USAID'S CLIMATE-RESILIENT ECOSYSTEMS AND LIVELIHOODS (CREL) PROJECT

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Carbon and Biophysical Forest Inventory Following a REDD+ Framework at Eight Protected Areas in Bangladesh

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Carbon and Biophysical Forest Inventory Following a REDD+ Framework at Eight Protected Areas in Bangladesh

SUBMITTED TO

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

BANGLADESH MISSION, DHAKA, BANGLADESH

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Table of 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, conducted a forest carbon inventory at eight Protected Areas (PAs) in the Chittagong, Sylhet and Dhaka Administrative Divisions of Bangladesh in 2014. The inventory was conducted to establish baselines for forest carbon and biophysical conditions, and the changes that resulted from deforestation and forest degradation. In coordination with the field inventory, land cover maps were also developed for the eight PAs using high-resolution rapid eye imagery. The purpose of the inventory and land cover mapping are, first, to develop baselines and Greenhouse Gas (GHG) accounting for the CREL project and, second, to use CREL resources to contribute to National REDD+ development in Bangladesh. Although CREL's activities are not national in scope, many of the methods for forest mapping, biomass sampling and GHG emission calculation are applicable to any scale. This report describes the methods and results used for CRELs baselines and how those methods and results inform National REDD+ development as outlined in the 2013 Bangladesh draft R-PP.

To ensure compatibility with National REDD+, CREL methods followed the general framework and guidance for a REDD+ program. As part of that process CREL reviewed past forest inventories and land cover mapping to identify those relevant under a REDD+ framework, harmonize the methods, and compile the results for a more complete synthesis of forest carbon and GHG emission in Bangladesh. This included:

1. Developing a Standard Operating Procedure [1] for inventorying carbon stocks and biophysical condition that is a unification of past SOPs, enabling comparability between forest inventories and relevance under a REDD+ system.
2. Implementing a grid based sampling design that follows common practice from past forest carbon inventories. This facilitates comparability between inventories and enables a future National Forest Inventory (NFI) to leverage CREL and other inventory results as a base for the NFI, which could substantially reduce the cost and effort.
3. Reviewing and integrating past land cover classification systems (LCCS) to develop a harmonized land cover classification system using the FAO's LCCS system. This process, that included land cover mapping with remote sensing and field inventories, enabled CREL to be a pilot for identifying and testing the LCCS mapping and inventorying of important land cover types and forest stratification relevant under a REDD+ system.

The forest inventories resulted in carbon stocks estimates for Sal forest (247Mg CO_2 ha^{-1}) and Hill forest (325Mg CO_2 ha^{-1}). Data from the 2009 Sundarbans Inventory [2] was used to establish Mangrove carbon stocks (497Mg CO_2 ha^{1}).

Forest degradation, certainly the most significant cause of GHG emissions and loss of quality biophysical condition for forests in Bangladesh, was assessed and preliminary results for emissions from degradation are presented. The process of land cover mapping and field inventories revealed two types of forest degradation in Bangladesh that would be important

[1] Standard Operating Procedures (SOP) for Forest Carbon Inventory, Bangladesh (2014)

[2] Forest Carbon inventory in the Sundarbans RF (2009)

under a REDD+ system: 1) forest degradation where a forest canopy remains (i.e. a forest definition is maintained at 0.5 hectares, trees higher than 5 meters, and a canopy cover > 10%); 2) forest degradation that results in shrubland like environment with forest canopy often below the forest definition (in this report called “degraded forest shrublands”). This would be important under a REDD+ system because areas remaining with forest canopy would need to be monitored for deforestation or ongoing degradation, while “degraded forest shrublands” do not need to be monitored but represent a significant opportunity for forest restoration.

As part of the inventory CREL measured some common non-forest land cover types in Bangladesh, including agricultural fields (5.8Mg CO_2 ha^{-1}), plantations (232Mg CO_2 ha^{-1}), rubber plantation (210Mg CO_2 ha^{-1}), village forest (142Mg CO_2 ha^{-1}), and tea garden (37Mg CO_2 ha^{-1}). By including non-forest land cover types in the inventory the CREL project was able to calculate the change in carbon stocks –and therefore emissions– that result from different land cover changes. From a REDD+ perspective this enabled *emission factors* to be estimated, which 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 eight PAs (Table a). The methods and results provide important contributions to Bangladesh’s R-PP and National REDD+ development.

General Results

Results show that the conversion of forest to “degraded forest shrublands” is the most significant cause of annual GHG emission and loss of forest biophysical condition overall, resulting in approximately 6,484Mg CO_2 yr^{-1} (Table a). Three PAs did not have any emission from the conversion of forest to degraded forest shrublands, which is possibly due to effective forest protection (as the case with Lawachara National Park). Emissions for all eight PAs from conversion to agriculture were 2,816Mg CO_2 yr, followed by settlement 1,759Mg CO_2 yr.

Table a. Results for baseline annual emissions for eight CREL PAs: Khadimnagar National Park (KhNP) at Sylhet, Lawachara National Park (LNP) at Moulavibazar, Satchari National Park (SNP), Rema-Kalenga wildlife sanctuary (RKWS) at Habigonj, Modhupur National Park (MNP) at Tangail, Kaptai National Park (KNP) at Rangamati, Chunati wildlife sanctuary (CWS) at Chittagong and Himchari National Park (HNP) at Cox's Bazar.

PA	Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation	Emission Factor	Baseline Annual Emissions
	Forest to:	ha	ha/yr	%	Mg CO_2 ha^1	Mg CO_2 yr^{-1}
CWS	Degraded Forest Shrubland*	169.0	14.1	1.32%	258	3,632
CWS	Settlement	20.8	1.7	0.16%	325	564
CWS	Agriculture	8.5	0.7	0.07%	319	227
CWS	Total	198.3	16.5	1.55%		4,422
HNP	Degraded Forest Shrubland*	30.6	2.6	1.40%	258	658
HNP	Bare soil	2.8	0.2	0.13%	325	75
HNP	Settlement	2.3	0.2	0.10%	325	61
HNP	Agriculture	2.0	0.2	0.09%	319	52
HNP	Total	37.6	3.1	1.73%		847
KhNP	Degraded Forest Shrubland*	2.5	0.2	0.04%	258	54
KhNP	Total	2.5	0.2	0.04%		54
KNP	Degraded Forest Shrubland*	94.6	7.9	0.21%	258	2,033
KNP	Agriculture	4.1	0.3	0.01%	319	109
KNP	Settlement	3.0	0.3	0.01%	325	81
KNP	Total	102	8	0		2,224
LNP	Agriculture	7.6	0.6	0.27%	319	203
LNP	Settlements	2.8	0.2	0.10%	325	76
LNP	Total	10.4	0.9	0.37%		278
MNP	Agriculture	110.2	9.2	0.38%	241	2,215
MNP	Settlements	47.4	4.0	0.17%	247	977
MNP	Total	157.6	13.1	0.55%		3,192
RKWS	Agriculture	0.4	0.0	0.00%	319	11
RKWS	Total	0.4	0.0	0.00%		11
SNP	Degraded Forest Shrubland*	5.0	0.4	0.18%	258	107
SNP	Total	5.0	0.4	0.18%		107

* In this study the shrubland degraded forest is a distinct land cover type that is dominated by shrubs. In most cases these lands do not meet the forest definition (>10% canopy cover over 0.5ha), however are called "degraded forest shrublands" because they are forest department lands and eligible for reforestation. This is in contrast to other areas where there is forest (i.e. it meets the forest definition) and it has been degraded, these land s are called "degraded forest." This distinction would be critical under a REDD+ system as these two land cover types would be monitored and reported in very different ways (See Section 6.3.2)

The total area of degraded forest shrublands in the CREL PAs is almost 19,000ha (8,433 in CREL core areas, and 13,246 in CREL landscapes) almost 53% of the total land in the eight PAs. If all this land was reforested into mature Hill Forest approximately 4.9 million Mg CO_2 would be sequestered over the period that it takes the forest to regrow (2.2Mg CO_2 in CREL core areas, and 3.4Mg CO_2 in CREL landscapes). Based on these results, the reforestation and effective protection of these lands would be the most significant GHG emission reduction program.

However, the conversion to degraded forest shrubland does not account for "actual" forest degradation, where the forest cover remains, but trees and deadwood are continually removed for things like fuelwood or construction. This type of forest degradation could not be quantified spatially across the PAs because it could not be mapped using satellite imagery (i.e. it is classified as forest in the land cover maps). However, it was estimated based on field measurements of stumps remaining in the forest, that on average the extraction of trees from existing forests range from 2.5 to 48.9Mg CO_2 ha^{-1}. If we multiply these averages by the total forest area the emission from forest degradation in the eight CREL PAs has resulted in around 331,000Mg CO_2. Unfortunately we can't say over what period of time the emission occurred (this is just CREL core areas). These results indicate that this type of forest degradation is a significant source of GHG emission and loss of forest biophysical condition.

Table b. Results for emissions from forest degradation (Mg CO_2 ha^1) from each CREL PA based on quantification of stumps.

Name of PA	Area of forests (ha)	Ave. No. stumps per ha	Ave. wood biomass extracted (Mg C/ha)	Ave. emissions from extraction of trees (Mg CO2/ha)	Percent of total forest CO_2 stocks	Total emissions from extraction of trees (Mg CO_2)
CWS	507	26	0.91	2.51	1.6%	1,272
KhNP	479	15	4.74	26.44	9.1%	12,663
KNP	3,786	65	17.81	48.89	17.0%	185,085
LNP	1,911	30	2.35	6.43	1.7%	12,281
RKWS	5,613	19	6.92	19.00	5.0%	106,639
SNP	222	40	6.56	18.02	7.7%	3,994
MNP	2,232	19	1.34	4.03	1.7%	9,004
ALL sites	14,749	31	5.80	17.90	6.3%	330,938

Associated with deforestation and forest degradation is a general loss of "biophysical condition." In the case of CREL, biophysical condition relates to 1) tree recruitment, 2) tree species richness and 3) the distribution of natural biomass from live vegetation, to dead wood and soil. Recruitment is the quantity of seedlings, saplings and live trees across multiple growth stages. Tree species richness1is represented as an index, with low values indicating a low number of

1Species richness is a measure of the number of species found in a sample population. This species richness index is Menhinick's index (known as D). Equation D=s/√N, where s=number of species in sample and N=the total number of individuals species to total trees, and high values high number of species to total trees (zero indicates no trees). Higher tree species diversity is an indication of a healthy natural forest that can, in turn, support a more diverse natural assemblage of plants and animals. Biomass distribution can also be a good indication of forest health as it provides an indication of the relationship between trees, non-tree vegetation, dead wood, litter and soil. These relationships provide insights into general vegetation structure, decomposition (through litter and dead wood), and soil organic matter (an important indication of soil fertility).This data is used to estimate relative changes in biophysical condition of an area that is converted from one land use to another (Table c). For example, for every hectare of forest converted to a plantation forest there is a drop in the recruitment of seedlings and saplings by 73% and 33% respectively. The abundance of live trees drops by 19% along with the overall diversity of tree species.

Table c. Results for biophysical condition for different land cover types based on data from eight CREL PAs

Land cover type	Ave. Seedlings	Ave. Sapling	Live trees	Spp. Richness index	Trees (above and below ground)	Dead trees	Non-Tree	Litter	Soil
	(ha)			Ratio	Mg CO_2/ha				
Forest	17,804	3,800	1,700	0.10	293.9	1.2	3.2	8.6	35.3
Plantation	4,815	2,556	1,376	0.07	222.2	0.6	7.1	7.2	29.7
Rubber	455	0	1,204	0.02	201.5	0.0	2.5	6.8	35.8
Village forest	1,393	746	929	0.06	136.3	1.1	1.0	3.2	15.9
Tea Garden	0	0	381	0.04	105.1	0.0	0.6	3.8	50.7
Degraded forest	1,178	1,763	447	0.03	57.1	0.2	4.1	4.9	26.2
Settlement/bare land	0	0	113	0.00	27.8	0.0	2.3	10.5	40.1
Agriculture	0	0	46	0.01	23.7	0.0	0.9	2.6	27.7

1. INTRODUCTION

This report presents the methods and results of the 2014 CREL2 forest inventory and land cover mapping for eight forest Protected Areas (PA) in Bangladesh. The inventory and mapping were conducted to establish baselines for GHG emissions and biophysical changes from deforestation and forest degradation and inform the development of Bangladesh's National REDD+3 program.

