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Contents

List of Figures	5
List of Tables	6
List of Acronyms	7
Executive Summary.....	9
1. Background of the Study	11
1.1. Overview of Dhaka Urban Forestry.....	11
1.2. US Forest Service in Bangladesh.....	13
1.3. iTree Tools.....	14
1.4. iTree tools and Urban Forestry in Bangladesh	15
2. Objective of this study	17
3. Methods and Materials	19
3.1. Planning and Designing.....	19
3.2. Land Use Zoning.....	20
3.3. Sampling Design	21
3.4. Capacity building of data enumerators	24
3.5. Secondary data collection.....	25
3.6. Primary field data collection	26
3.7. Hot check and Cold check.....	27
3.8. New species integration	28
3.9. Data analysis and reporting.....	28
3.9.1. Tree Characteristics	28
3.9.2. Density and basal area.....	28
3.9.3. Growing stock.....	29
3.9.4. Above ground biomass.....	29
3.9.5. Below ground biomass	29
3.9.6. Means, totals, and variance.....	29
3.9.7. Phytosociological attributes	30
3.9.8. Diversity indices.....	30
3.9.9. Air pollution removal	31
3.9.10. Carbon Storage and Sequestration.....	32
3.9.11. Oxygen Production.....	32
3.9.12. Avoided Runoff	32
3.9.12. Land-use and ground cover	33
4. Inventory Results and Discussion.....	36
4.1. Key results of Dhaka's Urban Tree Inventory	36
4.2. Basic attributes of the tree resources in Dhaka city.....	36
4.2.1. Species richness by stratum	37
4.2.2. Species richness by land use and origin	37
4.2.4. Tree structural composition.....	38

4.3. Tree density, ground cover and leaf area.....	38
4.3.1. Phytosociological attributes	41
4.3.2. Diversity indices of the tree species per zone of Dhaka city.....	43
4.4. Air Pollution Removal by Urban Trees.....	44
4.5. Biomass and Carbon Sequestration.....	46
4.5.1. Biomass of Dhaka	46
4.5.2. Carbon Sequestration.....	47
4.5.3. Tree carbon stock	48
4.6. Growing stock of Dhaka city.....	52
4.6.1. Growing stock by land use.....	52
4.6. Oxygen Production.....	54
4.7. Avoided Runoff	54
4.8. Comparisons with other urban tree inventory studies.....	56
5. Conclusion	59
6. Recommendations.....	61
6.1 Short-term recommendations.....	61
6.2 Long-term recommendations.....	61

List of Figures

Figure 1: History of USFS works in Bangladesh	13
Figure 2: i-Tree tools	14
Figure 3: i-Tree Eco model basics.....	19
Figure 4: Land Zoning map of DSCC.....	20
Figure 5: Plot distribution map of DNCC	22
Figure 6: Schematics of a sample plot.....	23
Figure 7: Inventory instruments used in Dhaka's Urban Tree Inventory	24
Figure 8: Tree population by diameter (DBH) class at DNCC and DSCC	38
Figure 9:Percent of land by ground cover classes in DNCC	39
Figure 10: Percent of land by ground cover classes in DSCC.....	40
Figure 11: Tree density and basal area per identified land use of DNCC.....	41
Figure 12: Tree density and basal area per identified land use of DSCC	41
Figure 13: Relative density of DNCC (left) and DSCC (right).....	42
Figure 14: Relative frequency of DNCC (left) and DSCC (right)	42
Figure 15: Relative abundance of DNCC (left) and DSCC (right)	43
Figure 16: Importance Value Index of DNCC (left) and DSCC (right)	43
Figure 17: Annual pollution removal (points) and value (bars) by urban trees and shrubs at DNCC	45
Figure 18: Annual pollution removal (points) and value (bars) by urban trees and shrubs at DSCC	45
Figure 19: Tree AGB (left) and BGB (right) stock in the land uses identified from DNCC	46
Figure 20: Tree AGB (left) and BGB (right) stock in the land uses identified from DSCC	47
Figure 21: Estimated annual gross carbon sequestration (points) and value (bars) for species with the greatest sequestration in DNCC	47
Figure 22:Estimated annual gross carbon sequestration (points) and value (bars) for species with the greatest sequestration in DSCC.....	48
Figure 23: Tree carbon stock in the land uses of DNCC- a) carbon in AGB, b) carbon in BGB, and c) total tree carbon	50
Figure 24: Tree carbon stock in the land uses of DSCC- a) carbon in AGB, b) carbon in BGB, and c) total tree carbon	51
Figure 25: Growing stock by land use of DNCC	52
Figure 26: Growing stock per land use identified from DSCC	53
Figure 27: Avoided runoff (points) and values (bars) for species with greatest overall impact on runoff at DNCC	55
Figure 28: Avoided runoff (points) and values (bars) for species with greatest overall impact on runoff at DSCC	55

List of Tables

Table 1: Stakeholders and responsibilities	19
Table 2: Zones/strata definition	21
Table 3: Land use zones and plot number	21
Table 4: Number targeted and sampled plots	23
Table 5: List of instruments used with their function.....	25
Table 6: Formula used for calculating phytosociological attributes of species recorded from DNCC	30
Table 7: Summary of which directly field-measured characteristics are used to estimate derived variables and ecosystem services. D= directly used; I= indirectly used; C= conditionally used.	33
Table 8: Land-use category definitions	33
Table 9: Ground cover category definitions	34
Table 10: Number of species and families per stratum in Dhaka city	37
Table 11: Number of species and families per land use	37
Table 12: Dominant species in DNCC and DSCC	38
Table 13: Tree density and basal area as per zones.....	40
Table 14: Diversity indices of the tree species per zone of Dhaka city.....	44
Table 15: DNCC tree carbon in AGB, BGB and total tree carbon per zone	48
Table 16: DSCC tree carbon in AGB, BGB and total tree carbon per zone.....	49
Table 17: Summary of growing stock.....	52
Table 18: Top 20 oxygen production species of Dhaka city.....	54
Table 19: Trees in different cities	56
Table 20: Totals of per acre of land area in different cities	56

List of Acronyms

AGB	Above Ground Biomass
BAPA	Bangladesh Poribesh Andolon
BD	Bangladesh
BDT	Bangladesh Taka
BELA	Bangladesh Environment Lawyers Association
BenMAP	Benefits Mapping and Analysis Program
BFD	Bangladesh Forest Department
BFI	Bangladesh Forest Inventory
BFRI	Bangladesh Forest Research Institute
BGB	Below Ground Biomass
BIP	Bangladesh Institute of Planners
BMD	Bangladesh Meteorological Department
BNH	Bangladesh National Herbarium
BUET	Bangladesh University of Engineering and Technology
C	Carbon
CA-ANN	Cellular Automata–Artificial Neural Network
CAGB	Carbon in Above Ground Biomass
CAMS	Continuous Air Monitoring Stations
CBGB	Carbon in Below Ground Biomass
CO	Carbon Monoxide
Compass	Community Partnerships to Strengthen Sustainable Development
CU	University of Chittagong
DAE	Department of Agriculture Extension
DBH	Diameter at Breast Height
DME	Distance Measuring Equipment
DNCC	Dhaka North City Corporation
DoE	Department of Environment
DSCC	Dhaka South City Corporation
ESV	Ecosystem Service Value
FAO	Food and Agriculture Organization
GCLU	Ground Cover Land Use
GFW	Global Forest Watch
GIS	Geographic information system
GPS	Global Positioning System
ha	Hectare
IFB	Institution of Foresters Bangladesh
IV	Importance Value
IVI	Importance Value Index
LGED	Local Government Engineering Department
LST	Land Surface Temperature
MCDA	Multi-Criteria Decision Analysis
NASA	National Aeronautics and Space Administration
NFI	National Forest Inventory
NGO	Non-Governmental Organization
NO ₂	Nitrogen Dioxide
PLOS	Public Library of Science

PM	Particulate Matter
PWD	Public Works Department
QA/QC	Quality Assurance/Quality Control
RAJUK	Rajdhani Unnayan Kartipakkha
RH	Relative Humidity
RIMS	Resource Information Management Systems
SE	Standard Error
SO ₂	Sulfur Dioxide
SOP	Standard Operational Procedures
Spp	Species
SVM	Support Vector Machine
TTB	Total Tree Biomass
TTC	Total Tree Carbon
USA	United States of America
USAID	United States Agency for International Development
USD	United States dollar
USDA	United States Department of Agriculture
VOC	Volatile Organic Compound
WD	Wood Density
YCC	Youth Conservation Corps

Executive Summary

Dhaka, the capital of Bangladesh, covers only 1% of the national territory yet houses more than 10% of the country's total population. The urban tree population in Dhaka is inadequate and unevenly distributed. As a rapidly expanding city, Dhaka is losing its green spaces at an alarming rate, with insufficient information when it comes to their extent and services. This lack of data limits the policymakers and urban planners from implementing effective and sustainable development plan for the mega city.

To address this information gap, Bangladesh Forest Department (BFD) and US Forest Service jointly conducted the first-ever urban tree inventory of Dhaka city in collaboration with the USAID's Compass program. The study aimed to establish a baseline for urban tree resources, including tree cover and density, for future monitoring. Additionally, it assessed the ecosystem services provided by urban trees and informed policy makers about the significance these services.

The study involved consultation with government and non-government agencies, civil society organizations, and intensive field surveys for tree biophysical data collection. Site-specific rainfall and pollution data from secondary sources were integrated, and the analysis was conducted using i-Tree Eco and R scripts.

The findings revealed 10.5% tree cover in Dhaka North City Corporation (DNCC) and 10.8% in Dhaka South City Corporation (DSCC). The pollutants removal capacity was measured at 302.5 tons/yr for DNCC and 241.7 tons/yr for DSCC, translating to an economic value of BDT 178 and 175 million, respectively. The study highlighted the economic importance of trees in mitigating environmental pollution and enhancing public health.

Furthermore, the study found that the trees in DNCC can produce 26.42 thousand metric tons of Oxygen annually, while DSCC's trees can produce 27.13 thousand metric tons. The inventory identified 110 tree species belonging to 33 families in Dhaka city, with 73 species from DNCC and 82 species from DSCC. The overall tree diversity is considered moderate to good based on the diversity indices. Mango, Mahogany, and Coconut are the three most dominant species across the city.

Interestingly, tree density is much higher in DSCC (65 trees/ha) compared to DNCC (37 trees/ha), but, the growing stock for trees with a diameter at breast height (DBH) ≥ 10 cm is higher in DNCC (44.97 ± 2.80 m³/ha) than in DNCC (41.24 ± 5.70 m³/ha). This suggests a prevalence of smaller-sized trees in DSCC.

In conclusion, the study findings provide a valuable reference for policymakers, urban planners, and city dwellers, offering insights to facilitate effective urban planning and sustainable development in Dhaka.

Chapter I

Background of the Study

1. Background of the Study

Ecosystem services from urban green spaces play an essential role in connecting cities with the biosphere and to reduce the ecological footprint and ecological debt of cities and at the same time enhance urban public health, resilience, and quality of urban life. These ecosystem services contribute directly or indirectly to human well-being providing many functions, including food supply, water supply, waste treatment, regulation of the urban heat island effect, clean air, water filtration, noise reduction, pollination, and climate regulation^{1,2}. Trees act as natural air purifiers, absorbing carbon dioxide and releasing oxygen, thereby improving air quality. Moreover, they provide shade and reduce surface temperatures during scorching summers. Access to green spaces promotes physical activity, reduces stress levels, and enhances mental well-being, collectively enhancing the overall quality of life for urban residents.

1.1. Overview of Dhaka Urban Forestry

The green spaces of Dhaka city, the capital of Bangladesh, primarily comprised of 27 parks, 10 playgrounds, 3 botanical gardens, rooftop gardens, and roadside vegetation³ with the majority situated in the southern part of the city. The city features 61.45 km of primary and 108.2 km of secondary roads, with significant roadside vegetation citywide⁴. However, Dhaka faces a decline of tree cover and green spaces, primarily due to the escalation of population burden and relentless demands on infrastructure, resulting in hasty and unplanned urbanization.

The city has witnessed unprecedented population growth and concrete infrastructure development over the years, fueled by rural-to-urban migration and natural population increase. This relentless influx has strained the available land, creating an urgent need for housing, infrastructure, and commercial establishments. Despite occupying just 1% of the national territory within an area of 1,528 km², Dhaka is home to over 10% of the country's total population and encompasses 36% of the nation's overall urban population⁵. Additionally, rampant tree felling, illegal encroachments on parks and open areas, and inadequate efforts to replant or maintain greenery have left Dhaka in an unhealthy urban environment⁶. Consequently, the natural green cover, including trees and vegetation, has been sacrificed to accommodate this demand, leading to a severe deficit of green spaces. It also disrupted the equilibrium between concrete structures and natural landscapes.

Historically, there has been no urban tree inventory in Dhaka, making it challenging to assess the actual tree count within the city. Some researchers have used global data like the Global Forest Watch (GFW) to estimate tree loss in Dhaka, while others have employed remote sensing techniques to analyze changes in green coverage. Results indicated⁷ less than 8.5% tree-covered land in Dhaka city, far below the ideal requirement of 20%. The city's carbon storage and tree diversity are unsatisfactory

¹ Haase, Dagmar, Neele Larondelle, Erik Andersson, Martina Artmann, Sara Borgström, Jürgen Breuste, Erik Gomez-Baggethun et al. "A quantitative review of urban ecosystem service assessments: concepts, models, and implementation." *Ambio* 43 (2014): 413-433.

² Langemeyer, J., Gómez-Baggethun, E., Haase, D., Scheuer, S., & Elmqvist, T. (2016). Bridging the gap between ecosystem service assessments and land-use planning through Multi-Criteria Decision Analysis (MCDA). *Environmental Science & Policy*, 62, 45-56.

³ Kafy, A. A., Al Rakib, A., Akter, K. S., Jahir, D. M. A., Sikdar, M. S., Ashrafi, T. J., ... & Rahman, M. M. (2021). Assessing and predicting land use/land cover, land surface temperature and urban thermal field variance index using Landsat imagery for Dhaka Metropolitan area. *Environmental Challenges*, 4, 100192.

⁴ Jaman, S., Zhang, X., & Islam, F. (2020). Carbon storage and tree diversity in the urban vegetation of Dhaka city, Bangladesh: a study based on intensive field investigation. *Arboricultural Journal*, 42(2), 76-92.

⁵ Political Economy of Urban Green Spaces of Dhaka City (2022), BUET and Compass, USDA Forest Service

⁶ Nawar, N., Sorker, R., Chowdhury, F. J., & Rahman, M. M. (2022). Present status and historical changes of urban green space in Dhaka city, Bangladesh: A remote sensing driven approach. *Environmental Challenges*, 6, 100425.

⁷ Rahman, K. A., & Zhang, D. (2018). Analyzing the level of accessibility of public urban green spaces to different socially vulnerable groups of people. *Sustainability*, 10(11), 3917.

due to inadequate vegetation coverage, emphasizing the need for initiatives for increasing tree diversity, density, and existing green space conservation⁴.

Furthermore, there is a considerable increase in built-up areas, a decline in vegetation cover (i.e., Dhaka lost 6.5% of its green cover from 2002 to 2020), and a rise in land surface temperature over the years. The staggering increase of built-up areas by 188.35% from 1990 to 2020, leading to a decrease in ecosystem service value (ESV) by 59.55% (85 million USD)⁸. Their results indicate a notable reduction in vegetation cover (5%) and an increase in built-up area (14%) from 2000 to 2020, contributing to a significant rise in land surface temperature (LST). Some researchers found the healthy green space in Dhaka has diminished from 17% in 1989 to only 2% in 2020 the pressing need for the restoration, augmentation and sustainable management of green spaces⁹. Some other findings indicated a notable decline in vegetation cover (5%) and a concurrent rise in built-up areas (14%) between 2000 and 2020. This substantial expansion of built-up areas corresponded to a 7.24 °C increase in Land Surface Temperature (LST) over the past two decades⁶. While, some other researchers recently found the vegetation coverage in DNCC is only 16.17 percent¹⁰. Altogether, its difficult to choose for decision makers which information to consider and take as baseline. To take this forward, it's essential to establish a comprehensive baseline information on Dhaka's green cover and tree resources.

Nevertheless, a comprehensive tree inventory and mapping initiative has been missing to accurately assess the existing tree cover in Dhaka. An inventory pivotal in providing crucial data for informed decision-making, enabling authorities to identify areas with the greatest need for afforestation and regeneration of green spaces. Additionally, community involvement with relevant information is vital during this process to garner public support and engagement, fostering a sense of ownership and responsibility among the residents. This study, involving an extensive tree inventory through field measurement, aims to establish comprehensive baseline information for tree resources and their services to humanity. It also actively engaged relevant stakeholders in the inventory process to promote community awareness. The study is expected to support the formulation of appropriate policies and regulations to protect and preserve existing trees and greenspaces within the city. The study recommends regulations with clear guidelines for sustainable construction and development, ensuring that a percentage of land is designated for green areas and tree planting. Incentives such as tax breaks or subsidies can be provided to encourage compliance with these regulations.

⁸ Rahman, M. M., & Szabó, G. (2021). Impact of land use and land cover changes on urban ecosystem service value in Dhaka, Bangladesh. *Land*, 10(8), 793.

⁹ Nawar, N., Sorker, R., Chowdhury, F. J., & Rahman, M. M. (2022). Present status and historical changes of urban green space in Dhaka city, Bangladesh: A remote sensing driven approach. *Environmental Challenges*, 6, 100425.

¹⁰ Shammi, M., Reza, F., Sarker, A. C., & Sakib, A. A. (2023). Prospects and challenges of achieving sustainable urban green-spaces: A case study of urban greening in Dhaka North City Corporation (DNCC), Bangladesh. *PLOS Sustainability and Transformation*, 2(5), e0000061.

1.2. US Forest Service in Bangladesh

The Forest Service has been working in Bangladesh for fifteen years, since 2009, in partnership with USAID to improve the relevant national organizations' natural resources management capacity. In its 15-year history working in Bangladesh, the Forest Service has successfully forged relationships with numerous partners, allowing for a wide range of programming and a breadth of technical exchange.

In 2015, Forest Service expanded on its partnership with the BFD, operating under the Silva Carbon Program, providing technical assistance in the design of a National Forest Inventory – a key component of the national forest monitoring system. Through the Silva Carbon program, the Forest Service has supported the development of the Resource Information Management Systems (RIMS) lab at the BFD, supported a 6-week fellowship to NASA Goddard Center for a Bangladeshi researcher, and extended the ongoing capacity building support for the RIMS unit by University of Maryland researchers. These partnerships allow Forest Service to leverage their expertise in Bangladesh and promote meaningful scientific exchange.

In 2019, USAID Bangladesh and Forest Service entered an inter-agency partnership, with funding from USAID Bangladesh, in which Forest Service is the implementing partner of the Compass program. Compass addresses natural resource management challenges in Bangladesh. Compass works through the five major components including: 1) Establishing a Youth Conservation Corps (YCC) in Bangladesh; 2) Strengthening community capacity and promoting public participation; 3) Increasing technical cooperation on forest and ecosystem management; 4) Strengthening the capacity of academic & research institutions in natural resource management and resilience; and 5) Promoting global exchange of natural resource knowledge and skills. Figure 1 represents the history of USFS works in Bangladesh.

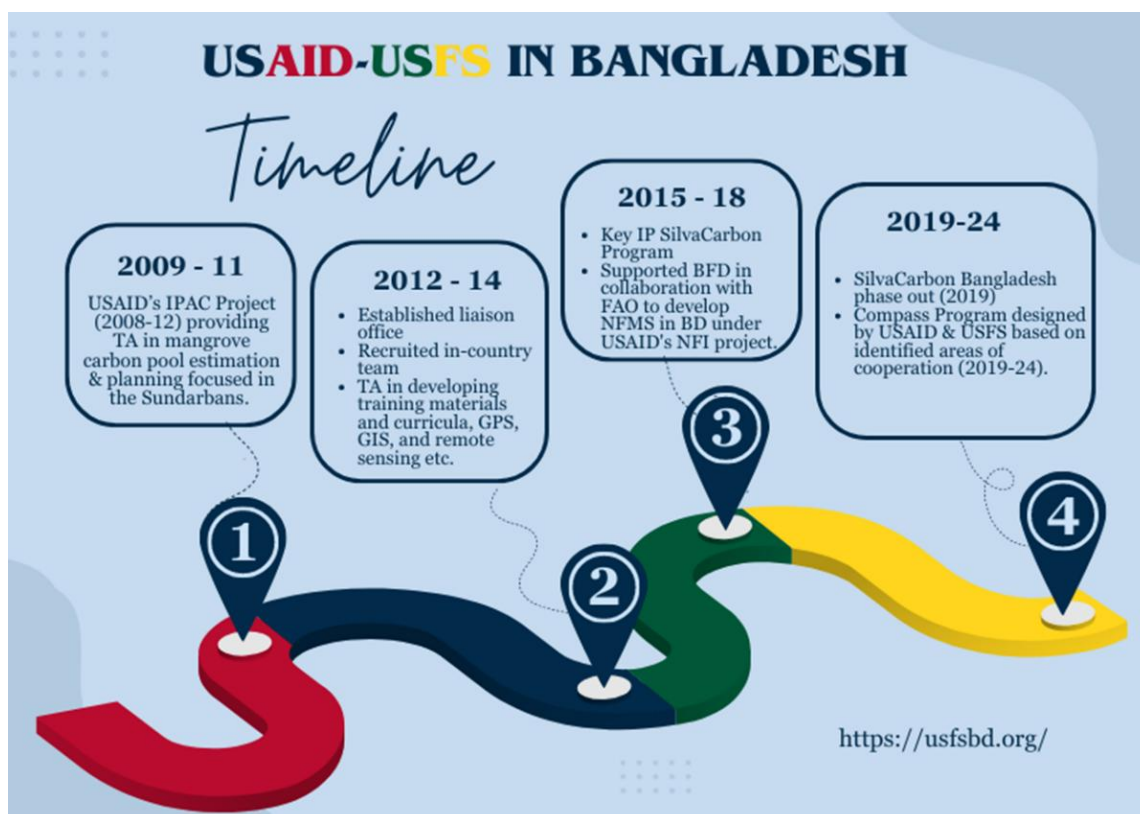


Figure 1: History of USFS works in Bangladesh

1.3. i-Tree Tools

i-Tree is a comprehensive suite of software tools and resources developed by the USDA Forest Service and its partners to assess and manage urban and community forests. i-Tree has emerged as a pivotal resource for a diverse range of users, including students, city planners, government officials, NGOs, researchers, and nature enthusiasts. Introduced in 2006, i-Tree has seen adoption in over 130 countries, where it has played a crucial role in assessing and managing urban forests, enabling communities of all sizes to evaluate tree cost, benefits, and management strategies. It provides a set of tools and methodologies to evaluate the value and benefits of trees in urban areas. The tools are freely available from i-Tree website (www.itreetools.org) and are designed to be accessible and user-friendly. i-Tree stands for "Inventory of Tree Resources: Environmental and Economic" and it is widely used to quantify the ecological and economic contributions of trees and other vegetation in urban environments. The tool has proven instrumental in promoting effective natural resource management by offering invaluable information for planning, decision-making, and standardizing monitoring. i-Tree tools aid in forest management decisions, education, and advocacy by working at various scales: from the individual tree to the property, neighborhood, city, and landscape levels.

In the i-Tree tools there are several programs in-built. Core programs provide the scope to assess forest tree populations, ecosystem services, and values. These main programs are designed to provide forest data and aid in improving forest management decisions. The tools are shown in Figure 2.

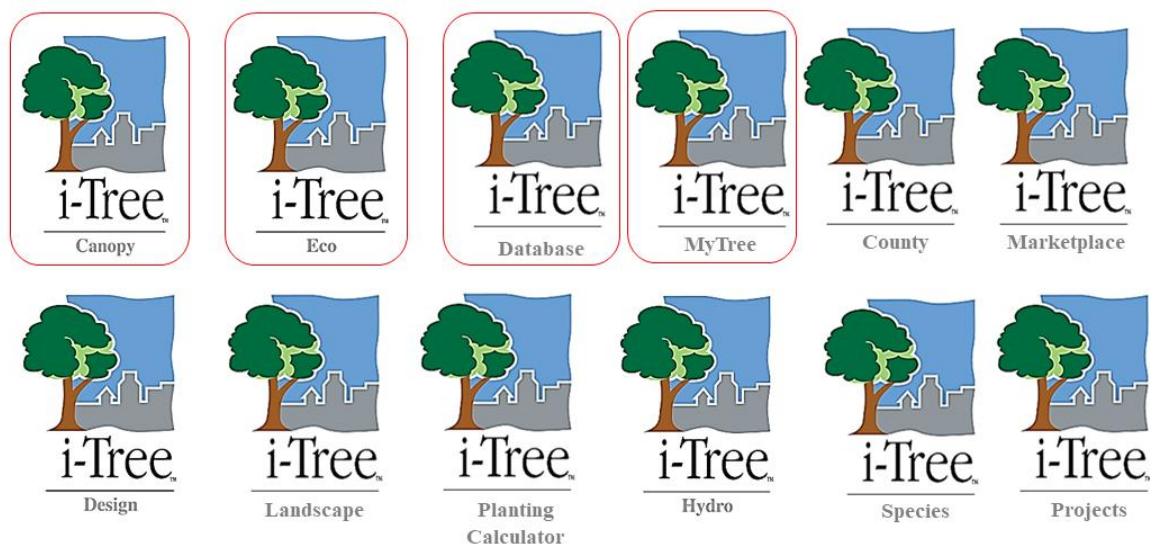


Figure 2: i-Tree tools

I.4. i-Tree tools and Urban Forestry in Bangladesh

USAID's Compass program has partnered with the BFD to introduce i-Tree for the purpose of conducting a comprehensive urban tree inventory in the metropolis of Dhaka, Bangladesh. Also, Compass took support from the i-Tree developer the Davey Institute, USA and established it for Bangladesh. I-Tree emerged as a potential solution to bridge the information gap and address the paucity of understanding regarding the benefits of trees within the urban landscape of Dhaka. I-Tree is a freely accessible tool, serves adequately in estimating and quantifying the multifarious benefits that trees confer upon communities. Moreover, by employing this software, it becomes possible to assess the substantial advantages that trees provide, encompassing aspects such as pollution reduction, carbon sequestration, and mitigating runoff. Use of i-Tree in the inventory provided a means to estimate the structure and functions of the urban forest of Dhaka. This includes crucial data regarding tree population, species distribution, and their respective contributions to the overall ecosystem. By leveraging the capabilities of i-Tree, authorities of Dhaka urban tree management can gain profound insights into the existing urban forest dynamics and plan judiciously for sustainable growth and development.

One of the significant impacts of i-Tree inventory results is the facilitation of strategic management in urban planning. Armed with precise data and analyses, urban planners can craft strategies that prioritize the preservation and augmentation of the urban forest. These strategies can be instrumental in orchestrating sustainable development, ensuring a harmonious coexistence between the city's concrete structures and its vital green lungs.

Furthermore, now-a-days tree inventory results become an essential tool to advocate funding programs. With empirical data showcasing the significant advantages of trees, proponents can effectively lobby for financial support and allocate resources to conservation and urban greening initiatives. The quantitative benefits lend credibility to funding appeals and strengthen the case for investing in sustainable urban development.

Chapter 2

Objective of this study

2. Objective of this study

The Urban Tree Inventory of Dhaka set out to comprehensively assess the benefits derived from urban trees in the city corporation area, establish a foundational understanding of the current urban tree population in Dhaka, and raise awareness about the pivotal role of trees in urban settings. The specific objectives of this initiative were as follows:

- (a) **Establishing Baseline Data:** The primary goal of the urban tree inventory of Dhaka was to establish a baseline for understanding the urban tree population in Dhaka. This baseline data can serve as a crucial reference point for assessing the changes in tree cover over time and guiding future urban development decisions. The objective specifically provides information on tree structure, and species diversity of Dhaka city.
- (b) **Assessing Urban Tree Benefits:** Another key objective was to evaluate the diverse benefits provided by urban trees. These benefits encompassed ecological, economic, and social advantages, such as air quality improvement, runoff regulation, carbon stock & sequestration, and oxygen production which enhance quality of life for residents.
- (c) **Raising Awareness:** The urban tree inventory aimed to create awareness among residents, policymakers, and relevant stakeholders about the critical role that trees play in urban environments. By highlighting the benefits of urban trees, the initiative sought to garner support for sustainable urban planning, conservation of urban green space and community involvement.

