as old growth forests (Das, 2020). Mangrove afforestation is the need of the hour but so is continued research to understand the long-term ecology of these forests. There is very little understanding about how these forests may respond to the increasing frequency of storms in the future. Our work shows that increasing intensity has momentary impact, but forests recover steadily when allowed to do so. However, this could change if the frequency of storms changes drastically or if the time interval between two high intensity storms is too small to allow for recovery. Similarly, by focusing on what local people value and prioritize rather than what people 'receive' from these forests can help design more effective solutions for management options. We reinforce this notion through our work on differences and similarities between how marginalized communities or genders, and other non-local actors converge on some (especially the storm protection value of the forests) but not all (livelihood security and quality of life) attributes. Future research can focus on how best to amalgamate these aspects about differing perspectives and what factors drive these differences for different mangrove sites. Similarly, marginalized communities and genders share an invisible burden of making rational choices on forest access and resource use on a day-to-day basis, for subsistence. For starters, as changemakers we need to change our perspective about forest dependence—from a relational to reciprocal interactions. Forests are providers but are also part of the environment where humans build a "dwelling". These relationalities may allow us to understand how connections can be strengthened for conservation.

9.5.1. Recommendations for mangrove ecology studies

Carbon credits rely on highly specific data of carbon assessments. At the moment, the infrastructure for continuous flux measurements of key carbon stocks through time are only available for a small area in the Sundarbans and the Pichavaram forest in Tamil Nadu. None of the other mangrove sites within the country have estimates of changing carbon assessments especially in the light of disturbances such as tropical storms. For example, a recent study noted that Pichavaram mangroves act as a modest carbon sink in the winter season and as a carbon source in the summer. Keeping these uncertainties in mind, and to increase our knowledge of the Indian mangrove ecosystem's structure and function, we must go beyond empirical studies toward a mechanistic understanding of their life history. One way of addressing these gaps is to invest in the establishment of a network of Flux towers across the country to develop long-term measurements of CO_2 fluxes at the soil-vegetation-atmosphere interface using the eddy covariance method (EC). EC measurements are useful in understanding how environmental controls such as climate, tidal activity and in turn salinity levels may interact with vegetation growth, productivity, and respiration at different times (hourly, daily, annually etc.), and scales (Barr et al., 2009). On the other hand, rates of net primary production (NPP) may determine if mangrove forests are able to keep pace with sea-level rise. This can help understand the important feedbacks between forests and the atmosphere, ultimately shedding light on the response of vegetation to the changing climate. These efforts could provide the improved understanding of mangrove ecology necessary to manage these forests at appropriate spatio-temporal scales and can be summarized as five key activities:

- Developing mangrove forest research and education field stations across the country.
- Increasing collaborations with national and local laboratory facilities and investing in laboratory capacity across field stations to conduct mangrove vegetation studies in the field.
- Training interested local communities in conducting field and lab research through accredited certification programs and appropriate compensation.
- Expanding open-source data sharing of mangrove research, deploying autonomous instruments and tools, and building research networks to collect and analyze mangrove ethnoecological data.
- Focusing scientific research surveys on mangrove vegetation in areas and at times where it is absent and where autonomous instruments cannot operate.

A combined effort across regional and local scales with local community stakeholders would provide the opportunity to integrate the generated data into novel models that consider both mangrove vegetation plot data in their biological and physical environment with global research efforts, enabling a holistic approach to ecosystem change research.

9.5.2. Recommendations for firewood dependence on blue carbon systems

While recognizing the need to reduce forest dependence for local energy needs, it is critical to understand that policies and technologies are needed for the entire spectrum of local energy needs. These may include preparing for large meals which are energy intensive, preferences for cooking certain curries or rice on *chullahs* or for keeping warm during winters. Similarly, fuel stacking is a reality of local communities which reinforces the idea that a complete replacement may not always be possible. Therefore, along with continued access to clean fuels like LPG, or promoting adoption programs like "Ujjwala," improvement in the frequent delivery of these fuels to households is also necessary. In a way also shifting to improved infrastructure like roads which can get obstructed during heavy thunderstorms and fail to supply demands or ensuring a steady source of power through maintenance of power lines. Finally, improved, or clean appliances like forced draft or pellet-based gasifier stoves, solar powered heaters, cookers, or water kettles can also provide alternatives to solid fuel consumption, reduce the exposure to air pollution but also help diversify available choices (Wathore et al., 2017; Jagger and Das,2018).

9.5.3. Recommendations for future research on blue carbon systems

Mangrove ecosystems provide both mitigation and adaptation benefits in the fight against climate change. Their conservation and restoration provide opportunities for corporate entities and governments to offset their carbon emissions through investing in mangrove blue carbon sinks. They also provide avenues for nations to incorporate plans to reduce their national emissions and adapt to the impacts of climate change, that is, towards their Nationally Determined Contributions (NDCs) to the Paris agreement. In this sense, the different chapters of this study contribute to different yet connected themes which can enhance nations efforts in conserving their mangrove blue carbon repositories.

Disturbances and carbon loss/gain

Although we find an increasing trend in mangrove productivity, our agent-based modeling results provide evidence that both trajectory of storms and wind speeds play a crucial role in influencing mangrove biomass loss. Based on the findings from this study, development of future studies should continue to assess how different disturbances such as tropical storms, marine heatwaves and rising sea-levels can impact permanence of the carbon stocks especially with the ongoing interest in blue carbon credits. For example, sediment supply can change mangrove recovery and resilience through upstream damming processes (Lovelock et al. 2015) which in turn can influence carbon sequestration rates. As these systems are highly dynamic, the uncertainty involved in carbon measurements is enormous (Adame et al. 2017). The carbon stored in this system is also a function of time and habitat connectivity. Therefore, more information on the variability in mangrove carbon stock and accumulation rates, and the factors driving this variability, to improve national blue carbon storage rates is necessary. Similarly, since large scale silvicultural practices across mangrove ecosystems are absent in countries like India, harvesting pressures need to be directed towards community owned and managed woodlots to encourage sustainable management of mangrove resources. Future research can investigate the feasibility of community managed woodlots for combating mangrove harvesting pressures especially near protected areas. Our findings also highlight the role of species diversity especially when recovering from disturbances and responding to changes in salinity or freshwater supply. Future research could focus on understanding which species can adapt to changing environmental gradients or which species combinations work well in the light of disturbances. Similarly, investing in models that build on traditional management practices can also provide crucial insights on management practices. For example, traditional rice-mangrove management systems such as those prevalent in Goa called Khazan lands provide opportunities for co-management in areas where rice or fish (or shrimp) farming is practiced (Kamat 2004). Finally, using a seascape approach based on the interactions between blue carbon habitats (mangroves, seagrasses, and marshes) provides a more holistic outlook towards understanding changes in carbon outflow and inflow processes.

Social justice in mangrove blue carbon policy and research

The latest IPCC report (2022) highlights that climate solutions that are feasible and effective conform to the principles of justice (AR6, WGII and WGIII). It recognizes that climate resilient development across the world is not equitably distributed. While echoing this sentiment, this study also shows that global disparities and inequities also manifest in regional and local levels. This study also provides evidence on how marginalized communities including genders face impediments navigating conservation and sustenance needs. It also highlights the disconnect between global, national, and local values towards mangrove conservation. The way forward for blue carbon research should not only be to acknowledge these disparities but work towards addressing them by using a gender transformative approach. By using a gender centric approach to understanding how inequities in climate change impacts, vulnerabilities as well as environmental decision-making manifest in local lived experiences provides opportunities to examine power imbalances across a wide spectrum of processes, structures, and relationships. An apt example includes that of climate gentrification (IPCC AR6) through poorly planned and implemented nature-based solutions. Therefore, research that identifies best practices but also opportunities to increase collaboration between community members, scientists and policy makers is crucial for successful blue carbon projects.

