ADAPTATION MECHANISMS OF PLANTS OF DECIDUOUS *SAL* AND EVERGREEN HILL FOREST STANDS IN BANGLADESH

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Dr. Mohammad Zabed Hossain
Ph.D. (UGAS, Iwate, Japan)
Post-Doc (SLU, Uppsala, Sweden)
Professor

Ecology and Environment Laboratory
Department of Botany
University of Dhaka
Dhaka -1000, Bangladesh

CERTIFICATE

This is to certify that the thesis entitled ***"Adaptation mechanisms of plants of deciduous Sal and evergreen hill forest stands in Bangladesh"*** *submitted by Mohammad Ataur Rahman has been carried out under my supervision in the Department of Botany, University of Dhaka. This is further to certify that it is an original work and suitable for submission for the award of Doctor of Philosophy in Botany.*

Date: 30 October, 2021

Supervisor
Mohammad Zabed Hossain (Ph. D.)

Tel. : 880-9661920-73/7555 **(Off.), Cell:** 88-01727736087, **Fax :** 88-02-9667222
E-mail: zabed@du.ac.bd **Website:** https://t.ly/Zabed

DECLARATION

I, Mohammad Ataur Rahman, hereby declare that the thesis entitled **"Adaptation mechanisms of plants of deciduous *Sal* and evergreen hill forest stands in Bangladesh",** submitted in partial fulfillment for the degree of Ph. D. in Botany at Ecology and Environment Laboratory, Department of Botany, University of Dhaka, is the result of my own investigation. This work has not been submitted before to this University or any other institution to obtain any degree, diploma, associateship, fellowship or any other similar title.

Date: 30 October, 2021 Mohammad Ataur Rahman

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The author

Dedication

To My Parents

ABSTRACT

Forests are fundamental sources of biological diversity and play important role in constituting terrestrial ecosystem on Earth. Plants, which are important for primary production, govern the structure of forest ecosystems. They play immense role in conserving biodiversity, ecosystem stability, natural resource sustainability, climate regulation, hydrologic cycling as well as providing habitat for plants and animals. Understanding the structure of vegetation and adaption mechanisms of forest plants is important for better management and conservation of forest ecosystems. In plant ecology, recent studies on the adaptation of plants to drought condition through changes in their leaf characteristics have received considerable interests although less is known about how tropical deciduous and evergreen forest plants adapt with their environment. The specific objectives of this study, therefore, were to (1) compare the vegetation structure (diversity and composition) of the selected study areas of Madhupur Sal forest and the Sitakunda Ecopark, (2) examine the relationships of plant vegetation structure with the soil properties of the study areas and (3) investigate the leaf morphological, physiological, and anatomical traits in relation to environmental variables such as soil properties and climatic factors to reveal the underlying adaption mechanisms of deciduous and evergreen forest plants. To study the vegetation of the two forests, a nested design with quadrats of 10 m × 10 m, 5 m x 5 m, and 1 m x 1 m was chosen. A total of 72 quadrats were studied, with 12 for each of the three different habits (herbs, shrubs and trees) under two different forest types. Soil samples were taken from 0-10 cm depth in the center of the quadrats for the analysis of physico-chemical properties. In three consecutive years 2017, 2018 and 2019, leaves were sampled from three individual plants for each of the 5 selected plant species from each forest types during summer (June) and winter (December). A total of 22 leaf parameters (8 morphological, 4 physiological, and 10 anatomical) were investigated and the results were averaged across three years to provide mean values for each season. Data revealed that the composition of herbs, shrubs and tree species differed between two forests. Difference in dominant and rare species between two forest types was revealed by the Importance Value Index. Madhupur Sal forest showed a significantly ($P = 0.05$) higher number of species (15.5) per quadrat than Sitakunda Ecopark (13.33). The 'productivity versus diversity' hypothesis was tested by regression analysis, which revealed significant negative correlations of tree ($R^2 = 0.29$, $P = 0.02$) and shrub ($R^2 = 0.18$, $P = 0.05$) species richness with soil P content across forest types. Plant density had a significant negative correlation ($R^2 = 0.39$, $P = 0.03$) with plant DBH (diameter at breast height) in the Madhupur Sal Forest, indicating a negative interaction between plant growth and density, though this relationship was stronger in Madhupur Sal Forest than in the Sitakunda Ecopark. Based on both physical and chemical properties of soil, Principal Component Analysis (PCA) revealed that the two forests were separated from one another. Based on the species score, Non-Metric Dimensional Scaling (NMDS) analysis revealed that plots of the two selected forests were divided into two groups, with the Madhupur Sal forest being characterized by highly dominant species of *Shorea robusta, Grewia nervosa, Mallotus philipensis, Glycosmis pentaphylla, Adina cordifolia, Litsea glutinosa, Antidesma acidum* and *Ficus hispida* and that of the Sitakunda Ecopark was characterized by that of *Castenopsis tribuloides, Erioglossum rubiginosum, Holarrhena antidysenterica, Phyllanthus emblica, Streblus asper and Suregada multiflora.* Data also revealed that soil factors such as P ($R^2 = 0.53$, $P = 0.01$), K ($R^2 = 0.27$, $P = 0.01$), available N ($R^2 = 0.42$, $P = 0.01$), C ($R^2 = 0.28$, $P = 0.01$), clay ($R^2 = 0.28$, $P = 0.01$), and sand ($R^2 = 0.25$, $P = 0.01$) were significantly correlated with NMDS axes, implying that soil properties played role in structuring forest vegetation. In both seasons, nested ANOVA statistics demonstrated that forest types had stronger influence on the majority of leaf functional attributes than species identity, indicating the importance of forest types in understanding forest plant adaptation to drought conditions. The Madhupur Sal forest had significantly larger leaf fresh weight, leaf turgid weight, leaf area, specific leaf area and leaf dry matter content. The Sitakunda Ecopark had higher leaf water content, chlorophyll content, and stomatal density. All of these changes in leaf attributes between these two forest types followed similar patterns throughout the summer and winter seasons demonstrating that the functional types had a considerable influence on plant leaf traits. Leaf morpho-physiological properties, which indicate leaf economic traits, were used to differentiate the Madhupur Sal Forest from Sitakunda Ecopark between seasons using PCA based on the correlations between the leaf traits of the two forests plants. Madhupur Sal forest had much higher leaf dry matter content, leaf fresh weight, and leaf turgid weight content than Sitakunda Ecopark implying that the plants in this forest were more water-use efficient than that in Sitakunda Ecopark. Plants in Madhupur Sal forests had a higher specific leaf area than those in Sitakunda Ecopark suggesting that they compensated for the loss of photosynthetic product due to leaf fall during the winter by increasing the specific leaf area to improve photosynthetic potential for the rest of the year. Despite having higher chlorophyll content than deciduous plants in Madhupur forests, higher stomatal pore index values and open stomata might be responsible for greater transpiration and water loss in plants of Sitakunda Ecopark. Overall, the findings of this study demonstrated that soil conditions played a significant role on the diversity of plant species and vegetation composition in the Madhupur Sal Forest and the Sitakunda Ecopark. Data also revealed that plants in the Madhupur Sal Forest and Sitakunda Ecopark responded to drought stress by using avoidance and tolerance strategies, respectively.

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CHAPTER 1

INTRODUCTION

1.1 **Background**

Forests are one of the most complex and diverse ecosystems on Earth (Gibson *et al.* 2011). They are the primary source of biological diversity in nature, and they play important role in net primary productivity, nutrient cycling and gaseous exchange. They provide habitats for plants and animals and thus support biodiversity. Forests are important ecosystems that help maintain ecological balance on earth. By providing provisioning, regulatory, and cultural services, forests allow humans to meet their fundamental requirements (Brockerhoff *et al.* 2017).

Forests are diverse in terms of physiognomy, community structure and life forms throughout the world. The total forest area of the Earth is 4.06 billion hectares representing 31% of the land surface of the Earth (FAO 2020) and providing global carbon storage (IPCC 2000). In other chiasmatic domains, tropical forests cover 45% of the total forest area (FAO 2020) and cover around 15% of the surface of the earth but contain more than two-thirds of the floral and faunal diversity of the world. (Pan *et al.* 2013; DeFries *et al.* 2005; Bierregaard *et al.* 1992). Tropical forests support ecosystem-based adaptation, which involves exploiting biodiversity and ecosystem services as part of a larger climate adaptation strategy (SCBD 2009; Lo 2016). Tropical forests area found in Central and South America, western and central Africa, western India, Southeast Asia, New Guinea, and Australia (FAO 2020).

Bangladesh is a transitory zone for the flora and fauna of the subcontinent and Southeast Asia, lying in the Oriental area at the intersection of the Indo-Himalayan and Indo-Chinese sub-regions (Mittermeier *et al.* 1998; Feeroz 2013; Stanford 1991). It is one of the most ecologically significant and biologically diverse environments in the region, including migratory species, stepping stones, staging grounds, and flyways for wildlife migrations (Myers *et al.* 2000). The total forest area of Bangladesh is 1.429 million hectares, or 11% of the total land area of the country, as per the Global Forest Resources Assessment (BFD 2015). Natural forest compensates 84% of total area of forest. Natural forms of forest include the three major types of forest such as Hill Forest, Mangrove Forest and Sal Forest that cover more than 70.8% of the total forest area in Bangladesh (BFD 2016). Sal forests and Hill forests are distinct forest types with differing life forms; the former is deciduous, while the latter is usually semi-evergreen.

Deciduous trees lose their leaves in the winter or during the dry season to reduce water loss through transpiration. Leaves of deciduous tree have a shorter life span of less than a year and a higher photosynthetic rate per unit leaf area that does not vary significantly during the leaf growth period, that of evergreen tree have a longer life span of more than a year and a higher photosynthetic rate per unit leaf area that does not vary significantly during the growth period of leaf (Jin *et al.* 2018). When the conditions are favorable, deciduous plants usually select an ecological strategy with a fast growth rate which means that they grow fast. These plants often occupy the upper structure of secondary forests that have been affected negatively by disturbances (Pollmann *et al.* 2002; Sato *et al.* 2009). Evergreen tree species, on the contrary, show a longer growing season and use a conservative strategy to offset the cost of their long-lasting leaves (Reich *et al.* 1992; Gonzalez-Zurdo *et al.* 2016). Shade-intolerant deciduous trees are found as pioneer or early successional species throughout forest succession in many studies, however shade-tolerant evergreen trees may be dominant at a later successional stage which are found in tropical and subtropical regions (Chi *et al.* 2016; Lu *et al.* 2017; Jamshidi *et al.* 2018). The trade-offs between photosynthetic capability and leaf life result in varied leaf habits between deciduous and evergreen tree plants (Kikuzawa *et al.* 2013). One of the most recent themes in plant ecology is to look for plant features that can indicate differences in ecological behavior between species (Garnier *et al.* 2001). Plant traits are functional adaptations to a variety of biotic and abiotic factors, and they may be useful indicators of a species' response to different environmental conditions (Milla and Reich 2011).

The construction of a large database for plant functional features is a high priority in the plant ecology research agenda, since it aids in the understanding and prediction of species distribution in current and future environments (Keddy 1992; Westoby 1998). Leaves are important organs in both taxonomy and ecology (Rogers and Clifford 1993). Leaf habits have long been recognized as useful tools in ecological research (Traiser *et al.* 2005); intimately linked to growth and survival (Westoby 1998; Garnier *et al.* 2001), and are usually regarded as accurate predictors of plant performance and efficient markers of resource-use strategies (Wilson *et al*. 1999).

Water is regarded as one of the most essential abiotic stresses for plant growth, survival, and distribution. Leaves are important organ that help plant adapt with environmental changes because they are not only the high sensitive and flexible organ to spatial and temporal variation in the environment but at the same time help improve plant adaptability through own regulation (Zhang *et al.* 2018). The study of how plants respond to drought by changing their leaf morphology has received a lot of interest although less is known about the topic (Stropp *et al.* 2017).

Plant leaves show morphological and anatomical adaptation with drought conditions. In dry condition, the plants develop thick and small leaves with a cracked appearance and small specific leaf area in addition to other traits. Drought changes the physiological and stoichiometric properties of plant leaves. Some studies reported that as the level of drought rises, the photosynthetic rate may decrease (Tanaka and Shiraiwa

2009). Drought affects negatively on plant nutrient (N and P) and positively on N to P ration (Lu *et al.* 2017).

Wright *et al.* (2004) developed a universal spectrum concept based on important chemical, structural and physiological properties of leaves. The leaf economic spectrum includes species with a “rapid investment return” startegy, such as those with high nitrogen content in the leaves, high photosynthetic and respiration rates, short life spans, and low specific leaf mass, while species with a "slow investment-return" strategy, for instances those with a long-life span, large specific leaf area, low tissue N content, photo assimilation rate, and respiration rate, are on the other end of the spectrum (Osnas *et al.* 2013).

Single-species based leaf traits of plants from different environmental conditions are important for reflecting particular adaptive strategies (Zhu *et al.* 2012; Ramirez-Valiente *et al.* 2015). Plant functional type indicates a group of plants that share several important functional properties responding to the environment similarly, and at the same time take part in similar ecological function (Semenova and van der Maarel 2000). Dominguez *et al.* (2012) reported that adaptive processes of plant showed difference between species and plant functional types. Although the environment is thought to be a major determinant of leaf functional traits at the species level (Bu *et al.* 2017), the phylogenetic relationship between species should also be taken into account because species with similar phylogenetic relationships may have similar functional traits (Grether 2005; Losos 2008). Plant functional types can represent a wide range of adaptive strategies, making them a helpful tool for detecting patterns of environmental change (Ian and Wolgang 2010). Furthermore, a fundamental difficulty in ecology is determining what adaptation mechanisms allow plants to successfully pass-through environmental stress conditions.

The correlations between leaf features, as well as how traits differ between or across growth patterns and plant functional types (deciduous versus evergreen), can provide valuable insight into the selective pressures that determined the development of the vegetation on Earth (Wright *et al.* 2005a). Plants of evergreen and deciduous functional types can exist together in a wide range of environmental conditions across the world, and both play key roles in structure and function of forest ecosystems (Wang *et al.* 2007a; Ouédraogo *et al.* 2016). The relative dominance of distinct leaf types (deciduous versus evergreen) is critical to the physiognomy of some forests, and it is frequently used as a dividing line between evergreen, deciduous, and mixed forests (Wu 1980; Franklin *et al.* 2015) although less attempt has been taken to address this issue in the tropical regions.

Plant functional characteristics of tropical forest were little known. With 56 tropical dry evergreen forest tree species, Udayakumar and Sekar (2017) discovered a substantial negative association between leaf area and wood density. Leaf traits can help researchers better understand the ecophysiology of forest tree species. The goal of the present study was to determine the degree to which major leaf features of tree species and soil conditions in the Madhupur Sal Forest and Sitakunda Ecopark are related.

Plant diversity helps to keep ecosystem processes and functions running smoothly, as well as affecting ecosystem services (Balvanera *et al.* 2006). Biodiversity is studied in order to conserve and manage natural habitats properly (Pielou 1995). It is crucial to conserve biodiversity in an environment since it is not always clear which species and amounts of those species are required to keep the ecosystem functioning normally (Burton *et al.* 1992). Information about the composition of a forest is critical for its efficient management in terms of economic worth and possible regeneration (Wyatt-Smith 1987).

In Bangladesh, there is a pressing need to adequately maintain and manage existing natural forests for future generations (Hossain *et al.* 2017). Understanding vegetation structure as well as exploring the underlying adaptation mechanism through leaf trait are important for gaining a better knowledge of tropical forest ecology and formulating national forest management policies (Reddy *et al.* 2011). Hence, the present study was undertaken with the following objectives.

1.2 Objectives

The specific objectives of the study were to

- compare the vegetation structure (diversity and composition) between Madhupur Sal forest and the Sitakunda Ecopark as deciduous and evergreen forests, respectively.
- examine the relationships of plant species composition with the soil properties of the study area
- compare the relative importance of effects of tree species identity and functional types such as deciduous (i.e., Madhupur Sal forest) and evergreen (i.e., Sitakunda Ecopark) forests on the leaf traits in order to ascertain their effects on plant adaptive strategies
- examine whether the effects of plant species and functional types on leaf traits vary with different seasons of the year and
- investigate the soil properties in order to examine their relations with the variation in leaf traits of the forest plants

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definition and significance of forest

According to Land having a tree canopy cover of more than 10% and an area of more than 0.5 ha with trees higher than 5 meters is defined as a forest (FAO 2020). Forests are simply defined by the presence of trees and the absence of other predominant land uses, and they include both natural forests and plantation forest. The formation of different forest types is greatly influenced by many factors including temperature, topography, wind, microclimate, soil types, soil moisture, rainfall, humidity and geography of the area (Das 1990). Forests are one of the most diverse and complex ecosystems on earth. They are the fundamental source of biological diversity that plays important role in functioning of the ecosystems on earth. Forests are important habitats for biodiversity and are also necessary for the supply of a variety of ecological services. Tropical forests, which hold up to 90% of terrestrial biodiversity, are particularly important in terms of species richness and endemic species concentration (Brooks *et al.* 2006). Forests are one of the most significant ecosystems, covering 31% of the Earth's land surface (FAO 2020) and providing global carbon storage (IPCC 2000). Forest ecosystems are the primary source of biodiversity of the terrestrial ecosystems (Brockerhoff *et al*. 2017). These are essential for life on Earth because they provide ecological services such as controlling climate and water resources and providing habitat for plants and animals. Plants provide crucial primary production and play role in ecosystem structure. Thus, forests provide provisioning, regulating and cultural services and hence provide humans with basic needs and also help maintain ecological balance of the Earth (Brockerhoff *et al.* 2017).

2.2 Global distribution of forest

Globally, forests are diverse in physiognomy, diversity, community composition and life forms. According to FRA 2020, the total forest area is 4.06 billion hectares and are not equally distributed around the globe. Among the total forest area, tropical forest cover 45% from other chiasmatic domain (FAO 2020). More than half of the world's forests are found in only five countries including the Russian Federation, Brazil, Canada, the United States of America and China. Two-thirds (66%) of forests are found in Australia, Congo, Indonesia, Peru, India and rest of the world. There are five major forests by climatic domain and ecological zone. The largest part of the forest (45%) is found in the tropics, followed by the boreal (27%), temperate (17%) and subtropical domains (11%). These domains are further divided into terrestrial global ecological zones, 20 of which contain forest cover (FAO 2012a; Buchhorn *et al.* 2019) as shown in Figure 2.1.

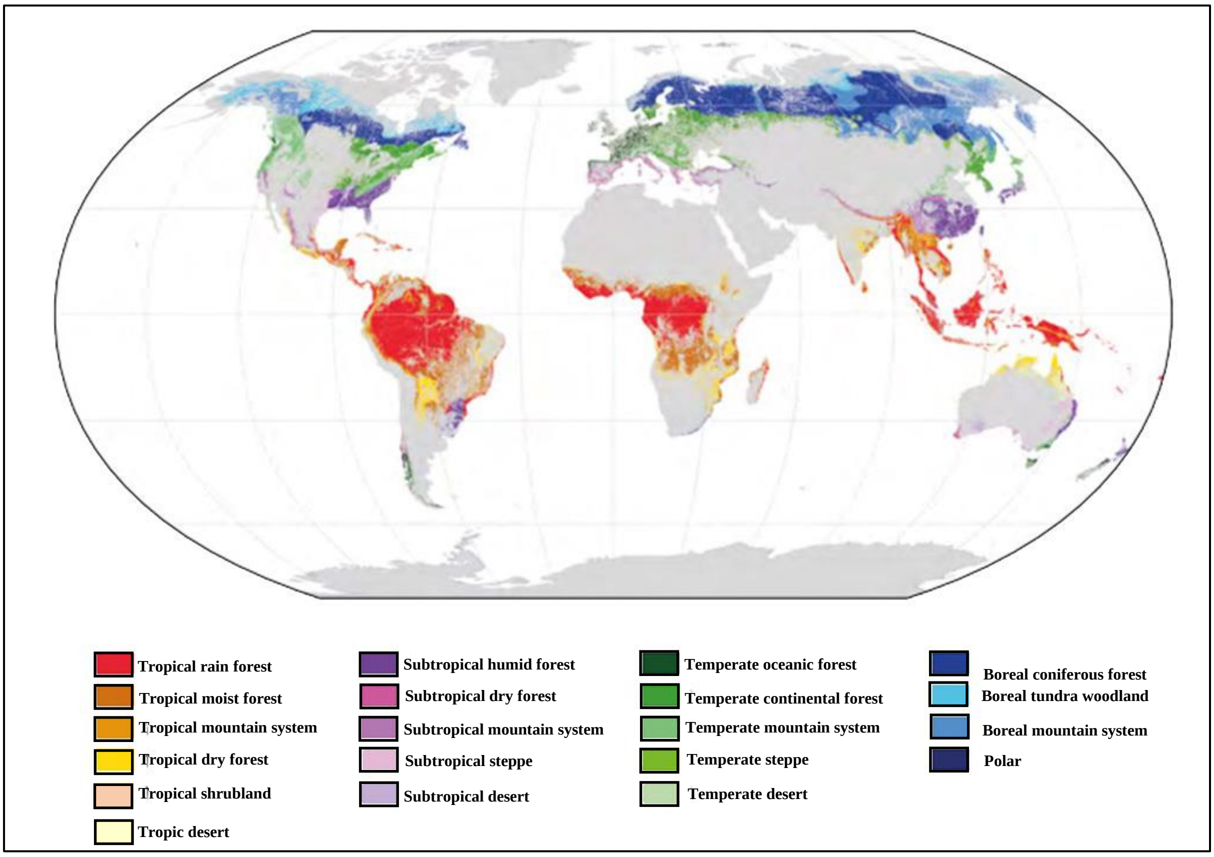


Figure 2.1: Map showing global forest cover. Source: FAO 2012a, Buchhorn *et al*. 2019.

2.3 Distribution of tropical forest in South Asia

Forests in the tropics covers nearly about 15% of the area on Earth although they support nearly two-thirds of the world floral and faunal diversity (Pan *et al.* 2013) and harbour approximately two-thirds of all living organisms (Hughes *et al.* 1997) including 96% of tree species (Poorter *et al.* 2015). Tropical forest contributes to ecosystem-based adaptation and provide services derived from biodiversity and ecosystem which is relevant in the context of global climate change scenario (SCBD 2009; Lo 2016). South Asia is one of the least-forested subregions in the Asia-Pacific region and forests have played a central role in the development of the tropical region and the production of wood and other products, the conservation of global biodiversity, climate change abatement and protection of land and water resources. The South Asian subregion covers a land area of 10.4% of Asia and the Pacific's land (FAO 2012b). About 19% of the total land areas are covered with forest area of the Asia-Pacific region (FAO 2009a). Among the total forest area in Asia and the pacific, South Asia forests cover 79 million hectares. In South Asia, in particular, 23% of the world's population relies on only 2% of global forest resources (FAO 2004). Forest zone of South Asia stretches from the Indian Ocean in the south to the Himalayas in the north, making it one of the most ecologically diverse subregions on the planet. The great range of rainfall, temperature, altitude, and soil conditions is accentuated by the various pattern of human interventions, resulting in a landscape that is extraordinarily diversified and complicated. Coastal mangroves are found in Bangladesh, India, the Maldives, Pakistan, and Sri Lanka, as well as alpine meadows in Bhutan, India, Nepal, and Pakistan, and tropical rain forests in Bangladesh, India, and Sri Lanka, as well as desert scrublands in India and Pakistan (FAO 2012b). The vast changes of subregion in soil, temperature, and rainfall have resulted in a highly diversified forest vegetation (FAO 2012b) as shown in Table 2.1.

Table 2.1: Main Forest types of South Asia (FAO 2012b)

Types of forest	Subtypes of forest	Countries
Tropical forests	Wet evergreen forests	Bangladesh, India and Sri Lanka
	Semi-evergreen forests	Bangladesh, India and Sri Lanka
	Moist deciduous forests	Bangladesh, India, Nepal and Sri Lanka
	Dry deciduous forests	India, Pakistan, Sri Lanka
	Thorn forests	India and Pakistan
	Littoral and swamp forests	Bangladesh, India, Maldives, Pakistan and Sri Lanka
Subtropical forests	Broadleaved hill forests	Bhutan, Bangladesh, India, Nepal and Pakistan
	Pine forests	Bhutan, Bangladesh, India, Nepal and Pakistan
	Dry evergreen forests	India and Pakistan
Temperate forests	Montane wet temperate forests	India and Sri Lanka
	Himalayan moist temperate forests	Bhutan, India, Nepal and Pakistan
	Himalayan dry temperate forests	Bhutan, India, Nepal and Pakistan
Alpine and subalpine forests		Bhutan, India, Nepal and Pakistan

2.4 Status of forest in Bangladesh

The vegetation of Bangladesh could be a part of rich biological diversity because of its unique geophysical location (Hossain 2001; Nishat *et al.* 2002). In terms of migratory species, stepping stones, staging grounds, and flyways for wildlife migrations, it is one of the most ecologically significant and biologically varied landscapes in the region, and it is part of the Indo-Burma biodiversity hotspot (Myers *et al.* 2000). The total area of forest land in Bangladesh is about 2.62 million hectares (BFD 2015). Out of the total forest area, 1.6 million hectares is under the control of the Forest Department (FD). Tree cover in forest land amounts to only 6.7% (FAO 2009b) which is much less than 17.62% of the land that has been designated as forest lands (BFD 2016). According to the Global Forest Resources Assessment, total forest area of Bangladesh is 1.429 million hectares, or 11% of the country's total land area (BFD 2015). Natural forest covers 84% of the entire forest area, while plantation forest covers approximately 16%. The three major types of forest, namely Hill Forest, Mangrove Forest and Sal Forest are natural types of forest in Banglagesh cover more than 70.8% of total forest area (BFD 2016) as shown in Figure 2.2. Of these forest types, the Hill forests and the Sal forests are distinct with different life forms; the former is deciduous and the other one is mostly semi-evergreen. The natural forests of Bangladesh have its unique geo-physical location. Due to this reason, these forests are considered as one of the richest and biologically diverse forest resources (Hossain 2001). Different natural heritages are manifested in different regions of Bangladesh. The great forest of Sundarbans lies in the southwestern region of the country, the Sal Forest in the middle and the evergreen hill forests in the southeast. In the forests of Bangladesh, there is a great variation in flora and fauna with different and distinct ecosystems (Khan *et al.* 2007). The country contains a rich biological heritage containing about 3,611 species of angiosperms

(Khan *et al.* 2007), of which 2,260 species are reported from Chittagong region alone (Heinig 1925; Khan *et al.* 2007). The diversity of trees is key to total tropical forest biodiversity, because tree provides resources and habitats for nearly all other forest species (Huston 1994; Canon *et al.* 1998; Hall and Swaine 1976).

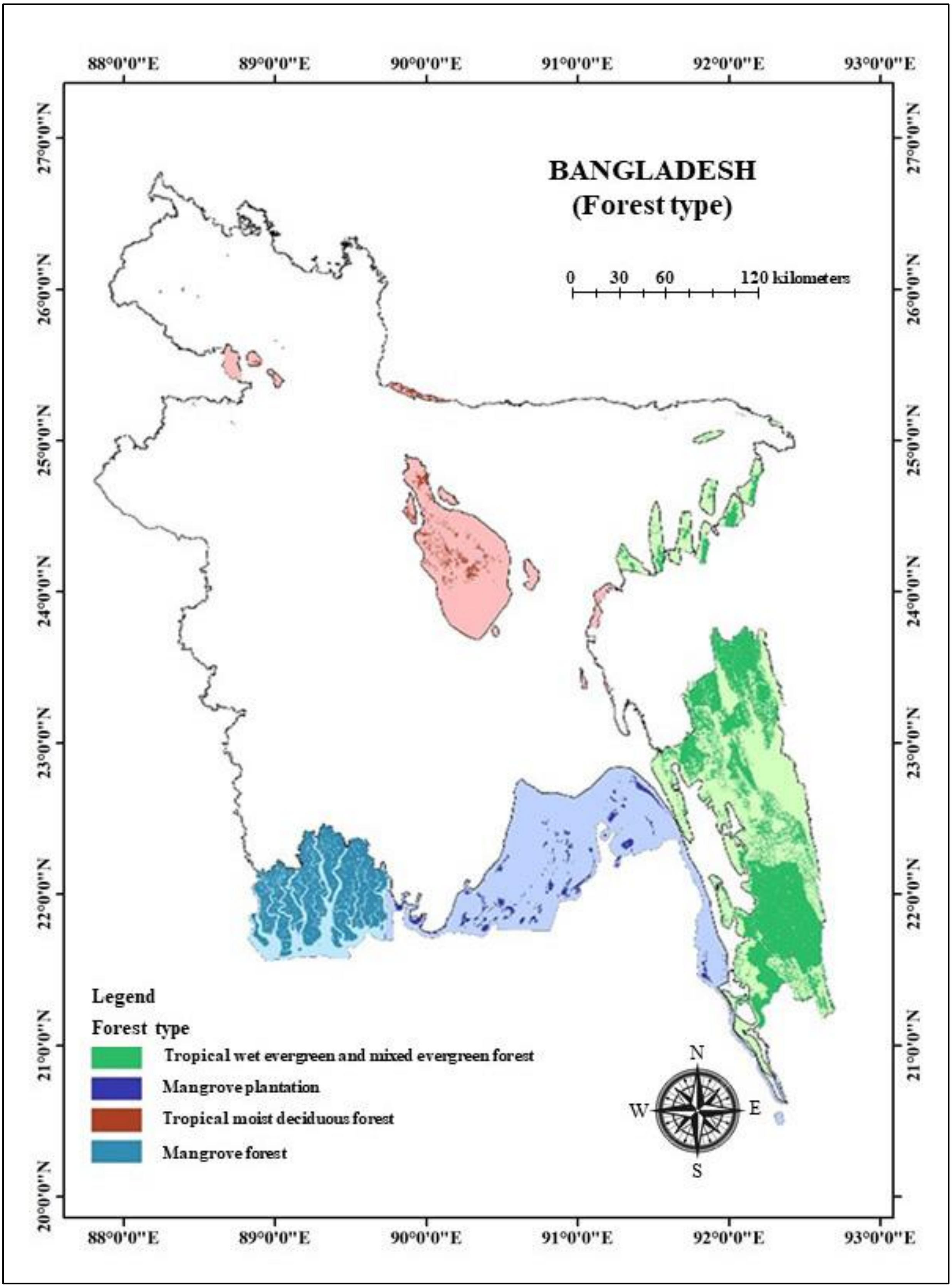


Figure 2.2: Map showing forest types of Bangladesh.

2.5 Distribution of tropical deciduous and semi-evergreen forest

Tropical deciduous forests can be found in the humid subtropics and along the equator between the tropics of Cancer and Capricorn. Forests of this type can be found in Bangladesh, India, Pakistan, Nepal, and Sri Lanka. In India, Pakistan, Nepal, and Sri Lanka. Around 40% of the earth's subtropical area is covered by open or closed forest, with tropical dry deciduous forest accounting for 42%, moist forest for 33%, and wet forest accounting for 25%. (Murphy and Lugo 1986). Sal woods can be found in both wet and dry areas. Sal forests are found mostly in South and Southeast Asia ranging from Assam to Punjab along the foot of the tropical Himalayas, in the eastern regions of Central India, and on the Western Bengal Hills. Sal forests are the most widely distributed of all Dipterocarpus, covering an estimated 13 million hectares in India alone, and over one million hectares in Bangladesh and Nepal combined. Sal forests span over 1,21,000 acres in Bangladesh, accounting for about 32% of the total forest area (BFD 2015).

Semi-evergreen forests are found adjacent to tropical wet evergreen forests, and they serve as a bridge between evergreen and moist deciduous forests. These forests can be found along the western coast of India, in Assam, on the lower slopes of the eastern Himalayas, and in the Andaman Islands; and in Bangladesh, in locations with slightly lower precipitation and air humidity than tropical evergreen vegetation. Evergreen and moist deciduous trees coexist in such forests. These woodlands have an evergreen character due to the undergrowth climbers. Climbers are thick, bamboos are scarce, and epiphytes are plentiful. A variety of huge trees with a proclivity for gregariousness dominate the woodland (i.e., growing in groups that are close together).

2.6 Deciduous forests in Bangladesh

Deciduous forests are those in which the principal constituent trees lose their leaves in the winter or during the dry season to limit water loss through transpiration. The Sal tree, *Shorea robusta* Gaertn., is the main species in this type of forest, accounting for about 90% of the major floral composition. The tree grows to a height of 10 to 25 meters and loses most of its leaves in the winter. The yearly rainfall in these forest areas is typically around 2000 mm (Dey 2007). A Sal Forest is a type of forest in which a single plant species dominates. These forests of Bangladesh are of two kinds: moist deciduous and dry deciduous. Moist deciduous are distributed in Madhupur tract while that in the Dinajpur district is dry deciduous in type (Hossain *et al.* 2010b). The deciduous Sal forests are considered as one of the richest ecosystems in regard to forest diversity in Bangladesh. However, the level of diversity is generally unknown to the scientific community, politicians, and local people and is, therefore, not well documented at all. The forests are facing a severe threat by anthropogenic disturbances caused by humans who directly or indirectly depend on forest resources for their social welfare. The topography, geology, and soil conditions all influence the distribution of Sal forests (BFD 2015). Though Sal is the single most important tree species in Sal Forest, yet about five hundred undergrowth species have been reported in association with Sal trees (Gain 2004). The vast association of undergrowth diversity in the Sal Forest ecosystem is facilitated by a unique sort of microclimate (Alam 2006). Sal forests rich in phytodiversity have been under severe threat due to over-exploitation, deforestation, excessive leaf-litter collection, encroachment, indiscriminate collection of specific economically important plant species (i.e., medicinal, fodder, etc.) and other forms of human interference due to their geographical location and topographical condition (plain land nature). The Sal used to compensate 70% of the trees in the Sal Forest. Nevertheless, Sal Forest patches have been decreased to the point where they no longer resemble the traditional Sal Forest in most places. The majority of the Sal Forest has been degraded and encroached upon, or taken over for commercial or industrial rubber, Acacia, Eucalyptus, Pineapple, or exotic fuel wood plantations. From a social standpoint, Sal Forest is one of the most important woodland areas in Bangladesh, where a diverse group of tribal people lives and depend on the forest for their entire livelihood. Because of its wealth of medicinal plants and natural habitat for threatened animals like the Hoolock gibbon (*Hylobates hoolock*), as well as international (as a dry and plain land tropical deciduous forest ecosystem) interest, such a disturbed but socioeconomically and environmentally important forest ecosystem requires a comprehensive development of the entire ecosystem (Rahman 2008). Overall, for ensuring a productive forest ecosystem, it is important to understand the mechanisms of adaptation in relation to the environment.

