




Species-Specific Nutrient Resorption Strategies of Mangroves in Response to Salinity Stress in the Sundarbans, Bangladesh

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Abstract

Mangroves adapt to saline and nutrient-poor environments through nutrient conservation strategies. This study evaluates nutrient resorption efficiencies (NRE) of nitrogen, phosphorus, and potassium in *Heritiera fomes* and *Excoecaria agallocha* from the Sundarbans Mangrove forest, Bangladesh. Soil and foliar samples were analyzed across seasons, nutrient resorption efficiency was calculated, and the relationship between the soil parameters (N, P, K, and Electrical Conductivity) and nutrient resorption efficiency of the studied species was also derived. Results showed that soil salinity was highest in the pre-monsoon season (5.03 ± 0.29 mS/cm). *E. agallocha* exhibited higher NRE across all nutrients, particularly nitrogen ($63.15 \pm 3.51\%$ in the pre-monsoon), reflecting superior adaptability to saline conditions. Conversely, *H. fomes* showed lower NRE, especially for phosphorus ($35.05 \pm 5.33\%$), indicating limited conservation efficiency under salinity stress. A strong correlation between salinity and nitrogen resorption ($r = 0.99$ for *E. agallocha*) further highlights the role of salinity in nutrient dynamics. Weak correlations among soil nutrients and nutrient resorption efficiency for both studied species suggest nutrient resorption is relatively independent of soil nutrient levels for the study site. These findings underscore the superior adaptive capabilities of *E. agallocha*, enabling it to conserve nutrients more effectively under saline and nutrient-deficient conditions. With rising salinity in the Sundarbans, *E. agallocha* is likely to gain dominance, potentially reshaping the region's mangrove species composition and posing challenges for conserving less resilient species like *H. fomes*. The foreseen shift in species dominance in the Sundarbans underscores the need for species-spe-

cific conservation and adaptive management strategies, with a focus on monitoring salinity-driven changes in composition and safeguarding vulnerable species like *Heritiera fomes*.

Keywords

Adaptation, *Excoecaria agallocha*, *Heritiera fomes*, Nutrient, Resorption, Sundarbans

1. Introduction

Mangroves are unique evergreen vegetation found along the coastlines of 124 tropical and subtropical countries. These species possess specialized adaptations to cope with challenging environmental conditions, including salinity, anaerobic soils from tidal inundation, unstable muddy substrates, nutrient-poor soils, and high levels of temperature, wind, and solar radiation. However, the degree of adaptation varies among species. Mangrove ecosystems provide a wide range of ecosystem services (provisioning, regulating, cultural, and supporting) at local, regional, and global scales (Tomlinson, 1986; Mahmood et al., 2008; Ribeiro et al., 2019). Bangladesh, as a coastal nation, contains approximately 4% of the world's total mangrove forest area, including the Sundarbans, the largest contiguous natural mangrove forest in the world. The Sundarbans is rich in floral and faunal diversity. This forest has three distinct salinity zones [e.g. Oligohaline/Less-saline zones ($<2 \text{ dS m}^{-1}$) (0.5 - 5 ppt), Mesohaline/Moderately saltwater ($2 - 4 \text{ dS m}^{-1}$) (5 - 18 ppt), Polyhaline/Saltwater ($>4 \text{ dS m}^{-1}$) (18 - 30 ppt)] (Siddiqi, 2001; Ahmed et al., 2011; Mahmood 2015). *Heritiera fomes*, *Excoecaria agallocha*, *Sonneratia apetala*, *Bruguiera sexangula*, *Avicennia officinalis* and *Ceriops decandra* are common species. *Heritiera fomes* and *E. agallocha* constitute the major vegetation types of the Sundarbans (Mahmood, 2015). *Heritiera fomes* is believed to be a climax species of this forest. The species composition and their dominance in different zones of the Sundarbans found to be influenced by the salinity (Ahmed et al., 2011). The species dominance, abundance, frequency, density, canopy cover, volume, and biomass of the major species of the Sundarbans have changed since 1960 (Siddiqi, 2001). Many natural and anthropogenic issues are believed to be responsible for the vegetation changes (Mahmood et al., 2021). Increased soil and water salinity of the Sundarbans habitat are major concerns for the changes in species composition (Ahmed et al., 2022), survival, and growth (Mahmood et al., 2014a; Nasrin et al., 2016; Chowdhury et al., 2019). The water and soil salinity of the Sundarbans found to vary with seasons and is believed to increase with time due to the decreasing flow of freshwater from upstream and climate change-induced salinity (Siddiqi, 2001). This increased salinity poses stresses to the mangrove species by limiting the uptake of nutrients (Alongi, 2009; Reef et al., 2010; Nasrin et al., 2016; Siddique et al., 2017).

