# Forest Carbon Inventory 2015:
# Five Protected Areas in Bangladesh

## Main Report

**Bangladesh Forest Department and**
**Winrock International**

**March 2017**

**Climate-Resilient Ecosystems and Livelihoods (CREL)**
**AID-388-A-12-00007**

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## Main Report

**By**

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## Contents

# Executive Summary

The Climate Resilient Ecosystems and Livelihoods (CREL) project, funded by USAID, implemented by Bangladesh Forest Department (BFD) with technical assistance of Winrock International (WI), conducted forest carbon inventory at five Protected Areas (PAs) of Bangladesh in 2015. The PAs are Baroiyadhala National Park (BDNP), Hazarikhil Wildlife Sanctuary (HWS), NijhimDweep National Park (NDNP), Tengragiri Wildlife Sanctuary (TGWS) and Ratargul Special Biodervisity Conservation Ecologically Critical Area (RSBCA). Following IPCC guidelines and lessons from previous forest inventories in the country as well as different Standard Operating Procedures (SOP) of BFD and Winrock International, concentric circular plots were systematically laid at suitable intervals. Data were recorded at 2m, 4m, 10m and 17.84m radii plots. Data collected from a total of 214 sample plots in five PAs covering 12,976.25 ha and analyzed using MS Excel. This area includes core areas of the PA plus some adjoining areas to cover different land cover classes. The CO2 (Mg/ha) estimates were made for five carbon pools, e.g. Trees (seedlings, saplings and live trees), dead wood (standing and lying deadwoods), non-tree vegetation (herbs, shrubs, cane, bamboo, liana etc.), litters and soil. The inventory was conducted to establish baselines for forest carbon and biophysical conditions, and the changes that resulted from deforestation and forest degradation. This report describes the methods and results used for CRELs baselines and how those methods and results confirm National REDD+ development as outlined in the 2013 Bangladesh draft R-PP.

The forest carbon inventory resulted in estimates of areas for different Land cover classes, tree recruitments, carbon stocks, deforestation & forest degradation, GHG emissions in the five selected PAs. The area distribution for different Land Cover Classes were estimated and given are as given in Table a.

Table a: Inventoried Area estimates in hectares for five PAs and land cover classes inventoried during 2015

| Land cover class | BDNP | HWS | NDNP | RSBCA | TGWS | Total (ha) |
|---|---|---|---|---|---|---|
| Forest | 1,716.11 | 1,696.36 | 4,158.20 | 65.56 | 2,518.34 | 10,154.57 |
| Degraded land | 1,145.64 | 671.66 | | 38.61 | 15.92 | 1,871.83 |
| Settlement | | 21.33 | 32.58 | | 56.17 | 110.08 |
| Agriculture | 45.83 | 24.11 | 168.26 | | 3.72 | 241.92 |
| Water | 1.30 | 29.82 | 40.05 | 19.03 | 99.28 | 189.47 |
| Intertidal area/Bare land/Sandbar | | | 291.29 | 36.05 | 81.04 | 408.38 |
| Inventoried area (ha) | 2,908.88 | 2,443.27 | 4,690.38 | 159.25 | 2,774.46 | 12,976.25 |

The recruitments in different tree size classes are an indication of forest health; therefore the number of seedlings, saplings, trees and stumps per hectare were estimated and are given in Table b.

Table b: Number of seedlings, saplings, trees and stumps observed per hectare in different PAs

| PA | Seedlings (N/ha) | Saplings (N/ha) | Trees (N/ha) | Stumps (N/ha) |
|---|---|---|---|---|
| BDNP | 4,294 | 1,210 | 1,370 | 8.75 |
| HWS | 1,813 | 707 | 1,144 | 3.61 |
| NDNP | 9,451 | 9,179 | 2,120 | 8.08 |
| RSBCA | 2,984 | 119 | 891 | - |
| TGWS | 2,215 | 1,054 | 1,165 | - |
| Grand Total | 5,154 | 3,715 | 1,508 | 5.33 |

The carbon ($CO_2$) stocks per hectares were estimated and are given in Table c.

The carbon stock varied from 184.19 at Baroiyadhala National Park (BDNP) to 424.01 $CO_2$ Mg/ha at Nijhum Dweep National Park (NDNP) among the five inventoried PAs in 2015.

Table c. Stock of $CO_2$ at Forest Carbon inventoried five PAs during 2015

| Protected area | Live Trees CO2 (Mg/ha) | Dead Wood CO2 (Mg/ha) | Non-Tree Vegetation CO2 (Mg/ha) | Litter CO2 (Mg/ha) | Plant ** CO2 (Mg/Ha) | Soil Carbon (Mg/ha) | Soil CO2(Mg/ha) | Grand Total CO2 Mg/ha |
|---|---|---|---|---|---|---|---|---|
| BDNP | 24.21 | 1.33 | 0.39 | 2.66 | 28.60 | 42.44 | 155.60 | 184.19 |
| HWS | 123.05 | 15.18 | 0.79 | 2.95 | 141.97 | 35.34 | 129.58 | 271.55 |
| NDNP | 155.98 | 0.01 | 0.02 | 1.31 | 157.32 | 72.73 | 266.69 | 424.01 |
| RSBCA | 98.48 | - | 0.49 | 1.48 | 100.44 | 36.77 | 134.82 | 235.26 |
| TGWS | 34.65 | 0.00 | 0.06 | 0.24 | 34.96 | 82.84 | 303.74 | 338.70 |
| Over all | 94.38 | 2.93 | 0.29 | 1.73 | 99.32 | 57.86 | 212.15 | 311.47 |

Note ** sum of carbon stocks excluding soils

**Table d: Carbon stock $CO_2$ Mg/Ha estimates (excluding soil) for different land cover classes at the five inventoried Protected Areas**

| Land cover | BDNP | HWS | NDNP | RSBCA | TGWS |
|---|---|---|---|---|---|
| Forest | 227.12 | 310.70 | | 273.37 | 389.84 |
| Plantation | 182.91 | 252.24 | 494.93 | | 341.26 |
| Degraded Forest | 178.21 | 192.92 | 312.54 | 188.68 | 292.98 |
| Settlement | 116.39 | 493.55 | 184.72 | | 181.75 |
| Agriculture | 105.01 | 167.23 | 185.18 | | 96.48 |
| Rubber | | 254.96 | | | |
| Tea Garden | | 221.99 | | | |
| Overall average | 184.19 | 271.55 | 424.01 | 235.26 | 338.70 |

Two types of degradations were identified from the Hansen data[1], one by conversion of forests to degraded forests or agriculture including settlements and another by removal of trees when the stumps were still there. Results show that the conversion of forest to "degraded forest or agriculture including settlements" is the most significant cause of annual GHG emission and loss of forest biophysical condition overall, resulting in approximately CO2Mg/year (Table d & e). Tengragiri WS PAs did not have any emission from the conversion of forest to degraded forest, which is possibly due to effective forest protection.

Emission Factors from deforestations for different PAs from conversion of forest to agriculture, settlements and bare lands varied from 15.07 to 183.58 CO2 Mg/year (Table d). There was no emissions recorded at Tengragiri WS.

Table e: Deforestation trends in five PAs inventoried during 2015

[1] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

| PA | Land cover change | Forests in 2001 | Forests in 2012 | Total area change (2001-2012) | Annual area change | Rate of Deforestation | Emission factor over 12 years | Baseline Annual emission |
|---|---|---|---|---|---|---|---|---|
| | Forest to: | ha | ha | ha | ha/yr. | % | | |
| BDNP | Agriculture | 1,723.40 | 1,716.11 | 0.18 | 0.01 | 0.0009 | 25.11 | 4.48 |
| HWS | Agriculture | 1,703.79 | 1,696.36 | 0.09 | 0.01 | 0.0004 | 171.4 | 15.43 |
| HWS | Settlement | | | 0.42 | 0.04 | 0.0021 | 171.54 | 72.12 |
| NDNP | - | - | - | - | - | - | - | - |
| RSBCECA | - | - | - | - | - | - | - | - |
| TGWS | - | - | - | - | - | - | - | - |

Table f: Forest degradation by change of land cover class (forest to degraded forests)

| PA | Land cover change | Total Forests in 2001 | Total Forests in 2012 | Total area change (2001-2012) | Annual area change | Rate of Degradation | Forest Plant | Degraded forest plant | Emission factor over 12 years | Baseline Annual emission |
|---|---|---|---|---|---|---|---|---|---|---|
| | Forest to: | ha | ha | ha | ha/yr. | % | CO2 Mg/Ha | CO2 Mg/Ha | CO2 Mg/ha | CO2 Mg/Ha |
| BDNP | Degraded forest | 1,723.40 | 1,716.11 | 7.11 | 0.59 | 0.0342 | 38.37 | 23.30 | 15.07 | 107.15 |
| HWS | Degraded forest | 1,703.79 | 1,696.36 | 6.82 | 0.57 | 0.0335 | 171.54 | 42.96 | 128.58 | 876.92 |
| HWS | Water | | | 0.09 | 0.01 | 0.0006 | 171.54 | - | 171.54 | 15.42 |
| NDNP | Intertidal area | 4,158.39 | 4,158.20 | 0.18 | 0.02 | 0.0005 | 183.58 | - | 183.58 | 33.04 |
| RSBCA | Degraded forest | 65.80 | 65.56 | 0.23 | 0.02 | 0.0304 | 137.53 | 55.10 | 82.43 | 18.96 |
| RSBCA | Wetlands | 65.80 | 65.56 | 0.0038 | 0.02 | 0.0304 | 137.53 | - | 137.53 | 0.53 |
| TGWS | - | - | - | - | - | - | - | - | - | 0 |

The total area of degraded forest in the five PAs is almost 14.16 ha in 12 years in inventoried area which is almost0.0091% in the five PAs. If all this land was reforested into mature forest then a large amount of $CO_2$ would be sequestered over period that it takes the forest to re-grow. Based on these results the reforestation and effective protection of these lands would be the most significant GHG emission reduction program.

The total emissions from extraction of trees by human interference were estimated at 31,253.53 $CO_2$ Mg from the forests. The annual emissions were not possible to estimate as the age of the stumps were not known Table f).

Table g. Degradation due to human interference (cutting of trees, leaving stumps)

| PA | Stumps | Emissions from extraction of trees | Total CO2 | Percent of total forest CO2 stocks | PA area | Total emissions from extraction of trees CO2 |
|---|---|---|---|---|---|---|
| | N/Ha | CO2 Mg/ha | Mg/ha | % | Ha | Mg |
| BDNP | 1.03 | 1.81 | 28.6 | 0.063286713 | 2,861.76 | 5,179.79 |
| HWS | 0.44 | 0.73 | 141.97 | 0.005141931 | 2,368.02 | 1,728.65 |
| NDNP | 0.94 | 6.06 | 157.32 | 0.038520214 | 4,158.20 | 25,198.69 |
| RSBCA | - | - | 100.44 | 0 | 104.17 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TGWS | 0.19 | 0.15 | 34.96 | 0.004290618 | 2,534.26 | 380.14 |
| Overall average | 0.65 | 2.6 | 99.32 | 0.02617801 | 12026.4 | 31,268.64 |

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The authors

# Acronyms

| | |
|---|---|
| ACCF | Assistant Chief Conservator of Forests |
| ACF | Assistant Conservator of Forests |
| ACL | Assistant Crew Leader |
| Ag | Permanent Agriculture |
| BD | Soil Bulk Density |
| BDNP | Baroiyadhala National Park |
| BFRI | Bangladesh Forest Research Institute |
| C | Carbon |
| CCF | Chief Conservator of Forests |
| CF | Conservator of Forests |
| CFCI | Consultant Forest Carbon Inventory |
| CL | Crew Leader |
| Cm/cm | Centimeter |
| CMC | Co-management Council |
| CMC | Co-management Committee |
| COP | Chief of Party |
| CREL | Climate Resilient Ecosystems and Livelihoods |
| Cum/cum | Cubic meter |
| CV | Coefficient of variation |
| DAB | Diameter above buttress (0.3 m above upper end of buttress |
| DBH, dbh, D | Diameter at Breast Height |
| DCCF | Deputy Chief Conservator of Forests |
| DCF/DFO | Deputy Conservator of Forests/Divisional Forest Officer |
| DCOP | Deputy Chief of Party |
| DF | Degraded forest |
| F | Forest |
| FAO | Food and Agriculture Organization (United Nations) |
| FCI | Forest Carbon Inventory |
| FD | Forest Department |
| FRMP | Forest Resources Management Project |
| G/g | Gram |
| GBH | Girth at Breast height |
| GBH, gbh, G | Girth at breast height |
| GOB | Government of Bangladesh |
| GPS | Global Positioning System |
| Ha, ha | Hectare |
| HWS | Hazarikhil Wildlife Sanctuary |
| IPAC | Integrated Protected Area Co-management Project |
| IUCN | International Union for Conservation of Nature |
| LRS | Long Rotation Species. |
| LUS | Land use class |
| M/m | Meter |
| Mg | Mega gram (Metric Ton) |
| MRV | Measurement, Reporting and Verification |
| NFI | National Forest Inventory |
| NNP | Nijhim Dweep National Park |
| NRM | Natural Resources Management |
| OC | Organic Carbon |
| OD | Oven Dried |
| ODA | Overseas Development Agency |
| PA | Protected Area |
| Pln. | Plantation |
| PSP | Permanent Sample Plots |
| REDD+ | Reducing Emission from forest Deforestation and forest Degradation |
| R-PP | Readiness Preparation Proposal |
| RSBCA | Ratargul Special Biodiversity Conservation Ecologically Critical Area |
| Sag | Shifting agriculture |

| | |
|---|---|
| SG | Stump Girth |
| SOP | Standard Operating Procedures |
| SRF | Sundarbans Reserve Forest |
| SRS | Short Rotation Species. |
| T | Ton (metric) |
| TGWS | Tengragiri Wildlife Sanctuary |
| Tk | Taka |
| TL | Team Leader |
| TOR | Terms of Reference |
| TSP | Temporary Sample Plots |
| UN | United Nations |
| UNDP | United Nations Development Program |
| UNREDD | United Nations Reducing Emission from Degradation & Deforestation |
| USAID | United States Agency for International Development |
| USDA | United States Department of Agriculture |
| USFS | United States Forest Service |
| VF | Village forest |
| WI | Winrock International |

# Forest Carbon Inventory 2016: Five Protected Areas in Bangladesh

M. A. Latif, R M. Chowdhury and M. S. Islam

## 1: Introduction and Background

Bangladesh Forest Department (FD) has been progressing with the implementation of Reducing Emissions from Deforestation and Forest Degradation) REDD+ activities with assistance from Food and Agricultural Organization of United Nations (FAO) and United National Development Program (UNDP). Some of the first steps have been developed for "REDD+ Readiness Roadmap" in December 2012 under the UN-REDD framework, and subsequently in December 2013, developed REDD+ Readiness Preparation Proposal (R-PP) which has a mandate to design and establish National Forest Inventory (NFI). Along with United Nations (UN) agencies, United States Agency for International Development (USAID) has come forward to facilitate implementation of components of the R-PP through a number of programs and through USAID's Climate Resilient Ecosystems and Livelihoods (CREL) project. The CREL project envisages strengthening collaborative management of forest of Protected Areas (PAs) with active involvement of Forest Department and local stakeholders as a follow-up of previous USAID finance Nishorgo Support Project (2003-2008) and Integrated Protected Area Co-management project (IPAC, 2008-2013).

The project took an initiative for conducting forest carbon inventories in a number of Protected Areas (PAs) across Bangladesh. It is anticipated that the Standard Operating Procedure (SOP) for PA level (i.e. sub-national) inventory designs could be taken into account while developing the National Forest Inventory (NFI) under Readiness Preparation Proposal (R-PP 2013) implementation in Bangladesh. As part of this activity the CREL project built capacity of local Forest Department personnel in forest carbon inventory as well as facilitating development of Measurement, Reporting and Verification (MRV) system in Bangladesh.

This document provides the results of Forest Carbon Inventory in five PAs (CREL working sites) following the proposed Standard Operating Procedure (SOP) of Forest Carbon Inventory. One of the primary objectives of writing the SOP to be in line with the future NFI for Bangladesh under UNREDD framework. While developing the proposed SOP, extensive consultation with concerned experts from FD, FAO, WI and CREL team was done; as well as review of earlier forest inventory designs with Bangladesh Forest Department including, Overseas Development Agency, Forest Resources Management Project National Forest and Tree Resources Assessment, Protocols for Measuring & Reporting Carbon Stocks in Mangrove Forests by USDA Forest Service (October 2009), Protocol for Forest Carbon Assessment by USAID's IPAC Project (April 2010), and SOP for Terrestrial Carbon Measurement by Winrock International's Ecosystem Service Unit (2012) were conducted. In particular, the proposed SOP was applied primarily in eight CREL project sites in 2014 and five PAs in 2015:

## 2. Carbon pools for measurements:

There are five carbon pools in a forest. These are 1) aboveground and belowground biomass of live trees including seedlings and saplings, 2) non-tree vegetation, 3) Standing and lying dead wood, 4) forest floor (litter), and 5) soil.

**Aboveground and belowground biomass:** This includes seedlings (all live trees less than breast height (1.3 m); saplings (all live trees reaching breast height (1.3 m), but having a diameter of breast height (dbh)<5.0cm; and trees (all live woody stems having a dbh≥5.0 cm. DBH is the stem diameter at 1.3 m above the ground level.

**Non-tree vegetation:** This includes shrubs, palms, canes, bamboos, lianas, herbaceous vegetation and grasses etc. which contains a large biomass component in the forests.

**Dead woods (standing and lying):** Standing dead woods are dead trees but standing and usually measures as live trees (greater than 5.0 cm DBH and taller than 1.3 m) as well as stumps (when a current height is less than 1.3 m). Lying dead woods refer all woody material on the ground with a diameter ≥10 cm. Lying dead wood is measured using the line-intersect method. The smaller diameter pieces of lying dead woods (diameter <10.0 cm) are considered as litter.

**Litters:** All dead organic surface material (including dead leaves, twigs, dead grasses, and small branches) on top of the mineral soil are considered as litter. Dead woods, on forest floor, with a diameter of less than 10 cm are also considered as litter.

**Soil Carbon:** Soil Carbon pool has three parameters namely i. soil depth, ii. Soil bulk density (BD, mass per volume) and iii. Organic carbon concentration (%OC).

# 3. Forest and Forest Carbon Inventories in Bangladesh

## 3.1 Important Forest Inventories

Bangladesh has a long history of scientific forest management. The first Forest Management Plan for Sundarbans was written by Curtis (1924) with proper data collection and analyses. The first detailed inventory of Sundarbans (Forestal 1960) and Chittagong Hill Tracts (Forestal 1964) was carried out during 1959 to 1963. The inventory of the village forests was carried out by Hammermaster (1981) and others. The Forest Inventory of the Sundarbans Reserved Forest (SRF) was carried out during eighties by Chaffy *et al* (1985) and Revilla and his group during 1994-1996 (Anon. 1966). A total of 1200 sample plots were laid out for collection of inventory data. The Global forest resources assessment 2005 (FAO 2006) was carried out in 2005-2007 covering all over the Bangladesh.