By quantifying the diverse benefits derived from urban trees, from their ecological contributions to economic advantages and social well-being, the study provided a solid foundation for informed decision-making and urban planning.

Chapter 3

Methods and Materials

3. Methods and Materials

The study followed a systematic process for promoting accuracy and reliability in the assessment of Dhaka's urban tree resources, encompassing initial planning through to the conclusive report. The key steps were planning and designing, land use zoning, sampling design, capacity building of data enumerators, secondary data collection, field data collection, quality assurance during the field measurement (hot check) and after the measurement (cold check), data compilation and cleaning, new species submission to i-Tree, data analysis and reporting.

3.1. Planning and Designing

Compass worked with BFD, DNCC, DSCC, Bangladesh National Herbarium (BNH), and Universities to design the urban tree inventory of Dhaka. In this connection, a Standard Operational Procedures (SOP) was developed aligned with the Bangladesh Forest Inventory. The field team followed this SOP during data collection. The planning team decided to use the i-Tree Eco for this inventory; the basis of the i-Tree modeling tools is given in Figure 3.

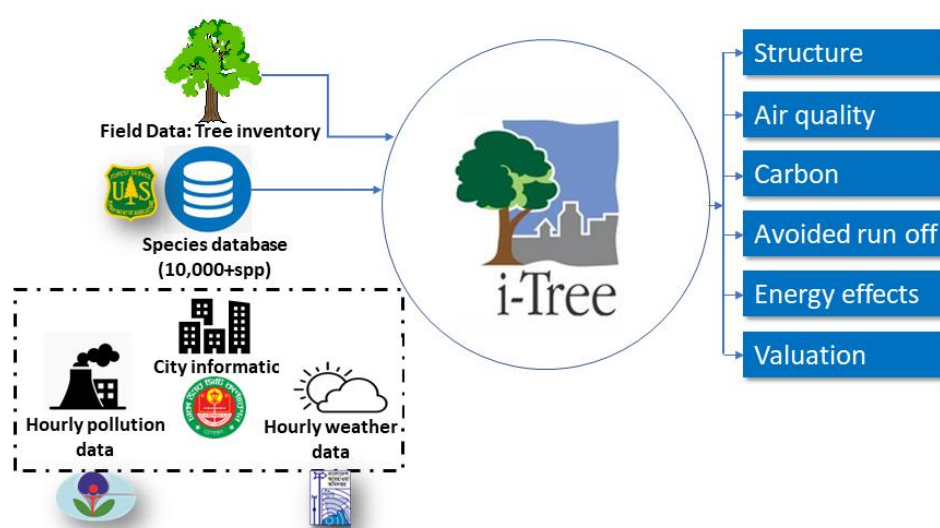


Figure 3: i-Tree Eco model basics

In addition to, existing i-Tree species database, tree inventory data, hourly pollution and precipitation data were incorporated into the i-Tree modeling software to get tree structure, pollution removal, carbon sequestration, carbon storage, avoided runoff and oxygen production benefits of the urban forestry. Table 1 represents the key collaborators from diversified professionals and technical agencies with their roles in the of the urban tree inventory of Dhaka.

Table 1: Stakeholders and responsibilities

Stakeholder(s)	Areas of collaboration for i-Tree establishment
RIMS unit, BFD	- i-Tree sampling strategy and design - Instruction of variable definition and field data collection - Strategic guidelines in fieldwork design - Guidance to align i-Tree data collection with Bangladesh Forest Inventory (BFI) - Instruction on usage of inventory instruments - QC & QA by hot¹¹ check and cold¹² check of i-Tree data

¹¹ Hot Check: 10 percent. The inspection team will be present on training and practice plots with the enumerators and provides immediate feedback about their performance.

¹² Cold Check: 06 percent of the sample plots will be cold checked by the QA /QC team by recollecting the plot data when the field teams complete data collection.

Green Savers	▪ Enumerator's engagement ▪ Training to enumerators ▪ Management of i-Tree field data collection ▪ Precipitation and rainfall data templating ▪ Dissemination and advocacy workshop
DNCC and DSCC	▪ Existing maps and geospatial boundaries ▪ Basic demographic data
DoE	▪ Spatio-temporal air pollution data
BMD	▪ Historical precipitation data
Davey Institute	▪ Technical backstopping to establish i-Tree ▪ New species inclusion in i-Tree tree list ▪ Set-up of i-Tree
University	▪ Enumerators for i-Tree field data collection ▪ Plant taxonomical support ▪ Sampling design

The research team shared the i-Tree concept with different institutions, including the Public Works Department (PWD), the Bangladesh Institute of Planners (BIP), the Bangladesh Environment Lawyers Association (BELA), the Department of Agriculture Extension (DAE), Local Government Engineering Department (LGED), Rajdhani Unnayan Kartipakkha (RAJUK), Dhaka South City Corporation (DSCC), Department of Soil, Water and Environment, Bangladesh Poribesh Andolon (BAPA), and Institution of Foresters Bangladesh (IFB). These multiple stakeholders are responsible for managing Bangladesh's Dhaka urban green space.

3.2. Land Use Zoning

We analyzed high-resolution worldview satellite imagery (0.5 meter) for land use zoning in both DNCC and DSCC for the urban tree inventory of Dhaka. The study team used the Support Vector Machine (SVM) algorithm in land use classification and zoning. This advanced approach enhances the accuracy of mapping and zoning for the sampling strategy of Dhaka's urban tree inventory.

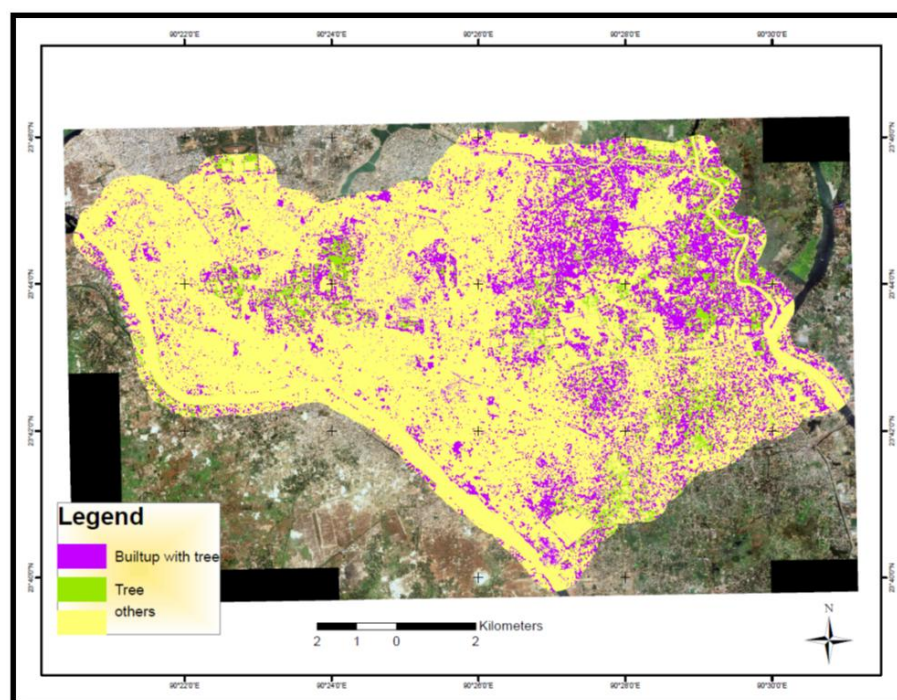


Figure 4: Land Zoning map of DSCC

The study team classified the urban area into three zones (strata): trees, built up with scatter trees and others. Definitions of the zones with little descriptions are given in Table 2.

Table 2: Zones/strata definition

#	Zone	Description
1	Trees	Tree patches greater than 400 m ² were identified on the map and defined as the tree stratum. This stratum represents the most vegetative areas of the Dhaka city. The botanical garden, parks, tree patches, Zoo, etc. green areas fall in this stratum.
2	Built up with scatter trees	Moderate to low vegetative areas having tree patches 200 m ² to 400 m ² fall under this stratum. For example, residential areas, institutional premises, commercial areas, schools, roadsides, development areas, etc. area fall under this stratum.
3	Others	The areas having less than 200 m ² tree patches along with the water bodies, fallow lands and open fields were identified on map and defined as “Others” stratum. The areas that are usually devoid of trees; specially the grasslands, playgrounds, roads marshy areas, barren areas, and residential areas not having noticeable vegetation fall under this stratum.

Areas and percentage coverage of the zones are given in the Table 3. While referring zones, for ease of presentation, we used the term “Scatter” to denote “Built up with scatter trees” zone across the document. Notably, for DNCC, the “Scatter” zone constitutes the largest area, whereas for DSCC, it falls under a “Others” zone.

Table 3: Land use zones and plot number

Zone	DNCC		DSCC	
	Area (ha)	Percentage of total area (%)	Area (ha)	Percentage of total area (%)
Tree	1,636	8.94	1,201	12.67
Built up with scatter trees	11,445	62.58	1,304	13.76
Others	5,209	28.48	6,974	73.57
Total	18,290	100.00	9,479	100.00

3.3. Sampling Design

The i-Tree Eco project followed a stratified random sampling (error margin-5%, confidence interval-95%) where “Tree”, “Built-up with scattered tree” and “Others” were the three strata. After delineating the strata on map, random points were generated using ArcGIS Pro for locating the sample plots (Figure 5).

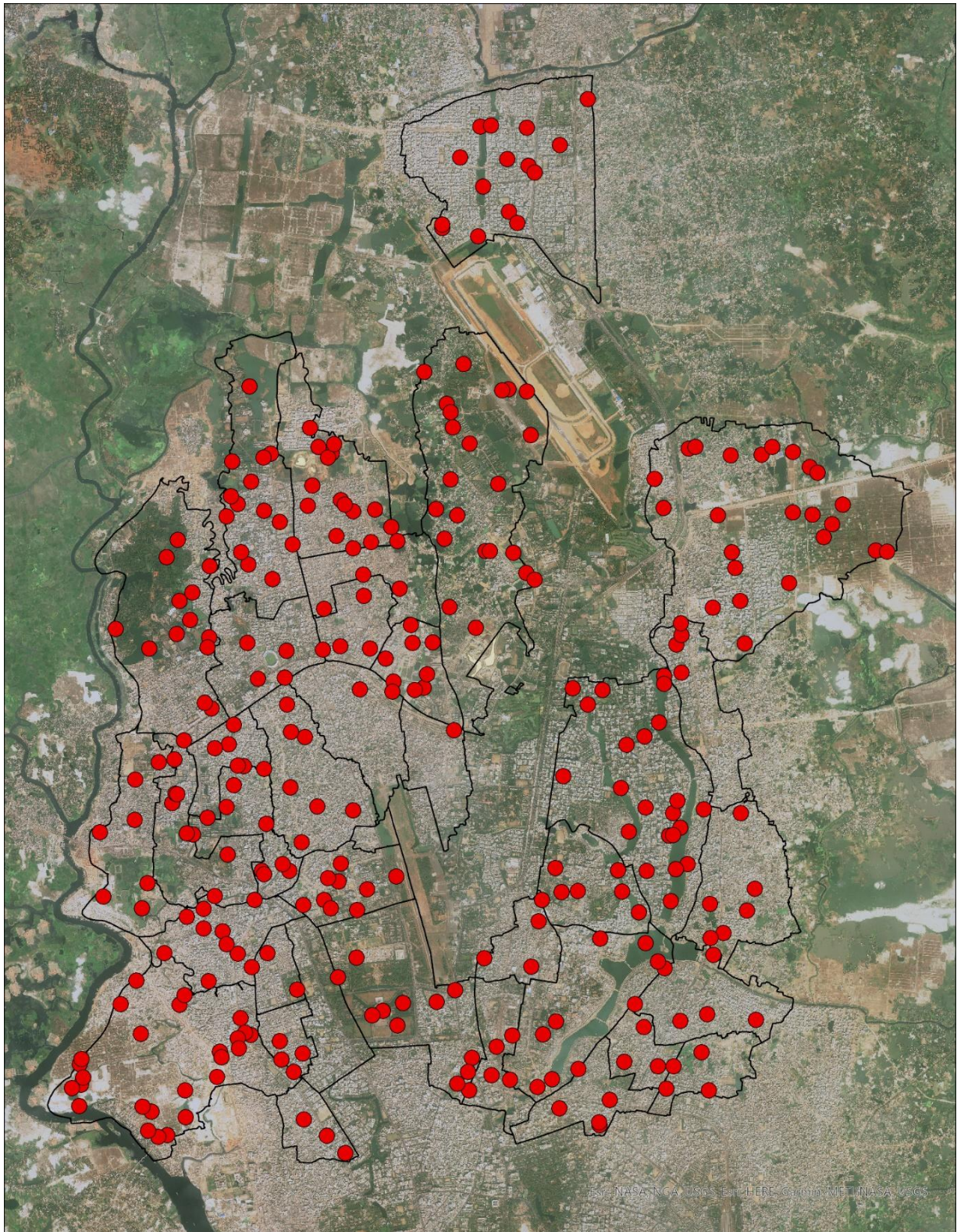


Figure 5: Plot distribution map of DNCC

The sample plots were circular with 11.35 m radius (0.04047 ha, 0.1 acre); it was fixed as per i-Tree Eco guidelines. Shown in Figure 6.

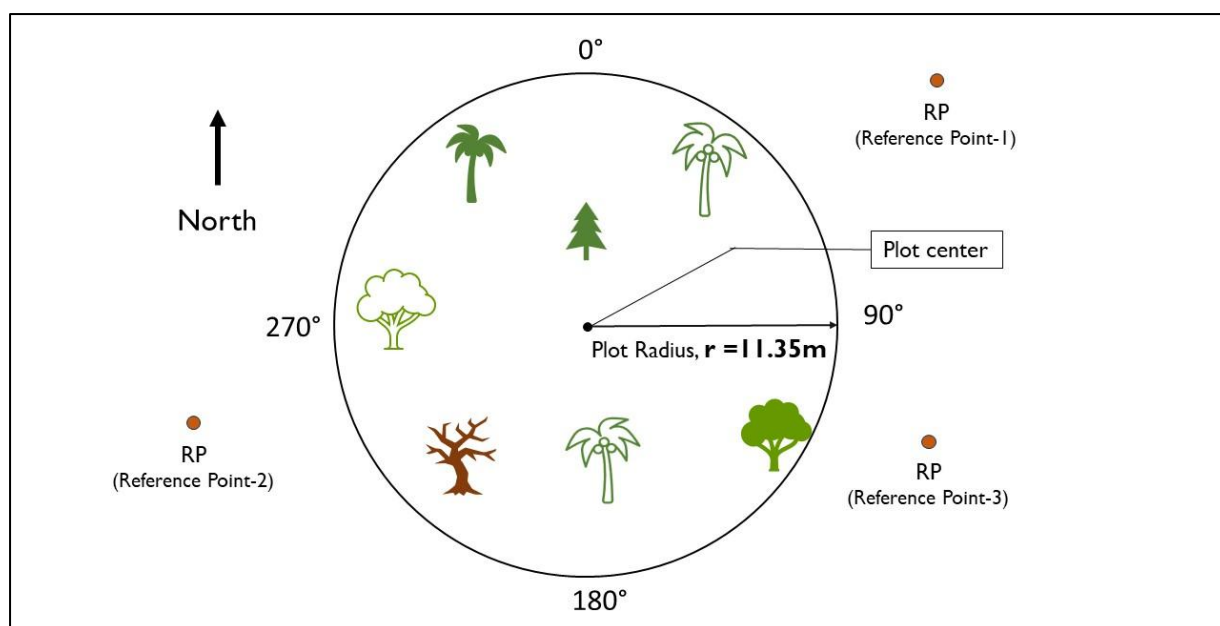


Figure 6: Schematics of a sample plot

The sampling intensity (0.09%) was same across the strata (Table 4; Eq 1). However, there were some non-sampled and partially sampled plots mostly due to security restrictions, and limited access to personal property. The achieved number of plots varied with stratum. The strata were sometimes referred as zone in this document.

$$\text{Sample size} = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \left(\frac{z^2 \times p(1-p)}{e^2 N} \right)} \text{-----Equation 1}$$

N = population size

e = Margin of error (percentage in decimal form)

z = z-score

The derived z-score for 95% confidence level was found 1.96.

Table 4: Number targeted and sampled plots

Zone	DNCC		DSCC	
	Targeted plots (No.)	Sampled plots (No.)	Targeted plots (No.)	Sampled plots (No.)
Tree	35	26	47	44
Built up with scatter trees	241	216	51	49
Others	110	102	272	260
Total	386	344	370	353

3.4. Capacity building of data enumerators

The research team trained the field enumerators with tree inventory techniques over a four-day period. The training covered a comprehensive overview of the theoretical aspects of tree inventory on day 1. Days 2 and 3 focused on hands-on practice with various tree parameter



Figure 7: Inventory instruments used in Dhaka's Urban Tree Inventory

measuring tools (Figure 7), including the Lager Range Finder, Diameter tape, Sunnto Clinometer, Global Positioning System (GPS), Distance Measuring Equipment (DME), and Densitometer. This training equipped enumerators with the knowledge and skills necessary for accurate and efficient tree data collection.





Photo: Training of enumerators

The fourth day centered on honing skills in tree identification and evaluating the effective application of the instruments. The Table 5 described inventory instruments and their uses.

Table 5: List of instruments used with their function

Name of instruments	Application/ Measurement
Laser Rangefinder	Total tree height, Crown base height, Crown top height, Crown width
Distance Measuring Equipment (DME)	Horizontal distance, plot radius
Sunnto Clinometer	Bearing, Compass, Tree height
Densitometer	Crown percent missing
GPS	Latitude and Longitude
GPS Essentials	Backup of GPS to acquire location data
Dia Tape	Diameter at Breast Height (DBH), DHB height
Measuring Tape	Distance, Plot radius
Tab	Data input

3.5. Secondary data collection

The research team compiled air quality data from the Department of Environment (DoE) spanning 2012 to 2019. This dataset included metrics such as Carbon Monoxide (CO), Nitrogen Dioxide (NO₂), Ozone (O₃), particulate matter (PM₁₀, PM_{2.5}), Sulfur Dioxide (SO₂), Nitrous Oxide (NO), CO-8hr, O₃-8hr, wind speed, wind direction, temperature, Relative Humidity (RH), and solar radiation. Additionally, precipitation data from the Bangladesh Meteorological Department (BMD) for the years 2015 to 2020 were collected. Following the i-Tree database template, the air pollution and

precipitation data underwent processing. The Davey Institute facilitated their integration into the i-Tree database.



Photo: Secondary data processing

3.6. Primary field data collection

The team engaged 40 enumerators from public and private universities, to undertake the collection of i-Tree plot inventory data during the period spanning 2022-2023. For the identification of tree species during the field enumeration supports were taken directly from plant taxonomists from University of Chittagong (CU) and BNH. In necessary cases, the taxonomists consulted existing taxonomic literature and resources available in the herbarium. The enumerators gathered comprehensive tree parameters from sample plots, including the tree species name, horizontal bearing from the plot center, DBH (Diameter at Breast Height) up to six stems, tree total height, crown base height, crown width, canopy percentage missing, canopy dieback, and crown light exposure. Additionally, they recorded information about tree ownership, whether the tree was located roadside or not, and the nature of ground cover under the trees.

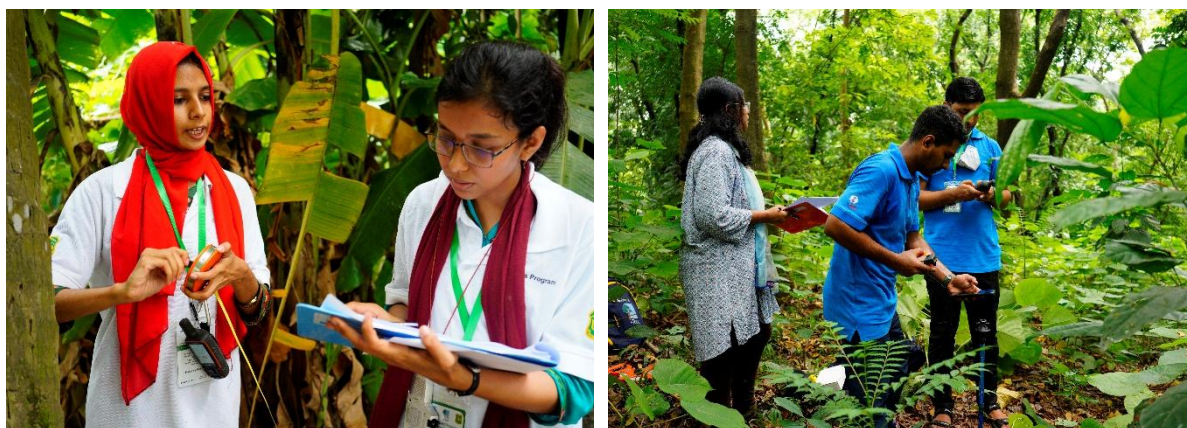




Photo: field data collection

Beyond individual tree details, the team also documented plot-specific information, such as actual land use, ground cover, reference objects, and GPS locations. The plots that fall in water were identified on the map and avoided during the field survey. However, if it was not identified on the map and detected during the field survey then it was recorded and measured as usual plot. To streamline and enhance fieldwork supervision, the research team tailored a customized Google 'My Map' for effective monitoring of the fieldwork and team management.

3.7. Hot check and Cold check

BFD's Quality Assurance/Quality Control (QA/QC) team checked 10% of the plots during fieldwork. In the hot check phase, the team closely observed enumerators in action, intervening to provide corrective instructions when necessary to ensure the data quality. Also, the QA/QC team visited 6% of the total plots for cold check. Cold check is recollecting the information of plots after completion for actual fieldwork.





Photo: Hot check and cold check

3.8. New species integration

The i-Tree database contains a list of more than ten thousand species in their server. During this inventory, team found 36 species which are not available in the i-Tree database and worked with the Davey Institute to incorporate those. Detailed information is required to incorporate in i-Tree database which are Genus, Species, Family, Order, and Common Name, while phenological information includes growth form (shrub or small tree, Palm, Tree), Percent Leaf type (Hardwood, palm, Picea, Pinus), Leaf Type (Deciduous, evergreen, Summer deciduous, Semi-evergreen), Growth Rate (Slow- 0-.24in/yr, Medium-.24-.41 in/yr, Fast- >.41 in/yr), Longevity (Short 0-35 years, Moderate 35-55 years, Long >55 years), Height at Maturity, and Native Continent. These species are now part of the central i-Tree database, accessible to users worldwide.

3.9. Data analysis and reporting

The research team used combination of i-Tree Eco and R scripts for data analysis to estimate a range of parameters. Eco quantified urban forest structure and its numerous effects, including air pollution removal, oxygen production, avoided runoff, etc.

3.9.1. Tree Characteristics

Total Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. The evaluation of invasive species involved a review of existing literature, consulting with national experts and taxonomists for identification.

3.9.2. Density and basal area

Tree density and basal area was estimated using the following equation 2 and 3 respectively.

$$D_{TPH} = \frac{N_k}{A_k} \text{-----Equation 2}$$

Here,

D_{TPH} = Density (tree per ha)

N_k = Number of individuals of all species in plot k

A_k = Area of plot k in ha

$$BA = \pi \times \frac{D^2}{4} \text{-----Equation 3}$$

Herre, BA = Basal area in m², D = Diameter at breast height in m.

3.9.3. Growing stock

Growing stock has been estimated for the trees having DBH ≥ 10 cm using the following equation 4.

$$V_g = \frac{D^2}{4} \times \pi \times H_{tot} \times f_{gross} \text{-----Equation 4}$$

Here,

V_g = Gross volume (m³) of individual tree,

D_{bh} = Tree diameter at breast height (m), (DBH ≥ 10 cm)

$\pi = 3.1416$,

H_{tot} = Tree total height (m),

f_{gross} = Average form factor of trees here 0.693 (taken from Bangladesh Forest Inventory).

3.9.4. Above ground biomass

Above ground biomass (AGB) was estimated using the pantropical allometric equation (Equation 5) provided by Chaves et al. (2014)¹³.

$$Y_{agb} = 0.0673 \times (\rho D^2 H)^{0.976} \text{-----Equation 5}$$

Here, Y_{agb} = Above ground biomass in kg

ρ = Wood density in g cm⁻³

D = Diameter at Breast Height in cm

H = Total height in m

The wood density was taken from the secondary sources especially from BFRl and global wood density database. An average wood density (0.6133782), adapted from the Bangladesh Forest Inventory Cycle-I¹⁴, was used for the species for which the wood density was not available.

3.9.5. Below ground biomass

The Pearson et al. (2007) (**Equation 6**) was used for estimating below ground biomass.

$$Y_{bgb} = \exp[-1.0587 + 0.8836 \ln(Y_{agb})] \text{-----Equation 6}$$

Here, Y_{bgb} = Below ground biomass

3.9.6. Means, totals, and variance

The plot level estimates of the tree density, tree cover, basal area, growing stock, above ground biomass, below ground biomass, total tree biomass, carbon in AGB, Carbon in BGB and total tree carbon per ha were used to calculate the means, totals and variance using the following equation 7 to 11.

$$\text{Stratum mean, } \bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h} \text{-----Equation 7}$$

$$\text{Stratified mean, } \bar{y} = \sum_{h=1}^k W_h \bar{y}_h \text{-----Equation 8}$$

$$\text{Stratum variance, } s_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2 \text{-----Equation 9}$$

¹³ Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B., ... & Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global change biology*, 20(10), 3177-3190.

¹⁴ GoB. 2020. Tree and forest resources of Bangladesh: Report on the Bangladesh Forest Inventory. Forest Department, Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh. <http://bfis.bforest.gov.bd/bfi/>

Stratified variance, $Var(\bar{y}) = \sum_{h=1}^k W_h^2 \left(1 - \frac{n_h}{N_h}\right) \frac{S_h^2}{n_h}$ ----- Equation 10

Weight, $W_h = \frac{N_h}{N}$ ----- Equation 11

Here,

y_{hi} = value of y of the i th units of the h th stratum ($i=1, 2, 3, \dots, n_h$; $h=1, 2, \dots, k$)

N_h = number of sampling units in the h th stratum

N = Population size ($\sum_{h=1}^k N_h$)

k = Number of strata

n_h = number of sampling units to be drawn in the h th stratum

n = Total sample size ($\sum_{h=1}^k n_h$)

3.9.7. Phytosociological attributes

Phyto-sociological attributes of the species were calculated for each stratum following Shukla and Chand¹⁵, Misra¹⁶, and Dallmeier¹⁷ (Table 6).

Table 6: Formula used for calculating phytosociological attributes of species recorded from DNCC

SN	Phytosociological attributes	Formula
1	Density (D)	$D = \frac{a}{b}$ ----- Equation 12
2	Relative density (RD)	$RD = \frac{a}{M} \times 100$ ----- Equation 13
3	Frequency (F)	$F = \frac{c}{b}$ ----- Equation 14
4	Relative frequency (RF)	$RF = \frac{F_i}{\sum_{i=1}^S (F_i)}$ ----- Equation 15
5	Abundance (A)	$A = \frac{a}{c}$ ----- Equation 16
6	Relative abundance (RA)	$RA = \frac{A_i}{\sum_{i=1}^S (A_i)}$ ----- Equation 17
7	Importance Value Index (IVI)	$IVI = RD + RF + RA$ ----- Equation 18

Here, a = number of individuals of the i th species occurred in the area of interest; b = total number of quadrats studied; c = total number of quadrats in which the species occurred; M = total number of individuals of all the species in the area of interest; F_i = frequency of i th species, S = number of species.

3.9.8. Diversity indices

Four common diversity indices namely Shannon-Wiener Diversity Index, Margalef's Richness Index, Simpson's Dominance Index and Pielou's Evenness Index were computed following Shannon¹⁸, Margalef¹⁹, Simpson²⁰ and Pielou²¹ using the equation 19 through 22.

¹⁵ Shukla, R.S. and Chandal, P.S. 2000. Plant Ecology and Soil Science (9th edn.). Ramnagar: S. Chand and Company Limited, New Delhi. pp. 121-376.

¹⁶ Misra, R. 1968. Ecology workbook. New Delhi, India: Oxford and IBH Publishing.

¹⁷ Dallmeier F, Kabel M, and Rice R. 1992. Methods for long term biodiversity inventory plots in protected tropical forests. In: F. Dallmeier (eds). Long term monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent plots. UNESCO, Paris, pp. 11-46.