9.6. In continuation.

I started this dissertation asking, "how does mangrove vegetation dynamics, gender relations, and historical legacies of use interact and influence politics of [blue carbon] conservation in protected areas?" by looking at three connected themes influencing mangrove ecology, and the human and more-than human environment. I asked this question deliberately believing that "blue carbon" is an outcome of how vegetation grows, survives, and continues to thrive in the environment it dwells in (focusing on mangrove vegetation dynamics). Similarly, every time I posed the statement— "Mangroves are also important because they store lots of carbon, act as sinks and mitigate climate change", to gauge what local villagers thought I received a reluctant "Yes". But an enthusiastic "Yes" to how mangrove trees formed a crucial part of people's lived realities in the past. I encountered this lived reality to extend to subsistence needs, cultural preferences, and social responsibilities through fuelwood dependence. In this interconnected seascape of blue carbon, it became evident that marginalized communities and genders face impediments to access alternatives, not that they are resistant to change. While extra-local actors push for reforms or schemes (blue carbon credits) that may at the outset not seem exclusionary through its focus on compensation for forfeiting forest relations, how does one justify those schemes in the context of protected areas where exclusion is the norm? With these questions, I conclude this dissertation to stir thought and be hopeful that these questions continue to be voiced for just and equitable mangrove blue carbon conservation.

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CHAPTER 10
STRATEGIC COMMUNICATION

The following sections are included as part of the Integrative Conservation Ph.D. Programs strategic communication requirement. I've presented by research in creative ways, through the medium of storytelling, peer-reviewed articles, and educational kits. I developed a mangrove educational kit which can be used for K-12 science education. This kit was shared with interested educators during SciREN, an annual networking event that connects researchers and teachers. It is also freely available for download on my website. Other communication projects included gameday STEM booths to facilitate dialogue and interesting titbits with tailgaters at StemZoneUGA and through SkypeAScientist classroom interactions and presentations of my research. I wrote multiple creative articles providing an ethnographic account of my field site and as outreach material to communicate my research as it relates to the causes, measurements, and impacts of disturbances to coastal communities and mangrove ecosystems.

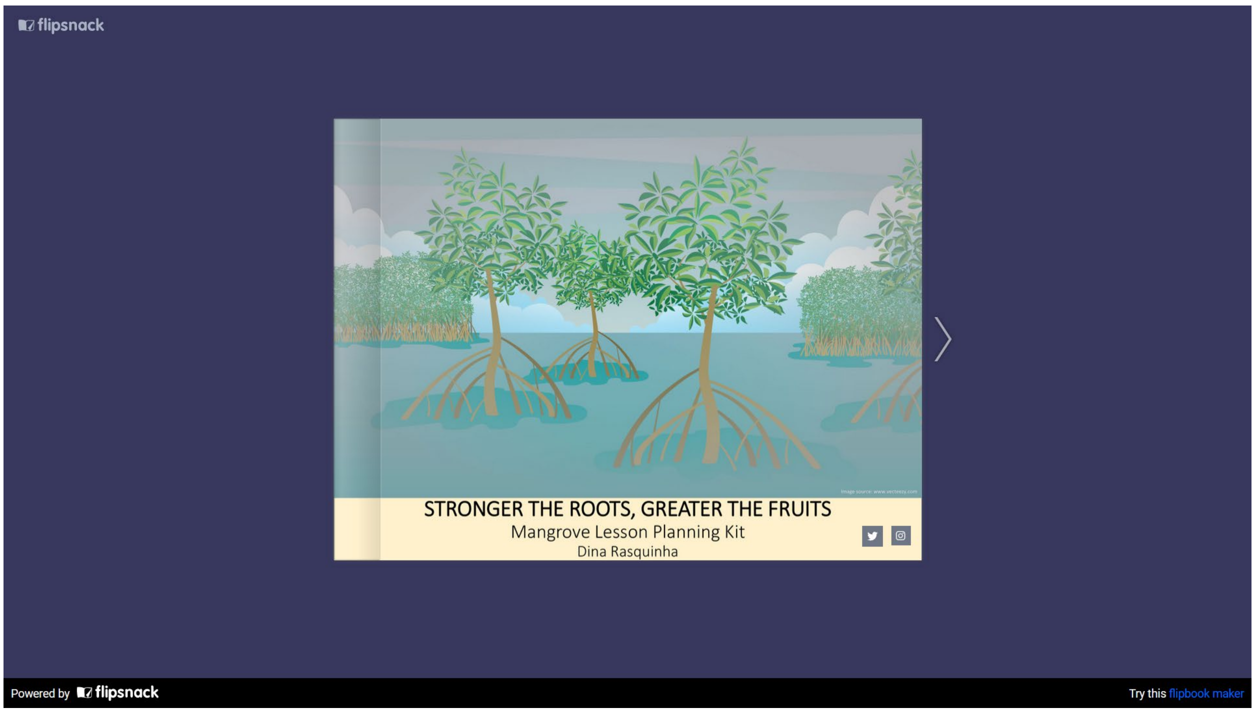
10.1. Mangrove Lesson plan

10.1.1. Stronger the Roots, Greater the Fruits[7]

I prepared a simple (not very fact heavy but still challenges students to think and reflect) lesson plan suitable for elementary students (Grade 1-6). The lesson kit includes a presentation alongwith three activities. Such as a mapping activity to understand the geographic location of mangrove forests, a playground activity that will help students understand the tangled root structure of these

[7] Rasquinha, D. Stronger the roots, greater the fruits. A mangrove lesson planning kit. https://www.flipsnack.com/drasquinha

forests which plays a unique role in trapping sediments and protecting our shoreline, and a classroom flashcard game which will help enhance student vocabulary on some of the plant's ecological adaptations along with the threats facing this ecosystem. The kit can be viewed here: https://www.flipsnack.com/drasquinha/mangrove-lesson-planning-kit-by-dina-rasquinha.html



Lesson Plan Information Sheet

Author(s):	Dina Rasquinha
Author Affiliation and Location (e.g. UGA, Athens, GA)	Department of Geography & Integrative Conservation Program University of Georgia, Athens, GA.
Author Contact Information (e.g. email)	drasquinha@uga.edu
Introduction/Abstract to Lesson Plan (max. 100 Words) Include aspects of the lesson that are unique and innovative.	The goal of this Lesson Plan is to familiarize students with mangrove ecosystems around the world, their unique ecological adaptations and threats to their survival today. This plan uses an experiential model where students will actively participate through games and learn about the role of mangroves in providing stability to our coasts.
List of Standards Addressed (This should be list of all full standards addressed by the lesson.)	
Learning Objectives using Measurable Verbs (what students will be able to do)	-Students will learn about mangrove plant adaptations. -They will develop an understanding of global mangrove distribution -They will also learn about mangrove benefits -They will understand threats to mangroves
Appropriate Grade Levels	Grades 1-6
Group Size/# of students, activities are designed for	Variable
Setting (e.g. indoors, outdoors, lab, etc.)	Indoors and outdoors/playground or open space