The primary objectives for the CREL project in Bangladesh are to conserve ecosystems and protected areas, to improve governance of natural resources and biodiversity, and to increase resilience to climate change through improved planning and livelihoods diversification. The project is focused on around 30 select locations in Bangladesh, where it implements a wide range of social, economic and environmental activities to meet its overall objectives. For each activity, CREL must meet performance targets to demonstrate positive impact. For many activities, success is measured against an assessment of the pre-intervention status quo or **baseline** condition. After the establishment of a baseline, project success is monitored at regular intervals or at project end. Examples of performance targets include changes in ecosystems, capacity of stakeholders and co-management organizations, socio-economic development of beneficiaries, and policy progress.

This report focuses specifically on CREL's baselines for **greenhouse gas (GHG) emissions** and **changes in forest biophysical condition** resulting from deforestation and forest degradation in eight forest PAs.

To establish these baselines CREL conducted a forest inventory to measure forest carbon and biophysical conditions. The inventory was conducted at eight forest PAs in the Chittagong, Sylhet and Dhaka Administrative Divisions of Bangladesh in 2014. In coordination with the field inventory, land cover maps were also developed for the eight PAs using high-resolution rapid eye imagery. As part of the process CREL conducted extensive reviews of existing forest inventories and land cover mapping in Bangladesh. All methods and results were developed in a manner to allow comparison with past forest inventories, and integration into any future forest inventory.

CREL developed these baselines in accordance with international standards for GHG accounting under a National REDD+ framework as set out by UNFCCC Intergovernmental Panel on Climate Change (IPCC). The goals of the activities outlined in this report are first, to ensure robust baselines and GHG accounting for the CREL project and, second, to use CREL resources to contribute to National REDD+ development in Bangladesh. Although CREL's activities are not national in scope, many of the methods for forest mapping, biomass sampling and GHG emissions calculation are applicable to any scale. As a result, the experience contained here can be a valuable contribution to nationwide accounting, including further development of National REDD+. Currently Bangladesh is in the process of developing their National REDD+ strategy, having completed their UN-REDD Road Map, REDD Readiness Preparation Proposal (R-PP), and 2 National Communications (NC) (2002 and in 2012). This report highlights the contributions that the CREL project has made toward National REDD+. The

2 USAID funded Climate Resilient Ecosystems and Livelihoods (CREL) project in Bangladesh

3 Reduced Emissions from Deforestation and Forest Degradation [plus enhancements and improved forest management]

blue text boxes at the beginning of some sections reference R-PP text that is relevant to that section and therefore CREL work that contributes to Bangladesh R-PP REDD readiness.

> Some sections of this report start with blue text boxes that reference relevant R-PP sections and identify contributions to the R-PP.

This report is not intended to be a general guidance document for how to undertake REDD+ accounting, but instead a supplement for those familiar with REDD+ and the current status of REDD+ in Bangladesh.

This report presents: 1) a review of past forest inventories, 2) an assessment of drivers of land use change in CREL PAs, 3) a harmonized land cover classification system (LCCS), 4) a review of the forest definition and forest stratification for Bangladesh, 5) benchmark land cover maps for eight CREL PAs, 6) a review and integration of forest sampling designs, 7) the development of a standard operation procedure for carbon and biophysical measurement of land cover, 8) emission factors for deforestation, 9) a review of forest degradation in the Bangladesh context, 9) the development of forest biophysical change factors, 10) baseline land cover changes from 2000 to 2012 using UMD's4 global deforestation dataset data combined with CREL benchmark maps for CREL's eight PAs, 11) the baseline GHG emissions and biophysical change for CREL PAs.

1. STRUCTURE OF THE REPORT

The report follows a general approach that a National REDD+ program would need to follow in order to establish National GHG historical emissions baselines, which is a necessary component of a REDD+ Reference Level. This report is organized as follows:

SECTION 2: BACKGROUND OF FOREST CARBON INVENTORIES IN BANGLADESH

Review of past forest inventories to develop and integrate methods that are compliant with international standards while building on exiting capacity within Bangladesh. For the CREL project this is important to ensure that their data are comparable with other work that has been done in Bangladesh and therefore applicable beyond the CREL project. For National REDD+ this is an important first step to ensure efficient development of national inventories.

SECTION 3: LOCATION OF CREL'S 2014 LAND COVER MAPPING AND INVENTORY

SECTION 4: DRIVERS OF DEFORESTATION AND DEGRADATION

Assessment of the drivers of deforestation and degradation in CREL PAs. The driver assessment is important for CREL as it identifies the dominant land-use changes occurring in the area and informs PA-level conservation interventions. On the analytical side, driver assessment helps to focus land-cover mapping and biomass sampling efforts towards the largest GHG emissions sources. While CREL's assessment is focused on local regions and not national scales, it does add to the database for common drivers of land use change in Bangladesh.

4(Hansen et al. 2013)http://earthenginepartners.appspot.com/science-2013-global-forest

SECTION 5: LAND COVER CLASSIFICATION

Develops and conducts a land cover classification based on existing Bangladesh land cover definitions and FAO's work on establishing a set LCCS5. The LCCS is informed by the driver analysis that identifies important land cover changes that should be mapped and monitored. A forest definition is established, the stratification of forest types are reviewed and established, and land cover maps are developed. For the CREL project this is important for creating the benchmark land cover maps and historic baseline land cover change that all future land cover changes will be measured against. For National REDD+ the process is a valuable assessment and exercise in defining key variables, such as land cover classification, forest definition, and forest stratification.

SECTION 6: FOREST INVENTORY – ESTABLISHING EMISSION FACTORS

Describes the development and implementation of the forest inventory at the eight CREL PAs. For CREL, establishment of carbon emission factors allows measuring the GHG impact of activities at each PA. For National REDD+, afield inventory sampling design and Standard Operating Procedures (SOP) were developed so as to be a template used for REDD+ National Forest Inventories (NFI). Under a REDD+ context the standardized stratum-specific emissions resulting from land use changes are called **"emission factors."**

SECTION 7: BASELINE RESULTS

Combines the historic land cover change maps with "emission factors" to develop baseline GHG emissions for each of the eight CREL PAs. Biophysical data can also be assessed in the same way and therefore baseline biophysical changes can be assessed. For CREL these baselines can be used to measure the impact of CREL interventions during the life of the project.

2. REDD+ OVERVIEW

When forests are degraded or cleared, carbon stored in trees, non-tree vegetation, roots, deadwood, litter, and soil is released into the atmosphere as carbon dioxide (CO_2, a major greenhouse gas [GHG]). Following degradation and deforestation, a forest's capacity for additional carbon sequestration is also reduced or lost. GHG emissions from deforestation and forest degradation are significant, and have been estimated to account for about 10% of global anthropogenic CO_2 emissions6. Therefore, policies related to REDD+ in developing countries have the potential to play a significant role in climate change mitigation.

A National REDD+ program provides a framework for countries to develop a Reference Level (RL) of expected future emissions that models a business-as-usual (BAU) scenario, and allows REDD+ actors to plan specific interventions to reduce emissions below BAU. The Reference Level is the projection of future emissions against which the performance of REDD+ interventions is ultimately assessed. In other words, a RL is essentially a national or sub-national baseline for GHG emissions that is used as the threshold or target from which

5 Land Cover Classification System (LCCS) is a FAO developed program that facilitates the development of land cover classes that are hierarchical enabling detailed classifications to be comparable with more simple classifications

6 Harris, NL, Brown, S, Hagen, SC, Saatchi, SS, Petrova, S, Salas, W, Hansen, M, Potapov, P, Lotsch, A. 2012. Baseline map of carbon emissions from deforestation in tropical regions. Science 336: 1573 – 1576.

reductions in emissions can be measured. Figure1shows a hypothetical example of historical emissions measurements that contribute to the projection (into the future) of a RL based on a BAU scenario.

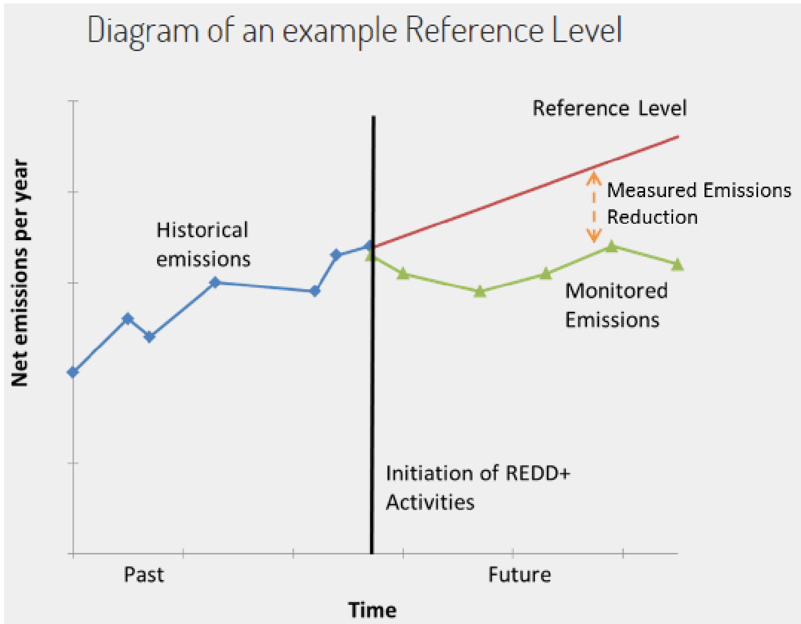


Figure1.Theoretical representation of historical emissions used to project a Reference Level. The initiation of REDD+ activates is when monitoring against the RL begins. The green line is a theoretical monitoring of emissions that activities that shows a successful REDD+ program as emissions are reduced below that RL. This is similar to monitoring against a baseline.

To achieve emission reductions against an RL, policies and measures must be established and implemented that will result in 1) reductions in forest emissions from deforestation or degradation or 2), enhanced removals by forests. For example, emissions reductions could be achieved by improving protection of forests through training, improved governance and supporting sustainable livelihoods. Projects to enhance carbon stocks of existing forests or to establish new forest areas can also contribute to national net GHG emissions reductions. To determine the true net emissions-reducing effect of REDD+ activities, post-intervention emissions and removals must be monitored and compared to the RL. Calculation of post-intervention emissions reductions demands a process of measurement, reporting, and verification of actual emissions taking place across the landscape. This suite of activities is known as an MRV System.

Under REDD+, emissions from deforestation and forest degradation are established by multiplying emission factors (EF) (e.g. t CO_2e ha^{-1}) and activity data (AD) (e.g. hectares). Emission factors are calculated as the change in carbon stocks per unit of magnitude of an activity between two points in time. In the forestry sector, EFs consider the GHG emissions and removals related to the decomposition or combustion of biomass, soil organic carbon loss, removals from vegetation growth, and carbon stored in wood products (e.g. furniture). For forest degradation, emissions are calculated from the difference in carbon stocks between non-degraded forest and degraded forest or from the specific flux of emissions and sequestration resulting from an activity (Figure 2). For deforestation, emissions are the difference in carbon stocks between forest and post-deforestation land cover (e.g. agricultural land) (Figure 2). This difference is usually calculated on a per unit area basis, therefore tons of carbon per hectare.

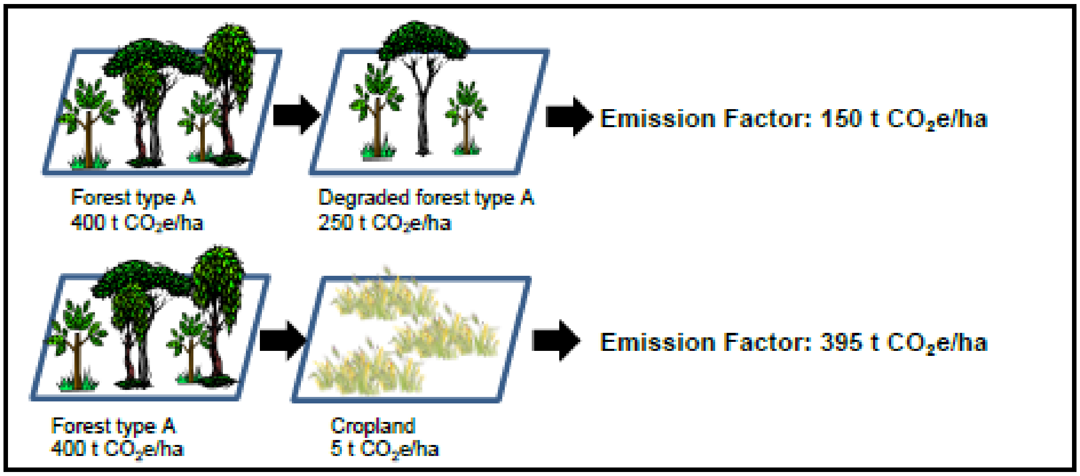


Figure 2. Representation of emission factors from forest degradation and deforestation.