¹⁸ Shannon, C.E. and Wiener, W. 1963. The Mathematical Theory of Communities. University of Illinois Press.

¹⁹ Margalef, R. 1958. Information theory in ecology. Computer & Chemistry, 3, 36-71.

²⁰ Simpson, E.H. 1949. Measurement of diversity. Nature, 163, 688.

²¹ Pielou, E.C. 1966. Species diversity and pattern diversity in the study of ecological succession. Journal of Theoretical Biology, 10, 370-383.

$$H = -\sum_{i=1}^S P_i (\ln P_i) \text{----- Equation 19}$$

$$R = \frac{(S-1)}{\ln(M)} \text{----- Equation 20}$$

$$S_D = \left(1 - \frac{\sum_{i=1}^S a_i(a_i-1)}{M(M-1)}\right) \text{----- Equation 21}$$

$$E = \frac{H}{\ln(S)} \text{----- Equation 22}$$

Here, H = Shannon-Wiener Diversity Index; R = Margalef's Richness Index; SD = Simpson's Dominance Index; E = Pilon's Evenness Index; M = total number of individuals of all the species; a = number of individuals of ith species; P_i = proportional occurrence of ith species (a_i/M); S = total number of species.

3.9.9. Air pollution removal

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, particulate matter less than 2.5 microns, and particulate matter less than 10 microns and greater than 2.5 microns. PM_{2.5} is generally more relevant when it comes to air pollution effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models²². As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere. Recent updates to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values^{23,24}.

Trees remove PM_{2.5} and PM₁₀* when particulate matter is deposited on leaf surfaces²⁵. This deposited PM_{2.5} and PM₁₀* can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, PM_{2.5} and PM₁₀* removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove. Resuspension can also lead to increased overall PM_{2.5} and PM₁₀* concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove PM_{2.5} and PM₁₀* but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

The number of adverse health effects and associated economic value is also calculated for the air pollutants mentioned above using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP)²⁶. The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal.

²² Baldocchi, D. D., Hicks, B. B., & Camara, P. (1987). A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. *Atmospheric Environment* (1967), 21(1), 91-101.

²³ Hirabayashi, S., Kroll, C. N., & Nowak, D. J. (2011). Component-based development and sensitivity analyses of an air pollutant dry deposition model. *Environmental Modelling & Software*, 26(6), 804-816.

²⁴ Hirabayashi, S. (2013). i-Tree Eco precipitation interception model descriptions. US Department of Agriculture Forest Service: Washington, DC, USA, 1, 0-21.

²⁵ Nowak, D. J., Hirabayashi, S., Bodine, A., & Hoehn, R. (2013). Modeled PM_{2.5} removal by trees in ten US cities and associated health effects. *Environmental pollution*, 178, 395-402.

²⁶ Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Tree and forest effects on air quality and human health in the United States. *Environmental pollution*, 193, 119-129.

For Dhaka, DoE observed CAMS-I station data (Sangshad Bhaban, Sher-e-Bangla Nagar- 23.76N 90.39E) were used. Values are then converted to local currency with user-defined exchange rates. For this analysis, pollution removal value is calculated based on the prices of Tk 173,622 per metric ton (carbon monoxide), Tk 1,222,420 per metric ton (ozone), Tk 1,222,420 per metric ton (nitrogen dioxide), Tk 299,268 per metric ton (sulfur dioxide), Tk 816,154 per metric ton (particulate matter less than 2.5 microns), Tk 816,154 per metric ton (particulate matter less than 10 microns and greater than 2.5 microns).

3.9.10. Carbon Storage and Sequestration

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using species specific equations and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations. Following Nowak 1994²⁷, biomass results for open-grown urban trees were multiplied by 0.8; no adjustment was made for trees found in natural stand conditions; and tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

Carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth²⁸ from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For this analysis, carbon storage and carbon sequestration values are calculated based on Tk 1,704 per metric ton.

3.9.11. Oxygen Production

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O₂ release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition²⁹.

3.9.12. Avoided Runoff

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The value of avoided runoff is based on BMD data values. For this analysis, avoided runoff value is calculated based on the price of Tk 254.95 per m³.

All together, the summary of inventory variables and associated application in the analysis is portrayed in Table 7 following the i-Tree manual³⁰.

²⁷ Nowak, D. J. (1994). Atmospheric carbon dioxide reduction by Chicago's urban forest. Chicago's urban forest ecosystem: Results of the Chicago urban forest climate project, 83-94.

²⁸ Nowak, D. J., Hoehn, R. E., Crane, D. E., Weller, L., & Dávila, A. (2011). Assessing urban forest effects and values, Los Angeles' urban forest. <https://doi.org/10.2737/nrs-rb-47>

²⁹ Nowak, D. J., Hoehn, R., & Crane, D. E. (2007). Oxygen production by urban trees in the United States. *Arboriculture and Urban Forestry*, 33(3), 220.

³⁰ Nowak, D. J. (2021). Understanding i-Tree: 2021 summary of programs and methods. US Department of Agriculture, Forest Service, Northern Research Station.

Table 7: Summary of which directly field-measured characteristics are used to estimate derived variables and ecosystem services. D= directly used; I= indirectly used; C= conditionally used.

	DERIVED VARIABLES		ECOSYSTEM SERVICES										
DIRECT MEASURES	Leaf Area	Leaf Biomass	Carbon Storage	Gross Carbon Sequestration	Net Carbon Sequestration	Energy Effects	Air Pollution Removal	Avoided Runoff	Transpiration	VOC Emission	Compensatory Value	Wildlife Suitability	UV Effects
Species	D	D	D	D	D	D	I	I	I	D	D		
Diameter at breast height (DBH)			D	D	D						D	D	
Total height	D	D	C	C	C	D	I	I	I	I		D	
Crown base height	D	D	C				I	I	I	I			
Crown width	D	D	C				I	I	I	I			
Crown light exposure			C	D	D								
Percent crown missing	D	D	C	C	C	D	I	I	I	I			
Crown health (condition/dieback)				D	D						D	D	
Field land use				D							D	D	
Distance to building						D							
Direction to building						D							
Percent tree cover						D	D	D				D	D
Percent shrub cover							D					D	
Percent building cover						D							
Ground cover composition							I					D	

3.9.12. Land-use and ground cover

Land use refers to the human activities and purposes for which a particular piece of land is utilized, while ground cover describes the physical features that cover the land surface. Dhaka city covers a diverse range of landuse and ground cover categories. For simplicity, land-uses have been categorized in ten types and the ground cover has been categorized in eight types.

Table 8: Land-use category definitions

#	Category	Definition
1	Agriculture	Cropland, pasture, orchards, nurseries that show evidence of management activity for a specific crop are included
2	Commercial/ Industrial	In addition to standard commercial and industrial land uses, this category includes outdoor storage/staging areas as well as parking lot areas that are not connected with an institutional or residential use
3	Cemetery/ Graveyards	Includes areas within cemetery grounds

4	Forest	Tree patches/gardens
5	Institutional	Schools, hospitals, medical complexes, colleges, religious buildings, government buildings, etc.
6	Residential	A residential complex and related greenspace
7	Parks	Parks are established maintained areas
8	Transportation	Includes limited access roadways and related green spaces; railroad stations, tracks and yards; airports; etc.
9	Vacant	If a parcel contains large unmaintained areas, possibly for expansion or other reasons, treat the area as Vacant
10	Other	Land uses that do not fall into one of the rest categories are categorized in this category

Table 9: Ground cover category definitions

#	Categories	Definitions
1	Building	Concrete build houses or complex
2	Cement/Concrete/Dhalai	Impervious ground with layer of cement or concrete
3	Water	Includes waterbodies such as ponds, rivers, lakes, canals etc.
4	Bare Soil	Includes naturally occurring soil, sand
5	Herbs	Herbaceous ground cover, other than grass, including agricultural crops
6	Other Impervious	Impervious ground cover with any other substances other than cement or concrete
7	Duff/Mulch/Litter	Loose organic material, leaf litter
8	Grass	Grasses

Chapter 4

Inventory Results and Discussion

4. Inventory Results and Discussion

Findings of the study have been summarized by zones for each city corporation area (DNCC and DSCC).

4.1. Key results of Dhaka's Urban Tree Inventory

The tree inventory result revealed that the tree canopy covers the area of 10.5% in the Dhaka North City Corporation (DNCC) and 10.8% in the Dhaka South City Corporation (DSCC). This study identified a total of 73 tree species in DNCC and 82 tree species in DSCC, with Mango, Mahogany, and Coconut being the most dominant species in both study areas where the DNCC demonstrates a density of approximately 37 trees per hectare and DSCC boasts a higher density of 65 trees per hectare. In terms of carbon storage, trees in DNCC store 98.74 thousand metric tons of CO₂, equivalent to BDT 168 million, whereas trees in DSCC store 103.1 thousand metric tons of CO₂, equivalent to BDT 171 million.

Furthermore, trees contribute to the removal of around 319.3 metric tons of air pollutants annually in DNCC, with an estimated economic value of BDT 262 million. and 219.2 metric tons of air pollutants in DSCC, with an economic value amounting to BDT 175 million. Overall, these findings underscore the significant role of trees in enhancing environmental quality and the economic value associated with their ecological services in the urban area. Key results are summarized below-

Key issues	DNCC	DSCC
Tree coverage	10.5 %	10.8 %
No of trees	682,800	616,900
Tree density	37 trees/hectare	65 trees/hectare
Leaf area	97.01 square kilometers	90.22 square kilometers
Dominating species	1. Mango 2. Mahogany 3. Coconut	1. Mango 2. Coconut 3. Mahogany
Carbon sequestration	11.12 thousand metric tons (Tk18.9 million/year)	10.8 thousand metric tons (Tk17.9 million/year)
Carbon storage	98.74 thousand metric tons (Tk168 million)	103.1 thousand metric tons (Tk171 million)
Oxygen production	26.42 thousand metric tons/year	27.13 thousand metric tons/year
Pollution removal	319.3 metric tons/year (Tk262 million/year)	219.2 metric tons/year (Tk175 million/year)
Avoided runoff	603.9 thousand cubic meter/year (Tk154 million/year)	378.4 thousand cubic meter/year (Tk93.8 million/year)
Exotic vs Native	38% native	36% native

4.2. Basic attributes of the tree resources in Dhaka city

The urban forest of DNCC has an estimated 682,800 trees with a tree cover of 10.5%. The three most common species are Mango (17.2 percent), Mahogany (16.9 percent), and Coconut (8.2 percent). On the other hand, DSCC has an estimated 616,900 trees with a tree cover of 10.8 percent. The three most common species are Mango (33.3 percent), Coconut (10.2 percent), and Mahogani (9.3 percent). of the study recorded a total of 110 species belong to 33 families from Dhaka city of which 73 species (under 30 families) were found in DNCC and 82 species (under 32 families) in DSCC (Annex X). It is relevant to note that this is a conservative estimate and there will be more tree species as the study is mainly designed for assessing the ecosystem services and their economic valuation. Tree density of DSCC (65 stem/ha) is much larger than that's of DNCC (37 stem/ha).

4.2.1. Species richness by stratum

Occurrence of the number of species varied from zone to zone within the city corporations, indicating large variations of the species composition and diversity across the city. Table 10 represents the number of species and families per stratum in Dhaka city. It may be explained by the diverse choice of people to plant different fruit, ornamental and avenue tree species in the roadsides, house and institutional premises that occur in the large extent of Scatter stratum.

Table 10: Number of species and families per stratum in Dhaka city

SI	Stratum	Number of species		Number of families		Number of native species		Number of Exotic species	
		DNCC	DSCC	DNCC	DSCC	DNCC	DSCC	DNCC	DSCC
1	Tree	45	54	20	27	24	27	21	27
2	Scatter	45	39	22	18	28	24	17	15
3	Others	27	52	17	24	12	32	15	20
All zones		75	84	31	33	45	51	30	33

4.2.2. Species richness by land use and origin

There are several major land uses in Dhaka city dominantly by agriculture, cemetery and graveyard, commercial and industrial, institutional, park, residential, transportation, vacant, and other. Land use wise species richness are summarized in Table 11. The recorded species under each land use were further categorized as exotic and native based on the literature indicating their history of occurrence. The number of both native and exotic tree species were highest in the residential areas. It is because of the varied choice of the house owners regarding plant species selection. Many households prefer to plant exotic fruiting and ornamental species in their house premise and rooftop gardens.

Table 11: Number of species and families per land use

SI	Land use	Number of species		Number of families		Number of native species		Number of exotic species	
		DNCC	DSCC	DNCC	DSCC	DNCC	DSCC	DNCC	DSCC
1	Agriculture	5	16	4	12	2	11	3	5
2	Commercial	12	13	9	11	8	7	4	6
3	Graveyard	3	9	3	7	1	4	2	5
4	Institutional	17	23	13	14	7	12	10	11
5	Park	23	18	11	13	12	7	11	11
6	Residential	45	57	24	25	24	35	21	22
7	Transportation	19	14	12	9	10	8	9	6
8	Others	8	21	7	13	5	13	3	8

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and

displace native species. About 38 percent in DNCC and about 36 percent in DSCC of the trees are species native to Bangladesh. Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These abilities enable them to displace native plants and make them a threat to natural areas.

4.2.4. Tree structural composition

DBH class represents the maturity and age of forest stands of a particular area. For Dhaka city, tree DBH ranges from 10 to 121.9 and more. The highest number of species are distributed in three classes which are class of 15.2-30.5 DBH, followed by 10-15.7 DBH class and 30.5-45.7 DBH class.

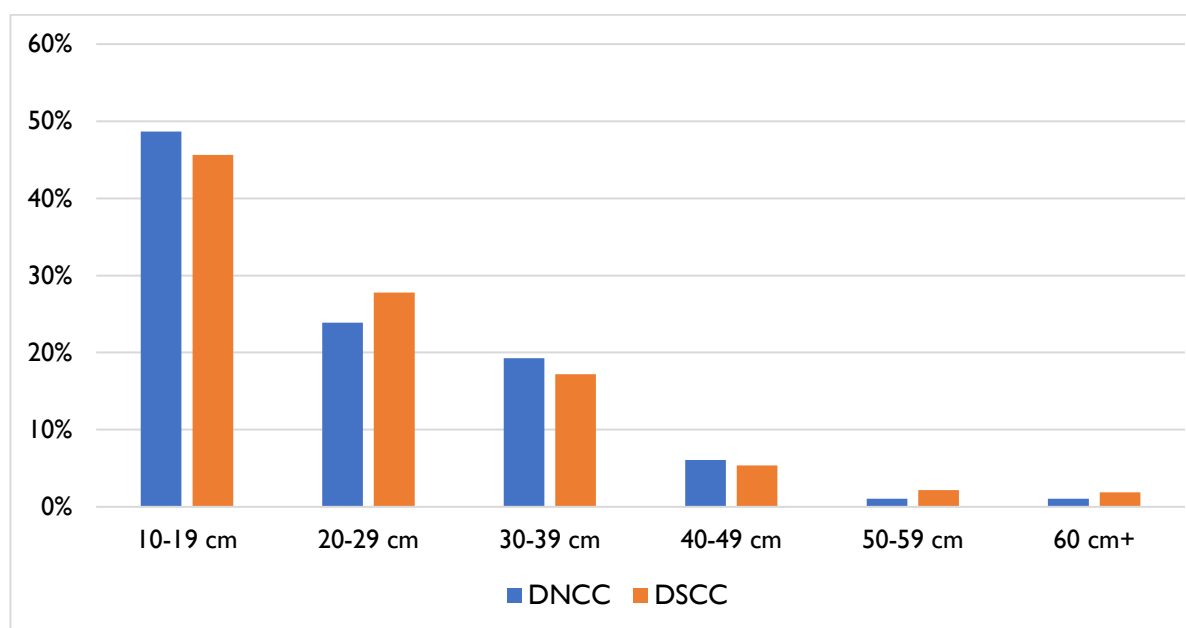


Figure 8: Tree population by diameter (DBH) class at DNCC and DSCC

4.3. Tree density, ground cover and leaf area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. However, total leaf area for both city corporations is greatest in Tree Zone followed by Built up with Scatter Trees Zone and Others Zone.

In DNCC, the most dominant species in terms of leaf area are Mahogani (*Swietenia mahogani*), Mango (*Mangifera indica*), and Mahogani (*S. macrophylla*). On the other hand, most dominant species in terms of leaf area in DSCC are Mango (*M. indica*), Mahogani (*S. mahogani*), and Sada koro (*Albizia procera*). The 10 species with largest Importance Values (IV) are listed in Table 12. Importance values are calculated as the sum of percent population and percent leaf area. High IVs do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure of Dhaka city.

Table 12: Dominant species in DNCC and DSCC

Species Name	DNCC			DSCC		
	Population (%)	Leaf Area (%)	IV	Population (%)	Leaf Area (%)	IV
<i>Swietenia mahogani</i>	16.9	19.8	36.7	9.3	7.7	17
<i>Mangifera indica</i>	17.2	19.4	36.6	33.3	28.1	61.4

<i>Artocarpus heterophyllus</i>	7.4	4.7	12	5.8	5.6	11.4
<i>Swietenia macrophylla</i>	5.1	6.7	11.8	-	-	-
<i>Cocos nucifera</i>	8.2	2.8	10.9	10.2	3.9	14.1
<i>Albizia lebbbeck</i>	2.2	6.6	8.8	1.4	2.8	4.2
<i>Peltophorum pterocarpum</i>	1.5	4.8	6.3	-	-	-
<i>Albizia procera</i>	2	3.9	5.9	1.9	7.1	9
<i>Syzygium cumini</i>	2.6	2.7	5.3	-	-	-
<i>Moringa oleifera</i>	2.5	1.2	3.7	-	-	-
<i>Azadirachta indica</i>	-	-	-	2.4	2.3	4.7
<i>Eucalyptus camaldulensis</i>	-	-	-	1.4	3.6	5
<i>Albizia niopoides</i>	-	-	-	1.3	2.6	3.9
<i>Albizia saman</i>	-	-	-	0.5	3.9	4.4

In both city corporations, the ground (including those beneath the trees) is mostly covered by concrete, buildings, water, bare soil, different sorts of impervious layers, duff/mulch, unmaintained grass, and herbaceous covers such as herbs, and grass. The buildings in DNCC cover the highest proportion of the total area 24.4% followed by Water bodies (23.9%). Similar to that of DNCC, in DSCC, Building (37.5%) occupies the highest proportion while Cement/Concrete/Dhalai (15.6 percent), details are in Figure 9 and Figure 10.

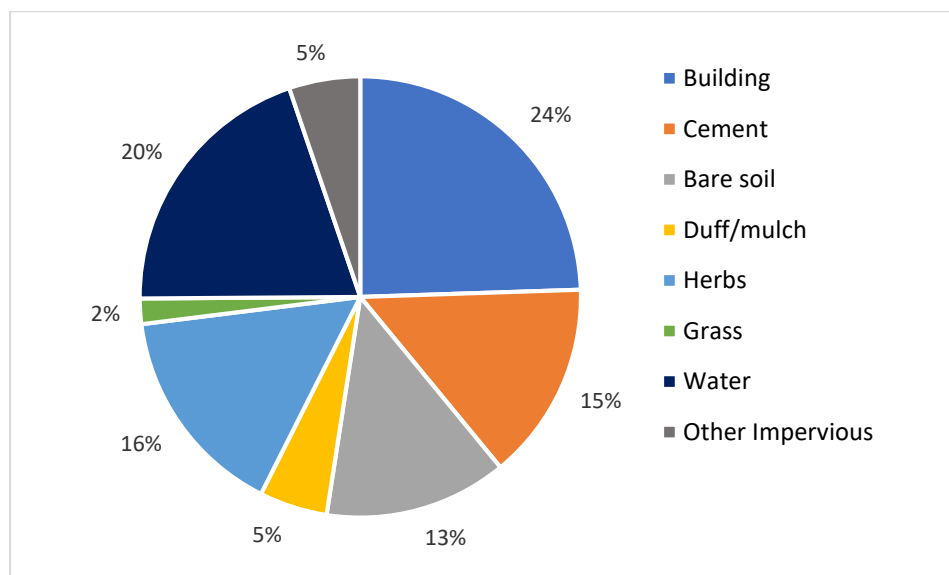


Figure 9: Percent of land by ground cover classes in DNCC

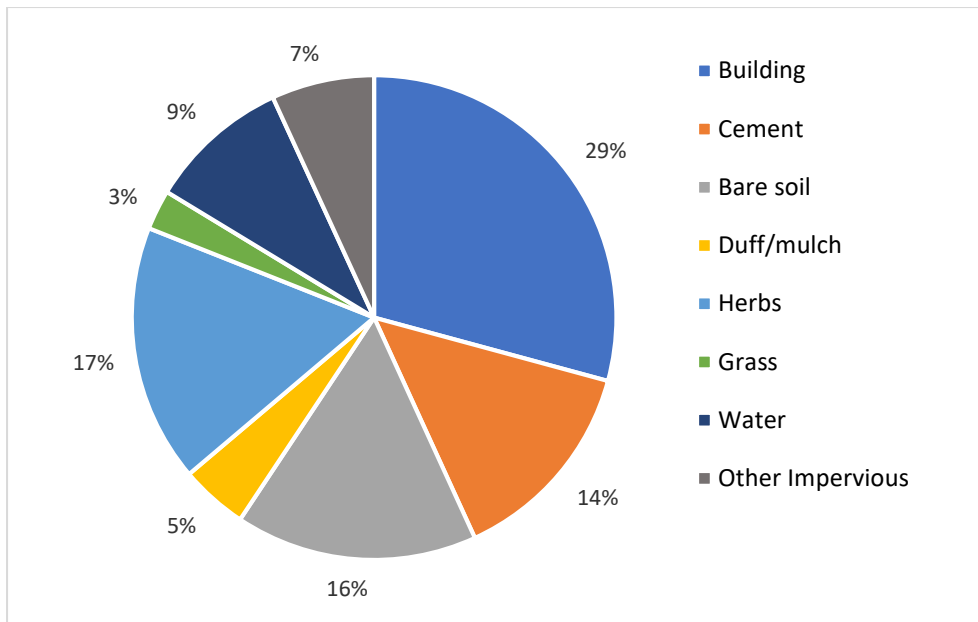


Figure 10: Percent of land by ground cover classes in DSCC

As expected, tree density is highest in Tree zone followed by Others and Scatter zones. In DNCC, the tree density is almost six times higher in Tree zone than that's of whole city corporation area. On the other side, in DSCC the tree density is close to 4 times in Tree zone compared to the tree density of the whole city corporation. The basal area and tree cover are also higher in tree zone. Details of tree density per ha and basal area per ha is shown in Table 13 and graphically presented in Figure 11 and Figure 12.

Table 13: Tree density and basal area as per zones

SI	Zone	Tree density in stem/ha (Mean $\pm$ SE)		Basal area in m ² /ha (Mean $\pm$ SE)	
		DNCC	DSCC	DNCC	DSCC
1	Tree	235 $\pm$ 32.70	254.95 $\pm$ 27.15	13.32 $\pm$ 1.82	17.70 $\pm$ 2.68
2	Scatter	16 $\pm$ 2.63	111.95 $\pm$ 19.19	0.73 $\pm$ 0.14	4.83 $\pm$ 0.90
3	Others	22 $\pm$ 4.71	22.62 $\pm$ 3.53	1.14 $\pm$ 0.29	1.33 $\pm$ 0.23
All Zones		37 $\pm$ 4.49	64.34 $\pm$ 6.51	1.97 $\pm$ 0.25	3.88 $\pm$ 0.48

In DNCC, the "Forest" land use has the highest tree density and basal area followed by Park, institutional premise and cemetery. In case of DSCC, there is no Forest land use but Parks revealed with highest tree density and basal area. However, there are also some scattered trees in other land uses including Agriculture, residential areas, transportation, etc.

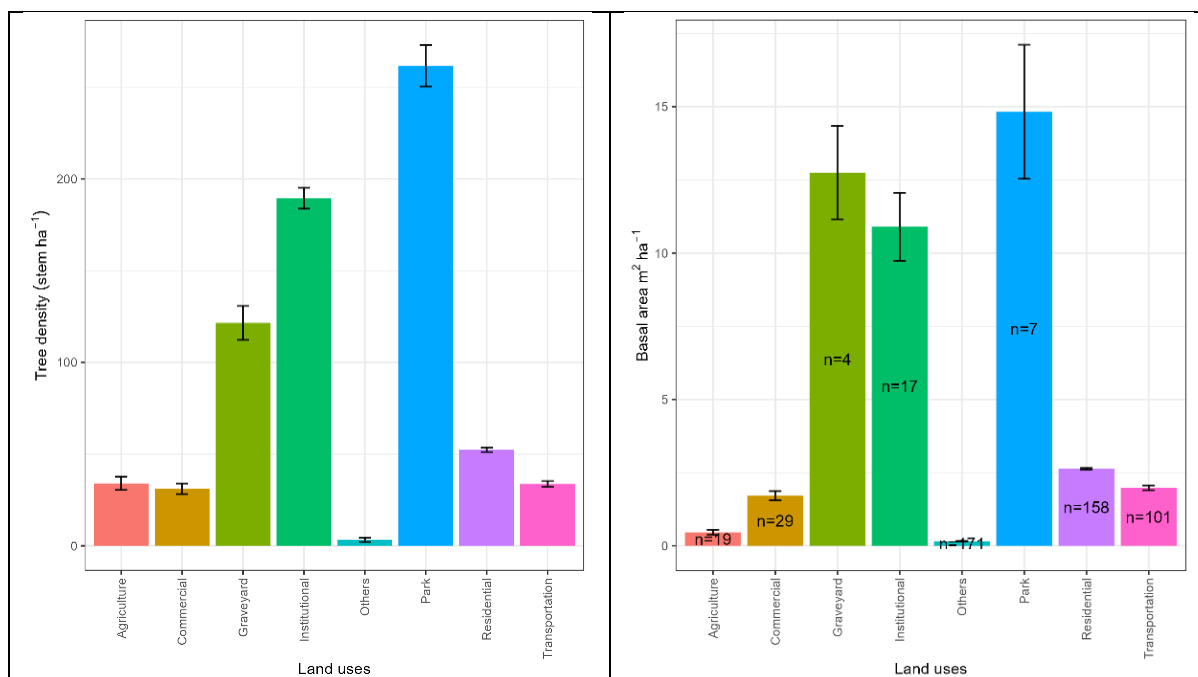


Figure 11: Tree density and basal area per identified land use of DNCC

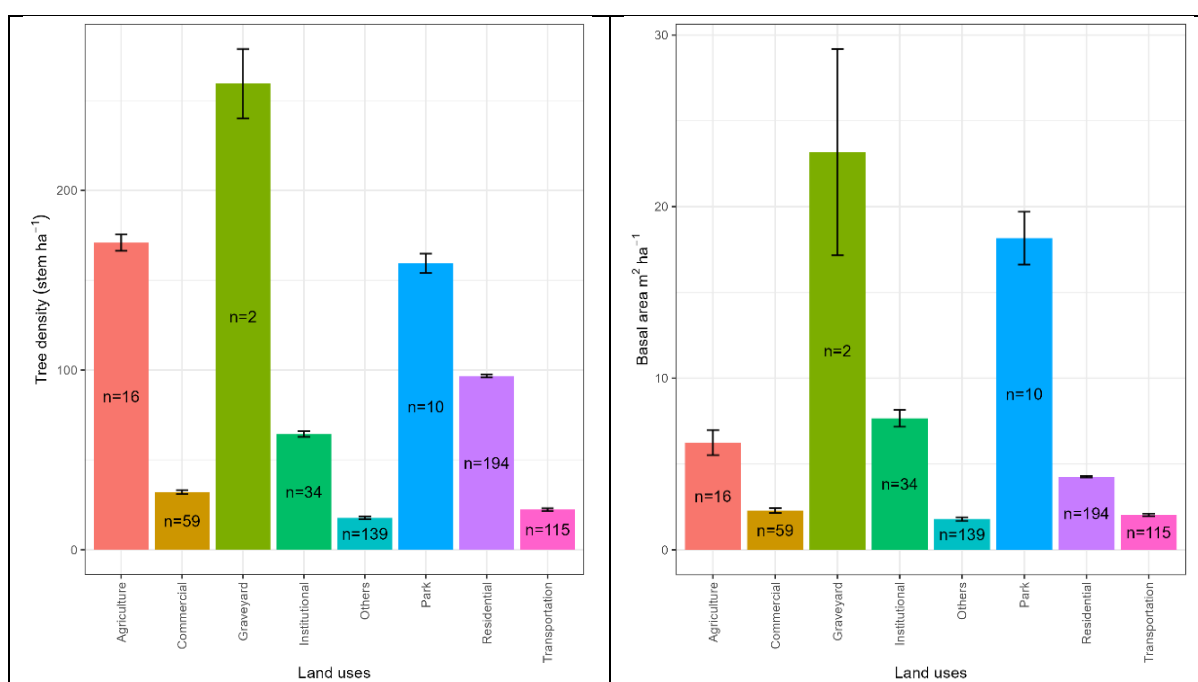


Figure 12: Tree density and basal area per identified land use of DSCC

4.3.1. Phytosociological attributes

The phytosociological attributes of the species in individual zones and all together indicated that Mango (*Mangifera indica*) is the dominant species in both DNCC and DSCC. The relative density, relative frequency and IVI of this species was highest in all the strata and whole Dhaka (Figure 13, Figure 14, Figure 15, and Figure 16). In terms of dominance, Mango is followed by Mahogani (*Swietenia mahogani*) and Jackfruit (*Artocarpus heterophyllus*). Coconut (*Cocos nucifera*) having higher IVI value comparable to Mango and Mahogani is another codominant species in Dhaka city.