Approximate Time of Lesson (Break down into 20-50-minute periods)	20 mins Presentation 20 mins for Flashcard Activity 50 mins for Playground Activity 20 mins for Mapping activity
Resources Needed for Students (e.g. scissors, paper, pencils, glue, etc.)	Color pencils/crayons
Resources Needed for Educators (e.g. blackboard, PowerPoint capabilities, etc.)	Projector Blackboard/whiteboard, Dice Lesson kit
Apps/Websites Needed	NA
Lesson Activity (step by step description of activity)	1. The Educator should discuss the provided presentation with the students explaining the described content. 2. Once the presentation has been shared with the students, they can begin with the Mapping activity. The activity is created in a way that students can use the map as a coloring worksheet to fill the areas demarcated for coloring. These areas are where mangroves are found around the world. There is also a separate map provided for North America. 3. Playground Activity: This activity requires an open space such as a playground. It can be played in multiple smaller groups if there are many students (more than 20). For a small class, students should be divided into three different groups. a. Group size for each group (It can vary depending on the number of students)

	1.Group 1: Mangrove Roots| Size: As many as possible 2. Group 2: Humans/Human property| Size: 1-2 3. Group 3: Mangrove threats | Size: 2-3 4. Group 4: Mangrove Propagules | Size: half of Mangrove Roots b. Game description First scenario: The group Roots will form a circle joining hands with other Root members. A member/members of the group Humans/Human property will be inside this circle. Group members belonging to Mangrove threats will now try to break the circle to enter and get to Human property signifying destroying it. Once a hold is broken, it cannot be restored. Group Threats must break every hold in order to enter and destroy Humans/Human Property. But Mangrove roots have a secret weapon, those are Mangrove propagules. They can seek their help when the first hold is broken. Each Propagule can replace the hold that was broken but it is weaker than its predecessor, hence a gentle touch is enough to break the hold between a Propagule and a Root. The Root group can use any strategy they wish in order to protect their Humans/Human Property. The first as described could be a simple circle formation, but subsequent turns can be different. To illustrate, Root members can cross their arms and join one arm with one student and the other with another student and so on. They can also take different positions to adjust for height or make

	multiple circles. The only condition is that all the students must be connected to another student enclosing a member from the Humans/Human Property group. The teacher can time how long it takes for the students to break the hold. Alternatively, the number of Mangrove Roots can be reduced as well to see how fast the breaks are broken. Reflection The teacher can discuss after the game about the stability and strength of mangrove roots, how they protect our coasts in a similar fashion using their unique tangled network structure. 4. Flashcard Activity This activity is based on the Tornado Cards game. Here, we will use the provided flashcards. Students can be divided into two teams for this activity. The cards have pictures of different mangrove root and leaf adaptations as well as threats on one side and numbers on the other. The teacher can stick the numbered cards on the whiteboard with the pictures facing the board and the numbers the students. Students can choose a number among the cards displayed. They must explain what the picture represents. If they answer appropriately, their team can draw a tree. If they happen to choose a card which has one of the threats, then the other team gets to erase the tree drawn by the opposing team. The first team with maximum trees wins. Reflection

	This activity can be used as an assessment tool to evaluate if the students have followed the presentation. It also provides an opportunity to understand how a threat can destroy a mangrove tree.
Final Product/Assessment (e.g. quiz, presentation, essay, etc.)	Students will learn through the process of experiencing and reflection.

10.2. Dispatches from the field

10.2.1. Fantastic creatures and where to find them[8]

"We don't go alone into the forest because there are crocodiles."

The woman states this while she stirs fragrant, crispy *mudi,* or puffed rice, on a wood-fired *chullah*. The walls of the hut were lined by mud, barely four feet tall and covered with a thatched roof. My field assistant and I crouched down to catch a glimpse. A glimpse to see how each rice kernel popped into a plateful of deliciousness. A few drops of freshly squeezed lime, some chilli powder and chopped onions. That's what you need to transform these crisp pops into a tasty snack, she instructed. The kind lady packed us some too.

[8] Published as Rasquinha, D. 2020, 'A tale of the misunderstood crocodile', Current Conservation, Vol 13, Issue 4. Reprinted here with permission of publisher.

Another day, another acquaintance.

A man recounts his encounter with a fascinating beast. “While I was fishing by the river, a crocodile attacked me out of nowhere. I somehow managed to escape unhurt.” Do you encounter crocodiles often? “They don’t come to us and attack us, but there are lots of crocodiles here. You’ll mostly find them resting alongside the *Hental-ban* (*Phoenix paludosa* forest). They often come into our ponds and eat our fish and shrimp.” The mangrove palm is also preferred by the locals for basket and mat weaving.

“Did you know the Forest Department *breeds* crocodiles here?” A concerned old man explains how the number of crocodiles in the vicinity are increasing because of the in-situ conservation efforts of the Forest Dept in the region. He is aghast at these efforts. He doesn’t understand why the Department invests resources in increasing the number of crocodiles. Crocodiles that eat their fish! Crocodiles that sometimes even harm them!

Bhitarkanika harbours the saltwater crocodile (*Crocodylus porosus*), the largest species of the crocodilian family in the world. Although presently this species is at a much lower risk of extinction, the ‘70s was a grim decade for all three crocodile species found in the country (the freshwater species *Gavialis gangeticus* or the gharial, and *Crocodylus palustris*, also known as the Indian mugger). Commercial killing and habitat loss were two major reasons that pushed these creatures to the verge of extinction. A UNDP-Indian government-FAO-led collaborative effort sowed the seeds of crocodile conservation in the country and established several crocodile breeding and rehabilitation centres. Since then, the Odisha Forest Department has continued these efforts through their “rear and release” approach in Bhitarkanika under the *Baula* Project (Odiya term for saltwater crocodile). The eggs of crocodiles are carefully collected from the wild and incubated for 60-70 days. The hatchlings are reared to grow till about a meter-and -a-half long when they can fend for themselves. Soon after, they're released back into nearby creeks and estuaries.

Every year, the Park is shut to visitors during the annual crocodile census scheduled in the first week of January. It's good earning time for some villagers, especially those who possess boats. A full day's wage can fetch villagers anything between INR 350 and 1000 for their services. According to news outlets, this year, officials reported about 1742 individual crocodiles. This is a marginal increase from the 1713 individuals reported in 2018.

Figure 10.1 Photographs of crocodiles from Bhitarkanika. Image credits: Dina Rasquinha.

Bijaya Kabi, the Director of APOWA, an NGO that been working in this region for decades, explains that occasionally, villagers may blame these oblivious creatures even without suffering any physical harm from them. Their discomfort is understandable in some way, however. They frequently encounter this species that enjoys a fearsome reputation among the masses. They don't understand the importance of in-situ conservation measures practised by the Forest Department staff, because they don't benefit from these efforts in any way.

Crocodiles and humans share a bittersweet relationship in this region, much like other places in the country. The crocodile frequently features in Hindu mythological stories.

The most popular of them all is a story of salvation, where Lord Vishnu had to descend from Heaven to Earth to rescue the elephant king Gajendra from the clutches of this aquatic beast. The elephant struggled for over a thousand years to free itself from the crocodile's powerful hold, finally resorting to divinely assistance.

During my time with the villagers, many narrated this tale explaining why they keep away from the infamous fearsome crocodile. It was also interesting to know how some felt keeping away was better than simply troubling the creature.

"But the tourists don't understand," the Forest Guard explained. "There are signboards everywhere, but they still throw stones at them because they want to see them move." He jokingly emphasizes, "These lazy creatures just like to stay put in one place and soak up the sun. Is that too much to ask?

It's interesting how religion sometimes plays such an intricate role in influencing how people interact with wildlife. The Indian mugger, for example, is often seen as the vehicle of the river goddess Gangadevi. The depiction portrays a calm and benign presence of the creature rather than the usual fearsome and deadly representation of the reptile.