## 3.2 Forest Carbon inventory in the Sundarbans Reserved Forest (SRF) (2009):

The SRF carbon assessment considered 150 out of these 1200 clustered plots composed of five circular subplots of the SRF inventory of 1994-96. Forest Department and USFS expatriates adopted this sampling design. These 150 plots were subset of 1200 temporary sample plots systematically laid at 1 minute interval. The circular subplots in a plot were laid as a center subplot with four more subplots oriented in cardinal directions (east, west, south, and north), 50m from the center. Each subplot had different sized concentric nested circles e.g. 2 m radius for seedlings and saplings, 4m radius for non-tree vegetation, 10m for trees. In addition 30"X30" square plots for litters, 10m transacts from center for woody debris also laid in each plot. For soil samples 0-30cm and 30-100 cm depth were taken from each plot using 1m long open Faced peat auger. Two 5cm-long samples (for bulk density and %OC) were taken from each of the mid-point of 0-30cm and 30-100 cm.

## 3.3 Forest carbon inventory at six protected areas 2010.

Almost similar to SRF inventory (2009) was adopted, by Forest Department and IPAC team, in 6 hill forest PAs at south-eastern part of the country; these includes, Teknaf wildlife sanctuary (TWS), Inani Reserved Forests (IFR), Medakachapia National Park (MNP), Fasiakhali Wildlife Sanctuary (FKWS), Dudpukuria-Dhopachari Wildlife Sanctuary (DDWS), and in Sitakunda eco-park Since these PAs are different in size and fragmented landuses, a varied number of samples designs were laid out with: TWS (area - 11,615 ha, 54 plots at 45 second interval), IRF (7,700 ha, 56 plots at 40″ interval), MKNP (396 ha, 41 plots 12″ interval), FKWS (1302 ha, 72 plots at 15″ interval), DDWS (4717 ha, 62 plots at 30″ interval) and Sitakunda Eco-Park (800 ha, 35 plots at 50″ interval).

## 3.4 Forest carbon inventory 2014 at eight protected areas.

The Climate Resilient Ecosystems and Livelihoods (CREL) project, funded by USAID, implemented by Bangladesh Forest Department (BFD) with technical assistance of Winrock International, conducted forest carbon inventory at eight Protected Areas (PAs) of Bangladesh in 2014. The PAs are Khadimnagar National Park (KhNP), Lawachara National Park (LNP), Satchari National Park (SNP), Rema-Kalenga Wildlife Sanctuary

(RKWS), Modhupur National Park (MNP), Kaptai National Park (KNP), Chunati Wildlife Sanctuary (CWS) and Himchari National park (HNP). Following IPCC guidelines and lessons from previous forest inventories in the country as well as different SOPs of BFD and Winrock International, concentric circular plots were systematically laid out at 30″X30″ intervals. Data were recorded at 2m, 4m, 10m and 17.84m radii plots. Data collected from a total of 377 sample plots in eight PAs covering 34,376 ha and analyzed using MS Excel. This area includes core areas of the PA plus some adjoining area of the Reserved Forests. The CO2 (Mg/ha) estimates were made for five carbon pools, e.g. Trees (seedlings, saplings and live trees), dead wood (standing and lying deadwoods), non-tree vegetation (herbs, shrubs, cane, bamboo, liana etc), litters and soil. The inventory was conducted to establish baselines for forest carbon and biophysical conditions, and the changes that resulted from deforestation and forest degradation. This report describes the methods and results used for CRELs baselines and how those methods and results confirm National REDD+ development as outlined in the 2013 Bangladesh draft R-PP.

The forest carbon inventory resulted in estimates of areas for different Land cover classes, tree recruitments, carbon stocks, deforestation & forest degradation, GHG emissions in the eight selected PAs. The recruitments in different tree size classes are an indication of forest health; therefore, the number of seedlings, saplings and trees per hectare were estimated. The CO2 stocks at different PAs and land cover classes were estimated and are given in Table c. It was observed that the total carbon $CO_2$ (Mg) stock in eight PAs was **8,001,323** Mg in 2014. The carbon stock varied from 52.8 to 370.7 $CO_2$ Mg/ha among the PAs. The highest carbon stock was observed at Rema-Kalenga WS (370.7 $CO_2$ Mg/ha) and lowest at Himchari NP (52.8 $CO_2$ Mg/ha). Emission Factors from deforestations for different PAs from conversion of forest to agriculture, settlements and bare lands varied from 0 to 279.01 $CO_2$ Mg/year with comparatively high 786.2 and 3204.5 $CO_2$ Mg/year at Chunati WS and Modhupur NP respectively.

Two types of degradations were identified from the inventory, one by conversion of forests to degraded forests and another by removal of trees when the stumps were still there. Results show that the conversion of forest to "degraded forest" is the most significant cause of annual GHG emission and loss of forest biophysical condition overall, resulting in approximately 6,487 $CO_2$Mg/year (Table e).Three PAs did not have any emission from the conversion of forest to degraded forest, which is possibly due to effective forest protection (as the case with Lawachara National Park), or it is replaced with forest loss from agricultural expansion (as is the case with Modhupur National Park).

The total emissions from extraction of trees by human interference were estimated at 325,031 CO2 Mg from the forests. The annual emissions were not possible to estimate as the age of the stumps were not known.

The total area of degraded forest in the CREL PAs is almost 9,589 ha in inventoried area which is almost 28% in the eight PAs. If all this land was reforested into mature forest then a large amount of $CO_2$ would be sequestered over period that it takes the forest to re-grow. Based on these results the reforestation and effective protection of these lands would be the most significant GHG emission reduction program.

## 3.5 Forest Carbon Inventory 2015 at five Protected Areas

The field data collection for forest carbon inventory of five PAs namely Baroiyadhala National Park (BDNP), Hazarikhil Wildlife Sanctuary (HWS), Nijhum Dweep National Park (NDNP), Tengragiri Wildlife Sanctuary (TGWS) and Ratargul Special Biodervisity Conservation Ecologically Critical Area (RSBCA) were collected in 2015 and the present report contains the findings of 2015 Forest Carbon Inventory. The figure 1 shows the locations of the selected five PAs.

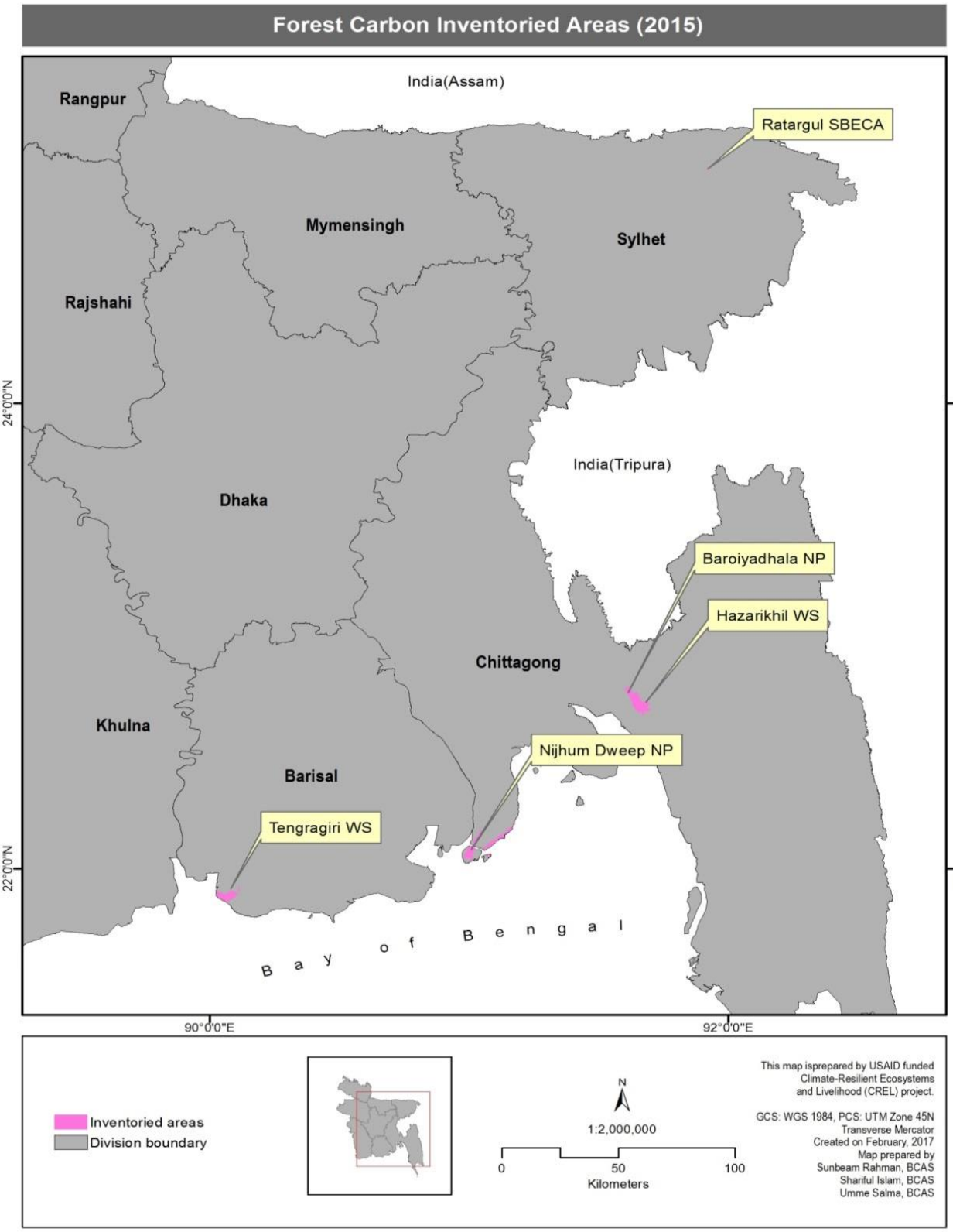



**Figure 1: Locations of five PAs selected for forest carbon inventory 2015**

# 4. Objectives of the Forest Carbon Inventory

The objectives of the present carbon inventory at five PAs were to develop a biophysical baseline of selected PAs as well as inventorying forest carbon stocks in different pools that can be used under a REDD+ framework. One of the primary goals of this inventory and the SOP is to provide a guideline for a NFI under UNREDD Framework.

# 5. Definitions and Sampling Design

## 5.1 Definitions

**Forest:** Land spanning over more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under Agricultural or urban land use.

1. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters in situ.
2. Areas under reforestation that have not yet but are expected to reach a canopy cover of 10 percent and tree height of 5 m are included, as are temporarily un-stocked areas, resulting from human intervention or natural causes that are expected to regenerate.
3. Included areas with bamboo and palms provided that height and canopy cover criteria are reached.
4. Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest.
5. Includes windbreaks, shelterbelt and corridors of trees with an areas of more than 0.5 ha and width of more than 20 m.
6. Included plantations primarily used for forestry or protection purposes, such as rubber-wood plantations and cork oak stands.
7. Excludes trees stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens.

**Bamboo or mixed Bamboo/broadleaved forest:** Forest in which more than 75% of the canopy covers consists of bamboo or more than 50% bamboo in mixture with broadleaved species

**Other wooded land:** Land not classified as "forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these threshold *in situ*; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.

**Other land:** Land not classified as forest or other wooded land, as described above.
Notes: Includes cultivated land, grasslands and pastures, built-on areas, barren land etc. ***Natural*** Land not classified as forest or other wooded land not used by man.

**Built-up areas:** Notes: a road is considered as a distinct Land Use Section (built-up area) is wider than 15 meters (from bottom of ditch on one side to the bottom of ditch on the other side when ditches exists, otherwise the width of the road bank) and is not a forest road.

**Settlements:** Without or with low tree cover, with tree cover; 0.1 – 0.5 ha, with tree cover; >0.5 ha

**Degraded Forests** – Any area of "forest" (see above definition) that has been impacted by human extraction of wood or other vegetation with canopy cover ≤30%

**Forest plantations:** Forests of introduced species and in some cases of native species established through planting or seeding for production of goods and services, characterized by few species, straight tree lines and even-aged stands

**Village forests:** An area of trees that is or can reach a forest definition (see above definition), but is planted within a village.

**Settlements/developments:** An area of developed land with little to no vegetation, such as a road or village.

**Permanent agricultures:** An area of agricultural land that is not allowed to natural re-growth of trees. This could be an area deemed under continuous agriculture at least once every two years.

**Wooded land with shifting cultivation (Fallow):** It refers to woody vegetation deriving from the clearing of natural forest for shifting agriculture. The area is generally allowed to naturally re-grow (3-10 years fallow) before being cleared again.

**Non-tree vegetation:** includes, depending on ecosystem, shrubs, leafy palms, cane, bamboo etc. which consists a large biomass component in the forests.

**Shrubs:** Refers to vegetation types where the dominant woody elements are shrubs i.e. woody perennial plants, generally of more than 0.5 ha area and less than 5 m in height on maturity and without a definite crown. A *shrub* is distinguished from a tree by its multiple stems and shorter height, usually less than 6 m (20 ft) tall.

**Herbaceous plants:** A *herbaceous plant* is a *plant* that has leaves and stems that die down at the end of the growing season. A *herbaceous* border is a collection of perennial *herbaceous plants* (*plants* that live for more than two years and are soft-stemmed and non-woody).

**Tea garden**– An area identified as a tea garden.

**Water bodies** – An area of land that is inundated for the whole year or deemed inundated for a period during the year and agriculture may be practiced during dry seasons.

**Diameter at Breast Height (DBH, D or dbh):** Diameter at Breast Height (DBH, D or dbh) is the stem diameter at 1.3 m above the ground level.

**Seedlings:** Seedlings includes all live trees less than breast height (1.3 m)

**Saplings:** Saplings includes all live trees reaching breast height (1.3 m), but having a Diameter at breast height (DBH or D or dbh) <5.0cm.

**Trees:** Trees includes all live woody stems reaching breast height (1.3 m), having a diameter at breast height of 5.0 cm or greater.

**Standing Dead woods**: Standing dead woods are dead trees but standing and usually measures as live trees (greater than 5.0 cm DBH and taller than 1.3 m) as well as stumps (when a current height of less than 1.3 m).

**Lying dead woods** refer all woody material on the ground with a diameter ≥10 cm. Lying dead wood is measured using the line-intersect method. However, smaller diameter pieces of lying dead woods are considered as litter.

**Stumps:** After a tree has been cut and felled, the stump or tree stump is usually a small remaining portion of the trunk with the roots still in the ground.

**Litters:** All dead organic surface material (including dead leaves, twigs, dead grasses, and small branches) on top of the mineral soil. Dead woods, on forest floor, with a diameter of less than 10 cm are considered as litter.

**Soil Carbon**: Soil C pool has three parameters namely i. soil depth, ii. Soil bulk density (BD; mass per volume), and iii. Organic carbon concentration (%OC).

**Canopy Cover:** Canopy Cover is a measure of presence or absence of forest canopy within a plot. It is estimated using densiometer readings at fixed distances from the plot center. This is measured as an average of 4 cardinal (North, South, East & West) readings of imaginary dots of the densiometer.

## 5.2 Sampling design and sample size

Remaining consistent with previous inventories, it was proposed to follow systematic sampling design at a spacing of 30″ X 30″ within the proposed PAs and their landscape forest reserves. Plots were manually stratified into major land uses prior to the inventory using high resolution satellite imagery. Field maps were developed with the plot centers, Google image as background and with 1:15,000 scales onto A0 paper size. The plots falling in the water bodies were not measured. As best as can be estimated from the high resolution imagery the plots were stratified. The plots centers were plotted at 30"X30" spacing in systematic way in Field Maps on Google images as background with 1:15000 scales onto A0 paper size.

### 5.2.1 Estimation of Sample Size (n):

The minimum number of sample plots (N) was estimated based on the total carbon estimates at different plots at eight PAs inventoried in 2014 (Table 1) with the formula as given below: .

n= (t*s/E)^2= (2*191.1/(207.1*0.1))^2=341

Where:

n= the number of sample plots (sample size),

t= the sample statistic from the t-distribution for 95% confidence interval; here t = 2 was used as the sample size for the present sites is not known.

s (STDEV)= standard deviation estimated from the number of trees found in each plot of Forest Carbon Inventory 2014 at eight PAs.

E = allowable error with 10% allowable error, Calculated by multiplying the mean number of tree/plot by the desired precision, i.e., mean*.1

**Table 1: Parameters of sample size (n) estimation for carbon inventory at proposed 8 PAs.**

| Statistics | Over all |
|---|---|
| STDEV | 191.1 |
| Mean | 207.1 |
| N | 377 |
| t-statistic | 2.0 |
| N (estimated with 10% allowable error) | 341 |

It was observed that approximately 341 plots were required to collect data to have an estimate of carbon stock with 10% allowable error (Table 2). These plots were distributed among the five PAs in proportion to PA areas. When these plots were laid out on maps, it was observed that about 214 plots fall on land and others fall in the water or outside the PA boundary.

**Figure 2: Estimation of Plots falling in different land uses in 5 PAs**

| Sl | Name of PA | Plots in Map grid | Proposed PA area (ha) | Inventory area (ha) | Sample plots (n) proportion to PA area | Map | Water | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | RSBCA | 20 | 1224 | 159.25 | 31 | 20 | | |
| 2 | BDNP | 38 | 2934 | 2,908.88 | 74 | 48 | | |
| 3 | HWS | 29 | 2904 | 2,443.27 | 33 | 36 | | |
| 4 | NDNP (in land area) | 62 | 1,6852 | 4,690.38 | 101 | 73 | 143 | |
| 5 | TGWS (in land area) | 34 | 4050 | 2,774.46 | 102 | 37 | 7 | |
| | Total | 183 | 27,964 | 12,976.5 | 341 | 214 | | |

Remaining consistent with previous inventories, it is proposed to follow systematic sampling design at a spacing of 30″ X30″ within the proposed PAs and their landscape forest reserves at BDNP, HWS, TGWS and NDNP, and 15”X15” at RSBCA to have reasonable number of sample plots to have an acceptable estimates as the PA area is small. The locations of the plots are shown in PA maps Figure 3-7).