Mangroves adopt various mechanisms to conserve and reuse nutrients for survival and growth in high-saline environments (Tomlinson, 1986; Mahmood et al., 2014a; Nasrin et al., 2019). Nutrient levels in soil and plant parts of a forest ecosystem fluctuate with species, plant growth form, species-specific development capacity, geomorphological settings, and climate variabilities (Mahmood, 2004; Vergutz et al., 2012; Limon et al., 2025). Mangrove plants usually shed their older leaves and bark to eliminate excessive accumulated salt from their tissues (Tomlinson, 1986; Acosta-Motos et al., 2017). Mangrove plants have a high rate of litterfall and are mostly washed by the tidewater (Mahmood et al., 2005), which may result in poor nutrient status in mangrove soil (Mahmood, 2004). The nutrient resorption mechanism in mangroves may be an important adaptation tool to cope with saline and nutrient-poor soil (Saenger, 2002; Hu et al., 2023), and the nutrient resorption mechanism and efficiency of mangroves vary with species and sites (Alongi, 2009; Alam et al., 2019; Nasrin et al., 2019). It is reported that this adaptation (nutrient resorption efficiency) is not only related to the salinity but also to the nutrient level in the soil and element mobility (Feller et al., 2003; Alongi, 2009; Blanco et al., 2009; Acosta-Motos et al., 2017). The variation in nutrient resorption efficiency will help to understand the nutrient conservation strategy and adaptation at the species level in a stress condition. *H. fomes* is a less salt-tolerant species than the *E. agallocha* in the Sundarbans (Siddiqi, 2001). It is reported that the vegetation coverage by *H. fomes* in the Sundarbans has decreased over time and more salt-tolerant species like *E. agallocha* and *C. decandra* are taking over (Chowdhury et al., 2019; Ahmed et al., 2022). Moreover, a declining growth rate was observed for *H. fomes* in the Sundarbans (Siddiqi, 2001).

We hypothesized that the recent increasing abundance of *E. agallocha* in the Sundarbans may be linked to its superior nutrient resorption efficiency and greater salt tolerance than *H. fomes*. These traits will allow *E. agallocha* to thrive in increasingly saline and nutrient-poor conditions, enabling it to outcompete *H. fomes*, which exhibits lower resorption efficiency and salt tolerance. The physiological advantage of *E. agallocha* will contribute to shifts in species dominance over time, particularly in response to rising salinity levels and changing nutrient dynamics in the Sundarbans ecosystem. Therefore, the present study aimed to evaluate i) the seasonal variation in nutrients (N, P, and K) concentration in soil, mature and senescent leaves of *H. fomes* and *E. agallocha*; ii) nutrients (N, P, and K) resorption efficiency for *H. fomes* and *E. agallocha*; iii) the relationship among the soil parameters (N, P, K, and EC) and nutrient resorption efficiency of *H. fomes* and *E. agallocha*.

2. Materials and Methods

2.1. Study Area

The study site was under the Chandpai Forest Range of the Sundarbans mangrove forest of Bangladesh (22°22'06.60" N in latitude and 89°38'42.20" E in longitude) (Figure 1). The climate is humid subtropical with 18 - 23°C and 27 - 31°C mean

temperatures during the post-monsoon and pre-monsoon, respectively. The study area receives an average annual rainfall of 1980 mm, with about 81% occurring during the monsoon season. The soil is silty clay in texture and has a pH of approximately 7.9. According to the salinity classification by Siddiqi (2001), the site is located in the less-saline zone (soil salinity $< 2 \text{ dS m}^{-1}$) (water salinity 0.5 to 5 ppt) of the Sundarbans. The salinity decreases during the monsoon season with increased freshwater flow and precipitation, and salinity increases in the post-monsoon and pre-monsoon. The study region contains *Heritiera fomes*, *Excoecaria agallocha*, *Avicenia officinalis*, *Amoora cucullata* and *Avicennia alba*, and the site is frequently submerged by tides (Siddiqi, 2001).