Figure 10.2. Kelaniya Ganga Devi. Flickr image, Image credits Anandajoti Bhikkhu

However, the large population density of crocodiles and humans in the region has made it difficult for both to keep their distance and live peacefully. A recent study reports that in the last

15 years, about 57 people were attacked by crocodiles in Bhitarkanika. Among those who were attacked, 27 lost their lives. The remaining suffered injuries, some major.

My interaction with the villagers, however, emphasized that people were more upset because they weren't adequately compensated for living in such close proximity to these stealthy creatures, oblivious of human-forest-water boundaries. Most felt the process to acquire compensation was tedious and non-transparent. It was a combination of factors, obviously. Wild boars frequently raided their fields and sometimes stole their goats; crocodiles sneakily stole their fish. Some strongly felt that if extracting firewood was a crime, they should at least be provided adequate compensation when they suffer losses from animal raids.

Interestingly, religious significance often overrides ecological significance in the country. Occasionally, both coincide beautifully and make for enriching stories. At other times, they don't. For instance, villagers value the mangrove forest, locally referred to as *Hental-ban* or Sundari-*ban*, for their ecological significance. The forest's ability to keep the shoreline intact, attenuate large waves, and provide a protective net against frequent storms is well known. In contrast, the ecological significance of the crocodiles is less clear. They are usually feared, at times revered too, but not for their important role in the river ecosystem.

These fantastic creatures that bask along riverbanks, soaking up the warm sun's rays, play a crucial role in the river food chain as the apex predator, much like the tiger. They help increase the general population of fish in the river by preying on predator fish that eat smaller fish and destroy fishnets. In fact, much of Odisha's intricate and artistic temple architecture displays this seemingly less popular ecological trivia. A stone crocodile is seen eating a fish in one of the carvings at the famous Sun Temple in Konark, Odisha.

Figure 10.3. Sculpture of a stone crocodile eating fish at Sun Konark Temple in Odisha. Image credits Wikipmedia Commons, Image credits SamhitaB

Similarly, the scavenging role in the ecosystem is almost never discussed. What keeps the river clean? The crocodile! They ensure carcasses decompose properly, keeping the rivers clean and healthy.

In this region, the crocodiles also play a very significant role in keeping mangrove forests healthy. Part of the government's efforts in reviving the species from the brink of extinction have made sure that *Phoenix paludosa*, a mangrove palm is part of the re-afforestation efforts in the park. The bushy and scrubby growth of the palm provides the perfect nesting habitat for the reptile. The reptile also creates a sense of fear and caution, keeping villagers away from deep forested areas. They only enter demarcated forest trails, always in groups to harvest firewood. Villagers also do not trouble the reptiles by destroying their habitat. If a nest is spotted, it is reported to the officials.

As you walk along the muddy roads in Bhitarkanika, you will notice ample green. Yellow-ish light green shade of the rice fields on one side, a dark dense green hue of the mangrove forest on the other. If you ask a villager where you can spot a crocodile, he'll point to both directions.

10.2.2. Muddy chronicles: When the tides out, the mud stays[9]

"Do we really need to collect this muck and bring back with us? Are you serious?!"

My field assistant was young, fresh out of college with an undergraduate degree in Geography with no prior field experience. She was here with me to explore, miles away from the comforts of typical city life. Little did she know about the exciting life of a grad student.

It was a sunny, cloudless day. The weather seemed perfect for some Field Spec measurements. We usually set out in the wee hours of morning. That way we didn't have to justify our need for boats when the tourists wanted to sight-see. An early start also ensured that we could board the only local bus in case we wanted to conduct village surveys. Our return rides were negotiated a day before with local auto drivers and on-demand bike rental services.

Some days we planned and some days we went with the flow. One field day, our village survey plans fell through when our usual auto-driver had to suddenly rush to town. Without him, we wouldn't have a return ride. And just like that, I decided to give this day a chance at some ecological data collection. A mix of activities usually kept our days exciting, and my assistant engaged. After managing the logistics and coordinating with my field assistant, we decided to

[9] Published as Rasquinha, D. 'Muddy chronicles: When the tides out, the mud stays', Fieldnotes. May 30, 2020. https://drasquinha.weebly.com/muddychronicles.html. Reprinted here with permission of publisher.

hitchhike on a tourist boat to record some observations, measure some trees and collect some mud.

Mangrove soils are tough bees. These trees stay put in the most turbulent areas. The ground they hold is tougher than you can imagine. If you've waded through one, you may have observed the dark grey clayey layer in which it bathes all day.

Figure 10.4. Photograph of mangrove mud and roots. Image credits Dina Rasquinha

The most fascinating aspect about this layer of slush is how it quickly disappears into the Earth's cradle when you wash it down. When dry, it is a hard nut to crack! I spent countless days pulverizing my soil samples in a wet laboratory where I tried to decipher its secrets.

Mud is the Earth's very own Pensieve, a gigantic memory box with millions of hidden secrets, each embedded in layers. We often pay very little attention to this space that's everywhere, just like trees. As trees stay fixed in the background, sometimes whistling with the wind, mud stays under our feet escaping our gaze until it clutches our feet. It's not just a background filler, but a complex mixture of nutrients and dirt that practically sustains the living world. Each layer (known as the soil horizon) is unique in its composition.

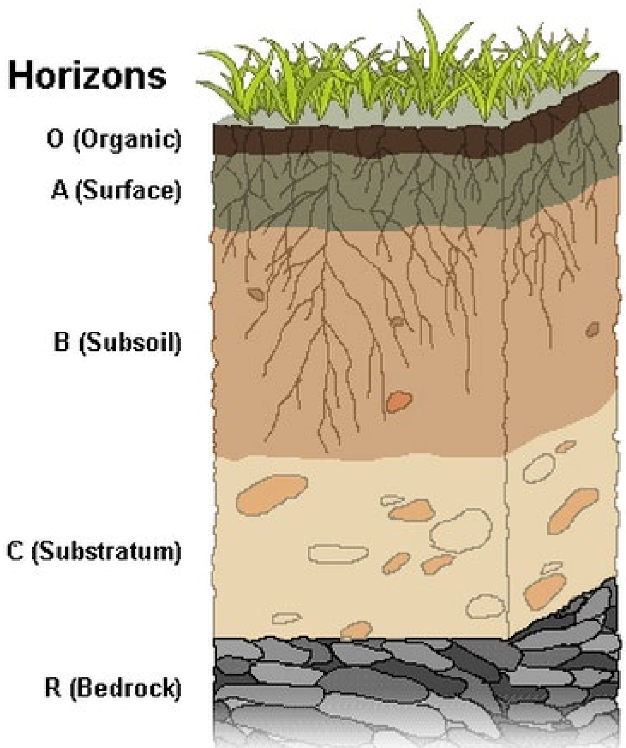


Figure 10.5.The different layers of soil. Image credit: Hridith Sudev Nambiar, shared under Creative Commons license.

The topmost layer (O) is also called the humus layer, consisting of mostly organic matter like decomposing leaves and other woody mass. The thickness of the O horizon varies in different soil types and the layer of organic matter decreases with depth. Mangrove soils are especially found to contain enormous quantities of plant litter and rich in organic matter in both their top and surface soils. The surface soil is rich in mineral content which is used by plants for their growth. The B horizon is generally a zone of accumulation where minerals, and other soluble salts and clay accumulate over time. The continuous influx of tidal water causes fluctuations in soil aeration levels, with lower layers of soils being more anaerobic, which means lacking in oxygen. Mangrove soils are generally poorly aerated which is also the reason for its dark color resulting from sulfides from the anaerobic processes.

What mysteries do these buried layers hold?