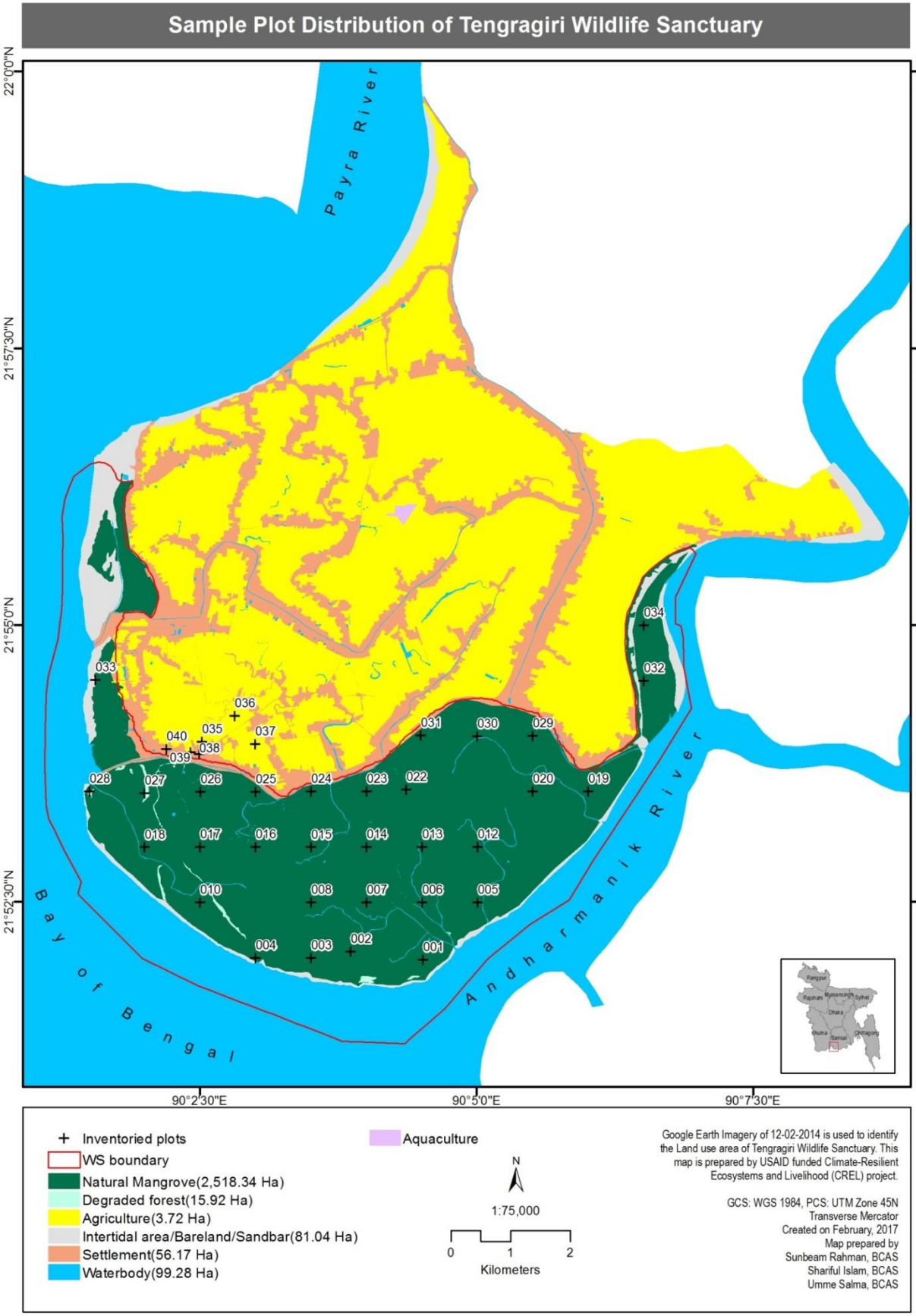



**Figure 3: Map of Tengragiri WS with sample plots locations**

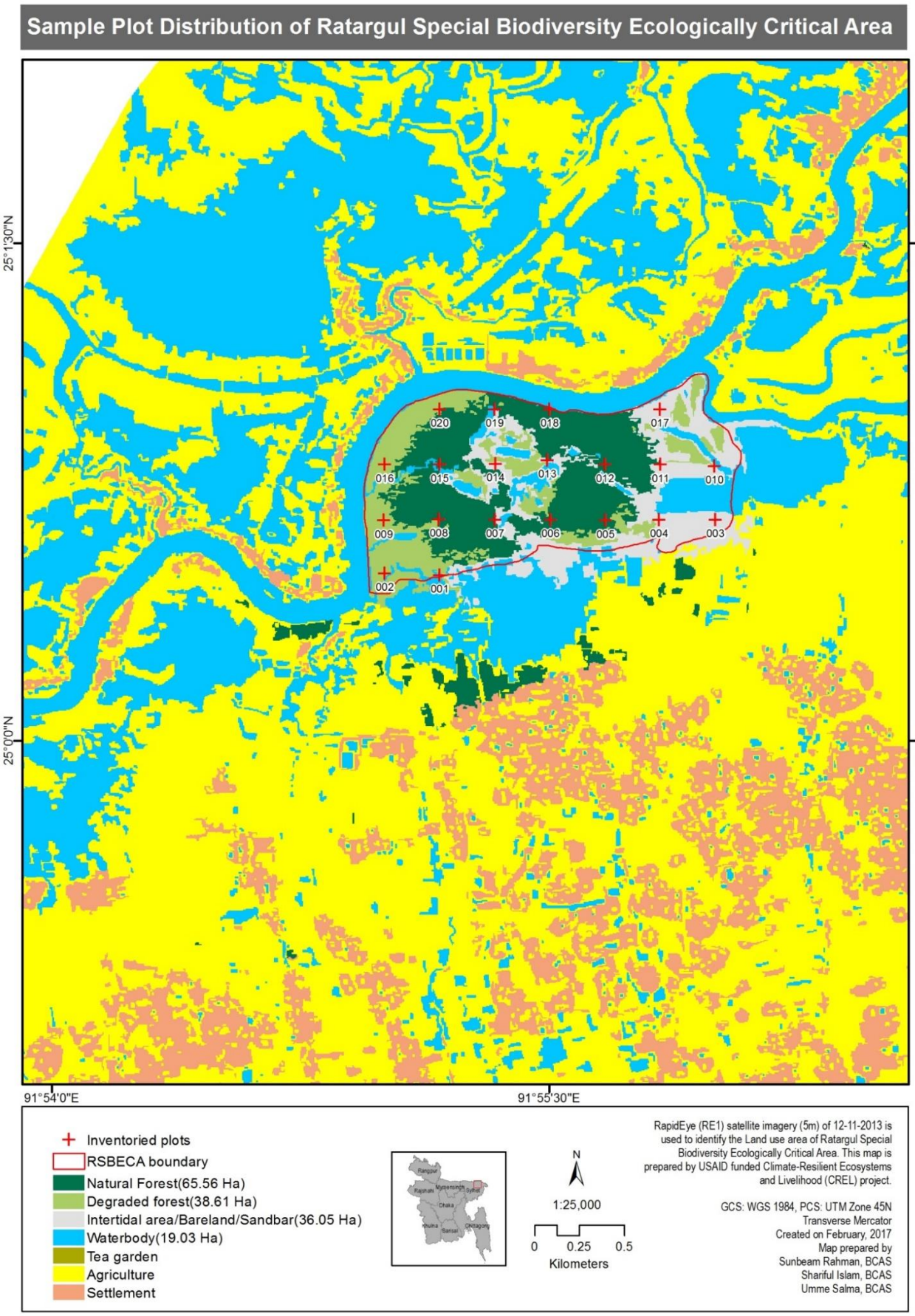



**Figure 4: Map of RSBCEA showing distribution of sample plot**

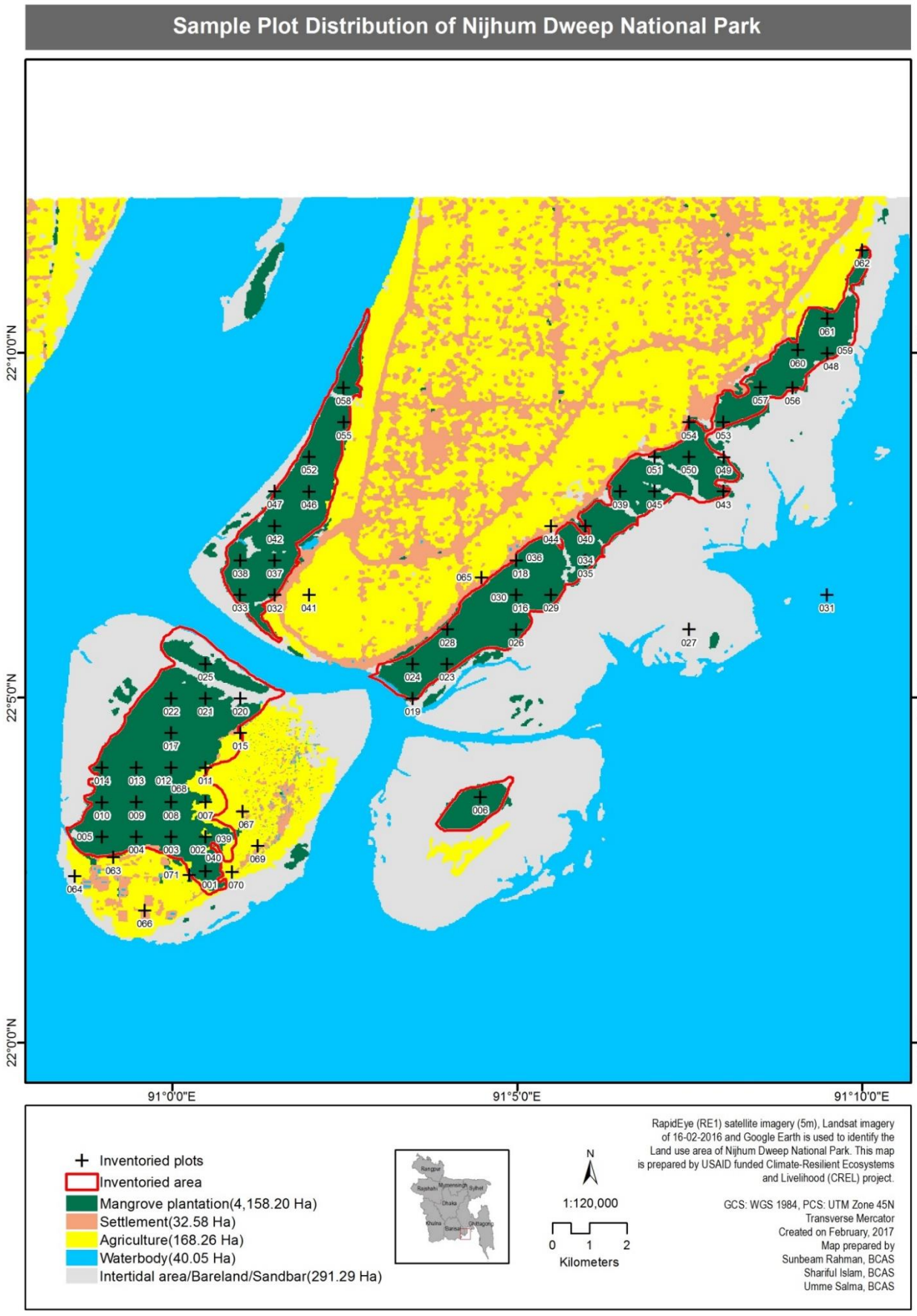



**Figure 5: Map of Nijhum Dweep National Park showing distribution of sample plots**

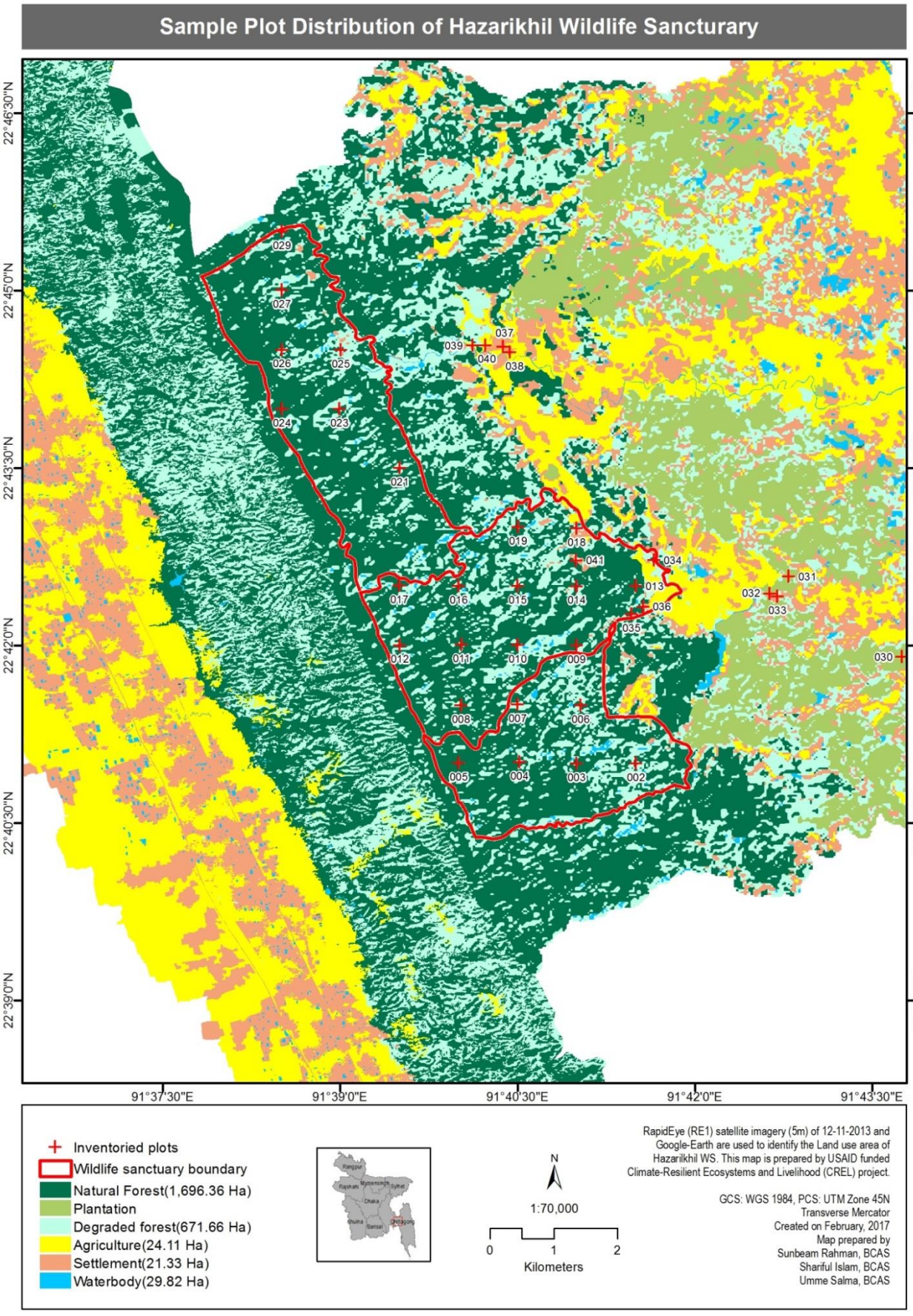



**Figure 6: Map of Hazarikhil WS showing the distribution of sample plots**

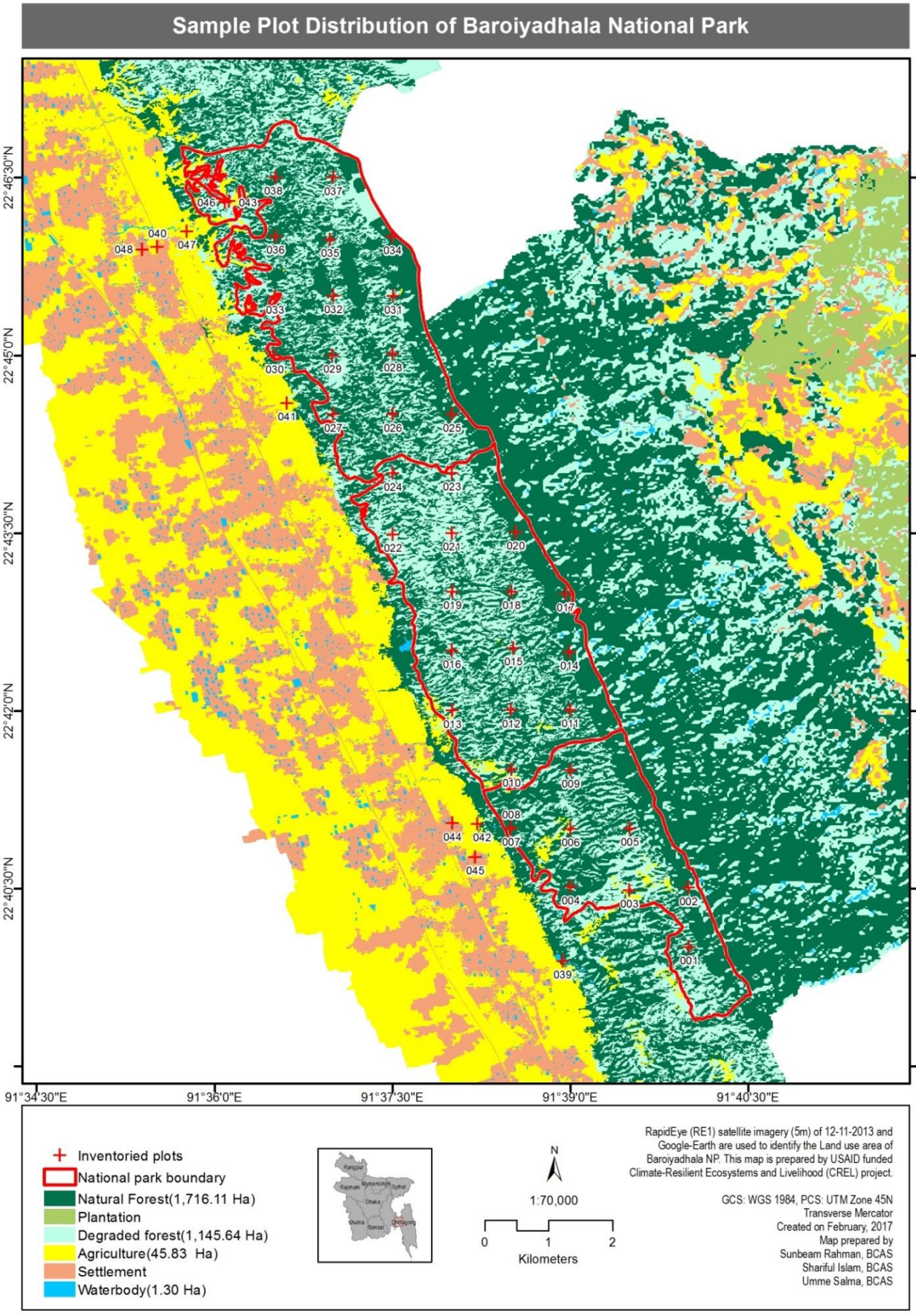



**Figure 7: Map of Baroiyadhala NP showing distribution of sample plots**

# 6. Field Inventory

The training to carry out the Forest Carbon Inventory was organized at Forest Academy, Chittagong in between January 18-20, 2015. The field inventory team members were trained on the use of field equipment and methods. The trainees learned the Standard Operating Procedures (SOP) of measurements, practiced the use of instruments, and discussed probable questions regarding the inventory process. CREL provided all the logistics required support to organize the training program. The experts from CREL, FD & BFRI put their full hearted efforts to make the training towards a successful Forest Carbon Inventory 2015 in the five Protected Areas (PAs) required for establishing the carbon baseline.