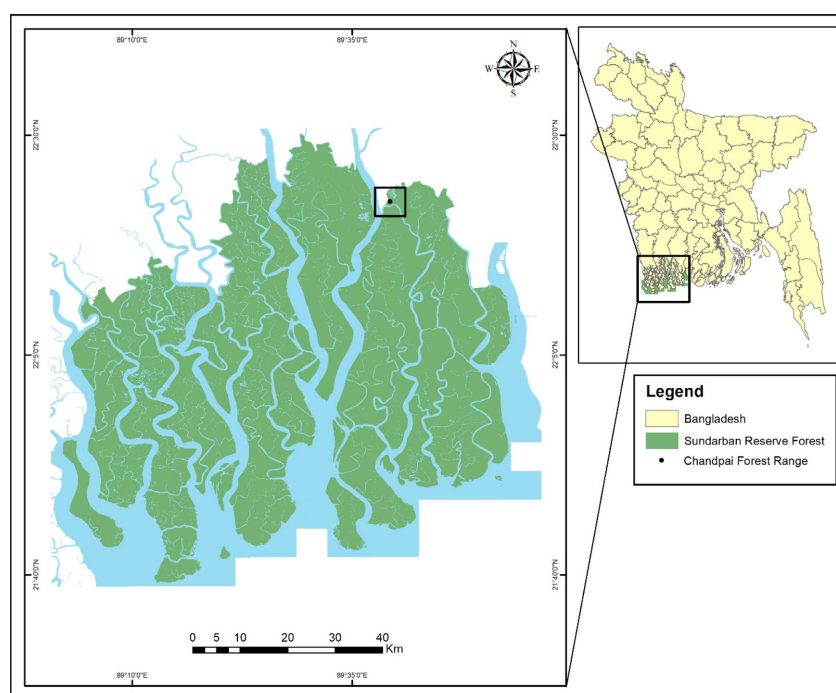


Figure 1. Location map of the study area.

2.2. Collection of Leaf and Soil Samples

Three random sample plots ($5 \times 5 \text{ m}$) were set up for each species in the study area. The sample plots were not strictly monospecific; however, each was dominated by the respective target species. From each plot, one dominant tree was chosen, resulting in three marked individuals of each species (*H. fomes* and *E. agallocha*) for further study. Green mature and yellowish senescent leaves (about 250 g for each category) of the selected individuals were collected during the pre-monsoon (March-May), monsoon (June-August) and post-monsoon seasons (October-November). Green mature leaves refer to the third pairs of green intact leaves, while senescent leaves refer to yellowish leaves ready to abscise when touched or when the branch is lightly shaken. Three soil samples from each plot were collected to obtain a homogeneous sample using an open-face core sampler (5 cm in diameter) up to a depth of 100 cm.

2.3. Nutrients in Soil and Leaf Samples

The collected green mature and yellowish senescent leaves were oven-dried separately according to species for 96 hours at 80°C. The oven-dried samples were crushed, sieved (2 mm mesh), and stored for further chemical analysis (Allen, 1989). Soil samples were air-dried and processed. Soil electrical conductivity (EC) of the collected samples was measured from 1:2 soil water extraction according to Allen (1989). The available forms of soil N, P, and K were extracted according to Allen (1989). Nitrogen and phosphorus concentrations in the sample extract were determined colorimetrically using a UV-visible Recording Spectrophotometer following Baethgen and Alley (1989) and Pote and Daniel (2000), respectively (HITACHI, U 2910, Japan). The potassium in the sample extracts was determined using a flame photometer (PFP7, Jenway LTD, England).

2.4. Nutrient Resorption Efficiency

Nutrient resorption was calculated according to Ricardo (1992) and Wang et al. (2003) (Equation (1)).

$$\text{NRE (\%)} = \{(\text{Ngr} - \text{Nsen})/\text{Ngr}\} * 100 \quad (1)$$

where,

NRE = Nutrient resorption efficiency;

Ngr = Nutrient concentration (mg/g) measured from green leaves;

Nsen = concentration (mg/g) measured from senescent leaves senescence.

2.5. Statistical Analysis

The nutrient (N, P, and K) concentrations and EC of soil samples were compared among seasons using one-way analysis of variance followed by the Duncan Multiple Range Test (DMRT, $p < 0.05$). Nutrients in green mature and senescent leaves of the studied species were compared among seasons using one-way ANOVA followed by the Duncan Multiple Range Test (DMRT, $p < 0.05$). The nutrient resorption efficiency of each nutrient for the studied species was compared among seasons using one-way ANOVA followed by the Duncan Multiple Range Test (DMRT, $p < 0.05$). At the same time, the unpaired “t” test was used to investigate the variation between the studied species in each season. Finally, Pearson’s correlation was conducted among the soil parameters (N, P, K, and EC) and the N, P, and K nutrient resorption efficiencies for the studied species. All the statistical analyses were performed using SAS® OnDemand for Academics version.

3. Results

3.1. Soil EC and Nutrients (N, P, and K)

Similar ($p > 0.05$) concentrations of soil available nitrogen (0.07 ± 0.01 mg/g), available phosphorus (16.88 ± 1.33 to 19.40 ± 0.32 µg/g), and available potassium (0.09 ± 0.001 to 10.00 ± 0.01 mg/g) were observed for all seasons (Figures 2(a)-(c)). However, comparatively ($p < 0.05$) higher soil EC (5.03 ± 0.29 mS/cm) was observed in summer, and the lowest was in monsoon (0.96 ± 0.05 mS/cm) (Figure 2(d)).