For one, by digging dirt that's under the bottom of lakes and marshy areas, scientists can decipher the past climate and shed light on disasters like hurricanes that have occurred. To decipher these mysteries, scientists usually dig cores to collect sediment (or dirt). A sediment corer, or an auger, is basically a hollow tube made of metal, which researchers push into the earth and then pull back out. What you get is a column or core of different layers of mud intact. The core can then be divided into segments to further study different natural processes and phenomena that have riled the earth's past. You know what? It's not just the past that's interesting to work out, but also what's stored in that dirt and how it influences our future.

Carbon is the future that mangrove soil has carefully preserved over the years…

One such interesting element is carbon. When we talk about carbon, our immediate reflex would be to think of vegetation and rightly so. All trees, through the process of photosynthesis, convert carbon in the air (carbon dioxide) to sugars and oxygen, and grow more green leaves and woody mass, like their trunks and roots where much of this carbon gets accumulated as the tree grows. Mangrove trees in fact are crucial in limiting our carbon levels by storing enormous quantities in their trunk and roots and thus acting as effective carbon sinks. They are found to sequester more carbon than any other terrestrial vegetation type, even rainforests. This carbon they store, along with seagrasses and salt marshes, is termed 'blue carbon'.

But mangrove mud can also store enormous quantities of carbon in its layers. Studies have shown this amount is roughly equivalent to billion metric tons. The carbon stays locked up in the soil until these forests are destroyed. Isn't that fascinating? Using lab procedures, scientists can determine this amount in the soil and then extrapolate it for a large area.

All this makes mangroves a significant game changer in the fight against climate change. It’s fascinating how an element that is literally the backbone of almost every biological molecule in this universe has finally become this entity that has gathered all the rightful attention it deserves. Alas, for the wrong reasons.

Memories of the mire

While we were sampling for this mud, villagers often looked bewildered. Some would wait patiently near the forest-road edge to make sure we got out just fine. Others would accompany us inside the forest and show us trails that were easier to navigate. We often got lost. So, having them around was reassuring.

I usually referred to the handheld GPS for directions as phone service was pretty iffy in this part of town. This one time both my phone and handheld GPS conked. We were deep inside the forest, a bit off from the main trail. Just me and my field assistant. In every direction were large dense trees, embedded in slushy, muddy ground with no end in sight. I started mentally preparing myself for ways to survive here in case we got stuck for a very long time. Did I know how to start a fire? Did we have enough food? Just snacks would get us by for another hour at the least. No, probably just another ten minutes because the stress was making us hungrier. Everything was wet and there was no way we could get a fire going. Plus, no dry ground to rest our tired bums.

We tried to stay calm. We also enjoyed the adventure but wouldn’t advise anyone to tread alone here. After many failed attempts, we finally stumbled upon a trail that led us to a large swath of open rice fields. A little further down, we spotted a mud house. We went inside to ask for further directions and inquired about handheld water pumps that we could use to wash our legs that were soaked in knee-deep-mud.

The woman noticed the zip lock bags we were carrying and asked us if there were crabs inside. She was baffled upon knowing it was “only” mud. She then looked at the sickle and our makeshift auger and asked my field assistant why we didn’t get any firewood?!

The women at my field site have a special relationship with this mud. Their sense of balance is admirably astonishing. If you’ve walked on a rice field filled with *KAdo* or mud, you’d know what I mean. If not, it’s as slippery as a marbled floor covered with soap water. The soles of their feet are often cracked just like the dry earth under their feet. Their toenails chipped, like delicately sturdy ballerinas. They slip through the gaps created by mangrove roots very easily too.

To them, the land underneath their feet is more than a provider for the firewood they collect to cook food and the rice they sow and harvest to earn a living. It's the material that shelters them. The place that connects them to their families, gives them a sense of comfort when their husbands and sons migrate in search of jobs. It connects them to the land, constant under their feet despite the battering from frequent cyclones. Their playful childhood wandering and working the secrets of the dense jungle, the camaraderie of village folk while toiling for wood.

It’s the memories they hold.

10.3. Research-Music-Poetry Collaboration

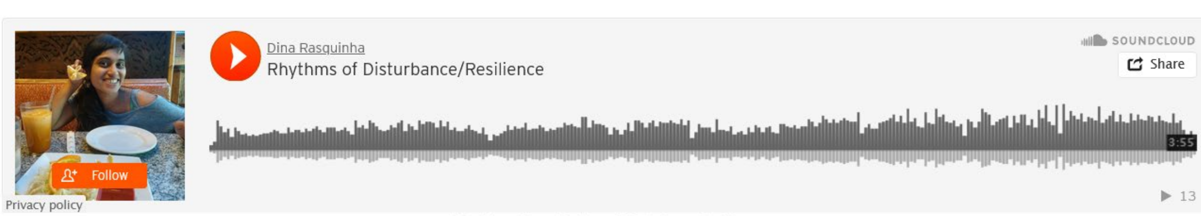
Rhythms of Disturbance/Resilience

In ecology, disturbance and resilience are often seen as two sides of the same coin. Ecosystems that experience moderate levels of disturbance are predicted to harbor more biodiversity and expected to be more resilient. Mangroves of my field site, Bhitarkanika are in fact known to exhibit the largest diversity of mangrove true species in the country. The region is also inhabited by a diversity of cultures—Odia, Bengali, and the many refugees that came here between 1961 and 1971 from Bangladesh. Added layers of religion, caste and gender further influence agency in decision making, land ownership and rights, as well as the level of state influence in changing the landscape. The rhythms of everyday life, intersect, with unequal positions of power across space and time, often transgressing the fuzzy boundaries of gender, religion, caste, and culture, just like the fuzziness between land-mangrove-water.

Through my poetry and a music collaboration, I wanted to highlight the intersectionality of human agency especially of marginalized communities—the diversity of voices in mangrove conservation that are underrepresented, silent or go unnoticed, the diversity of mangrove species—each with different levels of resilience, recovery time and regeneration and the stressors that make/break ecosystems.

The poetry and music try to encapsulate the rhythm of these systems by using different instruments that resemble how individual components are interconnected in an ecosystem. The forest struggles to maintain harmony, reflected through the increasing note intensities that resemble the myriad disturbances that these trees encounter. Similarly, women in my field who have direct interactions with these forests are entangled in cultural and socioeconomic norms which don't generally conform to ideas of conservation, but essentially live it through the choices they make each day.

Listen to Rhythms of Disturbance/Resilience



From mud

unfurls

sturdy networks

coiling toward

the sky

Swirls of

rising waters

engulf

interwoven tangles

Dampen, break, mould

with

the shifting sand

Waltzing with the moon

toiling through seasons

in mud

Roots exposed

bare fallen floating

moving upwards

moving forward

resilient

Research-Music Concert: Disturbance/Resilience

Scientist: Dina Nethisa Rasquinha

Composer: Kathryn Eleanore Koopman

Musicians

Guitar: James Matthew Terrell

Viola: Daniel Karcher

Violin: Alexis Rose Boylan

Tabla: Freeman Leverett

Percussionist: Andrew Blair

As part of the ICC 2020 researcher-composer concert, I collaborated with Kathryn Koopman, from the Hugh Hogdon school of music on Disturbance/Resilience.

Disturbance/Resilience translates the tangled networks that dominate mangrove ecosystems on the east coast of India. It resembles the different interactions that create a mangrove ecosystem. It draws attention to the disturbances (small to large, ecological, and human induced) that threaten a tree's identity. At the same time, it also signifies the resilience with which the disturbance is absorbed through sturdy root networks, and the dense weave of the forest.