The team leaders, NRM personnel and some of the students had participated in the training. The team leaders worked mostly as recorders and reviewers of data. The foresters and students worked as enumerators. Before starting field work each day, the groups sat together with detailed maps and GPS units to plan for the next plots. Local knowledge of laborers, guards, and FD staff aided the crews' efforts to find suitable routes to plots and minimize hiking time. Generally each group completed 2-3 plots per day, but often this pre-planning activity helped the groups to complete sometimes more than 3 plots a day. The field data collection started from February 24, 2015 and continued up to 2nd week of April, 2015.

## 6.1 Data and Sample Management

Strict precautionary measures were taken in the process of data collection and data entry to minimize error. Completed data forms were checked and reviewed in the field. The data entry was reviewed by BCAS officers. At the end of the inventory, completed data forms were stored in physically secure locations (Forest Department/CREL offices). The final electronic data files, including one version with only field-collected numbers and one version with C computations, will be stored with FD personnel and CREL offices. Soil, litter and herbaceous samples were sent to BFRI, Chittagong. Soil carbon analyses were conducted in the laboratory of the soil sciences division of the BFRI. The oven dry weights to a constant weight for other samples were also taken at BFRI laboratory.

## 6.2 Personnel and Training

The Forest Carbon Inventory field data collection was carried out by five inventory teams. Each team was headed by the concerned Assistant Conservator of Forest (ACF) from the local Forest Division. The other members of the field data collection team were as given below:

Local Forester/Beat Officer– 1

Forestry graduate student- 1

Local Forest Guard -1

Local CMO representative -1

Local labour-1

The list of the trainers and trainees and field data collection forms are given in Appendix-I.

## 6.3 Establishment of the sample plots

The plot locations were superimposed on Google maps and classified recent imageries for land uses (e.g. Forests, Degraded Forests, Agriculture, Settlements/developments and Water bodies). The plot locations (latitude &longitude) of the plots for each PA were uploaded to each team's GPS. The team members of the teams approached to the plots with the help of the map and GP. A set of field data collection forms were designed for data collection and are presented in Appendices.

The starting points for access to the plots were marked as way points by signs on trees or by recording the GPS co-ordinates. After reaching to the plot center, the plot center was marked with a uPVC pipe or a stake driven into

the soil. Then, marked three trees that generally surround the plot center and that are as close as possible to plot center with a small dot at DHB height facing plot center, so that they can be used to triangulate plot center in the future if the stake cannot be found.

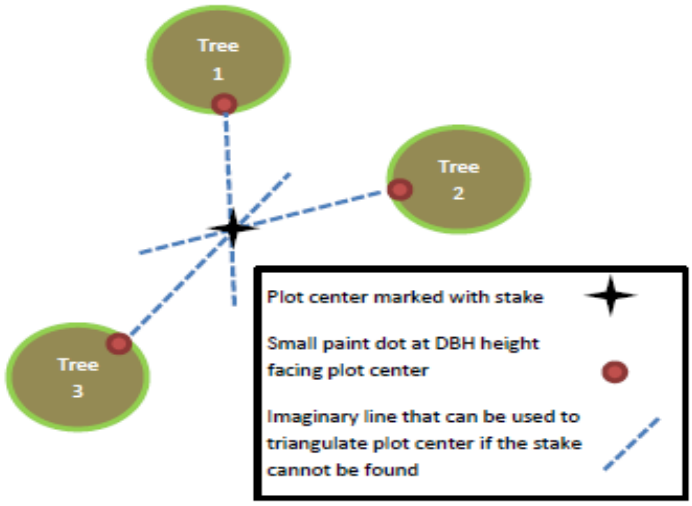



**Figure 8 Example of how to mark the 3 trees around plot center so that they can be used to triangulate plot center in the future if the stake cannot be found.**

It was decided to take concentric circular plots of radii 2m, 4m, 10m and 17.84m. The plot layout is given in Figure 9.

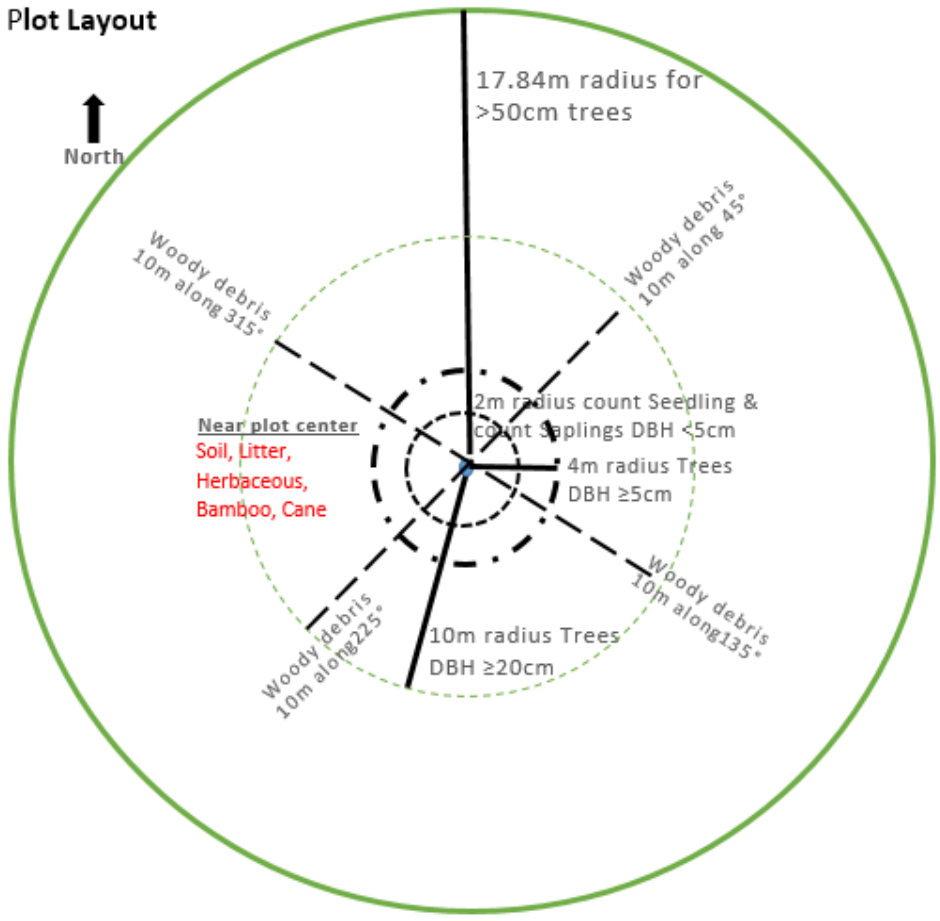



**Figure 9: Plot layout for Carbon Inventory 2015 at 8 PAs in Bangladesh**

## 6.4 Parameters recorded/ measured:

The parameters were recorded/ measured from different sample plots are given in Table 2.

**Table 2: Forest carbon plot dimensions for data collection for different carbon pools**

| Parameters | Activities | Plot radius (m) |
|---|---|---|
| Seedlings count | Counted the number of live seedlings ≤1.3 m tall for all species. | 2 |
| Saplings count | Counted the number of live saplings with DBH≤ 5.0 cm & Height> 1.3 m for all species & recorded the name of the most dominant species. | 2 |
| Trees DBH | Measured DBH of all trees (including standing dead trees) with DBH > 5.0cm with species name<br>Measured stumps (≥10 cm base diameter) diameter | 0 – 4 |
| DBH, heights &counts | Recorded data for non-tree woody. Plot radius was variable with intensity of occurrences | 2, 4, 10 or 17.84 |
| Palm DBH & height | Measured the height of all palm species, and if available DBH | 4 – 10 |
| Trees DBH | Measured DBH of trees ≥50 cm (including standing dead trees), with species name;<br>Measured Stumps (≥10 cm base diameter) | 10 - 17.84 |
| Trees height | Measured heights of three co-dominant trees | 17.84 |
| Lying deadwood | Measured all lying dead wood≥10cm diameter, if it is ≥50% above the ground. Measured along transect line from plot centre to 25m at each cardinal direction (45, 135, 225 & 315 degrees) | 25m long, 4 transects |
| Litter | Measured Litter layer from clip plots of 50cmX 50cm square plot; laid out at 10 meters from the center of the plot at four transects at 45, 135, 225 and 315 degrees. Mixed the four samples thoroughly and took a sub-sample (200-300g) for oven-dry weight estimation. | Square clip plot |
| Grass and herbs | Cut and measured grass and herbaceous vegetation from the square clip plots described above (litter). Mixed the four samples thoroughly and took a sub-sample (200-300g) for oven-dry weight estimation. | Square clip plot |
| Weight of shrubs | In case of plots with shrubs only: Cut all shrubs, took weight of all shrubs and took one sub-sample (200-500g) of the shrubs for oven-dry weight estimation. | 2 |
| Soil Organic Carbon | Soil Samples for estimation of organic carbon were taken using soil sampler/pit method at different locations (covering valley, slope and flat) to 0-15, 16-30 cm depth for hill forests and 0-15, 16-30, 31-50 and 51-80 cm soil depths for coastal. All samples were mixed thoroughly and then took a sub sample (200-300g) for laboratory analyses. | As mention in column 2 |
| Soil Bulk Density | Soil samples for estimation of bulk density (BD) were taken from two depths 0-15, 16-30 cm depth for hill forests and four samples for coastal areas from 0-15, 16-30, 31-50 and 51-80 cm soil depths for coastal. Each bulk density sample was placed in an individual air-tied sample bag for lab analyses. | As mention in column 2 |
| Canopy cover | Took canopy cover with Densiometer at 10 meters from the plot center at four cardinal directions at due north, east, south & west. | At the end of 10 m |

Described land and vegetation conditions of plot (Form-1) and if there is anything unique or unusual in the plot or directly surrounding the plot. This could include things such as small streams, trails, large boulder or termite nest, and proximity to a paved road. Took four photos of the plot and recorded the photo numbers on the plot

sheet. Each photo was taken facing each of the cardinal direction (N, E, S, W). The data collection forms are given in Forms 1-6 at the end of this report.

## 6.5 Measurements of Seedlings, Saplings, Trees and Palms.

The number of seedlings was counted and recorded on data Form 2. Similarly, counted the number of saplings (sapling trees with DBH<5 cm and >1.3 m tall) and recorded. The name of the most dominant species was also recorded.

Then, measured the trees at different concentric radii plots of different DBH classes. To avoid either miss trees or double recording, measurement began from the North and the first tree was flagged. After a tree is measured, a chalk mark facing the center of the plot was marked to allow the person recording the data to track measured and unmeasured trees.

The DBH was measured on the *upslope* side of the tree. Leaning tree were always measured the height of a measurement (1.3 m) parallel with the tree, *not* perpendicular to the ground. Multi-stem tree were recorded it as if each stem were a different tree on the data sheet with a note that the stems make up one tree. For buttressed tree, if the buttress is shorter than 1.3 m, measured the DBH at the standard (1.3 m) height and if the buttress is taller than 1.3 m, measured the diameter at 30 cm above top of buttress. The height of the measurement was with a spot of paint. Tree DBH was measured to the nearest 0.1 cm. The height of trees, palms, and other plants were usually measured by creating two right triangles. The distance from the object and the person measuring was measured and two angles were measured. The actual height is then calculated using trigonometry during data analysis.

The height has a better relationship with biomass than DBH for palm. Heights of palms were measured and recorded on the data sheet Form 2 for all palms in the 10m plot with bole height ≥1.3m. All smaller palms were ignored. Only coconut & date palm were found in the plots

## 6.6 Measurements of Stumps from Human Degradation

To estimate the carbon loss due to human interference, measured the base diameter in cm of all stumps with a base diameter ≥10cm within the 17.84m plot & recorded Form 3A. Recorded yes or no if the stump results in a canopy gap in the forest. A canopy gap is a clear opening (no branches or leaf cover) in the forest canopy that would not otherwise be there if the tree had not been cut.If yes, recorded whether the canopy gap is small, medium or large.

- Small: the gap seems to be no less than 5m across on average. Sunlight would probably not reach the forest floor or only for about an hour per day.
- Medium: the gap seems to be less than 15m across on average. Sunlight would likely reach the forest floor for more than a few hours.
- Large: the gap seems to be greater than 15m across on average. Sunlight would likely reach the forest floor for more than a few hours.

## 6.7 Measurement of Dead Wood

### 6.7.1 Measurement of Standing Dead Wood (not cut by humans) (Form 4A)

Standing dead wood refers to trees that have died but are still upright. Measurements of standing dead wood took concurrently with live tree measurements (following the same plot dimensions as live trees) and record in Form-3A. Each standing dead tree was marked as dead on the plot sheet and classified into two classes (see Figure below):

**Class 1:** Dead tree with branches and twigs and resembles a live tree except for absence of leaves (make sure tree is dead and not deciduous)

**Class 2:** Trees ranging from those containing small and large branches to those with bole only

By classifying trees into these two simplified classes, a conservative estimate of biomass was taken.

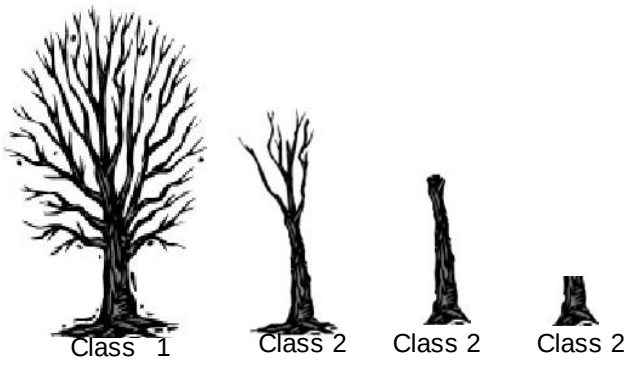



**Figure 10: Example of trees in Class 1 and Class 2**

**Class 1 tree:** Followed the same measurement procedures as for the measurement of live trees; including the measurement of tree variables. Marked tree as 'Dead' on datasheet.

**Class 2 trees:** The biomass of these trees was based on estimating the volume of the remaining tree and multiplying the volume by the wood density. The DBH was measured using methods for live trees. The diameter at the base of the tree ($D_{base}$) was also measured following height of stem (H). The diameter at top of stump ($D_{top,}$) if possible was also measured.

### 6.7.2 Measurement of Lying Dead Wood (Form 4B):

Lying dead wood is defined as all woody material on the ground with a diameter ≥10 cm. Smaller diameter pieces of wood were sampled as part of the litter pool.

It is common to locate lying dead wood transects in association with tree plots. Along the four transects. Four 25 m lines at right angles within the land use type along the four cardinal directions were laid out. Along the length of the line, measured the diameter of each intersecting piece of coarse dead wood (≥ 10 cm diameter. Calipers work best for measuring the diameter.

A piece of dead wood was measured if: (a) more than 50% of the log is aboveground, and (b) the sampling line crosses through at least 50% of the diameter of the piece.

If the log is hollow at the intersection point, measured the diameter of the hollow; the hollow portion in the volume estimates was excluded. Each piece was recorded into three density states: sound, intermediate, or rotten. To determine what density class a piece of dead wood fits into, each piece was struck with a machete. If the machete did not sink into the piece (bounces off), classified it as sound. If the machete sinked partly into the piece, and there had some wood loss, classified it as intermediate. If the machete slicked into the piece, if there were more extensive wood loss, and the piece was crumbly, classified as rotten. The volume of lying dead wood and then carbon stocks were estimated using the diameters of each piece of wood and the length of the line transect.

## 6.8 Measurement of non-tree vegetation:

Non-tree vegetation pool of carbon includes herbs, shrubs, bamboo, cane, lianas etc. The size classes of bamboos were divided into small, medium, and large. Small was based on an average stem size >4cm, medium was based on average stem sized ≤4cm and <8cm, and large ≥8cm. Depending on the intensity of occurrence, measured the

DBH and Height of average bamboo culm for each class from 2m or 4 m or 10 m or 17.84m radius were recorded in Form-5. If the bamboos formed a clump the number of stems was estimated to the best of the ability of the field team. The cane and other non-timber vegetation were also measured similarly.

The small areas where litter and herbaceous (non-woody) was measured are here referred to as 'clip plots'. A square clip plot frame made of PVC pipe 50 cm x 50 cm were made for sampling. It remained in pieces so that it could construct around existing vegetation. The 'elbows' used to connect two pieces of piping together were glued to one piece of piping.

As five individual teams were engaged for data collection, a fixed bearing of 45, 135, 225, 315 degrees and at a distance of 10 m from the center was followed. The weight of an empty polyethylene bag was taken and recorded. Then placed the clip plot at one of the desired four locations, removed all litters, put the litters in the polyethylene bag, then took the weight and recoded the weight. This weight was the weight of empty polyethylene bag + the weight of the litters. Similarly, weights of the litters were taken from remaining three locations and weights were recorded. Then all the four litter samples were placed in the bag, thoroughly mixed and a subsample of about 100-150 g was taken. The sample was then labeled with plot ID#, litter, date of collection and latter send for estimating oven dried weight.

Similar to litter plots, the weight of an empty polyethylene bag was taken and recorded. Then placed the clip plot at one of the desired four locations, removed all herbaceous plants, put in the polyethylene bag, then took the weight and recoded the weight. This weight was the weight of empty polyethylene bag + the weight of the herbaceous plants. Similarly, weights of the herbaceous plants were taken from remaining three locations and weights were recorded. Then all the four herbaceous plant samples were placed in the bag, thoroughly mixed and a subsample of about 100-150 g was taken. The sample was then labeled with plot ID#, herbaceous plants, date of collection and latter send for estimating oven dried weight.

## 6.9 Measurement of Litter:

The litter was defined as all dead organic surface material on top of the mineral soil. Some of this material was still be recognizable (dead leaves, twigs, dead grasses, and small branches) and some was unidentifiable decomposed fragments of organic material. Note that dead wood with a diameter of less than 10 cm was included in the litter layer.