Sal forests can be found in the drier central and northern parts of Bangladesh, particularly in the districts of Gazipur, Tangail, Mymensingh, Jamalpur, Cumilla, Dinajpur, Thakurgaon, Rangpur, and Rajshahi. Smaller surviving patches of forest lands (containing around 14,000 hectares) are found in the districts of Rangpur, Dinajpur, Thakurgaon, and Naogaon, with some remaining in Shalban Vihara of cumilla, Mainamati, and Rajeshpur (about 200 ha). These forests existed as a continuous swath from Cumilla in Bangladesh to Darjeeling in India until the late nineteenth century.

2.7 Madhupur Sal forest

Madhupur Sal Forest, the oldest protected area comprises a significant part of tropical moist deciduous forest in the central region of Bangladesh. A total of 174 plant species was recorded under 131 genera and 54 families in Madhupur Sal Forest of which about 102, 17, 34 and 21 species were classified as under tree, shrub, herb and climber, respectively according to their growth habits and as regards to diversity of species by genera (Malaker *et al.* 2010). Rahman *et al.* (2017) found a total of 385 plant species belonging 293 genera and 95 families. The habit form distribution indicates that among the 385 plants, number of tree species were maximum (140) followed by 135 herb, 48 shrub, 46 climber, 9 fern, 5 epiphyte and 2 parasites. Some other study recorded that there were 139 tree species belonging to 100 genera and 40 families (Rahman *et al.* 2019).

2.8 Semi-evergreen forest in Bangladesh

The enormous variation in soil, temperature and rainfall have created highly diverse forest vegetation in the hill tracts of Bangladesh. About 44% of total hill forest managed by the Forest Department and the total area of Hill Forests is 0.67 million hectares, which is 4.65% of the total area of the country (Khan *et al*. 2007). Hill forest refers to the natural forest found in the mountainous parts of Chittagong, Chittagong Hill Tracts, Cox's Bazar, and Sylhet. It is made up of moist tropical evergreen, semi-evergreen, and deciduous trees that are all of different ages. In this forest, there are fewer shrubs and herbs as undergrowth. The Hill Forests are rich in diverse variety of flora and fauna. Different tribal people dwell in hill forest areas, especially in the three hill tract districts. For their livelihood, tribal people depend on these forests. Based on geographical location, climate, topography and management principles, the hill forests of Bangladesh can be classified into two forest types, namely, Tropical Wet Evergreen Forests and Tropical Semi–Evergreen Forests. The forests in the north and south east are mostly semi-evergreen (Feeroz *et al.* 2011; Feeroz 2013). In the Chittagong Hill Tracts in the southeast, some rather extensive sections of mixed-evergreen forests still exist (Khan 2008). Although evergreen plants predominate in semi-evergreen trees, deciduous plants also do exist.

2.9 Sitakunda Ecopark

The Sitakunda Ecopark is a part of semi-evergreen forest in nature. The Park is located in the Southern Sitakunda Reserved Forest under the Chittagong North Forest Division. The Bangladesh Wildlife Preservation (Amendment) Act 1974 established it in the year 2000. The eco-park was previously located in the Chandranath block of Sitakunda Beat in the Bariadhala Range of Chittagong North Forest Division, and it had exotic biodiversity as well as endangered and threatened species (Alam 2001; Misbahuzzaman and Alam 2006). During their expedition to Chittagong in 1851, Hooker and Thomson collected a number of botanical specimens from Sitakunda and listed numerous species in the Flora of British India between 1872 and 1892 (Khan 1991). Bangladesh Forest Research Institute (BFRI 1989) recorded 29 tree species that occurred in the past, 12 middle sized to small trees, 7 species near the streams, aroids and ferns. From the entire Sitakunda Forest Reserve, Rahman and Uddin (1997) identified 203 species in 154 genera and 54 families. On the hills of the Sitakunda Botanical Garden and Eco-Park area, Alam (2001) found 55 shrubs and 62 herbs. Uddin *et al.* (2005) found 54 medicinal plant species in the park area, divided into 34 families, comprising 23 species were trees, 19 shrubs, 4 herbs, and 8 climbers. This Ecopark has a total of 332 vascular plant species from 266 genera and 93 families, including cultivated, wild, and plantations. A total of 324 species of angiosperm and 8 species of gymnosperm were identified, with 140 species being trees in the plant community, followed by 90 herbs, 66 shrubs, climbers (25 species), 9 ferns, and 2 epiphytes (Dutta *et al.* 2014). Sitakunda botanical garden is expected to host a great variety of native angiosperm and gymnosperm species, as well as some exotic species that have been imported.

2.10 Environmental determinants of the distribution of forest plants

The association between climate and some traits is well documented, and functional traits of tree species suggested patterns of adaptation to their environment (Reich 2014; Wright *et al.* 2005b). Functional traits can represent plant performance, stress, and allocation, and are thus influenced by selecting forces, as evidenced by trait variation over environmental gradients, which indicates genetic adaptation (Reich *et al.* 2003). By definition, functional characteristics are related to their environment and population differentiation along climate gradients can be used to assess the relative contribution of climate factors to trait differentiation patterns (Madani *et al.* 2017).

Ecologists have always been interested in understandins about the long-term viability of plant species in the face of climate change (Brown 1984; Gade and Peterman 2019; Fescenko *et al.* 2020). Since plant species have different environmental requirements, their abundance and distribution change as the environment changes (Iqbal *et al.* 2017; Liang *et al.* 2020; Liu *et al.* 2020). The impact of a variety of environmental factors on the distribution and abundance of plant species has recently become a hot topic in environmental and ecological sciences (Zhang *et al.* 2012; Nguyen *et al* 2015; Manan *et al.* 2020; Shi *et al.* 2020).

Recent research has revealed that regional topographic variables (e.g. slope), edaphic factors (e.g., chemical and physical properties), and related human impact factors are frequently linked to vegetation patterns (Hoang *et al.* 2011; Khan *et al.* 2012; Khan *et al.* 2016; Bano *et al.* 2018; Metzen *et al.* 2019; Bhat *et al.* 2020). Topographic variables and soil type information are the second most important category of variables in defining a vegetation of an area, following rainfall and temperature. Climatic conditions become the key determinants of the abundance of specific species in a given terrain (Maestre and Escudero 2009). Climate factors play a big role in determining species diversity (Sharma *et al.* 2009). In addition to topographic characteristics at regional and local scales, altitude is one of the influencing elements considerably regulating plant species diversity (Khan *et al.* 2015). In addition, topographic characteristics such slope plays an important role in the spatial variance of vegetation (Cielo-Filho *et al.* 2007). Declines in plant diversity have resulted in broad ecosystem function as a result of human disturbances such as deforestation and the afforestation of non-native plants as a result of climate change (Barnes *et al.* 2016).

Plants can adapt to climate change by changing their physical characteristics or moving to areas with better environmental circumstances (Madani *et al.* 2017). In a successive community structure and in biodiversity the vegetation characteristics of plant communities are the products of the interaction between plants and their living environments (Pinder *et al.* 1997). In the field of plant ecological research, the relationship between plant communities and their habitats is vital (Woodward and Mckee 1991). The combined effects of environmental factors at different scales are responsible for the differences of plant composition of natural plant communities (Burke 2001; Borcard *et al.* 1992). Soil physical and chemical properties are environmental factors such as soil nutrients, directly or indirectly shape natural plant communities (May 1992).

Soil nutrients are the prime requirements for the growth and development of plants. The degree of efficiency of nutrient uptake differs among various plant species (Bardgett 2005). Based on this feature, plants can be divided into two groups; fast growing plants and slow growing plants. The fast-growing plants require more nutrients for their growth and the slow growing plants require lower amount of nutrients (Krouk *et al.* 2011). It is generally accepted that fast growing plants proliferate in fertile soil (Bardgett 2005). Fast growing plants produce easily decomposable litter that is rich in nutrients. On the other hand, slow growing plants produce nutrient poor litter (Bardgett 2005; Hossain *et al*. 2010a)

Nitrogen, phosphorus and potassium are the three most important nutrients for plant growth. These three nutrients are required in larger quantities than other nutrients. High levels of nutrients enhance the growth rate of plants. In the long term, N:P ratios are insufficient to forecast how changes in nitrogen supply will influence plant species composition. However, the findings suggest that biomass N:P ratios represent the relative availability of N and P to plants and may be more reliable than fertilization studies in predicting the degree of N or P deficit experienced by a plant community. Güsewell *et al.* (2003) employed N:P ratios to study how the relative availability of N and P affects key ecological processes and how it is influenced by human impacts or management.

Infertile soil restricted to wild plants, on the other hand, have lower maximum potential growth rates and are less responsive to nutrient addition than equivalent plants from more fertile soils (Auchmoody and Smith 1979; Veerkamp *et al.* 1980; Chapin *et al.* 1983). Plant growth and nutritional requirements change as they get older. Early-successional species grow rapidly and respond to nutrient addition when young but have a lower relative growth rate and show less nutrient response in older age classes (van Cleve 1983). This is in part due to a proportional increase in maintenance respiration as trees age. Late successional species, on the other hand, may continue to respond to nitrogen additions at considerably older ages (Chapin *et al.* 1986).

Determination of the directly available of nutrients to plants is difficult. It is possible to quantify the instantaneously available pools of the nutrients (i.e., N or P) that most commonly limit plant growth, although these pools rapidly change over the course of a season. In determining the availability of nutrients to plants, the flux of nutrients through the available pool is at least as significant as the instantaneous pool sizes. Incubations to quantify nitrogen turnover (Matson and Boone 1984), soil bioassays (Peace and Grubb 1982) and perhaps ion-exchange resins in the field (Binkley and Matson 1983) have all been established as indices of nutrient availability in natural ecosystems. The results of these tests are usually correlated with a number of traits linked to nutrient insufficiency (Pastor *et al.* 1984). Each of these indicators assess a separate soil process such as microbial growth and turnover versus ion-exchange phenomena.

2.11 Role of nutrients on distribution of plants

Nutrients are chemicals necessary for growth organisms, in any ecosystems. There are two types of nutrients: macro- and micronutrients. Macronutrients are required in relatively large amounts and micronutrients in relatively small amount. N, P, K, Ca, Mg and S are considered as macronutrients and Fe, Mo, Na, B, Cu, Mn, Zn, Cl and Co are considered as micronutrients.

Among the soil nutrients, N is the most commonly used mineral nutrient. N is essential to all living systems for protein production. It makes the N cycle which is one of the Earth’s most important nutrient cycles. About 78% of Earth’s atmosphere is made up of N gas. It is a major component of chlorophyll and thus essential for photosynthesis. Plants use N by absorbing either nitrate or ammonium ions through the roots. Phosphorous is an important component for all living organisms. For their normal growth and maturity plants must uptake P. Like N, foliar P concentration is also related to the content of chlorophyll and carboxylation enzymes that are linked to photosynthesis (Duursma and Marshall 2006). P plays a vital role in respiration, energy storage and transfer, cell division, cell enlargement and other several processes in plants. Aerts and Chapin (2000) suggested that N:P ratios above 16 indicates P deficiencies and ratios below 14 indicate N deficiencies. Ca plays an important role in forest productivity, particularly in plant growth (McLaughlin and Wimmer 1999), nutrition as well as in cell wall deposition. It promotes proper cell elongation in plants.

Hou and Merkle (1950) divided plants into two groups based on their leaf Ca content: calcicole and calcifugous. Potassium is an essential plant nutrient that must be consumed in significant quantities for optimum growth and reproduction. It serves a variety of functions in plants. K controls the opening and closing of stomata in photosynthesis and CO_2 uptake. It also has a significant impact on water level regulation. K is required for the formation of Adenosine Triphosphate and for the activation of enzymes (ATP). It has an impact on plant shape, size, color, flavor, and other characteristics associated with healthy produce. Magnesium is an essential macronutrient for both plant development and health. It plays a variety of important roles in a variety of plant functions. It is a component of chlorophyll. Many enzymes in plant cells require magnesium to function properly. For plant development and metabolism, iron is the third most limiting nutrient (Zuo and Zhang 2011; Samaranayke *et al.* 2012). Almost all living organisms require it as a micronutrient. It is important for metabolic processes such as DNA synthesis, respiration and photosynthesis (Rout and Sahoo 2015).

The uptake, use, release, and storage of nutrients by plants and their environments is referred to as the nutrient cycle (or ecological recycling). It is the cycle of biological and chemical elements and compounds in precise patterns through substances in an ecosystem. It is the continuous transfer of nutrients from the physical environment to a living organism and back to the physical environment. In an ecosystem, this biochemical cycle is an essential process. Carbon, nitrogen, water, sulfur, phosphorus and oxygen cycles are examples of nutrient cycles found in nature. In combination with enormous amounts of photosynthetically fixed carbon, nutrients, particularly N and P, are cycled from forest trees to the surface soil and litter layer. The processes of breakdown and mineralization then make these nutrients available for intake again. These activities play a critical role in regulating nutrient availability and, as a result, forest development rates (Attiwill *et al.* 1993). Because the amount of important nutrients entering an environment each year is generally minimal, plant productivity in many ecosystems is heavily reliant on this nutrient recycling (Aber and Melillo 1991; Schlesinger 1997).

2.12 Adaptation of forest trees

Adaptations are special traits of plants that enable them to exist under different environmental conditions. Plant functional traits can be defined as plant characteristics that respond to the environmental conditions (Gitay and Noble 1997) that influence the distribution of species (Diaz *et al.* 2007). The ecological roles of plant species can be described by their functional traits, which are physiological, morphological, or anatomical characteristics (Russo 2010).

Adaptation, distribution and net primary productivity of plants are influenced by many factors including water (Wright *et al.* 2001). Traits which are thought to be selected in response to water-limiting conditions include leaf properties that reduce water loss or improve water-use efficiency (Wright *et al.* 2002; Sterck *et al.* 2011; Wright *et al*. 2001). Therefore, study on leaf traits is relevant for enhanced knowledge about the adaptation mechanisms of plants.

Seasonal climates with wet and dry seasons control a significant amount of the terrestrial ecosystems (Kottek *et al.* 2006). Water is one of the main factors that limits net primary production and therefore affects distribution of species (Ordonez *et al*. 2009). Leaf traits can help reduce water loss (Westoby *et al.* 2002) or improve water-use efficiency under drought condition (Wright *et al.* 2001). Thus, two distinct strategies, drought avoidance and drought tolerance, are followed by plants for coping with seasonal drought conditions (Nelson *et al.* 2002; Markesteijn and Poorter 2009). Drought avoidance has been linked to deciduous plants that can remove their leaves when soil water potentials reduce during dry seasons (Reich and Borchert 1984). Evergreen species have been linked to drought tolerance because they keep their leaves throughout the dry season (Ackerly 2004; Kursar *et al.* 2009; Markesteijn *et al.* 2011). Deciduous plants may be able to maintain high photosynthetic rates during wet seasons when conditions are favorable for growth because they escape dry periods (Cornelissen *et al.* 1996; Givnish 2002).

2.13 Leaf traits associated with adaptation of forest plants

The existence of two ends in the strategy to utilize and acquire resources, a leaf economics spectrum sense, is revealed by many studies based on the analysis of morpho-physiological and phenological properties of plants known as functional traits (Violle *et al.* 2007). The structure and composition of plant communities, as well as their functional traits, have been linked to changes in the availability of light during early secondary succession in several ecosystems, including tropical forests (Swaine and Whitmore 1988; Ellsworth and Reich 1996; Guariguata and Ostertag 2001; Selaya *et al.* 2008; Schönbeck *et al.* 2015).

Leaf traits do not vary at random, but are limited by trade-offs associated with carbon investment in leaves (Wright *et al.* 2004). Leaves serve an important role in plant function and long-term environmental adaptation. Leaf functional traits are one of the most important group of functional traits that plant follow for their adaptation (Cornelissen *et al.* 2003). Because, leaves are fundamental structures of plants which are directly involved in photosynthetic carbon fixation, respiration and transpiration and also are the most sensitive parts to climatic changes (Carlson *et al.* 2016; Chen *et al.* 2012).

Leaf traits play key roles in plant functions under different climatic condition and can provide insight into the adaptive evolutionary changes that help plants adapt with the surrounding environmental conditions (Liu *et al.* 2019; Guo *et al.* 2017; Wang *et al.* 2014, 2015). Water is one of the main factors that limits net primary production and therefore, affects distribution of species (Wright *et al.* 2001; Ordonez *et al.* 2009).

Leaf traits can vary greatly among species, functional groups and across plant communities, then different species show their differences in leaf traits, even within a locality (Qin *et al.* 2019). Under different environmental conditions the study on leaf morpho-physiological and anatomical characteristics of leaves of individual single species are important for demonstrating a particular adaptive strategy at the species level as well as plant functional type level. The world leaf economic spectrum consistently explains the complicated interaction between environment and leaf traits, in addition as leaf structure and performance coordination (Reich *et al.* 1997; Donovan *et al.* 2011).

2.14 Morpho-physiological traits

The ability of plant to adapt with environmental conditions is determined by foliar morphology patterns (Givnish 1987). Variation in the morphological patterns of plant may be influenced by several factors including soil moisture, wind, light availability, as well as both intra- and interspecific variation (Aguiar *et al.* 2002). Variations in foliar patterns, on the other hand, are linked to phenological variation in leaves, which is influenced by altitude, latitude, and edaphic conditions (Tang and Oshawa 1999). However, while foliar morphology is mostly determined by genetics, it is exposed to severe selection pressure in the environment, resulting in a variety of morphologies and foliar sizes.

Variation in leaf morphology, dimensions, form, petiole size, venation pattern, dry mass per unit area, water content, canopy, stomatal density, trichomes, and cuticular composition can be observed between species as well as within species and such variation can be useful in taxonomical and ecological studies (Rogers and Clifford 1993). In ecological research, leaf habits are identified as valuable instruments (Traiser 2005). They are closely associated with growth and survival (Garnier 2001; Westboy 1998) and are widely considered as reliable predictors of plant performance and act as efficient indicators of resource-use strategies (Wilson *et al.* 1999).

Functional traits can be utilized to describe community composition and organization at the interspecific level (Lavorel and Garnier 2002; Daz *et al.* 2004). According to Grime (1977), functional traits can also be used to identify plant species and explain the existence and distribution of species (Daz *et al.* 1998). The leaf traits define the functional trends across the groups. Leaf traits such as leaf length, leaf breadth and petiole length show large variation among the species. However, within a given community, there is a spectrum of foliar variations, and such variation can help explain coexistence of plant species in a habitat (Alvarez 2006). A study on leaf characteristics of *Qercus crassifolia* showed that changes in foliar morphology were primarily attributed to different environmental conditions. Leaves play the great role in photosynthesis, transpiration, respiration and storage. The leaves are exposed to environmental conditions and therefore, are under continuous process of selection in response to environmental changes. Leaves, thus, have the capacity to adapt with the environmental changes.

Leaf traits such as area, specific leaf area, fresh weight and dry weight are of usually studied in crop physiology and plant ecology. Substantial studies are available on these aspects. Leaf area of a plant species at a certain growth stage is defined since the capacity of the plant protects intercepting photosynthetically active radiation required for production of tissues and organic matter. As a result biomass production of a crop is the result of a genotype and its interaction with the environment (Rincón *et al.* 2007). Study of plant growth is now a days is regarded as a tool for crop improvement, crop physiology and crop ecology. The leaf area could be a fundamental aspect of research on plant physiology in agriculture and dendrology (Broadhead *et al.* 2003). The leaf area is crucial in agronomy, biology, ecology, and physiology for a spread of reasons, including growth analysis, photosynthesis, transpiration, light interception, biomass estimation, and water balance (Kucharik *et al.* 1998). The plant physiologists, biologists and agronomists have demonstrated the importance of leaf area within the growth analysis, the estimation of potential biological and agronomic yield, basis of the efficient use of radiation and mineral nutrition (Sonnentag 2007).

The relative growth rate, stress tolerance, and leaf life span are all indicators of specific leaf area, which is an important plant functional trait. The majority of intraspecific variation in specific leaf area is thought to be the product of phenotypic plasticity caused by the environment (Liu *et al.* 2017). From the early twentieth century forward, specific leaf area has been regarded as a critical element in studies of plant productivity (Blackman 1919; Clifford 1972). Populations of different species would be able to adapt to changing environmental conditions by modifying their unique leaf area plasticity. This phenotypic flexibility may allow populations to adapt genetically to environmental changes in the long run through genetic assimilation (Price *et al.* 2003).

The specific leaf area of a plant is the ratio of leaf area to its dry biomass which affects adaptation of a species to its environmental condition. The thickness of the leaves is expressed by the specific leaf area, which is susceptible to environmental conditions

(Santos and Segura 2005). When the temperature decreases, the plants generate a huge leaf area to capture as much light as possible (Killi *et al.* 2017). Low specific leaf area helps to leaf life duration, nutrition retention, and desiccation resistance due to thicker and/or denser leaves (Ackerly *et al.* 2002). The specific leaf area demonstrates the variation in growth between species to a greater extent. Species with substantially higher growth rates under ideal environmental conditions have a larger specific leaf area. When the particular leaf area increases, it means the leaf generates less biomass per unit leaf area. A number of physiological and chemical characteristics are strongly linked to this variable. Proteins, minerals, and organic acids are thought to be more abundant in cytoplasmic components in species with a larger specific leaf area. High specific leaf area values are suited to cooler, wetter conditions, and this pattern is coordinated with high nitrogen levels (Wright *et al.* 2004). On the contrary, plant species showing a smaller specific area have higher cell wall components such as lignin contents. This kind of leaf is extremely tough and unappealing to grazing wild animals. These are also known for having more dry matter (dry weight/fresh weight) and having longer roots and leaves. The larger leaf area and leaf dry mass are thought to indicate a smaller specific leaf area.

Specific leaf area and leaf dry matter content, among other leaf traits, have been found to be stronger indicators of plant resource-use strategies (Wilson *et al.* 1999). In a global plant functional traits compilation study, leaf dry matter content was identified as a cardinal attribute, along with specific leaf area and leaf lifespan (Shipley 2006). Due to the fact that a high dry matter content indicates minimal intercellular space and high mesophyll resistance to gas diffusion (Bussotti and Pollastrini 2015), diffusion resistance in forest plants with a high dry matter content may be enhanced to reduce leaf evaporation. Higher leaf dry matter content may enhance leaf moisture diffusion resistance, and leaf dry matter content may be a good indicator of leaf water content.

Higher specific leaf area may increase water loss, but higher leaf dry matter content and leaf thickness may increase moisture diffusion resistance and distance; however, these negative correlations were not observed in temperate forest herbs, possibly due to low water loss in low-temperature and light-limited environments. Climate can shape and shift functional biodiversity in forests. Trait correlations might differ between environments, which can be a facet to think about regarding global climate change. Fresh weight can be considered as a good indicator of the physiological status of a leaf in plant grown under different environmental conditions such as soil and weather conditions. Leaf anatomy and leaf area may influence the process of transpiration and reflect the leaf moisture condition, and may be related to water-use efficiency (Wang *et al.* 2019). Furthermore, the leaf water content may be related with the productivity of root system in terms of absorbing water content from the soil, which is related to leaf turgidity.

2.15 Anatomical traits

Anatomical features of the leaf such as stomatal traits, are linked to plant adaptation to various conditions over a vast geographic scale (Tian *et al.* 2016). Stomatal length, density, and stomatal pore area index are leaf anatomical features that indicate the long-term adaptation of leaf stomatal morphology and photosynthetic capacity (Westoby and Wright 2006; Hernández-Vargas *et al.* 2019). Stomata are microscopic structures on the epidermis of leaves that control water vapor and gas exchange between plants and the atmosphere. They are surrounded by a pair of guard cells (Hetherington and Woodward 2003). Leaves can open or close in response to changing environmental conditions, or exhibit long-term stomatal morphological modifications (Engineer *et al.* 2014). Stomatal density is negatively correlated with stomatal size or length (Franks and Beerling 2009), and stomatal characteristics are susceptible to environmental changes such as light intensity (Hovenden and Schoor 2006), temperature (Yang *et al.* 2014; Fraser *et al.* 2009; Zheng *et al.* 2013), and water status (Straussdebenedetti and Bazzaz 1991; Mott 2009).

Stomata with a smaller surface area to volume ratio can respond more quickly to environmental changes by opening and closing (Hetherington and Woodward 2003; Woodward *et al.* 2002). A larger mesophyll surface under strong irradiance can create CO_2 diffusion resistance, which can be reduced by increasing stomatal density (Bosabalidis and Kofidis 2002). This could explain why plants in subtropical forests have small and dense stomata. Furthermore, low temperatures inhibit cell division, resulting in larger and fewer stomata in temperate forest plants (Korner *et al.* 1986). The stomatal pore index was linked with the maximum stomatal conductance (Sack *et al*. 2003). Reduced stomatal conductance resulted to a greater stomatal pore index in temperate forests, because CO_2 diffusion is reduced at low temperatures.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the study sites

3.1.1 Geographical location of the study sites

The Madhupur Sal Forest and Sitakunda Ecopark were selected in order to address the research questions (Fig. 3.1). The latitude and longitude of the study sites were shown in Table 3.1. The selected sampling sites of the Madhupur Sal Forest were distributed between 24°38´30´´ - 24°39´50´´ N latitude and 90°04´50´´ - 90°05´20´´ E longitude. And the study plots of Sitakunda Ecopark were distributed between 22°36´05´´ - 22°37´05´´N latitude and 91°40´55´´ - 91°41´25´´E longitude (Table 3.1). A total of 12 plots of 10m × 10m in size were selected from each of the 2 forests for the study.

Madhupur Sal Forest

The study plots were selected in the forest of the Madhupur Sal Forsest at Jalchatra area which is under the Arankhola union of the Madhupur upazilla (Sub-district) in Tangail district. Madhupur Sal Forest locally is known as "Madhupur Garh" which is the largest deciduous forest of Bangladesh and comprises an area of 8,436 ha (DoE 2015; IUCN 2015). The forest is situated in the northeastern part of Tangail Forest Division along the boundary with Mymensingh district and 125 km away from Dhaka. It is located from 24°36' to 24°42' North latitudes and 90°00' to 90°06' East longitudes. Madhupur National Park began as Madhupur Sal Forest, but was later on declared as National Park on 24 February 1982 (BFD 2015). The forest got the national park status in 1962 (BFD 2015).

Sitakunda Ecopark

The Sitakunda Ecopark is a part of semi-evergreen forest in nature. The Sitakund Botanical Garden and Ecopark is situated on the southeast part of Bangladesh. This Ecopark is at the northwestern part of Chittagong district lying between 22°36′–22°39′N and 91°40′–91°42′E. It comprises an area of about 808 ha, of which the botanical garden covers 405 ha and the rest is the eco-park (Nandi and Vacik 2014). The area of this park is under the Southern “Sitakunda Reserved Forest” of Chittagong Forest Division. The area of this park is vegetated with natural evergreen forest plants and possesses high diversity in plant and animal species.

Table 3.1: Geographical location of the study plots of Madhupur Sal Forest and Sitakunda Ecopark

Plot No.	**Madhupur Sal Forest**		**Sitakunda Ecopark**	
	Latitude	**Longitude**	**Latitude**	**Longitude**
1	24° 38' 43.58" N	90° 05' 09.67" E	22°36′56.12″N	91°41′24.58″E
2	24° 38' 42.25" N	90°0 5' 08.56" E	22°36′55.87″N	91°41′22.60″E
3	24° 38' 42.04" N	90° 05' 08.02" E	22°36′52.13″N	91°41′23.39″E
4	24° 38' 42.43" N	90° 05' 12.41" E	22°36′49.72″N	91°41′22.24″E
5	24° 38' 41.64" N	90° 05' 13.70" E	22°36′47.77″N	91°41′22.67″E
6	24° 38' 39.52" N	90° 05' 16.01" E	22°36′45.14″N	91°41′22.99″E
7	24° 38' 36.53" N	90° 05' 05.68" E	22°36′44.89″N	91°53′06.00″E
8	24° 38' 37.46" N	90° 05' 05.82" E	22°36′42.12″N	91°41′17.66″E
9	24° 38' 36.64" N	90° 05' 03.05" E	22°36′07.16″N	91°40′46.09″E
10	24° 38' 36.24" N	90° 05' 02.04" E	22°36′12.20″N	91°40′53.44″E
11	24° 38' 35.30" N	90° 04' 58.19" E	22°36′13.28″N	91°40′56.14″E
12	24° 38' 34.08" N	90°0 4' 53.58" E	22°36′08.71″N	91°40′54.62″E

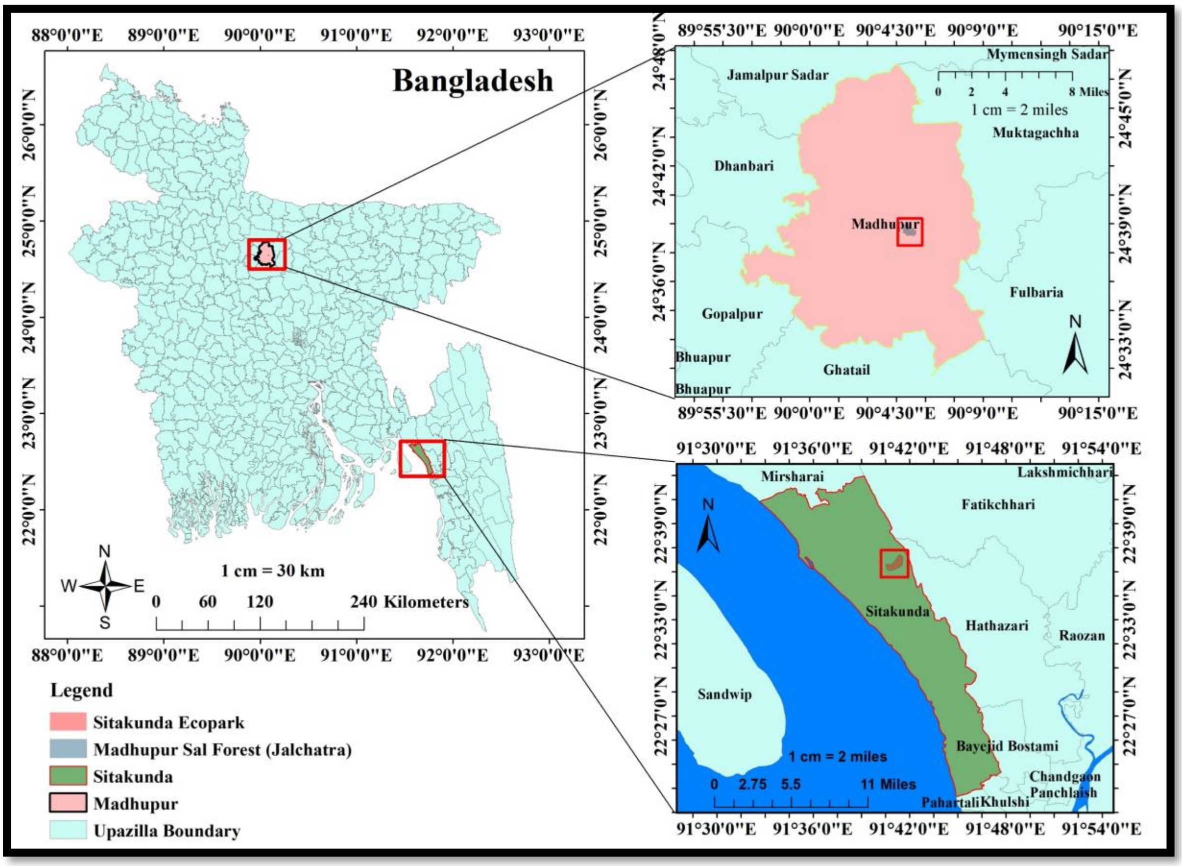


Figure 3.1: Map showing the geographical location of the two study areas.

3.1.2 Vegetation of the study sites

Madhupur Sal Forest

The Madhupur Sal Forest of Bangladesh is a part of the tropical moist deciduous forest, locally known as the inland Sal Forest (Rashid *et al*. 1995). This forest is deciduous in nature. It is dominated by deciduous species mostly by Sal (*Shorea robusta* Roxb. ex Gaertn). A total of 174 plant species was recorded under 131 genera and 54 families in Madhupur sal forest of which about 102, 17, 34 and 21 species were classified as under tree, shrub, herb and climber, respectively according to their growth habits (Malaker *et. al* 2010). Photos showing the vegetation of summer and winter of the Madhupur Sal Forest are shown in Figure 3.2.

Sitakunda Ecopark

The Sitakunda Ecopark is very important due to its unique habitat and rich biodiversity. Though evergreen plants were dominated in the Sitakunda Ecopark, but also had some deciduous plants were also present. The Sitakunda Ecopark contained a large number of native angiosperm and gymnosperm along with some introduced exotic species. A total of 332 vascular plant species belonging to 266 genera and 93 families including cultivated, natural and plantations were recorded from this Ecopark. Trees contributes major category (140 species) of the plant community followed by herbs (90), shrubs (66), climbers (25), ferns (9) and epiphytes (2) (Dutta *et al.* 2014). Photographs showing vegetation of summer and winter of the Sitakunda Ecopark are shown in Figure 3.3.