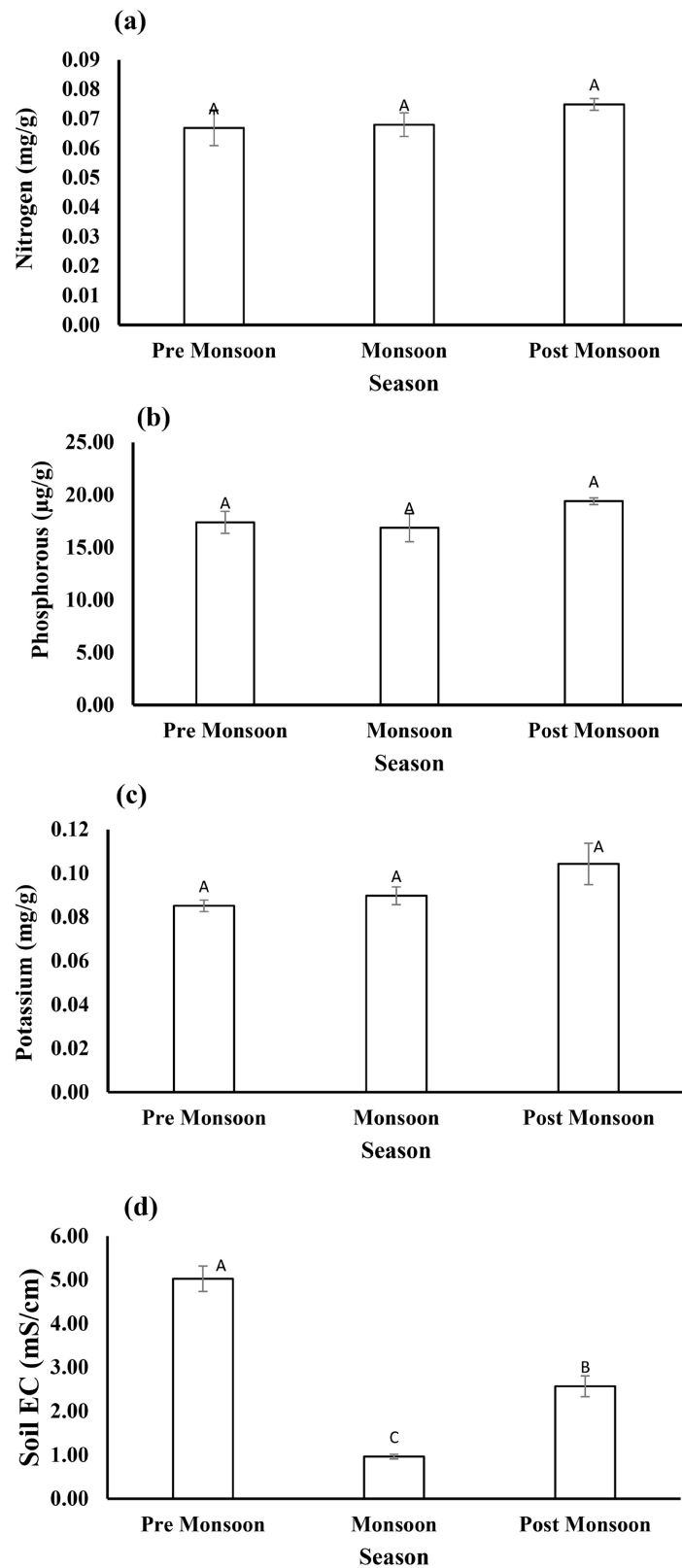


Figure 2. Soil available nutrient status in different seasons of the study site (a) Nitrogen, (b) Phosphorous, (c) Potassium and (d) Soil Electrical conductivity (EC). Similar letter on the bar indicates no significant (ANOVA, DMRT, $p > 0.05$) variation.

3.2. Foliar Nutrient Concentrations

Comparatively ($p < 0.05$), a higher concentration of N (12.64 ± 1.09 mg/g), P (0.42 ± 0.03 mg/g), and K (10.79 ± 0.33) was observed in green mature leaves of *H. fomes* in the monsoon. Their concentrations varied significantly ($p < 0.05$) with the seasons, except N and P in pre- and post-monsoon. The senescent leaves of *H. fomes* contained higher N (10.84 ± 0.88 mg/g) and P (0.27 ± 0.02 mg/g) concentrations during the monsoon season, while higher K concentration (5.51 ± 0.25 mg/g) was found in the pre-monsoon season, but P and K concentrations did not vary significantly ($p > 0.05$) in pre-monsoon and post-monsoon seasons (Table 1). In the case of *E. agallocha*, similar ($p > 0.05$) concentrations of N (8.33 ± 1.20 to 9.76 ± 1.30 mg/g) and P (0.31 ± 0.03 to 0.38 ± 0.01 mg/g) were detected in green mature leaves for all seasons. In contrast, a higher K concentration (12.02 ± 0.20 mg/g) was detected in the monsoon season. The senescent leaves of *E. agallocha* showed a higher concentration of N (6.41 ± 0.40 mg/g) in the monsoon and higher K (7.52 ± 0.08 mg/g) in pre-monsoon (Table 2).