Clip plots were used to sample litter and the same clip plots were also used for herbaceous vegetation measurements. The weight of an empty polyethylene bag was taken and recorded. Then placed the clip plot at one of the desired four locations, removed all litters, put the litters in the polyethylene bag, then took the weight and recoded the weight. This weight was the weight of empty polyethylene bag + the weight of the litters. Similarly, weights of the litters were taken from remaining three locations and weights were recorded. Then all the four litter samples were placed in the bag, thoroughly mixed and a subsample of about 100-150 g was taken. The sample was then labeled with plot ID#, litter, date of collection and latter send for estimating oven dried weight.

## 6.10 Destructive Samples of Seedlings, Saplings, Palms, Bamboos, Shrubs and others

We have volume table and densities of all important tree species in Bangladesh (Appendix II). We used these for estimation of biomasses of trees. But, we do not have equations/models to estimate the biomasses of seedlings, saplings, bamboos, canes& shrubs. We collected destructive samples for estimation of biomasses for these.

### 6.10.1 Measuring the Weight of an Average Sapling & Seedling

The weight of an empty polyethylene bag was taken and recorded. Then selected one/two representative saplings covering the full range of sizes (from small to large samples) were cut and put in the polyethylene bag (cutting

into small pieces if required), then took the weight and recoded the weight. This weight was the weight of empty polyethylene bag + the weight of the saplings. Then a subsample of about 100-150 g was taken. The sample was then labeled with plot ID#, sapling, and date of collection and latter send for estimating oven dried weight.

Similarly, seedlings were cut, weight and properly labeled and latter send for estimating oven dried weight.

### 6.10.2 Destructive Sampling of non-tree vegetation

The weight of an empty polyethylene bag was taken and recorded. Then, one representative vegetation covering the full range of sizes (from small to large samples) were cut and put in the polyethylene bag (cutting into small pieces if required), then took the weight and recoded the total weight. This weight was the weight of empty polyethylene bag + the weight of the vegetation. Then a subsample of about 100-150 g was taken. The sample was then labeled with plot ID#, vegetation, and date of collection and latter send for estimating oven dried weights.

## 6.11 Canopy cover

Canopy Cover is a measure of presence or absence of forest canopy within a plot. It is estimated using densiometer readings at fixed distances from the plot center. This is measured as an average of 4 cardinal (North, South, East & West) readings of imaginary dots of the densiometer.

A spherical densiometer was used to estimate canopy cover. The densiometer was hold about 30-40 cm in front of body of the observer and at elbow height, so that head is not visible in the mirror and level the instrument using the level bubble.

In each square of the grid, there are four dots, representing the center of quarter-square subdivisions of each of the squares (Figure 12). Systematically counted the number of dots NOT occupied by canopy sky at that dot).Recorded this number on the datasheet. Made four readings per plot at 10m from plot center in each of the 4 cardinal directions (north, south, east, and west).

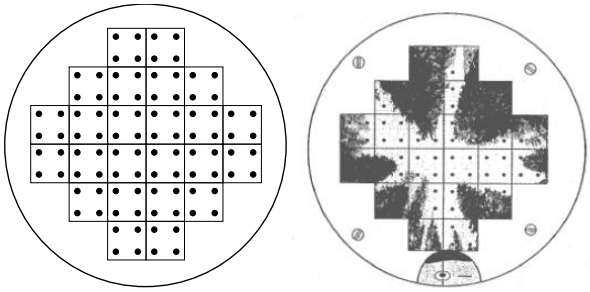


**Figure 11: Schematic of densitometer mirror, with the 4 dots depicted in each square. Count the number of dots NOT occupied by the canopy, in the 4 cardinal directions at each subplot.**

## 6.12 Soil % Organic Carbon and Bulk density

Soil carbon was estimated by collecting soil to a depth of 0-30 cm and then analyzing it at BFRI laboratory for carbon content. This information was then combined with a collected bulk density measurement to estimate the average mass of carbon within the soil to a certain depth.

### 6.12.1 Soil % Organic Carbon

Soil samples were collected following Soil pit method. Pits were dug one at top, one at valley, one at slope and the last one on flat locations (covering all different soil carbon deposits) in the hilly areas, took uniform thick slice (0-15 and 16-30 cm) of soil from vertical walls of each of soil pits. The slices were uniform throughout the profile. Then mixed all samples thoroughly to a uniform color and consistency and placed one thoroughly mixed subsample of about 200 gram soil into a labeled sample bag for laboratory analyses. The bag was labeled as % OC with Plot ID number and date of collection. The soil samples from the NDNP and TGWS were taken at 0-15 cm, 16-30 cm, 31-50 cm and 51-80 cm depths following the same sampling procedure due to distinct Characteristics of the coastal soils. The land configuration of these two PAs was almost flat, there was no need to distribute the plots in top, valley or flat.

### 6.12.2 Soil Bulk Density

Took samples in the same pit dug for carbon estimation soil sample for estimation for Bulk density estimation. Two samples were taken using a bulk density ring one at 0-15cm depth and a second at 16-30cm depth for hill forests. When taking samples of bulk density, care was taken to avoid any loss of soil from the ring and any compaction of soil. The goal of the bulk density sample is to get an accurate quantity and density of soil from each layer. Covered the bulk density ring with a piece of wood and hammered the ring into the side of the soil pit (avoid compacting the soil).

When the ring was flush with the side of the soil pit dug around the ring until the soil ring could be removed along with all the soil inside. If soil falls out of the ring, the process was repeated. Carefully placed the soil contained in the bulk density ring into a sample bag and labeled BD1 and BD2 along with Plot ID number and date of sample collections. The soil samples for estimation of bulk density of the soils of NDNP and TGWS were taken at 0-15 cm, 16-30 cm, 31-50 cm and 51-80 cm soil depth following the same procedures.

Therefore, each sampling plot (e.g. tree plot) had four soil samples: two bags for soil carbon estimation and two bags for bulk density estimation for hill forests. For NDNP and TGWS two samples for each of 0-15 cm, 16-30 cm, 31-50 cm and 51-80 cm soil depths were taken one for carbon estimation and one for bulk density estimation. So, there were four samples for carbon estimation and four samples for bulk density estimations. Attempts were taken to collect Soil samples from at least three plots for each of the major land uses to have an acceptable estimates.

## 6.13 Laboratory Processing of Soils and plant samples

Soils samples were sent to BFRI laboratory for estimation of percentage of organic carbon and bulk density following the standard procedures. The analyzed data have been used to soil carbon estimation. The non-tree vegetation sub-samples have also been sent to determine the oven dry constant. These data were used to estimate the forest carbon and carbon dioxide reserved in the forest.

# 7. Data compilation:

Data were entered manually in computer from the data collection Forms. The data forms were handy and easy to computer processing with small modifications. The procedures of data compilation for different components are given below:

## 7.1 Live Trees:

a) Above ground Volume ($cm^3$) = Estimation of volume by using available volume functions table (Appendix II).
b) Wood densities from wood density table (Appendix II).

c) Adjusted plot area (m^2) = COS (RADIANS (Slope in degrees))*PI()*(Plot radius)^2 (The terrain was hilly. So, slope corrections were necessary to get the proper estimates.
d) Plot area expansion factor to hectare = 10000/Adjusted plot area
e) Above ground biomass (g/cm^3) = Volume (cu cm) * Wood density (g/cm^3)*1.2 ( a factor to includes biomasses of branches + leaves (factor)
f) Gram biomass to Kilograms: (Kg = No. 5/1000)
g) Plot area expansion factor *biomass (volume*density)*0.5 (to convert biomass to carbon and then divide by 1000 (to convert kilogram to tone, Mg/ha)
h) Above ground CO2= Above ground C*44/12 is the above ground CO2 adjusted (Mg/ha)
i) Below ground CO2 adjusted (Mg/ha) = Above ground CO2 (Mg/ha)*.24
j) The sum of 8 and 9 above gives the total CO2 Mg/ha.

The detailed procedures and results are given in different worksheets of the spreadsheet files.

## 7.2 Compilation of Stumps:

For human degradation and loss

a) Estimate the volume of the stumps in cubic centimeters
b) Consider a stump height (say here it is 20 cm)
c) The plot radius for stump plots was 17.84m.
d) Convert the slope in degrees (as it was taken in %) = Degrees(ATAN(slope %/100)
e) Estimated the adjusted plot area as the field is not flat as=COS(RADIANS(DEGREE))*pi()*plot Radius^2
f) Calculate the plot area expansion factor to hectare=10000/Adjusted plot area
g) Estimate the volume per tree by using available volume function for the species, if not found then use function for misc species
h) Record the wood density.
i) Estimate biomass in kg=PI()*(base diameter/2)^2*stump height/10000
j) C carbon =Biomass in kg*0.5
k) Estimate below ground C stump Mg)= Above ground biomass*0.24
l) Above ground C adjusted (Mg/ha)=Plot area conversion factor to hectare*C of the stump (Mg)
m) Estimate the below ground C adjusted (Mg/ha)= Above ground AC4*W4
n) Above ground CO2 adjusted (Mg/ha)= C biomass*44/12
o) Below ground CO2 adjusted (Mg/ha)= Above ground CO2 adjusted (Mg/ha)*0.24
p) The sum of above 14 and 15 is the total stump CO2 Adjusted (Mg?ha)
q) Estimate the biomass of the tree prior to cutting (Kg)=Volume*density/1000
r) Estimated above ground CO2 adjusted (Mg/ha)=Estimated above ground C with branches and leaves*44/12
s) Below ground CO2 = Above ground CO2 adjusted *0.24
t) Total CO2 is the sum of 18 and 19 above.

## 7.3 Standing dead wood:

a) Volume(cu cm)=1/3*pi()*(Base diameter/2)^2*stump height in centimeter
b) Adjusted Plot area= COS(RADIANS(DEGREE))*pi()*plot Radius^2
c) Plot area expansion factor to hectare=10000/ Adjusted Plot area
d) Biomass (Kg) above ground including branches and eaves=Volume*density*1.2/1000
e) Above ground C adjusted (Mg/ha)= Plot area expansion factor to hectare*biomass above ground*0.5/1000
f) Above ground CO2 adjusted (Mg/ha)= Above ground C adjusted (Mg/ha)*44/12
g) Below ground CO2 Adjusted (Mg/ha)= Above ground CO2 adjusted (Mg/ha)* 0.24

## 7.4 Lying dead wood:

The estimates were made by the methods described in SOP, WI 2012.

## 7.5 Non-tree Vegetation:

- Biomass above ground=Number of clump*number of culm/clump*average weight/culm*conversion factor to estimate oven dry weight from green weight
- Above ground C adjusted (Mg/ha) = Plot area expansion factor to hectare*above ground biomass * conversion factor to estimate oven dry weight*0.5/1000
- Above ground CO2 adjusted (Mg/ha) = Above ground C adjusted (Mg/ha) *44/12
- Below ground CO2= Above ground CO2 adjusted (Mg/ha) *0 .24
- 3+4 above gives the total

## 7.6 Saplings & Seedlings:

a) Adjusted plot area (m^2)=Cos(Radians(slope in degrees)*pi()*Plot rarius^2
b) Plot area expansion factor to hectare=1000/ Adjusted plot area
c) C biomass above ground (Kg)=Number of saplings*weight per seedlings*wood density*0.5/1000
d) C below ground = C biomass above ground (Kg)*0.24
e) Above ground C/ha adjusted =Plot area expansion factor to hectare*C Biomass above ground(Kg)/1000

## 7.7 Litters/Herbaceous:

- Adjusted plot area (m^2)=Cos(Radians(slope)*pi()*Plot radius^2
- Plot area expansion factor to hectare=10000/Adjusted plot area
- C biomass above ground (Kg)=Litter weight/plot*conversion factor to estimate oven dry weight
- Above ground C adjusted (Mg/ha) = Plot area conversion factor to hectare*C biomass above ground(kg)*0.5/1000
- Above ground CO2 adjusted (Mg/ha)= Above ground C adjusted (Mg/ha)*44/12
- Below ground CO2 adjusted (Mg/ha) = Above ground CO2 adjusted (Mg/ha)*0.24
- 5 + 6 above make the total

# 8 Results and Discussions:

During data analyses, it was observed that Land Cover Classes (LCC) Categories were used some times with the same or similar meanings. Therefore, these similar Land Cover Classes were grouped together with the similar one name and reduced to eight LCC only. Then area estimated to estimate for carbon stocks.

## 8.1 Land covers areas:

It was not possible to different natural forests and plantations during satellite imagery (RapidEye, 2013) analyses. Therefore, the natural forests and plantations in the hills and coastal areas areas was grouped together as forests. and field inventory sample plots identified six land cover classes identified from satellite imagery. in the PAs inventoried. The area distributions in different land cover classes are given in Table 3.

**Table 3: Area estimates for different Land Class Category in inventoried five PAs**

| Land cover class | BDNP | HWS | NDNP | RRF | TGWS | Grand Total |
|---|---|---|---|---|---|---|
| Forest | 1,716.11 | 1,696.36 | 4,158.20 | 65.56 | 2,518.34 | 10,154.57 |
| Degraded forest | 1,145.64 | 671.66 | | 38.61 | 15.92 | 1,871.83 |
| Settlement | | 21.33 | 32.58 | | 56.17 | 110.08 |
| Agriculture | 45.83 | 24.11 | 168.26 | | 3.72 | 241.92 |
| Water | 1.30 | 29.82 | 40.05 | 19.03 | 99.28 | 189.47 |
| Intertidal area/Bareland/Sandbar | | | 291.29 | 36.05 | 81.04 | 408.38 |
| Grand Total | 2,908.88 | 2,443.27 | 4,690.38 | 159.25 | 2,774.46 | 12,976.25 |

It was possible during field inventory to differentiate the natural forest (called Forest), plantation forests (Plantations), rubber znd tea gardents. A total of 214 sample plots were laid out at five selected PAs. The number of sample plots laid out in five PAs for each Land Cover Classes are recounted and presented in Table 5.

Table 4: Distribution of Plots at Different Land Use Category based on Inventory in the selected five PA

| PA | Agriculture | Degraded Forest | Natural Forest | Plantation Forest | Settlement | Rubber & Tea Garden | Grand Total |
|---|---|---|---|---|---|---|---|
| BDNP | 5 | 12 | 19 | 7 | 5 | | 48 |
| HWS | 3 | 5 | 15 | 4 | 3 | 6 | 36 |
| NDNP | 5 | 11 | | 52 | 5 | | 73 |
| RSBCA | | 9 | 11 | | | | 20 |
| TGWS | 3 | 3 | 26 | 2 | 3 | | 37 |
| Grand Total | 16 | 40 | 71 | 68 | 16 | 6 | 214 |

The plant samples collected for estimation of carbon stocks were sent to Bangladesh Forest Research Institute, Chittagong. The results are given in Table 5

**Table 5: Conversion factors to estimate oven dry weights from green weights in the selected five PAs**

| PA | Bamboos | Canes | Grass & Herbs | Litters | Saplings | Seedlings | Shrubs |
|---|---|---|---|---|---|---|---|
| BDNP | 0.493 | | 0.310 | 0.868 | 0.391 | 0.431 | 0.341 |
| HWS | 0.334 | 0.447 | 0.382 | 0.837 | 0.441 | 0.325 | 0.472 |
| NDNP | | | **0.210** | 0.690 | 0.457 | 0.372 | |
| RSBCA | | | 0.315 | 0.795 | 0.246 | 0.326 | |
| TGWS | | | 0.376 | 0.803 | 0.429 | 0.421 | 0.462 |
| Grand Total | 0.468 | 0.447 | 0.329 | 0.828 | 0.408 | 0.390 | 0.449 |

Soil carbon carbon were estimated for o-15 cm and 16-30 cm depths which was pooled to 0-30 cmdepths for mainland forests. Simillarly the soils of coastal PAs (NDNP & TGWS) were estimated for 0-15, 16-30, 31-50 and 51-80 cm depths and pooled to estimate 0-80 cm depth. The estimated soil carbon stocks are presented in Table 6.

**Table 6: The soil carbon stocks stored in the soils of five inventoried for different land use classes of the five selected Protected Areas (PAs) during 2015**

| PA | Soil Depths (cm) | Agriculture | Degraded Forest | Natural Forest | Plantation Forest | Settlement | Tea Garden |
|---|---|---|---|---|---|---|---|
| BDNP | 0-30 | 25.02 | 42.25 | 51.478 | 42.38 | 26.01 | |
| HWS | 0-30 | 45.57 | 40.904 | 37.95 | 28.60 | 28.31 | 25.56 |
| NDNP | 0-80 | 50.50 | 40.688 | | 84.91 | 41.23 | |
| RSBCA | 0-30 | | 36.429 | 37.05 | | | |
| TGWS | 0-80 | 26.15 | 77.476 | 93.05 | | 49.57 | |

Carbon stocks were estimated for different sub-pools (i.c: live tree, seedlings and saplings), dead wood (standing and lying trees), non-tree vegetation (herbs & grasses, shrubs, bamboos ans canes) and litters. Carbon stocks for different land cover classes and carbon pools in the inventoried five Protected Areas were estimated and are given In Table 7.