Remote sensing methods can quantify the area of deforestation between two points in time by creating maps of the extent of forest cover (Figure 3). The area and rate of deforestation can be established by comparing forest cover across maps representing several points in time. Some forms of forest degradation can also be mapped using remote sensing, but this process is much more difficult to detect with a high degree of precision, and therefore degradation is often measured based on ground data, or is conservatively ignored. Enhancements within existing forest areas are also difficult to quantify using remote sensing alone due to the incremental nature of tree growth. Therefore, enhancements are more easily calculated through a combination of field data of hectares planted or enhanced and remote sensing monitoring.

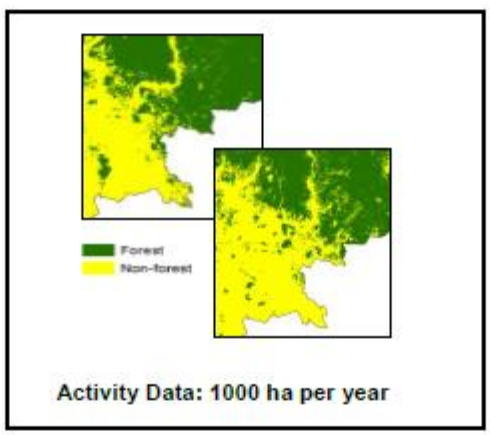


Figure 3.Representation of deforestation Activity Data from remote sensing land cover maps.

As stated in the current version of the R-PP, "*it is difficult to ascertain how Bangladesh's RELs/RLs will be developed and based on historical data, and/or adjusted on historical data. However, decision 12/CP.17 specifies that the development of the REL/RLs will be performed following a step-wise approach enabling Parties to improve the forest REL/RLs by incorporating better data, improved methodologies and, where appropriate, additional pools, noting the* *importance of adequate and predictable support as referenced by decision 1/CP.16, paragraph 71*." **The following report attempts to contribute to Bangladeshis REL/RL development.**

2. BACKGROUND OF FOREST CARBON INVENTORIES IN BANGLADESH

> R-PP Section 4.3.2: … Comprehensive review of existing inventory designs is required to develop a multi-purpose NFI design that will allow measuring and reporting of the emission from forestry sector as well as provide necessary information on biodiversity and other co-benefits etc. NFI will identify the existing carbon pools (above-ground biomass, below-ground biomass, litter, soil and dead wood).

The history of forest inventories in Bangladesh goes back to the late 1960s. Traditionally forest inventories have been used to estimate the availability and volume of timber trees. In Bangladesh in 1989traditional logging was stopped due to the limited availability of existing forest. Over the last decade interest in forest for its role in mitigating the effects of climate change has refocused the need for forest inventories toward quantifying the potential for carbon storage. The primary driving force for national and regional forest carbon inventories comes from UNFCCC's7REDD+8initiative that seeks to establish a multilateral agreement where developed countries, will pay developing countries emissions reduction credit for reducing emissions associated with deforestation, forest degradation, and enhancing carbon stocks areas through activities such as reforestation.

Bangladesh is currently in the process of developing their National REDD+ strategy, having completed a UN-REDD Road Map, their REDD Readiness Preparation Proposal (R-PP), and 2 National Communications (NC) (2002 and in 2012). For Bangladesh one of the key steps in developing National REDD+, and reporting accurate GHG flux from the land use sector, is conducting national or regional carbon inventories.

This analysis conducted a thorough review of past forest carbon inventories conducted in Bangladesh and identified those inventories that should be considered as a basis for an NFI. It is important to note that forest inventories can be compiled from multiple periods of time, and NFI sampling designs can be developed to account for previous local inventories, thereby leveraging past work and reducing the overall resources needed for the NFI (see Section 6.1). One of the purposes of CREL's work was to review and synthesize previous carbon inventories and develop a set of methods and data that would inform and enable a future NFI so that it could leverage past work by CREL and others.

The only national scale inventory for Bangladesh was done in 2005-2007 by the Forest Department, FAO & local experts. This inventory took a systematic sampling where the entire country of Bangladesh was gridded and laid out at10 minutes longitude and 15 minutes latitude intervals, resulting in 299 plots. Among other things the carbon pools measured were above and below ground tree, seeding, saplings, non-tree vegetation, litter and soil. The study results showed above ground carbon in forests (96t C/ha), cultivated lands (9t C/ha), villages (72t C/ha) and urban areas (46t C/ha) and inland water (1t C/ha). However, this inventory was not focused on forests therefore the sampling design under sampled forest areas and did not address important topics like forest stratification and forest degradation, and therefore is less relevant

7 United Nations Convention on Climate Change - http://unfccc.int/2860.php

8 Reduced Emissions from Deforestation and Degradation [plus

under a REDD+ framework. For a REDD+ program it is highly recommended that an NFI be stratified by forest areas so that sampling is focused on the appropriate areas and therefore statistically relevant carbon stocks estimations are achieved.

The two past inventories that met the standards for inclusion into a REDD+ forest carbon NFI were the Forest Carbon inventory in the Sundarban Reserve Forest (SRF) (2009), and the IPAC Forest Carbon inventory in hill forest protected areas (2010). Both of these inventories followed similar protocols that are robust and would qualify as adequate for inclusion under an NFI that seeks to establish a REDD+ program.

Forest Carbon inventory in the Sundarbans Reserve Forests (SRF) (2009): The SRF carbon assessment, like an earlier forest inventory (WB financed FRMP inventory 1996), sampled150 clustered plots composed of five circular subplots (Figure 4). Bangladesh Forest Department (FD) and United States Forest Service (USFS) adopted this sampling design for the 2009 SRF. These 150 plots are a subset of the 1200 temporary sample plots (of 1996 inventory) distributed systematically at one minute intervals. The plots are laid out from a center subplot with four more subplots oriented in cardinal directions (east, west, south, north), 50m from the center. Each subplot has different sized concentric nested circles (2 m radius for seedlings and saplings, 4m radius for non-tree vegetation, 10m for trees). In addition 30cmX30cm square plots for litters, and 10m transacts from center for woody debris are also included in each plot. For soil samples, 0-30cm and 30-100 cm depth samples were taken from each plot using 1m long open-faced peat augers. Two 5cm-long samples (for bulk density and %OC) were taken from each of the mid-point of 0-30cm and 30-100cm.

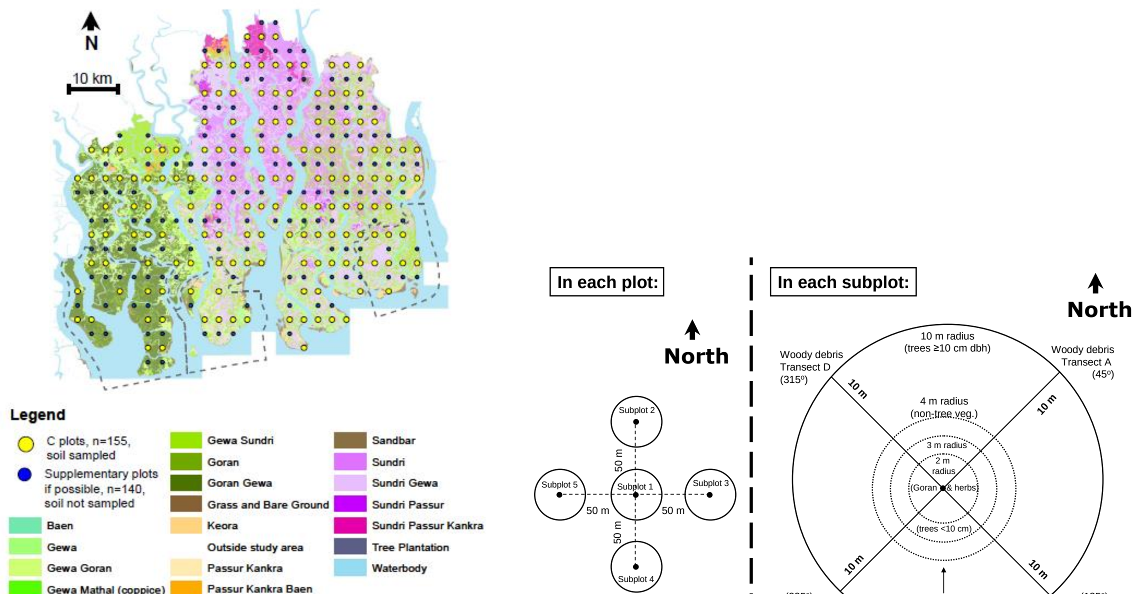


Figure 6. Proposed sampling scheme for Sundarbans carbon and forest inventory. A systematic grid is employed, with 295 plots spaced at regular intervals of latitude/longitude. Gaps in the grid are due to watercourses. These plots are a systematic subsample of an existing inventory grid of ~1200 plots that were measured in the 1990s, thus enabling past inventory data to be utilized for baseline comparisons.

Figure 4. Forest carbon inventory for the Sundarbans RF, sampling design (left side) and clustered plot layout (right side)

forest carbon inventory in hill forest protected areas (2010): An approach similar to SRF inventory (2009) was adopted by an FD and IPAC team in 6 hill forest PAs in the south-eastern part of the country. These PAs include 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 differ in size and fragmentation of land use, the sampling design for each PA varied along the number of samples taken and the distribution of plot locations, as shown in Table 1.

Table 1.Sampling strategy for 2010 IPAC inventory

PA	Area (ha)	Number of Plots	Sampling Grid Interval
Teknaf WS	11,615	54	45”
Inani RF	7,700	56	40”
Medakachapia NP	396	41	12”
Fasiakhali WS	1,302	72	15”
Dudpukuria-Dhopachari WS	4,717	62	30”
Sitakunda eco-park	800	35	50”

This inventory measures the same carbon pools as SRF with the exception that soils were only measured to 30cm depth, and a pool for non-tree woody that includes shrubs, cane and bamboo was included. The non-tree woody pool is non-existent in the SFR therefore it was not an omission. In total the carbon pools were, above and below ground trees (including seedling and saplings), non-tree woody (shrubs, cane, and bamboos), herbaceous, litter, deadwood, and soil.

These two inventories were used as the basis for the development of the CREL 2014 forest inventory. As such, the sampling design was developed to be consistent with these inventories, with a few refinements(see Section 7.1).The Standard Operating Procedures (SOP) for fieldwork were reviewed, adapted, improved and published as the “Standard Operating Procedures For Forest Carbon Inventories, Bangladesh” (2013) (see Section 6). Both the sampling design and SOP meet UNFCCC REDD+ reporting requirements. A detailed report of the forest inventory methods and results is presented by Latif, Chowdhury and Netzer, 2014.9.

9Latif, M. A.; Chowdhury, R. M. and Netzer, M. 2015: Forest Carbon Inventory 2014 at Eight Protected Areas in Bangladesh. CREL Project Bangladesh Forest Department and Winrock International. (Mimiograph)

3. LOCATIONS OF CREL'S 2014 LAND COVER MAPPING AND INVENTORY SITES (PAS)

The goal of the CREL 2014 forest carbon inventory and land cover mapping was to first establish baseline forest GHG emissions, and biophysical conditions in eight Protected Areas (PA) and their surrounding Landscapes (area around the PA where CREL activities are conducted). Second the inventories were seen as an opportunity for the CREL project to use its resources and experience to establish a set of methods and results that that meet with UNFCCC REDD+ reporting requirements and therefore could inform future NFI plans and provide an initial quantification of GHG emissions from the land use sector.