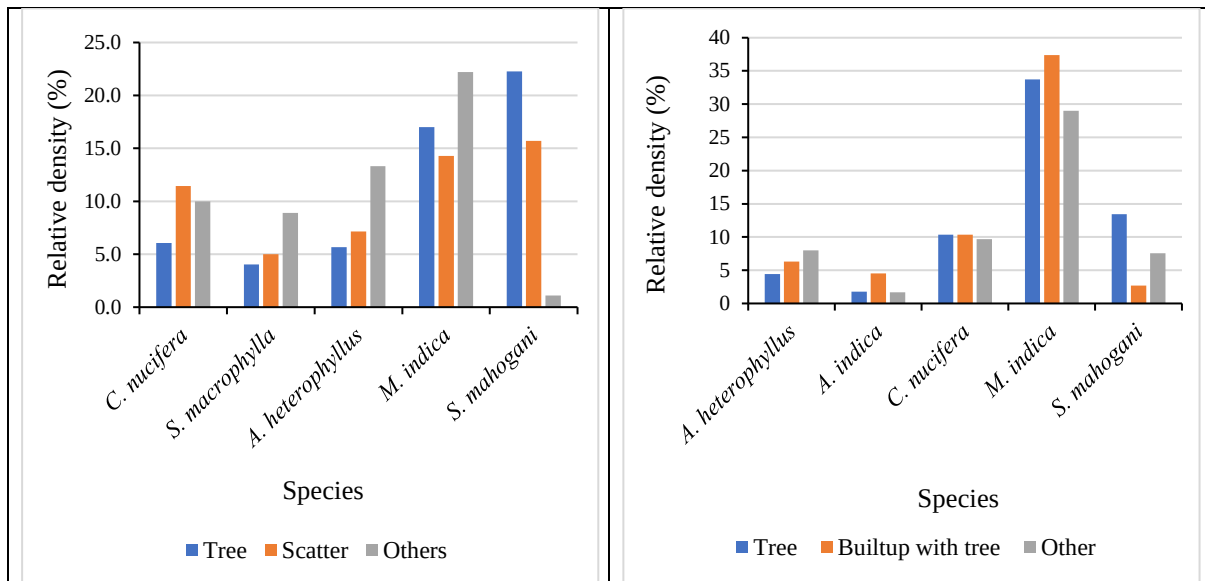


Figure 13: Relative density of DNCC (left) and DSCC (right)

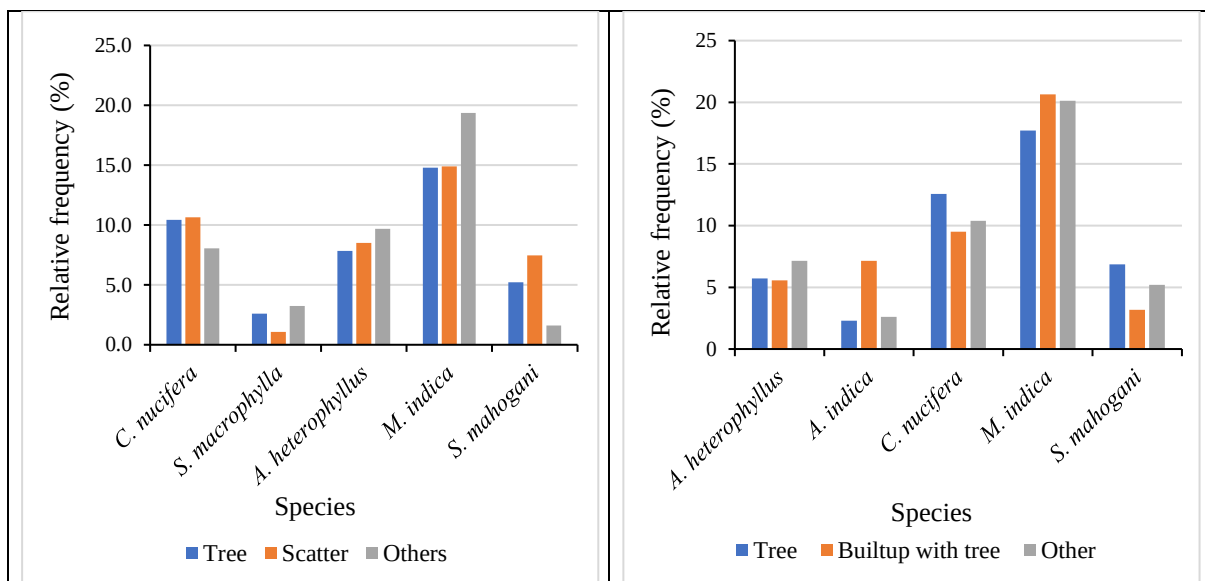


Figure 14: Relative frequency of DNCC (left) and DSCC (right)

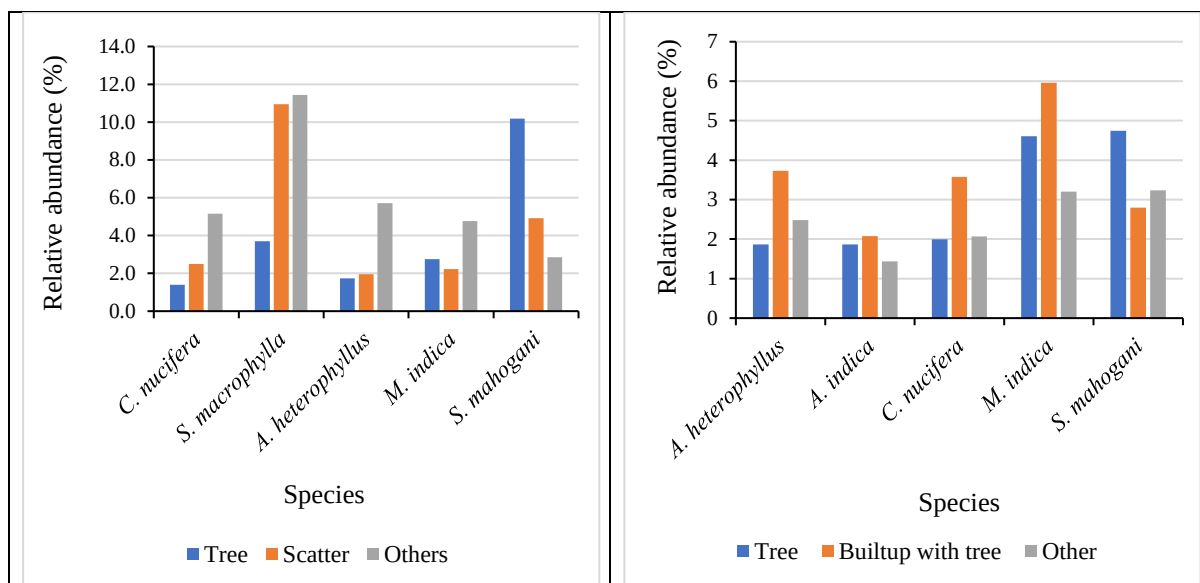


Figure 15: Relative abundance of DNCC (left) and DSCC (right)

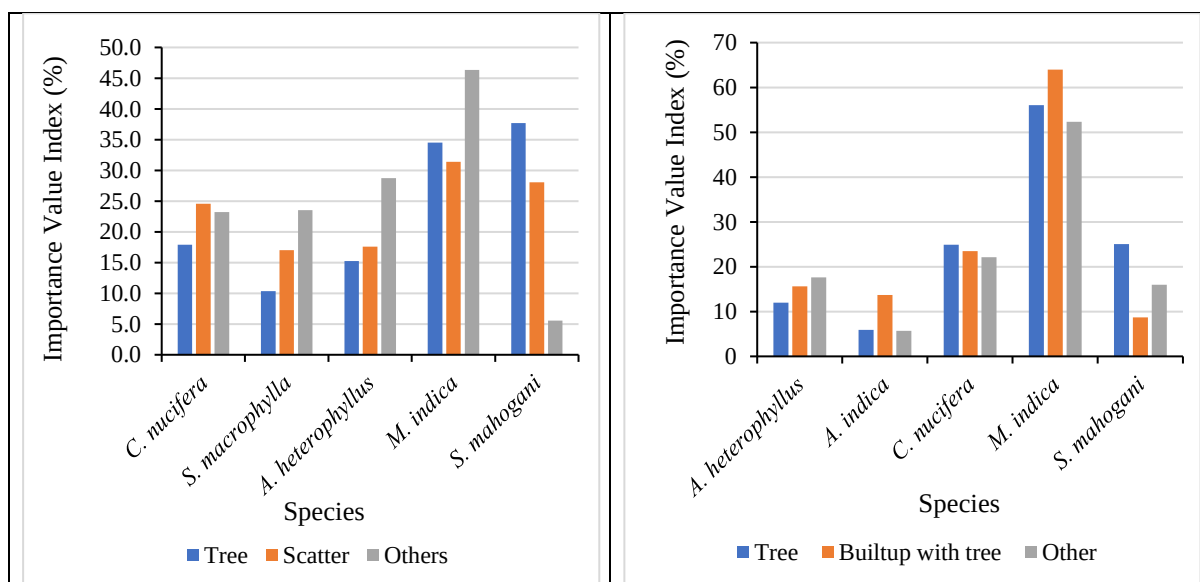


Figure 16: Importance Value Index of DNCC (left) and DSCC (right)

4.3.2. Diversity indices of the tree species per zone of Dhaka city

The four common diversity indices indicate a moderate to good plant diversity in Dhaka city. The Shannon-Wiener Diversity Index is highest in Scatter zone in DNCC, whereas in DSCC, it is highest in Tree zone (

Table 14). The findings suggest that species richness is greater in the Scatter zone of DNCC, whereas the Tree zone of DSCC exhibits the highest species richness. The Pielou's species evenness index is higher for Others zone (0.84) in DNCC and Tree zone (0.89) in DSCC. It is due to the record of a single individual, a minimum equal number, of several tree species from Others zone. Overall, the diversity indices indicated presence of diverse tree species in DNCC.

Table 14: Diversity indices of the tree species per zone of Dhaka city

Sl	Zone	Shannon-Wiener DI		Margalef's species richness index		Simpson's Dominance Index		Pielou's Evenness Index	
		DNCC	DSCC	DNCC	DSCC	DNCC	DSCC	DNCC	DSCC
1	Tree	2.96	3.01	7.99	9.32	0.91	0.89	0.78	0.89
2	Scatter	3.15	2.64	8.9	7.03	0.93	0.84	0.83	0.84
3	Others	2.78	2.76	5.78	8.66	0.91	0.85	0.84	0.85
All zones		3.27	2.99	11.99	12.17	0.92	0.86	0.76	0.67

4.4. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas across the world, posing threats to human health, causing harm to landscape materials and ecosystem processes, and reducing visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation³¹.

The study estimated the pollution removal by trees and shrubs in Dhaka city. It used the field data and recent pollution and weather data from relevant state organization. It is estimated that the current state trees and shrubs can remove 319.3 metric tons of all pollutants annually in DNCC and 219.2 metric tons in DSCC (Figure 17 and Figure 18). Removed air pollutants are ozone (O₃), carbon monoxide (CO), nitrogen dioxide (NO₂), particulate matter less than 2.5 microns (PM_{2.5}), particulate matter less than 10 microns and greater than 2.5 microns (PM₁₀)³², and sulfur dioxide (SO₂). Among the different categories of pollutants, removal of PM10 was greatest in both city corporation. The economic value of the pollutant removal is estimated as Tk 262 million in DNCC and Tk 175 million in DSCC.

³¹ Nowak, D. J., & Dwyer, J. F. (2007). Understanding the benefits and costs of urban forest ecosystems. In *Urban and community forestry in the northeast* (pp. 25-46). Dordrecht: Springer Netherlands.

³² Trees remove PM_{2.5} and PM₁₀* when particulate matter is deposited on leaf surfaces. This deposited PM_{2.5} and PM₁₀* can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors.

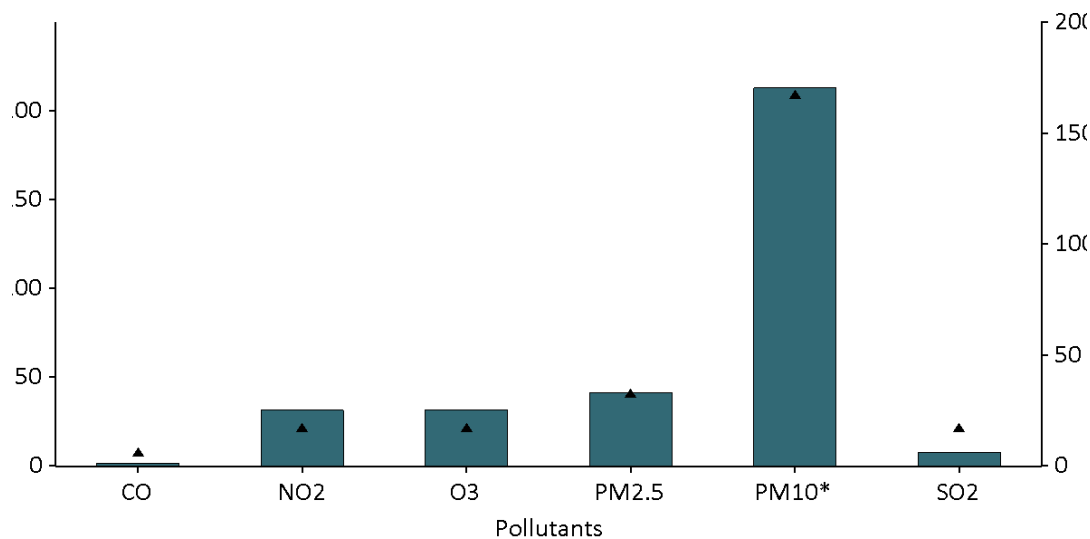


Figure 17: Annual pollution removal (points) and value (bars) by urban trees and shrubs at DNCC

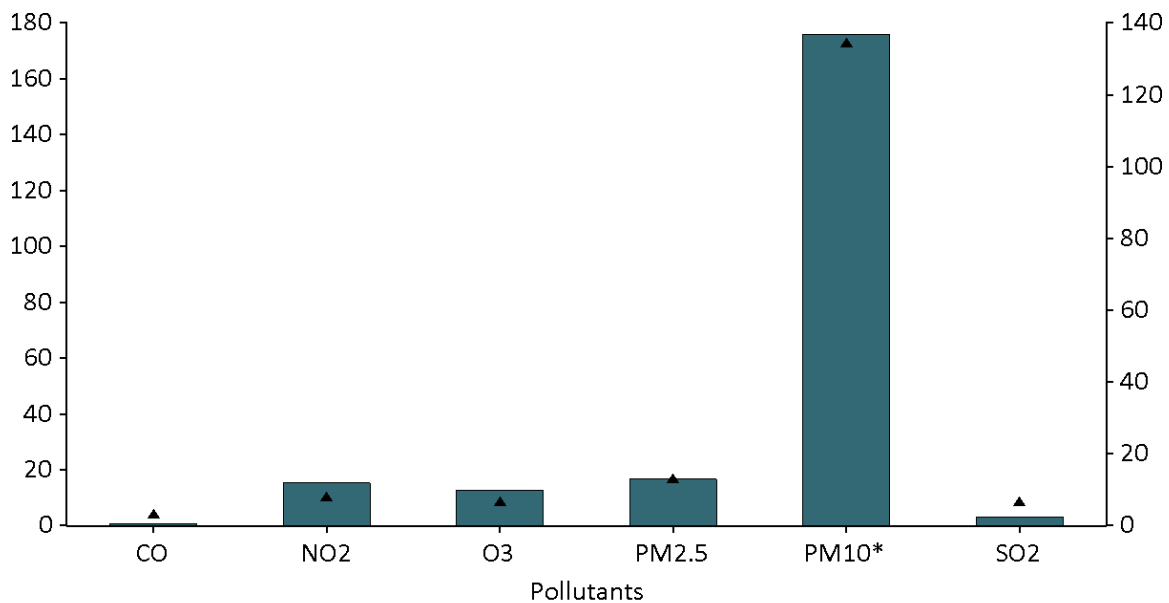


Figure 18: Annual pollution removal (points) and value (bars) by urban trees and shrubs at DSCC

In 2022, trees in DNCC emitted an estimated 170.4 metric tons of volatile organic compounds (VOCs) (109 metric tons of isoprene and 61.34 metric tons of monoterpenes). Emissions vary among species based on species characteristics and amount of leaf biomass. Thirty percent of the urban forest's VOC emissions were from *Mangifera indica* and *Eucalyptus globulus*. Similarly, trees in DSCC emitted an estimated 127.9 metric tons of volatile organic compounds (VOCs) (58.36 metric tons of isoprene and 69.52 metric tons of monoterpenes). Fifty- five percent of the urban forest's VOC emissions were from *Mangifera indica* and *Eucalyptus camaldulensis*. These VOCs are precursor chemicals to ozone formation³³.

³³ Some economic studies have estimated VOC emission costs. These costs are not included here as there is a tendency to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in relation to ozone. This combining of dollar values to determine tree effects

4.5. Biomass and Carbon Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power sources. Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. Trees in DNCC are estimated to store 98,700 metric tons of carbon (Tk168 million). Of the species sampled, *Swietenia mahogany* stores and sequesters the most carbon (approximately 21.4% of the total carbon stored and 19.6% of all sequestered carbon). On the other hand, trees in DSCC are estimated to store 103,000 metric tons of carbon (Tk171 million). Of the species sampled, *Mangifera indica* stores and sequesters the most carbon (approximately 22.2% of the total carbon stored and 20.4% of all sequestered carbon). Research by Jaman et. al⁴. found totals above-ground biomass 106.46, 90.94, 387.01 and 223.27 Mg ha⁻¹, whereas carbon stocks were 53.23, 45.47, 193.50 and 109.53 Mg ha⁻¹, in urban park, playground edge plantation, botanical garden and roadside plantation, respectively. Dhaka's tree biomass, carbon sequestration, carbon stock are detailed below-

4.5.1. Biomass of Dhaka

Highest amount of biomass has been recorded in the forest type land-use both for above ground and below ground in DNCC. On the other hand in DSCC, parks showed the highest concentration of above and below ground biomass. In DNCC above ground biomass below 150tha⁻¹, whereas above ground biomass in DSCC surpluses 150 tha⁻¹. Above ground and below ground biomass is in Figure 19 for DNCC and Figure 20 for DSCC.

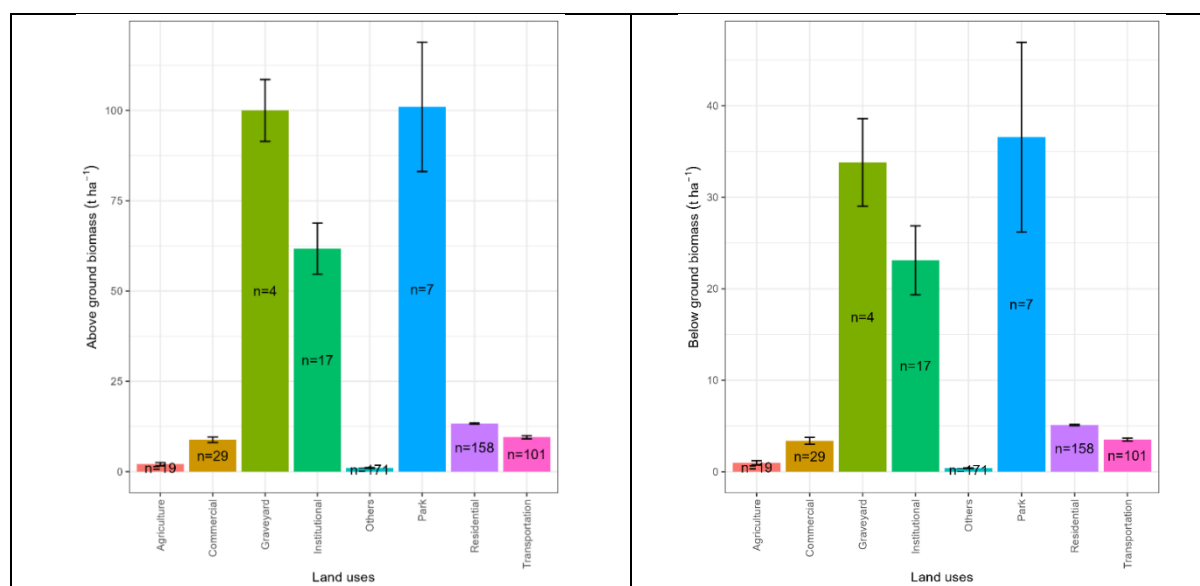


Figure 19: Tree AGB (left) and BGB (right) stock in the land uses identified from DNCC

should not be done, rather estimates of VOC effects on ozone formation (e.g., via photochemical models) should be conducted and directly contrasted with ozone removal by trees (i.e., ozone effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have been shown to significantly reduce ozone concentrations (Cardelino and Chameides 1990; Nowak et al 2000), but are not considered in this analysis. Photochemical modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on ozone concentrations.

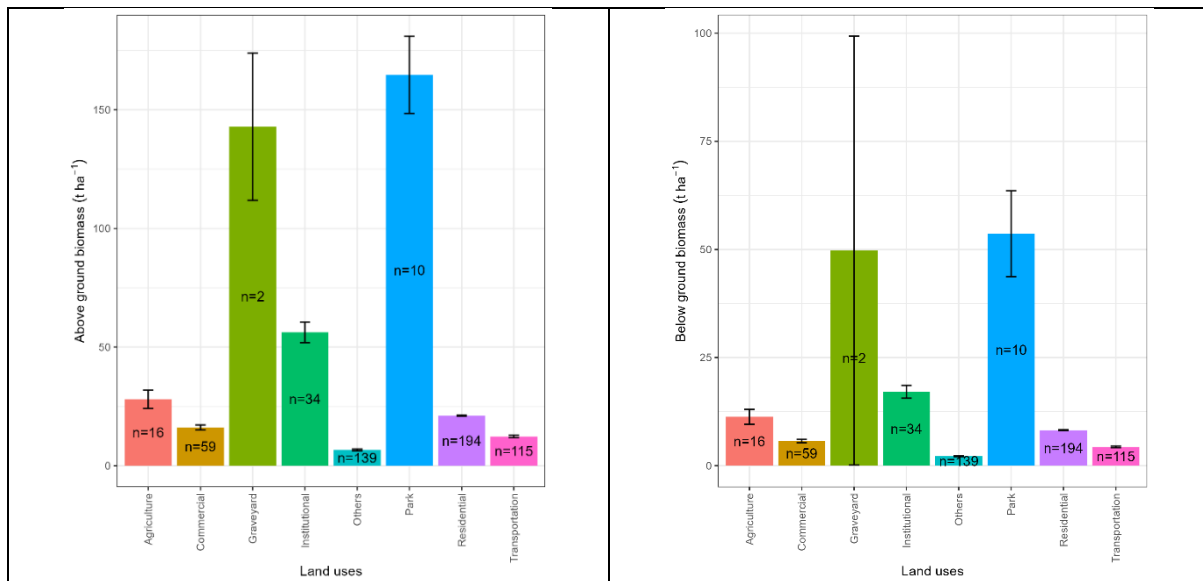


Figure 20: Tree AGB (left) and BGB (right) stock in the land uses identified from DSCC

4.5.2. Carbon Sequestration

The amount of carbon annually sequestered is increased with the size and health of the trees. The gross carbon sequestration by trees in DNCC is about 11.12 thousand metric tons of carbon per year with an associated monetary value of Tk 18.9 million. Net carbon sequestration in the urban forest is about 9.906 thousand metric tons. Similarly, gross sequestration of DSCC trees is about 10.8 thousand metric tons of carbon per year with an associated value of Tk 17.9 million. Net carbon sequestration in the urban forest is about 10.17 thousand metric tons.

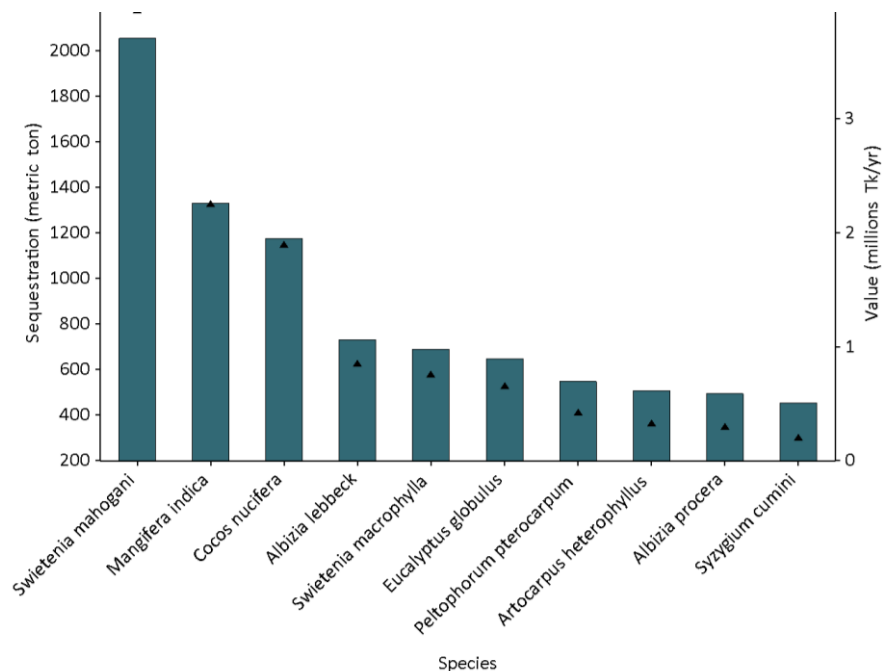


Figure 21: Estimated annual gross carbon sequestration (points) and value (bars) for species with the greatest sequestration in DNCC

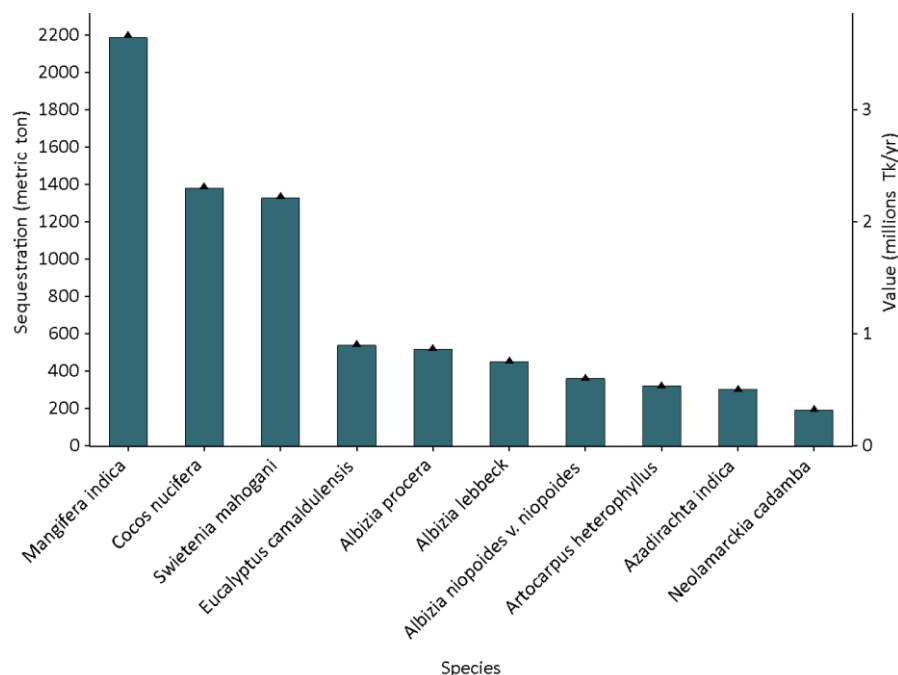


Figure 22: Estimated annual gross carbon sequestration (points) and value (bars) for species with the greatest sequestration in DSCC

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emission.