**Table 7: Carbon stock estimates for different land cover classes and carbon pools for the five inventoried Protected Areas**

| PA | Land Cover Class | Trees CO2 (Mg/ha) | Dead Wood CO2 (Mg/ha) | Non-Tree Vegetation CO2 (Mg/ha) | Litter CO2 (Mg/ha) | Plant CO2 (Mg/Ha) | Soil Carbon (Mg/ha) | Soil CO2(Mg/ha) | Grand Total CO2 Mg/ha |
|---|---|---|---|---|---|---|---|---|---|
| BDNP | All LCC | 24.21 | 1.33 | 0.39 | 2.66 | 28.60 | 42.44 | 155.60 | 184.19 |
| BDNP | Forest | 34.12 | 0.00 | 0.67 | 3.58 | 38.37 | 51.48 | 188.75 | 227.12 |
| BDNP | Plantation | 14.71 | 9.15 | 0.21 | 3.44 | 27.50 | 42.38 | 155.40 | 182.91 |
| BDNP | Degraded Forest | 20.63 | - | 0.21 | 2.46 | 23.30 | 42.25 | 154.91 | 178.21 |
| BDNP | Settlement | 20.54 | - | 0.06 | 0.43 | 21.02 | 26.01 | 95.37 | 116.39 |
| BDNP | Agriculture | 12.16 | - | 0.32 | 0.78 | 13.26 | 25.02 | 91.75 | 105.01 |
| HWS | All LCC | 123.05 | 15.18 | 0.79 | 2.95 | 141.97 | 35.34 | 129.58 | 271.55 |
| HWS | Forest | 166.77 | 0.28 | 0.31 | 4.17 | 171.54 | 37.95 | 139.16 | 310.70 |
| HWS | Plantation | 98.77 | - | 1.51 | 4.04 | 104.32 | 40.34 | 147.92 | 252.24 |
| HWS | Degraded Forest | 38.33 | 0.00 | 1.68 | 2.93 | 42.94 | 40.90 | 149.98 | 192.92 |
| HWS | Settlement | 203.89 | 185.84 | - | - | 389.73 | 28.31 | 103.82 | 493.55 |
| HWS | Agriculture | - | - | 0.14 | - | 0.14 | 45.57 | 167.09 | 167.23 |
| HWS | Rubber | 160.21 | - | 0.68 | 3.58 | 164.46 | 24.68 | 90.50 | 254.96 |
| HWS | Tea Garden | 124.02 | - | 2.54 | 1.72 | 128.28 | 25.56 | 93.71 | 221.99 |
| NDNP | All LCC | 155.98 | 0.01 | 0.02 | 1.31 | 157.32 | 72.73 | 266.69 | 424.01 |
| NDNP | Plantation | 182.04 | 0.01 | 0.03 | 1.50 | 183.58 | 84.91 | 311.35 | 494.93 |
| NDNP | Degraded Forest | 161.92 | 0.01 | - | 1.41 | 163.35 | 40.69 | 149.19 | 312.54 |
| NDNP | Settlement | 33.00 | - | 0.01 | 0.55 | 33.55 | 41.23 | 151.16 | 184.72 |
| NDNP | Agriculture | - | - | 0.00 | - | 0.00 | 50.50 | 185.17 | 185.18 |
| RSBCECA | All LCC | 98.48 | - | 0.49 | 1.48 | 100.44 | 36.77 | 134.82 | 235.26 |
| RSBCECA | Forest | 135.34 | - | 0.18 | 2.01 | 137.53 | 37.05 | 135.84 | 273.37 |
| RSBCECA | Degraded Forest | 53.42 | - | 0.86 | 0.83 | 55.10 | 36.43 | 133.57 | 188.68 |
| TGWS | All LCC | 34.65 | 0.00 | 0.06 | 0.24 | 34.96 | 82.84 | 303.74 | 338.70 |
| TGWS | Forest | 48.29 | 0.00 | 0.01 | 0.35 | 48.65 | 93.05 | 341.19 | 389.84 |
| TGWS | Plantation | - | 0.01 | 0.06 | - | 0.07 | 93.05 | 341.19 | 341.26 |
| TGWS | Degraded Forest | 8.87 | - | 0.03 | - | 8.90 | 77.48 | 284.08 | 292.98 |
| TGWS | Settlement | - | - | - | - | - | 49.57 | 181.75 | 181.75 |
| TGWS | Agriculture | - | - | 0.62 | - | 0.62 | 26.14 | 95.86 | 96.48 |
|  | Overall average | 94.38 | 2.93 | 0.29 | 1.73 | 99.32 | 57.86 | 212.15 | 311.47 |

The carbon stocks (CO2 Mg/ha) were also estimated for different land cover classes for the five inventoried Protected Areas during 2015 were estimated and are given in Table 8.

**Table 8: Carbon stock $CO_2$ estimates (excluding soil) for different land cover classes at the five inventoried Protected Areas**

| Land cover class | BDNP | HWS | NDNP | RSBCECA | TGWS | Grand Total |
|---|---|---|---|---|---|---|
| Natural Forest | 38.37 | 171.54 | | 137.53 | 48.65 | 85.63 |
| Plantation Forest | 27.50 | 104.32 | 183.58 | | 0.07 | 155.82 |
| Degraded Forest | 23.30 | 42.94 | 163.35 | 55.10 | 8.90 | 70.35 |
| Settlement | 21.02 | 389.73 | 33.55 | | - | 90.13 |
| Agriculture | 13.26 | 0.14 | 0.00 | | 0.62 | 4.29 |
| Rubber | | 164.46 | | | | 164.46 |
| Tea Garden | | 128.28 | | | | 128.28 |
| Grand Total | 28.60 | 141.97 | 157.32 | 100.44 | 34.96 | 99.32 |

## 8.2 Biophysical Results

The numbers of seedlings, saplings, trees and stumps per hectare for different land cover classes at different PAs were estimated and are given in Table 9 and overall for all PA in Table 10. The overall data are also shown graphically in Figure 12.

**Table 9: Number of seedlings, saplings, trees and stumps in different PAs and Land Cover Classes**

| PA and land cover class | Seedlings (N/ha) | Saplings (N/ha) | Trees (N/ha) | Stumps (N/ha) |
|---|---|---|---|---|
| BDNP | 4,293.87 | 1,210.24 | 1,370.30 | 8.75 |
| Agriculture | 5,729.58 | - | 239.18 | - |
| Degraded Forest | 3,846.24 | 1,458.92 | 1,357.26 | 8.33 |
| Natural Forest | 4,313.94 | 1,172.72 | 1,601.20 | 3.16 |
| Plantation Forest | 5,229.38 | 1,818.91 | 1,589.09 | 32.86 |
| Settlement | 2,546.48 | 1,114.08 | 1,348.98 | 6.00 |
| HWS | 1,812.60 | 707.36 | 1,143.92 | 3.61 |
| Bare land | - | - | - | - |
| Degraded Forest | 1,273.24 | 1,273.24 | 543.61 | 6.00 |
| Natural Forest | 2,758.69 | 1,220.19 | 2,035.33 | - |
| Plantation Forest | 2,501.01 | 113.68 | 1,012.50 | 12.86 |
| Settlement | - | - | 209.16 | 10.00 |
| Tea Garden | - | - | 212.21 | - |
| NDNP | 9,451.19 | 9,178.66 | 2,120.39 | 8.08 |
| Agriculture | - | - | - | - |
| Bare land | - | - | - | - |
| Degraded Forest | 14,613.32 | 11,213.19 | 2,716.69 | 0.91 |
| Plantation Forest | 10,567.89 | 10,933.94 | 2,286.36 | 11.60 |
| Settlement | 159.15 | - | 2,117.43 | - |
| RSBCA | 2,984.16 | 119.37 | 891.31 | - |
| Degraded Forest | 2,741.00 | 176.84 | 723.57 | - |

| | | | | |
|---|---|---|---|---|
| Natural Forest | 3,183.10 | 72.34 | 1,028.55 | - |
| TGWS | 2,215.26 | 1,053.86 | 1,164.73 | - |
| Agriculture | - | - | - | - |
| Bare land | - | - | - | - |
| Degraded Forest | - | - | 888.62 | - |
| Natural Forest | 3,152.49 | 1,499.73 | 1,530.48 | - |
| Plantation Forest | - | - | 318.31 | - |
| Overall | 5,153.94 | 3,714.85 | 1,507.78 | 5.33 |

**Table 10: Average number of Seedlings/ha, Saplings/ha and tree/ha (Recruitments) in the forest land for all land cover classes**

| PA | Seedlings (N/ha) | Saplings (N/ha) | Trees (N/ha) | Stumps (N/ha) |
|---|---|---|---|---|
| BDNP | 4,294 | 1,210 | 1,370 | 8.75 |
| HWS | 1,813 | 707 | 1,144 | 3.61 |
| NDNP | 9,451 | 9,179 | 2,120 | 8.08 |
| RSBCA | 2,984 | 119 | 891 | - |
| TGWS | 2,215 | 1,054 | 1,165 | - |
| Grand Total | 5,154 | 3,715 | 1,508 | 5.33 |

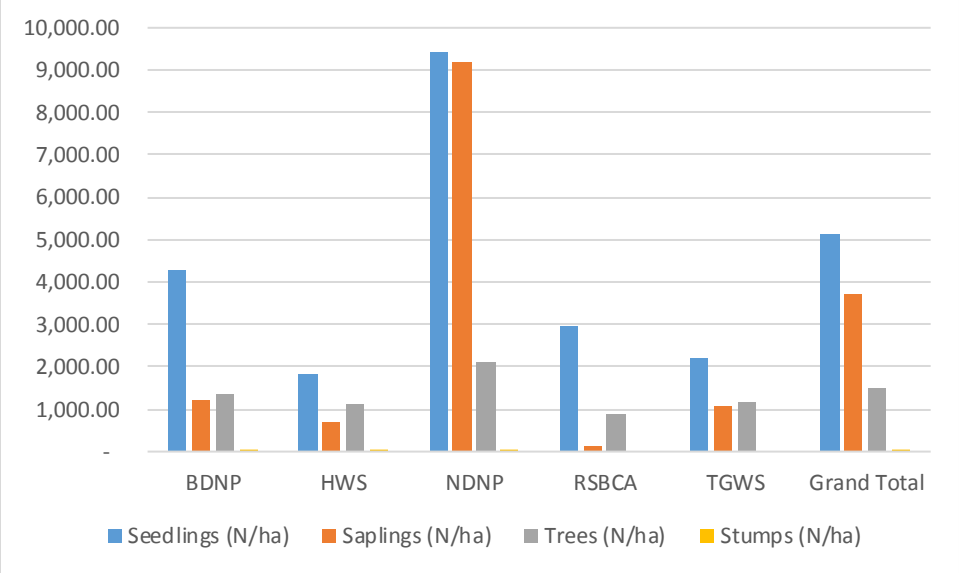



**Figure 12: Number of seedlings, saplings and trees per hectare in the inventoried forest areas**

Total area inventoried (in 5 PAs): 12976.25 ha
Average for all five PA Carbon Stock (CO2):11.47 Mg/ha
Over all Total CO2 Stock (Mg) in 5 PAs: 4,041,713 Mg/ha

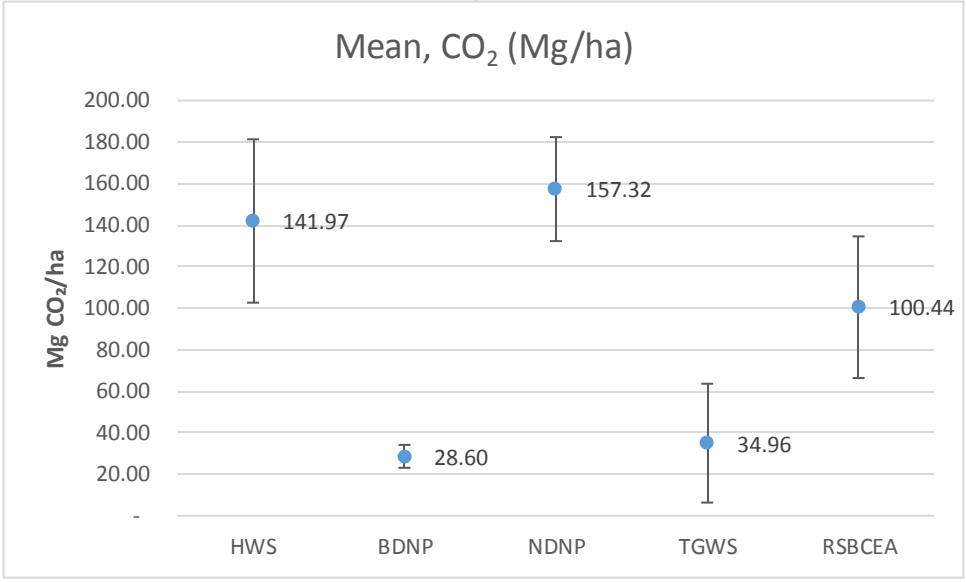
It was observed that the total carbon CO2 (Mg) stock in five PAs was 4,041,713 Mg/ha. The carbon varied from 184.19 to 424.01 $CO_2$ for each PA. The highest carbon stock was observed at NDNP and lowest at BDNP (Table 8).

The confidence intervals at 90% confidence level were estimated to have an idea about the estimates and are given in Table 11 and figure 13

**Table 6: Mean $CO_2$ (MG/ha) stock with confidence level (All land cover classes)**

| PA | Mean | STDEV | N | SE | t-value | CI (+/-) at 90% | High | Low |
|---|---|---|---|---|---|---|---|---|
| HWS | 141.97 | 142.11 | 37.00 | 23.36 | 1.68 | 39.34 | 181.31 | 102.63 |
| BDNP | 28.60 | 22.66 | 48.00 | 3.27 | 1.68 | 5.51 | 34.10 | 23.09 |
| NDNP | 157.32 | 108.44 | 72.00 | 12.78 | 1.96 | 25.05 | 182.37 | 132.28 |
| TGWS | 34.96 | 103.40 | 37.00 | 17.00 | 1.68 | 28.63 | 63.59 | 6.34 |
| RSBCEA | 100.44 | 88.22 | 20.00 | 19.73 | 1.73 | 34.11 | 134.55 | 66.33 |

Figure 13: Mean $CO_2$ stocks for five PAs with error bars showing 90% confidence level




## 7.8 Species Diversity and Species Richness:

The species diversity indices at different PAs were estimated by Shannon's species diversity index method. The numbers of species observed at individual PAs were divided by the total number of species observed in the five PAS to get the ration (p). Then this "'p" was used to estimate the Shannon's species diversity index known as H'=-p*ln(p).

Species Richness is a measure of number of species found in a sample population. This species richness index is Menhinicks's index known as "D". The estimation procedure is D= (Number of species found in a PA/√ (Total number of individuals found in the whole population means eight PAs). The results of the species diversity and species richness are given in Table 14 and Shanon's species diversity index in Figure 14.

**Table 7: Shannon's species diversity and Species richness at the five PAs in 2015**

| PA | Number of species | Number of Individuals | Menhinicks's Species Richness Index (D) | p=number of species in the PA/Total number of species in the PA | Shannon's species Diversity Index = -p*ln(p) |
|---|---|---|---|---|---|
| BDNP | 58 | 227 | 1.40 | 0.54 | 0.33 |
| HWS | 45 | 164 | 1.08 | 0.42 | 0.36 |
| NDNP | 11 | 765 | 0.27 | 0.10 | 0.23 |
| TGWS | 16 | 451 | 0.39 | 0.15 | 0.28 |
| RRF | 7 | 119 | 0.17 | 0.07 | 0.18 |
| Total | 107 | 1723 | 2.58 | 1.00 | - |

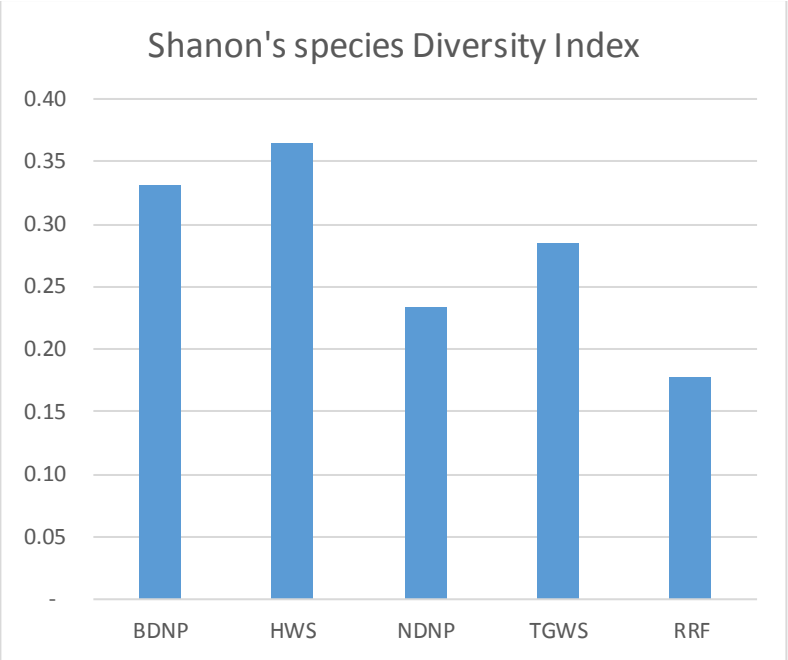



**Figure 14: Shannon's species diversity in the inventoried five PAs in 2015**

## 8.5. Emissions from deforestation and forest degradation

In GHG accounting, land cover change i.e. deforestations and forest degradations, due to anthropogenic pressures are important. This inventory, coupled with Global Forest Loss-gain data (Hansen et. al. 2013) land sat imageries during 2001-2012, calculated annual land cover change and estimated emission factors for five PAs. Emission factors are estimated as the difference between the forest $CO_2$ stocks before and after the land cover class change (i.e. post-deforestation). Emissions occur when the conversion results in a decrease in carbon stocks. In contrast, sequestration can occur when a unit of land is converted to higher carbon stocks, for example when degraded land is allowed to re-grow into forest, or an agricultural area is planted with trees. Table 11 shows the rate of deforestation and emission factors for eight PAs.

Two types of degradations were identified from the inventory, one by conversion of forests to degraded forests or agriculture including settlements and another by removal of trees when the stumps were still there. Results show that the conversion of forest to "degraded forest or agriculture including settlements" is the most significant cause of annual GHG emission and loss of forest biophysical condition overall, resulting in approximately $CO_2$Mg/year (Table 15 & 16).Tengragiri WS PAs did not have any emission from the conversion of forest to degraded forest, which is possibly due to effective forest protection.

Emission Factors from deforestations for different PAs from conversion of forest to agriculture, settlements and bare lands varied from 15.07 to 183.58 $CO_2$ Mg/year (Table 15). There was no emission recorded at Tengragiri WS.

**Table 8: Emission factor, by land cover classes (unit, $CO_2$ Mg/ha)**

| PA | Land cover change | Total Forests in 2001 | Total Forests in 2012 | Total area change (2001-2012) | Annual area change | Rate of Deforestation | Emission factor over 12 years | Baseline Annual emission |
|---|---|---|---|---|---|---|---|---|
| | Forest to: | ha | ha | ha | ha/yr | % | | |
| BDNP | Agriculture | 1,723.40 | 1,716.11 | 0.18 | 0.01 | 0.0009 | 25.11 | 4.48 |
| | | | | | | | | |
| HWS | Agriculture | 1,703.79 | 1,696.36 | 0.09 | 0.01 | 0.0004 | 171.4 | 15.43 |
| | | | | | | | | |
| HWS | Settlement | | | 0.42 | 0.04 | 0.0021 | 171.54 | 72.12 |
| HWS | Water | | | 0.09 | 0.01 | 0.0005 | 171.54 | 16.26 |
| NDNP | Intertidal area | 4,158.39 | 4,158.20 | 0.18 | 0.02 | 0.0004 | 183.58 | 33.61 |
| | | | | | | | | |
| RSBCECA | Wetlands | | | 0.00 | 0.00 | 0.0005 | 137.53 | 0.53 |
| TGWS | - | - | - | - | - | - | 0 | 0 |

**Table 9: Forest degradation by change of land covers class (forest to degraded forests)**

| PA | Land cover change | Total Forests in 2001 | Total Forests in 2012 | Total area change (2001-2012) | Annual area change | Rate of Degradation | Emission factor over 12 years | Baseline Annual emission |
|---|---|---|---|---|---|---|---|---|
| | Forest to: | ha | ha | ha | ha/yr | % | CO2 Mg/ha | CO2 Mg/ha |
| BDNP | Degraded forest | | | 7.11 | 0.59 | 0.0344 | 15.7 | 64.20 |
| HWS | Degraded forest | | | 6.82 | 0.57 | 0.0334 | 128.6 | 61.61 |
| NDNP | - | - | - | - | - | - | 0 | 0 |
| RSBCE CA | Degraded forest | 65.80 | 65.56 | 0.23 | 0.02 | 0.0292 | 82.43 | 2.08 |
| TGWS | - | - | - | - | - | - | 0 | 0 |
| Total | | | | 14.16 | 1.18 | 0.0091 | | |

The total area of degraded forest in the CREL PAs is almost 14.16 ha in 12 years in inventoried area which is almost 0.0091% in the five PAs. If all this land was reforested into mature forest then a large amount of $CO_2$ would be sequestered over period that it takes the forest to re-grow. Based on these results the reforestation and effective protection of these lands would be the most significant GHG emission reduction program.

