Mitigating Salinity Stress on *Sonneratia apetala* in the Indian Sundarbans: Management Strategies for Sustainable Mangrove Growth

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Abstract

Mangrove ecosystems are crucial for carbon sequestration, coastal protection, and several ecosystem services. However, increasing salinity levels pose significant threats to their biomass, and subsequent carbon sequestration potential. This study, conducted during October 2024 across 24 stations in the Indian Sundarbans, evaluates the influence of salinity on the Above Ground Biomass (AGB), Above Ground Carbon (AGC), and CO_2-equivalent of *Sonneratia apetala*. Results indicate that AGB, AGC, and CO_2-equivalent values are highest in low saline stations, moderate in mid saline stations, and lowest in high saline stations. Based on these findings, a management action plan is proposed that includes rainwater harvesting, channelling harvested water to high saline zones, and interlinking estuarine networks to mitigate salinity stress on the endemic mangrove flora. These strategies offer sustainable solutions for maintaining mangrove biomass and ecosystem stability in the Indian part of Sundarbans.

Keywords: Indian Sundarban, Mangroves, Above Ground Biomass (AGB), Above Ground Carbon (AGC), CO_2-equivalent

1. Introduction

Mangroves are vital coastal ecosystems that provide ecological services, including carbon sequestration, shoreline stabilization, and biodiversity support. However, increasing salinity due to climate change, sea-level rise, and reduced freshwater inflow poses a significant threat to their growth and productivity.

Scientists observed that although mangroves cover just 0.1% of the Earth's surface (Hamilton and Casey, 2016), they are important halophytic vegetations that play a significant role in mitigating and adapting to climate change. They are remarkable carbon sinks, storing up to five times more carbon per hectare than tropical rainforests (Donato *et al*., 2011). This exceptional ability to sequester carbon, coupled with their role in coastal protection and supporting biodiversity, underscores the importance of conserving these unique habitats. However, their position at the delicate interface between land and sea exposes mangroves to a variety of climate-induced stressors. Among these, sea-level rise and changing precipitation patterns stand out as critical challenges. These factors alter salinity levels in mangrove habitats, significantly impacting their growth and development. Elevated salinity levels lead to dwarf forms (stunted growth) of mangroves (Feller, 1995; Ball, 2002; Lovelock *et al*., 2005; Mitra *et al*., 2010; Banerjee *et al*., 2010; Banerjee *et al*., 2013; Bhattacharjee *et al*., 2013; Mitra, 2013; Zaman *et al*., 2013; Mitra *et al*., 2015; Mitra and Zaman, 2015; Banerjee *et al*., 2017; Mitra, 2018; Mitra and Zaman, 2020), disrupt essential physiological and functional processes, and in extreme cases, lead to homeostatic collapse (Chowdhury *et al*., 2019).

In the Indian Sundarbans, *Sonneratia apetala* serves as an indicator species for ground testing the impact of salinity stress on mangrove biomass. Thus, this study aims to assess the effect of salinity on the AGB, AGC, and CO_2-equivalent of *Sonneratia apetala* across different salinity zones and propose management strategies for sustaining mangrove ecosystems.

2. Materials and Methods

The entire work conducted during 2024 encompasses the following phases:

2.1. Study Area and Site Selection

Twenty-four stations in the Indian Sundarbans were selected based on their salinity gradients: low saline, mid saline, and high saline zones (Table 1). The selection criteria ensured comprehensive spatial representation, covering estuarine and deltaic regions with varying salinity profiles.

Table 1. Salinity-based demarcations of 24 stations in the Indian Sundarbans

Stations in low saline zones	Stations in mid saline zones	Stations in high saline zones
Muriganga (Stn. 1)	Arbesi (Stn. 8)	Saptamukhi (Stn. 2)
Jambu Island (Stn. 22)	Jhilla (Stn. 9)	Thakuran (Stn. 3)
Lothian Island (Stn. 23)	Pirkhali (Stn. 10)	Herobhanga (Stn. 4)
Sagar Island (Stn. 24)	Panchamukhani (Stn. 11)	Ajmalmari (Stn. 5)
	Harinbhanga (Stn. 12)	Dhulibasani (Stn. 6)
	Katuajhuri (Stn. 13)	Chulkati (Stn. 7)
	Chamta (Stn. 14)	Matla (Stn. 15)
	Chandkhali (Stn. 16)	Chhotahardi (Stn. 19)
	Goasaba (Stn. 17)	
	Gona (Stn. 18)	
	Bagmara (Stn. 20)	
	Mayadwip (Stn. 21)	

2.2. Experimental Species

Sonneratia apetala (Fig. 1) was chosen as the experimental species due to its widespread distribution and sensitivity to salinity variations.