4.5.3. Tree carbon stock

The estimates of tree carbon in AGB, BGB along with the total tree carbon per zone are provided in Table 15 & Figure 23 for DNCC while

Table 16 & Figure 24 depicts the same estimates for DSCC. The findings of the study reveal that Carbon in AGB (CAGB) is relatively higher in the Tree zones of DSCC (55.13 t/ha) compared to DNCC (40.08 t/ha). However, the overall CAGB across DSCC (11.18 t/ha) surpasses that of DNCC (5.43 t/ha). Nevertheless, the total tree carbon density, encompassing both AGB and BGB, is comparable between DNCC (7.46 t/ha) and DSCC (15.15 t/ha).

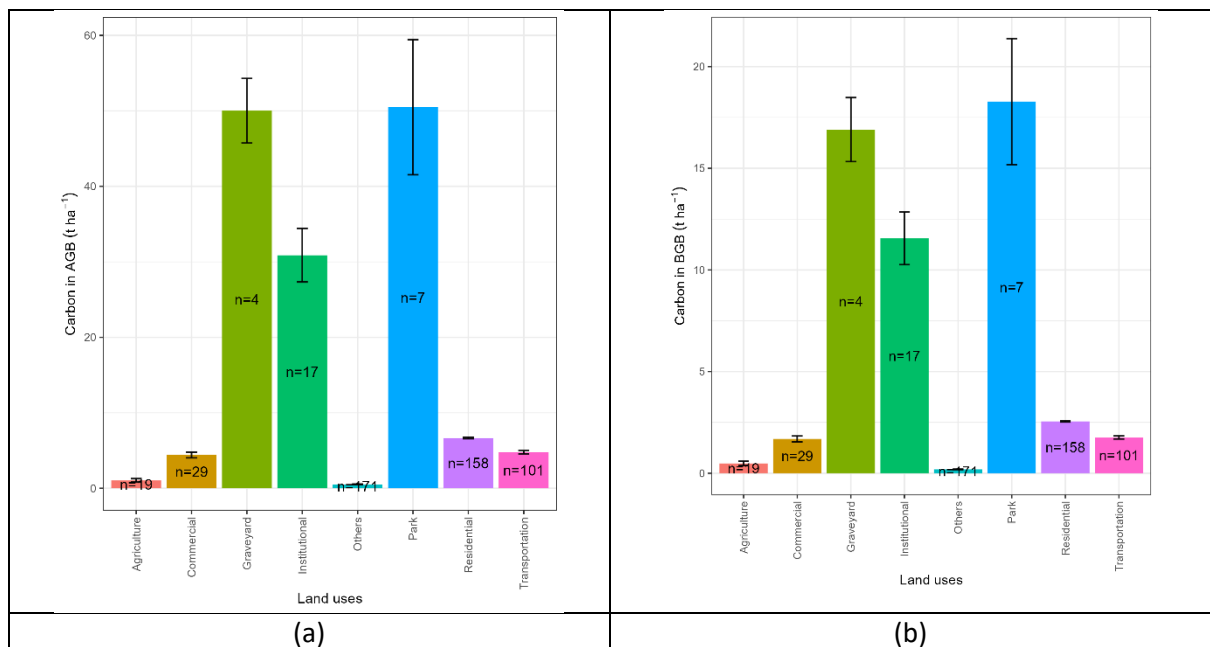
Table 15: DNCC tree carbon in AGB, BGB and total tree carbon per zone

SN	Zone	CAGB (t/ha)*		CBGB (t/ha)		Total tree carbon (t/ha)	
		Mean	SE (±)	Mean	SE (±)	Mean	SE (±)
1	Tree	40.08	6.45	14.80	2.28	54.88	8.73
2	Scatter	1.63	0.32	0.64	0.12	2.27	0.44
3	Others	2.89	0.84	1.09	0.30	3.98	1.14
4	All zones	5.43	0.79	2.03	0.29	7.46	1.08

*Here, CAGB = Carbon in AGB, CBGB = Carbon in BGB

Table 16: DSCC tree carbon in AGB, BGB and total tree carbon per zone

SN	Zone	CAGB (t/ha)		CBGB (t/ha)		Total tree carbon (t/ha)	
		Mean	SE ($\pm$)	Mean	SE ($\pm$)	Mean	SE ($\pm$)
1	Tree	55.13	8.47	18.89	2.52	74.02	10.96
2	Built-up with tree	12.18	2.96	4.60	1.00	16.78	3.95
3	Others	3.43	0.68	1.27	0.24	4.70	0.92
4	All zones	11.18	1.52	3.96	0.49	15.15	2.01



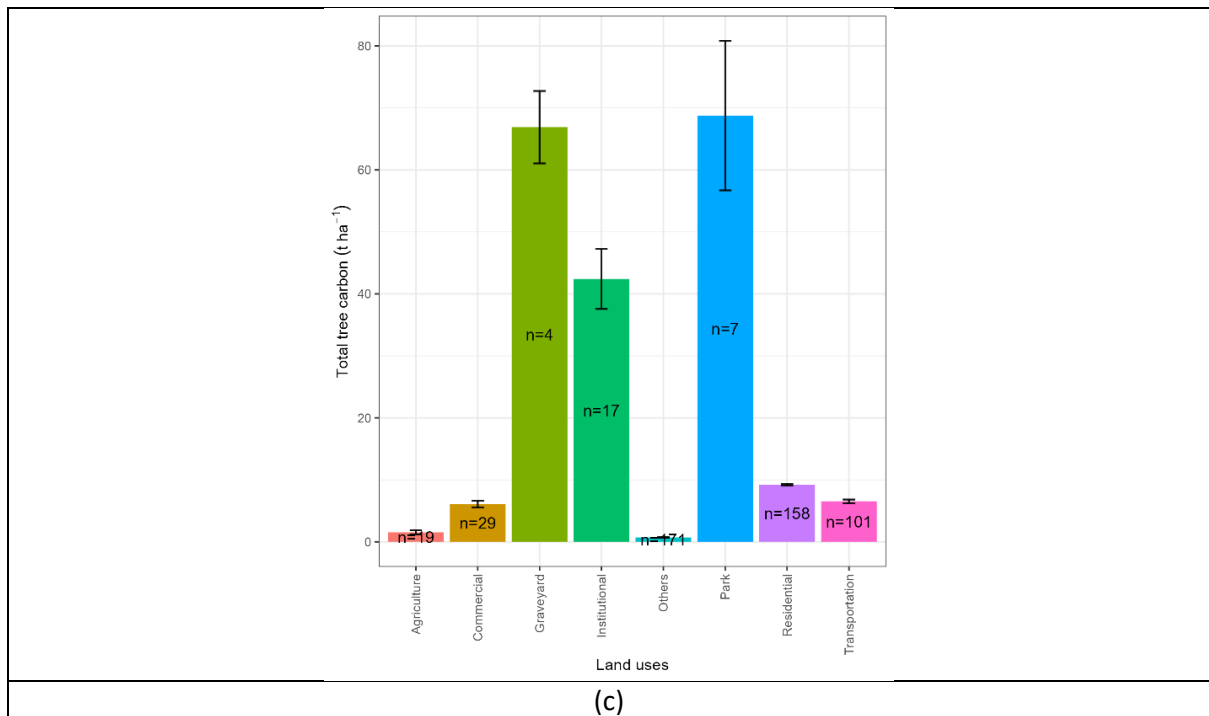
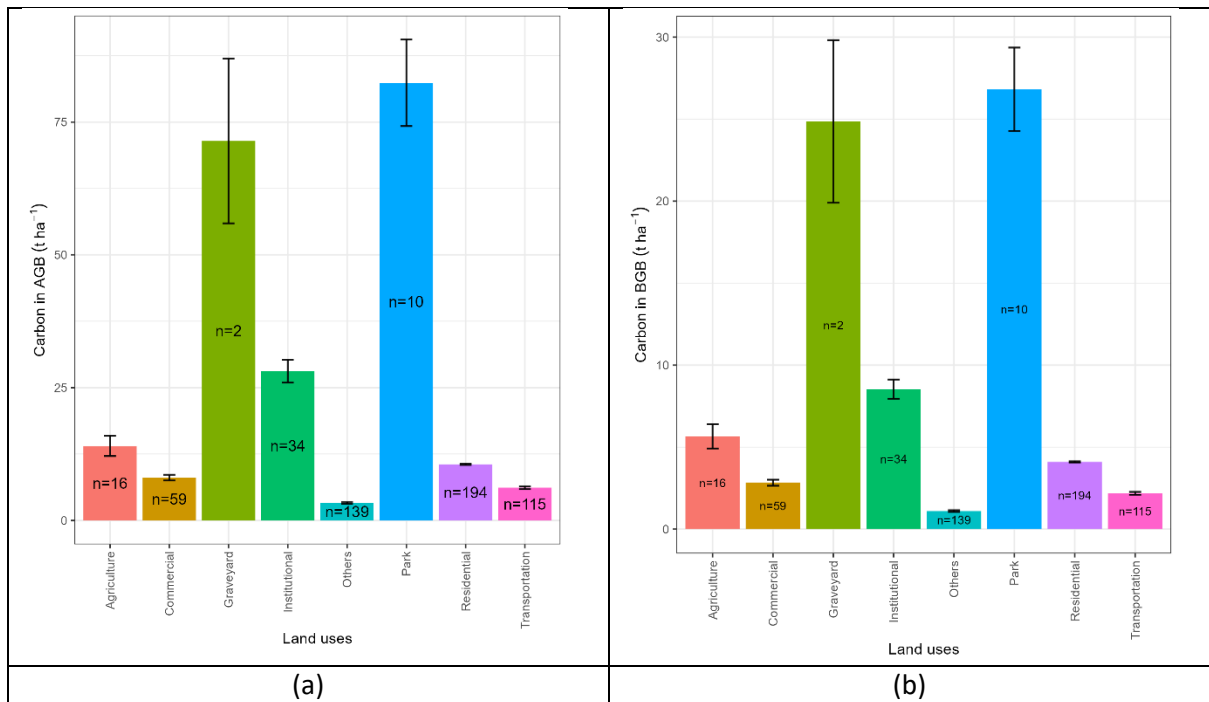


Figure 23: Tree carbon stock in the land uses of DNCC- a) carbon in AGB, b) carbon in BGB, and c) total tree carbon



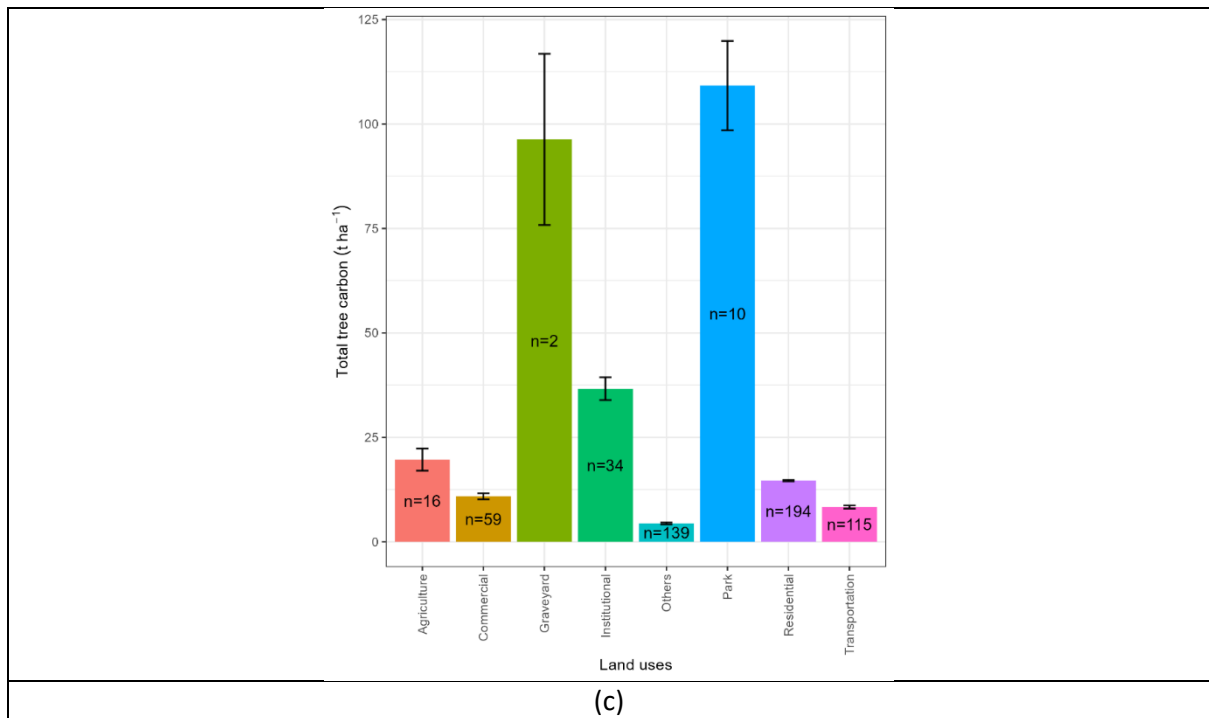


Figure 24: Tree carbon stock in the land uses of DSCC- a) carbon in AGB, b) carbon in BGB, and c) total tree carbon

4.6. Growing stock of Dhaka city

The growing stock is estimated for the trees having DBH ≥ 10 cm, aligning with the FAO's definition for Global Forest Resources Assessment 2020. It is crucial to note that the volume of bamboo is excluded due to its distinct growth form. Table 17 offers a summary of the growing stock categorized by zones. As anticipated, the Tree zones exhibit the highest growing stock, with DNCC recording 139.21 ± 22.78 m³/ha) and DSCC registering 197.24 ± 32.04 m³/ha.

Table 17: Summary of growing stock

Sl	Zones	Mean $\pm$ SE (m ³ /ha)		Total growing stock (m ³ /ha)	
		DNCC	DSCC	DNCC	DSCC
1	Tree	139.21 ± 22.78	197.24 ± 32.04	227743	236890
2	Scatter	5.70 ± 1.17	43.72 ± 11.88	65184	57017
3	Others	10.32 ± 3.14	12.11 ± 2.38	53754	84448
4	All zone	18.95 ± 2.80	39.91 ± 5.64	346686	378354

4.6.1. Growing stock by land use

The growing stock in different land uses of DNCC indicated that, likewise basal area, it is highest in Forests (around 240 m³/ha) followed by Park and Cemetery nearly 279 m³/ha (Figure 25). Besides these, institutional premises showed a substantial stock of 98 m³/ha. The growing stock in all other land uses is less than 25 m³/ha with the minimum in vacant areas (0.67 m³/ha). On the other hand, highest growing stock is in parks, followed by institutional, and others in DSCC (Figure 26).

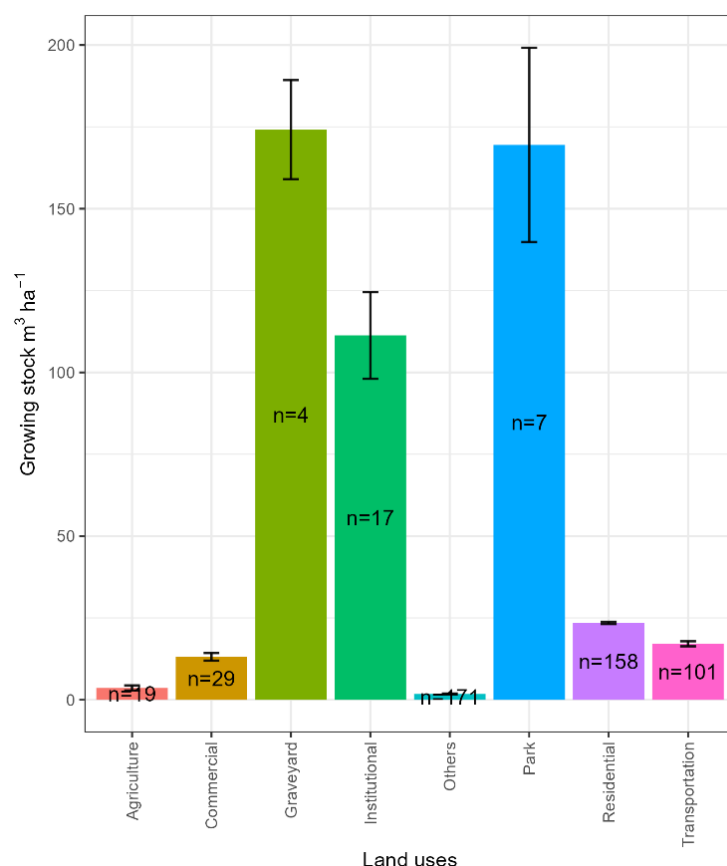


Figure 25: Growing stock by land use of DNCC

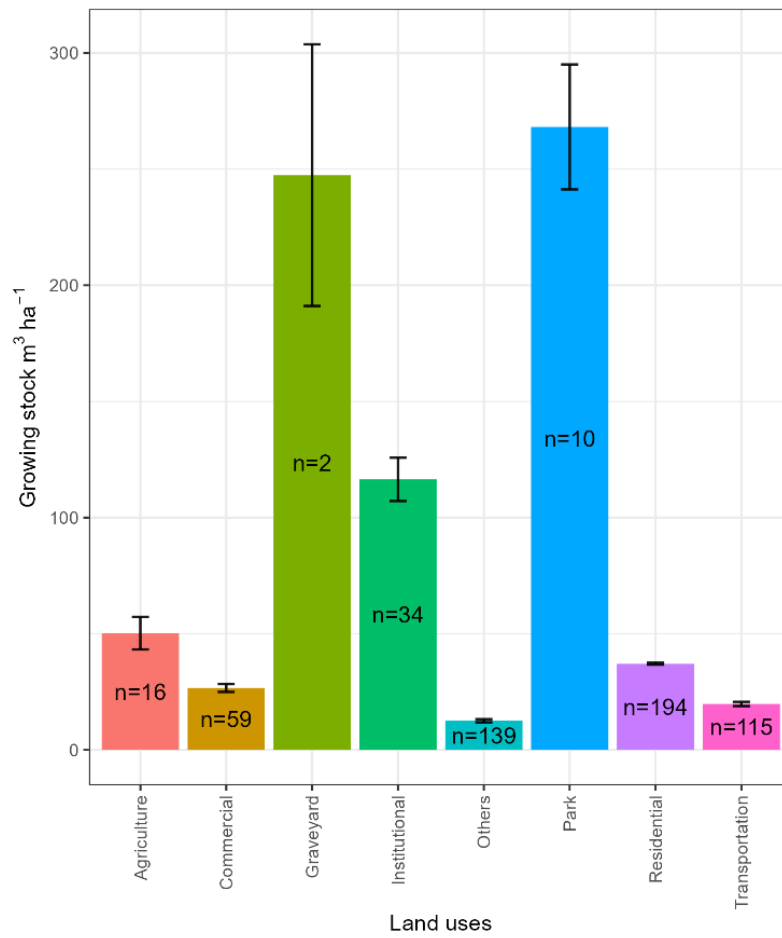


Figure 26: Growing stock per land use identified from DSCC

4.6. Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass. Trees in DNCC are estimated to produce 26.42 thousand metric tons of oxygen per year. List of top 20 oxygen production species of Dhaka city is provided in Table 18.

Table 18: Top 20 oxygen production species of Dhaka city

DNCC		DSCC	
Species	Oxygen (kg/yr)	Species	Oxygen (kg/yr)
<i>Swietenia mahogani</i>	3902.3	<i>Mangifera indica</i>	8685.4
<i>Mangifera indica</i>	2485.8	<i>Cocos nucifera</i>	5494.3
<i>Cocos nucifera</i>	2171.4	<i>Swietenia mahogani</i>	5260
<i>Eucalyptus globulus</i>	1345	<i>Eucalyptus camaldulensis</i>	2139.9
<i>Swietenia macrophylla</i>	1262.1	<i>Albizia procera</i>	2060.7
<i>Albizia lebbeck</i>	1090.8	<i>Albizia lebbeck</i>	1798.7
<i>Peltophorum pterocarpum</i>	781.3	<i>Albizia niopoides</i>	1429.8
<i>Artocarpus heterophyllus</i>	680.2	<i>Artocarpus heterophyllus</i>	1277.8
<i>Albizia procera</i>	591.6	<i>Azadirachta indica</i>	1205.7
<i>Syzygium cumini</i>	551.4	<i>Neolamarckia cadamba</i>	763.1
<i>Derris robusta</i>	505.5	<i>Roystonea regia</i>	690.7
<i>Eucalyptus camaldulensis</i>	360.6	<i>Ficus benghalensis</i>	612.8
<i>Areca catechu</i>	336.5	<i>Swietenia macrophylla</i>	581.8
<i>Albizia niopoides</i> v. <i>niopoides</i>	331.2	<i>Pongamia</i>	578.7
<i>Delonix regia</i>	329.6	<i>Syzygium cumini</i>	563.1
<i>Azadirachta indica</i>	291.9	<i>Areca catechu</i>	540.7
<i>Ficus benghalensis</i>	252.8	<i>Albizia saman</i>	503
<i>Albizia saman</i>	213.4	<i>Tamarindus indica</i>	480.2
<i>Psidium guajava</i>	205.3	<i>Artocarpus</i>	469.7
<i>Moringa oleifera</i>	191.3	<i>Livistona chinensis</i>	455.4

4.7. Avoided Runoff

Surface runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff²⁴. In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees and shrubs of DNCC help to reduce runoff by an estimated 604,000 cubic meters a year with an associated value of Tk150 million. On the other hand, trees and shrubs of DSCC help to reduce runoff by an estimated 378,000 cubic meters a year with an associated value of Tk94 million. Avoided runoff is estimated based on local weather from the user-designated weather station. Total annual precipitation in 2018 was 180.9cm and 173.7cm in DNCC and DSCC respectively.

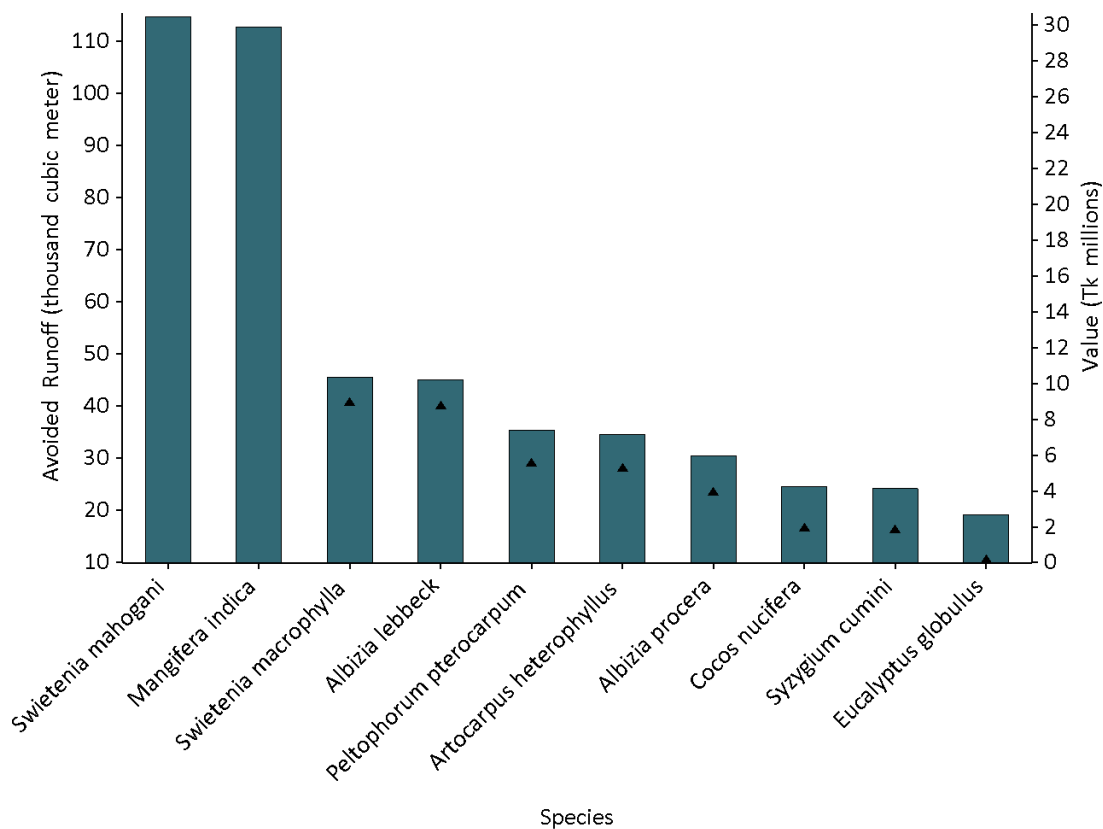


Figure 27: Avoided runoff (points) and values (bars) for species with greatest overall impact on runoff at DNCC

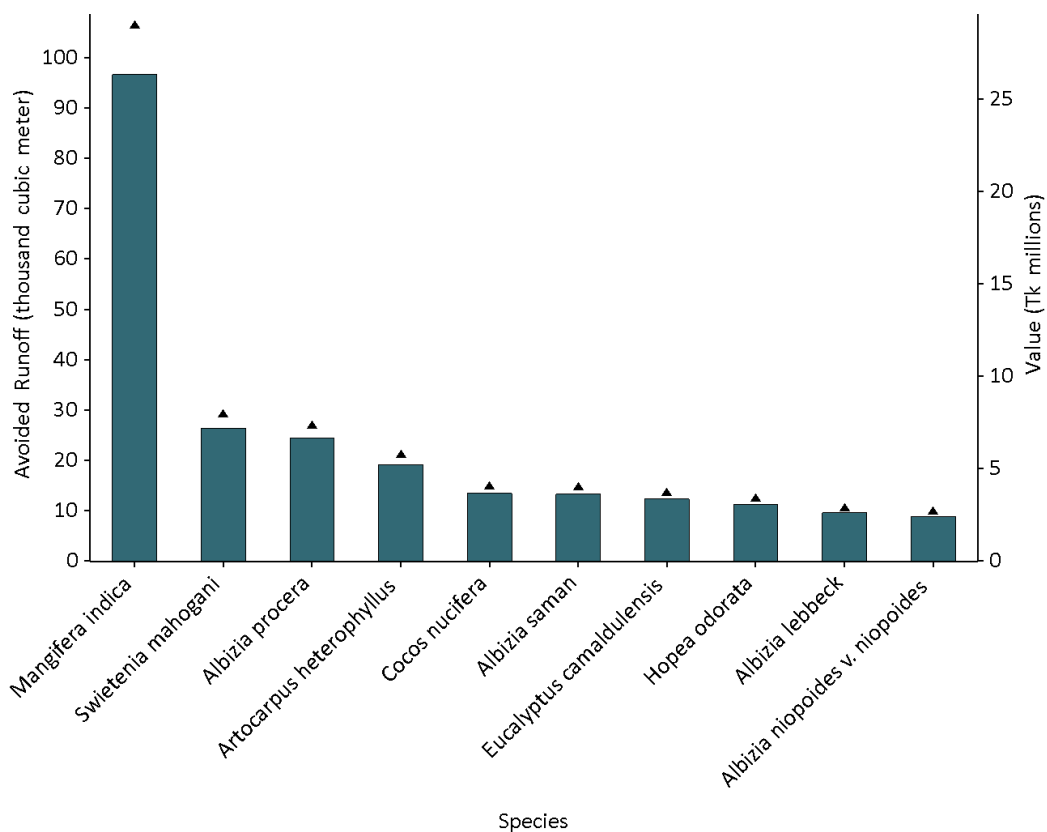


Figure 28: Avoided runoff (points) and values (bars) for species with greatest overall impact on runoff at DSCC

4.8. Comparisons with other urban tree inventory studies

Unlike Dhaka, similar studies using plot based tree inventory estimates have been conducted in North American cities as summarized in Table 19, adopted from Yale 2020³⁴. It appears that most of the cities including Washington DC of USA and Toronto of Canada have much higher (even higher than the WHO recommended proportion) tree cover than that's of Dhaka. However, there are cities having, for example, Los Angeles, having tree cover comparable to Dhaka.