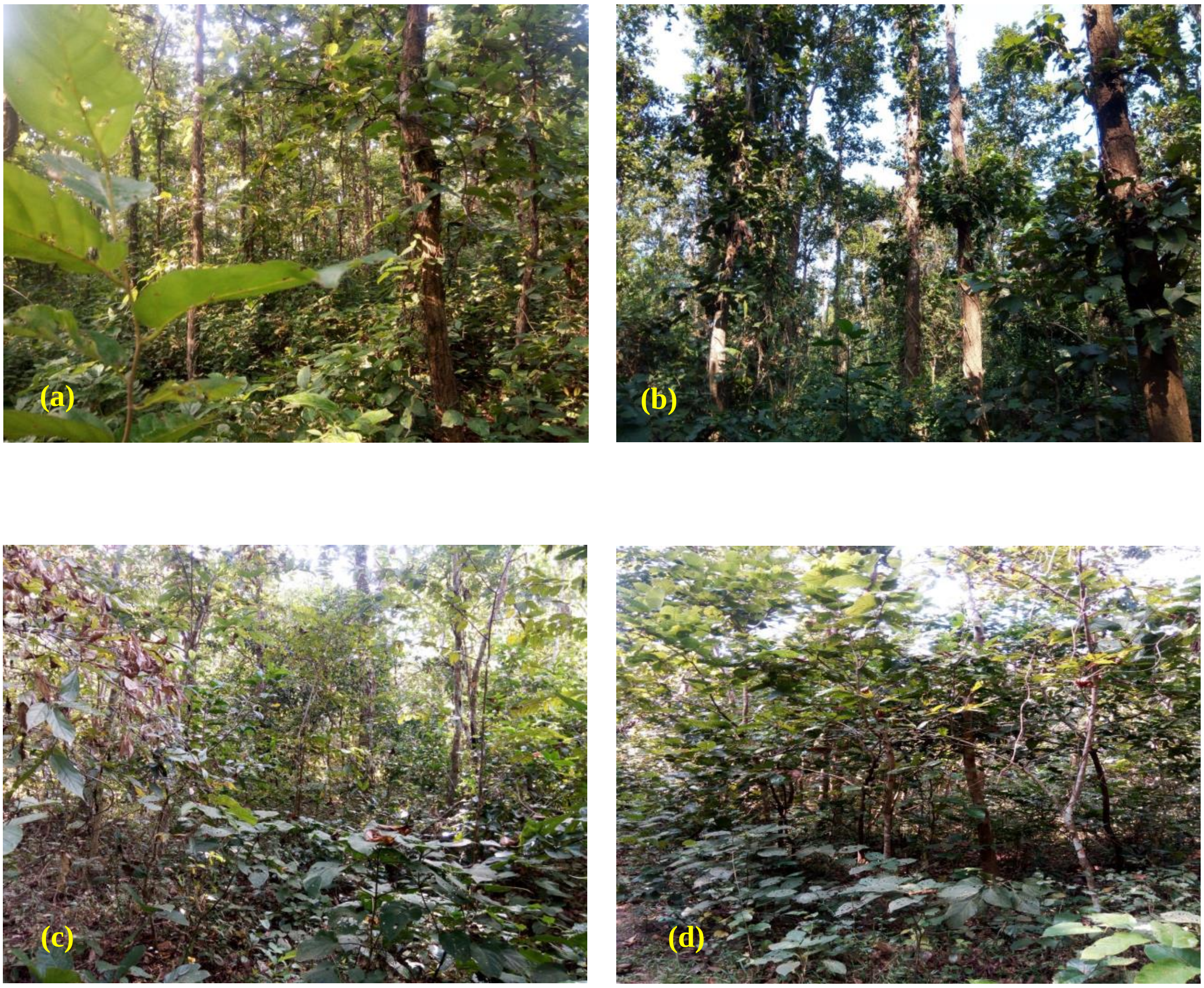


Figure 3.2: Photographs showing the vegetation of Madhupur Sal Forest during summer (a-b) and winter (c-d).

Figure 3.3: Photographs showing the vegetation of Sitakunda Ecopark during summer (a-b) and winter (c-d).

3.1.3 Climatic condition

The Madhupur Sal Forest is relatively uniform in climatic condition. The climate of the Tract varies slightly from north to south, the northern reaches being much cooler in winter. Average temperatures vary from 28°C to 32°C in summer, falling to 20°C in winter, with extreme lows of 10°C. Rainfall ranges between 1,000 mm and 1,500 mm annually. Severe storms are unusual but tornadoes have struck the southern areas (Banglapedia 2021).

The climate of Sitakunda Ecopark is tropical in nature with the maximum rainfall during the period from June to September. The area remains dry for about 4 to 5 months of the year. Cool season persists during the from December to February. The mean annual temperature is 26.6 ºC with the highest in May. Rainfall occurs during May to September with the maximum in July and the average is 689.2 mm. The lowest humidity is found in the month of February (72.7%) and maximum (85%) during June-July (Nandi and Vacik 2014).

3.1.4 Topographic settings

Different topographies are found in the Madhupur National Park. The area consists of plain lowland, cultivated land, forest and others. The altitude of the park is about 20 m above the mean sea level (Khan and Ahsan 2011). There are a number of low and high hill in the Sitakunda Ecopark with peak slopes and streams. Sandstones and shales made the hill of Sitakunda Ecopark. The range of heights of lower hill are from 15.24 m to 76.2 m. The medium high hills ranges between 76.2 m and 152.4 m while the high hills between 152.4 m and 365.76 m. The sea level height of the Sitakunda Ecopark is about 15 to 65m (Islam *et al.* 2016).

3.1.5 Sampling design

Sampling was done by using quadrat method following nested sampling design. A 10 ×10 m^2 quadrat was placed in each location in the Madhupur National Park and Sitakunda Ecopark to collect plant and soil samples. In total, 24 square plots of both study areas have been established in the undisturbed zone. Inside a plot, data were sampled on smaller plots fixed in the field on the basis of plant habit. The quadrat size used in the present study was 2m × 2m for herbs and grasses, 5m × 5m for shrubs and 10m × 10m for tree (Fig. 3.4). Plants with inflorescence were collected in case it was not possible to identified in the field.

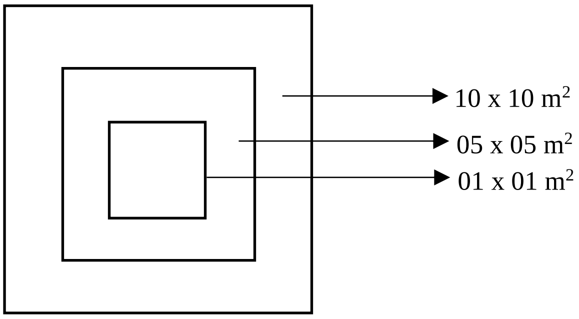


Figure 3.4: A sample plot

There were depressions in the landscape of the forests. Further, there were forest gaps, or bare land. Therefore, it was not always possible to establish the plots in a regular distance. Plots were placed continuously at 100 m distance in areas with a more or less closed forest cover. As a result, where there were fragmentations, the next plot was taken at 100 m -200 m interval.

3.2 Vegetation analysis

3.2.1 Field survey and identification of plant species

A total of twelve field trips were made during two prominent sampling seasons of the year from 2017 to 2019 during the study year. Plant specimens those were not identified in the field were collected and then identified through consultation with the experienced taxonomist and matched with the respective voucher specimens preserved at the Salar Khan Herbarium, Department of Botany, University of Dhaka and Bangladesh National Herbarium (BNH), Mirpur, Dhaka as well as with taxonomic descriptions and keys available in the relevant literature (Rahman *et al.* 2009; Paul *et al.* 2013; Islam *et al* 2016; Dutta *et el.* 2014; Hossain *et al.* 2017; Rahman *et al.* 2017) and type images available in the websites of different international herbaria). Nomenclature of the plants were verified with the updated nomenclatural systems available online such as International Plant Name Index (2008) and TROPICOS (2010). Taxonomic and systematic information including binomial name with original citation, family name, local name, functional types, and habit have been provided.

3.2.2 Phytosociological analysis

The Importance Value Index (IVI) was calculated in order to understand the structural role and dominance of the species on the basis of relative frequency, abundance and dominance. The relative values of frequency, abundance and density for each single species were used to determine IVI value for each plot according to the following equations:

$$\text{Frequency} = \frac{Total\ number\ of\ quadrats\ in\ which\ the\ species\ occured}{Total\ number\ of\ quadrats\ studied}$$

Abundance = $\frac{Total\ number\ of\ an\ individual\ present\ in\ all\ quadrats}{Number\ of\ quadrats\ in\ which\ species\ occur}$

Density = $\frac{Total\ number\ of\ an\ individual\ present\ in\ all\ quadrats}{Number\ of\ quadrats\ studied}$

Relative Frequency = $\frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} \times 100$

Relative Abunance = $\frac{Abundance\ of\ a\ species}{Total\ abundance\ of\ all\ species} \times 100$

Relative Density = $\frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species} \times 100$

IVI = relative frequency + relative density + relative frequency

3.2.3 Life form spectrum

Life-form composition analyzed by follow a procedure as proposed by Raunkiaer (1934). All species were assigned a suitable life form according to Raunkiaer life form classification such as Therophytes, Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes, Hydrophyte and Epiphyte.

The percentage life form was calculated as follows

% Life Form = $\frac{Number\ of\ species\ in\ any\ life\ form}{Total\ number\ of\ species\ of\ all\ life\ forms} \times 100$

3.2.4 Collection of leaf samples

For the study of leaf traits, fully expanded youngest fresh leaves were collected from the selected plants. Un-damaged leaf samples were collected, taken into separate plastic bags and then brought to the Ecology and Environment Laboratory, Department of Botany, University of Dhaka. After collection, samples were labeled properly and brought to the laboratory within the shortest possible time. Leaf weight, dry leaf weight, turgid weight, leaf length, leaf breadth, leaf area, specific leaf area, % open stomata, % closed stomata, stomatal density and stomatal pore index were determined from leaf samples.

3.2.5 Collection of soil samples

Soil was collected from the center of each quadrat placed in the forest. Soil core sampler was collected at 0-10 cm depth, taken into separate plastic bags and then labeled properly. Soil pH, electrical conductivity and moisture were determined immediately after collection. Soil chemical properties like available N, total P, total organic C and Na were determined immediately from the collected soil samples at the Ecology and Environment Laboratory, Department of Botany, University of Dhaka.

.3.3 Biodiversity indices

3.3.1 Species richness

Species richness is the direct count of number of different species in a given area. The species richness was measured for the determination of the sensitivity of these ecosystems and their resident species. The actual number of species calculated thus is an arbitrary number. Species richness was expressed as follow:

$$\text{Species richness} = \frac{\text{No.of species}}{\text{quadrat}}$$

3.3.2 Shannon-Wiener Index (Diversity Index)

Shanon-Wiener index was measured in order to determine the species diversity and community composition in different forest sites and national parks as well. This study used the following formula to determine Shannon-Wiener diversity index (Shannon and Wiener 1963) as given by Magurran (1988):

$$H = -\sum p_i \ (ln\, p_i)$$

Where, p_i is the proportion of the *i*th species and the number of all individuals of all species (n_i/N).

3.3.3 Simpson Index

Simpson's index (Simpson 1949) determined the concentration of dominance (CD). The present study used the following formula for the determination of Simpson similarity:

$$CD = \sum_{i=1}^{s} (p_i)^2$$

Where, p_i is the same as for the Shannon-Wiener information function

3.3.4 The Evenness

The following equation was followed to determine the Evenness by Pielou's index as given by Magurran (1988):

$$E = \overline{H}/ln\ S$$

Where, $\overline{H}$ is the Shannon-Wiener diversity index and S is the number of species

3.3.5 Similarity Index (Community Coefficient)

The similarity index was measured in order to find out the species overlapping, similarity and contrarily dissimilarity among or between different plant habit of the Madhupur Sal Forest and Sitakunda Ecopark. Sørensen index (Sørensen 1948) were calculated as

$$Sorensen\ Index = \frac{2C}{A+B}$$

Where, C is the number of species common in both forests, *A* is the number of species in forest

A and *B* is the number of species in forest B.

3.4 Determination of leaf traits

3.4.1 Selection of plants

Five dominant tree species were selected from each of the two forests for collection of leaf samples (Table 3.2). These 5 tree species were selected from three plots those were located at least 50 m away from each other within the forests.

Table 3.2: Selected plant species from Madhupur Sal Forest and Sitakunda Ecopark for the study of leaf traits.

Serial	**Scientific name**	**Local name**	**Family**
Madhupur Sal Forest			
01	*Shorea robusta* Gaertn.	Sal	Dipterocarpaceae
02	*Adina cordifolia* (Roxb.) Brandis	Kaika	Rubiaceae
03	*Mallotus philippensis* (Lam.) Müll. Arg.	Sinduri	Euphorbiaceae
04	*Litsea glutinosa* (Lour.) C. B. Rob.	Kharajhora	Lauraceae
05	*Zanthoxylum rhetsa* (Roxb.) DC.	Bajnagota	Rutaceae
Sitakunda Ecopark			
06	*Grewia nervosa* (Lour.) G. Panigrahi	Datoi	Malvaceae
07	*Streblus asper* Lour.	Sheura	Moraceae
08	*Castanopsis tribuloides* (Sm.) A.DC.	Batna	Fagaceae
09	*Syzygium cymosum* (Lam.) DC.	Khudijam	Primulaceae
10	*Ardisia solanacea* (Poir.) Roxb.	Konok	Myrtaceae

3.4.2 Collection of leaf samples

Three individual plants were selected for each species from each plot for the collection of leaf samples for further analysis. Fully expanded leaves were collected from the selected plants during summer and winter seasons for 3 consecutive years 2017, 2018 and 2019. Then, 6 leaves for each plant were analyzed for functional traits. Thus, a total of 1,080 (6 leaves × 3 plants × 2 forests × 10 species × 2 seasons × 3 years) leaves were studied during this study.

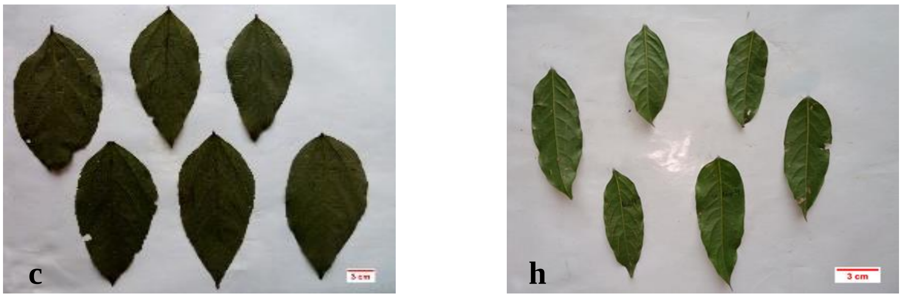
3.4.3 Determination of leaf morphological traits

Measurement of leaf length

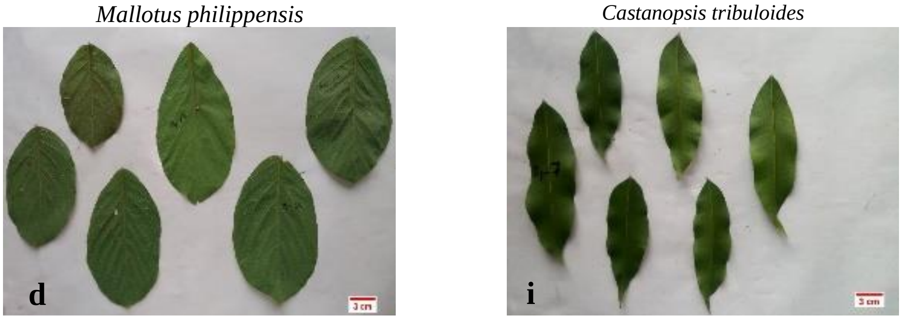
Measurement of leaf length was done using a software named ImageJ Ver: k 1.45. Among the leaf samples; randomly 6 fresh leaves of each species from each quadrat per study site were taken (Fig. 3.5). Then, 6 fresh leaves were spread over a plain glass sheet along a centimeter ruler. Image of the leaves was captured using a camera (Canon EOS 1500D). By this way, single image of each 6 leaves for each sample was captured separately. Then, from each image leaf length was measured using the software ImageJ. Captured image was open by ImageJ Software. Then from the scale bar, scale was set by width tool in centimeter (cm) chosen from analyze menu. Then the color image was converted with grayscale (8 bit) from image menu. Image was adjusted in threshold to get red leaf image. The red leaf image was selected by wand tool and selected image data was added in ROI manager window from analyze menu. Then, result was analyzed by clicking on Measure box.

horea robusta *Grewia nervosa*

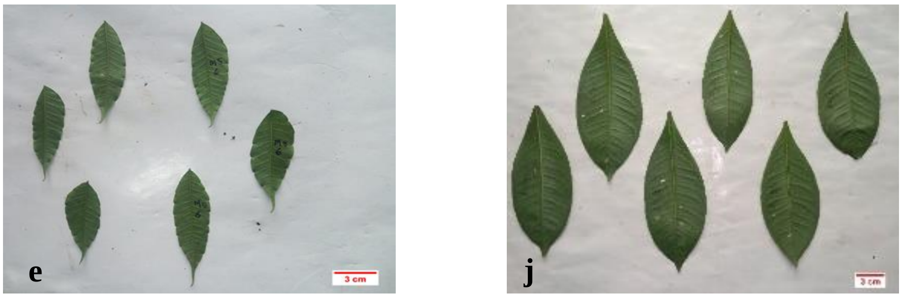
Adina cordifolia *Streblus asper*



Mallotus philippensis *Castanopsis tribuloides*



Litsea glutinosa *Syzygium cymosum*



Zanthoxylum rhetsa *Ardisia solanacea*

Figure 3.5: Image of the leaves of selected plants of Madhupur Sal Forest (a-e) and Sitakunda Ecopark (f-j) taken by a camera (Canon EOS 1500D) for the determination of leaf length, leaf breadth, leaf perimeter and leaf area by using ImageJ software.

Determination of leaf breadth

The determination of leaf length, leaf breadth was done using the same software ImageJ Ver: k 1.45 in similar method after the leaf length was measured. Measurements were expressed in cm scale.

Determination of leaf perimeter

After taking the measurement of leaf length and leaf breadth, the leaf perimeter was done using the same software ImageJ Ver: k 1.45 in similar method. The unit of the leaf perimeter was cm.

Determination of leaf area

For the determination of leaf area, same software ImageJ Ver: k 1.45 was used. The unit was expressed in cm^2.

Leaf breadth, perimeter and leaf area were analyzed by same way as already mentioned earlier.

Determination of specific leaf area

Specific Leaf Area (SLA) is the one-sided area of a fresh leaf, divided by its oven-dry mass. Measurement of leaf area as described in earlier was also used for the determination of specific leaf area. It was calculated as leaf area of the sampled leaves divided by their dry mass. SLA was calculated by the following formula:

$$\text{SLA} = \frac{\text{Leaf are}}{\text{Leaf dry weight}}\ \text{cm}^2\text{g}^{-1}$$

3.4.4 Determination of leaf physiological traits

Determination of relative water content

Relative Water Content (RWC) is expressed in percentage of the water content at a given time and tissue as related to the water content at full turgor. Fresh weight of six leaves was taken. The leaves were wrapped immediately to minimize evaporation. Weight of the leaves was taken as the value of fresh weight. Then, the leaves were immerged in de-ionized water overnight and kept away the samples from physiological activity by physical inhibition of growth and respiration. After 24 h, the leaves were blotted with tissue paper, then the leaf was reweighted. This weight was turgid weight. Leaves were then kept in oven at 80º C for 24 h. After 24 h, dry weight was taken. RWC was calculated by the following formula:

$$\text{RWC} = \frac{\text{FW}-\text{DW}}{\text{TW}-\text{DW}}\ \text{g g}^{-1}$$

Where,

FW=Fresh Weight

TW=Turgid weight

DW=Dry weight

Determination of leaf dry matter content

For the determination of Leaf Dry Matter Content (LDMC), fresh weight of six leaves was taken. The leaves were then kept in oven at 80º C for 24 h. Leaf dry mass was divided by their fresh mass. LDMC was calculated by the following formula:

$$\text{LDMC} = \frac{\text{Leaf dry mass}}{\text{Leaf fresh mass}}\ \text{g g}^{-1}$$

Determination of leaf water content

Leaf water content (LWC) per unit area was determined as leaf fresh biomass minus dry biomass, divided by leaf area. LWC was calculated by the following formula:

$$\mathrm{LWC} = \frac{\text{Fresh mass} - \text{dry mass}}{\text{Leaf area}}\ \mathrm{g\ cm^{-2}}$$

Determination of leaf chlorophyll content

In order to determine chlorophyll contents of leaves, 6 fully expanded youngest leaves were selected per plant. Leaf chlorophyll content was determined with the help of chlorophyll meter (SPAD- 502Plus, Konica, Minolta, Japan) and the unit was µg cm^{-2}. At first the chlorophyll meter was calibrated.

3.4.5 Determination of leaf anatomical traits

Study of stomata using impression technique

Leaf was spread gently upon a plain field of glass sheet. A thick swath of clear nail polish was painted upon the ventral side of the leaf. After the nail polish has dried, peel of nail polish swath was taken away gently from the leaf completely. A cloudy impression of the leaf surface now attached to the nail polish was found. One drop of glycerin was put and then the leaf impression was kept on a clean slide and then covered with cover slip and observed under microscope. Photograph of the field of leaf under microscope (Axio Lab. A1 Microscope, Carl Zeiss Microscopy GmbH, Germany was taken. Three images were taken from each leaf and three stomata from each image was selected to study stomatal parameters. Three leaves were taken from each species from each site.

Measurement of stomata length

Measurement of stomatal length was done using a software named ImageJ Ver: k 1.45. Captured image was open by ImageJ software. From the scale bar, scale was set by line width tool in micrometer (µm) scale from analyze menu. The selected line data was added in ROI manager window from analyze menu. Then, result was analyzed by clicking on Measure box.

Measurement of stomatal breadth

ImageJ Ver: k 1.45 software was used for the measurement of stomatal breadth. Measurements were expressed in micrometer (µm).

Measurement of stomatal perimeter

The measurement of stomatal perimeter was done using the same software ImageJ Ver: k 1.45 in similar method. The unit of the stomatal perimeter was µm.

Measurement of stomatal area

For the determination of stomatal area, same software ImageJ Ver: k 1.45 was used. The unit was used in cm^2.

Measurement of pore size

Pore length and pore breadth were done using the same software ImageJ Ver: k and the unit was expressed by µm.

Stomatal breadth, perimeter, area and pore size were analyzed by the same way that explained in earlier.

Measurement of stomatal density

For the measurement of stomatal density (individual mm^{-2}), the number of stomata per unit area (mm^{-2}) was counted from the images at a magnification of 10 × 40 and visual field area = (32×22) μm. Stomatal density was calculated by the following formula:

Area of FOV = πr^2

Stomatal density = number of stomata in entire FOV / area (mm^2)

FOV = field of view

Determination of Stomatal Pore Index

Stomatal Pore Index is an integrative parameter of stomatal density and stomatal length that reflects the stomatal conductance of leaves. Increased SPI leads to higher stomatal conductance and photosynthetic capacity in leaves. SPI (%) was calculated by the following formula:

SPI = Stomatal density × Stomatal length^2 × 10^{-4}

3.5 Soil analysis

The soil of Madhupur Sal Forest acidic in nature (pH=5.2 - 5.5) which contains poor nutrient (Coppin *et al.* 2004). The soils of the Tract have developed largely on Madhupur clays. The texture of the forest soil is contained sandy loam to silty loam. They are red or brown in color. The organic matter content in surface soil ranges from low (< 1.5%) under grassland to moderate (2-5%) under forest cover (Coppin *et al.* 2004).

In the Sitakunda Ecopark the soils are strongly acidic in nature, color of top soil is greyish brown to dark brown, sandy loam to loam, moderately granular or crumby, neutral to acidic (Dutta and Hossan 2016). On the other hand, subsoils were characterized by yellowish brown to yellowish red in color, sandy loam to silty clay loam, moderate to strong blocky structure, strongly to very strongly acidic in nature. Nandi and Vacik (2014) reported some soils to be hard concretionary at variable depths.

3.5.1 Determination of soil pH

Soil pH was recorded in the laboratory within 24 h after collection from the field. Soil pH was determined in suspension with distilled water (2:1, v: w). 10 g soil was taken in a beaker and then 20 ml distilled water was added to make a suspension by shaking well. The suspension was kept for a while for settling down of the particles. The pH meter (Hanna pH meter, pHeP) was calibrated with known pH. Then, the pH values were recorded for each of the soil sample.

3.5.2 Determination of soil conductivity

Soil conductivity was recorded in the laboratory within 24 h after collection from the field. Soil conductivity was determined in suspension with distilled water (5:1, v: w). 10 g soil was taken in a beaker and then 50 ml distilled water was added to make a suspension by shaking well. The suspension was kept for a while for settling down of the particles. The conductivity meter was calibrated with known conductivity. Then, the conductivity values were recorded for each of the soil sample.

3.5.3 Determination of soil moisture content

Soil moisture was determined from 10 g fresh soil after taking into a cup made with aluminum foil. Soil was kept in an oven at 80 °C for 24 h. Soil moisture content was measured by the following formula:

Soil moisture content (weight basis) (%) = $\frac{\mathrm{F-D}}{\mathrm{F}} \times 100$

Where, F= Weight of fresh soil

D= Weight of dry soil

3.5.4 Determination of soil organic carbon

Organic carbon of the soil was determined by Walkley and Black method (Black 1965). For the determination of soil organic carbon, 2.0 g soil which was passed through 2 mm sieve was weighted and transferred to a 500 ml clean dry conical flask. Ten ml of normal potassium dichromate solution was added. Then, 10 ml conc. H_2SO_4 was added and mixed thoroughly. The flask was allowed to cool on a sheet of asbestos with occasional shaking for half an hour. After changing the color into green, an additional 10 ml $K_2Cr_2O_7$ was added. After half an hour, when the flask was cool, approximately 150 ml distilled water, 10 ml phosphoric acid and 0.2 g of sodium fluoride was added. Then, 3 ml of diphenylamine indicator was added. The color of the solution was deep violet. The excess of chromic acid left in the flask was titrated with the help of normal ferrous sulfate solution. At the end point, the color of the solution was changed to deep bottle green. A blank experiment was done in the same way with all reagents except soil.

Calculation:

1000 ml of N $K_2Cr_2O_7$ = 1000 ml of N C = 3 g of C

(eq. wt. of C = 12/4= 3)

Or, 1 ml of N $K_2Cr_2O_7$solution = 0.003 g of C

% of organic carbon = $\frac{(B-T)\times f\times 0.003\times 100}{W}$

Where,

B = Amount in ml of N $FeSO_4$ solution required in this experiment

T = Amount in ml of N $FeSO_4$ solution required in experiment with soil

f = Strength of N $FeSO_4$ solution (from blank experiment)

W = Weight of soil taken

Organic matter (%) = Total organic carbon (%) × 1.72 (Van Bemmelen factor)

3.5.5 Determination of available nitrogen (N) in soil

Available nitrogen in soil was determined by following the Kjeldahl method (Black 1965). For determination of available nitrogen, 5 g soil was taken in a 100 ml plastic bottle. 50 ml 1N KCl solution was added to it and shaken and then it was left for 1 hour. Then, the samples were filtered with Whatman filter paper. Then, 10 ml of extract was distilled with 10 ml of 10% NaOH using micro Kjeldahl distillation apparatus. Devarda's alloy of 0.2g was added into the funnel where sample and 10% NaOH were given. The distillate was collected in 10 ml 2% H_3BO_3 until the volume was about 50 ml. About 60 ml volume of distillate (ammonium borate) was collected in a 125 ml conical flask containing 10 ml of boric acid with mixed indicator. Then, the distillate was titrated against the standard H_2SO_4. The end point was indicated by pink color of the solution. A blank experiment was done simultaneously using all the chemicals except soil.

$$\text{Available N } (\mu g/g) = \frac{14 \times N \times (T - B) \times Total\ extract \times 1000}{1000 \times Amount\ of\ sample \times Aliquents\ taken}$$

Where,

N = Normality factor of N/100 H_2SO_4 (= 0.0112 N)

B = Amout in ml of N/100 H_2SO_4 required in titration of the blank experiment

T = Amout in ml of N/100 H_2SO_4 required in titration of the experiment with soil

3.5.6 Determination of total phosphorus (P) in soil

Phosphorus in soil was determined by following the colorimetric method. For the determination of soil phosphorus content, 1 g finely powdered soil was taken in a beaker.

10 ml HNO_3 was added to it and dried. Then, 5 ml $HClO_4$ was added to it and dried again. Little amount of water was added and filtrated. 5 ml of this solution was taken into a 25 ml volumetric flask. 5 ml coloring reagent was added and finally volume was made up to 25 ml in volumetric flask with distilled water. A blank experiment was done simultaneously using all the chemicals except soil. Five standard solutions were prepared by using all chemicals and phosphorus of known concentrations 0, 2, 3, 5 and 7 instead of soil. Absorbance was determined using a spectrophotometer at 440 nm. By using the absorbance of 5 concentrations standard curve was drawn and from this standard curve, concentration of sample phosphorus was determined.

Calculation:

% of P was calculated by using the following formula:

$$\% \text{ of P} = \frac{ppm \times 25 \times 50 \times 100}{vol.\ taken\ for\ color \times wt.\ of\ soil \times 10^6}$$

3.5.7 Determination of total Potassium (K) in soil

The digest solution prepared for the determination of phosphorus was also used for the determination of Potassium (K). Five standard solutions (0, 5, 10, 20 and 50 ppm) were prepared by using K_2SO_4. Absorbance was determined using a flame photometer. By using the absorbance of five concentrations, standard curve was drawn and from this standard curve, concentration of sample K was determined.

$$\% \text{ of K} = \frac{ppm \times 25 \times 50 \times 100}{vol.\ taken\ for\ color \times wt.\ of\ soil \times 10^6}$$

3.5.8 Determination of total Sodium (Na) in soil

The digest solution prepared for the determination of phosphorus was also used for the determination of Sodium (Na). Five standard solutions (0, 5, 10, 20 and 50 ppm) were prepared by using $NaClO_4$. Absorbance was determined using a flame photometer. By using the absorbance of five concentrations, standard curve was drawn and from this standard curve, concentration of sample Na was determined.

$$\% \text{ Of Na} = \frac{ppm \times 25 \times 50 \times 100}{vol.\ taken\ for\ color \times wt.\ of\ soil \times 10^6}$$

3.6 Soil particle

At first 32 g soil was taken in a beaker with 100 ml tap water and 5 ml H_2O_2. Then these were boiled for 10 minutes at 60^oC temperature. After cooling, 100 ml calgon was added and kept overnight. Mechanical stirrer was used for shaking the mixture for 2-3 minutes with dispersal cup. Then, it was taken in 1000 ml cylinder and volume was made up to 1000 ml by adding distilled water. A wood padal was used for shaking and then after 40 second, Hydrometer reading was counted. Then, after 2 hours, Hydrometer reading was counted without shaking. Blank Hydrometer reading was taken by using distilled water and room temperature was measured by thermometer.

Calculation

For 40 second readings:

Correction of Hydrometer reading, t_{40s} = (Reading after 40 second – Blank)
Temperature correction, $T_{40s} = (t_{40s} - 19.4) \times 0.3$

Corrected Hydrometer reading (40s) after temperature correction = (Hydrometer reading + T_{40s}).

For 2 hours reading:

Correction of Hydrometer reading, t_{2hr} = (Reading after 40 second – Blank)
Temperature correction, $T_{2hr} = (t_{2hr} - 19.4) \times 0.3$

Corrected Hydrometer reading after temperature correction H_{2hr} = (Hydrometer reading + T_{2hr}).

$$\text{Sand (\%)} = \frac{\text{Corrected Hydrometer reading (40s) after temperature correction} \times 100}{\text{Soil weight – oven dry moisture (105 degree temp.)}}$$

$$\text{Clay (\%)} = \frac{\text{Corrected Hydrometer reading (2 hours) after temperature correction} \times 100}{\text{Soil weight – oven dry moisture (105 degree temp.)}}$$

Silt (%) = 100 - (% of Sand + % of Clay).