The eight PAs where the CREL inventory and land cover mapping was conducted in 2014 are Khadimnagar National Park (KhNP) at Sylhet, Lawachara National Park (LNP) at Moulavibazar, Satchari National Park (SNP), Rema-Kalenga wildlife sanctuary (RKWS) at Habigonj, Modhupur National Park (MNP) at Tangail, Kaptai National Park (KNP) at Rangamati, Chunati wildlife sanctuary (CWS) at Chittagong and Himchari National Park (HNP) at Cox's Bazar. A report describing the Forest Carbon Inventory Design, data collections and data compilation procedures and preliminary results have been prepared and submitted to CREL (Latif, Chowdhury and Netzer, 2014).Figure 5 shows the locations of each of the eight CREL PAs.

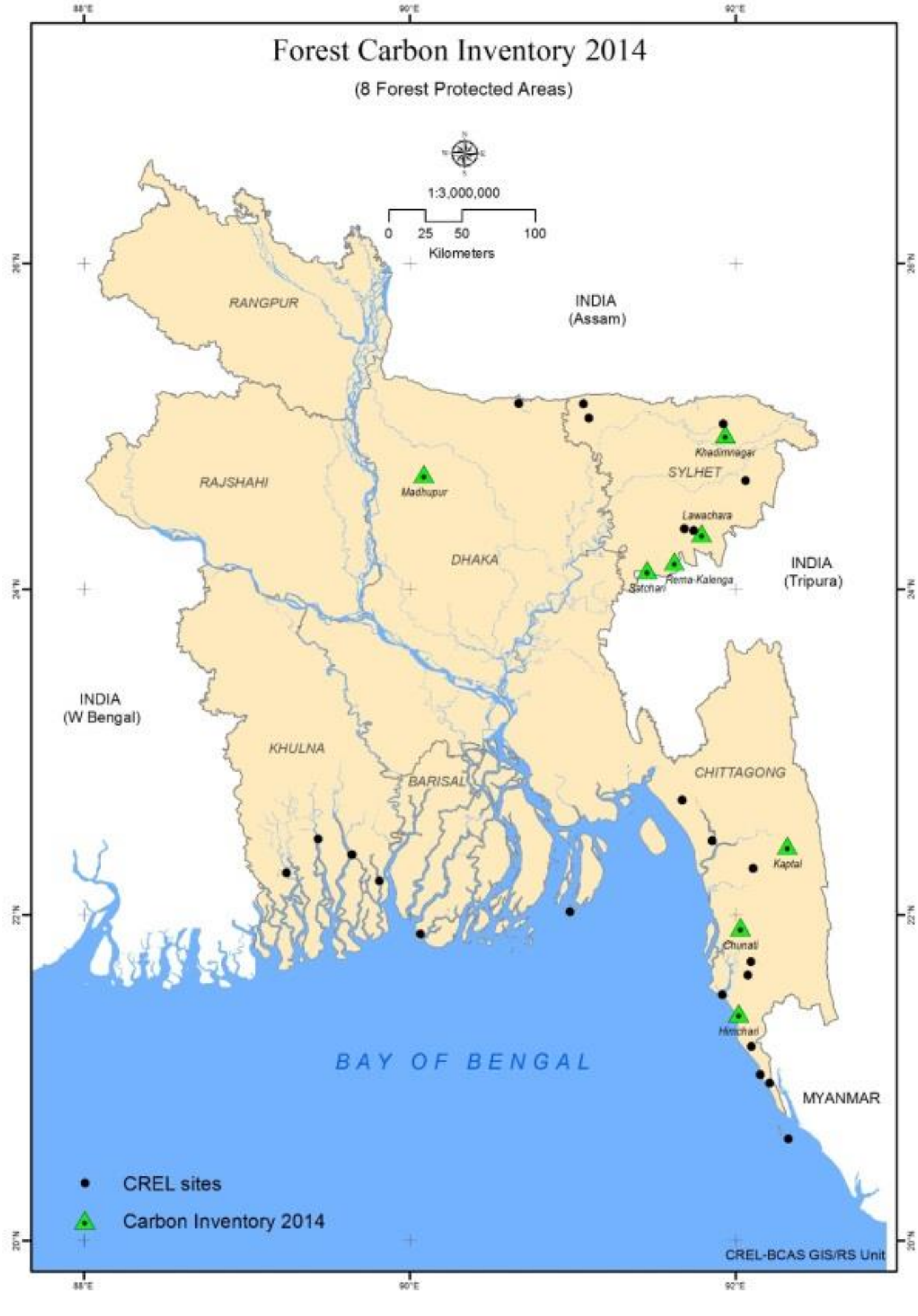


Figure 5. Map of CREL inventory locations, 8 Protected Areas.

4. DRIVER OF DEFORESTATION DEGRADATION & OTHER LAND USE CHANGE

The assessment of direct drivers of deforestation and other land use changes is an important first step before land cover mapping and field inventories begin because it identifies the important land cover changes that are occurring, and provides information on what land cover types should be inventoried and mapped. While the CREL assessment is not applicable for the National REDD+ scale, it does provide some insight to common direct drivers in Bangladesh. The results from CREL's analyses are shown in Table 2. The results highlight the fact that the predominant causes of forest loss are agriculture, development (roads and settlement), pasture, agroforestry, mining, illegal logging and illegal fuel wood collection. In Sylhet, tea plantations were an important driver. Natural disturbance was dominated by sea level rise in Chittagong/Cox and Sundarbans, and in Sylhet upstream development was the concern. With this data CREL engaged in discussion between the forestry teams (responsible for forest inventories) and the remote sensing teams to decide on the important land cover changes occurring in the area and therefore what should be inventoried and mapped. This informed the land cover classification described in Section 5 and the land cover types that were identified as important to the inventory described in Section 6.

One important result that came from the driver analysis is that wetland loss and degradation are major components of the land use change occurring in Bangladesh, and little is known about the extent of these changes or the impact on ecosystem services. Other components of the CREL project have focused on assessing wetlands. However, this does not include GHGs and the authors of this report are not aware of any other work in Bangladesh assessing the carbon flux from land use changes in wetlands, therefore it is identified as a significant gap in Bangladesh's GHG accounting.

Table 2. Results from the driver analysis at CREL sites in Chittagong/Cox, Sylhet and Sundarbans

	Driver	Land use change
Chittagong/Cox's Bazar	Agriculture	Deforestation/wetlandloss/other
	Agriculture - betal leaf	Deforestation/wetlandloss/other
	development - settlement	Deforestation/wetlandloss/other
	development - roads	Deforestation/wetlandloss/other
	fish/shrimp pond	Wetland Degradation
	fuel wood collection	Forest Degradation
	logging (illegal cutting)	Forest Degradation
	Agroforestry	Deforestation/wetlandloss/other
	Pasture	Deforestation/wetlandloss/other
	Mining	Deforestation/wetlandloss/other
	environment - sea level	non-anthropogenic
	environment - fire	non-anthropogenic

Sylhet

Driver	Land use change
Agriculture	Deforestation/wetlandloss/other
Agriculture - Tea	Deforestation/wetlandloss/other
development - settlement	Deforestation/wetlandloss/other
development - roads	Deforestation/wetlandloss/other
fish/shrimp pond	Wetland Degradation
fuel wood collection	Forest Degradation
logging (illegal cutting)	Forest Degradation
Agroforestry	Deforestation/wetlandloss/other
Pasture	Deforestation/wetlandloss/other
Upstream development	Wetland Degradation

Sundarbans

Driver	Land use change
Agriculture	Deforestation/wetlandloss/other
fuel wood collection	Forest Degradation
environment - sea level	non-anthropogenic
environment - storm	non-anthropogenic

5. LAND COVER CLASSIFICATION

From R-PP Section 3.3.2: Remote sensing data are vital to map past forest land area changes for the five REDD+ activities. The feasibility of using remote sensing techniques depends on the availability of past satellite imageries, the quality, spatial, temporal, and spectral resolution of the satellite imageries and the available human, technical and financial capacities. Several satellite imageries are already used in Bangladesh and were used to develop past land cover and land use maps. At current status one national forest land map has been developed.

Land-cover maps are an important component of the estimation of historical emissions from the landscape. By comparing maps and data layers from different time periods they allow rapid assessment of the area of all land-cover transitions. As mentioned in the Introduction (Section 1.2) under a REDD+ context the area of change from one land-cover class to another is called "activity data." Each unique potential transition (for example forest type A to agriculture) is associated with a certain level of GHG emissions per hectare of transition (i.e. emissions factor). Digital maps present an efficient method for estimating the hectares of transitions between two time periods. Land-cover maps are made for two time periods and compared to one another. Areas that differ between maps (e.g. "forest" in 2000 and "agriculture" in 2010) are interpreted to be land-cover transitions, and a GHG emission is associated with the change.

This section highlights CREL's harmonized land cover classification system, reviews and makes recommendations for a forest definition, reviews options for forest stratification, and presents the results for the land cover maps for CREL's eight PAs. While the land-cover classification work of CREL was primarily done to support the drafting of management plans for PAs, all of the activities undertaken parallel the steps necessary to develop National REDD+.

This section, describing CREL's engagement in land-cover mapping, supports national REDD+ in several ways:

1. Presents a novel land-cover classification system that has been adapted from existing systems in Bangladesh and is catered to application for GHG estimation
2. Reviews forest definitions and stratification that could be implemented at a national scale.
3. Provides preliminary estimates of land cover for eight PAs.

5.1 Data used to inform the definition of land cover classes

5.1.1 Developing a harmonized land cover classification using LCCS

> R-PP Section 4.2.3: Currently, different classifications and definitions are used for mapping natural resources in Bangladesh. The classification systems are using by the organizations also varies for a single thematic area. Therefore the data cannot be compared between types, locations and different time periods; on the other hand, different data have been developed for different purposes, regardless of a national framework for monitoring forest cover in space and time. In order to support a system for monitoring forest and land cover, in the context of REDD+ and the preparation of the GHG inventory for the UNFCCC, the various forest and land cover classification efforts need to be harmonized. The different legends and collected field data should be used to develop a common and functional classification system that could be used for mapping, assessment and monitoring the land cover using remote sensing.
>
> 1. Develop a harmonized classification system of land use;
> 2. Test the suitability of the use of Land Cover Classification System (LCCS) in identifying the land cover for different purposes including REDD+.
> 3. Provide recommendations on forest definitions, forest classification and forest stratification

Past mapping efforts in Bangladesh have used an assortment of classification systems that are not fully compatible with one another. In order for change over time to be observed, it is imperative that the classification systems between maps are the same, or are at least translatable. UN-REDD has already begun the process of harmonizing existing classification systems. Akhter and Shaheduzzaman (2013) present a list and summary of the most prominent examples of classification systems in Bangladesh. They are:

1. Regional Level:
   a. ICIMOD 2010 (based on 2000 data)
2. National Level
   a. Forest Department, 2007 National Forest Assessment (Figure 6)
   b. Soil Resources Development Institute (SRDI)
3. Sub-National
   a. Forest Department, Numerous maps of individual protected areas, 1950s-present

CREL reviewed these existing classification systems and derived one that met the following objectives:

- Compatible with other classification systems in Bangladesh
- Defined within FAO's LCCS framework
- Classes are relevant for monitoring carbon stocks
- Classes could plausibly be monitored with existing remote sensing data sources and techniques

Figure 6: Forest Department national classification system, 2007

The classification system used by the forest department in the mapping of Bangladesh in 2007 was used as the template for development of CREL's own system. The CREL system expanded on the general classification system to allow for more detailed categories, and include a wetland class. The wetland class had been omitted from previous land cover classification; this may be because wetlands can be hard to accurately classify using remote sensing due to their seasonally changing nature. However, based on the knowledge that wetlands are one of the most prominent land cover types in Bangladesh and are under threat of conversion, it is recommended that effort be applied to accurately mapping and monitoring wetlands in Bangladesh. The conversion of wetlands could be an important contributor to GHG emission and should be assessed even under a REDD+ framework.

The CREL classification system is shown in Table 3. The classification is organized into three levels, with level three classes directly related to level two, and level two directly related to a single class in level one. The reason for developing a hierarchical classification is to enable different land cover mapping efforts to use a single set of classification rules that allow comparability between maps, while providing flexibility for more or less detailed classification. For example, a high-resolution mapping effort may be able to distinguish between swamp forest, mangrove forest and upland forest (Hill and Sal forest), while a lower resolution mapping effort can only distinguish forest from non-forest. By creating a hierarchical classification the more detailed forest classification can be grouped and compared with the less detailed forest classification.