Table 19: Trees in different cities

City	% Tree Cover	Number of Trees	Carbon Storage (metric tons)	Carbon Sequestration (metric tons/yr)	Pollution Removal (metric tons/yr)
Toronto, Canada	26.6	10,220,000	1,108,000	46,700	1,905
Atlanta, USA	36.7	9,415,000	1,220,000	42,100	1,509
Los Angeles, USA	11.1	5,993,000	1,151,000	69,800	1,792
New York, USA	20.9	5,212,000	1,225,000	38,400	1,521
Chicago, USA	17.2	3,585,000	649,000	22,800	806
Washington DC, USA	28.6	1,928,000	477,000	14,700	379

Table 20 shows the tree density, carbon stock, carbon sequestration and pollution removal rate in different cities across North America; adopted from Yale 2020³⁴. This table also shows the yearly pollution removal.

Table 20: Totals of per acre of land area in different cities

City	Number of Trees/ha	Carbon Storage (metric tons/ha)	Carbon Sequestration (metric tons/ha/yr)	Pollution Removal (kg/ha/yr)
Toronto, Canada	160.4	17.4	0.73	29.9
Atlanta, USA	275.8	35.7	1.23	44.2
Los Angeles, USA	48.4	9.4	0.36	14.7
New York, USA	65.2	15.3	0.48	19.0
London, Canada	185.5	15.3	0.53	15.7
Chicago, USA	59.9	10.9	0.38	13.5
Washington, USA	121.1	29.8	0.92	23.8

Tree cover estimates based on plot information from this study, which are 10 to 11% for all of Dhaka city, are well below estimates from other studies using different methods. For example, Endreny, Sica, and Nowak (2020)³⁵, using two methods, one with photo interpretation of randomly sample imagery points, and another with moderate resolution satellite imagery, estimated 23% and 18%, respectively,

³⁴ <https://facilities.yale.edu/sites/default/files/tree-management-plan-ecosystem-services-plan.pdf>

³⁵ Endreny, Theodore, Francesco Sica, and David Nowak. "Tree cover is unevenly distributed across cities globally, with lowest levels near highway pollution sources." *Frontiers in Sustainable Cities* 2 (2020): 16.

tree cover for Dhaka city. This study's estimates are also nearly half of the average tree cover of major cities from the same study (20 and 18%, respectively from each method). In a separate study, Nowak and Greenfield (2020)³⁶ used similar remote sensing methods to determine a global average of 26.5% of all urban areas, and 24.2% for Asian urban areas.

Taken together, these comparisons reveal the importance of urban tree inventory data in estimating tree cover, and that Dhaka city is lacking in adequate city dweller access to green spaces and tree benefits than other cities in Asia and worldwide.

³⁶ Nowak, David J., and Eric J. Greenfield. "The increase of impervious cover and decrease of tree cover within urban areas globally (2012–2017)." *Urban Forestry & Urban Greening* 49 (2020): 126638.

Chapter 5

Conclusion

5. Conclusion

The tree cover in Dhaka plays a pivotal role in providing a multitude of environmental and economic benefits, encompassing pollution removal, carbon storage and sequestration, oxygen production, and runoff management. These values underscore the crucial role of trees in fostering a sustainable and ecologically balanced urban environment while contributing significantly to the urban community's wellbeing. Bangladesh Forest Department and US Forest Service, through USAID's Compass program, collaboratively conducted Dhaka city's urban tree inventory, aiming to bridge the information void of urban tree information.

The result of the inventory reveals a moderate tree cover of 10.5% in DNCC and 10.8% in DSCC, falling well below the recommended minimum of 20% for a megacity in terms of total area. It is also much lower than global tree cover estimates, suggesting that Dhaka as a whole lags in providing adequate green space for its population. The net worth of the selected trees is estimated at 457.7 million BDT/year for DNCC and 602.9 million BDT/year for DSCC, totaling is 1060.6 million BDT/year for Dhaka city. Despite the monetary value, the current tree population proves insufficient to sustain a healthy urban environment for the city's inhabitants while compared to the standard requirement advice by the WHO. Beyond the tangible benefits, these trees also contribute to monetary profit, supporting natural resources sustainability and energy saving. Future tree planting initiatives must prioritize species with the highest benefit values, ensuring diversity to maximize impact.

Additionally, the inclusion of resilient native trees with potential yet often overlooked should be a priority in urban plantations not only in Dhaka but also in other urban areas. This inventory report will serve as a valuable asset and baseline for the city planners and policymakers, providing essential information to integrate urban forestry and the necessity for urban green spaces into future urban development plans.

Chapter 6

Recommendations

6. Recommendations

6.1 Short-term recommendations

- **Environmental benefits:** This inventory uncovers that certain tree species dominate, providing a majority of the city's environmental benefits, such as absorbing atmospheric carbon, neutralizing air pollution, and reducing surface runoff. These dominant species thrive due to their high survival rates, resilience to microclimates, and popularity among Dhaka residents. Therefore, it is advisable to prioritize tree species like Mahogany, Mango, Kalo Koroi, Konok Chura, Jackfruit, Sada Koroi, Coconut, and Jam considering the species site matching and safety concerns in the urban settings. Rather than focusing solely on beautification, priority should be given to addressing environmental concerns.
- **Emphasis on native:** Given the higher prevalence of exotic species compared to native ones in Dhaka, there is a need for more emphasis on native species during urban plantation programs. This will enhance biodiversity and create habitats that are friendly to local bird species. Native plants are better suited to local ecosystems, contributing to overall urban ecological health.
- **Focused plantation:** Various land uses harbors the existing trees of Dhaka city. To make the most of this, focused plantation programs can be implemented, like in cemetery and institutional premises. This targeted approach will ensure efficient resource allocation and maximize the impact of tree planting initiatives.

6.2 Long-term recommendations

- **Plantation guideline:** This inventory provides insights into the tree species that deliver the highest environmental benefits. Utilizing this data, a site-specific plantation guideline can be formulated. Presently, there is a lack of comprehensive guidelines specifying where a specific tree species should be planted, particularly in the densely populated city settings like Dhaka. Developing such guidelines would provide a structured approach to urban tree planting, ensuring optimal environmental impact.
- **Master plan:** For the sustained improvement of Dhaka's urban tree cover, the formulation of an urban greening master plan is crucial. This long-term strategy will outline goals and actions to systematically improve the city's green coverage. This will ensure coordinated efforts among stakeholders engaged in urban greening, maximizing the positive effects on the urban environment, aesthetics, and overall well-being of its residents.
- **Potential Site Identification:** A GIS analysis that identifies the most suitable areas for tree planting is needed to inform the master plan. The analysis could include criteria such as poverty levels, population density and tree cover within administrative units to determine locations where additional trees will yield the most benefits. The tree inventory data of the current study will be crucial for understanding baselines in coverage, biomass and species distributions and could be used for training spatial models. By incorporating this information, city planners can make informed decisions that prioritize sustainability, environmental benefits, and the overall quality of urban spaces.
- **Regular monitoring:** It is crucial to ensure regular monitoring of the urban green resources and a sustained flow of information platform which is shared publicly. This can be hosted and managed by either BFD or City Corporations.

Annexes

Annex 1: Phytosociological attributes of the tree species recorded from different strata of DNCC

S N	Botanical name	Density (stem per ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				Importance Value Index			
		Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC
1	<i>Acacia</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
2	<i>Aegle marmelos</i>	1.9	0.23		0.31	0.81	1.43		0.84	1.74	2.13		1.48	1.11	1.56		0.82	3.66	5.12		3.13
3	<i>Albizia chinensis</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
4	<i>Albizia lebbek</i>	7.6	0.11	0.24	0.82	3.24	0.71	1.11	2.10	3.48	1.06	1.61	2.21	2.22	1.56	2.86	1.36	8.94	3.34	5.58	5.67
5	<i>Albizia niopoides</i> v. <i>niopoides</i>	2.85			0.26	1.21			0.63	1.74			0.74	1.67			1.23	4.62			2.59
6	<i>Albizia procera</i>	8.55			0.77	3.64			1.89	3.48			1.48	2.5			1.84	9.62			5.20
7	<i>Albizia saman</i>	0.95	0.11		0.16	0.4	0.71		0.42	0.87	1.06		0.74	1.11	1.56		0.82	2.39	3.34		1.98
8	<i>Anacardium occidentale</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
9	<i>Annona reticulata</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
10	<i>Annona squamosa</i>	0.95	0.11		0.16	0.4	0.71		0.42	0.87	1.06		0.74	1.11	1.56		0.82	2.39	3.34		1.98
11	<i>Areca catechu</i>	5.7	0.34	0.24	0.79	2.43	2.14	1.11	2.10	2.61	2.13	1.61	2.21	2.22	2.35	2.86	1.36	7.26	6.62	5.58	5.67
12	<i>Artocarpus heterophyllus</i>	13.3	1.14	2.91	2.73	5.67	7.14	13.3 3	7.55	7.83	8.51	9.68	8.49	1.73	1.96	5.72	1.28	15.22	17.61	28.73	17.31
13	<i>Artocarpus lacucha</i>	0.95	0.11	0.24	0.23	0.4	0.71	1.11	0.63	0.87	1.06	1.61	1.11	1.11	1.56	2.86	0.82	2.39	3.34	5.58	2.55
14	<i>Averrhoa carambola</i>	0.95	0.23		0.23	0.4	1.43		0.63	0.87	2.13		1.11	1.11	1.56		0.82	2.39	5.12		2.55
15	<i>Azadirachta indica</i>	3.8	0.34	0.48	0.69	1.62	2.14	2.22	1.89	2.61	3.19	3.23	2.95	1.48	1.56	2.86	0.92	5.71	6.9	8.31	5.76
16	<i>Borassus</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
17	<i>Carica papaya</i>	0.95		0.97	0.36	0.4		4.44	1.05	0.87		3.23	1.11	1.11		5.72	1.36	2.39		13.39	3.52
18	<i>Caryota mitis</i>	1.9			0.17	0.81			0.42	0.87			0.37	2.22			1.64	3.9			2.42
19	<i>Cinnamomum verum</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
20	<i>Cocos nucifera</i>	14.2 6	1.83	2.18	3.04	6.07	11.4 3	10	8.39	10.4 3	10.6 4	8.06	9.96	1.39	2.5	5.15	1.21	17.9	24.57	23.21	19.56
21	<i>Codiaeum variegatum</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
22	<i>Crateva religiosa</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
23	<i>Delonix regia</i>	0.95	0.34	0.48	0.44	0.4	2.14	2.22	1.26	0.87	3.19	3.23	2.21	1.11	1.56	2.86	0.82	2.39	6.9	8.31	4.29
24	<i>Derris</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40

S N	Botanical name	Density (stem per ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				Importance Value Index			
		Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC
25	<i>Derris robusta</i>		0.34		0.21		2.14		0.63		1.06		0.37		4.69		2.45		7.9		3.45
26	<i>Dillenia indica</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
27	<i>Dypsis lutescens</i>		0.46		0.29		2.86		0.84		2.13		0.74		3.13		1.64		8.11		3.21
28	<i>Elaeocarpus</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
29	<i>Elaeocarpus serratus</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
30	<i>Eucalyptus</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
31	<i>Eucalyptus camaldulensis</i>	1.9			0.17	0.81			0.42	1.74			0.74	1.11			0.82	3.66			1.98
32	<i>Eucalyptus globulus</i>	3.8			0.34	1.62			0.84	0.87			0.37	4.44			3.27	6.93			4.48
33	<i>Eucalyptus grandis</i>	1.9			0.17	0.81			0.42	0.87			0.37	2.22			1.64	3.9			2.42
34	<i>Ficus benghalensis</i>		0.11	0.48	0.21		0.71	2.22	0.63		1.06	3.23	1.11		1.56	2.86	0.82		3.34	8.31	2.55
35	<i>Ficus carica</i>		0.11	0.24	0.14		0.71	1.11	0.42		1.06	1.61	0.74		1.56	2.86	0.82		3.34	5.58	1.98
36	<i>Ficus hispida</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
37	<i>Ficus racemosa</i>	0.95	0.11		0.16	0.4	0.71		0.42	0.87	1.06		0.74	1.11	1.56		0.82	2.39	3.34		1.98
38	<i>Firmiana simplex</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
39	<i>Gmelina arborea</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
40	<i>Heritiera</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
41	<i>Hibiscus rosa-sinensis</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
42	<i>Khaya</i>	9.5			0.85	4.05			2.10	0.87			0.37	11.11			8.18	16.03			10.64
43	<i>Lagerstroemia indica</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
44	<i>Lannea coromandelica</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
45	<i>Leucaena leucocephala</i>	1.9			0.17	0.81			0.42	1.74			0.74	1.11			0.82	3.66			1.98
46	<i>Limonia acidissima</i>	0.95	0.11		0.16	0.4	0.71		0.42	0.87	1.06		0.74	1.11	1.56		0.82	2.39	3.34		1.98
47	<i>Litchi chinensis</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
48	<i>Litsea</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
49	<i>Mallotus philippensis</i>	2.85			0.26	1.21			0.63	0.87			0.37	3.33			2.45	5.42			3.45
50	<i>Mangifera indica</i>	39.9 2	2.29	4.85	6.38	17	14.2 9	22.2 2	17.1 9	14.7 8	14.8 9	19.3 5	15.8 7	2.75	2.23	4.77	1.56	34.53	31.41	46.34	34.62
51	<i>Mesua ferrea</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
52	<i>Mimusops elengi</i>		0.11	0.48	0.21		0.71	2.22	0.63		1.06	3.23	1.11		1.56	2.86	0.82		3.34	8.31	2.55

S N	Botanical name	Density (stem per ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				Importance Value Index			
		Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC	Tree	Scatter	Others	DNCC
53	<i>Moringa oleifera</i>	4.75	0.46	0.73	0.92	2.02	2.86	3.33	2.52	4.35	4.26	4.84	4.43	1.11	1.56	2.86	0.82	7.48	8.68	11.03	7.76
54	<i>Musa acuminata</i>		0.34		0.21		2.14		0.63		1.06		0.37		4.69		2.45		7.9		3.45
55	<i>Neolamarckia cadamba</i>			0.48	0.14			2.22	0.42			3.23	0.74			2.86	0.82			8.31	1.98
56	<i>Nyctanthes arbor-tristis</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
57	<i>Peltophorum pterocarpum</i>	4.75		0.48	0.56	2.02		2.22	1.47	0.87		1.61	0.74	5.56		5.72	2.86	8.45		9.55	5.07
58	<i>Phyllanthus</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
59	<i>Plumeria alba</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
60	<i>Polyalthia longifolia</i>	2.85	0.11	0.48	0.46	1.21	0.71	2.22	1.26	0.87	1.06	3.23	1.48	3.33	1.56	2.86	1.23	5.42	3.34	8.31	3.96
61	<i>Psidium guajava</i>	4.75	0.34	0.48	0.78	2.02	2.14	2.22	2.10	4.35	3.19	3.23	3.69	1.11	1.56	2.86	0.82	7.48	6.9	8.31	6.60
62	<i>Spondias mombin</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
63	<i>Spondias pinnata</i>			0.24	0.07			1.11	0.21			1.61	0.37			2.86	0.82			5.58	1.40
64	<i>Swietenia macrophylla</i>	9.5	0.8	1.94	1.90	4.05	5	8.89	5.24	2.61	1.06	3.23	2.21	3.7	10.95	11.44	3.41	10.36	17.01	23.55	10.86
65	<i>Swietenia mahagoni</i>	0.95			0.09	0.4			0.21	0.87			0.37	1.11			0.82	2.39			1.40
66	<i>Swietenia mahogani</i>	52.2 7	2.52	0.24	6.32	22.2 7	15.7 1	1.11	16.3 5	5.22	7.45	1.61	5.17	10.18	4.92	2.86	4.56	37.67	28.08	5.58	26.08
67	<i>Syzygium</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
68	<i>Syzygium cumini</i>	7.6	0.11	0.73	0.96	3.24	0.71	3.33	2.52	6.09	1.06	3.23	3.69	1.27	1.56	4.29	0.98	10.6	3.34	10.85	7.19
69	<i>Syzygium samarangense</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
70	<i>Terminalia arjuna</i>	1.9			0.17	0.81			0.42	0.87			0.37	2.22			1.64	3.9			2.42
71	<i>Terminalia bellirica</i>	5.7			0.51	2.43			1.26	0.87			0.37	6.67			4.91	9.97			6.53
72	<i>Terminalia catappa</i>		0.11		0.07		0.71		0.21		1.06		0.37		1.56		0.82		3.34		1.40
73	<i>Terminalia kaernbachii</i>	0.95	0.23		0.23	0.4	1.43		0.63	0.87	1.06		0.74	1.11	3.13		1.23	2.39	5.62		2.59
74	<i>Trema orientalis</i>		0.46		0.29		2.86		0.84		1.06		0.37		6.26		3.27		10.18		4.48
75	<i>Ziziphus jujuba</i>	0.95	0.23	0.97	0.50	0.4	1.43	4.44	1.47	0.87	2.13	6.45	2.58	1.11	1.56	2.86	0.82	2.39	5.12	13.76	4.87
All plant species		235	16	22	37	100	100	100	100	100	100	100	100	100	100	100	100	300	300	300	300

Annex 2: Phytosociological attributes of the tree species recorded from different strata of DSCC

S N	Species	Tree density (t/ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				IVI			
		Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC
1	<i>Acacia acuminata</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
2	<i>Acacia auriculiformis</i>	2.25			0.28	0.88			0.44	1.14			0.44	1.87			1.53	3.89			2.40
3	<i>Aegle marmelos</i>	3.37		0.10	0.50	1.32		0.42	0.77	2.29		0.65	1.10	1.40		1.44	1.07	5.01		2.51	2.93
4	<i>Albizia lebbeck</i>	5.05	2.02		0.92	1.98	1.80		1.42	1.71	0.79		0.88	2.80	7.47		2.48	6.49	10.06		4.78
5	<i>Albizia niopoides v. niopoides</i>	5.05		0.29	0.85	1.98		1.26	1.31	0.57		0.65	0.44	8.39		4.32	4.58	10.95		6.23	6.33
6	<i>Albizia procera</i>	5.05	1.51	0.48	1.20	1.98	1.35	2.10	1.86	1.71	2.38	1.30	1.76	2.80	1.87	3.60	1.62	6.49	5.60	7.00	5.24
7	<i>Albizia saman</i>	2.81			0.36	1.10			0.55	1.71			0.66	1.55			1.27	4.37			2.48
8	<i>Alstonia scholaris</i>	1.68		0.10	0.28	0.66		0.42	0.44	1.14		0.65	0.66	1.40		1.44	1.02	3.20		2.51	2.11
9	<i>Annona cherimola</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
10	<i>Annona reticulata</i>	0.56	0.50	0.19	0.28	0.22	0.45	0.84	0.44	0.57	0.79	0.65	0.66	0.93	1.87	2.88	1.02	1.72	3.11	4.37	2.11
11	<i>Annona squamosa</i>	2.81		0.29	0.57	1.10		1.26	0.88	2.29		1.95	1.54	1.17		1.44	0.87	4.55		4.65	3.29
12	<i>Areca catechu</i>	4.49	3.03	0.38	1.27	1.76	2.70	1.68	1.97	1.14	3.17	1.95	1.98	3.73	2.80	1.92	1.53	6.63	8.68	5.55	5.47
13	<i>Artocarpus</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
14	<i>Artocarpus heterophyllus</i>	11.23	7.06	1.81	3.72	4.41	6.31	7.98	5.80	5.71	5.56	7.14	6.15	1.87	3.73	2.48	1.44	11.98	15.60	17.61	13.40
15	<i>Artocarpus indica</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
16	<i>Artocarpus lacucha</i>	2.25	1.01	0.29	0.63	0.88	0.90	1.26	0.98	2.29	1.59	1.95	1.98	0.93	1.87	1.44	0.76	4.10	4.36	4.65	3.73
17	<i>Averrhoa carambola</i>	2.25	0.50	0.48	0.70	0.88	0.45	2.10	1.09	1.14	0.79	2.60	1.54	1.87	1.87	1.80	1.09	3.89	3.11	6.50	3.72

S N	Species	Tree density (t/ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				IVI			
		Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC
18	<i>Azadirachta indica</i>	4.49	5.04	0.38	1.54	1.76	4.50	1.68	2.41	2.29	7.14	2.60	3.74	1.87	2.07	1.44	0.99	5.91	13.72	5.72	7.13
19	<i>Baccaurea ramiflora</i>	0.56		0.10	0.14	0.22		0.42	0.22	0.57		0.65	0.44	0.93		1.44	0.76	1.72		2.51	1.42
20	<i>Barringtonia acutangula</i>	1.12			0.14	0.44			0.22	1.14			0.44	0.93			0.76	2.52			1.42
21	<i>Borassus flabellifer</i>	0.56		0.10	0.14	0.22		0.42	0.22	0.57		0.65	0.44	0.93		1.44	0.76	1.72		2.51	1.42
22	<i>Ceiba pentandra</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
23	<i>Cinnamomum camphora</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
24	<i>Citrus grandis</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
25	<i>Cocos nucifera</i>	26.39	11.60	2.19	6.55	10.35	10.36	9.66	10.18	12.57	9.52	10.39	10.99	1.99	3.58	2.07	1.42	24.92	23.46	22.12	22.58
26	<i>Crateva religiosa</i>		1.01		0.14		0.90		0.22		1.59		0.44		1.87		0.76		4.36		1.42
27	<i>Delonix regia</i>	0.56		0.29	0.28	0.22		1.26	0.44	0.57		1.95	0.88	0.93		1.44	0.76	1.72		4.65	2.08
28	<i>Dillenia indica</i>	1.12	3.03	0.19	0.70	0.44	2.70	0.84	1.09	1.14	4.76	1.30	2.20	0.93	1.87	1.44	0.76	2.52	9.33	3.58	4.06
29	<i>Diospyros blancoi</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
30	<i>Dyopsis lutescens</i>		1.01		0.14		0.90		0.22		0.79		0.22		3.73		1.53		5.43		1.96
31	<i>Elaeocarpus serratus</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
32	<i>Erythrina fusca</i>			0.19	0.14			0.84	0.22			0.65	0.22			2.88	1.53			4.37	1.96
33	<i>Eucalyptus camaldulensis</i>	6.18	0.50	0.10	0.92	2.42	0.45	0.42	1.42	1.14	0.79	0.65	0.88	5.13	1.87	1.44	2.48	8.69	3.11	2.51	4.78
34	<i>Ficus benghalensis</i>	0.56		0.86	0.70	0.22		3.78	1.09	0.57		5.19	1.98	0.93		1.62	0.85	1.72		10.59	3.92
35	<i>Ficus benjamina</i>			0.19	0.14			0.84	0.22			1.30	0.44			1.44	0.76			3.58	1.42

S N	Species	Tree density (t/ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				IVI			
		Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC
36	<i>Ficus cyathistipula</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
37	<i>Ficus elastica</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
38	<i>Ficus hispida</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
39	<i>Ficus racemosa</i>		0.50	0.38	0.35		0.45	1.68	0.55		0.79	1.95	0.88		1.87	1.92	0.95		3.11	5.55	2.38
40	<i>Ficus religiosa</i>			0.19	0.14			0.84	0.22			1.30	0.44			1.44	0.76			3.58	1.42
41	<i>Ficus rumphii</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
42	<i>Gmelina arborea</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
43	<i>Gustavia augusta</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
44	<i>Hopea odorata</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
45	<i>Lagerstroemia speciosa</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
46	<i>Lannea coromandelica</i>		2.02		0.28		1.80		0.44		2.38		0.66		2.49		1.02		6.67		2.11
47	<i>Leucaena leucocephala</i>	0.56		0.10	0.14	0.22		0.42	0.22	0.57		0.65	0.44	0.93		1.44	0.76	1.72		2.51	1.42
48	<i>Limonia acidissima</i>	2.25		0.10	0.35	0.88		0.42	0.55	1.71		0.65	0.88	1.24		1.44	0.95	3.84		2.51	2.38
49	<i>Litchi chinensis</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
50	<i>Litsea glutinosa</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
51	<i>Livistona chinensis</i>	2.81			0.36	1.10			0.55	0.57			0.22	4.66			3.82	6.34			4.58
52	<i>Mallotus nudiflorus</i>	1.12		0.19	0.28	0.44		0.84	0.44	0.57		0.65	0.44	1.87		2.88	1.53	2.88		4.37	2.40
53	<i>Mangifera indica</i>	85.92	41.86	6.56	21.47	33.70	37.39	28.99	33.37	17.71	20.63	20.13	19.34	4.60	5.96	3.20	2.64	56.02	63.98	52.32	55.36
54	<i>Manilkara zapota</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
55	<i>Mesua ferrea</i>	3.37			0.43	1.32			0.66	0.57			0.22	5.60			4.58	7.49			5.45

S N	Species	Tree density (t/ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				IVI			
		Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC
56	<i>Microcos paniculata</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
57	<i>Mimusops elengi</i>	1.12		0.48	0.49	0.44		2.10	0.77	1.14		1.30	0.88	0.93		3.60	1.34	2.52		7.00	2.98
58	<i>Moringa oleifera</i>	3.93	4.54	0.19	1.26	1.54	4.05	0.84	1.97	3.43	3.17	1.30	2.64	1.09	4.20	1.44	1.14	6.06	11.43	3.58	5.75
59	<i>Murraya paniculata</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
60	<i>Neolamarckia cadamba</i>	0.56		0.38	0.35	0.22		1.68	0.55	0.57		1.95	0.88	0.93		1.92	0.95	1.72		5.55	2.38
61	<i>Peltophorum pterocarpum</i>	0.56		0.10	0.14	0.22		0.42	0.22	0.57		0.65	0.44	0.93		1.44	0.76	1.72		2.51	1.42
62	<i>Phoenix dactylifera</i>	2.81		0.10	0.43	1.10		0.42	0.66	1.71		0.65	0.88	1.55		1.44	1.14	4.37		2.51	2.68
63	<i>Phoenix sylvestris</i>	1.12		0.10	0.21	0.44		0.42	0.33	0.57		0.65	0.44	1.87		1.44	1.14	2.88		2.51	1.91
64	<i>Phyllanthus acidus</i>		0.50		0.07		0.45		0.11		0.79		0.22		1.87		0.76		3.11		1.09
65	<i>Polyalthia longifolia</i>	1.12	1.01	0.19	0.42	0.44	0.90	0.84	0.66	1.14	0.79	1.30	1.10	0.93	3.73	1.44	0.92	2.52	5.43	3.58	2.67
66	<i>Pongamia</i>	1.68	1.51	0.19	0.56	0.66	1.35	0.84	0.88	1.14	0.79	0.65	0.88	1.40	5.60	2.88	1.53	3.20	7.75	4.37	3.28
67	<i>Premna</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
68	<i>Psidium guajava</i>	1.12	0.50	0.29	0.42	0.44	0.45	1.26	0.66	1.14	0.79	1.95	1.32	0.93	1.87	1.44	0.76	2.52	3.11	4.65	2.74
69	<i>Roystonea regia</i>	1.68			0.21	0.66			0.33	0.57			0.22	2.80			2.29	4.03			2.84
70	<i>Samanea</i>	0.56			0.07	0.22			0.11	0.57			0.22	0.93			0.76	1.72			1.09
71	<i>Spondias mombin</i>		1.51		0.21		1.35		0.33		2.38		0.66		1.87		0.76		5.60		1.75

S N	Species	Tree density (t/ha)				Relative density (%)				Relative frequency (%)				Relative abundance (%)				IVI			
		Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC	Tree	Scatter	Others	DSCC
72	<i>Spondias purpurea</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
73	<i>Swietenia macrophylla</i>	3.37	0.50	0.10	0.57	1.32	0.45	0.42	0.88	1.14	0.79	0.65	0.88	2.80	1.87	1.44	1.53	5.26	3.11	2.51	3.28
74	<i>Swietenia mahogani</i>	34.26	3.03	1.71	6.02	13.44	2.70	7.56	9.30	6.86	3.17	5.19	5.27	4.74	2.80	3.24	2.70	25.03	8.68	15.99	17.28
75	<i>Syzygium cumini</i>	1.12	2.52	0.57	0.91	0.44	2.25	2.52	1.42	1.14	3.97	3.90	2.86	0.93	1.87	1.44	0.76	2.52	8.09	7.86	5.04
76	<i>Syzygium jambos</i>	0.56	2.02		0.35	0.22	1.80		0.55	0.57	3.17		1.10	0.93	1.87		0.76	1.72	6.84		2.41
77	<i>Syzygium samarangense</i>	2.25	1.51	0.29	0.70	0.88	1.35	1.26	1.09	2.29	2.38	1.30	1.98	0.93	1.87	2.16	0.85	4.10	5.60	4.72	3.92
78	<i>Tamarindus indica</i>	1.68	2.02	0.10	0.56	0.66	1.80	0.42	0.88	1.71	3.17	0.65	1.76	0.93	1.87	1.44	0.76	3.31	6.84	2.51	3.40
79	<i>Tectona grandis</i>	1.68			0.21	0.66			0.33	0.57			0.22	2.80			2.29	4.03			2.84
80	<i>Terminalia arjuna</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
81	<i>Terminalia catappa</i>		0.50	0.10	0.14		0.45	0.42	0.22		0.79	0.65	0.44		1.87	1.44	0.76		3.11	2.51	1.42
82	<i>Trema orientalis</i>			0.38	0.28			1.68	0.44			0.65	0.22			5.75	3.05			8.08	3.71
83	<i>Vachellia nilotica</i>			0.10	0.07			0.42	0.11			0.65	0.22			1.44	0.76			2.51	1.09
84	<i>Ziziphus mauritiana</i>	3.37	3.53		0.91	1.32	3.15		1.42	3.43	3.17		2.20	0.93	3.27		0.99	5.68	9.60		4.61
	All plant species	255	112	23	64	100	100	100	100	100	100	100	100	100	100	100	100	300	300	300	300

Annex 2: Data template for urban tree inventory

Plot Info		Date:	
Plot ID:	Stratum: 1=Tree 2= Scatter 3= Others	Crew/Group:	
Per. of Plot Measured (%)	Total Tree Cover (%) DBH>10cm: Tree Cover (%) % of plot in Rooftop- Rooftop tree cover (%)	Shrub Cover (%)	Stake- NO
Plot Address: _____			
Map Coordinates (Use GPS)/Plot center			
Lat.	Long.		
Land uses			
Land Use	% of Plot		
Agriculture			
Cemetery (Graveyard)			
Commercial/ Industrial			
Forest			
Institutional			
Other			
Park			
Residential			
Transportation			
Vacant			
Water/Wetland			
Ground Covers			
Ground covers	% of Plot		
Bare soil			
Building			
Cement/ Concrete (Dhalai)			
Duff/Mulch/Litter			
Grass (Maintained)			
Herbs and shrubs			
Other impervious			
Water			

Did this Plot have any Trees? (Y/N): _____

Plot Photo ID(s): N _____ E _____ S _____ W _____

Reference Objects: Determine reference objects/landmarks

Ref. Object 1: Object description _____
Direction (Degree)/Bearing _____ Distance (m): _____
Latitude _____ Longitude _____
If tree write: Species _____ DBH (cm) _____

Ref. Object 2: Object description _____
Direction (Degree)/Bearing _____ Distance (m): _____
Latitude _____ Longitude _____
If tree write: Species _____ DBH (cm) _____

Ref. Object 3: Object description _____
Direction (Degree)/Bearing _____ Distance (m): _____
Latitude _____ Longitude _____
If tree write: Species _____ DBH (cm) _____

Plot area Layout/ Sketch or Additional Comments:

[illegible][illegible]

Annex 2: List of tree species recorded in DNCC and DSCC [Asterisks (*) under the DNCC and DSCC columns indicate record of the corresponding plants during the survey.]