Fig. 1. *Sonneratia apetala* – candidate species for the present study

2.3. Data Collection

Biomass and stored carbon related parameters, including AGB, AGC, and CO_2-equivalent sequestration, were measured using standard ecological assessment techniques. Data were collected from ten 10m × 10m quadrats at each station, covering a total of 240 quadrats during October 2024. Surface water salinity was checked simultaneously using a refractometer after proper calibration.

2.4. Data Analysis

We used the Python script for data analysis, designed for a Streamlit app, that takes user inputs related to tree measurements, such as height, circumference, and population density. It calculated the AGB, AGC, and CO_2 -e of the tree species (Fig. 2). Correlation coefficients were computed between the variables using SYSTAT.

```
    name = st.text_input("Name of the Species")
    N = st.number_input("No.of trees per 100 Sq. m", min_value=1, value=None)
    D = st.number_input("Population Density (in No./100 Sq. m)", min_value=0.0,
step=0.1, value=None)
    H = st.number_input("Height (in m)", min_value=0.0, step=0.1, value=None)
    two_pi_r = st.number_input("Circumference at breast height (in m)",
min_value=0.0, step=0.1, value=None)
    two_pi_R = st.number_input("Circumference at base (in m)", min_value=0.0,
step=0.1, value=None)
with col2:
    st.image("https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcRv-i-
gzBOF0X1YedDCDTd2AOb5zqWiQAcn_g2kCNFPWEAbfQWZlubNpasF3G3d2YfsItc&usqp=CAU")
    st.image("https://www.ecostan.com/wp-content/uploads/2024/11/Introduction-to-
Biomass-Energy-and-Its-Benefits.jpg")
# Calculate r and R
def calculate_r_R(two_pi_r, two_pi_R):
    r = two_pi_r / (2 * math.pi)
    R = two_pi_R / (2 * math.pi)
    return r, R

# Calculate from factor
def calculate_from_factor(r,R):
    from_factor=(r*r)/(R*R)
    return from_factor

#calculate stem biomass for single tree
def calculate_stem_biomass_per_tree(r,H,D,from_factor):
    stem_bio_per_tree=math.pi*r*r*H*D*from_factor
    return stem_bio_per_tree
```

Fig. 2. AGB, AGC, and CO2-e Calculation Using Streamlit

3. Results

The study revealed highly significant negative correlations of salinity with AGB, AGC, and CO_2-equivalent ($p < 0.01$) in *Sonneratia apetala* (Table 2; Figs. 2 – 4). The highest AGB, AGC, and CO_2-equivalent values were recorded in low saline stations, followed by mid saline stations, while the lowest values were observed in high saline zones. This trend highlights the adverse impact of increasing salinity on mangrove productivity.

Table 2. Inter-relationship between salinity and AGB, AGC and CO_2 equivalent of *S. apetala*