Table 1. Seasonal variation in nutrient concentration (mg/g) in green mature (GL) and senescent (SL) leaves of *Heritiera fomes* of the Sundarbans. Similar alphabate along the column according to seasons has no significant (ANOVA, DMRT, $p > 0.05$) difference.

Species	N (mg/g) \pm SE		P (mg/g) \pm SE		K (mg/g) \pm SE	
	GL	SL	GL	SL	GL	SL
Pre-monsoon	8.50 ± 0.61^B	2.00 ± 0.35^C	0.30 ± 0.03^B	0.17 ± 0.02^B	8.46 ± 0.24^B	5.51 ± 0.25^A
	12.64 ± 1.09^A	10.84 ± 0.88^A	0.42 ± 0.03^A	0.27 ± 0.02^A	10.79 ± 0.33^A	3.45 ± 0.24^B
Monsoon	8.67 ± 0.66^B	4.00 ± 0.36^B	0.33 ± 0.03^B	0.17 ± 0.01^B	7.05 ± 0.10^C	5.07 ± 0.33^A
	8.33 ± 1.20^A	3.00 ± 0.29^C	0.31 ± 0.03^A	0.23 ± 0.03^A	10.89 ± 0.12^B	7.52 ± 0.08^A
Post-monsoon	9.76 ± 1.30^A	6.41 ± 0.40^A	0.38 ± 0.01^A	0.21 ± 0.03^A	12.02 ± 0.20^A	4.33 ± 0.03^C
	9.00 ± 0.36^A	4.83 ± 0.58^B	0.32 ± 0.03^A	0.23 ± 0.03^A	10.62 ± 0.20^B	5.11 ± 0.06^B

Table 2. Seasonal variation in nutrient concentration (mg/g) in green mature (GL) and senescent (SL) leaves of *Excoecaria agallocha* of the Sundarbans. Similar alphabate along the column according to seasons has no significant (ANOVA, DMRT, $p > 0.05$) difference.

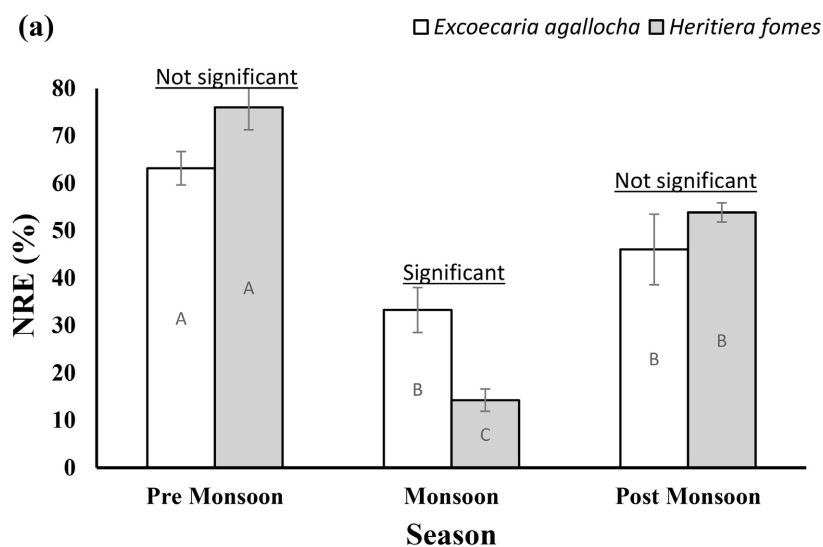
Species	N (mg/g) \pm SE		P (mg/g) \pm SE		K (mg/g) \pm SE	
	GL	SL	GL	SL	GL	SL
Pre-monsoon	8.33 ± 1.20^A	3.00 ± 0.29^C	0.31 ± 0.03^A	0.23 ± 0.03^A	10.89 ± 0.12^B	7.52 ± 0.08^A
	9.76 ± 1.30^A	6.41 ± 0.40^A	0.38 ± 0.01^A	0.21 ± 0.03^A	12.02 ± 0.20^A	4.33 ± 0.03^C
Monsoon	9.00 ± 0.36^A	4.83 ± 0.58^B	0.32 ± 0.03^A	0.23 ± 0.03^A	10.62 ± 0.20^B	5.11 ± 0.06^B
	8.33 ± 1.20^A	3.00 ± 0.29^C	0.31 ± 0.03^A	0.23 ± 0.03^A	10.89 ± 0.12^B	7.52 ± 0.08^A
Post-monsoon	9.76 ± 1.30^A	6.41 ± 0.40^A	0.38 ± 0.01^A	0.21 ± 0.03^A	12.02 ± 0.20^A	4.33 ± 0.03^C
	9.00 ± 0.36^A	4.83 ± 0.58^B	0.32 ± 0.03^A	0.23 ± 0.03^A	10.62 ± 0.20^B	5.11 ± 0.06^B