Table 3: Classification system developed by CREL using LCCS

Level 1 Classification	Level 2 Classification
1. Forest	1.a. Rubber / Acacia plantations
	1.b. Hill forests (evergreen or semi-evergreen)
	1.c. Sal forests (deciduous)
	1.d. Mangroves
	1.e. Swamp forests
	1.f. Bamboos
	1.g. Plantation forests
	1.h. Degraded forests
	1.i. Village forests/ homesteads

Level 1 Classification	Level 2 Classification	
2. Wetlands	2.a.Haors/Beels	
3. Permanent water bodies	2.a. Natural freshwater (permanent)	3.a.1. Rivers
		3.a.2. Canal and Lakes
	2.b. Manmade water features	3.b.1 Ponds
		3.b.2 Salt pans
		3.c. Aquacultures
	2.d. Sea	
3. Settlements	3.a. Urban settlements	
	3.b. Homestead vegetation/Rural settlements	
4. Non-forest upland vegetation	4.a. Permanent and Biannual crops	4.a.1. Tea
		4.a.2 Tree crops
		4.a.3 Pineapples
		4.a.4 Citruses
		4.a.5 Betel leafs
	4.b. Degraded lands (non-cultivated)	4.b.1. Sun grass
		4.b.2. Scattered trees
5. Irrigated Agricultures	5.1 Rice	
	5.1 Others	

CREL participated in the FAO-led workshop 24-28 March 2014 “Land cover classification in the contexts of REDD+ in Bangladesh,” where the importance of LCCS for the standardizing national mapping for REDD was emphasized. In accordance with this recommendation, CREL has defined all of the classes used in its protected area mapping within LCCS and made this available to the Forest Department.

The Land Cover Classification System (LCCS) is an FAO system for standardizing the definitions that underlie land-cover classes. Terms like “forest” and “wetland” can be interpreted very differently by both map producers and users. Furthermore, different maps, although possessing similar class names, may, in fact, be based on different criteria used to define those classes. In LCCS, a user is asked to define the precise characteristics of each class using a provided list of descriptors. For example, a “Forest” class in a mapping project might be defined by height, pattern (continuous, patchy), phenology, and geographic characteristics such as altitude. While LCCS is still restricted by the pre-set list of descriptors, and cannot therefore capture all potential information for land cover types, it does allow for much more transparent interpretation of maps by future users. Furthermore, if two maps are produced with LCCS, it is more feasible to compare maps and correctly identify areas of change.

5.1.2 FOREST DEFINITION

The forest definition for the CREL inventory was defined after thorough review of national, regional, and international standards. Typically forest definition includes threshold values for minimum level of crown cover, minimum height, and minimum area. For example, the three thresholds agreed to in the Marrakesh Accords are: 10% - 30% for crown cover, 2 - 5 m for height, and 0.05 - 1 ha for minimum area. Examples of forest definitions in other countries in the region are given in Table 4.

Table 4.Examples of forest definitions from other countries in the region from UNFCCC (http://cdm.unfccc.int/DNA/bak/index.html.)

Country	Forest definition criteria			Other forest types included	
	A single minimum tree crown cover value between 10 and 30 per cent	A single minimum land area value between 0.05 and 1 hectare	A single minimum tree height value between 2 and 5 meters	Palm trees	Bamboos
Cambodia	10	0.5	5	no	yes
India	15	0.05	2	not indicated	not indicated
Laos People's Democratic Republic	20	0.5	5	no	no
Malaysia	30	0.5	5	not indicated	not indicated
Myanmar	10	0.1	2	not indicated	not indicated
Thailand	30	0.16	3	not indicated	not indicated
Viet Nam	30	0.5	3	not indicated	not indicated

Bangladesh has not yet reported a forest definition to the UNFCCC. However, the Bangladesh FD has set its own forest definition at 10% canopy cover over 0.5ha of land with trees that can reach >5m high. This definition is compatible with international standards and relevant for regional ecology. Therefore, CREL's inventory adopted the FD definition of forest.

For this inventory, "Forest" is defined as land spanning over more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

It must be noted that setting the forest definition at 10% canopy cover does have a significant impact on forest area in Bangladesh. A quick analysis of national forest cover using the Global forest cover dataset by Hansen et al. (2013) using two different forest definitions >10% and >30% canopy cover shows a change in forest cover from 2.03 million ha with 30%, to 2.71 million ha with 10% canopy cover, an increase of 25%.

5.1.3 Forest classification and stratification

As mentioned above the forest was divided into 9 primary classes based on existing FD classification, harmonization of past land cover maps, and utilization of the FAO LCCS system. While "forest" as an overarching class could be readily identified with the RapidEye imagery used in this analysis, not all of the forest sub-types could be accurately classified using remote sensing (Table 5). Therefore, wherever possible these forest types were classified using ancillary data. The ancillary data that was used to define the natural forest types of Sal, Hill and Mangrove forest was the 2009 FAO land cover map. Rubber and plantation forest also could not be identified using computer automated remote sensing techniques, and therefore ground validation and manual digitization using Google Earth high-res imagery was used. Degraded forests could be mapped (with relatively low accuracy) in cases where the area is dominated by shrubs, but could not be mapped in cases where the forest canopy remained relatively intact (see Section 6.3.2 for description of the different types of degradation).

Table 5. Review of forest classification and stratification.

Major class	Sub-class	Able to be classified using RapidEye Satellite imagery?	Ancillary data used for stratification
1. Forest(the major class of forest can easily be mapped using RapidEye)	1.a. Rubber / Acacia plantation	No	Field data + manual digitization from high-res imagery
	1.b. Hill forests (evergreen or semi-evergreen)	No	FD 2010 land cover map
	1.c. Sal forests (deciduous)	No	FD 2010 land cover map
	1.d. Mangroves	No	FD 2010 land cover map
	1.e. Swamp forests	Not in CREL PAs	
	1.f. Bamboo	Not in CREL PAs	
	1.g. Plantation forests	No	Field data + manual digitization from high-res imagery
	1.h. Degraded forests	In some cases*	
	1.i. Village forests	No	Possibly classify all forest areas that are not in known forestry land and are not plantations.

*degraded forests that are dominated by shrub lands were able to be mapped however accuracy was low, degraded forests that maintained a tree canopy were not able to be mapped using RapidEye imagery.

The resulting CREL land cover classification using RapidEye satellite imagery was able to:

1. Stratify natural forest into three classes Sal, Hill and Mangrove. It is believed that this could easily be done at a national scale using the same methods as used in the 2009 FAO land cover map.

2. Map plantation forest and rubber using information from ground inventories and manual digitization using Google Earth high-resolution imagery. To do manual digitization at regional or national scale would require considerable effort. However, considering the importance of plantations in Bangladesh it is highly recommended that this be undertaken. This effort could include a combination of 1) compiling existing spatial data on all plantations, 2) supplemented by a diligent and structured effort to manually digitize all industrial plantations (excluding things like small household plantations)10.

3. Map degraded forest in some cases. Degraded forest is an important land cover type in Bangladesh as it represents a significant area, and forest degradation is likely the largest contributor of GHGs in the forestry sector. Based on the experience of CREL there are two important degraded forest types: 1) those areas dominated by shrubland, and 2) those areas that are degraded but maintain a tree canopy cover. This distinction is

10 Under the CREL project, BCAS in coordination with Winrock is developing methods for this type of manual digitization.

important because given the right remote sensing methods and data the shrublands can be mapped, but it is unlikely that degraded forest that maintains a significant canopy cover will be able to be mapped given current technologies (See Section 6.3.2 for further description of degraded forest).

4. Village forest was not classified separately in the CREL land cover maps, but it is an important component of the landscape in Bangladesh and it is recommended that any future national forest mapping efforts take the time to separate village forest from other forest types. It is believed that this could be done by simply classifying all forests in rural and urban areas that are not plantation as village forest. However this method needs to be critically assessed.

5.2 METHODS FOR LAND COVER CLASSIFICATION

This study relied on RapidEye and Landsat data from 2013 to produce land-cover maps. RapidEye imagery has the advantage of high resolution, and high return frequency. However, in comparison to Landsat OLI, there is a loss of spectral information in the longer wavelengths (Table 6). While this analysis relied primarily on RapidEye data, it is advantageous to use multiple sources of imagery in tandem in order to utilize the strengths of each source.

Table 6. Comparison of imagery sources

Imagery Source	Resolution	Return Frequency	Spectral Range (µm)
Landsat TM, ETM+, OLI	30m	16 days	0.44 - 0.85 (Blue – NIR)
RapidEye	5m	5.5 days	0.43 - 12.51 (UV – Thermal IR)

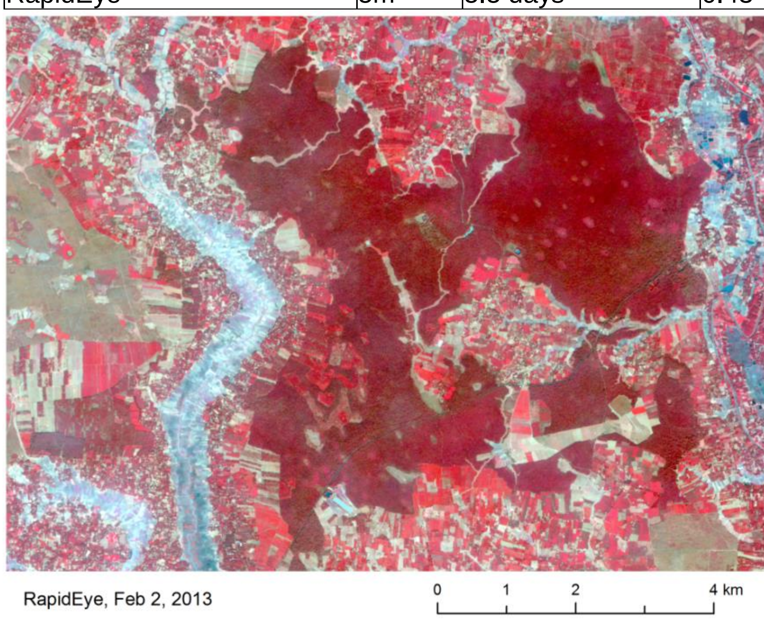


Figure 7. Example of imagery used in classification, Modhupur Reserve Forest

The GOFC-GOLD 2013 sourcebook presents six potential methods for producing land-cover maps from remote sensing data (Table 2.1.3). The method chosen by CREL is “object based segmentation with unsupervised clustering and visual labeling.” GOFC-GOLD recommends this as a preferred method, because it is “repeatable and efficient.” This method relies on a combination of computer-aided image interpretation with visual inspection and classification by a user familiar with the land-cover types of the particular landscape. First, a computer algorithm identifies contiguous areas of pixels that share similar spectral characteristics. These correspond to patches of land that have similar cover, such as forests of similar age and species, or human settlements of a particular density. Once the boundaries of these segments are produced, it is the job of the analyst to “assign” each of them to a class used in the mapping project, such as Forest or Settlement.

This method was applied for all eight protected areas inventoried by CREL. The segmentation step works well in areas where there are clear geographic boundaries between classes. However, in Bangladesh there are many forests that exhibit a gradual transition from agriculture to degraded land to forest over several kilometers. In such areas, accuracy is expected to be lower. The results of land cover classification are presented in Section 5.3.

Accuracy statistics, including users and producers accuracy, were calculated for each land-cover class in all mapped PAs. CREL undertook accuracy assessment using on-screen validation of maps against high-resolution open access imagery such as Google Earth and Bing Maps. CREL produced a Standard Operating Procedure (SOP) for this accuracy assessment process, and includes it among the potential contributions to National REDD+ and future biophysical monitoring.