Texture class:

Soil texture class was determined from soil texture triangle (Fig. 3.6)

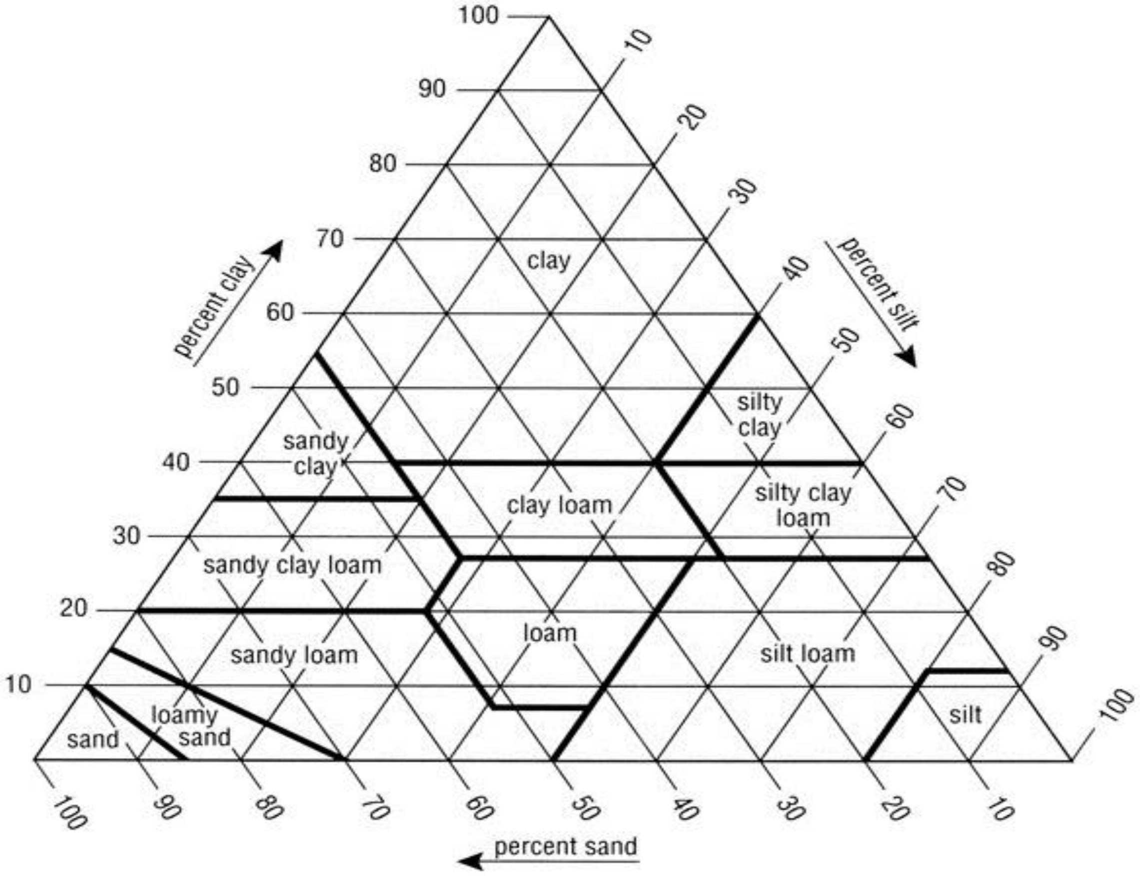


Figure 3.6: Soil texture triangle for the determination of soil type of the Madhupur Sal Forest and Sitakunda Ecopark.

3.7 Statistical analysis

3.7.1 Vegetation structure analysis

Student’s t-test was done to test the significance level among means of taxonomic diversity and soil properties between the Madhupur Sal Forest and Sitakunda Ecopark. Principal component analysis (PCA) was done on using correlations among the soil properties by using JMP software (SAS Institute). Regression analyses was done to examine the relationships between the variables of interests.

Non-metric Dimensional Scaling (NMDS) analysis was performed to examine the compositional difference between the two plant communities and to see the role of soil properties on the composition of the plant species using the vegan R package. Species abundance data was transformed to square-root followed by a Wisconsin double standardization. Bray-Curtis dissimilarity was used as the optimal measure of ecological distance. A total of 20 random starts (default) were attempted to ensure a global solution. Shepard (stress) plot was done to get a feel for how well the configuration in two dimensions matches the original data patterns. Species composition have particular environment for the distribution pattern. So, environmental factor was fit on the ordination plot. The *envfit* function in the vegan R package to investigate how the environmental factors influenced the grouping of species composition among forest. All analyses were conducted in R version 3.6.3.

3.7.2 Analysis of seasonal variation of leaf traits

Nested ANOVA was conducted separately for summer and winter seasons to compare the effect of species and forest on leaf functional traits. Species were nested within the forest. The relative proportions of sums of squares (SS) among species and within-forest types were calculated, respectively, to elucidate relative importance of the effects of species and forest on leaf traits. Student’s t-test was done to test the level of significance between seasons for each species for the leaf traits. The effects of season and forest on soil properties were tested by two-way ANOVA. Principal Component Analysis (PCA) was done separately for leaf traits and soil properties to examine whether the forest and seasons showed difference on the basis of leaf traits and soil properties, respectively. Dendrogram was constructed by R software.

CHAPTER 4

RESULTS

4.A Vegetation structure of Madhupur Sal Forest and Sitakunda Ecopark

(a) Taxonomic diversity

Taxonomic diversity of the plant vegetation of Madhupur Sal Forest and Sitakunda Ecopark are shown in Table 4.1. The present study recorded a total of 47 plant species belonging to 42 genera and 24 families in the Madhupur Sal forest. These were represented by 28 tree species, 8 shrub species, 2 climbers and 9 herbs. Sitakunda Eco-Park represented 60 plant species belonging to 55 genera and 28 families and these species were represented by 43 trees, 10 shrub and 7 herbs. Phyllanthaceae was the dominant family in the Madhupur Sal forest with 5 species followed by Fabaceae, Lamiaceae, Moraceae, Myrtaceae, Rubiaceae, Rutaceae with 3 species each (Table 4.3). In the Sitakunda Eco-Park, Fabaceae was the dominant family which represented maximum 6 species and 5 species by Lamiaceae and Rubiaceae, Moraceae and Myrtaceae 4 species each, Euphorbiaceae, Fagaceae, Malvaceae and Poaceae by 3 species each (Table 4.4).

There were no significant differences in the taxonomic diversity of genus and species in case of herbs group even though the number of genus and species were higher in Madhupur Sal Forest than Sitakunda Ecopark. But the number of family differed significantly ($P = 0.01$) from each other (Fig. 4.1 a, b and c). The number of family, genus and species were higher in Madhupur Sal Forest than Sitakunda Ecopark in case of shrubs. They showed significant difference ($P < 0.0005$) in case of taxonomic diversity of shrub between the two forests (Fig. 4.1 d, e and f). There was no significant difference in the number of family, genus and species between the two forests for tree. However, the number of family, genus and species was higher in Sitakunda Ecopark than Madhupur Sal Forest

(Fig. 4.1 g, h, i). The number of family was significantly (P = 0.0008) higher in Madhupur Sal Forest than Sitakunda Ecopark in case of all plant groups (Fig. 4.1. j). Although the number of genus was higher in Madhupur Sal Forest but there was no significant differences between the two forests (Fig. 4.1 k). Species richness was also higher in Maddhupur Sal Forest and was significantly (P = 0.05) different from the other forests (Fig 4.1 l).

Table 4.1: Taxonomic diversity of the Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP).

Taxa	**Madhupur Sal Forest**					**Sitakunda Ecopark**				
	Herb	**Shrub**	**Tree**	**Climber**	**Total**	**Herb**	**Shrub**	**Tree**	**Climber**	**Total**
Family	7	7	17	1	24	5	5	23	-	28
Genus	9	7	25	1	42	7	7	41	-	55
Species	9	8	28	2	47	7	10	43	-	60

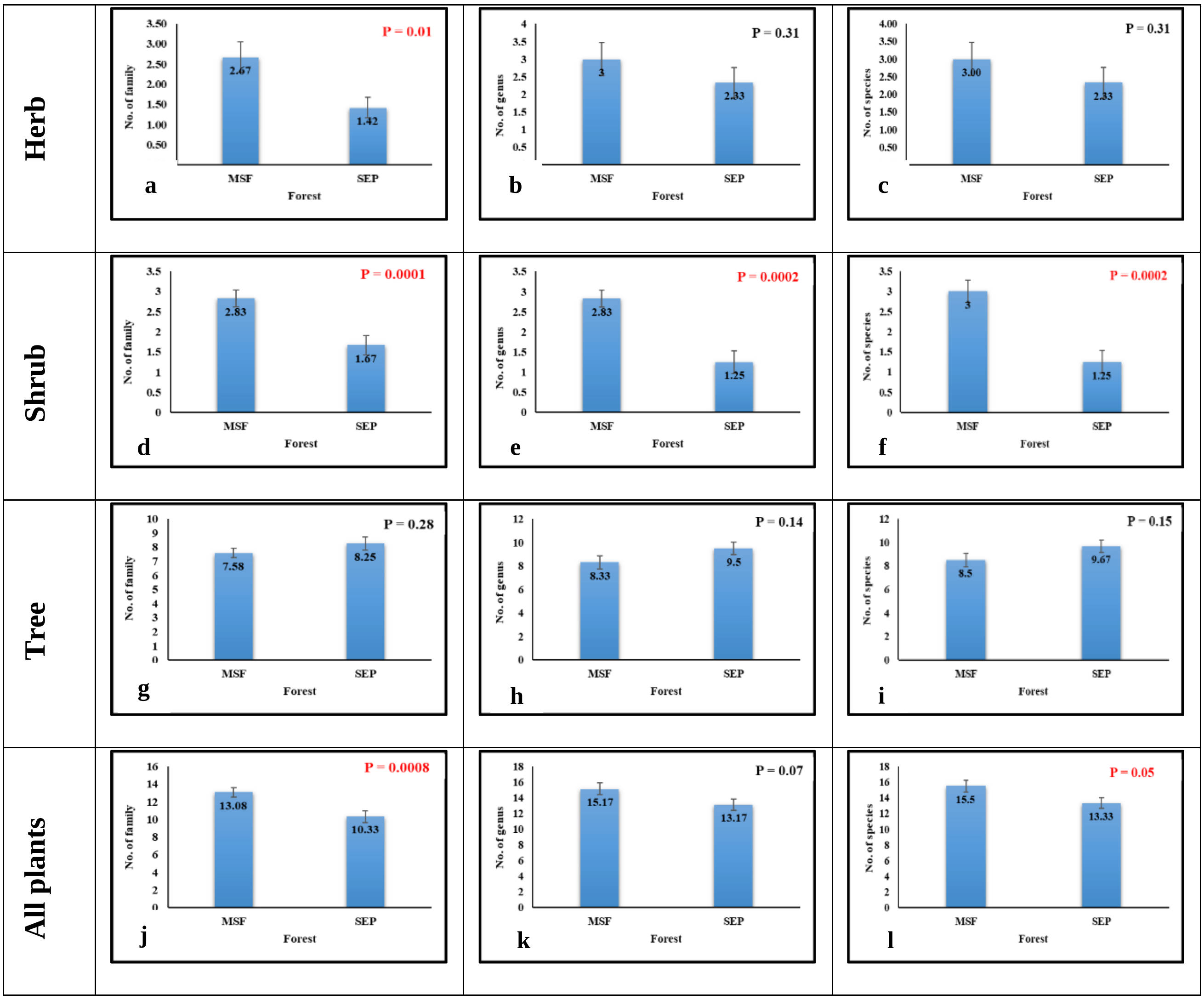


Figure 4.1: Diversity of taxa (family, genus and species) of the herb (a-c), shrub (d-f), tree (g-i) and all plants (j-l) between Madhupur Sal Forest (MSF)and Sitakunda Ecopark (SEP) (n=12).

(b) Diversity indices

The Shannon diversity (*H*), Simpson diversity and Pielou’s evenness were calculated for both study forests. Statistically no significant difference appeared for diversity indices between the two forests. The Madhupur Sal Forest showed higher value of Shannon diversity index (1.71) than the other forests (Fig. 4.2 a). Simpson diversity index was higher in Madhupur Sal Forest (0.64) than Sitakunda Ecopark (Fig. 4.2 b). The higher value of Pielou’s evenness was also found in Madhurpur Sal Forest (Fig 4.2 c).

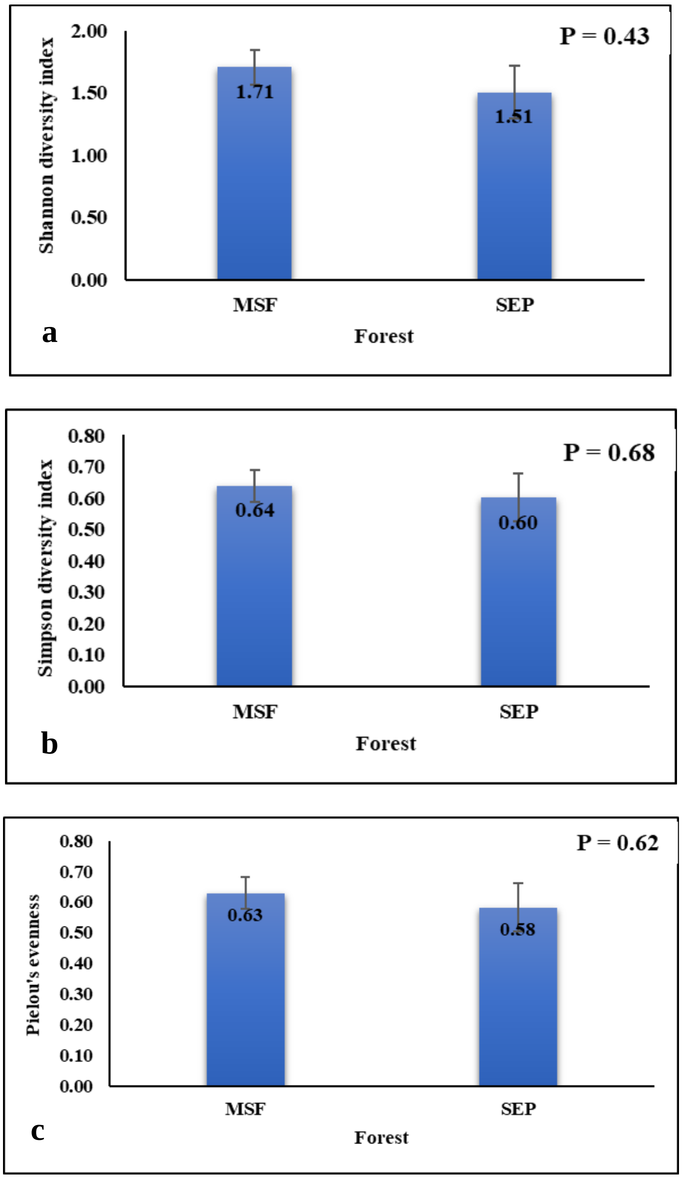


Figure 4.2: Mean values of diversity indices a: Shannon diversity index, b: Simpson diversity index and c: Pielou’s evenness between Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP) (n=12).

(c) Similarity index

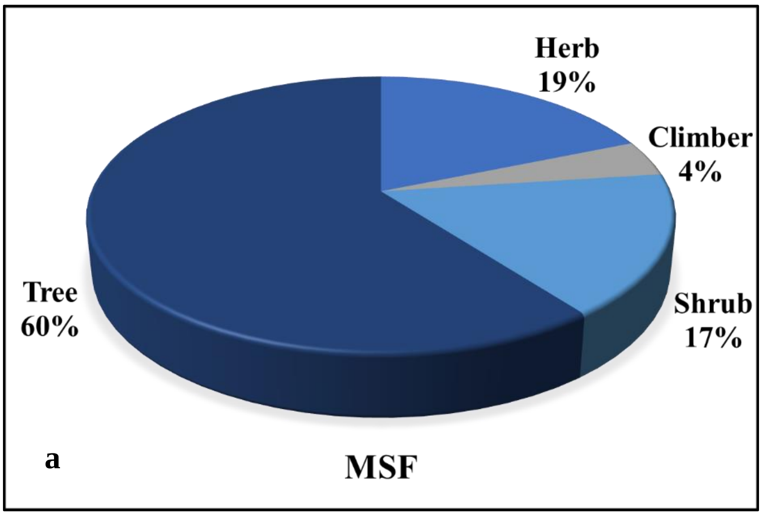
The similarity index between Madhupur Sal Forest and Sitakunda Ecopark under different taxon are shown in Table 4.2. According to Sorenson’s coefficient, among the two forests there were no much overlapping or similarity. Sorenson’s coefficient between the two forest was 0.33. This indicated that 33% of all species existed in both forests. In case of climber, there was no similarity between the two forests. Herbs and tree showed higher similarity value between the two forests than shrub community.

Table 4.2: Sørensen similarity index between Madhupur Sal Forest and Sitakunda Ecopark under different taxa.

Habit	**Species richness**		**Species overlapping**	**Similarity index**
	Madhupur Sal Forest	**Sitakunda Ecopark**		
Climber	2	0	0	0.00
Herb	9	7	3	0.38
Shrub	8	9	2	0.24
Tree	29	44	13	0.36
All plants	48	60	18	0.33

(d) Species composition

The species composition of different habits are shown in Figure 4.3. Among the recorded plant species in Madhupur Sal forest, the highest proportion was contributed by tree (60%) followed by shrub (17%), climber (4%) and herb (19%). In Sitakunda Ecopark, the highest proportion was contributed by tree (77%) following by shrub (11%) and herb (12%). Climber was not found in Sitakunda Ecopark.



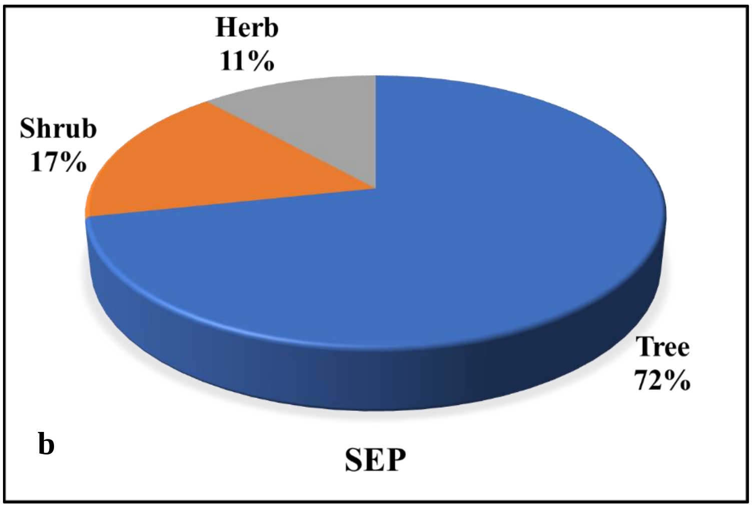


Figure 4.3: Species composition of different habits of (a) Madhupur Sal Forest (MSF) and (b) Sitakunda Ecopark (SEP).

(e) Life-form spectrum of the species of Madhupur Sal Forest and Sitakunda Ecopark

Five different life forms, based on Raunkiaer's were identified in the two forest types taken under the present study as shown in Figure 4.4. Phanerophytes occupied a dominant position in both Madhupur Sal Forest and Sitakunda Ecopark represented by 78% and 88%, respectively. Other life forms also showed a range of variation between these two forests: chamaephytes (6% and 5%), hemicryptophytes (8% and 2%), therophytes (5% and 3%) and geophytes (3% and 2%) were in the Madhupur Sal Forest and Sitakunda Ecopark, respectively.

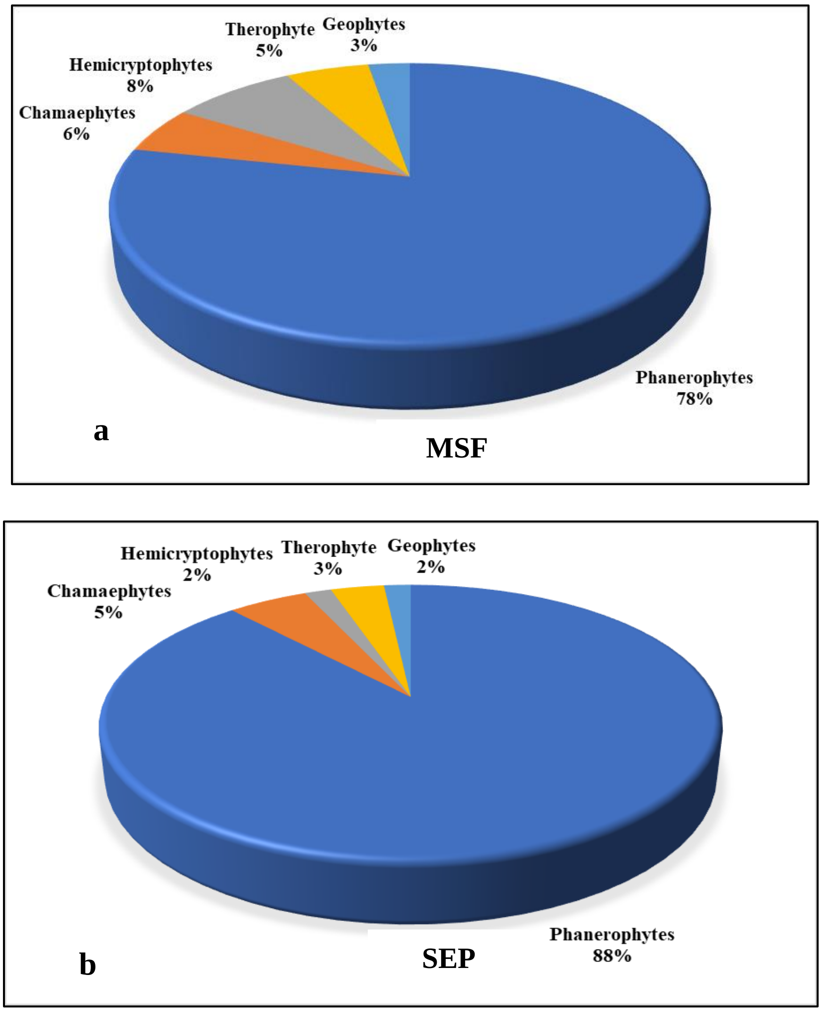


Figure 4.4: Life form spectrum of the vegetation of Madhupur Sal Forest (MSF) (a) and Sitakunda Ecopark (SEP) (b) of the present study.

(f) Importance Value Index

The tree species of the Sitakunda Ecopark with IVI values were shown in Table 4.3. In the Sitakunda Eco-Park, top five dominant tree plant species were *Grewia nervosa* IVI (25.96), followed by *Erioglossum rubiginosum* (17.72), *Streblus asper* (16.30), *Castenopsis tribuloides* (15.97) and *Phyllanthus emblica* (15.26). On the other hand, *Adina cordifolia*, *Albizia procera*, *Antidesma acidum*, *Gmelina arborea* and *Xylia dulabiformis* were rare species with IVI value (1.80) of each. In case of shrub, *Clerodendrum viscosum* (55.83) was dominant and *Randia dumetorum* was rare (12.38) as shown in Table 4.3. *Panicum repens* (115.09) was dominant and *Ceilocostus speciosus* (4.14) was rare herbs in the Sitakunda Ecopark.

Recorded IVI values of the plant species of the Madhupur Sal Forest were shown in Table 4.4. Five dominant tree plant species with IVI value recorded in the Madhupur Sal Forest were *Shorea robusta* (37.89), followed by *Grewia nervosa* (31.88), *Mallotus philipensis* (27.46), *Glycosmis pentaphylla* (24.53), and *Adina cordifolia* (19.91). The two species *Ardisia solanaceae* and *Micromelum minutum* were rare species with IVI value 1.80 each. In the Madhupur Sal Forest, in case of herb, *Panicum repens* (186.51) was dominant and *Vernonia cineria* (4.90) was rare. In case of shrub, *Calamus rotung* (74.89) was dominant and *Chromolaena odorata* (6.76) was rare.

Table 4.3: Phytosociological analysis of different species in the Madhupur Sal Forest.

Growth form	**Scientific name**	**Family**	**Local name**	**RD**	**RF**	**RA**	**IVI**
Herb	*Panicum repens* L.	Poaceae	Baranda ghas	87.18	33.33	66.00	186.51
	Curcuma zedoaria (Christm.) Roscoe	Zingiberaceae	Soti	5.00	19.44	6.49	30.94
	Pteris vittata L.	Pteridaceae	Pteris	3.65	8.33	11.06	23.04
	Axonopus compressus (Sw.) P.Beauv.	Poaceae	Ghas	1.68	8.33	5.09	15.10
	Typhonium trilobatum (L.) Schott	Araceae	Gherkochu	1.13	11.11	2.57	14.81
	Uraria rufescens (DC.) Schindl.	Fabaceae	Belai leja	0.22	8.33	0.66	9.22
	Lygodium flexousum (L.) Sw.	Lygodiaceae	Fern	0.47	5.56	2.16	8.19
	Desmodium triflorum (L.) DC.	Fabaceae	Kodalia	0.44	2.78	3.98	7.20
	Vernonia cineria (L.) Less.	Asteraceae	Kukshima	0.22	2.78	1.99	4.99
Shrub	*Calamus rotung* L.	*Arecaceae*	Bet	32.18	19.15	23.56	74.89
	Clerodendrum viscosum Vent.	Lamiaceae	Vaat	31.98	21.28	21.07	74.32
	Canthium parviflorum Roxb.	Rubiaceae	Monkata	19.55	23.40	11.71	54.67
	Ziziphus rugosa Lam.	Rhamnaceae	Anaigota	7.54	14.89	7.09	29.52
	Urena lobata L.	Malvaceae	Banokra	3.05	4.26	10.06	17.37
	Ziziphus oenoplia (L.) Miller.	Rhamnaceae	Tungiboroi	2.24	8.51	3.69	14.44
	Calamus viminalis Willd.	Arecaceae	Jatbet	1.22	2.13	8.05	11.40
	Glochidion multiloculare (Roxb. Ex. Willd) Voigt	Phyllanthaceae	Keora	0.81	2.13	5.37	8.31
	Ichnocarpus frutescens (L.) W.T.Aiton	Apocynaceae	Dodhilata	0.81	2.13	5.37	8.31
	Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	Assamlata	0.61	2.13	4.03	6.76

Table 4.3 (Continued): Phytosociological analysis of different species in the Madhupur Sal Forest.

Growth form	**Scientific name**	**Family**	**Local name**	**RD**	**RF**	**RA**	**IVI**
Tree	*Shorea robusta* Gaertn.	Dipterocarpaceae	Sal	19.28	11.76	6.85	37.89
	Grewia nervosa (Lour.) Panigrahi	Malvaceae	Datoi	15.20	10.78	5.89	31.88
	Mallotus philippensis (Lam.) Muell.Arg.	Euphorbiaceae	Sinduri	12.38	9.80	5.28	27.46
	Glycosmis pentaphylla (Retz.) DC.	Rutaceae	Motkila	10.66	8.82	5.05	24.53
	Adina cordifolia (Roxb.) Hook. f.	Rubiaceae	Kaika	7.52	8.82	3.56	19.91
	Litsea glutinosa (Lour.) C.B.Rob.	Lauraceae	Kharajora	6.43	7.84	3.42	17.69
	Swietonia mahagoni (L.) Jacq.	Meliaceae	Mahagoni	2.82	0.98	12.02	15.82
	Ficus hispida L.	Moraceae	Dumur	5.17	5.88	3.67	14.73
	Lagerstroemia speciosa (L.) Pers.	Lythraceae	Jharul	1.88	0.98	8.01	10.88
	Phyllanthus sikkimensis Müll.Arg.	Phyllanthaceae	Sikimala	1.88	0.98	8.01	10.88
	Antidesma acidum Retz.	Phyllanthaceae	Chutkigota	2.35	4.90	2.00	9.26
	Syzygium cymosum (Lam.) DC.	Myrtaceae	Khudijam	2.35	3.92	2.50	8.78
	Litsea monopetala (Roxb.) Pers.	Phyllanthaceae	Shuira	1.41	0.98	6.01	8.40
	Phyllanthus reticulatus Poir.	Combretaceae	Chitki	1.72	1.96	3.67	7.36
	Terminalia belerica (Gaertn.) Roxb.	Rutaceae	Bahera	1.57	2.94	2.23	6.73
	Zanthoxylum rhetsa (Roxb.) DC.	Rubiaceae	Bajnagota	1.25	3.92	1.34	6.51
	Streblus asper Lour.	Moraceae	Sheura	1.25	2.94	1.78	5.98
	Morinda angustifolia Roxb.	Lamiaceae	Jangli bansak	0.94	0.98	4.01	5.93
	Tectona grandis L.f.	Phyllanthaceae	Segun	0.94	1.96	2.00	4.90
	Aporosa diocia (Roxb.) Müll.Arg.	Lamiaceae	Kechua	0.63	0.98	2.67	4.28
	Careya arborea Roxb.	Moraceae	Gadila	0.47	0.98	2.00	3.45
	Artocarpus heterophyllus Lam.	Moraceae	Kathal	0.31	0.98	1.34	2.63

Table 4.3 (Continued): Phytosociological analysis of different species in the Madhupur Sal Forest.

Growth form	**Scientific name**	**Family**	**Local name**	**RD**	**RF**	**RA**	**IVI**
Tree	*Cassia siamea* Lam.	Lauraceae	Minjiri	0.31	0.98	1.34	2.63
	Syzygium cumini (L.) Skeels.	Myrtaceae	Jam	0.31	0.98	1.34	2.63
	Syzygium grande (Wight) Walp.	Myrtaceae	Borojam	0.31	0.98	1.34	2.63
	Toona ciliate M. Roem.	Meliaceae	Toon	0.31	0.98	1.34	2.63
	Ardisia solanaceae Roxb.	Primulaceae	Konok	0.16	0.98	0.67	1.80
	Micromelum minutum (G.Forst.) Wight & Arn.	Rutaceae	Bankunch	0.16	0.98	0.67	1.80

RD = Relative Density, RF = Relative Frequency, RA = Relative Abundance, IVI = Importance Value Index

Table 4.4: Phytosociological analysis of different species in the Sitakunda Ecopark

Growth form	Scientific name	Family	Local name	RD	RF	RA	IVI
Herb	*Panicum repens* L.	Poaceae	Baranda ghas	52.22	32.14	30.73	115.09
	Axonopus compressus (Sw.) P.Beauv.	Poaceae	Ghas	20.73	25.00	15.68	61.42
	Crotalaria juncea L.	Poaceae	Shonpat	11.67	14.29	15.44	41.39
	Mimosa pudica L.	Fabaceae	Lajjaboti	10.64	10.71	18.78	40.13
	Spermacoce remota Lam.	Rubiaceae	Tenijil	3.02	3.57	16.00	22.60
	Curcuma zedoaria (Christm.) Roscoe	Zingiberaceae	Soti	1.63	10.71	2.88	15.23
	Cheilocostus speciosus (J.Konig) C.Specht	Costaceae	Banduki	0.09	3.57	0.48	4.14
Shrub	*Clerodendrum viscosum* Vent.	Lamiaceae	Vaat	25.00	13.33	17.50	55.83
	Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	Assamlata	17.86	6.67	25.00	49.52
	Ixora nigricans R.Br. ex Wright & Arn	Rubiaceae	Kalo rangan	9.52	6.67	13.33	29.52
	Premna esculenta Roxb.	Lamiaceae	Lalong	9.52	6.67	13.33	29.52
	Calycopteris floribunda (Roxb.) Lam. ex Poir.	Combretaceae	Guiccha lata	14.29	20.00	6.67	40.95
	Flemingia stricta Roxb.	Fabaceae	Charchara phan	10.71	13.33	7.50	31.55
	Croton caudatus Geiseler	Euphorbiaceae	Sabarjala	4.76	6.67	6.67	18.10
	Canthium parviflorum Roxb.	Rubiaceae	Monkata	3.57	6.67	5.00	15.24
	Melastoma malabathricum L.	Melastomataceae	Tejbahal	2.38	6.67	3.33	12.38
	Randia dumetorum (Retz.) Lam.	Rubiaceae	Mon kantha	2.38	13.33	1.67	17.38

Table 4.4: (continued): Phytosociological analysis of different species in the Sitakunda Ecopark

Growth form	Scientific name	Family	Local name	RD	RF	RA	IVI
Tree	*Grewia nervosa* (Lour.) Panigrahi	Malvaceae	Datoi	13.56	7.76	4.64	25.96
	Erioglossum rubiginosum (Roxb.) Blume	Sapindaceae	Harina	7.82	6.90	3.01	17.72
	Streblus asper Lour.	Moraceae	Sheura	7.36	5.17	3.78	16.30
	Castenopsis tribuloides (Sm.) A. DC.	Fagaceae	Sadabatna	6.90	6.03	3.03	15.97
	Phyllanthus emblica L.	Phyllanthaceae	Amloki	6.67	5.17	3.42	15.26
	Suregada multiflora (A.Juss.) Baill	Euphorbiaceae	Bon lotkon	5.29	5.17	2.71	13.17
	Holarrhena antidysentery (L.) Wall. ex A. DC.	Apocynaceae	Kuruch	4.37	5.17	2.24	11.78
	Litsea glutinosa (Lour.) C.B.Rob.	Lauraceae	Kharajora	3.91	4.31	2.41	10.63
	Syzygium cymosum (Lam.) DC.	Myrtaceae	Khudijam	3.91	3.45	3.01	10.37
	Ficus hispida L.	Moraceae	Dumur	3.45	3.45	2.66	9.55
	Glycosmis pentaphylla (Retz.) DC.	Rutaceae	Motkila	2.99	1.72	4.60	9.31
	Garuga pinnata Roxb.	Burseraceae	Kapila	2.76	3.45	2.12	8.33
	Callicarpa arborea Roxb.	Lamiaceae	Bormala	2.30	1.72	3.54	7.56
	Eucalyptus obliqua L'Hér.	Myrtaceae	Eucalyptu	2.30	3.45	1.77	7.52
	Steriospermum colais (Buch. -Ham. ex Dillw.) DL Mabberley	Bignoniaceae	Dharmara	2.30	2.59	2.36	7.25
	Caesalpinia pulcherrima (L.) Sw.	Fabaceae	Radhachura	2.07	3.45	1.59	7.11
	Vitex pendicularis Wall ex. Schauer	Lamiaceae	Vitex	1.38	0.86	4.25	6.49
	Lithocarpus elegans (Blume) Hatus. *ex* Soepadmo	Fagaceae	Shil batna	1.61	1.72	2.48	5.81
	Mallotus philippensis (Lam.) Muell.Arg.	Euphorbiaceae	Sinduri	1.61	1.72	2.48	5.81
	Swintonia floribunda Griff.	Anacardiaceae	Boilam	1.15	0.86	3.54	5.55
	Syzygium cumini (L.) Skeels.	Myrtaceae	Jam	1.38	2.59	1.42	5.38

Table 4.4: (continued): Phytosociological analysis of different species in the Sitakunda Ecopark

Growth form	Scientific name	Family	Local name	RD	RF	RA	IVI
Tree	*Artocarpus chaplasha* Roxb.	Moraceae	Chapalish	1.38	1.72	2.12	5.23
	Ardisia solanaceae Roxb.	Primulaceae	Konok	1.15	1.72	1.77	4.64
	Terminalia catappa L.	Combretaceae	Katbadam	1.15	1.72	1.77	4.64
	Litsea bourdillonii Gamble	Lauraceae	Menda	0.92	0.86	2.83	4.61
	Nyctanthes arbor-tristis L.	Oleaceae	Sheuli	0.92	0.86	2.83	4.61
	Pterospermum semisagittatum Buch. Ham. ex Roxb.	Malvaceae	Bara asar	0.92	0.86	2.83	4.61
	Syzygium firmum Thwaites	Myrtaceae	Dhakijam	0.92	0.86	2.83	4.61
	Toona ciliate M. Roem.	Meliaceae	Toon	0.92	0.86	2.83	4.61
	Dalbergia latifolia Roxb.	Fabaceae	Bonsonalu	0.69	0.86	2.12	3.68
	Dipterocarpus turbinatus C.F.Gaertn.	Dipterocarpaceae	Garjan	0.69	0.86	2.12	3.68
	Garcinia cowa Roxb.	Clusiaceae	Kau	0.69	0.86	2.12	3.68
	Mimusops elengi L.	Sapotaceae	Bokul	0.69	0.86	2.12	3.68
	Protium serratum (Wall. ex Colebr.) Engl.	Burseraceae	Gutgutiya	0.69	0.86	2.12	3.68
	Shorea robusta Gaertn.	Dipterocarpaceae	Sal	0.69	0.86	2.12	3.68
	Artocarpus heterophyllus Lam.	Moraceae	Kathal	0.46	1.72	0.71	2.89
	Bombax ceiba L.	Malvaceae	Shimul Tula	0.46	1.72	0.71	2.89
	Castenopsis indica (Roxburgh ex Lindl.) A. DC.	Fagaceae	Batna	0.46	0.86	1.42	2.74
	Adina cordifolia (Roxb.) Hook. f.	Rubiaceae	Kaika	0.23	0.86	0.71	1.80
	Albizia procera (Roxb.) Benth.	Fabaceae	Sada koroi	0.23	0.86	0.71	1.80
	Antidesma acidum Retz.	Phyllanthaceae	Chutkigota	0.23	0.86	0.71	1.80
	Gmelina arborea Roxb.	Lamiaceae	Gamari	0.23	0.86	0.71	1.80
	Xylia dulabiformis Benth.	Fabaceae	Lohakath	0.23	0.86	0.71	1.80

RD = Relative Density, RF = Relative Frequency, RA = Relative Abundance, IVI = Importance Value Index

(g) Tree morphometric traits

Plant density of the tree species was higher in Madhupur Sal Forest (53.4 individual/100m^2) than Sitakunda Ecopark (36.6 individual/100m^2). The density was significantly ($P = 0.006$) different between the two forests (Fig. 4.5 a). The Madhupur Sal Forset showed the higher value of diameter at breast height (14.68 cm) than Sitakunda Ecopark (13.51 cm) (Fig. 4.5 b). Although DBH was higher in Madhupur Sal Forest than Sitakunda Ecopark but there was no significant difference between the two forests.