	AGB	**AGC**	**CO_2- equivalent**
Salinity	-0.8386	-0.83983	-0.83978

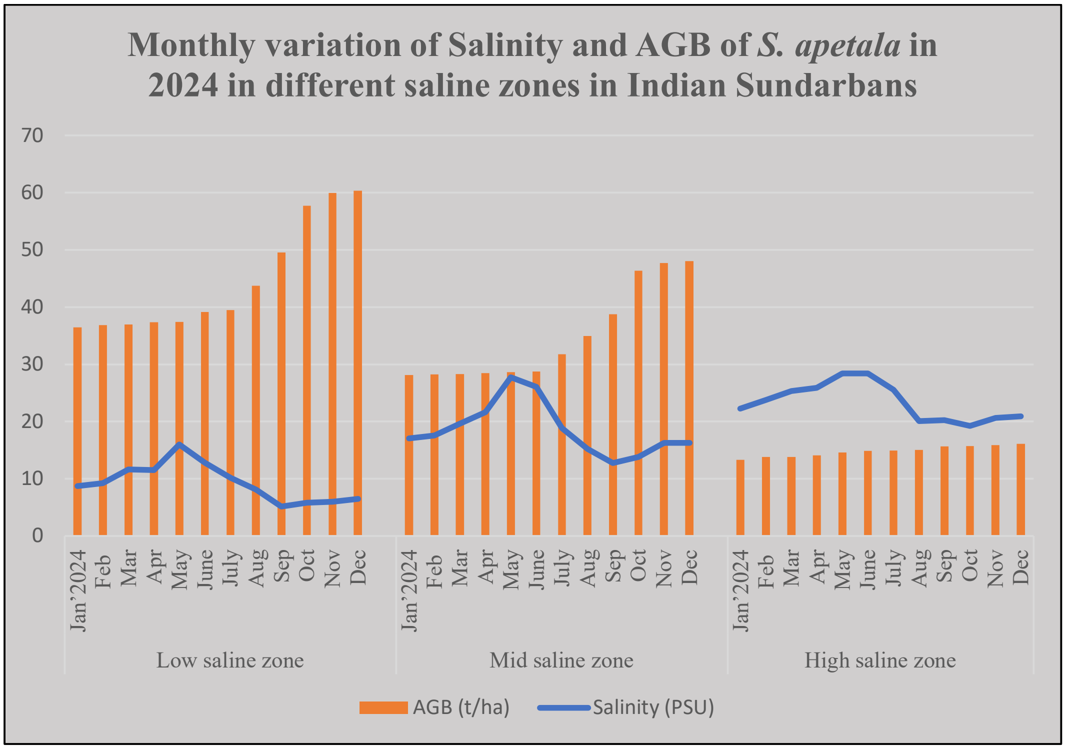

Fig. 2. Graph showing the impact of salinity on the AGB of *Sonneratia apetala*

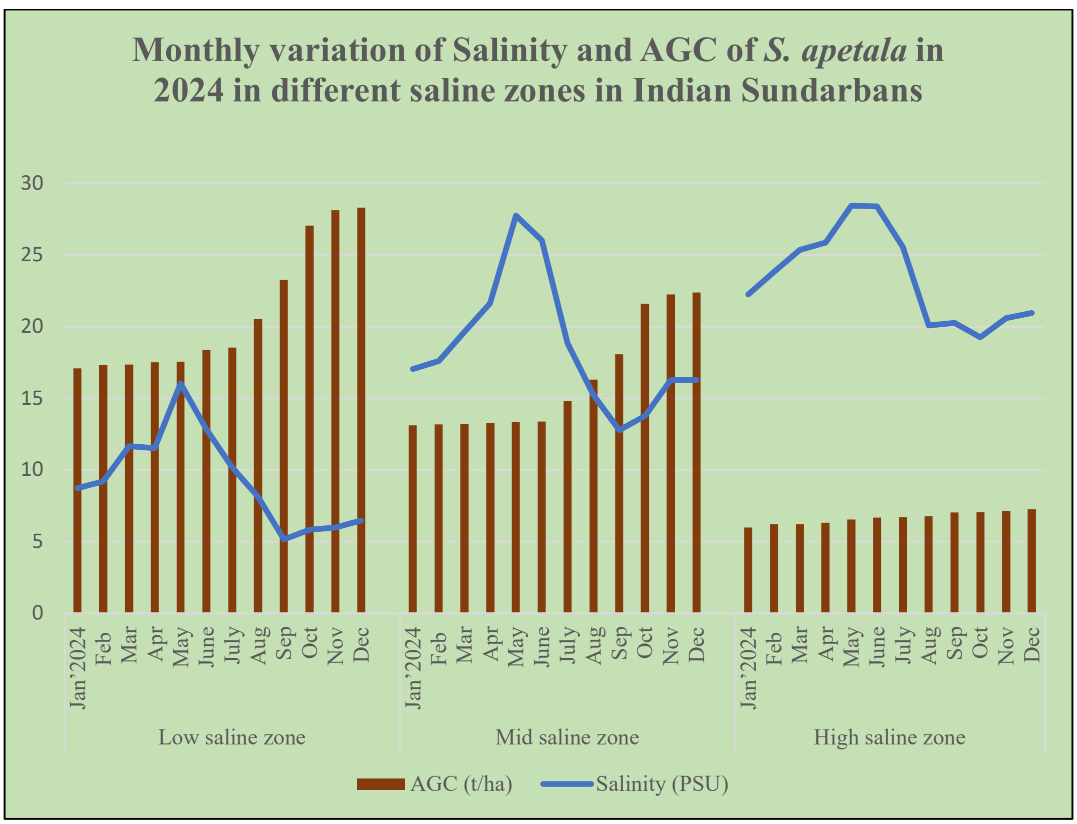

Fig. 3. Graph showing the impact of salinity on the AGC of *Sonneratia apetala*

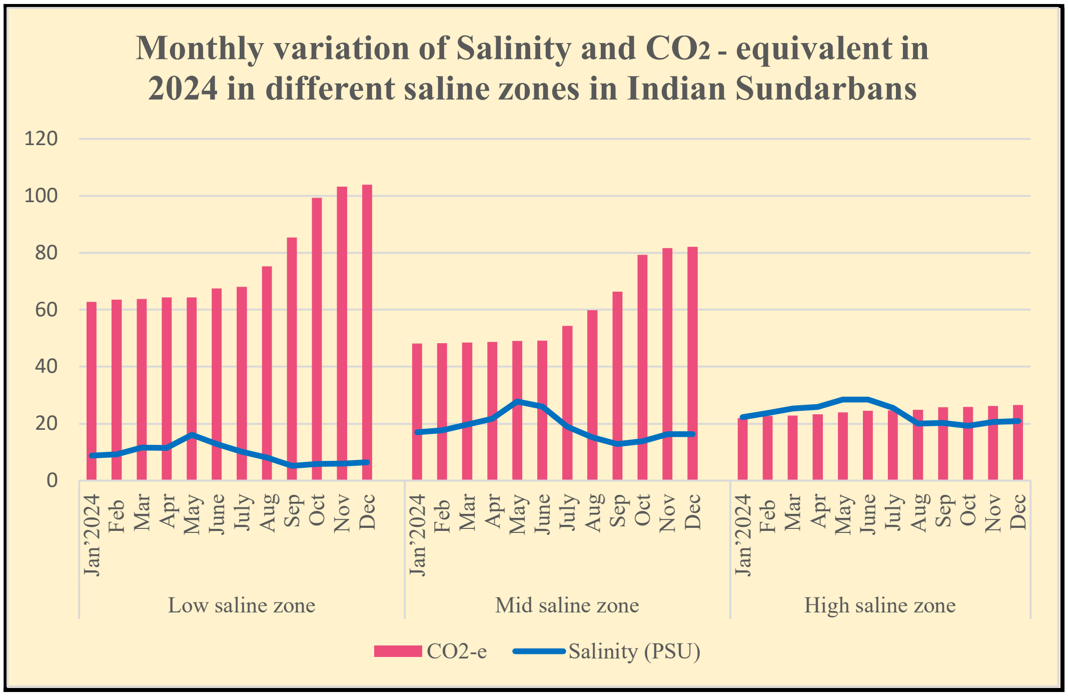

Fig. 4. Graph showing the impact of salinity on the CO_2-e of *Sonneratia apetala*

4. Discussion

Mangrove growth is significantly influenced by salinity stress, which affects osmotic balance, nutrient uptake, and carbon sequestration capacity. High salinity conditions lead to reduced AGB due to energy allocation towards stress adaptation mechanisms. While mangroves have evolved mechanisms to tolerate varying degrees of salinity and exhibit significant morphological plasticity (Vovides et al., 2014), the escalating rate of environmental change poses an unprecedented challenge. Projections like those of Sarker et al. (2021) predict a 50% increase in salinity levels in the Sundarbans by 2050, with potentially devastating consequences for mangrove ecosystems. Such an increase is anticipated to reduce ecosystem productivity by as much as 30%, threatening multiple ecosystem services these forests provide (Mitra, 2020). These projections highlight the urgent need for comprehensive studies to understand how salinity stress affects mangrove forests, particularly in terms of biomass accumulation and carbon storage capacity.

Given the increasing threat of salinity intrusion, effective management strategies are essential to sustain mangrove ecosystems.

5. Management Action Plan

5.1. Rainwater Harvesting and Channelling

- Constructing rainwater harvesting structures in high saline zones to reduce salinity levels during dry seasons.