The mangrove motive and its ecosystem

The "mangrove motive" is played by the guitar/viola/violin. Their parts sound tangled and interwoven like the roots of a mangrove tree. Even though their parts are different, they are intertwined and make the most sense when you have them all playing together. The tabla represents different types of disturbances the trees encounter, both human induced and ecological, and the "mangrove" motive responds to these different disturbances in different ways: sometimes it is hesitant and takes a while to lock back into a groove, while other times it is very confident in its resilience. The percussion plays environmental sounds to echo the space of the estuary, sometimes working in tandem and sometimes against the disturbances.

10.4. Poems on Mangroves

The Mangrove trees [10]

Every year

a swirl of the sea with gushes of wind

circles through

the shore

the giant waves carry away

[10] Rasquinha, D. The Mangrove trees. To be submitted to Coastal Shelf

sand, roofs, and people
tiny boats tied to fishing posts
are swept away with ease
giant boats tremble in the sea.
Before crossing through the
the network of walking trees
villages float, doorways submerge
under the rising seas
flooding gullies of meandering streams
filling shrimp ponds
and rice fields.
Now wading slowly
making its way to the interior villages
on the other side
of salt-loving trees
the trees, the trees
the salt-loving trees
with crawling roots, and buzzing bees
slow down the winds, the gushing sea.
The trees, the trees
the mangrove trees
say the villagers
are the reason they didn't flee.

The roots and branches that hold the ground[11]

They float on water

They grow in salt

They stand uptight through crushing waves & squalls

But sometimes they fall

When the tide seems too much to halt

Or the passage through land is covered with asphalt

mosquitoes swarm abound

fish, crabs, and skippers sway with the sound

in this world of grit so profound

of roots and branches that hold the ground

Through the dense weave on the floor

Spring new shoots that

Swim the shore

a rocky patch

a muddy flat pool

a place to chill

a place to cool

a spot secured

amidst the swirling whirlpool

The swooshes of the sea

[11] Rasquinha, D. The roots and branches that hold the ground. To be submitted to Storyweaver

on the floating trees

gather the birds and bees

rabbling in worry

the women hurry

without a sound

to gather bare necessities

on their crowns

Through roots and branches that hold the ground

They warn us

Not to stomp the ground

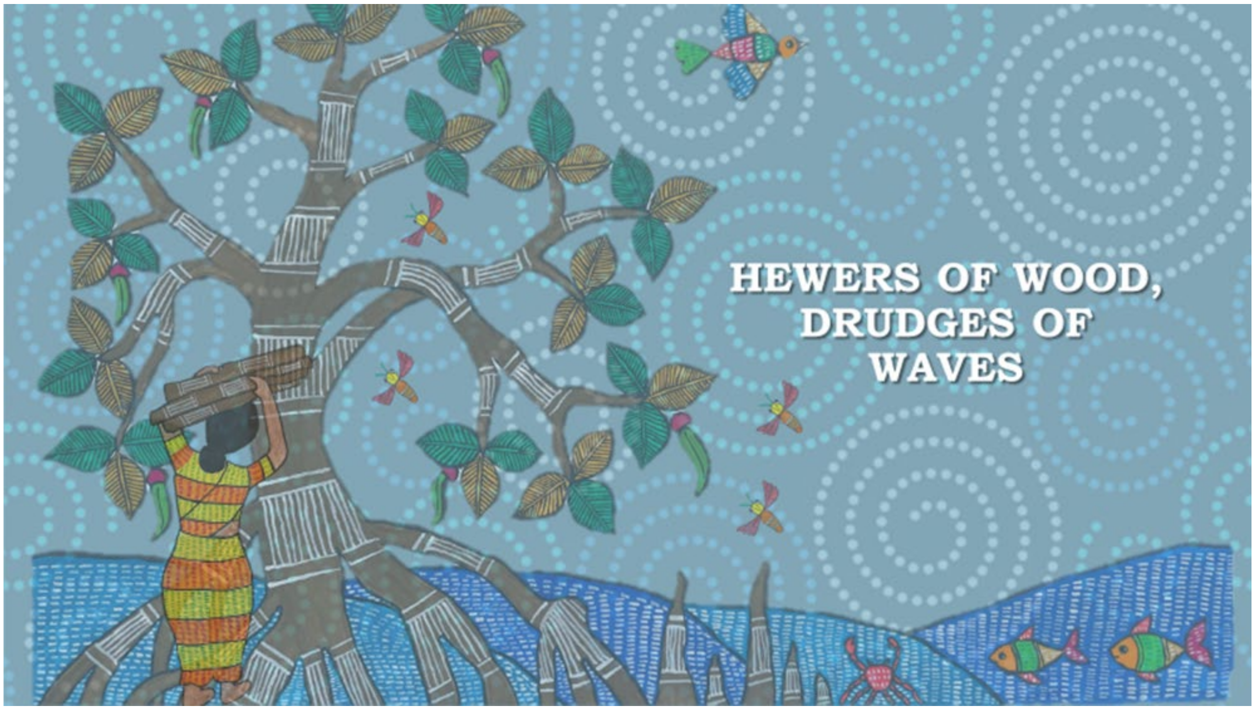
To disturb the home

of crawlies around

10.5. Mangrove illustration summarizing my research[12]

I collaborated with a good friend and artist, Rutuja Dhamale to illustrate my research in the form of art. She sketched the individual components (the woman, the bees, crabs, fish and the mangrove tree) of this illustration whereas I graphically edited the individual images, illustrated the dotted swirls to portray tropical storms and combined all the individual components together so that it reflects my research.