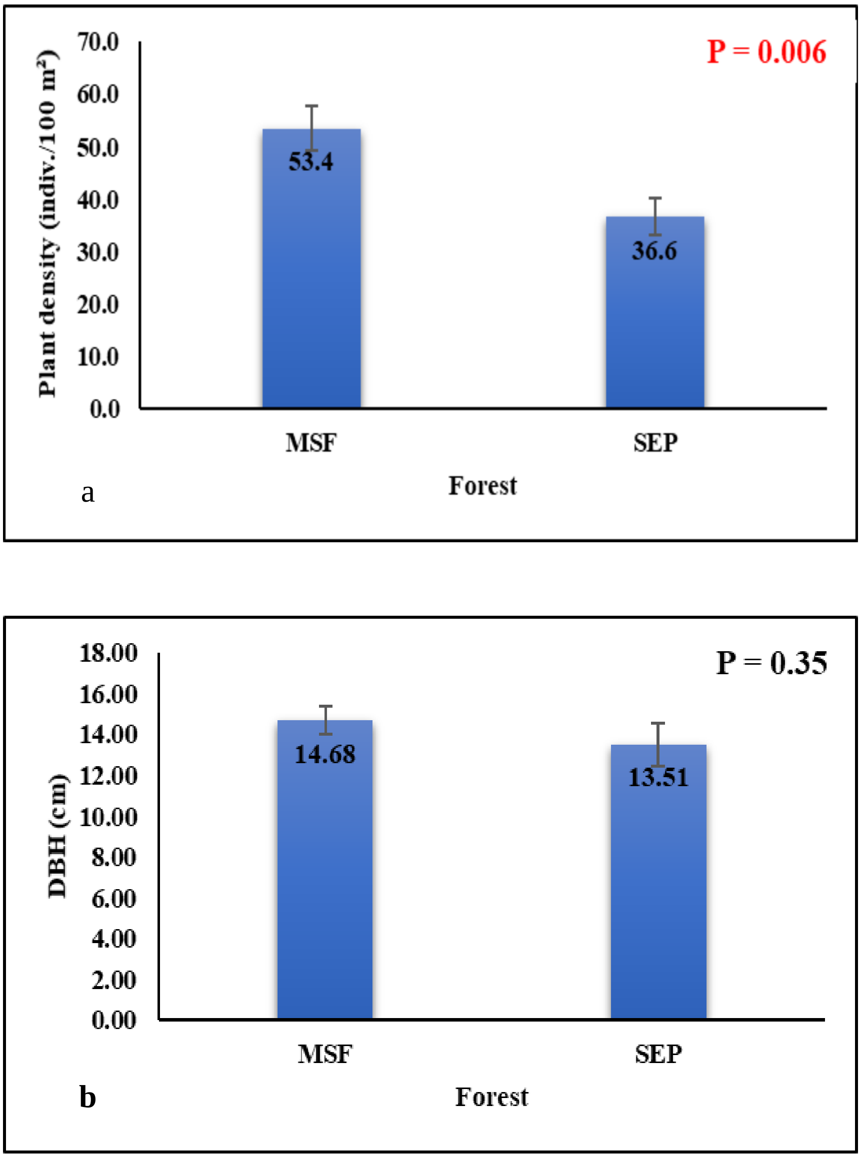
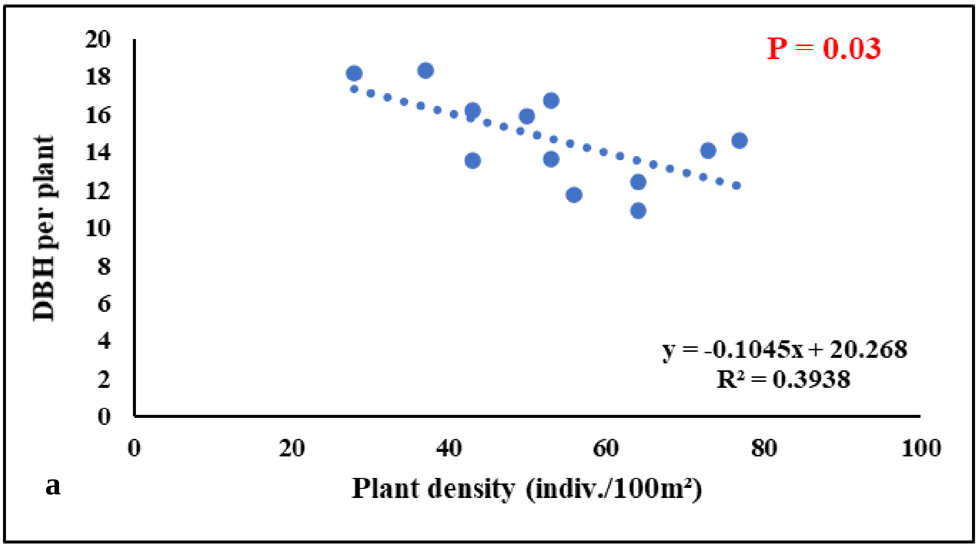


Figure 4.5: (a) Density (individuals/100m^2) and (b) Diameter at breast height (DBH) per plant between Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP) (n=12).

(h) Correlation between Diameter at Breast Height and plant density

In the present study correlation between DBH and plant density was done. Plant density showed a significant negative correlation ($R^2 = 0.39$, $P = 0.03$) with the DBH in the Madhupur Sal Forest (Fig. 4.6 a) which indicated a negative interaction between plant growth and density. However, Sitakunda Ecopark showed no such negative correlation. Such relationship was more prominent in Madhupur forests than the Sitakunda Ecopark (Fig. 4.6 b).



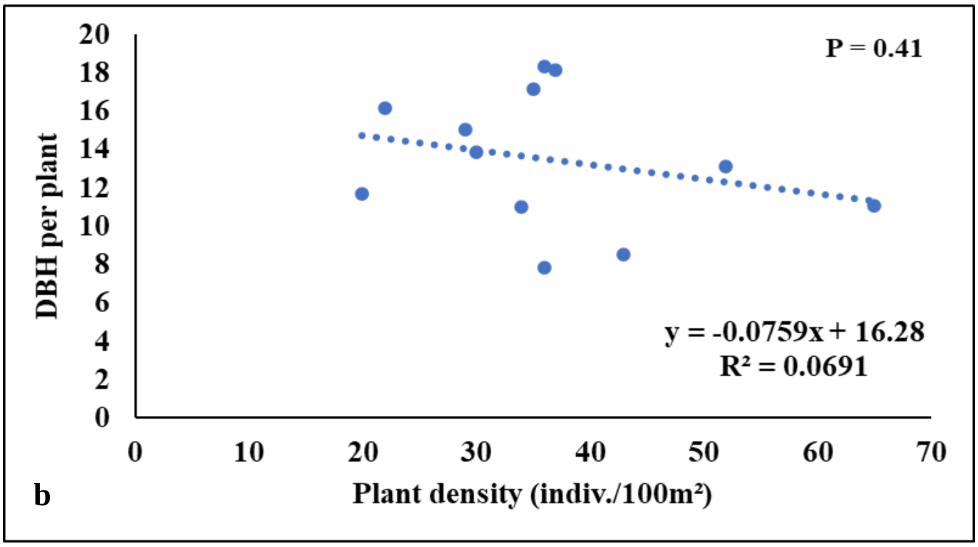


Figure 4.6: Correlation between Diameter at Breast Height (DBH) per plant and density of Madhupur Sal Forest (a) and Sitakunda Ecopark (b) (n=12).

4.B Soil properties of Madhupur Sal Forest and Sitakunda Ecopark

(a) Physical properties of soil

The physical properties of soil of the two forests are shown in Figure 4.7. Soil moisture was slightly higher in Madhupur Sal Forest (17.47 ± 0.38) than Sitakunda Ecopark (17.00 ± 0.74) (Fig. 4.7 a). Clay showed significant (P = 0.04) difference between the two forests (Fig. 4.7 b). Higher value of clay was found in Sitakunda Ecopark (45.86 ± 2.43) than Madhupur Sal Forest (39.85 ± 1.25). Silt was higher in Madhupur Sal Forest (26.59 ± 1.08) than Sitakunda Ecopark (25.05 ± 3.08) (Fig. 4.7 c). The higher value of sand was found in Madhupur Sal Forest (33.56 ± 1.38) than Sitakunda Ecopark (29.09 ± 4.95) (Fig. 4.7 d). Although, silt, sand and moisture were higher in Madhupur Sal Forest than Sitakunda Ecopark but there were no significant differences.

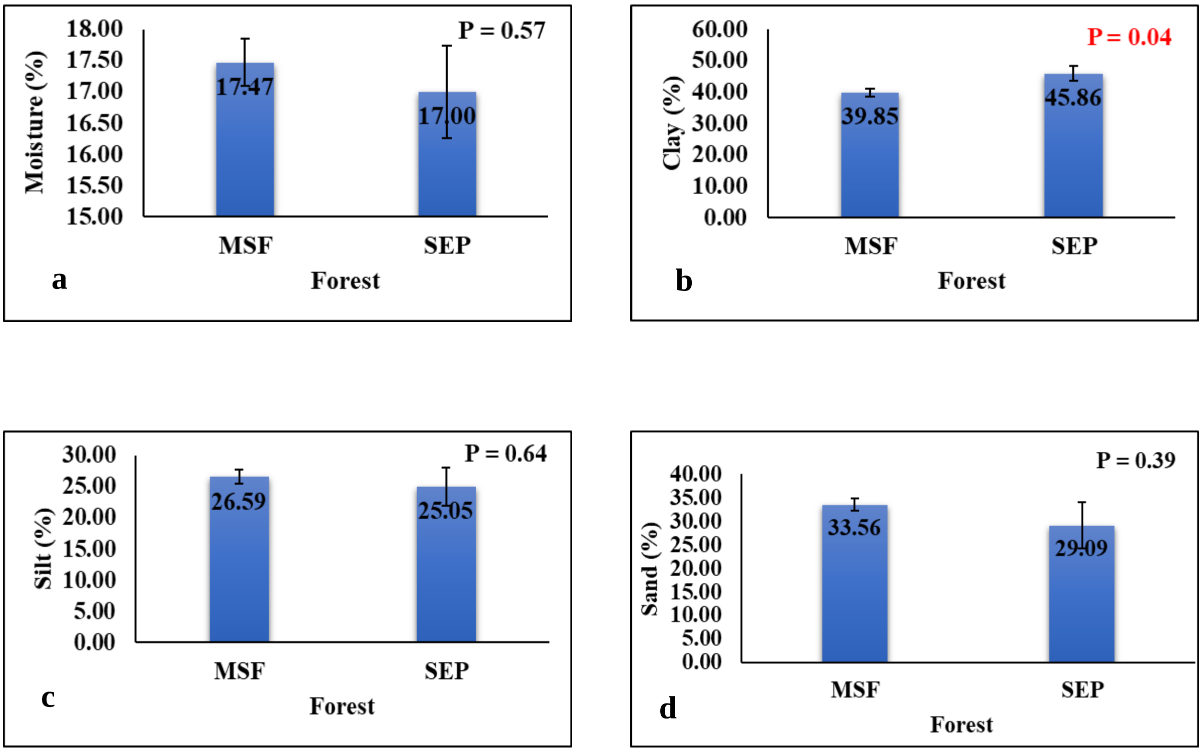


Figure 4.7: Mean values of the physical properties of soil (a-d) between Madhupur Sal forest and Sitakunda Ecopark (n=12).

(b) Chemical properties of soil

Soil chemical properties are shown in Figure 4.8. The soil pH was higher in Sitakunda Ecopark (5.37 ± .08) than Madhupur Sal Forest (5.19 ± .09) (Fig. 4.8 a). The higher value of electrical conductivity was found in Sitakunda Ecopark (29.58 ± 2.94) than Madhupur Sal Forest (22.46 ± 2.14) (Fig. 4.8 b). Although the pH and electrical conductivity were higher in Sitakunda Ecopark but there was no significant differences with Madhupur Sal Forest. The Madhupur Sal Forest showed higher value of organic carbon (0.33 ± 0.02) than Sitakunda Ecopark (0.29 ± .09) (Fig. 4.8 c). They did not differ significantly in case of organic carbon. The highest available nitrogen was found in Madhupur Sal Forest (100.79 ± 7.10) than Sitakunda Ecopark (85.38 ± 10.06) (Fig 4.8 d) although Phosphorous was significantly ($P = 0.005$) higher in Sitakunda Ecopark (0.06 ± .005) than Madhupur Sal Forest (0.05 ± 0.001) (Fig. 4.8 e). Potassium contents in soils differed significantly ($P = 0.0007$) between Madhupur Sal Forest and Sitakunda Ecopark. With the higher value in Madhupur Sal Forest than Sitakunda Ecopark (Fig. 4.8 f). Although the sodium was higher in Madhupur Sal Forest (1.35 ± 0.10) than Sitakunda Ecopark (0.84 ± .08) but they did not differ significantly (Fig. 4.8 g).

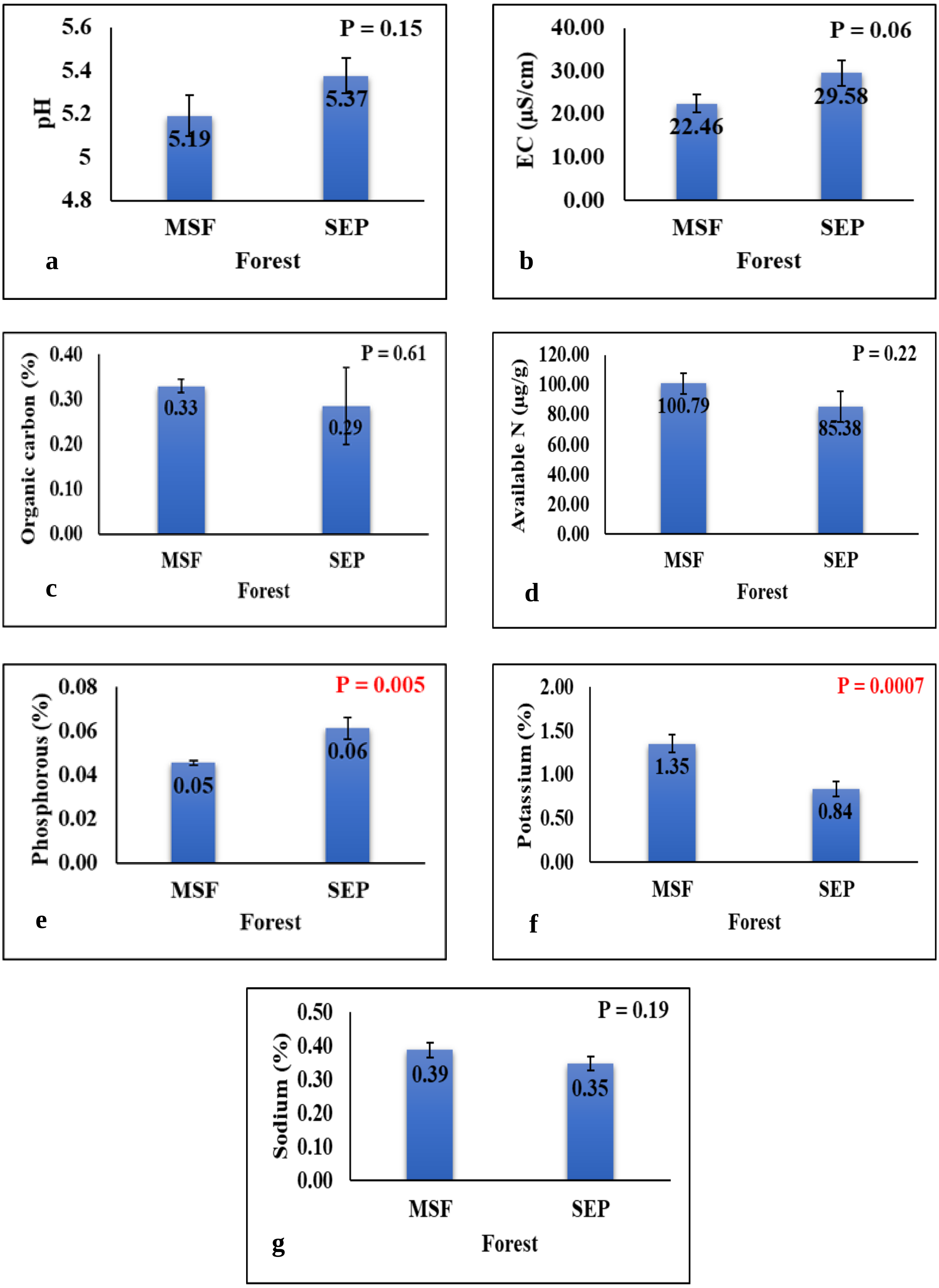


Figure 4.8: Mean values of the chemical properties of soil (a-g) between Madhupur Sal forest (MSF) and Sitakunda Ecopark (SEP) (n=12).

The biplot graph obtained from PCA done based on soil properties of Madhupur Sal Forest and Sitakunda Ecopark is shown in Fig. 4.9. PC1 represented X axis and PC3 represented Y axis representing 25.35% and 15.42% of total variation, respectively. Along PC1 and PC3, the two forests were separated from each other. Coefficients of correlation of soil properties with PC1 and PC3 are shown in Table 4.5. PC1 showed significant positive correlation with phosphorus ($r = 0.57$, $P < 0.005$), available N ($r = 0.41$, $P = 0.05$), clay ($r = 0.83$, $P < 0.000$) and silt ($r = 0.72$, $P < 0.000$). It showed negative correlation with sand ($r = -0.93$, $P < 0.0001$). PC3 showed significant negative correlation with soil pH ($r = -0.55$, $P = 0.01$), phosphorus ($r = -0.65$, $P < 0.005$) and available N ($r = -0.41$, $P < 0.05$). It showed positive correlation with soil organic carbon ($r = 0.45$, $P < 0.05$) and silt ($r = 0.54$, $P < 0.05$).

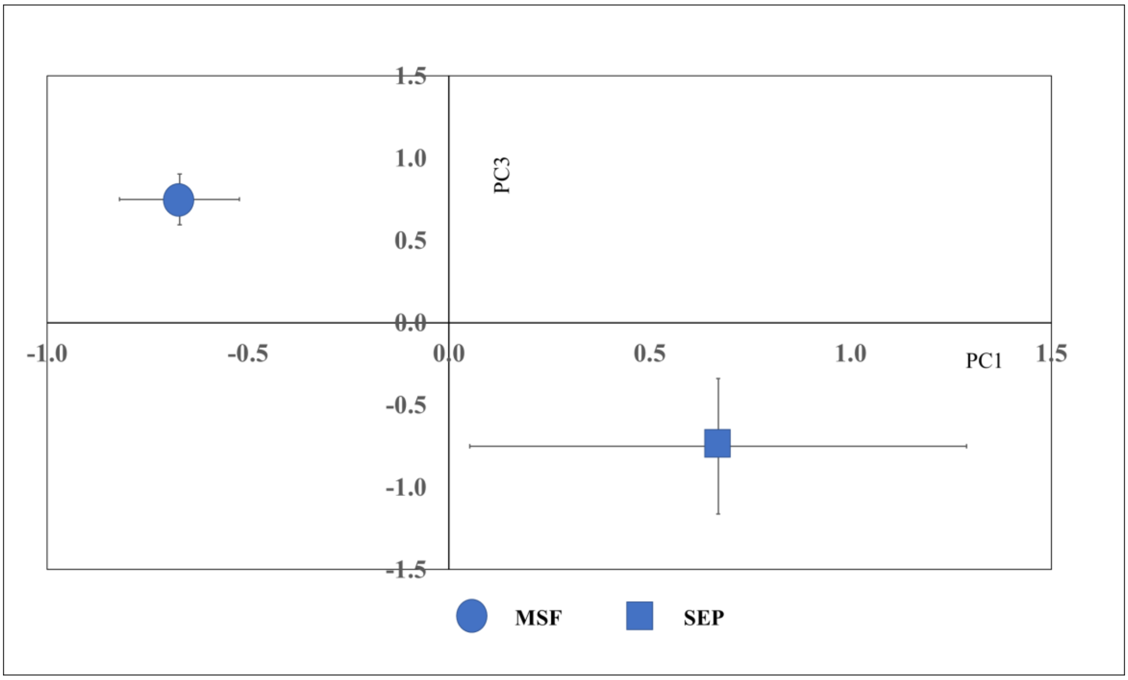


Figure 4.9: Principal Component Analysis (PCA) done on using correlations among the soil properties of Madhupur Sal Forest (MSF) and Sitakunda Eco-Park (SEP).

Table 4.5: Coefficients of correlations between PC (Principal Component) 1 and 3 with soil properties. Values within parenthesis indicates p-values.

Soil properties	**PC1**	**PC3**
P^{H}	0.09 (0.69)	-0.55 (0.005)
Electrical conductivity	0.27 (0.21)	-0.02 (90.92)
Soil moisture	-0.17 (0.43)	0.26 (0.20)
Phosphorous	0.57 (0.004)	-0.65 (0.001)
Sodium	-0.07 (0.79)	0.09 (0.68)
Potassium	-0.24 (0.25)	0.38 (0.06)
Available nitrogen	0.41 (0.048)	-0.41 (0.048)
Organic carbon	0.27 (0.20)	0.45 (0.027)
Clay	0.83 (0.000)	-0.07 0.75
Silt	0.72 (0.000)	0.54 (0.007)
Sand	-0.93 (0.000)	-0.30 (0.16)

4.C Relationships between species distribution and soil properties

(a) Correlation between plant species richness and soil phosphorous contents

Regression analysis showed significant negative correlations of species richness of tree (R^2 = 0.28, P = 0.008) and shrub (R^2 = 0.18, P = 0.04) with soil P content across forest types supporting the 'productivity versus diversity' hypothesis that explains diversity of organisms through competitive exclusion principle. There was no significant correlation of species richness of herb with soil P content (Fig. 4.10. a-c).

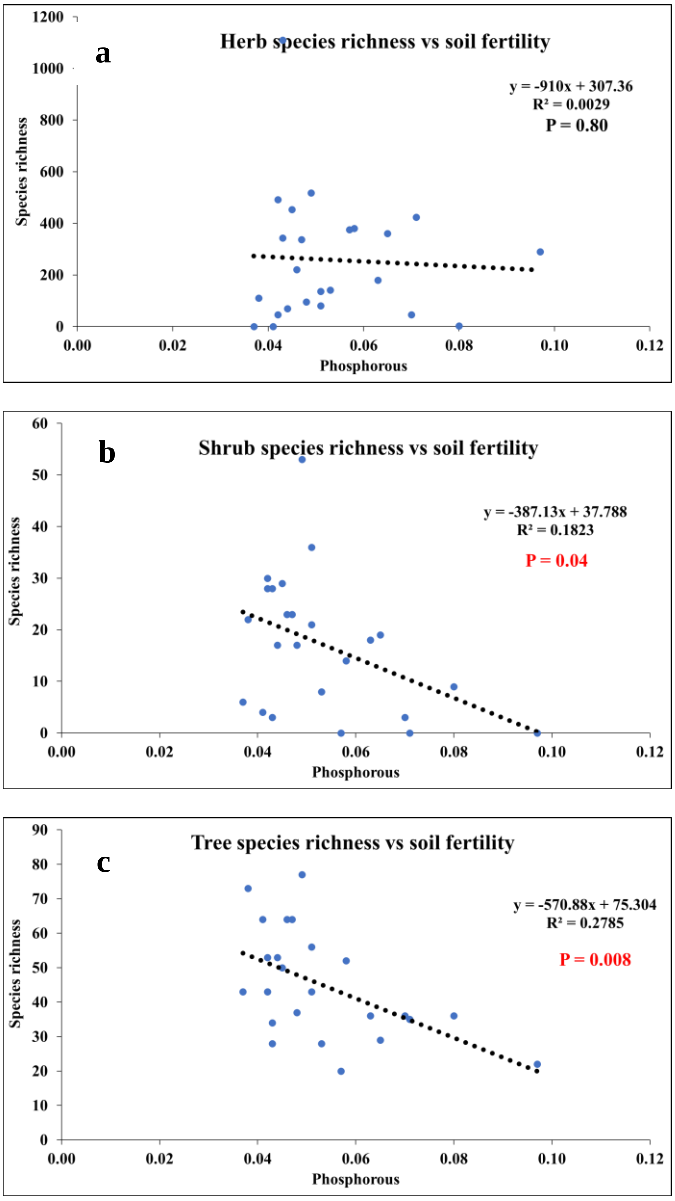


Figure 4.10: Correlation of species richness of herb (a), shrub (b) and tree (c) with soil Phosphorous (P) of Madhupur Sal Forest and Sitakunda Ecopark (n=24).

(b) Multivariate analysis on species distribution

The Shepard diagram was run with two dimensions with the calculated stress value 0.17. The points falling on monotonic line continuously increased. This stress was calculated from the residuals of the points. Shepard diagram was done by correlation between ordination distance and observed dissimilarity. There was perfect correlation between the two. Since calculated stress value was less than 0.2, so the goodness of fit of the NMDS ordination plot was perfect (Fig. 4.11).

On the Non-Metric Dimensional Scaling ordination plot, NMDS1 explained X axis and NMDS2 explained Y axis. Plot diversity in Madhupur Sal Forest and Sitakunda Ecopark formed two distinct groups within axis 1 and 2 of the NMDS ordination (Fig. 4.12). NMDS analysis based on the species score showed that plots of the two selected forests were separated into two groups where the Madhupur Sal forest was characterized by highly dominant species of *Shorea robusta, Grewia nervosa, Mallotus philipensis, Glycosmis pentaphylla, Adina cordifolia, Litsea glutinosa, Antidesma acidum, Ficus hispida* and *Syzygium cymosum*. Sitakunda Ecopark was characterized by *Castenopsis tribuloides, Erioglossum rubiginosum, Holarrhena antidysenterica, Phyllanthus emblica, Streblus asper* and *Suregada multiflora.* Data also revealed that NMDS axes were significantly correlated with the soil factors such as P ($R^2 = 0.53$, P = 0.001), K ($R^2 = 0.27$, P = 0.04), available N ($R^2 = 0.42$, P = 0.01)), C ($R^2 = 0.28$, P = 0.02), clay ($R^2 = 0.28$, P = 0.01) and sand ($R^2 = 0.25$, P = 0.05) suggesting that soil properties played role in structuring forest vegetation (Table 4.6).

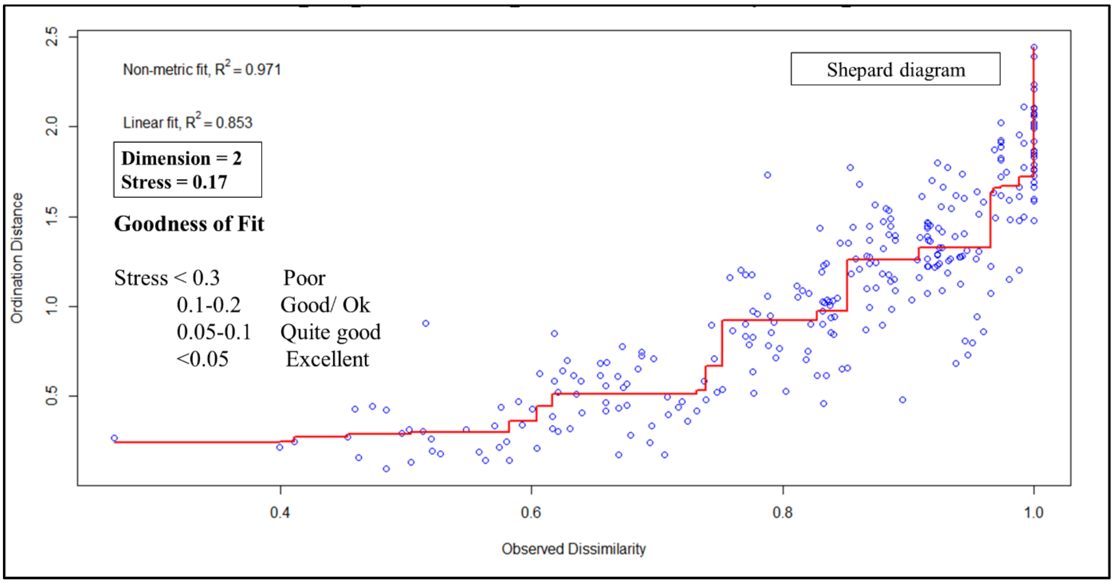


Figure 4.11: Shepard diagram showing the correlation between ordination distance and observed dissimilarity in plant species composition in relation to soil properties.

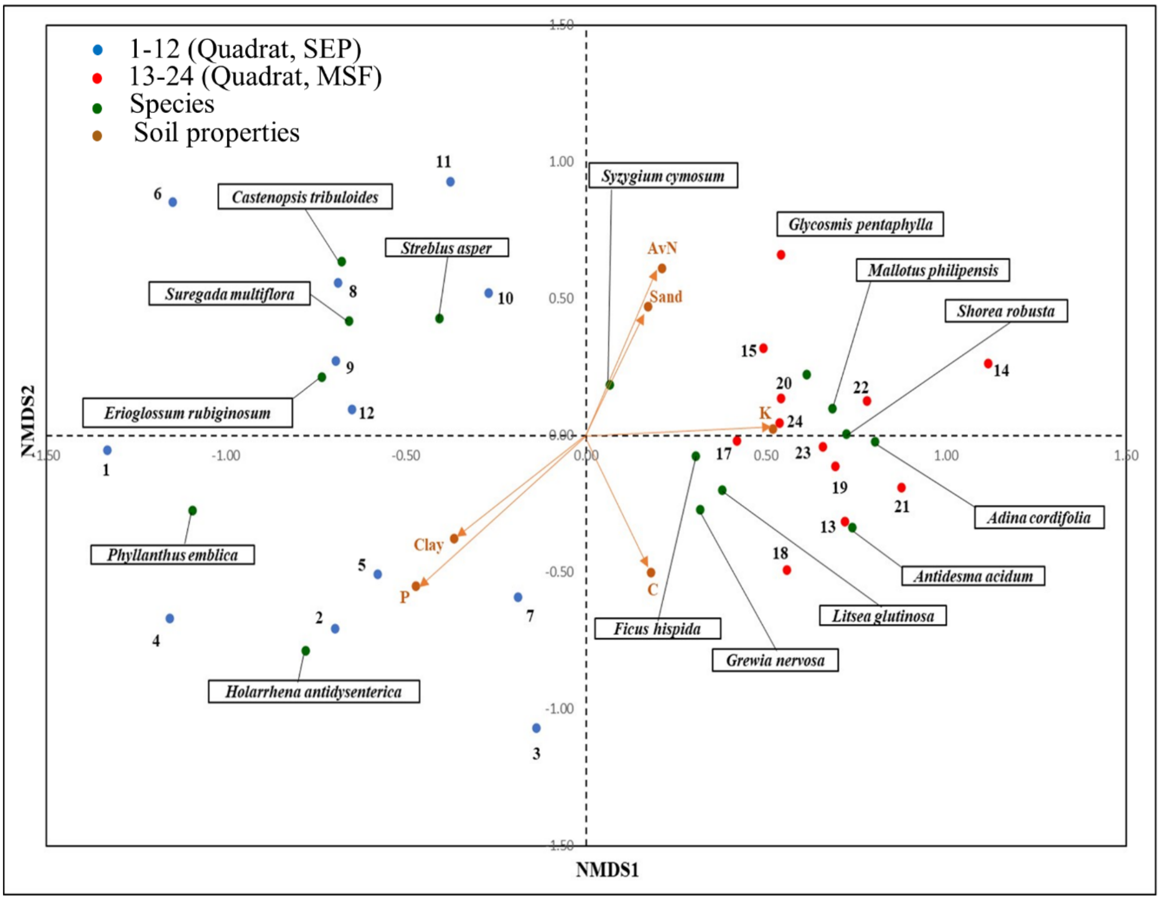


Figure 4.12: Non-Metric Dimensional Scaling (NMDS) showing the variation in plot species composition within and among sites. The lengths of arrows indicating environmental factor Fits were scaled by R^2. Arrows point in the direction of increasing values of that environmental factor.