5.3 RESULTS FOR LAND COVER CLASSIFICATION

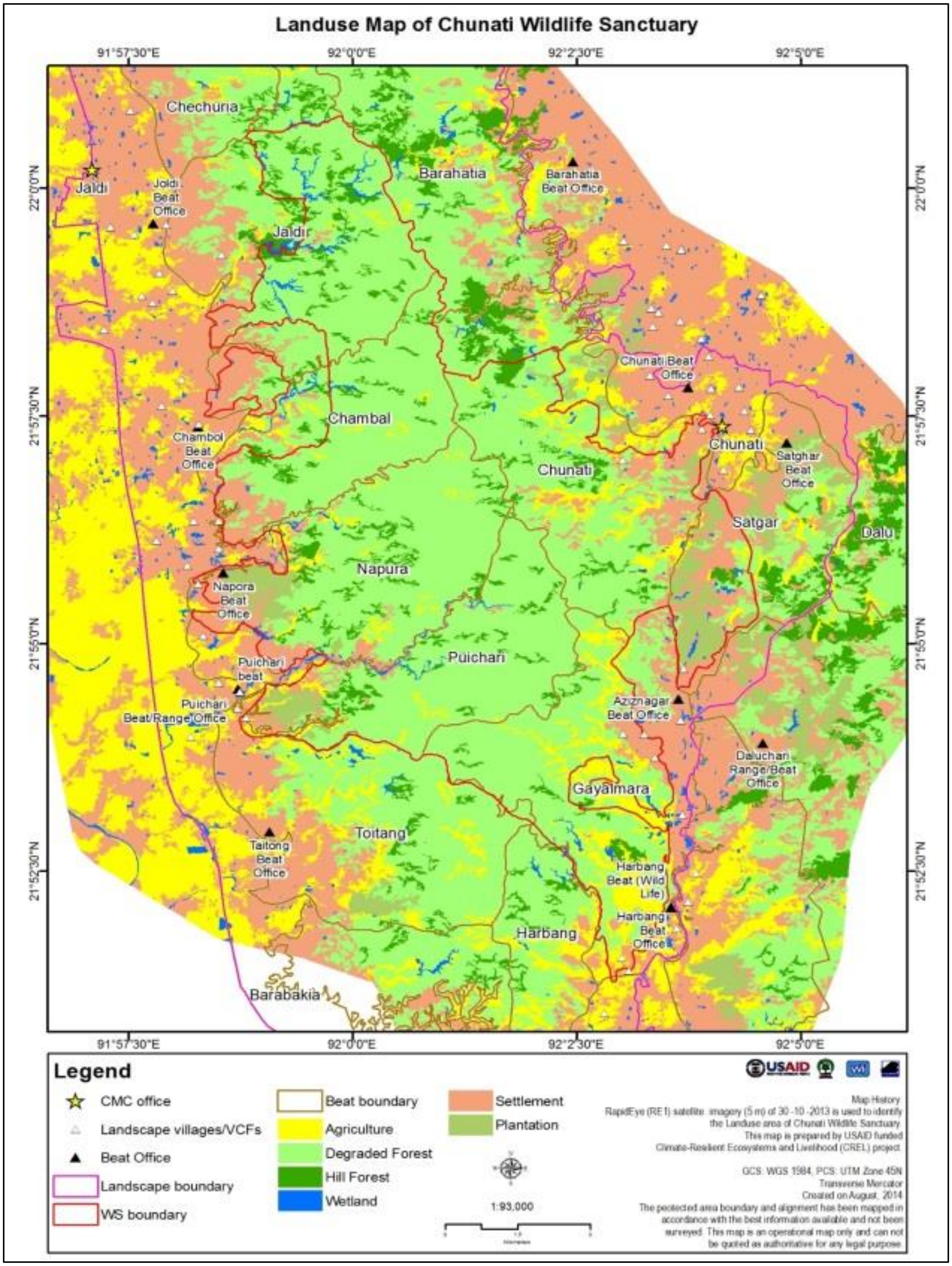
5.3.1 The Benchmark land cover maps

CREL produced land-cover maps for the eight protected areas. The extent of these maps cover both the core PA, as well as a surrounding buffer zone termed the “landscape.” For CREL’s purposes, these maps are one component of a “biophysical baseline.” Future landscape changes can be identified by comparison to these maps, and the loss or gain of ecosystem function can be at least partially attributed to the project. The total area of each land-cover class within PAs identified through RapidEye imagery is indicated in Table 7. This section also presents the maps and legends that were produced through this activity. The legends associated with each map may differ from the more generalized classes presented in Table 7. This is because in order to make meaningful comparisons across PAs, classes have been aggregated following the hierarchy of CREL’s LCCS (Table 3).

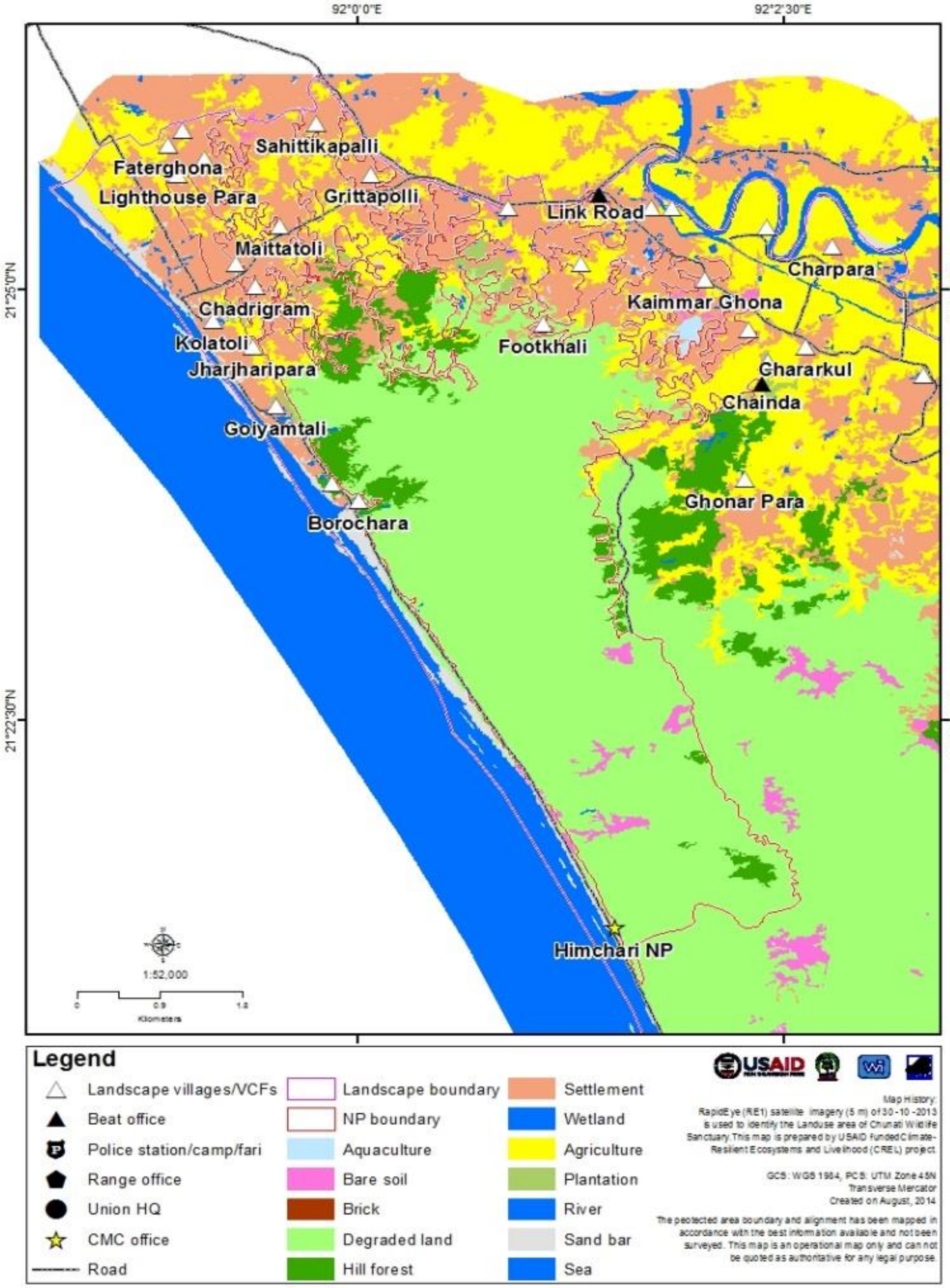
Accuracy statistics for each map are provided in an Appendix 2, and vary greatly both among classes, and across PAs. However, there are some general trends. In PAs with well-defined frontiers between forest and non-forest land use, the methods employed here were able to accurately delineate the boundaries between forest, agriculture, settlement and other classes. An example is Madhupur National Park. However, in heavily degraded forests experiencing high human pressure, there is often no precise boundary between classes. In reality, tree cover transitions occur gradually over a distance of hundreds of meters from a dense to a virtually non-forested state. This pattern is common in Hill Tract forests, and the resulting accuracy of maps in these areas suffers as a result.

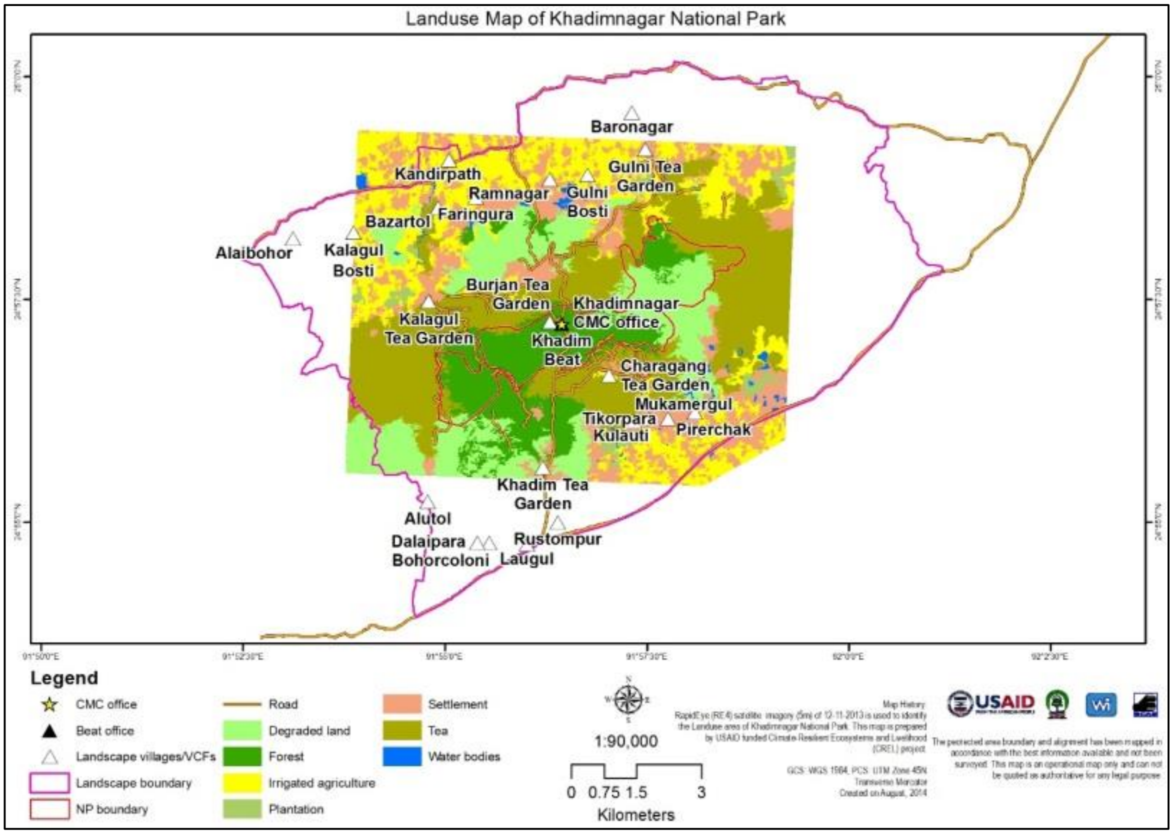
Table 7. Area of CREL PAs, by land-cover class. C and L denote, respectfully, the Core and Landscape (buffer) zones. Cells with an asterisk (*) denote PAs where data availability only permitted mapping the core PA zone.