Sl.	Scientific Name	Local Name	Family	Origin	DNCC	DSCC
1	<i>Acacia acuminata</i>	Akashmoni	Fabaceae	Exotic		*
2	<i>Acacia auriculiformis</i>	Akashmoni	Fabaceae	Exotic	*	*
3	<i>Aegle marmelos</i>	Bel	Rutaceae	Indigenous	*	*
4	<i>Albizia chinensis</i>	Chakua koro	Fabaceae	Exotic	*	
5	<i>Albizia lebbeck</i>	Kalo koro	Fabaceae	Indigenous	*	*
6	<i>Albizia niopoides</i>		Fabaceae	Exotic	*	*
7	<i>Albizia procera</i>	Shada koro	Fabaceae	Indigenous	*	*
8	<i>Albizia saman</i>	Rain tree	Fabaceae	Exotic	*	*
9	<i>Alstonia scholaris</i>	Chatim	Apocynaceae	Indigenous		*
10	<i>Anacardium occidentale</i>	Kaju badam	Anacardiaceae	Indigenous	*	
11	<i>Annona cherimola</i>		Annonaceae			*
12	<i>Annona reticulata</i>		Annonaceae	Exotic	*	*
13	<i>Annona squamosa</i>		Annonaceae	Indigenous	*	*
14	<i>Areca catechu</i>	Supari	Arecaceae	Exotic	*	*
15	<i>Artocarpus altis</i>	Bread fruit	Moraceae	Indigenous		*
16	<i>Artocarpus heterophyllus</i>	Kathal	Moraceae	Indigenous	*	*
17	<i>Artocarpus lacucha</i>	Dewa	Moraceae	Indigenous	*	*
18	<i>Averrhoa carambola</i>	Kamranga	Oxalidaceae	Indigenous	*	*
19	<i>Azadirachta indica</i>	Neem	Meliaceae	Indigenous	*	*
20	<i>Baccaurea ramiflora</i>	Lotkon	Phyllanthaceae			*
21	<i>Barringtonia acutangula</i>	Hijol	Lecythidaceae	Indigenous		*
22	<i>Borassus flabellifer</i>	Taal	Arecaceae	Indigenous	*	*
23	<i>Carica papaya</i>	Pepe	Caricaceae	Indigenous	*	
24	<i>Caryota mitis</i>	Fishtail palm	Arecaceae	Indigenous	*	
25	<i>Ceiba pentandra</i>	Burmese shimul	Malvaceae	Exotic		*
26	<i>Cinnamomum camphora</i>	Korpur	Lauraceae	Exotic		*
27	<i>Cinnamomum verum</i>	Daruchini	Lauraceae	Exotic	*	
28	<i>Citrus grandis</i>	Jambura	Rutaceae	Exotic		*
29	<i>Cocos nucifera</i>	Narikel	Arecaceae	Indigenous	*	*
30	<i>Codiaeum variegatum</i>	Pata bahar	Euphorbiaceae	Exotic	*	
31	<i>Crateva religiosa</i>	Borun	Capparaceae	Indigenous	*	*
32	<i>Delonix regia</i>	Krishnochura	Fabaceae	Exotic	*	*
33	<i>Derris robusta</i>		Fabaceae	Indigenous	*	
34	<i>Derris spp</i>		Fabaceae	Indigenous	*	
35	<i>Dillenia indica</i>	Chalta	Dilleniaceae	Indigenous	*	*
36	<i>Diospyros blancoi</i>	Bilati gab	Ebenaceae	Exotic		*
37	<i>Dyopsis lutescens</i>	Areca palm	Aracaceae	Exotic	*	*
38	<i>Elaeocarpus serratus</i>	Jolpai	Elaeocarpaceae	Indigenous	*	*
39	<i>Elaeocarpus spp</i>		Elaeocarpaceae	Indigenous	*	
40	<i>Erythrina fusca</i>	Mandar	Fabaceae	Indigenous		*

Sl.	Scientific Name	Local Name	Family	Origin	DNCC	DSCC
41	<i>Eucalyptus camaldulensis</i>	Eucalyptus	Myrtaceae	Exotic	*	*
42	<i>Eucalyptus globulus</i>	Eucalyptus	Myrtaceae	Exotic	*	
43	<i>Eucalyptus grandis</i>	Eucalyptus	Myrtaceae	Exotic	*	
44	<i>Eucalyptus spp</i>	Eucalyptus	Myrtaceae	Exotic	*	
45	<i>Ficus benghalensis</i>	Bot	Moraceae	Indigenous	*	*
46	<i>Ficus benjamina</i>	Jhiri bot	Moraceae	Indigenous		*
47	<i>Ficus carica</i>		Moraceae	Exotic	*	
48	<i>Ficus cyathistipula</i>		Moraceae	Exotic		*
49	<i>Ficus elastica</i>	Rubber bot	Moraceae	Indigenous		*
50	<i>Ficus hispida</i>	Kak dumur	Moraceae	Indigenous	*	*
51	<i>Ficus racemosa</i>	Joggo dumur	Moraceae	Indigenous	*	*
52	<i>Ficus religiosa</i>	Ashwatha	Moraceae	Indigenous		*
53	<i>Ficus rumphii</i>	Goya ashwatha	Moraceae	Indigenous		*
54	<i>Firmiana simplex</i>		Malvaceae	Indigenous	*	
55	<i>Gmelina arborea</i>	Gamar	Verbanaceae	Indigenous	*	*
56	<i>Gustavia augusta</i>	Gustavia	Lecythidaceae	Exotic		*
57	<i>Heritiera spp</i>		Malvaceae	Indigenous	*	
58	<i>Hibiscus rosa-sinensis</i>	Joba	Malvaceae	Exotic	*	
59	<i>Hopea odorata</i>	Telsur	Dipterocarpaceae	Indigenous		*
60	<i>Khaya spp</i>	Mehogoni	Meliaceae	Exotic	*	
61	<i>Lagerstroemia indica</i>	Furus	Lythraceae	Indigenous	*	
62	<i>Lagerstroemia speciosa</i>	Jarul	Lythraceae	Indigenous		*
63	<i>Lannea coromandelica</i>	Jiol bhadi	Anacardiaceae	Indigenous	*	*
64	<i>Leucaena leucocephala</i>	Ipil ipil	Fabaceae	Exotic	*	*
65	<i>Limonia acidissima</i>	Kodbel	Rutaceae	Indigenous	*	*
66	<i>Litchi chinensis</i>	Lichu	Sapindaceae	Indigenous	*	*
67	<i>Litsea glutinosa</i>	Kharajora	Lauraceae	Indigenous		*
68	<i>Litsea spp</i>		Lauraceae	Indigenous	*	
69	<i>Livistona chinensis</i>	Chinese palm	Arecaceae	Exotic		*
70	<i>Mallotus nudiflorus</i>	Pitali	Euphorbiaceae	Indigenous		*
71	<i>Mallotus philippensis</i>	Sinduri	Euphorbiaceae	Indigenous	*	
72	<i>Mangifera indica</i>	Aam	Anacardiaceae	Indigenous	*	*
73	<i>Manilkara zapota</i>	Sofeda	Sapotaceae	Exotic		*
74	<i>Mesua ferrea</i>	Nageshwar	Calophyllaceae	Indigenous	*	*
75	<i>Microcos paniculata</i>	Ashar	Malvaceae	Indigenous		*
76	<i>Mimusops elengi</i>	Bokul	Sapotaceae	Exotic	*	*
77	<i>Moringa oleifera</i>	Sojne	Moringaceae	Exotic	*	*
78	<i>Murraya paniculata</i>	Kamini	Rutaceae	Indigenous		*
79	<i>Neolamarckia cadamba</i>	Kodom	Rubiaceae	Indigenous	*	*
80	<i>Nyctanthes arbor-tristis</i>	Shewly	Oleaceae	Indigenous	*	
81	<i>Peltophorum pterocarpum</i>	Konokchura	Fabaceae	Exotic	*	*
82	<i>Phoenix dactylifera</i>	Khejur	Arecaceae	Indigenous		*

Sl.	Scientific Name	Local Name	Family	Origin	DNCC	DSCC
83	<i>Phoenix sylvestris</i>	Khejur	Arecaceae	Indigenous		*
84	<i>Phyllanthus acidus</i>	Orboroi	Phyllanthaceae	Exotic		*
85	<i>Phyllanthus spp</i>		Phyllanthaceae	Indigenous	*	
86	<i>Plumeria alba</i>	Kathgolap (sada)	Apocynaceae	Exotic	*	
87	<i>Polyalthia longifolia</i>	Debdaru	Annonaceae	Exotic	*	*
88	<i>Pongamia pinnata</i>	Koroch	Fabaceae	Indigenous		*
89	<i>Premna spp</i>	Goniyari	Lamiaceae	Indigenous		*
90	<i>Psidium guajava</i>	Peyara	Myrtaceae	Indigenous	*	*
91	<i>Roystonea regia</i>	Bottle palm	Arecaceae	Exotic		*
92	<i>Spondias mombin</i>	Aamra	Anacardiaceae	Indigenous	*	*
93	<i>Spondias pinnata</i>		Anacardiaceae	Indigenous	*	
94	<i>Spondias purpurea</i>		Anacardiaceae	Indigenous		*
95	<i>Swietenia macrophylla</i>	Mehogoni (boro pata)	Meliaceae	Exotic	*	*
96	<i>Swietenia mahagoni</i>	Mehogoni (choto pata)	Meliaceae	Exotic	*	*
97	<i>Syzygium cumini</i>	Jam	Myrtaceae	Indigenous	*	*
98	<i>Syzygium jambos</i>	Golapjam	Myrtaceae			*
99	<i>Syzygium samarangense</i>	Jamrul	Myrtaceae	Exotic	*	*
100	<i>Syzygium spp</i>	Jam	Myrtaceae	Indigenous	*	
101	<i>Tamarindus indica</i>	Tetul	Fabaceae			*
102	<i>Tectona grandis</i>	Shegun	Verbanaceae			*
103	<i>Terminalia arjuna</i>	Arjun	Combretaceae	Indigenous	*	*
104	<i>Terminalia bellirica</i>	Bohera	Combretaceae	Indigenous	*	
105	<i>Terminalia catappa</i>	Kathbadam	Combretaceae	Exotic	*	*
106	<i>Terminalia kaernbachii</i>		Combretaceae	Exotic	*	
107	<i>Trema orientalis</i>	Jibon brikkho	Cannabaceae	Indigenous	*	*
108	<i>Vachellia nilotica</i>	Babla	Fabaceae			*
109	<i>Ziziphus jujuba</i>	Boroi	Rhamnaceae	Indigenous	*	
110	<i>Ziziphus mauritiana</i>	Boroi	Rhamnaceae	Indigenous		*

Annex 4: List of the data enumerators

Sl. No.	Name	Institute/University	Degree	Gender
1	Anika Islam	North South University	BSc in Environmental Science and Management	Female
2	Antara Rizwani	North South University	BSc in Environmental Science and Management	Female
3	Atia Yeasmeen Huma	Bangladesh University of Professionals	BSc in Environmental Science	Female
4	Atika Rahman Akhi	Bangladesh University of Professionals	MSc in Environmental Science	Female
5	Aynun Nishat Farhabi	Khulna University	MSc in Forestry	Male
6	Emita Khanam Oishe	Bangladesh University of Professionals	MSc in Environmental Science	Female
7	Fahim Tasnim	University of Chittagong	MSc in Environmental Science	Female
8	Fahima Begum	University of Chittagong	MSc in Environmental Science	Female
9	Farhana Ferdous Mitu	University of Chittagong	MSc in Environmental Science	Female
10	Mahedi Hasan Rony	Forestry Science and Technology Institute	Diploma in Forestry	Male
11	Mahmuda Binte Qader Shammi	Sher-E-Bangla Agricultural University	MSc Agroforestry and Environmental Sciences	Female
12	Md Imran Hossain Rakib	Bangladesh University of Professionals	BSc in Environmental Science	Male
13	Md Rakib Hasan	Bangladesh University of Professionals	MSc in Environmental Science	Male
14	Md Tawfic Noor	North South University	BSc in Environmental Science and Management	Male
15	Md Zannatul Nayem Jion	Stamford University of Bangladesh	BSc in Environmental Science	Male
16	Md. Abdullah Al-Mamun Palash	Khulna University	MSc in Forestry and Wood Technology	Male
17	Md. Habibul Hasan	University of Chittagong	MSc in Environmental Science	Male
18	MD. Rashedul Islam Rasel	Bangladesh University of Professionals	BSc in Environmental Science	Male
19	Md. Sadik Shihab Enan	North South University	BSc in Environmental Science and Management	Male
20	Md. Sami Ul Hasan	Bangladesh University of Professionals	MSc in Environmental Science	Male
21	Md. Samiul Islam Sifat	Bangladesh University of Professionals	MSc in Environmental Science	Male
22	Md. Siddiq Hasan	University of Dhaka	BSc in Botany	Male
23	Mohammad Ali	Jahangirnagar University	MSc in Geography and Environment	Male
24	Mohammad Naqib Azam	North South University	BSc in Environmental Science and Management	Male
25	Mojahed Billah	Forestry Science and Technology Institute	Diploma in Forestry	Male
26	Munia Tahsin	Jahangirnagar University	MSc in Geography and Environment	Female
27	Nazia Sultana Lina	University of Chittagong	BSc in Environmental Science	Female
28	Nova Dewan	University of Chittagong	MSc in Environmental Science	Female
29	Pinky Rani Sarkar	Bangladesh University of Professionals	MSc in Environmental Science	Female
30	Pramila Paul	University of Chittagong	MSc in Environmental Science	Female
31	Sadia Jahan Rothi	Bangladesh University of Professionals	BSc in Environmental Science	Female
32	Shamim Ahmed Mridha	Bangladesh University of Professionals	MSc in Environmental Science	Male

Sl. No.	Name	Institute/University	Degree	Gender
33	Silmoon Islam	Shahjalal University of Science and Technology	BSc in Forestry and Environmental Science	Female
34	Sumyea Behesti	Sher-E-Bangla Agricultural University	MSc Agroforestry and Environmental Sciences	Female
35	Syeda Akhter	Bangladesh University of Professionals	BSc in Environmental Science	Female
36	Tahsin Tabassum	Bangladesh University of Professionals	BSc in Environmental Science	Female
37	Tareq Rahman	Bangladesh University of Professionals	BSc in Environmental Science	Male
38	Utpal kumar Sheel	Sher-E-Bangla Agricultural University	MSc Agroforestry and Environmental Sciences	Male
39	Yaqub Ali	University of Chittagong	BSc in Forestry	Male
40	Yonus Ali	Forestry Science and Technology Institute	Diploma in Forestry	Male

Annex 5: R script for inventory data analysis

Structure of the data collected applying i-Tree Canopy platform from DNCC and DSCC is almost similar, hence the following r-script is used to estimate the tree biophysical attributes for both DNCC and DSCC. To avoid the repetition the r-script for DNCC is provided below. Species richness, tree density, basal area, tree cover, phytosociological attributes, diversity indices of the tree species, growing stock, biomass and carbon are the major variables estimated using this r-script. There are three strata and 11 land uses in DNCC. The key parameters were estimated for per strata and land uses.

a. Sampling process

The quadrat were 11.35 m radius circular plots.

b. Brief information regarding the databases used in this script

- plot = All plot basic data from i-Tree Eco Project
- tree = All tree data from i-Tree Eco Project
- gclu = Ground cover and land use data at plot level from the i-Tree Eco Project
- zone = Basic information regarding the three strata
- wd_sp_bd = Wood density database from BFR1
- wd_sp = Wood density per species
- wd_gen = wood density per genus
- wd_fam = Wood density per family
- spp_info = family, local name and origin of the species recorded from DNCC

c. Data import

```
# Remove memory
rm(list = ls())

# Set working directory
setwd("G:/My Drive/3_Other works/38_COMPASS/iTree")

# Import survey data - DSCC
plot <- read.csv("./DNCC DSCC/DSCC plot05nov2023.csv", stringsAsFactors = F)
tree <- read.csv("./DNCC DSCC/DSCC tree05nov2023.csv", stringsAsFactors = F)
lu <- read.csv("./DNCC DSCC/DSCC lu05nov2023.csv", stringsAsFactors = F)
gc <- read.csv("./DNCC_DSCC/DSCC_gc05nov2023.csv", stringsAsFactors = F)

# Auxiliary data
zone <- read.csv("./DNCC DSCC/stratum info.csv", stringsAsFactors = F)
spp_info <- read.csv("./Auxiliary data/tree info updated.csv", stringsAsFactors = F)
wd_sp_bd <- read.csv("./Auxiliary data/wd_bd.csv", header=T, stringsAsFactors = F)
wd_fam <- read.csv("./Auxiliary data/wd_fam.csv", header=T, stringsAsFactors = FALSE)
wd_gen <- read.csv("./Auxiliary data/wd_gen.csv", header=T, stringsAsFactors = FALSE)
wd_sp <- read.csv("./Auxiliary data/wd_sp.csv", header=T, stringsAsFactors = FALSE)

# Run the necessary libraries
library(data.table)
library(plotrix)
library(gtools)
require(reshape2)

## Loading required package: reshape2

##
## Attaching package: 'reshape2'
```

```
## The following objects are masked from 'package:data.table':
##
## dcast, melt

library(ggplot2)
```

d. Data preparation

```
#source("Data_preparation_231112.R")
# Rename the columns in plot data of DSCC
colnames(plot) <- c("plot_id", "stratum", "address", "lat", "long", "date",
  "crew", "contact", "pa_ha", "ploto", "stake", "tree_p",
  "shrub_p", "sampled_p", "notes", "complete")
# Consider the sampled plots only
plot <- plot[plot$complete=="TRUE",]
# Sampled area per plot
plot$sai <- (plot$sampled_p/100)*(pi*11.35^2)/10000
# Preparing tree cover data per plot
plot$tree_p2 <- ifelse(plot$tree_p=="100%", 100,
  ifelse(plot$tree_p=="95% - 99%", 97,
    ifelse(plot$tree_p=="90% - 95%", 92.5,
      ifelse(plot$tree_p=="85% - 90%", 87.5,
        ifelse(plot$tree_p=="80% - 85%", 82.5,
          ifelse(plot$tree_p=="75% - 80%", 77.5,
            ifelse(plot$tree_p=="70% - 75%", 72.5,
              ifelse(plot$tree_p=="65% - 70%", 67.5,
                ifelse(plot$tree_p=="60% - 65%", 62.5,
                  ifelse(plot$tree_p=="55% - 60%", 57.5,
                    ifelse(plot$tree_p=="50% - 55%", 52.5,
                      ifelse(plot$tree_p=="45% - 50%", 47.5,
                        ifelse(plot$tree_p=="40% - 45%", 42.5,
                          ifelse(plot$tree_p=="35% - 40%", 37.5,
                            ifelse(plot$tree_p=="30% - 35%", 32.5,
                              ifelse(plot$tree_p=="25% - 30%", 27.5,
                                ifelse(plot$tree_p=="20% - 25%",
                                  22.5,
                                  ifelse(plot$tree_p=="15% - 20%", 17.5,
                                    ifelse(plot$tree_p=="10% - 15%", 12.5,
                                      ifelse(plot$tree_p=="5% - 10%", 7.5, ifelse(plot$tree_p=="1% - 5%", 3, ifelse(plot$tree_p=="0%", 0, "Not Entered"))))))))))))))))))))

# Prepare GC and LU data
gc_s <- dcast(gc, Plot~Ground.Cover, value.var = "X..of.Plot")
gc_s$tot_gc <- rowSums(gc_s[2:9], na.rm = T)
lu_s <- dcast(lu, Plot~Land.Use, value.var = "X..of.Plot")
lu_s$tot_lu <- rowSums(lu_s[2:11], na.rm = T)
# Merge GC and LU data
gclu <- merge(gc_s, lu_s, by="Plot", all=T)
names(gclu) <- c("plot_id", "GC bare soil", "GC building", "GC cement", "GC duff", "GC herbs", "GC maintained grass", "GC otherOimpervious", "GC water", "tot_gc", "LU agriculture", "LU cemetery", "LU commercial industrial", "LU institutional", "LU other", "LU park", "LU_residential", "LU_transportation", "LU_vacant", "LU_water_wetland", "tot_lu")
# Convert NAs into 0
gclu[2:21][is.na(gclu[,2:21])] <- 0

# Add ground cover and land use with plot
plot <- merge(plot, gclu, by="plot_id", all.x=T)

# Prepare tree data of DSCC
```

```
colnames(tree) <- c("plot_id", "tree_id", "date", "status", "distance",
  "direction", "species", "lu", "d1", "d1h", "d1m", "d2",
  "d2h", "d2m", "d3", "d3h", "d3m", "d4", "d4h", "d4m", "d5",
  "d5h", "d5m", "d6", "d6h", "d6m", "cd_p", "th", "cth",
  "cbh", "cwns", "cwew", "cm_p", "i_p", "t_shrub_p", "cle",
  "st", "hd", "bearing", "public", "t_lat", "t_long", "t_comment")
```

Add additional species information with the tree data base

```
tree <- merge(tree, spp_info, by="species", all.x=T)
tree$count <- 1
```

Add stratum name with tree

```
tree <- merge(tree, plot[,c("plot_id", "stratum", "ai")], by="plot_id", all.x=T)
```

e. Species richness

Species composition

```
sp_comp <- unique(tree[,c("species", "family", "exotic_nat")])
write.csv(sp_comp, file="/DNCC_DSCC/analysis_outputs/1. Species composition_DSCC.csv", row.names = F)
```

e.1 Species richness by stratum

#DNCC

Species number per stratum

```
t_z <- unique(tree[,c("stratum", "species", "local_name", "family", "exotic_nat", "count")]) # t_z = Number of tree species per stratum
```

```
t_z$exotic <- ifelse(t_z$exotic_nat=="Exotic", 1, 0)
```

```
t_z$native <- ifelse(t_z$exotic_nat=="Native", 1, 0)
```

```
t_z <- data.table(t_z)
```

```
t_z2 <- t_z[,list(spp_no = length(unique(species)),
  fam_no = length(unique(family)),
  native = sum(native),
  exotic = sum(exotic),
  by="stratum")]
```

Export output

```
write.csv(t_z2, file="/DNCC_DSCC/analysis_outputs/3.1.1. Number of species per stratum_DSCC.csv", row.names = F)
```

Number of species in all zone

```
length(unique(tree$species))
```

```
## [1] 84
```

Number of families in all zone

```
length(unique(tree$family))
```

```
## [1] 33
```

Number of exotic species

```
length(unique(tree[,c("species", "exotic_nat")][tree$exotic_nat=="Exotic,")$exotic_nat)
```

```
## [1] 33
```

Number of native species

```
length(unique(tree[,c("species", "exotic_nat")][tree$exotic_nat=="Native,")$exotic_nat)
```

```
## [1] 51
```

e.2 Species richness by land use

Species number per land use

```
t_lu <- unique(tree[,c("lu", "species", "local_name", "family", "exotic_nat", "count")])
```

```
t_lu$exotic <- ifelse(t_lu$exotic_nat=="Exotic", 1, 0)
```

```
t_lu$native <- ifelse(t_lu$exotic_nat=="Native", 1, 0)
```

```
t_lu <- data.table(t_lu)
```

```
t_lu2 <- t_lu[,list(spp_no = length(unique(species)),
  fam_no = length(unique(family)),
```

```

native = sum(native),
exotic = sum(exotic)),
by="lu"]

```

Export output

```
write.csv(t_lu2, file="/DNCC_DSCC/analysis_outputs/3.1.2. Number of species per land use_DSCC.csv", row.names = F)
```

f. Phytosociological attributes

List of variable names prepared and used in the data frame for analysis

- a = number of individuals of the ith species occurred in the area of interest;
- b = total number of quadrats studied;
- c = total number of quadrats in which the species occurred;
- M = Total number of individuals of all the species in the area of interest,
- F = frequency of ith species, S = number of species.
- ai_s = Sampled area per stratum

f.1 Phytosociological attributes per stratum

Number of individuals (a) per species and stratum

```
PA_s <- aggregate(data=tree, count~stratum+species, sum)
```

```
names(PA_s)[3] <- "a"
```

Add the sampled area and number of quadrats per stratum

```
PA_s <- merge(PA_s, zone[zone$location=="DSCC",][,c("stratum", "sampled_plot_no", "sampled_area_ha")], by="stratum", all.x = T)
```

```
names(PA_s)[names(PA_s)=="sampled_plot_no"] <- "b"
```

```
names(PA_s)[5] <- "ai_s"
```

Number of plots occurred per species and stratum

```
npo <- unique(tree[,c("plot_id", "stratum", "species", "count")])
```

```
np_ss <- aggregate(data=npo, count~species+stratum, sum) #np_ss = no. of plots occurred by species and stratum
```

```
names(np_ss)[3] <- "c"
```

```
PA_s <- merge(PA_s, np_ss, by=c("stratum", "species"), all.x=T)
```