Inventoried PAs, alike other forest reserves in the country are constantly affected by extractions of forest resources, in particular removal of saplings and poles in addition to cane, bamboo and fuel wood. In most cases forests are being converted as shrub lands where trees often cannot grow above 5cm DBH. In this inventory, stumps were measured from the sample plots and degradation from tree removals are estimated, based on the relation of stump basal diameter to tree DBH and subsequent calculation of $CO_2$ Mg/ha extracted. It is observed that BDNP has the highest stump measurements. However, at RSBCA, no stumps were observed due submersion by water. The estimates of emissions from extraction of trees are given in Table 12.

$$\text{Biomass extracted (Mg/ha)} = \text{Biomass of sample tree(Mg/ha)} - \text{Biomass stump(Mg/ha)}$$

The total emissions from extraction of trees by human interference were estimated at 31,253.53 $CO_2$ Mg from the forests. The annual emissions were not possible to estimate as the ages of the stumps were not known Table 17).

**Table 17: Forests degradation due to human interference (cutting of trees, stumps)**

| PA | Stumps | Emissions from extraction of trees | Total CO2 | Percent of total forest CO2 stocks | PA area | Total emissions from extraction of trees CO2 |
|---|---|---|---|---|---|---|
| | N/Ha | CO2 Mg/ha | Mg/ha | % | Ha | Mg |
| BDNP | 1.03 | 1.81 | 28.6 | 0.063286713 | 2,861.76 | 5,179.79 |
| HWS | 0.44 | 0.73 | 141.97 | 0.005141931 | 2,368.02 | 1,728.65 |
| NDNP | 0.94 | 6.06 | 157.32 | 0.038520214 | 4,158.20 | 25,198.69 |
| RSBCA | - | - | 100.44 | 0 | 104.17 | 0 |
| TGWS | 0.19 | 0.15 | 34.96 | 0.004290618 | 2,534.26 | 380.14 |
| Overall average | 0.65 | 2.6 | 99.32 | 0.02617801 | 12026.4 | 31,268.64 |

## 8.6. Discussions

This report provides the results from the CREL forest inventory during 2015. The analyses of the results also provide important recommendations and contributions to Bangladesh's National REDD+ development.

The analysis of forest degradation suggests that degraded forests are a significant cause of GHG emissions and loss of quality biophysical condition for forests in Bangladesh. As part of the inventory CREL also measured some common non-forest land cover types in Bangladesh, enabling preliminary *emission factors* that could be the basis for further national scale inventory.

Integrated with the forest inventory CREL developed a unique set of metrics for assessing the biophysical condition of forest and other land cover types, including tree recruitment, species richness, and general structure related to live biomass, dead biomass and soil organic matter that can give an indication of forest health and resiliency.

By combining the data for GHG emissions and changes in forest biophysical condition with baseline land cover change maps, the CREL project is able to establish baselines for five PAs. The methods and results provide important contributions to Bangladesh's R-PP and National REDD+ development.

Some important findings from this report are:

1. Estimated carbon stocks for forest and non-forest lands that enable a preliminary estimate of emission factors for deforestation in Bangladesh.
2. Estimated carbon stocks and emissions from the conversion of forest to degraded forest. This provides the first estimation of the impact of forest degradation in Bangladesh that we are aware of.
3. A unique assessment of the relative impact and emission from illegal tree cutting in five forest protected areas based on an inventory of tree stumps. This helps to quantify the threat and impact of tree cutting on exiting protected forests.
4. Degradation appears to be the most significant threat to forest GHG emission and loss of biophysical condition.
5. Degraded forest needs to be mapped with higher degree of accuracy for a REDD+ program in Bangladesh.
6. Plantation forest is also an important component of Bangladesh's forests. These can be very hard to map with RS therefore manual digitization by GPS should be considered as a viable option.

**Data archives: Lists of spread sheets submitted along with the report.**

Baroiyadhala National Park (BDNP), Hazarikhil Wildlife Sanctuary (HWS), Nijhumdweep National Park (NDNP), Tengraghiri Wildlife Sanctuary (TGWS), and Ratargul Reserved Forest (RSBCA). Archive: *C:\Users\Ruhul\Dropbox\CREL_Bangladesh\CREL_Forest_Inventory2016\LatifCarbon Inventory Files\C Inventory 2015Results.*

**Archive:** ***RIMS Unit, Forest Department and C:\Users\Ruhul\Dropbox\CREL_Bangladesh\FCI2017***

After the compilation of the different parameters of the carbon pools individually, the total carbon production were summarized plot and Protected area wise. We have produced different Excel Spread and work sheets (Table 5). Then Land use, pools and PA wise were analyzed (Table 5). PA, land use and plot wise data were also summarized and are given in Appendices 4-10) for ready reference.

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## Form 1: Plot Setup and Description

Name of PA:_____PlotID:_____Range:_____Beat:_____Block:_____

Mouza: _____ Union:_____ Upazila_____

Team Leader:_____ Data recorded by:_____ # people in team: _____

GPS in DDMMSS.ss:Lat. (N)_____ Long. (E)_____WP:_____GPS Accuracy (±m) ___

Plot location _____

Entry Waypoint/nearest landing:_____

Date:_____/_____/_____Start Time:_____ End time:_____ Total Time: _____

Land Cover Classes (circle one):

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Forest | Degraded forest | Shrub land | Plantation forest | Village forest | Settlement/ developed | Agriculture | Shifting Cultivation | Tea garden | Others (specify) |

Topography (circle one):

| | | | | |
|---|---|---|---|---|
| Depression | Flat | Low hills | High hills | Valley |

Disturbance Evidence (circle one):

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| No disturbance | Forest fire | Illicit timber removal | Encroachment | Grazing | Fuel wood removal | Sun grass removal | Other (specify) |

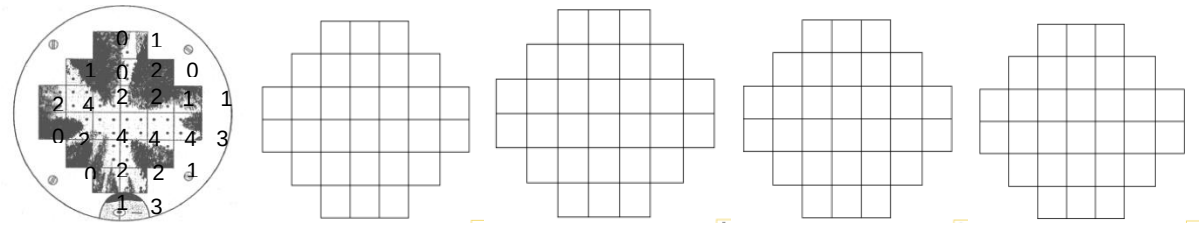
**Storm Cyclone damage:**

| | | | |
|---|---|---|---|
| No evidence | Low (<30%) | Medium (30-70% | High (>70%) |

**Disease:**

| | | | |
|---|---|---|---|
| No evidence | Low (<30%) | Medium (30-70% | High (>70%) |

**Canopy cover**



Record the number of dots **NOT occupied** by canopy (You can see sky at the dots)

North reading Sum of dots _____

East reading Sum of dots _____

South reading Sum of dots _____

West reading Sum of dots _____

Notes:

Data recorded by (name, date, notes)

Review (name, date, notes)

## Form 2: Measurement of Seedlings, Saplings, Trees and Palms

Name of PA:_____ Plot ID:_____Slope (%): _____

Photo Number(s):N_____E_____S_____W_____

Seedlings Plot Dimension radius 2.0 m; Saplings Plot Dimension radius 2.0 m:

# of Seedlings: _____ # of Saplings: _____Dominant Species Name _____

Live Tree Measurements: Nested Plots

| Plot radius: small, 4.0m<br>Tree diameter: small, ≥5.0cm | | | Plot radius: medium, 10.0m<br>Tree diameter: medium, ≥20.0cm | | | Plot radius: medium, 17.84m<br>Tree diameter:large, ≥50.0cm | | |
|---|---|---|---|---|---|---|---|---|
| Tree # | Species | DBH (cm) | Tree # | Species | DBH (cm) | Tree # | Species | DBH (cm) |
| 1. | | | 1 | | | 1 | | |
| 2. | | | 2 | | | 2 | | |
| 3. | | | 3 | | | 3 | | |
| 4. | | | 4 | | | 4 | | |
| 5. | | | 5 | | | 5 | | |
| 6. | | | 6 | | | 6 | | |
| 7. | | | 7 | | | 7 | | |
| 8. | | | 8 | | | 8 | | |
| 9. | | | 9 | | | 9 | | |
| 10. | | | 10 | | | 10 | | |
| 11. | | | 11 | | | 11 | | |
| 12. | | | 12 | | | 12 | | |
| 13. | | | 13 | | | 13 | | |
| 14. | | | 14 | | | 14 | | |
| 15. | | | 15 | | | 15 | | |
| 16. | | | 16 | | | 16 | | |
| 17. | | | 17 | | | 17 | | |
| 18. | | | 18 | | | 18 | | |
| 19. | | | 19 | | | 19 | | |
| 20. | | | 20 | | | 20 | | |

| Co-dominant Trees and Palms where height is measured | | | | | | |
|---|---|---|---|---|---|---|
| Tree # | Species | Height (m) | Clinometer angle | | Eye to tree (m) | Equipment Used |
| | | | + | - | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Notes:

Data recorded by (name, date, notes)

Review (name, date, notes)

## Form 3: Measurement of Stumps, Standing Dead Wood and Lying Dead Wood Measurements

Name of PA: _____Plot ID #:_____

Form 3A: Stumps from human degradation

| Stump ID# | Base diameter (cm) at 15 cm from ground level | Stump Height (cm) | Stump ID# | Base diameter (cm) at 15 cm from ground level | Stump Height (cm) |
|---|---|---|---|---|---|
| 1 | | | 8 | | |
| 2 | | | 9 | | |
| 3 | | | 10 | | |
| 4 | | | 11 | | |
| 5 | | | 12 | | |
| 6 | | | 13 | | |
| 7 | | | 14 | | |

Form 3B: Standing Dead Wood Measurements

| Diameter at base, at 15cm; (cm) | DBH at 1.3 m; (cm) | Diameter at top (cm) (if measured directly) | Height (m) (if measured directly) | Height Measurement | | | |
|---|---|---|---|---|---|---|---|
| | | | | Clinometer angle | | Distance from eye to tree (m) | Remarks |
| | | | | + | - | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Form 3C: Lying Dead Wood Measurements

(wood greater than 10 cm diameter)

Transect length (m) = _____25 m_____

| Diameter (cm) | Density Class (S/I/R) | Hollow Diameter (cm) | Diameter (cm) | Density Class (S/I/R) | Hollow Diameter (cm) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

S=Solid, I=Intermediate, R=Rotten

Notes:

Data recorded by (name, date, notes)

Review (name, date, notes)

## Form 4: Non-Tree Woody Vegetation: Bamboos& Canes

Name of PA:_____ Plot ID:_____

***Plot radius 0- 4 m***

| Clump # | Species Small, medium and large | Average DBH (cm) of the culm | Height (m) | Average Height (m) of the culm | | | | Number of Culms/Stems in the clump (n) | Plot radius (m) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Clinometer angle (%) | | Distance from eye to tree (m) | Height of eye (m) | | |
| | | | | + | - | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Bamboo: Small (diameter< 4cm), Medium (diameter 4-8cm) and Large (diameter>8cm)

## Form 5: Destructive harvest samples & sub-samples (Seedlings, Sapling, Bamboo, Cane, Palm, Shrub, litter and herbaceous vegetation)

| Plot ID (Land cover) | Particulars | DBH (cm) | Height (m) | Sample | | | Sub-sample | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight of bag (g) | Weight of bag+ material (g) | Weight of sample (g) | Weight of bag (g) | Weight of bag+ material (g) | Weight of sample (g) |
| | Bamboo: Small (dbh< 4cm) | | | | | | | | |
| | Bamboo: Med. (dbh 4-8cm) | | | | | | | | |
| | Bamboo: Large (dbh>8cm) | | | | | | | | |
| | Litter 1 | - | - | | | | | | |
| | Litter 2 | - | - | | | | | | |
| | Litter 3 | - | - | | | | | | |
| | Litter 4 | - | - | | | | | | |
| | Grass & Herbaceous 1 | - | - | | | | | | |
| | Grass & Herbaceous 2 | - | - | | | | | | |
| | Grass & Herbaceous 3 | - | - | | | | | | |
| | Grass & Herbaceous 4 | - | - | | | | | | |
| | Shrubs | - | | | | | | | |
| | Seedlings (1 number) | - | | | | | | | |
| | Saplings (1 number) | - | | | | | | | |
| | Palm | | | | | | | | |

## Form 6: Soil

Soil type (circle): clay, sandy-clay, loam, Sandy-loam, silty-clay, silty-loam;

| Plot No | Land Use | Soil depth (cm) | Soil %C | Bulk density | Remarks |
|---|---|---|---|---|---|
| | | 0-15 | OC1 | BD 01 | |
| | | 15-30 | OC2 | BD 02 | |
| | | 30-50 | OC3 | BD 03 | |
| | | 50-80 | OC4 | BD 04 | |

Notes:

Data recorded by (name, date, notes)

Review (name, date, notes)

# Appendix I: Training for Forest Carbon Inventory 2016

List of Participants for Hands-on Orientation on Forest Carbon inventory (18-20 Mar 2016)

## Climate-Resilient Ecosystems and Livelihoods (CREL) Project

## Forest Carbon Inventory 2015

## Inventory sites:
## Baroiyadhala NP, Hazarikhil WS, Nijhum Dweep NP, Tengragiri WS, Ratargul RF

**Technical Team for field data collection:**

| Sl | Name of Participants | Designation | Contacts |
|---|---|---|---|
| 1. | Mr. Md. Enamul Hoque Bhuiyan | ACF, Chittagong North Forest Division | 01714 216 974; email: enamul_bhuiyan@yahoo.com |
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| 3. | Mr. Alauddin | ACF, Noakhali Forest Division, Noakhali | 01911 746 323; email: m.alauddin18@yahoo.com |
| 4. | Mr. Md. Altaf Hossain | ACF, Borguna, Patuakhali Forest Division | 01750 202 772 |
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| 11. | Mr. Shital K. Nath | CCPAM Officer, Chittagong Region, CREL | 01711479721; email:smati71@yahoo.com |
| 12. | Mr. Iftekhar Hossain | Monitoring Officer, Chittagong Region, CREL | 01716-955894; email: iftienv@yahoo.com |
| 13. | Mr. MohtashamBillah | Monitoring Officer, Khulna Region, CREL | 01753743382, 01944431040; email: mbillah@winrock.org |
| 14. | Mr. ShahinulKabir | Monitoring Officer, Sylhet Region, CREL | 01717 008 246; email: bipul.agri@gmail.com |
| 15. | Ms. Sukla Sinha | NRM Facilitator, Khadimnagar NP, Sylhet, CREL | 01912 716118; e-mail:shuklasust@gmail.com |
| 16. | Mr. M. A. Latif Fakir | Consultant, Forest Carbon Inventory 2015 | 01715 669 884; Email: latif.fakir@yahoo.com |
| 17. | Sunbeam Rahman | GIS Specialist, CREL, Dhaka | 01914 114648; email: sunbeam.rahman@bcas.net |
| 18. | Ruhul Mohaiman Chowdhury | M&E Specialist, CREL Project, Dhaka; Coordinator FCI2015 | 01726 892 305; email: rmchowdhury@winrock.org; ruhulforester@yahoo.com |

# Appendix II: Pools of CO2 in different PAs

Appendix III-1: Estimates of Forest Carbon (CO2) stock for different pools at Baroiyadhala National Park
Appendix III-2: Estimates of Forest Carbon (CO2) yield for different pools at Hazarikhil Wildlife Sanctuary HWS)
Appendix III-3: Estimates of Forest Carbon (CO2) yield for different pools at Nijhum Dweep National Park
Appendix III-4: Estimates of Forest Carbon (CO2) yield for different pools at Tengragiri Wildlife Sanctuary
Appendix III-5: Estimates of Forest Carbon (CO2) yield for different pools at Ratargul Reserved Forest