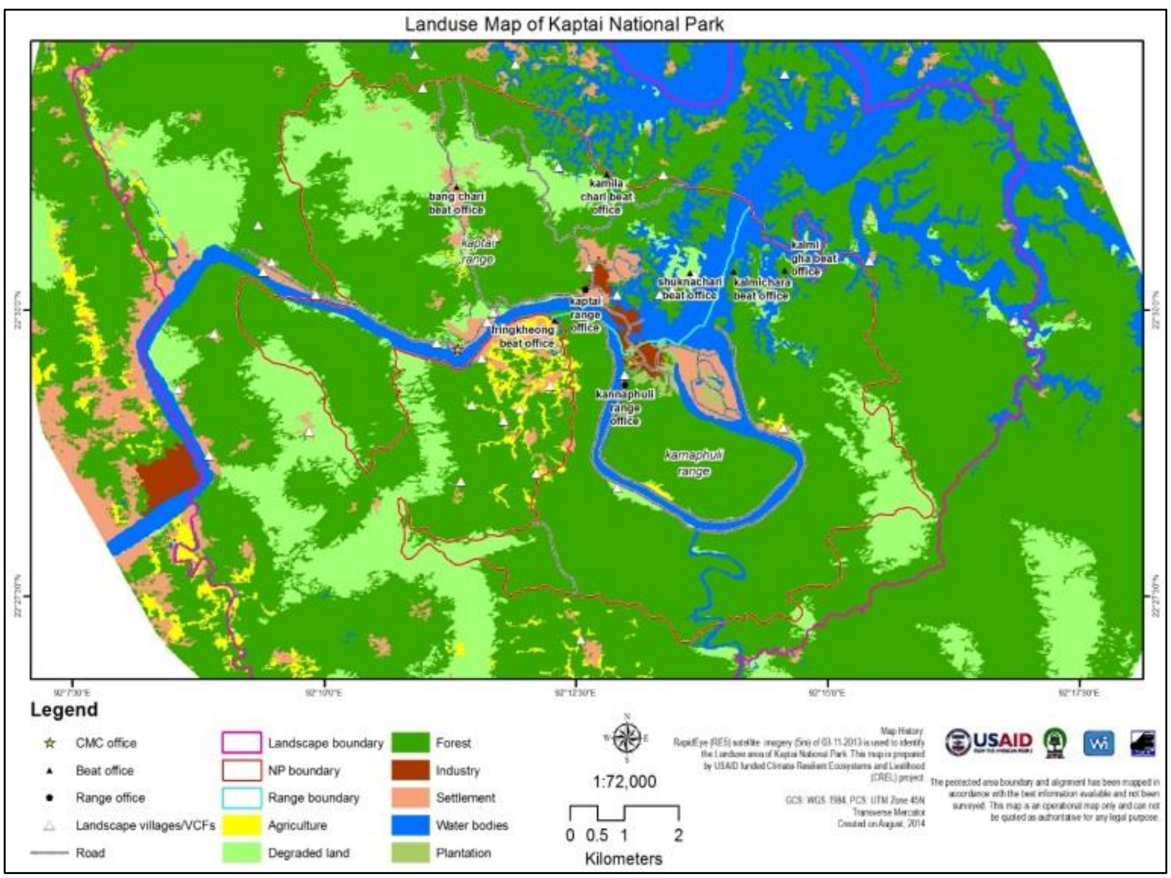
PA	Zone	Agriculture	Bare Land	Degraded Forest	Forest	Plantation	Rubber	Settlement	Tea Garden	Total Land Area
CWS	C	600	0	5,871	507	361	0	981	0	8,319
	L	1,728	0	7,655	809	583	0	4,227	0	15,003
	C+L	2,328	0	13,526	1,316	944	0	5,209	0	23,323
HNP	C	119	28	1,379	131	13	0	0	0	1,670
	L	2,306	279	3,828	975	237	0	2,390	0	10,015
	C+L	2,425	307	5,207	1,106	250	0	2,390	0	11,685
KNP	C	23	61	966	3,786	42	0	210	0	5,089
	L	131	61	1,763	7,547	42	0	433	0	9,975
	C+L	154								15,064
LNP	C	55	0	0	1,079	0	0	51	34	1,219
	L	992	0	0	2,095	0	91	1,542	3,420	8,140
	C+L	1,046	0	0	3,174	0	91	1,593	3,454	9,359
RKWS	C	82	0	0	1,704	5	0	2	0	1,793
	L	*	*	*	*	*	*	*	*	*
	C+L*	82	0	0	1,704	5	0	2	0	1,793
KhNP	C	3	0	198	479	0	0	1	98	779
	L	*	*	*	*	*	*	*	*	*
	C+L*	3	0	198	479	0	0	1	98	779
MNP	C	2,083	0	0	2,232	578	496	2,873	0	8,262
	L	*	*	*	*	*	*	*	*	*
	C+L*	2,083	0	0	2,232	578	496	2,873	0	8,262
SNP	C	0	0	19	222	0	0	0	2	242
	L	*	*	*	*	*	*	*	*	*
	C+L*	0	0	19	222	0	0	0	2	242

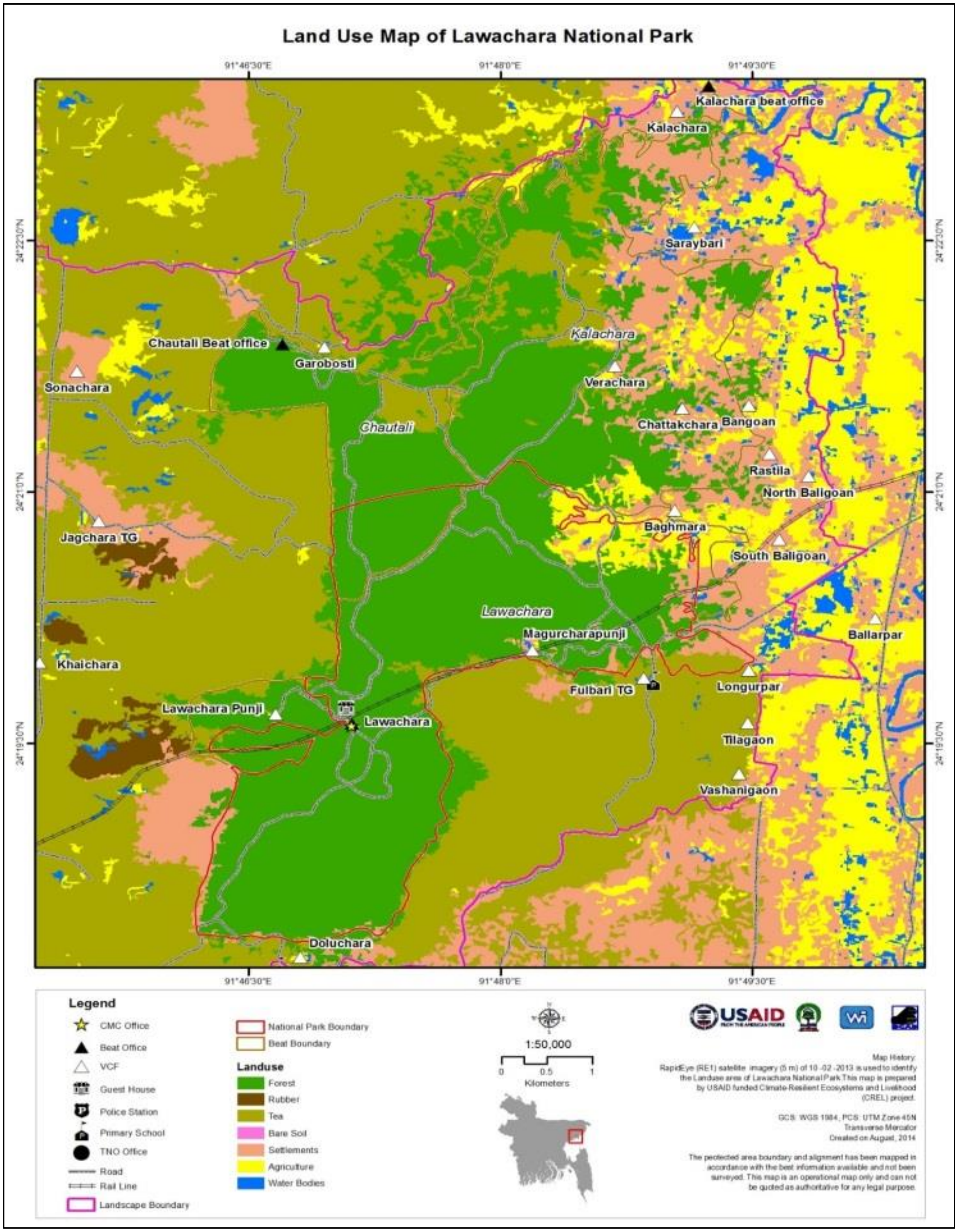

Landuse Map of Chunati Wildlife Sanctuary
91°57'30"E
92°0'0"E
92°2'30"E
92°5'0"E
22°0'0"N
21°57'30"N
21°55'0"N
21°52'30"N
Chechuria
Jaldi
Joldi Beat Office
Jaldi
Barahatia
Barahatia Beat Office
Chunati Beat Office
Chambal
Chambol Beat Office
Chunati
Chunati
Satghar Beat Office
Satgar
Dalu
Napura
Napora Beat Office
Puichari
Puichari beat
Puichari Beat/Range Office
Aziznagar Beat Office
Daluchari Range/Beat Office
Gayalmara
Toitang
Taitong Beat Office
Harbang Beat (Wild Life)
Harbang Beat Office
Harbang
Barabakia
Legend
CMC office
Landscape villages/VCFs
Beat Office
Landscape boundary
WS boundary
Beat boundary
Agriculture
Degraded Forest
Hill Forest
Wetland
Settlement
Plantation
1:93,000
Map History
RapidEye (RE1) satellite imagery (5 m) of 30-10-2013 is used to identify the Landuse area of Chunati Wildlife Sanctuary.
This map is prepared by USAID funded Climate-Resilient Ecosystems and Livelihood (CREL) project.
GCS: WGS 1984, PCS: UTM Zone 45N
Transverse Mercator
Created on August, 2014
The protected area boundary and alignment has been mapped in accordance with the best information available and not been surveyed. This map is an operational map only and can not be quoted as authoritative for any legal purpose.

Landuse Map of Himchari National Park



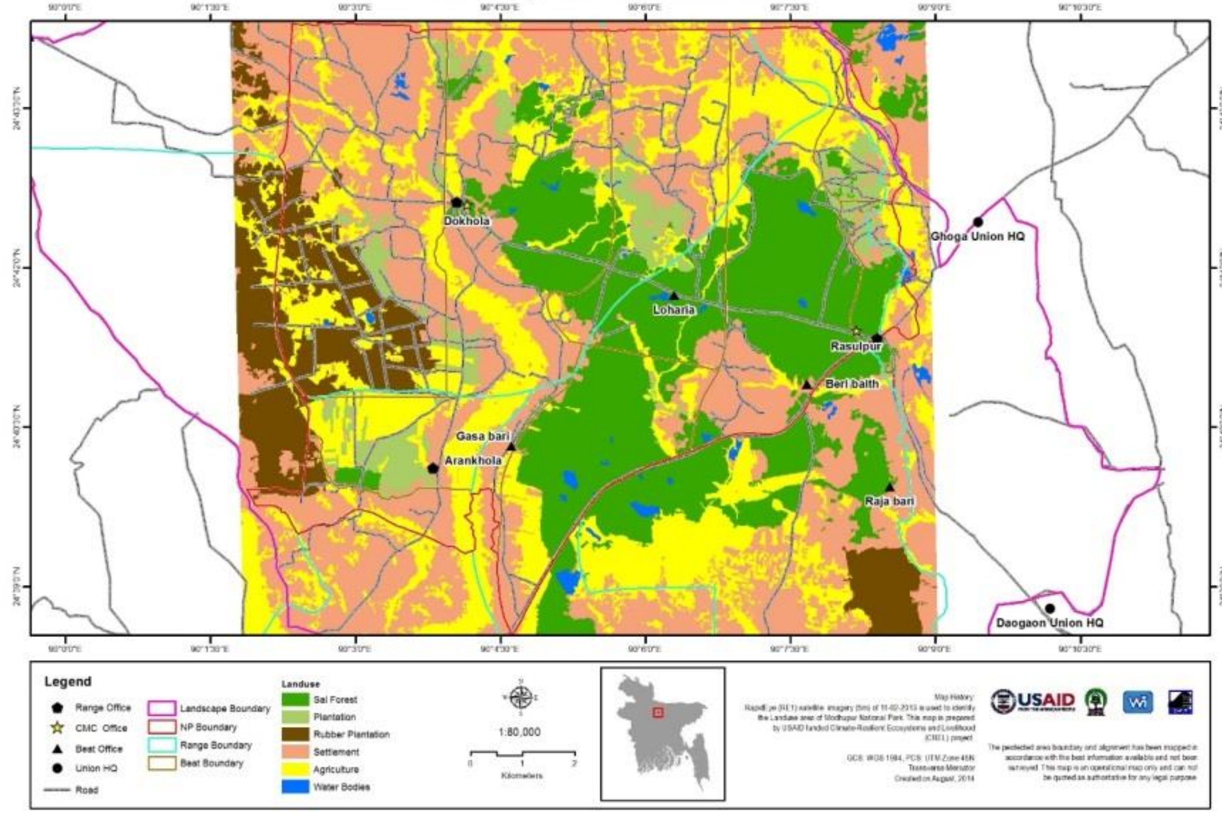

Landuse Map of Khadimnagar National Park
Baronagar
Gulni Tea Garden
Kandirpath
Ramnagar
Gulni Bosti
Faringura
Bazartol
Alaibohor
Kalagul Bosti
Burjan Tea Garden
Khadimnagar CMC office
Kalagul Tea Garden
Khadim Beat
Charagang Tea Garden
Mukamergul
Tikorpara
Kulauti
Pirerchak
Khadim Tea Garden
Alutol
Dalaipara
Bohorcoloni
Rustompur
Laugul
Legend
CMC office
Beat office
Landscape villages/VCFs
Landscape boundary
NP boundary
Road
Degraded land
Forest
Irrigated agriculture
Plantation
Settlement
Tea
Water bodies
1:90,000
0 0.75 1.5 3
Kilometers
USAID