Table 4.6: Correlation co-efficients between soil properties and NMDS axis of the Madhupur Sal Forest and Sitakunda ecopark.

Soil Properties	NMDS1	NMDS2	r^2	Pr (> r)
pH	-0.87	0.50	0.16	0.20
Electrical Conductivity	-0.93	0.37	0.20	0.10
Moisture (%)	0.85	-0.53	0.10	0.30
P (%)	-0.65	-0.76	0.53	0.001 ***
Na (%)	0.79	-0.61	0.04	0.70
K (%)	1.00	0.05	0.27	0.038 *
AvN (%)	0.32	0.95	0.42	0.006 **
C (%)	0.34	-0.94	0.28	0.020 *
Clay (%)	-0.70	-0.72	0.28	0.040 *
Silt (%)	0.04	-1.00	0.18	0.10
Sand (%)	0.34	0.94	0.25	0.049 *
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				
Permutation: free				
Number of permutations: 999				

4.D Seasonal variation in leaf traits of Madhupur Sal Forest and Sitakunda Ecopark

The effects of species and forest types on different leaf traits analyzed by the Nested ANOVA are shown in Table 4.7. Percent Sum of Square (SS) was calculated to explain the relative importance of the effects of species and forest functional types (deciduous and evergreen) on the leaf traits. Most of the leaf morpho-physiological traits were significantly affected by forests whereas anatomical traits were significantly affected by species within each forest.

Table 4.7: Nested ANOVA statistics done separately for summer and winter seasons on the effects of species and forest types (Madhupur Sal Forest and Sitakunda Ecopark) on different leaf traits. Percent Sum of Square (SS) was calculated from the fit model.

Types of leaf traits	Trait	**% SS**			
		Summer		Winter	
		Species	Forest	Species	Forest
Morphological	Leaf length (cm)	96.37***	3.63	88.67***	11.33
	Leaf breadth (cm)	18.60***	81.40***	18.71***	81.29***
	Leaf perimeter (cm)	25.94***	74.06***	24.38***	75.62***
	Leaf area (cm^2)	21.37***	78.63***	21.31***	78.69***
	Fresh weight (g)	67.50***	32.50***	57.24***	42.76***
	Turgid weight (g)	50.38***	49.62***	47.80***	52.20***
	Dry weight (g)	40.52***	59.48***	37.37***	62.63***
	Specific leaf area (cm^2 g^{-1})	44.17***	55.83***	26.67***	73.33***
Physiological	Chlorophyll (µgcm^{-2})	13.41***	86.59***	19.34***	80.66***
	Relative water content (g g^{-1})	2.1	97.90***	7.08***	92.92***
	Leaf dry matter content (g g^{-1})	74.18***	25.82***	90.80***	9.2
	Leaf water content (g cm^{-2})	24.62***	75.38***	32.52***	67.48***
Anatomical	Stomatal length (µm)	86.72***	13.28**	90.47***	9.53*
	Stomatal breadth (µm)	66.83***	33.17**	62.49***	37.51***
	Stomatal area (µm^2)	73.69***	26.31***	80.71***	19.29*
	Stomatal perimeter (µm)	81.63***	18.37**	75.69***	24.31***
	Pore length (µm)	84.90***	15.10**	85.35***	14.65
	Pore breadth (µm)	55.70***	44.30***	100.00***	0
	Stomatal density (individual/mm^2)	24.00***	76.00***	34.76***	65.24***
	Percent of open stomata (%)	81.21***	18.79	63.55***	36.45
	Percent of close stomata (%)	81.21***	18.79	63.55***	36.45
	Stomatal pore index (%)	35.87***	64.13***	95.19***	4.81

*, **, *** Indicates significant at $P = 0.05$, **$P < 0.05$ and $P < 0.0001$, respectively

(a) Leaf morphological traits

Leaf length was significantly ($P < 0.0001$) affected by species in both seasons but there was no significant effect of forest type (Table 4.7). Leaf length was higher in Madhupur Sal Forest. Leaf breadth and leaf perimeter were higher in Madhupur Sal Forest than Sitakunda Ecopark (Fig. 4.13 a-f). They were significantly affected by species ($P < 0.0001$) and forest types ($P < 0.0001$) in both summer and winter seasons. The significant effects of forest types on leaf breadth and leaf perimeter were relatively higher which explained 81.40% and 74.06% of total variation respectively than the effects of species in both seasons. Madhupur Sal Forest showed higher mean values of leaf area and specific leaf area than that of Sitakunda Ecopark (Fig. 4.13 g-j). Leaf area and specific leaf area were significantly affected by species and forest types in both seasons. Forest types explained the effects on leaf area in the summer and winter season explaining 78.63% and 78.69% variation, respectively. Specific leaf area was affected by forest types which explained 55.83% in the summer season and 73.33% in the winter season. Mean values of fresh weight, turgid weight and dry weight were higher in Madhupur Sal Forest than Sitakunda Ecopark (Fig. 4.13 k-p). Species showed relatively high significant effects on leaf fresh weight in the summer and winter season explaining 67.50% and 57.24% of total variation than forest types explaining 32.50% and 42.76% of variation, respectively. In the Summer season, leaf turgid weight showed highly significant effect by species (50.38%) than forest types (49.62%). But, in the winter season, the effects of forest type (52.20%) on leaf turgid weight were relatively higher than that of species (47.80%). The significant effects of forest types on leaf dry weight were relatively high which explained 59.48% of variation than the effects of species (37.37%) in both seasons.

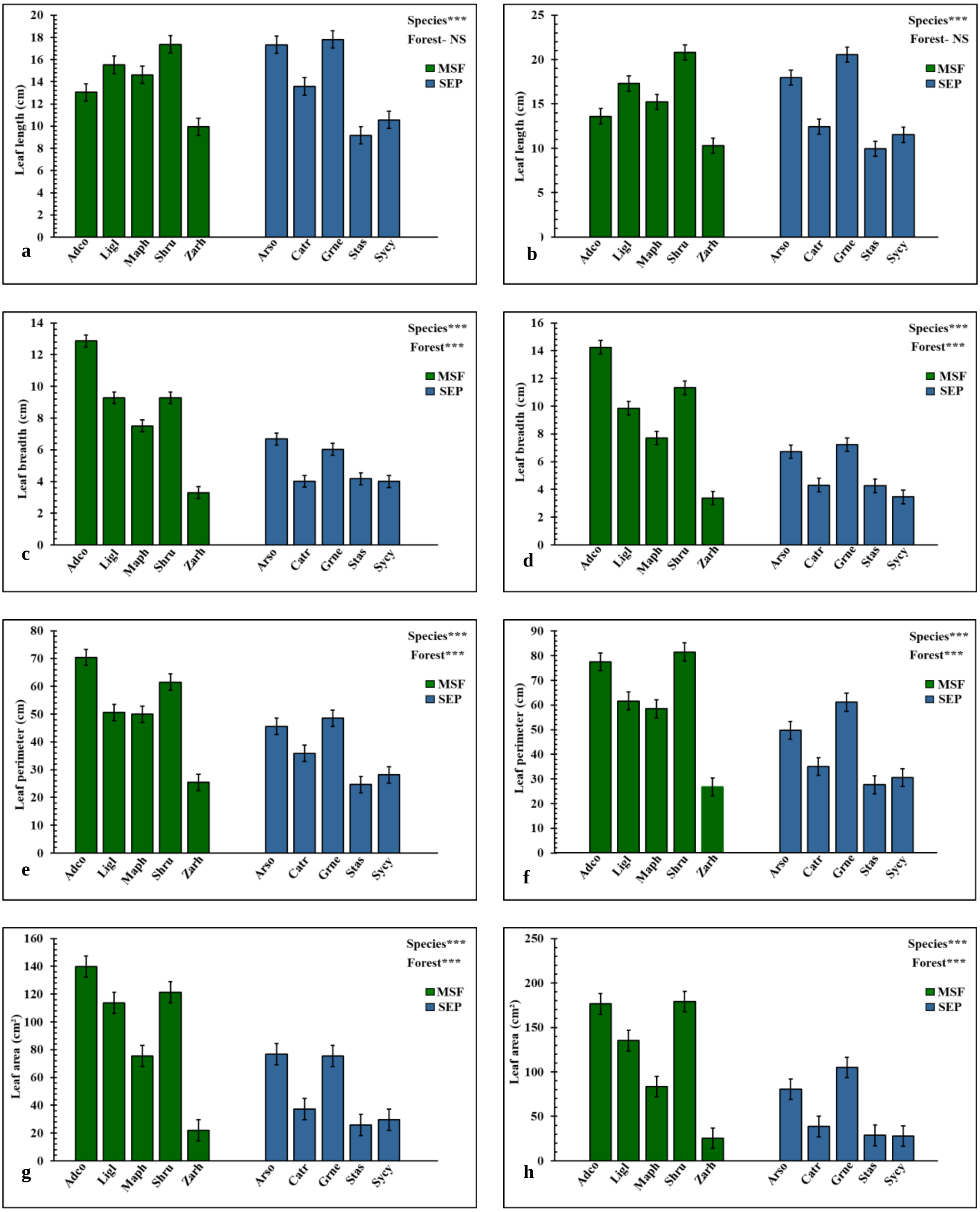


Figure 4.13: Mean values of the effects of species and forest types on leaf morphological traits of plants of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows (a-b) leaf length, (c-d) leaf breadth, (e-f) leaf perimeter and (g-h) Leaf area. *** indicates significant at $P < 0.0001$. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum.*

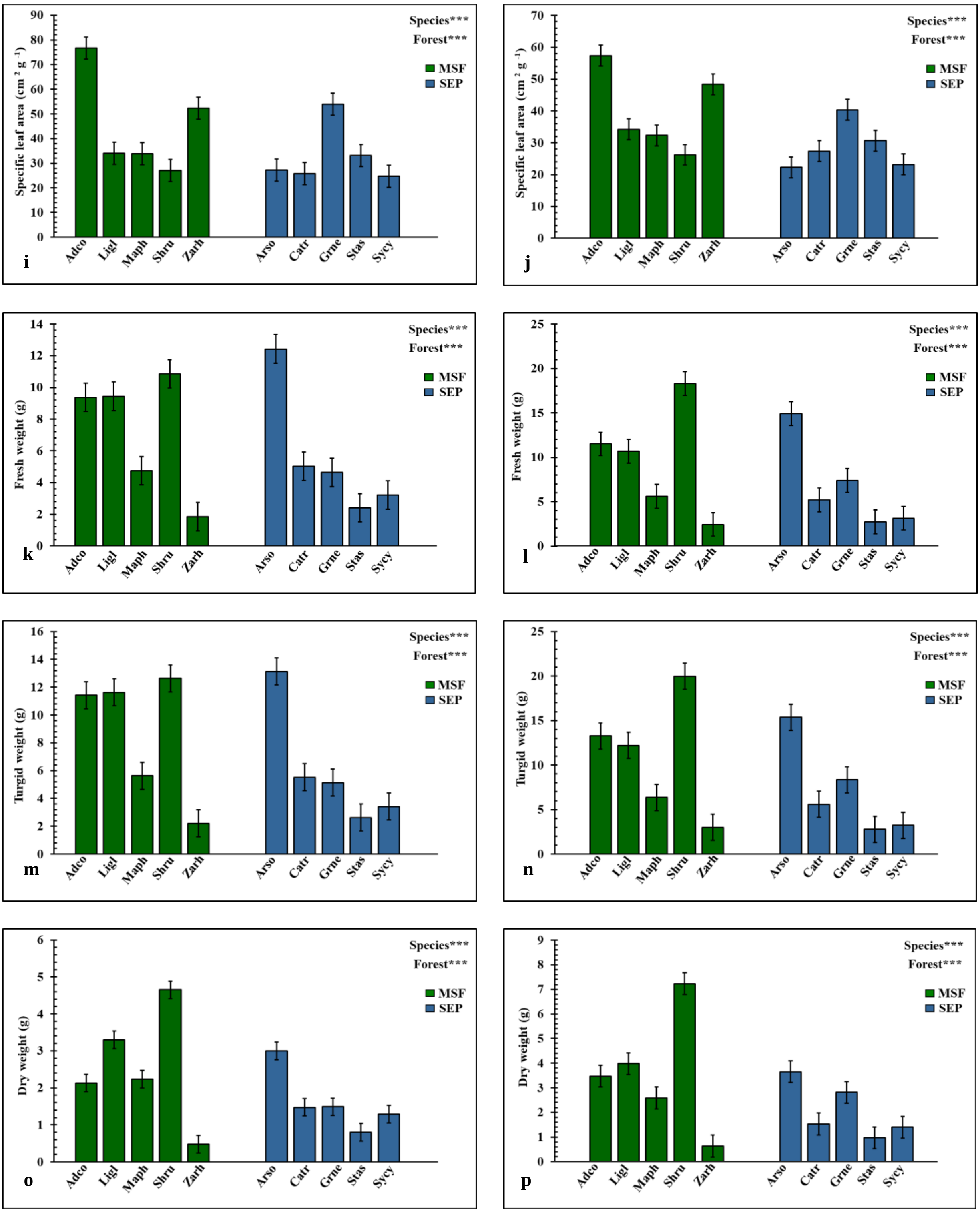


Figure 4.13.(Continued): Mean values of the effects of species and forest types on leaf morphological traits of plants of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows (i-j) specific leaf area, (k-l) fresh weight, (m-n) turgid weight and (o-p) dry weight. *** indicates significant at $P < 0.0001$. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum*.

(b) Leaf physiological traits

Nested ANOVA statistics on leaf physiological traits were shown in Table 4.7. Leaf physiological traits such as leaf water contents was significantly affected by species ($P < 0.0001$) and forest type ($P < 0.0001$) in both seasons. Leaf water contents was higher in Sitakunda Ecopark (Fig. 4.14 a-b). Leaf water content was significantly affected by forest types which explained 75.38% and 67.48% of total variation in the summer and winter, respectively. Relative water content was higher in Sitakunda Ecopark in both seasons. In the summer season, relative water content was not significantly affected by species but significantly ($P < 0.0001$) affected by forest type (Fig. 4.14 c). The species and forest type showed significant effects on relative water content in the winter season (Fig. 4.14 d). Relative water content was affected by forest types explaining 97.90% and 92.92% of the variation in the summer and winter seasons, respectively. Leaf dry matter content was significant affected by species ($P < 0.0001$) in the summer and winter which explained 74.18% and 90.80% of variation, respectively. The forest types showed significant ($P < 0.0001$) effects on leaf dry matter content in the summer season but not showed significant effects in the winter season. Madhupur Sal Forest showed higher leaf dry matter content in both seasons (Fig. 4.14 e-f). Leaf chlorophyll content was significantly affected by species ($P < 0.0001$) and forest type ($P < 0.0001$) in both seasons. Chlorophyll content was higher in Sitakunda Ecopark (Fig. 4.14 g-h). Forest type explained the effects on leaf chlorophyll content in the summer and winter season with the variation 86.59% and 80.66%, respectively.

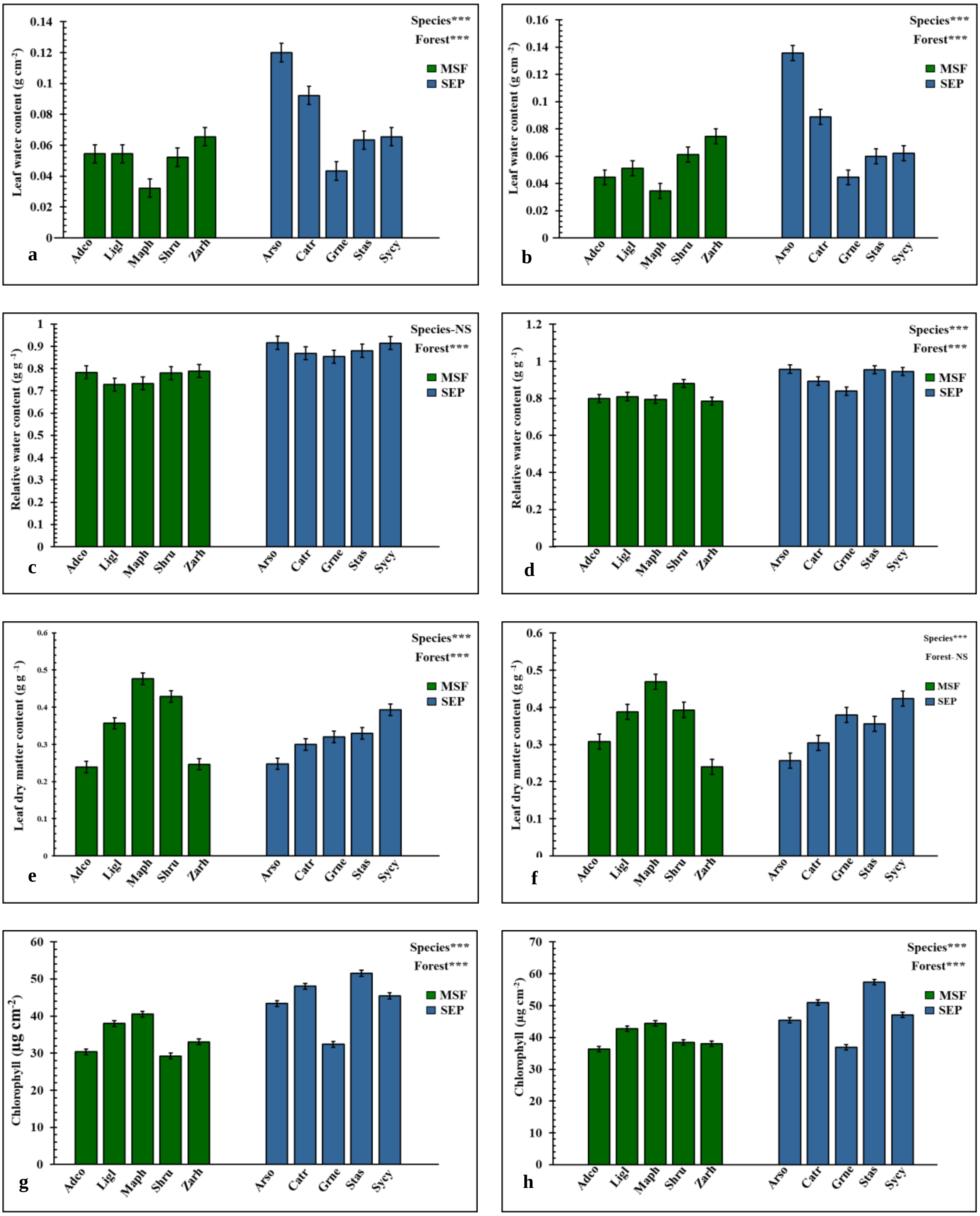


Figure 4.14: Mean values of the effects of species and forest types on the leaf physiological traits of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows (a-b) leaf water content, (c-d) relative water content, (e-f) leaf dry matter content and (g-h) chlorophyll content. *** indicates significant at $P < 0.0001$, NS = non-significant. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum.*

(c) Leaf anatomical traits

Nested ANOVA demonstrated that most of the leaf anatomical traits were significantly affected by species within each forest types as shown in Table 4.7. Stomatal length was significantly affected by species ($P < 0.0001$) and forest types ($P < 0.05$) in the both seasons. The effects of species on stomatal length in the summer and winter season explained 86.72% and 90.47% variation, respectively (Fig. 4.15 a-b). Stomatal breadth, stomatal area, stomatal perimeter, pore length and pore breadth were significantly affected by species ($P < 0.0001$) within forest and were also significantly affected by forest type in the both seasons. Mean values of stomatal breadth, area, perimeter, pore length and breadth were higher in Madhupur Sal Forest than Sitakunda Ecopark (Fig. 4.15 c-l). Stomatal density and stomatal pore index values were higher in Sitakunda Ecopark than Madhupur Sal forest (Fig. 4.15 m-p). Stomatal density was significantly affected by species and forest type. Effects of forest types explained 76.00% and 65.24% variations, respectively on stomatal density in the summer and winter season. Species showed significant ($P < 0.0001$) effects on stomatal pore index in the both seasons. But stomatal pore index was significantly affected by forest type ($P < 0.0001$) in the summer season but there were no significant effects of forest types in the winter season. Among the leaf anatomical traits, percentage of open stomata was higher in Sitakunda Ecopark than Madhupur Sal Forest in the summer season (Fig. 4.15 q-r). It was significantly affected by species in the Summer and Winter seasons which explained 81.21% and 63.55% variation, respectively. In the summer season, percentage of open stomata was not significantly affected by forest type but that was significantly affected by forest type ($P < 0.0001$) in the winter season. Similar pattern was found in case of percentage of close stomata (Fig. 4.15 s-t).

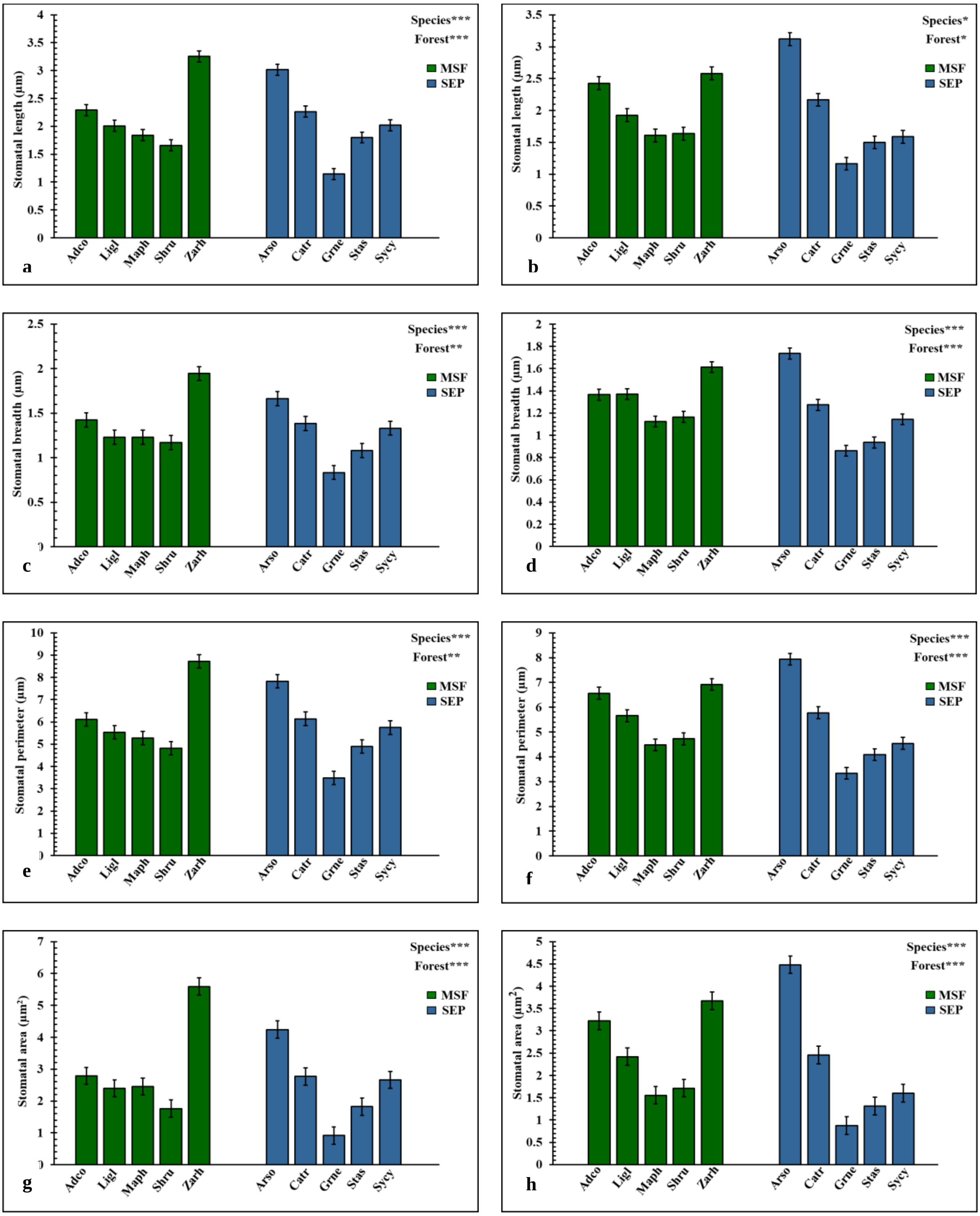


Figure 4.15: Mean values of the effects of species and forest types on the leaf anatomical traits of plants of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows stomata length (a-b), stomata breadth (c-d), stomata perimeter (e-f) and stomata area (g-h). *** indicates significant at P < 0.0001. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum*

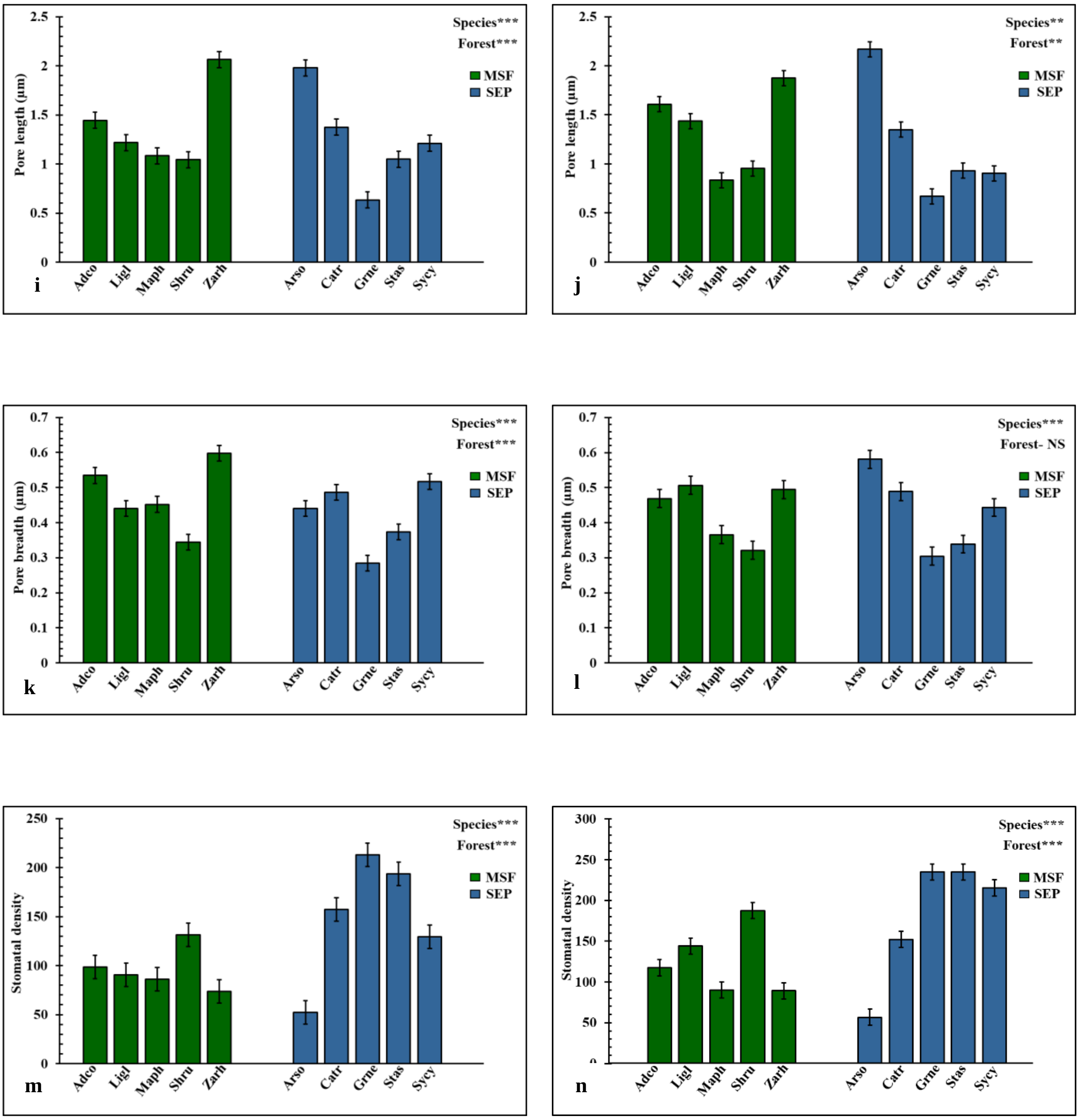


Figure 4.15 (continued): Mean values of the effects of species and forest types on the leaf anatomical traits of plants of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows pore length (i-j), pore breadth (k-l) and stomatal density (m-n). **, *** and NS indicate significant at $P < 0.01$, $P < 0.0001$ and NS = non-significant. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum.*

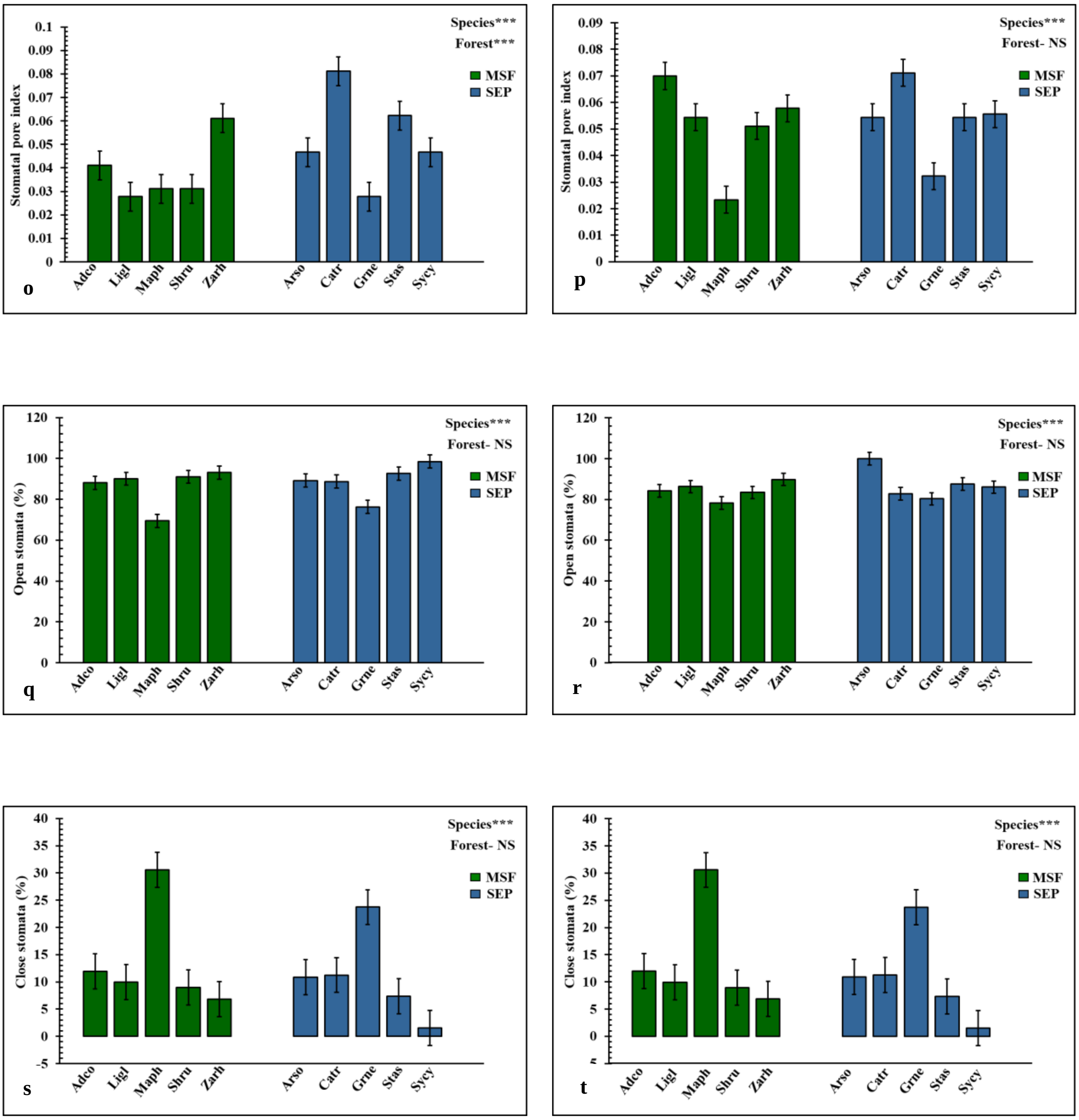


Figure 4.15(continued): Mean values of the effects of species and forest types on the leaf anatomical traits of plants of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows stomatal pore index(o-p), percentage of open stomata (q-r) and percentage of close stomata (s-t). *** indicate significant at P < 0.0001 and NS = non-significant. Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum.*

(d) Multivariate analysis on leaf traits

(i) Principal Component Analysis (PCA)

The biplot graph obtained from PCA done using the leaf traits of the plants of Madhupur Sal Forest and Sitakunda Ecopark are shown in Fig. 4.16. PC1 explained X axis (35.77%) and PC2 explained Y axis (26.69%). The two forests were separated from each other along PC2. Coefficients of correlation of leaf traits with PC1 and PC2 are shown in Table 4.8. PC2 showed strongly significant positive correlation with most of the leaf morpho-physiological traits whereas PC1 showed strongly significant negative correlation. Most of the anatomical traits showed strongly significant positive correlation with PC1. PCA data, thus, suggested that the two forests were separated from each other based on the morpho-physiological leaf traits. Based on morpho-physiological traits, the two forests were separated seasonally from each other also (Fig. 4.17).