Total number of individuals (M) of all species per stratum

```
ni_s <- aggregate(data=PA_s, a~stratum, sum) #Number of individuals of all species per site
```

```
names(ni_s)[2] <- "M"
```

```
PA_s <- merge(PA_s, ni_s, by="stratum", all.x=T)
```

Add the number of species per stratum from "t_z2" data frame

```
PA_s <- merge(PA_s, t_z2[,c("stratum", "spp_no")], by="stratum", all.x = T)
```

```
names(PA_s)[8] <- "S"
```

Stem density per ha

```
PA_s$td_ha <- PA_s$a/PA_s$ai_s
```

Density

```
PA_s$D <- PA_s$a/PA_s$b
```

```
PA_s$RD <- (PA_s$a/PA_s$M)*100
```

Frequency

```
PA_s$F <- PA_s$c/PA_s$b
```

```
PA_s$RF <- ifelse(PA_s$stratum=="Tree", (PA_s$F/sum(PA_s[PA_s$stratum=="Tree",]$F))*100,
  ifelse(PA_s$stratum=="Builtup with tree", (PA_s$F/sum(PA_s[PA_s$stratum=="Builtup with tree",]$F))*100,
  ifelse(PA_s$stratum=="Others", (PA_s$F/sum(PA_s[PA_s$stratum=="Others",]$F))*100, NA)))
```

Abundance

```
PA_s$A <- PA_s$a/PA_s$c
```

```
PA_s$RA <- ifelse(PA_s$stratum=="Tree", (PA_s$A/sum(PA_s[PA_s$stratum=="Tree",]$A))*100,
  ifelse(PA_s$stratum=="Builtup with tree", (PA_s$A/sum(PA_s[PA_s$stratum=="Builtup with tree",]$A))*100,
  ifelse(PA_s$stratum=="Others", (PA_s$A/sum(PA_s[PA_s$stratum=="Others",]$A))*100, NA)))
```

```

# Importance Vlaue index (IVI)
PA $IVI <- PA $RD+PA $RF+PA $RA
# Prepare the IVI table
PA $ T <- PA $[PA $stratum=="Tree",][,c("species", "td_ha", "RD", "RF", "RA", "IVI")]
colnames(PA $ T)[2:6] <- paste("Tree ", colnames(PA $ T)[2:6])
PA $ S <- PA $[PA $stratum=="Builtup with tree",][,c("species", "td_ha", "RD", "RF", "RA", "IVI")]
colnames(PA $ S)[2:6] <- paste("Scatter ", colnames(PA $ S)[2:6])
PA $ O <- PA $[PA $stratum=="Others",][,c("species", "td_ha", "RD", "RF", "RA", "IVI")]
colnames(PA $ O)[2:6] <- paste("Other ", colnames(PA $ O)[2:6])
PA $ F <- merge(PA $ T, PA $ S, by="species", all=T)
PA $_F2 <- merge(PA $_F, PA $_O, by="species", all=T)

# Export the output
write.csv(PA $_F2, file="/DNCC_DSCC/analysis_outputs/Phytosociological attributes per statum_DSCC.csv", row.names
= F)

```

f.2 Phytosociological attributes for DNCC

```

# Stem density per ha per species
PA $ <- merge(PA $, zone[,c("stratum", "Wh")], by="stratum", all.x=T)
PA $wtd_ha <- PA $td_ha*PA $Wh #wtd_ha = weighted tree density per ha
td_sp <- aggregate(data=PA $, wtd_ha~species, sum)

# Number of individuals (a) per species
PA <- aggregate(data=tree, count~species, sum)
names(PA)[2] <- "a"
# Add the total number of quadrat studied
PA$b <- sum(zone$sampled_plot_no)

# Number of plots occurred per species
npo_sp <- unique(tree[,c("plot_id", "species", "count")])
np_sp <- aggregate(data=npo_sp, count~species, sum) #np_sp = no. of plots occurred by species
names(np_sp)[2] <- "c"
PA <- merge(PA, np_sp, by="species", all.x=T)

# Total number of individuals (M) of all species
PA$M <- sum(PA$a)

# Add stem density per ha
PA <- merge(PA, td_sp, by="species", all.x=T)

# Density
PA$D <- PA$a/PA$b
PA$RD <- (PA$a/PA$M)*100

# Frequency
PA$F <- PA$c/PA$b
PA$RF <- (PA$F/sum(PA$F))*100

# Abundabce
PA$A <- PA$a/PA$c
PA$RA <- PA$A/sum(PA$A)*100

# Importance Vlaue index (IVI)
PA$IVI <- PA$RD+PA$RF+PA$RA

# Add the stratum PA
PA_F <- merge(PA[,c("species", "wtd_ha", "RD", "RF", "RA", "IVI")], PA $_F2, by="species", all=T)

# Export the output
write.csv(PA, file="/DNCC_DSCC/analysis_outputs/Phytosociological attributes_DSCC.csv", row.names = F)
write.csv(PA_F, file="/DNCC_DSCC/analysis_outputs/Phytosociological attributes_all stratum and DSCC.csv", row.names
= F)

```

g. Diversity indicators of the tree species

Four diversity indices were calculated.

g.1 Diversity indicators of the tree species per stratum

```
DI_s <- PA_s[,c("species", "stratum", "a", "M")]
DI_s$Pi <- DI_s$a/DI_s$M
DI_s$Pi2 <- DI_s$Pi^2
DI_s$Pi_LnPi <- DI_s$Pi*log(DI_s$Pi)
DI_s$aiai_l <- DI_s$a*(DI_s$a-l) #aiai_l = (a(a-l)) of the equation

# Prepare the diversity indices per stratum table
DI_sF <- data.table(DI_s)
DI_sF <- DI_sF[,list(H = sum(-Pi_LnPi),
                    Sd_l = sum(aiai_l)), by="stratum"]

# Add number of species and total number of individuals per stratum
DI_sF <- merge(DI_sF, unique(PA_s[,c("stratum", "M", "S")]), by="stratum", all.x=T)
DI_sF$R <- (DI_sF$S-1)/log(DI_sF$M) # R = Richness index
DI_sF$Sd <- 1-(DI_sF$Sd_l)/(DI_sF$M*(DI_sF$M-1)) # Sd = Simpson's Dominance Index
DI_sF$E <- DI_sF$H/log(DI_sF$S) # E = Pilon's evenness index

# Export the output
write.csv(DI_sF, file="/DNCC_DSCC/analysis_outputs/Diversity indices per stratum_DSCC.csv", row.names = F)
```

g.2 Diversity indicators for whole DNCC

```
DI <- aggregate(data=tree, count~species, sum)
names(DI)[2] <- "a"
DI$M <- sum(DI$a)
DI$Pi <- DI$a/DI$M
DI$Pi2 <- DI$Pi^2
DI$Pi_LnPi <- DI$Pi*log(DI$Pi)
DI$aiai_l <- DI$a*(DI$a-l)

# Prepare the diversity indices per stratum table
DIF <- data.frame(H = sum(-DI$Pi_LnPi),
                  R = (length(unique(tree$species))-1)/log(sum(DI$a)),
                  Sd = 1-(sum(DI$aiai_l)/(sum(DI$a)*(sum(DI$a)-1))),
                  E = sum(-DI$Pi_LnPi)/log(length(unique(tree$species))))

# Export the output
write.csv(DIF, file="/DNCC_DSCC/analysis_outputs/Diversity indices for whole DSCC.csv", row.names = F)
```

h. Estimating the key variables at tree level

h.1 Basal Area

```
tree$d1_m <- tree$d1/100
tree$d2_m <- tree$d2/100
tree$d3_m <- tree$d3/100
tree$d4_m <- tree$d4/100
tree$d5_m <- tree$d5/100
tree$d6_m <- tree$d6/100

tree$ba1 <- (pi*(tree$d1_m^2))/4 #ba1 = Basal area based on diameter l in m2
tree$ba2 <- (pi*(tree$d2_m^2))/4
tree$ba3 <- (pi*(tree$d3_m^2))/4
tree$ba4 <- (pi*(tree$d4_m^2))/4
tree$ba5 <- (pi*(tree$d5_m^2))/4
tree$ba6 <- (pi*(tree$d6_m^2))/4

which(colnames(tree)=="ba1") #To know the column number

## [1] 59
```

```
match("ba6", names(tree)) #To know the column number

## [1] 64

tree[,59:64][is.na(tree[,59:64])] <- 0 # Convert NAs into 0
tree$ba <- tree$ba1+tree$ba2+tree$ba3+tree$ba4+tree$ba5+tree$ba6
```

h.2 Growing Stock

Growing stock is estimated using the quarter girth equation with an average form factor (0.693) applicable for Bangladesh. The form factor was adopted from BFI Cycle I data analysis method.

```
tree$gs1 <- ifelse(tree$d1>=10, (pi*(tree$d1 m^2)*tree$th*0.693)/4, 0) #gs1 = Growing stock in m3 based on DBH 1
tree$gs2 <- ifelse(tree$d2>=10, (pi*(tree$d2 m^2)*tree$th*0.693)/4, 0) #gs2 = Growing stock in m3 based on DBH 2
tree$gs3 <- ifelse(tree$d3>=10, (pi*(tree$d3 m^2)*tree$th*0.693)/4, 0) #gs3 = Growing stock in m3 based on DBH 3
tree$gs4 <- ifelse(tree$d4>=10, (pi*(tree$d4 m^2)*tree$th*0.693)/4, 0) #gs4 = Growing stock in m3 based on DBH 4
tree$gs5 <- ifelse(tree$d5>=10, (pi*(tree$d5 m^2)*tree$th*0.693)/4, 0) #gs5 = Growing stock in m3 based on DBH 5
tree$gs6 <- ifelse(tree$d6>=10, (pi*(tree$d6_m^2)*tree$th*0.693)/4, 0) #gs6 = Growing stock in m3 based on DBH 6

# gs1 column number
which(colnames(tree)== "gs1")

## [1] 66

match("gs6", names(tree)) #To know the column number

## [1] 71

# Convert NAs into zero
tree[,66:71][is.na(tree[,66:71])] <- 0
tree$gs <- tree$gs1+tree$gs2+tree$gs3+tree$gs4+tree$gs5+tree$gs6
```

h.3 Biomass

h.3.1 Above Ground Biomass

Above Ground Biomss (AGB) is estimated using the pantropical allomet Chaves et al 2014.

```
# Adding wood density data
treeB <- merge(tree, wd sp bd[,c("tree spp scientific_name", "wd_bd")], by.x="genus_species",
  by.y="tree spp scientific name", all.x = T)
treeB <- merge(treeB, wd_sp[,c("Binomial", "wd_sp")], by.x = "genus_species", by.y="Binomial",
  all.x =TRUE)
treeB <- merge(treeB, wd_gen[,c("Genus", "wd_gen")], by.x = "genus_species", by.y="Genus",
  all.x =TRUE)
treeB <- merge(treeB, wd_fam[,c("Family", "wd_fam")], by.x = "family", by.y="Family", all.x=TRUE)

# Prepare wd column with wd from different columns
treeB$wd <- ifelse(!is.na(treeB$wd bd), treeB$wd bd,
  ifelse(!is.na(treeB$wd sp), treeB$wd sp,
    ifelse(!is.na(treeB$wd gen), treeB$wd gen,
      ifelse(!is.na(treeB$wd fam), treeB$wd fam,
        0.6133782)))) # wd= wood density in g/cm3

# Checking NA in wd column
treeB_NAWD <-treeB[is.na(treeB$wd),]

#Applying Chaves et al. (2014) best-fitted pantropical equation for above ground biomass (AGB) estimation
treeB$agb1 <- 0.0673*(treeB$wd*(treeB$d1^2)*treeB$th)^0.976 #agb1 = AGB in kg for DBH 1
treeB$agb2 <- 0.0673*(treeB$wd*(treeB$d2^2)*treeB$th)^0.976 #agb2 = AGB in kg for DBH 2
treeB$agb3 <- 0.0673*(treeB$wd*(treeB$d3^2)*treeB$th)^0.976 #agb3 = AGB in kg for DBH 3
treeB$agb4 <- 0.0673*(treeB$wd*(treeB$d4^2)*treeB$th)^0.976 #agb4 = AGB in kg for DBH 4
treeB$agb5 <- 0.0673*(treeB$wd*(treeB$d5^2)*treeB$th)^0.976 #agb5 = AGB in kg for DBH 5
treeB$agb6 <- 0.0673*(treeB$wd*(treeB$d6^2)*treeB$th)^0.976 #agb6 = AGB in kg for DBH 6

# Check agb1 and agb6 column number
which(colnames(treeB)== "agb1")
```

```
## [1] 78

match("agb6", names(treeB)) #To know the column number

## [1] 83

# Convert NA in agb1 to agb6 into zero
treeB[,78:83][is.na(treeB[,78:83])] <- 0

# agb in kg per tree
treeB$agb <- treeB$agb1+treeB$agb2+treeB$agb3+treeB$agb4+treeB$agb5+treeB$agb6
# agb in ton
treeB$agb_t <- treeB$agb/1000
```

h.3.2 Below ground biomass

Below Ground Biomass (BGB) is calculated using Pearson et al. (2007) equation for BGB. According to Pearson et al. (2007), $BGB = \exp(-1.0587 + 0.8836 \times \ln AGB)$.

```
treeB$bgb_t <- exp(-1.0587 + 0.8836*log(treeB$agb_t))
```

h.3.3 Total tree biomass

```
treeB$ttb_t <- treeB$agb_t+treeB$bgb_t
```

h.4. Carbon

Carbon in AGB and BGB is estimated as 50% of the AGB and BGB respectively.

```
# A separate file for carbon
treeC <- treeB
# Carbon in AGB
treeC$cagb_t <- treeC$agb_t*0.5 #Tree carbon is considered as 50% of tree biomass
# Carbon in BGB
treeC$cbgb_t <- treeC$bgb_t*0.5
# Total carbon per tree
treeC$carbon_t <- treeC$cagb_t+treeC$cbgb_t
```

i Estimating means at strata and DNCC level

Under this section the key variables- stem density, basal area, tree cover, growing stock, AGB, BGB, TTB, CAGB, CBGB, and TTC were estimated per stratum and whole DNCC.

```
# All key variable at plot level
kv_p <- data.table(treeC)
kv_p <- kv_p[,list(nt_p = sum(count),
  ba_p = sum(ba),
  gs_p = sum(gs),
  agb_p_t = sum(agb_t),
  bgb_p_t = sum(bgb_t),
  ttb_p_t = sum(ttb_t),
  cagb_p_t = sum(cagb_t),
  cbgb_p_t = sum(cbgb_t),
  ttc_p_t = sum(carbon_t)),
  by = "plot_id"] #kv_p = key variables per plot

# add sampled area and tc of all measured plots
kv_p2 <- merge(kv_p, plot[,c("plot_id", "stratum", "tree_p2", "ai")], by="plot_id", all.y=T)

# Convert NAs into zero
kv_p2[,2:10][is.na(kv_p2[,2:10])] <- 0

# Calculate the variables per hectare basis
kv_p2$nt_p_ha <- kv_p2$nt_p/kv_p2$ai
kv_p2$ba_p_ha <- kv_p2$ba_p/kv_p2$ai
```

```

kv_p2$gs_p_ha <- kv_p2$gs_p/kv_p2$ai
kv_p2$agb_p_tha <- kv_p2$agb_p_t/kv_p2$ai
kv_p2$bgb_p_tha <- kv_p2$bgb_p_t/kv_p2$ai
kv_p2$ttb_p_tha <- kv_p2$ttb_p_t/kv_p2$ai
kv_p2$cagb_p_tha <- kv_p2$cagb_p_t/kv_p2$ai
kv_p2$cbgb_p_tha <- kv_p2$cbgb_p_t/kv_p2$ai
kv_p2$ttc_p_tha <- kv_p2$ttc_p_t/kv_p2$ai

# Convert tree cover as numeric
kv_p2$tree_p2 <- as.numeric(kv_p2$tree_p2)

# Key variable at stratum level
kv_s <- data.table(kv_p2)
kv_s <- kv_s[,list(nt_ha = mean(nt_p_ha),
  nt_se = std.error(nt_p_ha),
  ba_ha = mean(ba_p_ha),
  ba_se = std.error(ba_p_ha),
  tc = mean(tree_p2),
  tc_se = std.error(tree_p2),
  gs_ha = mean(gs_p_ha),
  gs_se = std.error(gs_p_ha),
  agb_ha = mean(agb_p_tha),
  agb_se = std.error(agb_p_tha),
  bgb_ha = mean(bgb_p_tha),
  bgb_se = std.error(bgb_p_tha),
  ttb_ha = mean(ttb_p_tha),
  ttb_se = std.error(ttb_p_tha),
  cagb_ha = mean(cagb_p_tha),
  cagb_se = std.error(cagb_p_tha),
  cbgb_ha = mean(cbgb_p_tha),
  cbgb_se = std.error(cbgb_p_tha),
  ttc_ha = mean(ttc_p_tha),
  ttc_se = std.error(ttc_p_tha)),
  by="stratum"]

# Add stratum weight
kv_s2 <- merge(kv_s, zone[zone$location=="DSCC"],[,c("stratum", "Wh")], by = "stratum", all.x=T)

# multiply key variables with stratum weights
kv_s2$nt_ha_w <- kv_s2$nt_ha*kv_s2$Wh
kv_s2$ba_ha_w <- kv_s2$ba_ha*kv_s2$Wh
kv_s2$tc_w <- kv_s2$tc*kv_s2$Wh
kv_s2$gs_ha_w <- kv_s2$gs_ha*kv_s2$Wh
kv_s2$agb_ha_w <- kv_s2$agb_ha*kv_s2$Wh
kv_s2$bgb_ha_w <- kv_s2$bgb_ha*kv_s2$Wh
kv_s2$ttb_ha_w <- kv_s2$ttb_ha*kv_s2$Wh
kv_s2$cagb_ha_w <- kv_s2$cagb_ha*kv_s2$Wh
kv_s2$cbgb_ha_w <- kv_s2$cbgb_ha*kv_s2$Wh
kv_s2$ttc_ha_w <- kv_s2$ttc_ha*kv_s2$Wh

# Key variables at DNCC levels
kv_DNCC <- data.frame(nt_ha = sum(kv_s2$nt_ha_w),
  nt_se = std.error(kv_s2$nt_p_ha),
  ba_ha = sum(kv_s2$ba_ha_w),
  ba_se = std.error(kv_s2$ba_p_ha),
  tc = sum(kv_s2$tc_w),
  tc_se = std.error(kv_p2$tree_p2),
  gs_ha = sum(kv_s2$gs_ha_w),
  gs_se = std.error(kv_p2$gs_p_ha),
  agb_ha = sum(kv_s2$agb_ha_w),
  agb_se = std.error(kv_p2$agb_p_tha),
  bgb_ha = sum(kv_s2$bgb_ha_w),
  bgb_se = std.error(kv_p2$bgb_p_tha),
  ttb_ha = sum(kv_s2$ttb_ha_w),
  ttb_se = std.error(kv_p2$ttb_p_tha),
  cagb_ha = sum(kv_s2$cagb_ha_w),

```

```

cagb_se = std.error(kv_p2$cagb_p_tha),
cbgb_ha = sum(kv_s2$cbgb_ha_w),
cbgb_se = std.error(kv_p2$cbgb_p_tha),
ttc_ha = sum(kv_s2$ttc_ha_w),
ttc_se = std.error(kv_p2$ttc_p_tha)

kv_DNCC$stratum <- "DSCC"

# Combine stratum and DNCC level estimates
kv_F <- smartbind(kv_s2, kv_DNCC)
# kv_F = rbind.fill(kv_s2, kv_DNCC) #library("plyr")

# Export the outputs
write.csv(kv_F[,c("stratum", "nt_ha", "nt_se", "ba_ha", "ba_se", "tc", "tc_se", "gs_ha", "gs_se", "agb_ha", "agb_se", "bgb_ha",
"bgb_se", "ttb_ha", "ttb_se", "cagb_ha", "cagb_se", "cbgb_ha", "cbgb_se", "ttc_ha", "ttc_se")], file = "/DNCC_DSCC/analysis_
s_outputs/key variables per stratum and DSCC.csv", row.names = F)

```

j. Estimating means of the key variables per land use and DNCC level

Under this section the key variables- stem density, basal area, tree cover, growing stock, AGB, BGB, TTB, CAGB, CBGB, and TTC were estimated per land uses (identified by the field teams) and whole DNCC.

```

# prepare the land use table
# Plot area in ha
pa <- (pi*11.35^2)/10000 # pa = plot area in ha

# LU area (ha) per plot
gclu$LU_agriculture_ha <- (gclu$LU_agriculture/100)*pa
gclu$LU_cemetery_ha <- (gclu$LU_cemetery/100)*pa
gclu$LU_commercial_industrial_ha <- (gclu$LU_commercial_industrial/100)*pa
gclu$LU_institutional_ha <- (gclu$LU_institutional/100)*pa
gclu$LU_park_ha <- (gclu$LU_park/100)*pa
gclu$LU_residential_ha <- (gclu$LU_residential/100)*pa
gclu$LU_transportation_ha <- (gclu$LU_transportation/100)*pa
gclu$LU_vacant_ha <- (gclu$LU_vacant/100)*pa
gclu$LU_water_wetland_ha <- (gclu$LU_water_wetland/100)*pa
gclu$LU_other_ha <- (gclu$LU_other/100)*pa

# Add complete status
gclu <- merge(gclu, plot[,c("plot_id", "complete")], by="plot_id", all.x=T)

# Select only completely measured plots
gclu <- gclu[!is.na(gclu$complete),]

# Total sampled area (ha) per land use
ai_lu <- data.frame(Vacant = sum(gclu$LU_vacant_ha),
  Residential = sum(gclu$LU_residential_ha),
  Water_Wetland = sum(gclu$LU_water_wetland_ha),
  Park = sum(gclu$LU_park_ha),
  Cemetery = sum(gclu$LU_cemetery_ha),
  Transportation = sum(gclu$LU_transportation_ha),
  Agriculture = sum(gclu$LU_agriculture_ha),
  Institutional = sum(gclu$LU_institutional_ha),
  Commercial_Industrial = sum(gclu$LU_commercial_industrial_ha),
  Other = sum(gclu$LU_other_ha))

# Melt the area per lu
# Create ID
ai_lu$lu <- "ai_lu_ha"
ai_lu_moltd <- melt(ai_lu, "lu")
# rename columns
names(ai_lu_moltd)[2:3] <- c("lu", "ai_lu_ha")
ai_luF <- ai_lu_moltd[,2:3]

```

```

# Key variables per lu
kv_lu <- data.table(treeC)
kv_lu <- kv_lu[,list(nt_lu = sum(count),
  ba_lu = sum(ba),
  gs_lu = sum(gs),
  agb_lu_t = sum(agb_t),
  bgb_lu_t = sum(bgb_t),
  ttb_lu_t = sum(ttb_t),
  cagb_lu_t = sum(cagb_t),
  cbgb_lu_t = sum(cbgb_t),
  ttc_lu_t = sum(carbon_t)),
  by = "lu"] #kv_lu = key variabels per land use
# Rename "Commercial/Industrial" land use
kv_lu$lu <- ifelse(kv_lu$lu=="Commercial/Industrial", "Commercial_Industrial", kv_lu$lu)

# Add sampled area per lu
kv_lu2 <- merge(kv_lu, ai_luF, by="lu", all.x=T)

# Estimate the variables per hectare basis
kv_lu2$nt_ha <- kv_lu2$nt_lu/kv_lu2$ai_lu_ha
kv_lu2$ba_ha <- kv_lu2$ba_lu/kv_lu2$ai_lu_ha
kv_lu2$gs_ha <- kv_lu2$gs_lu/kv_lu2$ai_lu_ha
kv_lu2$agb_tha <- kv_lu2$agb_lu_t/kv_lu2$ai_lu_ha
kv_lu2$bgb_tha <- kv_lu2$bgb_lu_t/kv_lu2$ai_lu_ha
kv_lu2$ttb_tha <- kv_lu2$ttb_lu_t/kv_lu2$ai_lu_ha
kv_lu2$cagb_tha <- kv_lu2$cagb_lu_t/kv_lu2$ai_lu_ha
kv_lu2$cbgb_tha <- kv_lu2$cbgb_lu_t/kv_lu2$ai_lu_ha
kv_lu2$ttc_tha <- kv_lu2$ttc_lu_t/kv_lu2$ai_lu_ha

# export the outputs
write.csv(kv_lu2[,c(1,12:20)], file="/DNCC_DSCC/analysis_outputs/key variables per land use_DSCC.csv", row.names = F
)

# Prepare graphs

## 3.2.2 Tree density per land use
p322_td <- ggplot(data = kv_lu2, aes(x = lu, y = nt_ha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Tree~density~(stem~ha^-1)))+
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

## Warning: The `size` argument of `element_line()` is deprecated as of ggplot2 3.4.0.
## i Please use the `linewidth` argument instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.

ggsave("/DNCC_DSCC/analysis_outputs/3.2.2. Tree density per land use_DSCC.tiff", p322_td, units="in", width=3.2,
  height=4, dpi=300, compression = 'lzw')

## Warning: Removed 2 rows containing missing values (`position_stack()`).

## 3.2.2 Tree basal area per land use
p322_ba <- ggplot(data = kv_lu2, aes(x = lu, y = ba_ha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Basal~area~m^2~ha^-1))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC_DSCC/analysis_outputs/3.2.2. Basal area per land use_DSCC.tiff", p322_ba, units="in", width=3.2,
  height=4, dpi=300, compression = 'lzw')

```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.5.2 Growing stock per land use

```
p352 <- ggplot(data = kv_lu2, aes(x = lu, y = gs_ha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Growing~stock~m^3~ha^-1))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC DSCC/analysis outputs/3.5.2. Growing stock per land use_DSCC.tiff", p352, units="in", width=6.4,
  height=5, dpi=300, compression = 'lzw')
```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.6.2 Above Ground Biomass per land use

```
p362 agb <- ggplot(data = kv_lu2, aes(x = lu, y = agb_tha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Above~ground~biomass~(t~ha^-1)))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC DSCC/analysis outputs/3.6.2. AGB per land use_DSCC.tiff", p362_agb, units="in", width=3.2,
  height=4, dpi=300, compression = 'lzw')
```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.6.2 Below Ground Biomass per land use

```
p362 bgb <- ggplot(data = kv_lu2, aes(x = lu, y = bgb_tha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Below~ground~biomass~(t~ha^-1)))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC DSCC/analysis outputs/3.6.2. BGB per land use_DSCC.tiff", p362_bgb, units="in", width=3.2,
  height=4, dpi=300, compression = 'lzw')
```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.7.2 Carbon in Above Ground Biomass per land use

```
p372 cagb <- ggplot(data = kv_lu2, aes(x = lu, y = cagb_tha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Carbon~"in"~AGB~(t~ha^-1)))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC DSCC/analysis outputs/3.7.2. CAGB per land use_DSCC.tiff", p372_cagb, units="in", width=3.2,
  height=3.7, dpi=300, compression = 'lzw')
```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.7.2 Carbon in Below Ground Biomass per land use

```
p372 cbgb <- ggplot(data = kv_lu2, aes(x = lu, y = cbgb_tha))+
  geom_bar(stat = "identity")+
  xlab("Land uses")+ylab(expression(Carbon~"in"~BGB~(t~ha^-1)))+ #expression for super script
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+
  theme_bw()+
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))

ggsave("/DNCC DSCC/analysis outputs/3.7.2. CBGB per land use_DSCC.tiff", p372_cbgb, units="in", width=3.2,
  height=3.7, dpi=300, compression = 'lzw')
```

```
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```

3.7.2 Total Tree Carbon per land use

```
p372 ttc <- ggplot(data = kv lu2, aes(x = lu, y = ttc_tha))+  
  geom_bar(stat = "identity")+  
  xlab("Land uses")+ylab(expression(Total~tree~carbon~(t~ha^~l)))+ #expression for super script  
  theme(axis.line = element_line(colour = "black", size = 0.5, linetype = "solid"))+  
  theme_bw()+  
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1))  
  
ggsave("/DNCC DSCC/analysis outputs/3.7.2. Total tree carbon per land use_DSCC.tiff", p372_ttc, units="in", width=6.4  
, height=4.3, dpi=300, compression = 'lzw')  
  
## Warning: Removed 2 rows containing missing values (`position_stack()`).
```