3.3. Nutrient Resorption Efficiency

H. fomes showed significant ($p < 0.05$) variation in nitrogen resorption efficiency among the seasons. Comparatively higher nitrogen resorption efficiency ($76.00 \pm$

4.72%) was in pre-monsoon, and the lowest was in the monsoon season ($14.26 \pm 2.34\%$). *E. agallocha* showed higher nitrogen resorption efficiency ($63.15 \pm 3.51\%$) in pre-monsoon, and no significant ($p > 0.05$) variation was observed for monsoon and post-monsoon seasons. The unpaired “t” test showed similar ($P(T \leq t) < 0.05$) nitrogen resorption efficiency for the studied species in pre-monsoon and post-monsoon seasons, and significant ($P(T \leq t) > 0.05$) variation in the monsoon season (**Figure 3(a)**). No significant ($p > 0.05$) variation in phosphorus resorption efficiency ($35.05 \pm 5.33\%$ to $47.91 \pm 1.32\%$) was observed for *H. fomes* among the seasons. While *E. agallocha* showed higher phosphorus resorption efficiency ($46.35 \pm 5.69\%$) in monsoon, no significant ($p > 0.05$) variation was observed for pre-monsoon and post-monsoon seasons. The unpaired “t” test showed similar ($P(T \leq t) < 0.05$) phosphorus resorption efficiency for the studied species in pre-monsoon and monsoon seasons, and significant ($P(T \leq t) > 0.05$) variation in the post-monsoon season (**Figure 3(b)**). Comparatively ($p < 0.05$) higher potassium resorption efficiency ($68.06 \pm 1.24\%$) was observed for *H. fomes* in the monsoon. Similarly, *E. agallocha* showed higher potassium resorption efficiency ($63.94 \pm 0.69\%$) also in the monsoon, and resorption efficiency varied significantly ($p < 0.05$) among seasons. In the case of species-wise comparison, only a significant variation ($P(T \leq t) > 0.05$) in potassium resorption efficiency was observed in post-monsoon (**Figure 3(c)**).

The relationship among the soil parameters (EC, N, P, and K) and the nutrients (N, P, and K) resorption efficiency (NRE) of *H. fomes* and *E. agallocha* indicates that soil salinity (i.e., Soil EC) has a significant ($p < 0.05$) relationship with nitrogen resorption of *H. fomes* ($r = 0.92$) and *E. agallocha* ($r = 0.99$), and potassium resorption efficiency of *E. agallocha* ($r = -0.99$). Soil nitrogen has weak correlations ($r = 0.03$ to -0.52) with NRE across both species. Soil phosphorus showed a strong negative correlation ($r = -0.83$) and a moderate positive correlation ($r = 0.6$) with the phosphorus resorption efficiency of *H. fomes* and *E. agallocha*, respectively (**Table 3**).