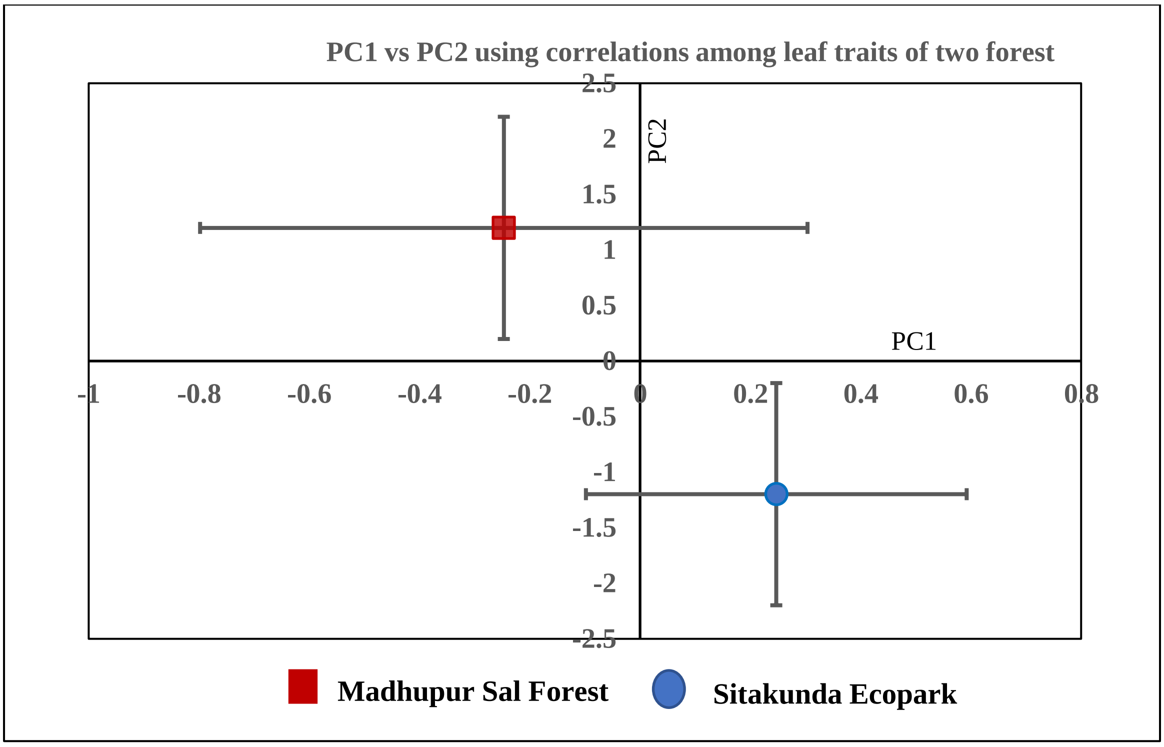


Figure 4.16: Biplots obtained from Principal Component Analysis (PCA) done using correlations among the leaf properties of the dominant plants of Madhupur Sal Forest and Sitakunda Eco-Park.

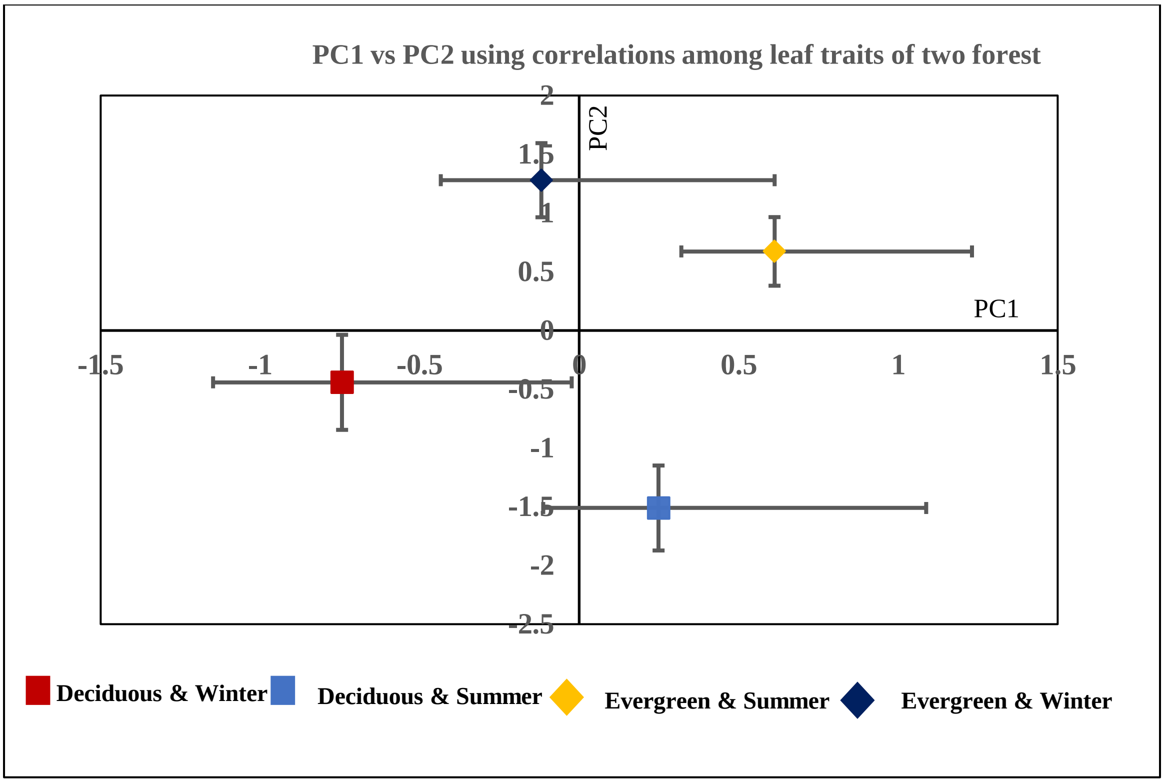


Figure 4.17: Biplot graph obtained from Principal Component Analysis (PCA) done using correlations among the leaf properties of the dominant tree species of Madhupur Sal Forest and Sitakunda Eco-Park during Summer and Winter seasons.

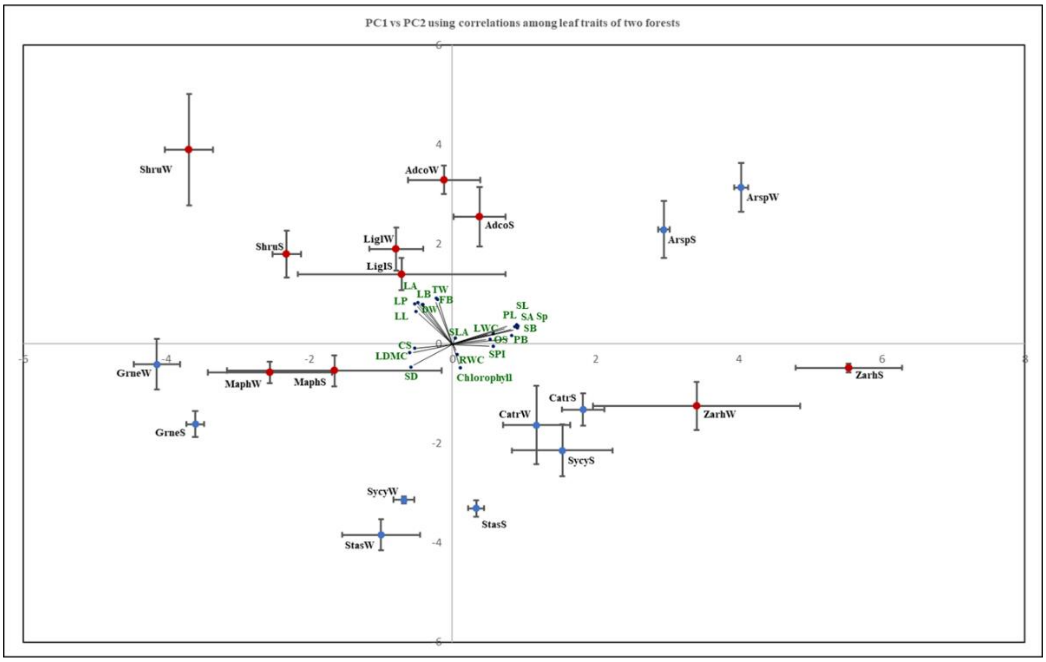


Figure 4.18: Biplot graph of species obtained from Principal Component Analysis (PCA) done using correlations among the leaf properties of the dominant tree species of the Madhupur Sal Forest and Sitakunda Ecopark during Summer and Winter seasons.

Table 4.8: Co-efficients of correlations of leaf traits with PC (Principal Component) 1 and PC2.

Types of traits	Trait	PC1	PC2
Morphological	Leaf length (cm)	-0.5097***	0.6449***
	Leaf breadth (cm)	-0.4111***	0.7918***
	Leaf perimeter (cm)	-0.5257***	0.8061***
	Leaf area (cm^2)	-0.4815***	0.8285***
	Fresh weight (g)	-0.2064	0.8905***
	Turgid weight (g)	-0.2288	0.9121***
	Dry weight (g)	-0.4227***	0.7945***
	Specific leaf area (cm^2 g^{-1})	0.0376	0.116
Physiological	Chlorophyll ($\mu g cm^{-2}$)	0.1146	-0.4775***
	Relative water content (g g^{-1})	0.0646	-0.2103
	Leaf dry matter content (g g^{-1})	-0.5992***	-0.1726
	Leaf water content (g cm^{-2})	0.5753***	0.1984
Anatomical	Stomatal length (µm)	0.913***	0.3522***
	Stomatal breadth (µm)	0.8755***	0.3398***
	Stomatal area (μm^2)	0.9038***	0.3234***
	Stomatal perimeter (µm)	0.9095***	0.3576***
	Pore length (µm)	0.8962***	0.3768***
	Pore breadth (µm)	0.8289***	0.1624
	Stomatal density (individual/mm^2)	-0.5802***	-0.472***
	Percent of open stomata (%)	0.5278***	0.0891
	Percent of close stomata (%)	-0.5278***	-0.0891
	Stomatal pore index (%)	0.5676***	-0.0446

*** indicates significant at $P < 0.0001$

(ii) Cluster dendrogram analysis

Cluster dendrogram was done by following ward method (Fig. 4.19). On the basis of similarity of leaf traits of the selected dominant tree species from the Madhupur Sal Forest and the Sitakunda Ecopark in both seasons. The agglomerative co-efficient was 0.82. Most of the species of Madhupur Sal Forest and Sitakunda Ecopark remained together in a separate cluster. However, among the deciduous species of the Madhupur Sal Forest named *Zanthoxylum rhetsa* moved to the Sitakunda Ecopark cluster. One species of Sitakunda Ecopark species named *Grewia nervosa* like moved to a cluster belonging to the Madhupur Sal Forest. These two species behaved both evergreen and deciduous functional types.

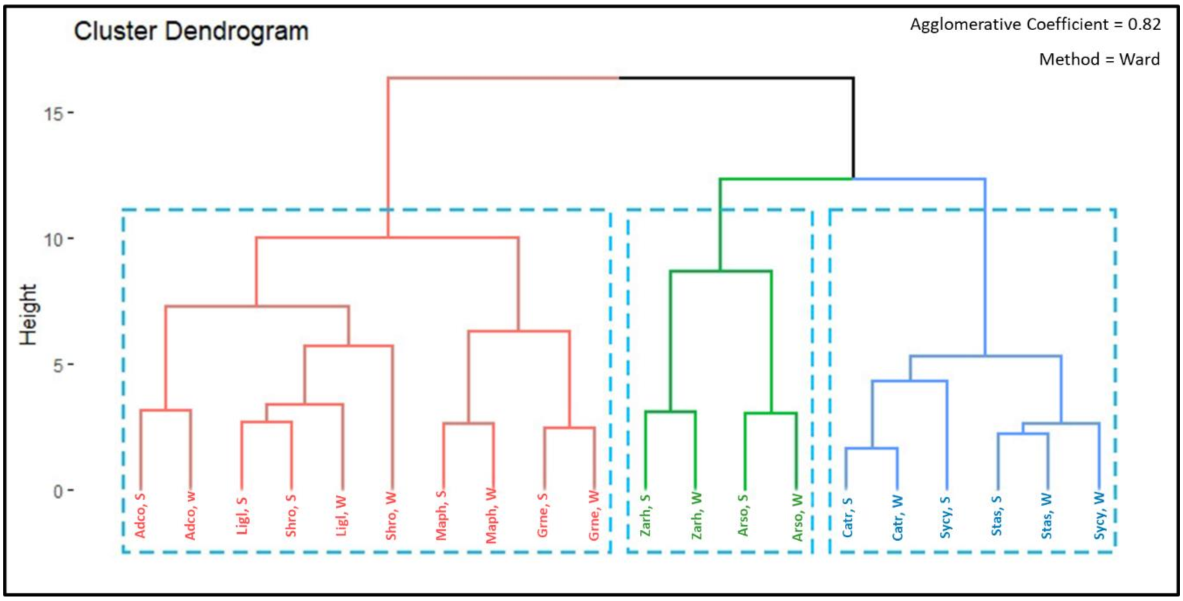


Figure 4.19: Dendrogram showing the clustering of the plant species of the Madhupur Sal Forest and Sitakunda Ecopark that represented the deciduous and evergreen forests, respectively. S = Summer, W = Winter, Adco = *Adina cordifolia*, Ligl = *Litsea glutinosa*, Maph = *Mallotus philippensis*, Shru = *Shorea robusta*, Zarh = *Zanthoxylum rhetsa*, Arso = *Ardisia solanaceae*, Catr = *Castenopsis tribuloides*, Grne = *Grewia nervosa*, Stas = *Streblus asper*, Sycy = *Syzygium cymosum.*

(e) Seasonal variation in soil properties of the forests

Two-way ANOVA statistics on soil pH, moisture (%), electrical conductivity (µs), available nitrogen (µg/g soil), total phosphorus (%), potassium (%), sodium (%) and organic carbon (%) are shown in Table 4.9. Two-way ANOVA was applied to examine the relative effects of forests, seasons and their interaction on soil parameters. Soil pH was significantly affected by season ($P < 0.001$). Soil moisture, electrical conductivity and available N were significantly affected by season ($P < 0.001$). Soil phosphorus was significantly affected by forest ($P < 0.0001$) and season ($P < 0.0001$) but not by their interaction. Soil potassium was significantly affected by forest ($P < 0.005$) and season

($P < 0.005$) and their interaction ($P < 0.005$). Sodium was significantly affected by forest ($P < 0.05$) and interaction of forest and season ($P < 0.0005$) but not by the season. Soil organic carbon was not significantly affected only season, forest or by their interaction.

Table 4.9: Two-way ANOVA statistics on the effects of forest, season and the interaction between forest and season on soil properties.

Soil properties	F Ratio		
	Forest	Season	Forest*Season
pH	2.38	11.96**	0.61
Electrical conductivity (µS cm^{-1})	2.90	12.81**	0.26
Soi moisture (%)	3.21	37.26***	0.95
Phosphorous (%)	30.67***	63.50***	0.16
Sodium (%)	5.69*	1.78	15.81***
Potassium (%)	10.43**	12.45**	12.69**
Available nitrogen (µg/g)	1.25	38.88***	0
Organic carbon (%)	0.37	2.79	2.14

*, **, *** indicate significant at $P < 0.05$, $P < 0.01$, $P < 0.0001$

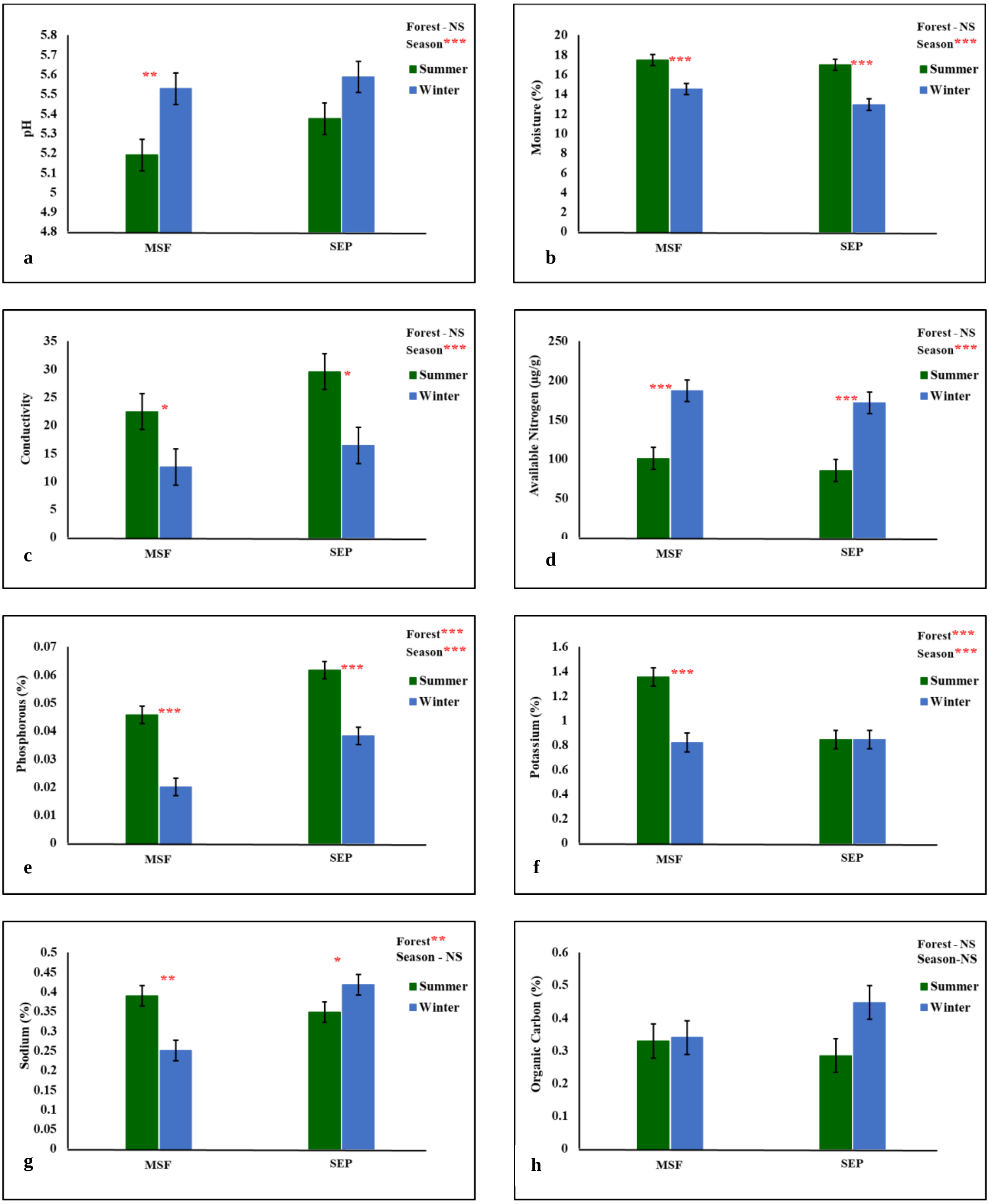


Figure 4.20: Mean values of the effects of forest and season on soil properties of the Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP). Graph shows pH (a), moisture (b), electrical conductivity (c), available N (d), phophorous (e), potassium (f), sodium (g).

*, **, *** indicate significant at P < 0.05, P < 0.01, P < 0.0001, NS = non-significant.

The biplot graph obtained from PCA done using soil properties of the Madhupur Sal Forest and Sitakunda Ecopark are shown in Fig. 4.21. PC1 explained X axis (35.48%) and PC2 explained Y axis (16.77%). Along PC1 and PC2, the soil properties were separated from each other seasonally. Coefficients of correlation between leaf traits with PC1 and PC2 are shown in Table 4.10. PC1 showed strongly significant correlation with soil moisture, phosphorous, potassium and available nitrogen whereas PC2 showed strongly significant correlation with electrical conductivity, sodium and organic carbon. Seasonally, the soil properties of the Madhupur Sal Forest separated by PC1. The soil properties of the Sitakunda Ecopark was separated by both PC1 and PC2 seasonally.

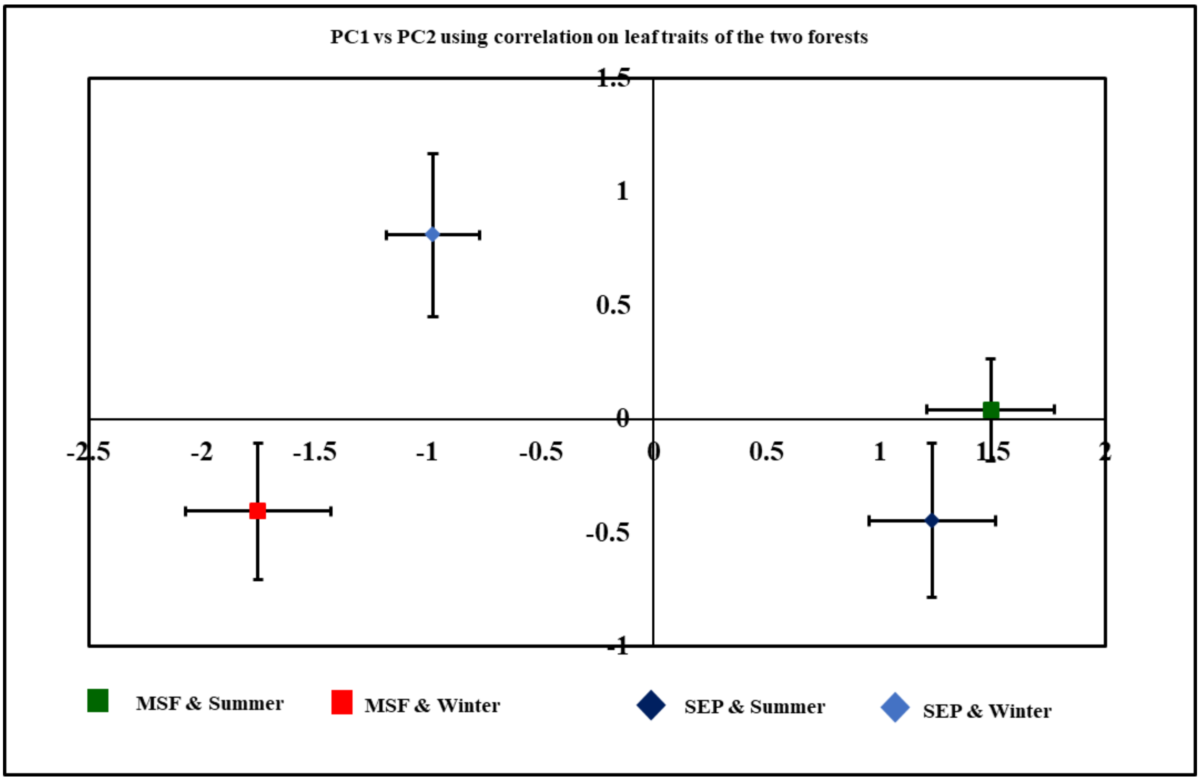


Figure 4.21: Biplots obtained from Principal Component Analysis (PCA) done using correlations among the soil properties of Madhupur Sal Forest (MSF) and Sitakunda Ecopark (SEP) of the two seasons (Summer and Winter).

Table 10: Co-efficients of correlations between soil properties and PC (Principal Component) 1 and PC2.

Soil properties	**PC1**	**PC2**
pH	-0.5661***	0.4915***
Electrical conductivity (µS cm $^{-1}$)	0.5162***	-0.6337***
Soi moisture (%)	0.662***	-0.1261
Phosphorous (%)	0.717***	0.2176
Sodium (%)	0.5154***	0.5853***
Potassium (%)	0.615***	0.2807
Available nitrogen (µg/g)	-0.7931***	-0.1615
Organic carbon (%)	-0.1609	0.4337***

***Indicate significant at $P < 0.0001$

CHAPTER 5

DISCUSSION

5.1 Vegetation structure

The vegetation of Madhupur Sal Forest and Sitakunda Ecopark of Bangladesh are deciduous and semi-evergreen in nature, respectively. The two forests are different in topography, geography and edaphic condition. Such variation in environmental conditions might have controlled the distribution pattern of the plant species in the Madhupur Sal forest and the Sitakunda Ecopark. The Madhupur Sal Forest was dominated by deciduous species *Shorea robusta*. Evergreen species were dominating in the Sitakunda Ecopark. Understanding the difference in vegetation structure of the Madhupur Sal Forest and the Sitakunda Ecopark and the comparative study of the different mechanisms of such plants is relevant for proper management and conservation of these ecosystems.

The Madhupur Sal Forest is almost homogenous in nature. Species number is comparatively poor than that of tropical semi-evergreen hill forest of Bangladesh (Rahman *et al.* 2017). The species richness of Madhupur Sal Forest and Sitakunda Ecoaprk differed significantly in the present study. The two forests were significantly different in case of the number of family as well. Madhupur Sal Forest had a higher number of families, genera, and species. The herb and shrub groups had the most family, genus and species in the Madhupur Sal Forest.

The result of the present study revealed that a total of 47 species were found in 12 quadrats of Madhupur Sal forest which was comparable with the other study. In a previous study, 21 species of trees under 9 families were identified in Madhupur Sal Forest on 5 quadrats, 9 species of herbs were discovered in 9 families, 5 species of shrubs were recognized in 5 families, and 5 species of climbers were identified in 4 families (Paul *et al.*

2013). Present study recorded a number of plant species belonging to 42 genera and 24 families on 12 quadrats in Madhupur Sal Forest. These were represented by 28 tree species under 17 families, 8 shrub species under 7 families, 2 climbers under 1 family and 9 herbs under 7 families. The species of the Sitakunda Ecopark was statistically comparable to that of the Madhupur Sal Forest, with 60 plant species belonging to 55 genera and 28 families recorded in the Sitakunda Ecopark. In the Madhupur Sal forest, Phyllanthaceae was the dominant family with 5 species, whereas in Sitakunda Ecopark, Fabaceae was the dominant family with maximum 6 species. With three species, the Fabaceae family was the second most dominant in Madhupur Sal Forest. Although Lamiaceae, Moraceae, Myrtaceae, and Rubiaceae were the second most common families in the two forests, they each had four species in the Sitakunda Ecopark. The tree cover at Sitakunda Ecopark (77%) was equivalent to the Madhupur Sal Forest (60%).

Among the recorded plant species composition, trees showed the highest proportion in the a Ecopark than Madhupur Sal Forest. Whereas shrub and herb groups were shown higher proportion in the Madhupur Sal Forest. Climber was absent in Sitakunda Ecopark

Species diversity in a community is determined by the ability of a species to adapt to their surroundings. Species diversity is influenced by species interactions such as competition and niche variation (Pianka 1966), which are particularly pronounced in tropical areas due to high temperatures and humidity (Ojo and Ola-Adams 1996). Tropical forests have a higher Shannon diversity index (Knight 1975). Shannon diversity index values in Indian forests ranged from 0.83 to 4.1 (Singh *et al*. 1984; Parthasarathy *et al.* 1992; Visalakshi 1995; Sundarapandian 1997). Shannon diversity (*H*), Simpson diversity, and Pielou's evenness of the Madhupur Sal Forest had the greatest values of 2.40, 0.88, and 0.88, respectively. Shannon diversity (*H*) was highest in Sitakunda Ecopark, whereas Simpson diversity and evenness were 2.48, 0.90, and 0.93, respectively.

The position of perennating buds in respect to the soil surface reflects adaptations to protect their renewing buds, according to Raunkiaer's (1934) classification system of plant life forms. Raunkiaer's life-forms occur as a consequence of plant adaptation to the climatic conditions of the environment (Raunkiaer 1937; Stepanovskih 2001; Andrusevich and Shtirts, 2014). They describe how different plant species adapt with the adverse climate and weather conditions during the winter (Matveev 2011). The vegetation of different communities in the same climatic zone can be studied using such spectra (Belgard, 1971). The complex relationships between plant species and environmental conditions are reflected by plant life forms as a complex of habitual traits evolving in the course of adaptive evolution (Semenova-Tyan-Shanskaya 1954).

Raunkiaer's life form classification explains life strategies connected with plants' ability to survive under specific environmental conditions. According to Abduloeva and Solomakhi (2011), the more complex the structure of the community is and the habitat's biological capacity is, the more diverse the climamorph spectrum is (life forms according to Raunkiaer). In both forests taken under the present study, phanerophytes were found to be the dominant life form. Annual and biennial species, as is widely known, are practically absent within stable formed plant communities (Ipatov *et al.* 1996). Data of the present study suggest that the presence of perennial plants in the community in the spectrum of flora life forms of the two forests suggests a high degree of community formation and stability.

The social status of a species is represented by the importance value index, which is frequently used to explain the pattern of association of dominating species in a community (Parthasarathy and Karthikeyan 1997a). *S. robusta* was the major tree species in Madhupur Sal Forest, with an IVI value of 37.89. Some other studies also found *S. robusta* as dominant species in the Sal Forest of Bangladesh (Rahman *et al.* 2009; Hossain *et al*. 2010b; Malakar *et al.* 2010; Paul *et al.* 2013; Kashem *et al*. 2015; Rahman *et al.* 2017). In Sitakunda Ecopark, *Grewia nervosa* was the dominant species, with IVI values of 25.96. But *G. nervosa* was second dominant tree species with IVI value 31.88 in the Madhupur Sal Forest. Result of the present study showed that *G. nervosa* was very much common in the two forests. In Madhupur Sal Forest, *Ardisia solanaceae* and *Micromelum minutum* were rare tree species. *Adina cordifolia, Albizia procera, Antidesma acidum, Gmelina arborea* and *Xylia dulabiformis* are among the rare species represented at Sitakunda Ecopark. In the case of herbs, *Panicum repens* was the dominant species in both forests. *Vernonia cineria* was found in Madhupur Sal Forest and Sitakunda Ecopark, where it was represented by *Ceilocostus speciosus,* a rare species. *Calamus rotun*g was the most common shrub in Madhupur Sal forest, whereas *Chromolaena odorata* was rare. In Sitakunda Ecopark, *Clerodendrum viscosum* was the most common species, whereas *Randia dumetorum* was uncommon.

The diversity of tree species is important for tropical biodiversity because trees support almost all other life forms directly or indirectly (Huston 1994; Whitemore 1998). Total tree species richness was found to be 8.5 species/100 m^2 in the Madhupur Sal Forest and 9.67 species/100 m^2 in the Sitakunda Ecopark, respectively. Ecopark appears to be a little more diversified than Madhupur Sal Forest.

The recent findings of some studies were compared to those of other studies conducted in Eastern Ghats tropical dry deciduous forest of India (Gandhi and Sundarapandian 2014). In the Sathanur reserve forest in Tamil Nadu, India, Gandhi and Sundarapandian (2014) identified 60 species/20 hectares. Chittibabu and Parthasarathy (2000) found 26-54 species per hectare in the Kolli hills of the Eastern Ghats. In the tropical dry woods of the middle Eastern Ghats, Premavani and Naidu (2014) estimated 34-48 species/ha.

According to Kadavul and Parthasarathy, differences in tree density between plots are connected to seed dispersal and establishment, as well as resource utilization levels by the local environment (1999). The functional variety, ecological processes, and ecosystem services of the forest are all influenced by tree density (Gopalakrishna *et al*. 2015).

The overall density of Madhupur Sal Forest is higher than that of Sitakunda Ecopark. In the Madhupur Sal Forest, *S. robusta* had the highest density. In the Sitakunda ecopark, *G. nervosa* had the maximum density. The Madhupur Sal Forest also has a higher density of *G. nervosa*.

5.2 Soil properties

Studies on the relationship between plant diversity and ecosystem functioning have indicated that productivity rises with diversity, which is primarily found in grasslands (Rajaniemi 2003). The present study found a unimodal productivity–biodiversity link. On natural productivity gradients, diversity patterns range from growing to unimodal to decreasing. At the largest scale, among biomes, the pattern is the most stable, and variability often rises with production. Within biomes, the pattern is more variable, but not within communities (Waide *et al.* 1999; Mittelbach *et al.* 2001). Similarly, Mittelbach *et al.* (2001) observed that unimodal curves, including positive, negative and even U-shaped curves, are the most common. In the grassland biome, Gross *et al.* (2000) found a unimodal curve in the six LTER (Long Term Ecological Research) locations in the United States. It is commonly considered that the "real" connection between production and diversity is unimodal (Rosenzweig and Abramsky 1993; Tilman and Pacala 1993; Abrams 1995). The pattern is more constant on experimental fertilization gradients: diversity diminishes as productivity rises (Rajaniemi 2003). Some studies have employed plant competition theory to explain plant-specific explanations of productivity-diversity connections. The whole competition intensity concept was developed by Grime (1977). According to the overall competition intensity hypothesis, competition intensity rises as production rises. Species that are resource-stress tolerant can survive with low productivity. Species that are able to compete for resources are able to maintain a high level of productivity. To investigate the biodiversity-productivity relationship, a linear regression analysis was performed between soil parameters and plant species richness in the current study. However, only soil P showed the strongest correlation with species richness. Regression analysis showed significant negative correlations of species richness of tree ($R^2 = 0.28$, $P = 0.008$) and shrub ($R^2 = 0.18$, $P = 0.04$) with soil P content across forest types supporting the 'productivity versus diversity' hypothesis that explains diversity of organisms through competitive exclusion principle. There was no significant correlation of species richness of herb with soil P content. Phosphorus is a vital mineral element in plants, where it contributes in plant growth, photosynthesis, metabolism and other physiological functions (Cadot *et al.* 2018).