[12] Artists: Rutuja Dhamale & Dina Rasquinha


HEWERS OF WOOD,
DRUDGES OF
WAVES

APPENDICES

Appendix A

SUPPLEMENTARY INFORMATION FOR CHAPTER 3

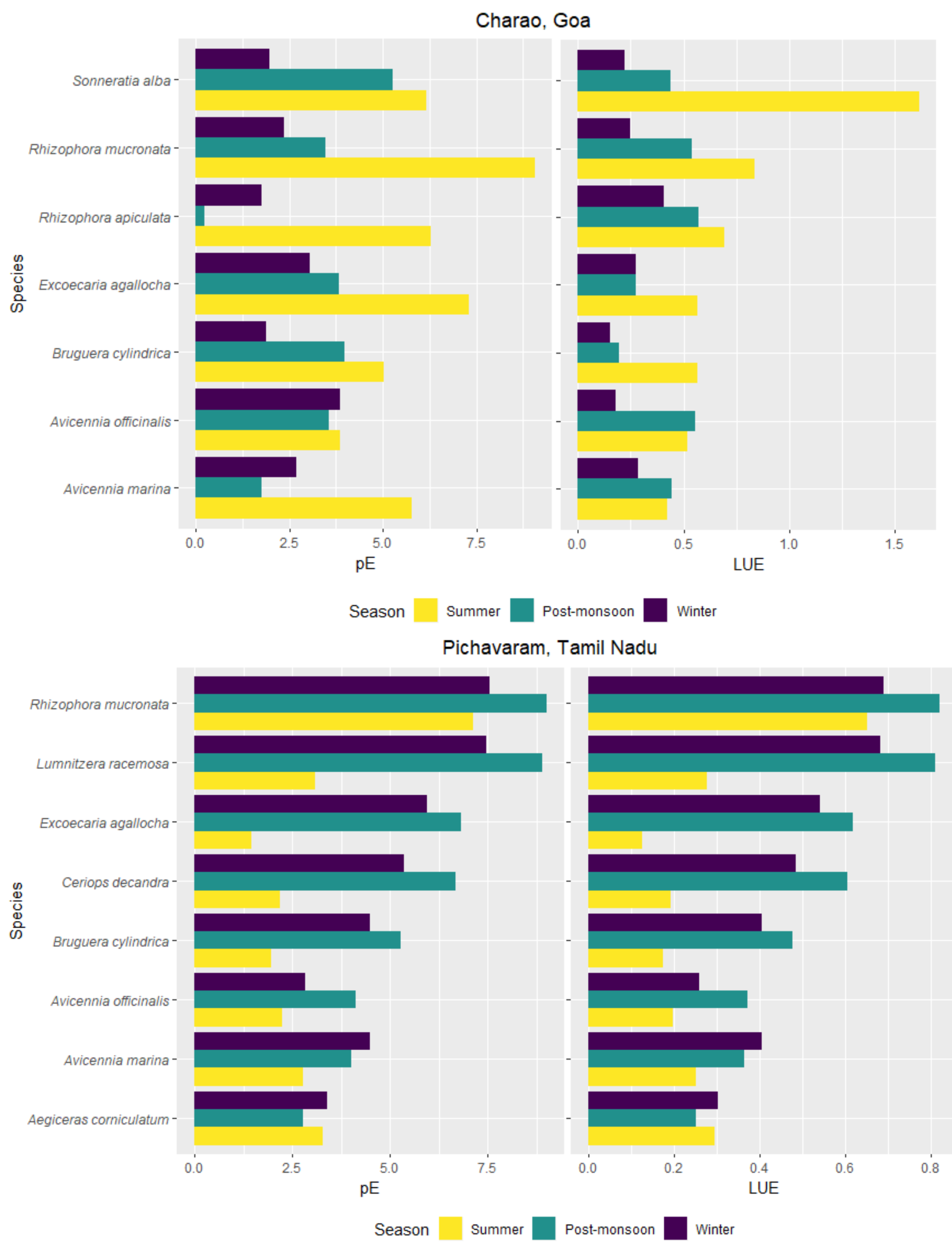


Figure A.1. Seasonal variation in daily carbon fixation in terms of photosynthetic rate (pE in g C m^{-2} day^{-1}) and Light use efficiency (LUE or ε in g C MJ^{-1}) in dominant mangrove species in Charao and Pichavaram

Appendix B

SUPPLEMENTARY INFORMATION FOR CHAPTER 4

Table B.1: Allometric equations used in this study. DBH- Diameter at breast height (cm), WD-Wood density (g/cm3) and H-height (m).

Species	Aboveground biomass	Belowground biomass
Aegiceras corniculatum	$\log(AGB) = 1.496 + 0.465*\log(DBH^2 H)$ (Tam et al., 1995)	$0.199 *WD^{0:899} *DBH^{2:22}$ (Komiyama et al., 2008)
Avicennia officinalis	$0.308*DBH^{2.11}$ (Comley and McGuinness, 2005)	$1.28*DBH^{1.17}$ (Comley and McGuinness, 2005)
Bruguiera sexangular	$0.186*DBH^{2.31}$ (Clough and Scott, 1989)	$0.199 *WD^{0:899} *DBH^{2:22}$ (Komiyama et al., 2008)
Rhizophora sp.	$0.1709*DBH^{2.516}$ (Putz and Chan, 1986)	$0.00698*DBH^{2.61}$ (Ong et al., 2004)
Xylocarpus mekongensis	$0.08233*DBH^{2.5883}$ (Clough and Scott, 1989)	$0.199 *WD^{0:899} *DBH^{2:22}$ (Komiyama et al., 2005)
All other species	$0.251 *WD*DBH^{2:46}$ (Komiyama et al., 2005)	$0.199 *WD^{0:899} *DBH^{2:22}$ (Komiyama et al., 2008)

Table B.2: Structural characteristics between harvested and non-harvested forest categories.

Parameters	Forest categories	
	Harvested	Non-harvested
Tree density (ha^{-1})	1522 ±587	3764 ± 1320
Average Tree Basal Area (sq.m/ha)	44.51± 20.87	43.23 ± 10.12
Species Richness	10	14
Species Abundance	233	676
H' (Shannon Diversity)	1.88	1.50
Cd (Simpson's)	0.81	0.68
J' (Evenness index)	0.35	0.25

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Appendix C

SUPPLEMENTARY INFORMATION FOR CHAPTER 6

Table C.1: Countries with the largest mangrove extent (Hamilton and Friess 2018), associated development indicators (data.worldbank.org and worldpopulationreview.com) and number of tweets posted between Jan 2019-Dec 2021.

Mangrove area rank	**Country name**	**Mangrove area (2012) (km²)**	GDP per capita (US$ for 2020)	Literacy rate %	% Living Less than $10/day	Number of tweets
1	Indonesia	23,324.29	3,869.6	96	83.31	3613
2	Brazil	7,674.94	6,796.8	93	39.66	721
3	Malaysia	4,725.84	10,412.3	95	10.14	821
4	Papua New Guinea	4,172.29	2,757.2	62	93.89	19
5	Australia	3,316.21	51,692.8	--	1.48	4623
6	Mexico	2,991.83	8,329.3	95	55.77	1516
7	Nigeria	2,653.99	2,097.1	62	98.76	1180
8	Myanmar	2,557.45	1,467.6	89	85.94	278
9	Venezuela	2,403.83	16,055.6	97	33.10 *	544
10	Philippines	2,064.24	3,298.8	96	84.34	916
11	Thailand	1,886.33	7,186.9	94	37.20	699
13	Colombia	1,671.86	5,334.6	96	55.80	503
14	Cuba	1,633.46	9,477.9	100	--	866
15	USA	1,568.60	63,593.4	99	2.75	12318
12	Bangladesh	1,772.98	1,961.6	75	94.42	503
16	Panama	1,323.94	12,509.8	96	26.94	151
19	Gabon	1,082.11	6,881.7	85	65.18	159

17	Mozambique	1,223.67	448.5	61	96.83	23
20	Ecuador	935.74	5,600.4	94	52.99	511
18	Cameroon	1,112.76	1,537.1	77	87.86	184

*Poverty rate for 2015. Data for less than $10/day not available.

Table C.2: Top 50 countries with highest number of tweets on mangroves between Jan 2019- Dec 2021.

ID	COUNTRY	NUMBER OF TWEETS
1	India	16015
2	United States	12318
3	United Kingdom	9535
4	Australia	4623
5	Canada	4050
6	Pakistan	3631
7	Indonesia	3613
8	France	3014
9	Kenya	1755
10	Germany	1618
11	Mexico	1516
12	Nigeria	1180
13	Philippines	916
14	Belgium	889
15	Colombia	866
16	Singapore	861
17	Netherlands	838

18	Malaysia	821
19	Sri Lanka	813
20	United Arab Emirates	802
21	Brazil	721
22	Thailand	699
23	South Africa	616
24	Switzerland	588
25	China	555
26	Venezuela	544
27	Jamaica	528
28	Italy	528
29	Ecuador	511
30	Bangladesh	503
31	Spain	492
32	Japan	470
33	Saudi Arabia	467
34	Belize	443
35	Tanzania	420
36	Uganda	402
37	Chad	389
38	Senegal	387
39	New Zealand	308
40	Madagascar	308
41	Sweden	302
42	Ghana	290
43	Myanmar	278
44	Ireland	259

45	Finland	222
46	Russian Federation	204
47	Cameroon	184
48	Gabon	159
49	Austria	159
50	Costa Rica	157

Appendix D

SUPPLEMENTARY INFORMATION FOR CHAPTER 8

Table D.1. Summary of structural characteristics of field data

Site	Field data collection period	Number of plots	Basal Area m2/ha	Max Height (m)	mean ABG (Mg/ha)
Bhitarkanika (Rasquinha and Mishra 2021a)	Sep 2018-March 2019	25	44.42	7.23	262.06
Bhitarkanika (Murthy et al. 2019)	Sep 2017-March 2018	20	28.47	5.79	1513.17
Andaman & Nicober islands (Ragavan et al. 2021)	Sep 2018 to May 2019	173	41.26	NA	469.2

Table D.2: Mean biomass change near edges

Category	Increase in biomass (Mg/ha)	Decrease in biomass (Mg/ha)
Shoreline	50.72	82.6
River edge	52.18	65.61
Forest edge	48.6	71.9

Table D.3a: Agent-based model runs for firewood harvesting

Group Size	Number of patches harvested	Biomass of patches before harvest Mg/ha	Biomass of patches after harvest Mg/ha	Biomass change Mg/ha	% change in biomass of patches harvested
1	238	733.47	571.29	162.18	22.11
3	347	721.74	513.17	208.57	28.9
5	343	720.77	510.04	210.73	29.24

Table D3b. Agent-based model runs for tropical storm impacts. Mean biomass of the entire mangrove forest region is estimated to be about 969.36 Mg/ha.