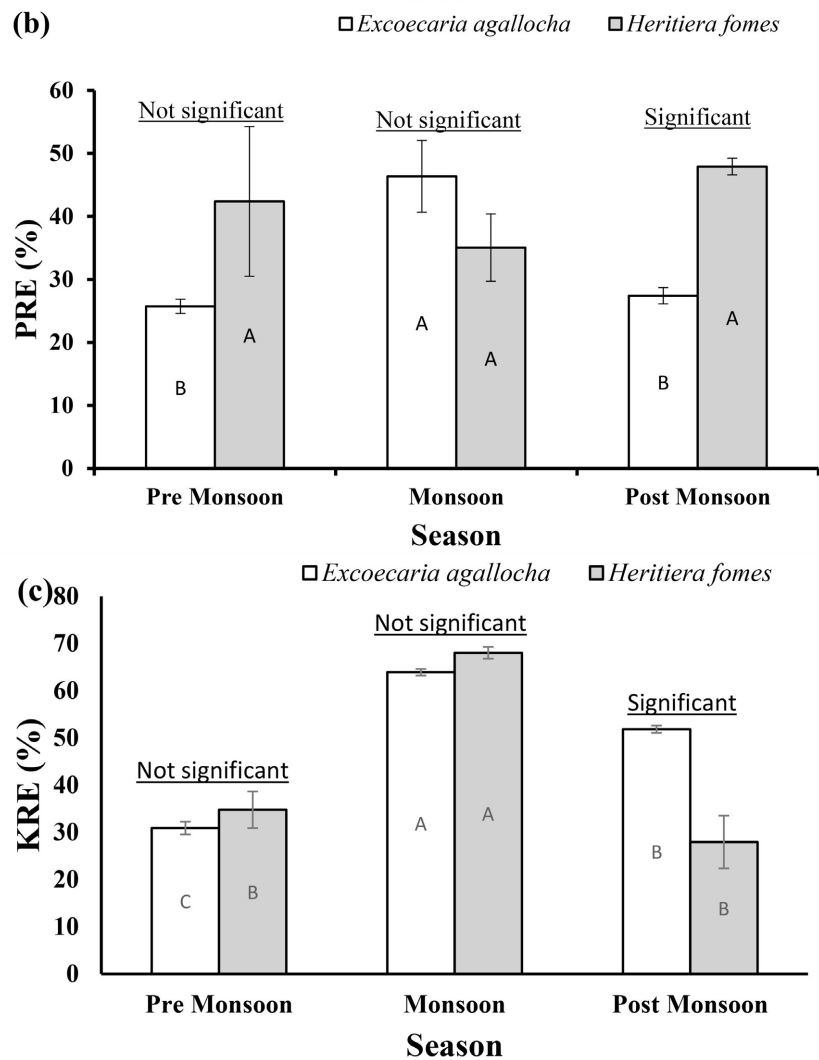


Figure 3. NRE of *Excoecaria agallocha* and *Heritiera fomes* leaves. (a) Nitrogen, (b) Phosphorous, and (c) Potassium; Similar letter on the bas according to the species indicated no significant (ANOVA, DMRT, $p > 0.05$) difference. Significance test (unpaired “t” test, $P (T \leq t)$ two tailed) between the species presented on the pairs of bar.

Table 3. Correlation among the soil parameters (EC, N, P, and K) and the nutrients (N, P and K) resorption efficiency (NRE). Astrisk (*) mark indicate the significant ($p < 0.05$) correlation.

Soil parameters	N-NRE of <i>H. fomes</i>	P-NRE of <i>H. fomes</i>	K-NRE of <i>H. fomes</i>	N-NRE of <i>E. agallocha</i>	P-NRE of <i>E. agallocha</i>	K-NRE of <i>E. agallocha</i>
Soil EC	0.92*	0.46	-0.69	0.99*	-0.65	-0.99*
Soil N	0.03	0.31	-0.52	-0.22	-0.31	0.28
Soil P	0.35	-0.83	-0.43	0.11	0.6	-0.04
Soil K	-0.07	0.67	-0.44	-0.31	-0.22	0.38

4. Discussion

Nutrients are limiting in mangrove soil (Lovelock et al., 2005), and the concentra-

tion varies among mangroves of the world and the dominant types (Feller et al., 2003). Compared to the studies of Mahmood (2004) and Hossain and Nuruddin (2016), the present study site contained relatively lower N and higher P in soil. The variation in soil nutrients among the mangroves and seasons is highly related to the natural process of weathering, environmental conditions, and nutrient flux in the mangroves (Feller et al., 2003; Mahmood, 2004; Reef et al., 2010). In the monsoon, nutrients become more available in the soil because of the influence of nutrient input and output sources (Alongi et al., 1992; Mahmood, 2004). Conversely, higher litter export during the monsoon may reduce the organic matter and nutrient levels in mangroves (Mahmood et al., 2005; Mahmood & Hoque, 2008). These consequences may control the fluctuation of soil nutrient levels in the mangroves. Our study found no significant variation in available soil nitrogen, phosphorus, and potassium concentrations across different seasons. This suggests that seasonal changes have minimal influence on soil nutrient availability in the studied mangrove environment. Such stability in soil nutrient levels could be attributed to the buffering capacity of mangrove soils, which are often rich in organic matter and maintain relatively consistent biogeochemical conditions despite external environmental fluctuations. Similar observations were reported by Alongi et al. (2000), who noted that nutrient concentrations in mangrove soils tend to remain stable due to slow nutrient turnover and strong retention capacity. Additionally, Krishna and Mohan (2017) highlighted that mangrove ecosystems, particularly in intertidal zones, experience limited seasonal shifts in soil nutrient levels due to reduced leaching and continuous input from tidal exchanges and litter-fall decomposition.

Nutrient concentration in leaves of mangroves varied with species, age of leaves, sites, seasons, and salinity (Mahmood, 2004; Alongi, 2009). High saline conditions limit the availability of nutrients to mangroves (Saenger, 2002; Singh et al., 2005; Alam et al., 2018). The present study showed that nutrient composition in green mature and senescent leaves of *H. fomes* responds to seasons or salinity. Mahmood et al. (2014a) observed a similar trend of decreasing nitrogen, phosphorus, and potassium concentrations in *H. fomes* seedlings as salinity increased. On the other hand, *E. agallocha* showed less seasonal variation in nitrogen and phosphorus levels in both mature green and senescent leaves. Nutrient composition in green leaves was found to vary with the species even if they are growing at the same site. The ability of mangroves to take up nutrients in response to salinity varies greatly between species (e.g., Reef et al., 2010; Mahmood et al., 2014a; Alam et al., 2019; Nasrin et al., 2019, 2021).