In the present study, higher value of clay was found in Sitakunda Ecopark (45.86 ± 2.43 %) than Madhupur Sal Forest (39.85 ± 1.25 %). Silt was higher in Madhupur Sal Forest (26.59 ± 1.08 %) than Sitakunda Ecopark (25.05 ± 3.08%). The higher value of sand was found in Madhupur Sal Forest (33.56 ± 1.38 %) than Sitakunda Ecopark (29.09 ± 4.95 %). These results were comparable with the previous studies e.g. the percentage of sand of 24 soil samples ranged from 16.34 to 24.24% with an average of 21.20% and that of silt were 41.52 to 54.33% with an average of 45.50% percent while the range of % clay was 29.30 to 36.33% with an average of 33.38%. The soil of the Arorkhola, Alokdia, Solakuri, and Ausnara unions of Madhupur upazila was classified as clay loam (Rahman *et al.* 2012). According to Hannan (1995), the textural classes of Madhupur tract soils were largely loam, silty clay, and clay. The mechanical fraction of Madhupur soil, according to Rahman et al.

(2007), was 24.24 % sand, 42 % silt, and 33.76 % clay, resulting in a silty clay loam texural class. Clay showed significant (P = 0.04) difference between the two forests. Although, silt, sand and moisture were higher in Madhupur Sal Forest than Sitakunda Ecopark, there were no significant differences in the present study. Soil moisture, electrical conductivity and pH are important factors that influence plant growth and development. They are found to respond differently to various human induced managements following conversion. Changes in physical properties due to land use change have been reported by substantial number of studies. The identity of the major tree species in the land types may be related to the significant difference in soil moisture content reported in the Madhupur Sal Forest (Kashem *et al.* 2015). Data of the present study showed that soil moisture content was higher in Madhupur Sal Forest (17.47 ± 0.38) than Sitakunda Ecopark (17.00 ± 0.74). The relatively high elevation of the Sitakunda Ecopark might be responsible for the low soil moisture of the park. The most important soil variable impacting the composition and distribution pattern of transitional vegetation in a very arid environment was soil moisture content (Ma *et al.* 2012).

The pH and electrical conductivity were higher in Sitakunda Ecopark than Madhupur Sal Forest although there were no significant. Data suggested that soil of Madhupur Sal Forest was slightly acidic in nature. Excessive acidity raises soil toxicity and the amount of fixed phosphorus available in the soil (Hart *et al.* 2013). Plant communities with different structures have been linked to soil environmental conditions. The pH of the soil influences fertility (Wilde 1954). Grubb (1963) observed a low pH (4.2) and low exchangeable potassium in Montane Forest soil with *Dialyanthere otoba*, *Barnedesia trianae* and *Haleocarpus popayanensis* as plants. In mixed woodland of Uganda, Eggeling (1947) observed a low pH (4.6 to 5.6). Despite a wide range of ecological conditions, Ovington and Madgwick (1957) found a positive correlation between the pH of soils at various levels in woodlands, as well as the pH of tree leaves and litter layers.

According to the findings of this study, Madhupur Sal Forest had a greater concentration of soil nitrogen (100.79 and 186.66 µg/g) than Sitakunda Ecopark (85.38 and 171.25 µg/g) during summer and winter, respectively. The amount of nitrogen in the soil has a favorable impact on plant biomass both above and below ground (Wang *et al.* 2007b). This result was compared to the Madhupur deciduous forest (0.094 %) (Kashem *et al.* 2015), Chattogram hill forest (0.115 %) (Hossain *et al.* 2014), and Sundarban mangrove forest (1.72 %) in Bangladesh (Hossain *et al.* 2012). Sitakunda Ecopark (0.06 ± 0.005%) has more phosphorus than Madhupur Sal Forest (0.05 ± 0.001%). Another study found phosphorus concentration in forest soil in Madhupur Sal Forest (0.03%) and Ratargul Swamp Forest (0.072%) (Kashem *et al.* 2015; Hossain *et al.* 2020). The potassium concentration of soils in Madhupur Sal Forest and Sitakunda Ecopark differed considerably. Madhupur Sal Forest had more potassium than Sitakunda Ecopark. Because accessible potassium is used directly by plants and K^+ metabolism is more robust than in salt-sensitive plants, the available potassium level in soil was the most essential element in ecological adaptation of licorice (Lang *et al.* 2017).

Nutrient components in the soil play a critical function in growth and development of plants (Rocha *et al.* 2020). Soil moisture, available nitrogen, and available phosphorus were found to be positively linked with plant distribution. Domingo *et al*. (2003) reported that soil water played significant role in the distribution of perennial plant species in the semi-arid environment. Other studies revealed that promoting changes in vegetation patterns due to soil could exert variations in plant community composition (Zuo *et al.* 2009; Khan *et al.* 2011). Thus, vegetation-soil relationships is a vital topic in order to study species abundance in a habitat. Several reports showed the relations of ecosystem functions with the abiotic factors such as organic C, N, P and K (Zuo *et al.* 2008, 2009; Maestre *et al.* 2012; Korol *et al.* 2016) although the role of these soil factors on the distribution of plants in the tropical region is poorly studied.

The biplot graph was developed by PCA based on soil parameters of Madhupur Sal Forest and Sitakunda Ecopark. PC1 had a strong positive relationship with phosphorus, available nitrogen, clay and silt. It was found to show a negative relationship with sand. PC3 had a strong negative relationship with soil pH, phosphorus, and available nitrogen. It had a positive relationship with organic carbon and silt in the soil. Both PC1 and PC3 separated the two forests from one another. These results thus indicated that soil properties could influence vegetation structure.

5.3 Species distribution in relation to soil properties

In forest ecology, study on the influence of soil variables on the spatial distribution of forest tree vegetation is an important topic. Evidence of links between soil variables and forest vegetation is available. Soil factors contribute to the spatial distribution of forest vegetation. Numerous studies on a comparatively small scale (Urbanova *et al*. 2015; Hume *et al*. 2016; James and Harrison 2016; Widenfalk *et al*. 2016) have discovered important correlations between soil characteristics and forest vegetation coverage and species composition. Different forest vegetation coverings, for instance, might be shaped by soil water dynamics (Hayati *et al*. 2018; Molina *et al*. 2019). Furthermore, some studies (Potter *et al*. 2003; Ter Steege *et al*. 2006; Wan *et al*. 2018) have indicated that soil factors can affect plant diversity and spatial patterns. New and innovative ecological research approaches have resulted from the study of plant species and their associations with environmental factors (Abbas *et al*. 2020).

Soil factors are the primary determinants of vegetation patterns (Ahmad *et al*. 2016; Rahman *et al*. 2016; Khan *et al*. 2020; Fang *et al*. 2020). Soil factors have a key role in plant production, growth, and development, bringing certain species to the top of the food chain in large numbers (He *et al.* 2020; Zhang *et al*. 2021). In the present study, Nonmetric multidimensional scaling (NMDS) ordination was used to map whether tree species composition was related to soil nutrient variation. Associations between species distributions and soil nutrient distribution was found to be correlated in the present study. Most soil variables were significantly associated to the NMDS ordination axes after the soil nutrient vectors were fitted to NMDS ordinations of species abundance quadrats. Contribution of each soil property to the ordering axes was indicated by the length of the arrow. Data also revealed that NMDS axes were significantly correlated with the soil factors such as phosphorous, potassium, available N, organic C, clay and sand. Phosphorous, available N and clay showed strong correlation with NMDS axis. Plot distribution in Madhupur Sal Forest and Sitakunda Ecopark formed two distinct groups within axis 1 and 2 of the NMDS ordination those were significantly affected by soil phosphorous, potassium and clay particle. NMDS analysis based on the species score showed that plots of the two selected forests were separated into two groups where the Madhupur Sal forest was characterized by highly dominant species of *S. robusta, G. nervosa, M. philipensis, G. pentaphylla, A. cordifolia, L. glutinosa, A. acidum, F. hispida* and *S. cymosum*. Sitakunda Ecopark was characterized by *C. tribuloides, E. rubiginosum, H. antidysenterica*, *P. emblica*, *S. asper* and *S. multiflora.*

5.4 Leaf traits of dominant tree species in relation to their adaptation

The structure and function of ecosystems are closely related to leaves those are fundamental structures of terrestrial plants and their traits (Sterner and Elser 2002). The environmental factors such as temperature (Li and Bao 2014), light intensity (Lusk *et al*. 2007; Bajpai *et al*. 2012) and water status (Bajpai *et al*. 2012; Bajpai *et al*. 2017) influence the leaf traits of plant. Therefore, leaf traits explain the different mechanisms of plants under resource limitation like water deficit conditions. Data of the present study showed that the leaf morpho-physiological and anatomical traits differed between the plants of Madhupur Sal Forest and Sitakunda Ecopark those are different by forest functional type.

The present study examined the adaptation mechanism of deciduous and evergreen plants by studying leaf morpho-physiological and anatomical traits such as leaf length, leaf breadth, leaf perimeter, leaf area, fresh weight, turgid weight, dry weight, specific leaf area, leaf chlorophyll content, relative water content, leaf water content, leaf dry matter content, stomatal length, breadth, area, perimeter, pore length, breadth, stomatal density, percentage of open and close stomata and stomatal pore index. A number of studies reported that leaf traits are associated with the adaptation of the plants of different functional types (Westoby 2002; Tomlinson *et al*. 2013; Rodriguez *et al*. 2016; Tian *et al*. 2016; Qin *et al*. 2019; Yan *et al. 2019*). Although plants of Madhupur Sal Forest and Sitakunda Ecopark are functionally different, adaptation through leaf traits of these two forests has not been well studied yet.

Leaf fresh weight can be regarded as an important indicator for the study of physiological status of plant grown under different environmental conditions including soil and climatic variables (Rodriguez *et al*. 2016). Variation in fresh weight, turgid weight and dry weight of leaves among the species can be attributed to water use efficiency by the plants. Variation in leaf area can influence transpiration which reflect the leaf moisture status. Salisbury and Ross (1994) reported that leaf water content might be related to the productivity of the root systems through water absorption from the soil. In the Madhupur Sal forest mean values of fresh weight and turgid weight of leaf were higher than Sitakunda Ecopark. Species showed relatively higher significant effects on leaf fresh weight in the summer and winter season than forest types. In the Summer season, leaf turgid weight showed highly significant effect by species than forest types. But, in the winter season, the effects of forest type on leaf turgid weight were relatively higher than that of species. Smaller leaf dry weight reflected the leaf construction investment. Leaves with a short and long-life span has lower leaf dry weight and higher leaf dry weight, respectively (Tian *et al*. 2016). The present study found that leaf dry weight was higher in Madhupur Sal Forest than Sitakunda ecopark. The significant effects of forest types on leaf dry weight were relatively higher than the effects of species in both seasons. These results suggested that plants of Madhupur Sal Forest are of short life span indicating that they are deciduous in nature.

Leaf length, breadth and perimeter represent the leaf area. Values of these parameters were higher in Madhupur Sal Forest than Sitakunda Ecopark. In the summer and winter seasons leaf length was significantly affected by species. Among these parameters leaf breadth and perimeter were significantly affected by species and forest types in both summer and winter seasons. The significant effects of forest types on leaf breadth and leaf perimeter were relatively higher than the effects of species in both seasons. The leaf area is essential in agronomy, biology, ecology, and physiology for a variety of reasons, including growth analysis, photosynthesis, transpiration, light interception, biomass estimation, and water balance (Kucharik *et al*. 1998). Higher leaf area of the plants of Madhupur Sal Forest indicated that these were of short life span and deciduous in nature.

Plant leaf size may influence gaseous cycling in the environment; higher leaf area leads to higher gas exchange as reported by Zwieniecki (2004). It may also provide protection against herbivory (Moles and Westoby 2000). Okajima *et al*. (2012) reported, on the other hand, that smaller leaf could lead to overheating avoidance. Thus, leaf size may contribute in plants' adaptation through modifying plant architecture like canopy size and plant hydraulics (Sack *et al*. 2012; Jensen and Zwieniecki 2013).

In both seasons, species had a major impact on leaf area. The leaf area of Madhupur Sal Forest was higher than that of Sitakunda Ecopark. Smaller leaf size may allow species to change their leaf display more precisely and affordably under varying water supply situations by swiftly decreasing or producing leaf area (Sterck *et al*. 1999). When transpiration is limited by soil water potentials, smaller leaves in drier settings may result in a thinner boundary layer, allowing greater vapour exchange for photosynthesis (Givnish and Vermeij 1976; Givnish 1986) and increased sensible heat loss (Yates *et al*. 2010). It is widely known that an oversized leaf area can enhance solar power capture (Yang *et al*. 2014), but also increases evapotranspiration. Therefore, leaf area is controlled in such way to keep the nutrient content at an optimal level for the given light and water status (Venema *et al*. 2000).

In ecological studies, the integrative parameter of leaf area and leaf dry weight is specific leaf area which is commonly used to explain plant productivity (Madani *et al*. 2017). The trade-off in plant function between rapid (high specific leaf area and low leaf dry matter content species) and slow (low specific leaf area and high leaf dry matter content species) biomass production is reflected in specific leaf area and leaf dry matter content (Reich 2014). It was absolutely found that the deciduous trees are fast nutrient users, they typically have a high specific leaf area and leaf length, while the other is true regarding evergreens within which nutrient conservation is very important (Reich 2014). Specific leaf area and leaf dry matter content are closely associated with plant functions because they are highly correlated with relative rate, photosynthetic capacity and leaf employee turnover, and further reflect fundamental trade-offs between growth and ecological strategy (Wilson *et al*. 1999; Diaz *et al*. 2004; Reich *et al*. 1999, 2007; Silva *et al*. 2015). Some study reported that a negative relationship between specific leaf area and leaf lifespan (Lambers and Poorter 1992; Wright *et al*. 2005a; Turner 1994; Wright and Westoby 2003). Wilson *et al*. (1999) reported that leaf dry matter content reflected growth rates and carbon assimilation. Specific leaf area is linked with carbon and water cycles in nature (Pierce *et al*. 1994).

In the present study, Madhupur Sal Forest showed higher mean values of SLA than that of Sitakunda Ecopark. In both seasons, specific leaf area was significantly affected by species and forest types. Specific leaf area was highly affected by forest types which explained 55.83% in the summer season and 73.33% in the winter season indicating greater role of season. Some study reported that plants have short lifetime with higher specific leaf area and long lifetime with lower specific leaf area (Tian *et al*. 2016). Lower specific leaf area indicates higher construction cost per unit area, and specific leaf area can reflect the potential of leaves to capture light, therefore higher specific leaf area in plants in temperate forests could also be an adaption to low light intensity (Liu *et al*. 2019). Shadded leaves may increase the efficiency of light capture by increasing specific leaf area (Evan *et al*. 2001).

Some studies (e.g. Ackerly *et al*. 2002) suggested that a decrease in specific leaf area might indicate an increased water use efficiency by plants. In drought condition, greater water-use efficiency was found which helped plants to increase dry matter accumulation and also to prolong leaf life in order to complete their life cycle. A number of studies reported that among the woody species, specific leaf area was substantially lower for evergreens than for deciduous species (Mediavilla *et al*. 2008; Wright *et al*. 2005; Prior *et al*. 2003; Villar and Merino 2001). Plant species having low specific leaf area focused on the conservation of acquired resources since they possess large leaf dry mass and leaf dry matter content. On the other hand, low specific leaf area is a mean of primary adaptation to drought stress (Marron *et al*. 2003). Larger and lighter leaves as well as higher specific leaf area are present in fast-growing deciduous species (Wright *et al*. 2004), nevertheless, a large variations in specific leaf area is observed within the deciduous group.

Low leaf area lowers water loss, while high specific leaf area is linked to the ability to obtain resources and maintain high levels of productivity, especially in drought conditions (Poorter and De Jong 1999; Wilson *et al*. 1999). Newly produced leaves have a larger specific leaf area than older leaves (Burak *et al*. 2016). Drought reduces specific leaf area while also increasing leaf thickness and dry mass (Casper *et al*. 2001; Marron *et al*. 2003; Laureano *et al*. 2008). Different leaf characteristics exist in different phenological groups (evergreen or deciduous), which represent physiological trade-offs and evolutionary adaptations (Pringle *et al*. 2011; Tomlinson *et al*. 2013). Evergreen species have a collection of leaf features that are typical of drought tolerant species, whereas deciduous plants have drought avoidance qualities (Franco *et al*. 2005).

In woody species, specific leaf area decreases as the environment becomes drier (Wright *et al*. 2001; Wright and Westoby 2002; Santiago *et al*. 2004), leading to the hypothesis that lower specific leaf area is adaptive to drier settings because it reduces transpiring leaf surfaces (Poorter *et al*. 2009). Specific leaf area is a variable feature that can be influenced by local environmental factors such as water stress and vapor deficit pressures (Schulze *et al*. 2006; Poorter *et al*. 2009).

Leaf physiological traits such as leaf water contents were significantly affected by species and forest type in both seasons which explained by forest types 75.38% and 67.48%

of variation in the summer and winter, respectively. Leaf water content was higher in Sitakunda Ecopark. Relative water content was affected by forest types explaining 97.90% and 92.92% of the variation in the summer and winter seasons, respectively. However, relative water content was not significantly affected by species. The species and forest type showed significant effects on relative water content in the winter season. Evergreen species had greater area-based leaf water content than deciduous species. Evergreen species had greater water content per unit area, but lower water use efficiency and high leaf water content may reduce damage to chloroplasts by converting excess energy to heat (Tomlinson *et al*. 2013).

Leaf dry matter content is increasingly used as an indicator of resource use strategy of plant species. It is positioned in a fundamental trade-off between a rapid assimilation and growth at one extreme and efficient conservation of resources within well-protected tissues at the other (Wilson *et al*. 1999; Garnier *et al*. 2001; Díazet 2004). A high dry matter content indicates little intercellular space and high mesophyll resistance to gas diffusion (Bussotti 2015). Therefore, diffusion resistance in subtropical forest plants with a high dry matter content may be increased to decrease leaf transpiration (Niinemets 2001). Previous studies have shown that leaf dry matter content reflects an investment in the persistent leaf structures of plants (Suter and Edwards 2013), and thus plants tend to invest more dry matter per leaf in a nutrient-poor environment (Shipley *et al*. 2005), Therefore, it is reasonable to expect that a high leaf dry matter content should be a common strategy for plants living in low-nutrient conditions in sub-humid to semi-arid environment. Madhupur Sal Forest showed higher leaf dry matter content in both seasons. Leaf dry matter content was significant affected by species in the summer and winter which explained 74.18% and 90.80% variation, respectively. The forest types showed significant effects on leaf dry matter content in the summer season but did not show significant effects in the winter season. Leaf chlorophyll content was higher in Sitakunda Ecopark. Chlorophyll is an essential pigment for photosynthesis and it is the most important source of energy for plant growth (Mackinney 1941; Baker 2008). Phylogeny is also an important factor for leaf chlorophyll content. Phyletic evolution has been shown to have a considerable impact on specific leaf traits, such as element content and wood properties as mentioned by some studies (He *et al*. 2010; Zhang *et al*. 2011; Liu *et al*. 2012; Zhao *et al*. 2014). Plants, on the other hand, are required to change their traits in order to adapt to new environments. As a result, it is widely assumed that plants should modify their chlorophyll levels to adapt to their surroundings and enhance photosynthesis. Climate and soils should play a key role in chlorophyll regulation, particularly at a large scale (Li *et al*. 2018). Thus, chlorophyll content might have role in adaptation of the evergreen species in the Sitakunda Ecopark area.

Leaf stomatal properties are important in studying adaptation of plants. Because, a number of stomatal features such as stomatal length, stomatal density and stomatal pore area index indicate adaptation of plants through leaf stomatal morphology and photosynthetic capacity at long-term scale (Westoby and Wright 2006; Hernández-Vargas *et al*. 2019). From tropical to temperate coniferous forests, stomatal length and stomatal density varied slightly (Tian *et al*. 2016). They reported that with increasing maximum monthly temperature, stomatal length decreased and stomatal density increased. In the present study it was clearly found that stomatal size was higher in Madhupur Sal forest than Sitakunda Ecopark. Among the anatomical traits, stomatal size, stomatal length, breadth, area and perimeter were higher in Madhupur Sal Forest than that of Sitakunda Ecopark. Stomatal length was significantly affected by the species and forest types in both seasons. Smaller stomata have the extent to volume ratio, so they are likely to respond quickly to environmental changes by opening and shutting rapidly (Hetherington 2003;

Woodward *et al*. 2002); Percentage of open stomata was significantly affected by species within both seasons and more prominently in Sitakunda Ecopark than Madhupur Sal forest. It has been found that stomata those are small in size can open and shut down faster and if stomata are of high density they permit the rapid increase in stomatal conductance and ultimately help maximize diffusion of CO_2 for photosynthesis under favorable environmental conditions (Hetherington 2003). Hetherington *et al*. (2003) suggested that open-close behaviors of stomata influence the balance of CO_2 uptake for photosynthesis against water loss by transpiration.

It was reported that higher stomatal density could reduce CO_2 diffusion resistance which was attributed to the greater size of mesophyll tissue under strong light condition (Bosabalidis *et al*. 2002). However, a negative correlation between stomatal length and density was reported in spite of a large variability of these traits (Franks *et al*. 2009; Hetherington 2003). Tian *et al*. (2016) also reported a negative correlation between stomatal density and stomatal length. This trade-off between stomatal density and stomatal length perhaps could be attributed to the physical and energetic constraints. The negative correlation between stomatal density and stomatal length governs the short-term (plastic) and long-term (evolutionary) adaptations of plant physiological processes to the environmental conditions. Franks *et al*. (2009) proposed that plants have the ability to adjust their stomatal size and density to optimize stomatal conductance while satisfying a given stomata-to-pavement cell ratio and hence the allocation of surface area of leaf epidermis to stomata is restricted.

The correlation of stomatal density and stomatal length was observed in all plant functional groups, which may be explained by physical and energetic constraints (Franks *et al*. 2009; Hetherington 2003). It is generally found that cell division increases under relatively higher temperature conditions which leads to a greater stomatal density as reported by a previous study (Luomala *et al*. 2005). Some studies reported that relatively small and dense stomata in tree plants were related with high stomatal conductance and transpiration (Franks and Beerling 2009; Drake *et al*. 2013), which benefits water and nutrient transmission through longer xylem pathways in woody plants (Woodward 1998).

Stomatal density at the community and species levels were positively correlated with forest net primary productivity providing new evidence for the relationship of plant traits with ecosystem function (Reichstein 2014). Community-level stomatal traits such as stomatal density could better characterize the capacity of gaseous (e.g. CO_2 and H_2O) exchange between plant community and atmosphere, and this topic therefore may be a new ecological indicator in modeling gaseous exchange at the community level (Wang *et al*. 2015). Stomatal density was significantly affected by species and forest type. Effects of forest types explained 76.00% and 65.24% variations, respectively on stomatal density in the summer and winter season. These results thus imply that stomatal traits could influence gaseous exchange at regional scale.

Stomatal pore index is an integrative metric of stomatal density and stomatal length that indicates leaf stomatal conductance, with a greater stomatal pore index resulting in higher stomatal conductance and photosynthetic capacity (Sack *et al*. 2003). In higher latitudinal regions, a higher stomatal pore index may enhance carbon gain and plant growth throughout the short growing season. Therefore, increasing stomatal pore index maximizes the photosynthetic rate at higher latitude and is one of the adaptive strategies of leaf stomatal traits to the changing environment (Tian *et al*. 2016). Stomatal pore index values were higher in Sitakunda Ecopark than Madhupur Sal forest. The species showed significant effects on stomatal pore index in both seasons. But stomatal pore index was significantly affected by forest type in the summer season. Leaves with a short and long-life span has higher stomatal pore index and lower stomatal pore index, respectively (Tian *et al*. 2016).

Stomatal characteristics have varied adaptive responses to the external environment at the species and community levels. Stomatal density and length represent a species-level adaptive mechanism for leaf stomata to respond to environmental changes. Stomatal features at the community level control species composition to enhance ecosystem production in a given habitat (Wang *et al*. 2015).

Principal Component Analysis (PCA) is a powerful multivariate analysis tool for grouping variables independently. PCA analysis was done on correlations of a number of leaf traits such as length, breadth, perimeter, area, fresh weight, turgid weight, dry weight, specific leaf area, chlorophyll content, relative water content, leaf water content, leaf dry matter content, stomatal length, breadth, area, perimeter, pore length, breadth, stomatal density, percentage of open and close stomata and stomatal pore index of plants of Madhupur Sal Forest and Sitakunda Ecoaprk. PC1 and PC2 together explained 62.46% of the total variation. Most of leaf morpho-physiological traits showed strong significant positive correlation with PC2 whereas PC1 showed strong significant negative correlation. PC1 showed strong positive correlation with most of the anatomical traits. Along PC1 and PC2 the two forests were separated from each other by PC2 which represented most of the morpho-physiological traits. So, the two forests ware separated by morpho-physiological traits. Seasonally, the two forests were also separated from each other by PC2. Most of the selected species of the Madhupur Sal Forest and Sitakunda Ecopark remained together in separate clusters. Among the deciduous species of the Madhupur Sal Forest, one species named *Z. rhetsa* moved to the Sitakunda Ecopark cluster. One species named *G. nervosa* of Sitakunda Ecopark moved to a cluster belonging to most of the species of the Madhupur

Sal Forest. All these results suggested that these two species behaved both evergreen and deciduous functional types.

Physical and chemical properties of soil influence growth and development of plants. Plant growth parameters are influenced by many soil properties either positively or negatively. Plants need to acquire nutrients from the soil in their nearby environment to complete their developmental cycle (Schachtman and Shin 2007; Gojon *et al*. 2009). Growth in plants is tightly controlled by nutritional status (Krouk *et al*. 2011). N and P are the most limiting nutrient factors that influence plant growth (Hobbie 1992). The differences in soil nutrient concentrations between habitats are expected to have an impact on vegetation structure (Rodrigues *et al*. 2018).

Changes in forest ecosystem processes and functioning are largely influenced by plant-soil interactions. Soil parameters influence plant trait relationships and, as a result, support soil function and productivity. Leaf characteristics related in nutrient acquisition have been shown to have diverse effects on resource acquisition, carbon storage, and soil ecosystems in some studies (Berner and Law 2016; Eisenhauer *et al*. 2018). Plant features influence the organization of soil communities and their physico-chemical properties, as well as ecological processes such as soil C dynamics, soil stability, soil erosion, soil nutrient dynamics, and soil microbial community abundance and diversity (Sugiyama *et al*. 2008; Faucon *et al*. 2017; Long *et al*. 2019).

Since soil factors are associated to changes in functional traits of a community, it is necessary to identify relationships between the functional traits of plants and surrounding environmental conditions (Reich *et al*. 2003). Variations in leaf functional traits may reflect environmental variations such as light and soil properties (Benner *et al*. 2010; Hidaka and Kitayama 2009, 2013; Reich 2014).

Among the soil properties soil pH was significantly affected by season. Higher values of soil pH were found in Sitakunda Ecopark than Madhupur Sal Forest. Soil of the two forests were slightly acidic in nature. Soil pH could indirectly influence the leaf functional traits of trees and shrubs through its relationship with soil C:N ratio and with total P (Hernández-Vargas *et al*. 2019). To some extent, soil pH can influence the concentration of soil nutrients, hence influencing vegetation composition and diversity. Annual herbs, perennial herbs, and semi-shrub plants have a linear relationship with soil pH, whereas shrubs and trees have no significant relationship with soil pH (Heikkinen and Neuvonen 1997). In southern Siberia, species diversity increased linearly with soil pH, with the variety of the species pool declining only when the soil water level dropped (Hajek *et al*. 2007).

Soil moisture is a key element that interacts with soil pH to determine vegetation diversification. It can affect plant growth and variations in leaf functional traits (Niu *et al.* 2010). The present study showed that soil moisture content is relatively lower in the soil of Sitakunda Ecopark than Madhupur Sal Forest. Soil moisture was significantly affected by season. Data of the present study showed that available N was significantly affected by season. Available nitrogen was higher in Sitakunda Ecopark than that of Madhupur Sal Forest. Soil phosphorus was significantly affected by forest and season but not by their interaction. Soil potassium was significantly affected by forest and season and their interaction. In the summer season phosphorous and potassium were higher in Madhupur Sal Forest. There was no significant effect of forest and season on soil organic carbon. Several studies have demonstrated the importance of plant species on soil characteristics. Plant species greatly influence C, N, and P content in both plants and soils at natural and afforested sites in China (Bai *et al*. 2019), while soil C and N vary between forests dominated by different tree species in northern Iran (Bai *et al*. 2019; Kooch *et al.* 2019).

Leaf traits are tightly linked with habitat fertility. Soil nutrient concentrations recorded in the tropical dry evergreen forests are nutrient-poor forests, having very poor N and P concentration (Udayakumar and Sekar 2017; Parthasarathy and Karthikeyan 1997b; Aerts and van der Peijl 1993). Nutrient poor habitat also has some advantages. In particular, poor N fertility, may limit the invasion of highly competitive plant species that rely on high N availability for survival (Ackerly *et al*. 2002). Studies demonstrated showed the relationship between soil nutrient and physiognomy (Pierce *et al*. 2017; Schimper 1903; Fonseca *et al*. 2000).

The influence of soil N on leaf characteristics is greater than that of soil P. Different life forms have different effects on soil nutrients and feedback on them (Booth *et al*. 2005). The response of plant to soil nutrients shows a trade-off between plant growth and soil formation. Several studies have been conducted on the relationship between leaf characteristics and this trade-off (Wright *et al*. 2017; Gong and Gao 2019). The smaller specific leaf area captured the larger amount of light, the more favorable the assimilation of C (Wilson *et al*. 2010). One of the most important variables influencing plant leaf characteristics is soil nutrition (Gong *et al*. 2019). The increase in soil nutrients was accompanied by a considerable increase in leaf nutrients. Diverse species have different ways of surviving strategies (Wright *et al*. 2005). Light energy use efficiency of plants increases as soil nutrients increases.

Burns (2004) identified specific leaf area as one of the important leaf traits connected to plant carbon uptake strategy since it could indicate plant distribution and adaption to different habitats (Saura-Mas and Lloret 2007). The ability of plants to retain nutrients is mostly reflected by the amount of dry matter in their leaves (Westoby *et al*. 2002). In addition to leaf N and P contents and N:P ratios, specific leaf area and leaf dry matter content are two key soil fertility predictors (Koerselman and Meuleman 1996; Poorter and Bongers 2006; Kleyer *et al*. 2008; Hodgson *et al*. 2011).

CONCLUSION

The present study demonstrated data on the vegetation structure in relation to soil properties of the Madhupur Sal Forest and Sitakunda Ecopark that represented deciduous and evergreen forests, respectively of Bangladesh. The study also explored the adaptation mechanisms through leaf traits of plants of these two forests. The vegetation composition of the two forests was different with respect to taxonomic diversity as well as composition under different life forms. The dominant and rare species were also different between the two forest types. Tree and shrub species diversity was significantly higher in Madhupur Sal forest than the Sitakunda Ecopark.

A significant negative correlation between plant density and stem diameter indicated a negative interaction between plant growth and density might be of great interests for forest productivity and hence forest management. The ‘trade-off’ in density versus productivity was more prominent in the vegetation of Madhupur Sal forest than Sitakunda Ecopark. A negative significant correlation between plant species diversity and soil P across forest types supported the “Productivity versus Diversity” hypothesis indicating competitive exclusion theory.

NMDS (Non-Metric Dimensional Scaling) analysis suggested that soil properties such as N, P, K, C and particle size played role in the vegetation composition of the two forests taken under the study. Thus, data of the present study revealed that soil properties could significantly influence the plant species diversity and vegetation composition of the Madhupur Sal forest and the Stakunda Ecopark.

The present study demonstrated that plants in Madhupur Sal Forest and Sitakunda Ecopark adapted with drought condition by following different mechanisms through leaf traits. Being deciduous in nature, plants of Madhupur Sal forest followed ‘avoidance’ while the evergreen plants of Sitakunda Ecopark followed ‘tolerance’ strategies in order to adapt with the drought condition. Deciduous plants of Madhupur forest compensated the loss of photosynthetic assimilation that occured due to leaf fall in winter by increasing specific leaf area during rest of the year. Plants of Madhupur Sal forest ware more efficient in water-use than that of Sitakunda Ecopark. Plants of Sitakunda Ecopark were less efficient in water use and less productive than the plants of Madhupur Sal forests.

The adaptive strategies of stomatal traits of leaves of Madhupur Sal Forest and Sitakunda Ecopark were different at community levels. The stomatal density and stomatal length represented adaptive mechanism of plants to respond to environmental changes at community level.

The two multivariate analyses (Principal Component Analysis and Cluster dendrogram) revealed that most of the selected species of the two forests taken under the present study grouped separately except *Zanthoxylum rhetsa* and *Grewia nervosa* that showed adaptive plasticity indicating that these two species could adapt in both the two forest conditions. Consistency in the variation of leaf traits across Summer and Winter seasons indicated strong influence of functional types on the adaptation of plants with the environmental condition.

The magnitude of variation in leaf traits varied greatly depending on the edaphic and climatic conditions. These differences aid species coexistence and adaption in the forest environment. These characteristics have an impact on the biomass production of trees. Results of the present study are therefore relevant for better management and conservation of forests.

CHAPTER 6

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