- Establishing artificial freshwater channels to distribute harvested rainwater to areas experiencing extreme salinity stress (preferably in mid and high saline zones as shown in Table 1).

5.2. Interlinking Estuaries

- Developing an inter-estuarine water exchange system (between Hugli estuary in the western sector and Matla estuary in the central sector) to enhance freshwater flow in high saline zones.
- Constructing controlled sluice gates to regulate the salinity gradient and maintain ecological balance.

5.3. Afforestation and Mangrove Buffer Zones

- Planting salinity-tolerant mangrove species (like *Avicennia* spp.) in high saline regions to stabilize biomass levels and prevent further degradation.
- Establishing buffer zones with mixed species plantations to create a gradual transition from high to low salinity areas.

5.4. Community-Based Conservation Initiatives

- Engaging local communities in mangrove conservation through participatory salinity water management programs.
- Promoting alternative livelihoods such as sustainable aquaculture and eco-tourism to reduce dependency on mangrove resources.

5.5. Monitoring and Adaptive Management

- Establishing long-term monitoring programs to assess the effectiveness of implemented strategies.
- Adapting management actions based on real-time data and climate change projections.

6. Conclusion

The study underscores the critical impact of salinity on the biomass productivity of *Sonneratia apetala* in the Indian Sundarbans. Implementing rainwater harvesting, estuarine interlinking, and afforestation strategies can mitigate salinity stress and ensure sustainable mangrove conservation. A collaborative approach involving scientific research, policy interventions, and community participation is essential to preserve the Sundarbans' ecological integrity in the face of climate-induced salinity changes.

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