# Appendix-III: List of volume equation and wood density

| Sl | Species | Scientific name | Reference | Volume equation | Wood Density |
|---|---|---|---|---|---|
| | Minjiri | *Cassia siamea* | Latif*et al*. 1995 | $\ln(V_{ob})$=- 8.602 + 2.4038×ln(D) | |
| 1 | Akashmoni | Acacia auriculiformis | Latif*et al*. 1995 | ln(V)=-8.208+2.2389*ln(D) | 0.7 |
| 2 | Arjun | *Terminalia arjuna* | Rahman et al. 2001 | ln(V)=2.222144*ln(G)-11.1885 | |
| 3 | Banderhola | *Duabanga grandiflora* | Latif et al. 195b | ln(V)=2.4987*ln(D)-9.2929 | 0.5 |
| 4 | Base dia-DBH | Dipterocarpus turbinatus | Latif et al. 1985b | DBH (cm)=0.792437*base dia (cm) | |
| 5 | Bhadi | Mise Sp. | Latif et al. 1985b | ln(V)=2.08627*ln(D)-7.574983 | 0.6 |
| 6 | Bohera | Terminalia ballerica | Latif et al. 1985b | ln(V)=2.1338*ln(D)-8.0446 | 0.7 |
| 7 | Chapalish | Artocarpus chaplasha | Latif et al. 1984c | ln(V)=2.24074*ln(D)-8.179774 | 0.4 |
| 8 | Chundul | Tetrameles nudiflora | Latif et al. 1985b | ln(V)=2.0291*ln(D)-7.077637 | 0.3 |
| 9 | Civit | Swintonia floribunda | Latif et al. 1985b | ln(V)=2.14002*ln(D)-7.631146787 | 0.6 |
| 10 | Dhakijam | Syzygiium grande (Plantations) | Latif et al. 1984b | V = 0.00552016- 0.0028213×D+ 0.00078431×$D^2$ | 0.7 |
| 11 | Dhakijam | Syzygiium grande (natural) | Latif et al. 1985b | V=-0.275876+0.009951*D+0.0005876*D^2 | 0.7 |
| 12 | Eucalyptus | Eucalyptus camaldulesnsis | Latif et al. 1999 | ln(V)=2.297689*ln(G)-11.177929 | 0.6 |
| 13 | Gamar | Gmelina arborea | Latif et al. 1984c | ln(V)=2.1472*ln(D)-7.9022697 | 0.4 |
| 15 | Garjan | *Dipterocarpus Turbinatus* | Latif et al. 1984a | ln(V)=2.35556*ln(D)-8.5116354 | 0.7 |
| 16 | Jackfruit | Artocarpus heterophyla | Latif&Zahir 2000 | ln(V)=2.18203*ln(G)-11.06320 | 0.4 |
| 17 | Jam | Syzigium cumini | Latif et al. 1985b | V=0.00506138D^2+0.00217385- 0.00111102* D | 0.6 |
| 18 | Jarul | Lagarastroemia Spp | Latif et al. 1985b | ln(V)=2.08627*ln(D)-7.574983 | 0.6 |
| 19 | Kadam | Anthocephalus chinensis | Latif et al. 1985b | ln(V)=2.32592*ln(G)-11.6329 | 0.4 |
| 20 | Kanak/Banak | | Latif et al. 1985b | ln(V)=1.6912*ln(D)-6.3428 | 0.7 |
| 21 | Koroi | *Albizia procera* | Latif*et al*. 1999 | ln(V)=2.463398*ln(G)-12.093533 | 0.7 |
| 22 | Mahogany | *Swietenia macrophylla* | Latif et al. 1999 | ln(V)=2.460647*ln(G)-12.045383 | 0.6 |
| 23 | Mangium | *Acacia mangium* | Latif*et al*. 1993 | $\ln(V_{ob})$ =- 8.209 + 2.2178×ln(D) | 0.5 |
| 24 | Mango | Mangifera indica | Latif&Zahir 2000 | ln(V)=2.24506*ln(G)-11.27269 | 0.5 |
| 25 | Neem | Azadracta indica | Latif and Zahir 2001 | ln(V)=2.25814*ln(G)-11.33340 | 0.7 |
| 26 | Pitraj | *Aphanamixis polystachya* | Latif et al. 1985b | ln(V)=2.4781*ln(D)-9.2157 | 0.5 |
| 27 | Rain Tree | Samania saman | Latif*et al*. 2000 | ln(V)=2.5086408*ln(G)-12.287524 | 0.5 |
| 28 | Rubber wood | Hevea brazelenisis | Zahir (in press) | ln(V)=-10.5628+2.1502*ln(G) | 0.5 |
| 29 | Sal | Shorea robusata | Latif et al. 1992 | ln(V)=2.51789*ln(D)-9.1727759 | 0.82 |
| 30 | Simul | Bombex ceiba | Latif et al. 1985b | ln(V)=2.3088*ln(D)-8.4630 | 0.6 |
| 31 | Sissoo | *Dalbergia sissoo* | Latif et al. 1999 | ln(V) = -12.14678171+2.49978991×ln(G) | 0.7 |
| 32 | Teak/Shegun | *Tectona grandis* | Latif et al. 1985a | ln(V)=2.12337*ln(D)-7.566916 | 0.6 |
| 33 | Urium | Mangifera sylvastica | Latif et al. 1985b | ln(V)=2.337*ln(D)-8.5703 | 0.5 |
| 34 | | Mixed SPP | Latif et al. 1985b | ln(V)=2.08627*ln(D)-7.574983 | 0.6 |

# Appendix –IV: List of Species and tree counts at each PA

| | | Name of Protected Area | | | | | |
|---|---|---|---|---|---|---|---|
| Serial No. | Species | BDNP | HWS | NDNP | RSBCA | TGWS | Total |
| 1 | Aam | 10 | 6 | | | 1 | 17 |
| 2 | Achargula | 1 | | | | | 1 |
| 3 | Achila | 1 | 9 | | | | 10 |
| 4 | Akashmoni | 2 | 1 | | | | 3 |
| 5 | Amdowa | | | | | 1 | 1 |
| 6 | Amloki | 5 | | | | | 5 |
| 7 | Amrah | 2 | | | | | 2 |
| 8 | Amur | | | | | 1 | 1 |
| 9 | Asfol | 4 | | | | | 4 |
| 10 | Asshoth | | 1 | | | | 1 |
| 11 | Assotoma | | 1 | | | | 1 |
| 12 | Athailla | 1 | | | | | 1 |
| 13 | Badam | 2 | | | | | 2 |
| 14 | Baen | | | 22 | | 4 | 26 |
| 15 | Baen kalo | | | 2 | | | 2 |
| 16 | Baen sada | | | 3 | | | 3 |
| 17 | Bahera | 3 | | | | | 3 |
| 18 | Barun | | | | 2 | | 2 |
| 19 | Bel | | 2 | | | | 2 |
| 20 | Bhadi | 6 | | | | | 6 |
| 21 | Boal | | | | | 1 | 1 |
| 22 | Boloi | | | | | 1 | 1 |
| 23 | Bon Gach | 1 | | | | | 1 |
| 24 | Bonjamir | 1 | | | | | 1 |
| 25 | Bonlota | 1 | | | | | 1 |
| 26 | Bormala | 1 | 9 | | | | 10 |
| 27 | Boro Dumur | 1 | | | | | 1 |
| 28 | Boroi | | 2 | | | | 2 |
| 29 | Borta | 1 | | | | | 1 |
| 30 | Bot | | | | 3 | | 3 |
| 31 | Bura | 2 | 8 | | | | 10 |
| 32 | Chakua Koroi | 2 | 7 | | | | 9 |
| 33 | Chalmugra | | 3 | | | | 3 |
| 34 | Chalsupari | | 1 | | | | 1 |
| 35 | Chambol | | | | | 14 | 14 |
| 36 | Chapalish | 3 | 1 | | | | 4 |
| 37 | Chatian | | 1 | | | | 1 |
| 38 | Chiba tita | 1 | | | | | 1 |

| | | Name of Protected Area | | | | | |
|---|---|---|---|---|---|---|---|
| Serial No. | Species | BDNP | HWS | NDNP | RSBCA | TGWS | Total |
| 39 | Chickrassi | | 1 | | | | 1 |
| 40 | Chundul | 1 | 3 | | | | 4 |
| 41 | Coconut | 2 | | | | | 2 |
| 42 | Dharmara | 12 | 1 | | | | 13 |
| 43 | Dumur | 11 | 6 | | | | 17 |
| 44 | Eucalyptus | 13 | | | | | 13 |
| 45 | Gab | 1 | 1 | | | | 2 |
| 46 | Gamar | 32 | 5 | | | | 37 |
| 47 | Gewa | | | 175 | | 263 | 438 |
| 48 | Goda | 3 | | | | | 3 |
| 49 | Goran | | | | | 5 | 5 |
| 50 | Gutgutia | 2 | | | | | 2 |
| 51 | Hausla | 1 | | | | | 1 |
| 52 | Hijal | | | | 27 | | 27 |
| 53 | Jam | 7 | 2 | | 1 | | 10 |
| 54 | Jolpai | | 1 | | | | 1 |
| 55 | Jungoir | 2 | | | | | 2 |
| 56 | Kadam | | | | 3 | | 3 |
| 57 | Kala koroi | 3 | | | | | 3 |
| 58 | Kalo bean | | | 3 | | | 3 |
| 59 | Kankara | | | 1 | | | 1 |
| 60 | Kanthal | 2 | 11 | | | | 13 |
| 61 | Karamja | | | | | 4 | 4 |
| 62 | Karula | 1 | | | | | 1 |
| 63 | Katajamir | 2 | | | | | 2 |
| 64 | Kaw | 1 | | | | | 1 |
| 65 | Keora | | | 549 | | 39 | 588 |
| 66 | Khejur | 1 | | | | | 1 |
| 67 | Khudi | | 1 | | | | 1 |
| 68 | Khurulla | 7 | 1 | | | | 8 |
| 69 | Kola bean | | | 1 | | | 1 |
| 70 | Koroi | 6 | 8 | | | | 14 |
| 71 | Kuruch | 8 | | | 82 | | 90 |
| 72 | Lal Dumur | 1 | | | | | 1 |
| 73 | Lohamorich | | 1 | | | | 1 |
| 74 | Lorkao | | 1 | | | | 1 |
| 75 | Mahogany | 4 | | 2 | | 2 | 8 |
| 76 | Malakana Koroi | 1 | | | | | 1 |
| 77 | Mendha | 3 | | | | | 3 |
| 78 | Moos | | 2 | | | | 2 |

| | | Name of Protected Area | | | | | |
|---|---|---|---|---|---|---|---|
| Serial No. | Species | BDNP | HWS | NDNP | RSBCA | TGWS | Total |
| 79 | Moricha | 5 | 2 | | | | 7 |
| 80 | Nichampa | 5 | | | | | 5 |
| 81 | Noon vat | | 5 | | | | 5 |
| 82 | Nunia jhau | | | 3 | | | 3 |
| 83 | Painnagola | | 1 | | | | 1 |
| 84 | Passur | | | | | 6 | 6 |
| 85 | Pitali | | | | 1 | | 1 |
| 86 | Pitraj | 1 | | | | | 1 |
| 87 | Rain tree | 12 | | | | 16 | 28 |
| 88 | Ramkola | | 1 | | | | 1 |
| 89 | Rubber | | 27 | | | | 27 |
| 90 | Shajana | | 1 | | | | 1 |
| 91 | Shil batna | | 5 | | | | 5 |
| 92 | Shingra | | | | | 14 | 14 |
| 93 | Simul | 2 | | | | | 2 |
| 94 | Sundri | | | | | 79 | 79 |
| 95 | Supari | | 3 | | | | 3 |
| 96 | Suruj | 1 | | | | | 1 |
| 97 | Tal | 1 | | | | | 1 |
| 98 | Teak | 6 | 10 | | | | 16 |
| 99 | Teli garjan | | 2 | 1 | | | 3 |
| 100 | Telsur | | 1 | | | | 1 |
| 101 | Tetua koroi | 8 | 3 | | | | 11 |
| 102 | Thona | 1 | | | | | 1 |
| 103 | Toon | | 1 | | | | 1 |
| 104 | Udal | 6 | 1 | | | | 7 |
| 105 | Uriam | | 2 | | | | 2 |
| 106 | Vella | | 2 | | | | 2 |
| 107 | Zill Gach | 1 | | | | | 1 |
| | Grand Total | 227 | 164 | 765 | 119 | 451 | 1723 |
| | No of Spp | 58 | 45 | 11 | 7 | 16 | 107 |

Table –7a: Carbon stock estimates for different land cover classes and carbon pool for the eight inventoried protected areas during 2014 (excluding soil)

| PA | Land Use category | Average of Total CO2 TREES (Mg/ha) | Average of Total CO2 DEAD TREES (Mg/ha) | Average of Total CO2 Non-trees (Mg/ha) | Average of Total CO2 LITTER (Mg/ha) | Average of Grand Total CO2 Mg/ha (minus soil) | Average of Soil Carbon (Mg/ha) | Average of Soil CO2 (Mg/Ha) | Average of Grand Total CO2 Mg/ha including soil |
|---|---|---|---|---|---|---|---|---|---|
| CSW | Agriculture | - | - | 0.74 | 4.84 | 5.57 | 13.00 | 47.67 | 53.24 |
| | Degraded forest | 75.45 | 0.20 | 6.41 | 7.40 | 89.45 | 27.13 | 99.48 | 188.93 |
| | Forest | 149.58 | 0.03 | 12.29 | 14.04 | 175.94 | 22.03 | 80.78 | 256.73 |
| | Plantation | 139.39 | 0.30 | 20.45 | 8.81 | 168.95 | 17.10 | 62.71 | 231.66 |
| | Settlement | 132.56 | 0.51 | 2.73 | 6.81 | 142.60 | 20.58 | 75.47 | 218.08 |
| CSW Total | | 103.79 | 0.19 | 10.47 | 8.87 | 123.33 | 23.07 | 84.60 | 207.93 |
| HNP | Degraded forest | 11.77 | - | 0.24 | 0.18 | 12.19 | 17.25 | 63.24 | 75.43 |
| | Forest | 101.12 | - | - | - | 101.12 | 16.19 | 59.36 | 160.47 |
| | Settlement | 114.50 | 1.73 | 0.00 | - | 116.24 | 3.82 | 13.99 | 130.23 |
| HNP Total | | 37.91 | 0.39 | 0.18 | 0.14 | 38.60 | 14.22 | 52.15 | 90.76 |
| KhNP | Degraded forest | 40.28 | - | - | - | 40.28 | 39.38 | 144.40 | 184.68 |
| | Forest | 330.59 | - | 1.08 | 9.36 | 341.04 | 21.45 | 78.66 | 419.69 |
| | Plantation | 313.43 | - | 0.78 | 7.69 | 321.90 | 28.98 | 106.26 | 428.16 |
| KhNP Total | | 264.17 | - | 0.81 | 7.10 | 272.07 | 26.27 | 96.33 | 368.41 |
| KNP | Agriculture | - | - | - | - | - | 27.10 | 99.37 | 99.37 |
| | Degraded forest | 57.94 | 0.32 | 0.63 | 2.65 | 61.55 | 27.24 | 99.87 | 161.42 |
| | Forest | 276.77 | 8.45 | 2.24 | 7.98 | 295.44 | 27.30 | 100.08 | 395.53 |
| | Plantation | 316.91 | 1.96 | 0.37 | 5.03 | 324.26 | 27.10 | 99.37 | 423.63 |
| | Settlement | 123.49 | 2.93 | 0.87 | 1.74 | 129.03 | 26.41 | 96.83 | 225.86 |
| KNP Total | | 222.01 | 3.31 | 0.98 | 5.00 | 231.30 | 27.17 | 99.63 | 330.92 |
| LNP | Bare Land | 27.77 | - | 2.29 | 10.52 | 40.58 | 40.07 | 146.92 | 187.50 |
| | Degraded forest | 25.85 | 25.30 | 4.14 | 6.42 | 61.71 | 37.04 | 135.83 | 197.54 |

| PA | Land Use category | Average of Total CO2 TREES (Mg/ha) | Average of Total CO2 DEAD TREES (Mg/ha) | Average of Total CO2 Non-trees (Mg/ha) | Average of Total CO2 LITTER (Mg/ha) | Average of Grand Total CO2 Mg/ha (minus soil) | Average of Soil Carbon (Mg/ha) | Average of Soil CO2 (Mg/Ha) | Average of Grand Total CO2 Mg/ha including soil |
|---|---|---|---|---|---|---|---|---|---|
| | Forest | 410.98 | 3.32 | 0.76 | 11.42 | 426.49 | 44.19 | 162.02 | 588.51 |
| | Plantation | 241.09 | 0.29 | 1.83 | 7.98 | 251.19 | 40.73 | 149.33 | 400.52 |
| | Settlement | 308.76 | - | - | - | 308.76 | 41.77 | 153.17 | 461.93 |
| | Tea Garden | 105.14 | - | 0.56 | 3.85 | 109.55 | 50.72 | 185.96 | 295.50 |
| | Waterbodies | | | | | - | | - | - |
| LNP Total | | 278.13 | 3.98 | 1.54 | 8.88 | 283.10 | 42.09 | 149.35 | 432.45 |
| MNP | Agriculture | - | - | - | 1.28 | 1.28 | 33.97 | 124.54 | 125.82 |
| | Forest | 238.63 | - | 0.71 | 7.73 | 247.07 | 30.55 | 112.00 | 359.07 |
| | Plantation | 147.09 | - | 0.32 | 4.31 | 151.72 | 37.14 | 136.19 | 287.91 |
| | Rubber | 201.51 | - | 2.18 | 6.75 | 210.44 | 35.79 | 131.22 | 341.67 |
| | Settlement | 138.61 | - | 0.32 | 5.88 | 144.81 | 18.28 | 67.01 | 211.82 |
| MNP Total | | 195.46 | - | 0.76 | 6.41 | 202.62 | 32.17 | 117.96 | 320.58 |
| RKW | Agriculture | 37.50 | - | - | - | 12.50 | 42.93 | 52.47 | 64.97 |
| | Degraded forest | 1.07 | - | 0.28 | 1.84 | 3.19 | 44.02 | 161.41 | 164.61 |
| | Forest | 379.03 | 0.02 | 0.72 | 5.64 | 385.41 | 47.03 | 172.45 | 557.86 |
| | Plantation | 202.12 | - | 1.60 | 4.97 | 208.70 | 41.14 | 150.86 | 359.56 |
| RKW Total | | 329.53 | 0.02 | 0.89 | 5.34 | 325.12 | 45.66 | 162.11 | 487.23 |
| SNP | Agriculture | 128.59 | - | 3.60 | 2.91 | 135.11 | 22.36 | 81.97 | 217.08 |
| | Degraded forest | 79.60 | - | 1.38 | 5.09 | 86.06 | 38.05 | 139.52 | 225.59 |
| | Forest | 259.40 | 0.37 | 0.88 | 13.80 | 274.46 | 39.26 | 143.94 | 418.40 |
| | Plantation | 247.00 | 0.31 | 0.80 | 12.94 | 261.05 | 31.45 | 115.32 | 376.38 |
| SNP Total | | 219.07 | 0.26 | 1.05 | 11.48 | 231.86 | 33.94 | 124.44 | 356.30 |
| Grand Total | | 192.62 | 0.96 | 3.73 | 6.77 | 202.46 | 30.31 | 110.24 | 312.71 |

## Table –8b: Carbon stock estimates for different land cover classes at the eight inventoried protected areas during 2014 (excluding soil)

| Land Use category | CSW | HNP | KhNP | KNP | LNP | MNP | RKW | SNP | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture | 5.57 | | | - | | 1.28 | 12.50 | 135.11 | 16.56 |
| Bare Land | | | | | 40.58 | | | | 40.58 |
| Degraded forest | 89.45 | 12.19 | 40.28 | 61.55 | 61.71 | | 3.19 | 86.06 | 66.92 |
| Forest | 175.94 | 101.12 | 341.04 | 288.51 | 426.49 | 247.07 | 385.41 | 274.46 | 307.09 |
| Plantation | 168.95 | | 321.90 | 301.01 | 251.19 | 151.72 | 208.70 | 261.05 | 224.29 |
| Rubber | | | | | | 210.44 | | | 210.44 |
| Settlement | 142.60 | 116.24 | | 129.03 | | 144.81 | | | 130.69 |
| Tea Garden | | | | | 109.55 | | | | 109.55 |
| Waterbodies | | | | | - | | | | - |
| Grand Total | 123.33 | 38.60 | 272.07 | 217.48 | 282.25 | 202.62 | 325.12 | 231.86 | 199.85 |