Total storms expected in a year	Storm event	Storm speed km/hr	Biomass loss Mg/ha
2	1	[331]	0.02
3	1	[132]	22.35
	2	[210]	26.03
4	1	[139]	25.17
	2	[265]	27.76
	3	[209]	49.47
5	1	[68]	23.66
	2	[180]	23.67
	3	[204]	24.49
	4	[271]	24.5
6	1	[115]	2.36
	2	[68]	6.13
	3	[349]	6.15
	4	[108]	31.41
	5	[36]	33.18
7	1	[133]	3.73
	2	[240]	6.99
	3	[84]	15.02
	4	[341]	15.04

	5	[194]	40
	6	[252]	41.40
8	1	[68]	8.91
	2	[160]	8.93
	3	[204]	17.98
	4	[200]	20.42
	5	[321]	21.38
	6	[133]	28.38
	7	[210]	32.53
9	1	[106]	25.98
	2	[57]	28.58
	3	[229]	28.59
	4	[125]	32.37
	5	[74]	33.14
	6	[211]	33.14
	7	[168]	33.26
	8	[81]	33.29
10	1	[246]	0.07
	2	[94]	1.86
	3	[182]	1.86
	4	[163]	6.1
	5	[51]	7.51
	6	[22]	7.51
	7	[187]	7.54
	8	[194]	14.93
	9	[25]	24.7
11	1	[8]	0.005
	2	[186]	0.01
	3	[223]	7.46
	4	[45]	7.62
	5	[224]	7.63
	6	[306]	16.47
	7	[242]	34.38
	8	[241]	44.25
	9	[156]	47.67
	10	[19]	56.67

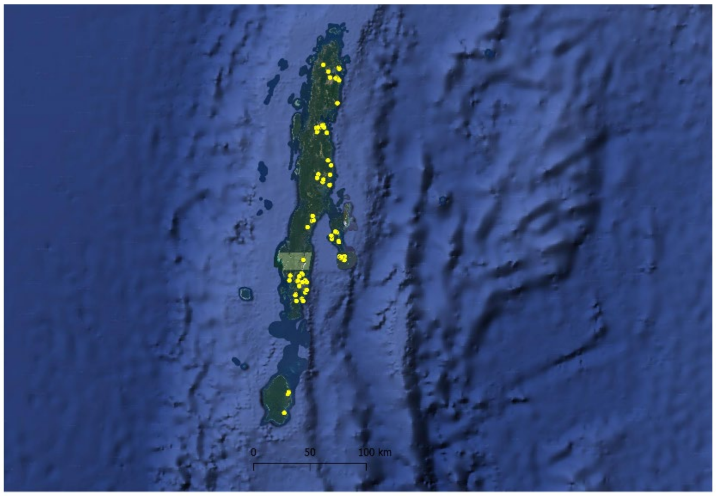

Figure D.1: Plot locations for Andamans

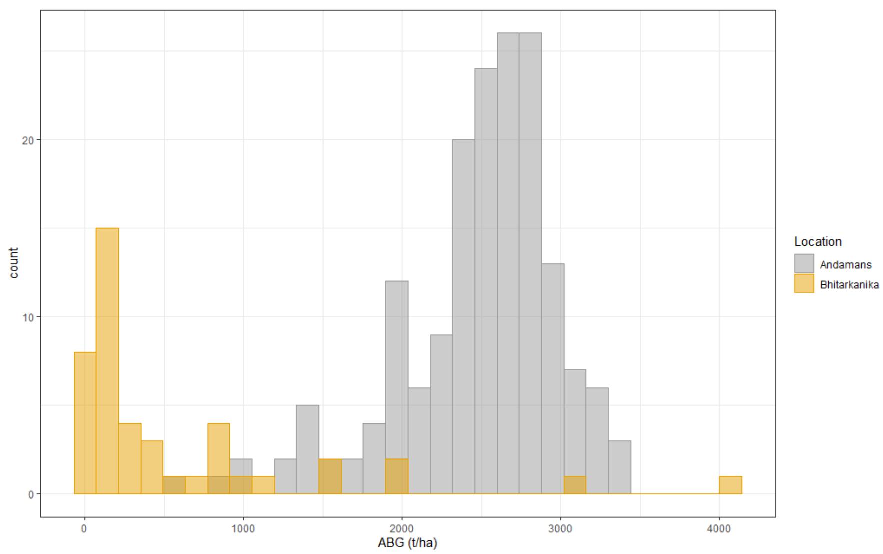

Figure D.2. The distribution histogram of the observed AGB values of all the field plots.

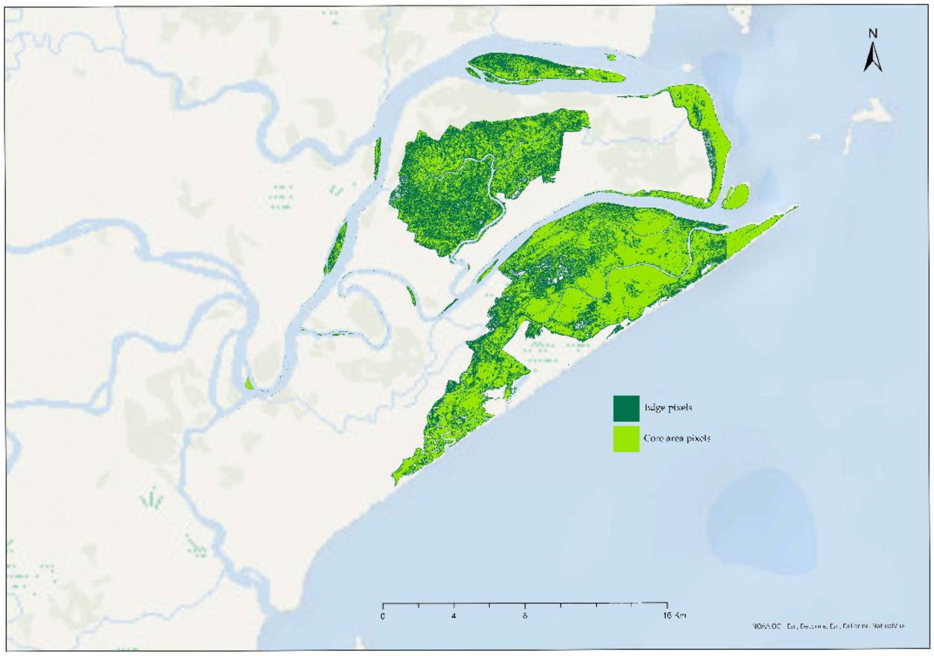

Figure D.3: Core and edge pixels