McKee and Faulkner (2000) claimed that mangroves resorb between 20 and 60% of N and 30 and 70% of Wang et al. (2003) found comparatively higher resorption efficiency of N (72%) and P (58%) for *Kandellia candel*. The range of the resorption efficiency of N, P, and K in the present study was 14 to 76%, 26 to 48%, and 28 to 68%, respectively. Mangrove species exhibit varying ranges of nutrient resorption efficiency depending on their physiological and ecological adaptations,

which are very much species- and site-specific (Feller et al., 1999, 2003; Reef et al., 2010). In the case of P resorption efficiency, the studied species showed lower efficiency than the study of McKee and Faulkner (2000) and Wang et al. (2003). Comparatively higher and similar available concentrations of P in soil throughout the seasons may influence the lower resorption efficiency for *H. fomes* and *E. agallocha*. This statement is supported by the findings of Feller et al. (2003). They observed higher P resorption efficiency for mangroves growing in highly saline conditions and soil with poor P content. The readily leaching nature of K from the leaf (Mahmood et al., 2014b) may influence the higher resorption during the monsoon. Alam et al. (2018) and Noor et al. (2015) observed a higher resorption efficiency of K for *Avicennia officinalis* and *Rhizophora* spp. during the monsoon. Higher nutrient resorption efficiency reflects the adaptive strategies of mangroves to maintain productivity and support ecosystem resilience in nutrient-limiting and saline conditions (Reef et al., 2010).

The seasonal fluctuation of available concentrations of nutrients and salinity levels strongly controls the nutrient resorption efficiency of mangrove plants. Even the same mangrove species in different geomorphological settings usually show different ranges of nutrient resorption efficiency (McKee & Faulkner, 2000; Lovelock & Feller, 2003; Reef et al., 2010). The present study demonstrated that *H. fomes* prioritizes nitrogen and phosphorus resorption in relation to salinity. Nitrogen resorption efficiency increases as mangroves prioritize nutrient conservation in saline conditions (Nasrin et al., 2019). Soil salinity plays a critical role in nutrient resorption strategies (Alongi, 2009), nutrient mobility, and ionic balance (Krauss et al., 2008). In the case of *E. agallocha*, the negative correlation between soil salinity and P resorption efficiency explains the luxury consumption hypothesis—plants retain less phosphorus when it is abundant (Aerts, 1996). Here, the negative correlation between soil salinity (measured as EC) and phosphorus resorption efficiency may reflect a context of sufficient phosphorus availability, where the species exhibits lower resorption in line with the luxury consumption hypothesis, where plants resorb less of a nutrient when it is sufficiently available in the environment, regardless of salinity stress. While the positive correlation between salinity and P resorption efficiency of *H. fomes* indicates that phosphorus resorption efficiency can be species-specific, which demands further study. The ionic competition between potassium and sodium can result in a negative relation for K resorption efficiency and salinity (Reef et al., 2010). The weak correlations between soil nutrients and nutrient resorption efficiency suggest that soil nutrient levels do not strongly affect resorption in *H. fomes* and *E. agallocha*. This matches our finding that soil N, P, and K did not change much across seasons. Salinity is known to affect nutrient uptake in mangroves (Alongi, 2009; Reef et al., 2010). However, the salinity at our study site was relatively low and showed little change (0.96 - 5.03 mS/cm), and this range falls within the lower salinity level of the less saline zone of the Sundarbans (Siddiqi, 2001). The low variation in salinity and relatively stable nutrient concentration likely control resorption efficiency through

species-specific traits. These may include nutrient storage, selective ion use, and internal recycling (Krauss et al., 2008). The species-specific differences in nutrient resorption strategies, particularly the superior efficiency of *E. agallocha*, may lead to long-term shifts in mangrove species composition under increasing salinity conditions in the Sundarbans. These findings underscore the need to integrate ecological understanding into mangrove management, particularly in the context of natural forest resilience and biodiversity conservation. The management actions need to focus on monitoring species dynamics in the Sundarbans and evaluating the salinity thresholds for vulnerable species like *H. fomes*.

5. Conclusion

Heritiera fomes and *Excoecaria agallocha* are two key species of the Sundarbans, exhibiting distinct nutrient conservation strategies. This study reveals significant differences in nutrient resorption efficiency for nitrogen, phosphorus, and potassium across species, seasons, and varying soil salinity. *Excoecaria agallocha* consistently showed higher nitrogen resorption efficiency during the monsoon season and higher potassium resorption efficiency in the post-monsoon season, showing its strong ability to adapt to changing conditions. For *E. agallocha*, the negative link between soil salinity and phosphorus resorption efficiency supports the luxury consumption idea—the plant holds on to less phosphorus when there is already some available in the soil. These findings suggest that *E. agallocha* is robust in salinity tolerance, which may facilitate its continued expansion and potentially reshape species dynamics within the Sundarbans ecosystem. Such a shift may alter forest structure, reduce canopy complexity, and negatively impact existing biodiversity. However, this study was limited to two species within a single salinity zone of the Sundarbans. Broader spatial coverage and inclusion of additional species and related parameters are recommended for future research.

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Conflicts of Interest

No conflict of interest.

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