Landuse Map of Kaptai National Park
bang chari beat office
kamila chari beat office
kaptai range
kalmi ghia beat office
shuknachari beat office
kalmichara beat office
kaptai range office
rringkheong beat office
kannaphuli range office
karnaphuli range
Legend
CMC office
Beat office
Range office
Landscape villages/VCFs
Road
Landscape boundary
NP boundary
Range boundary
Agriculture
Degraded land
Forest
Industry
Settlement
Water bodies
Plantation
1:72,000
0 0.5 1 2
Kilometers
USAID

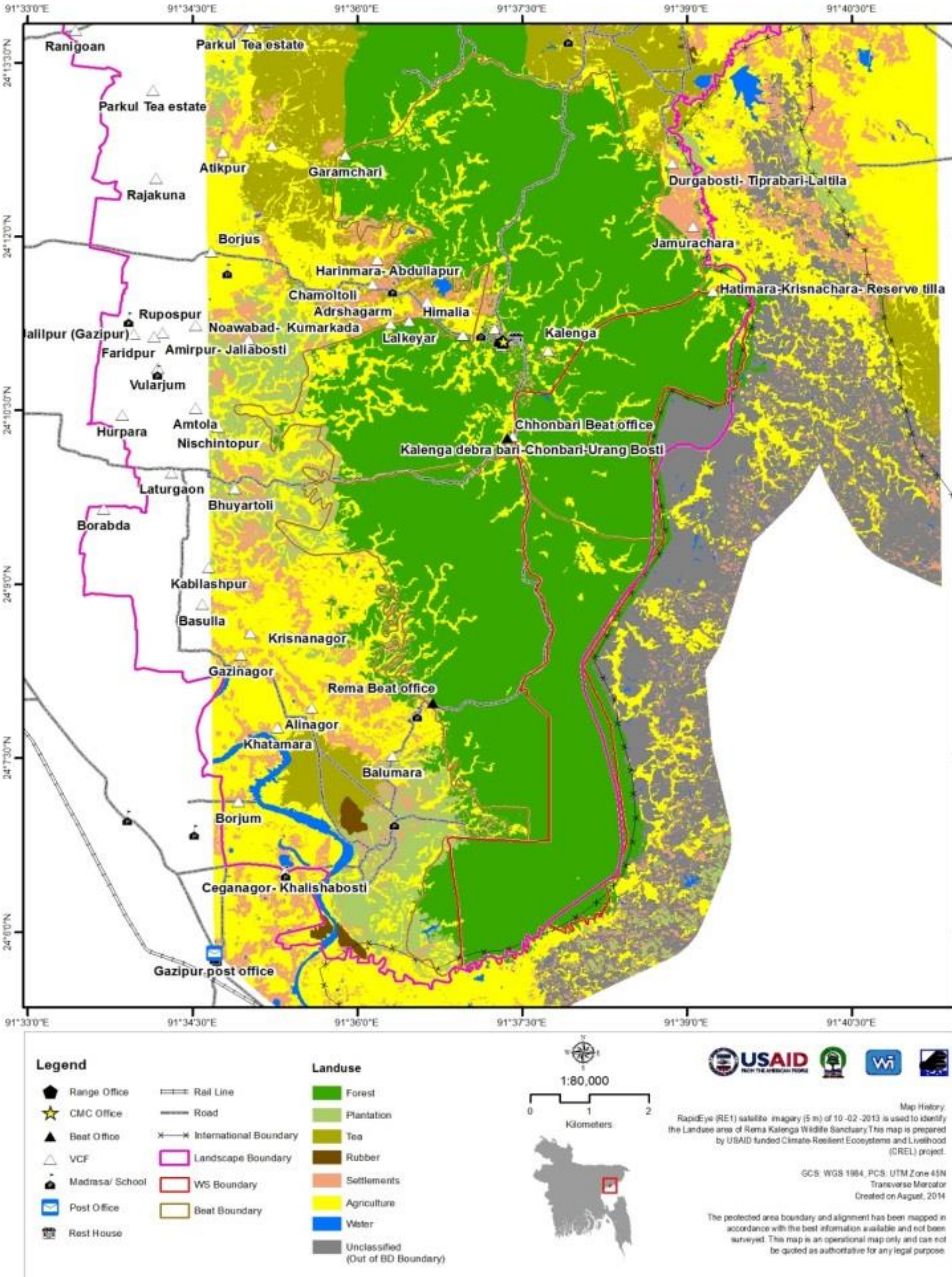


Land Use Map of Lawachara National Park
91°46'30"E
91°48'0"E
91°49'30"E
24°22'30"N
24°21'0"N
24°19'30"N
Kalachara beat office
Kalachara
Saraybari
Kalachara
Chautali Beat office
Garobosti
Sonachara
Verachara
Chattakchara
Bangoan
Chautali
Rastila
North Baligoan
Baghmara
Jagchara TG
South Baligoan
Lawachara
Magurcharapunji
Ballarpar
Khaichara
Fulbari TG
Longurpar
Lawachara Punji
Lawachara
Tilagaon
Vashanigaon
Doluchara
Legend
CMC Office
Beat Office
VCF
Guest House
Police Station
Primary School
TNO Office
Road
Rail Line
Landscape Boundary
National Park Boundary
Beat Boundary
Landuse
Forest
Rubber
Tea
Bare Soil
Settlements
Agriculture
Water Bodies
1:50,000
0 0.5 1
Kilometers
USAID
Map History:
RapidEye (RE1) satellite imagery (5 m) of 10-02-2013 is used to identify the Landuse area of Lawachara National Park. This map is prepared by USAID funded Climate-Resilient Ecosystems and Livelihood (CREL) project.
GCS: WGS 1984, PCS: UTM Zone 45N
Transverse Mercator
Created on August, 2014
The protected area boundary and alignment has been mapped in accordance with the best information available and not been surveyed. This map is an operational map only and can not be quoted as authoritative for any legal purpose.

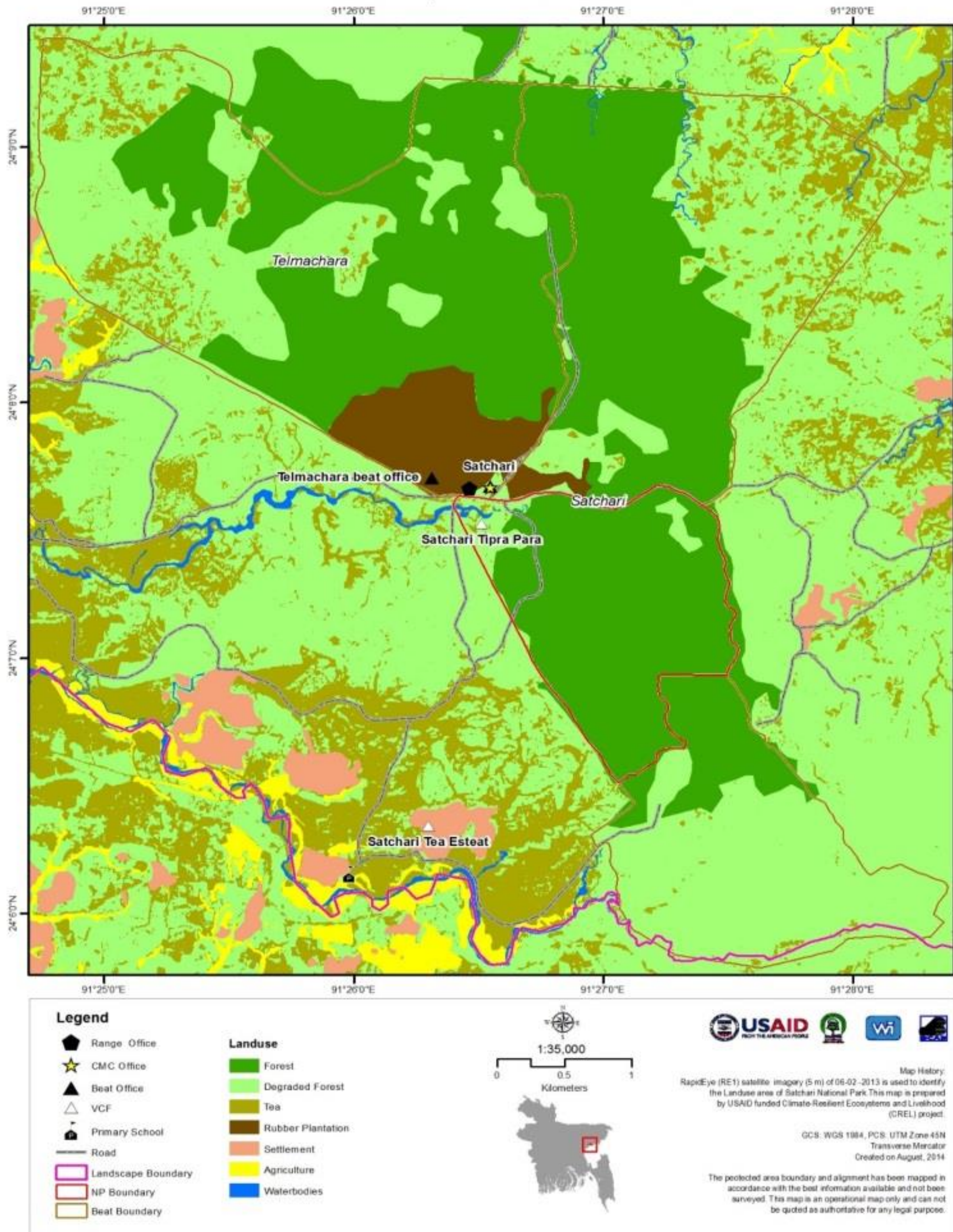
Land Use Map of Modhupur National Park



Land Use Map of Rema Kalenga Wildlife Sanctuary



Land Use Map of Satchari National Park



5.3.2 Linking remote sensing with field measurements

> R-PP Section 4.3.2: The design will take into consideration IPCC guidelines to ensure that the outputs from the NFI will be in line with the UNFCCC reporting requirements. The NFI will be designed to provide the necessary data for the calibration of satellite data interpretation. This implies that methods for NFI and the satellite monitoring system must be consistent

It is important that a unified set of land-cover class definitions are employed by both field crews conducting an inventory, as well as remote sensing analysts producing maps. Classification terms which can seem unambiguous can often be difficult to put into practice.

In CREL's mapping work, canopy cover % is an example of an important term that can cause difficulty. It is related to the forest definition, and therefore is central to mapping forest change. CREL attempted to ensure consistency between areas mapped as "forest" and inventoried as "forest" by taking field measurements of canopy density, as well as referencing a global map of canopy density (Hansen et al. 2013). However, difficulties related to the presence of heavy underbrush in unforested or sparsely forested field plots caused many suspiciously high canopy density values to be recorded in areas mapped as non-forest classes. This is just one example, but many other areas of confusion could exist, for example:

1. Agricultural land appears to be either wetland, water or grassland based on seasonal cycles
2. Settlements with tree vegetation transition over distance into forest PAs with encroachment
3. Mixing of native and non-native species in areas subject to historical afforestation resemble both plantation and natural forest.

These are examples of potential sources of inaccuracy that must be thoroughly cataloged and discussed with both field inventory and remote sensing analysts. It is imperative that good communication is maintained between these partners, and that strategies are developed to resolve conflicts. Extensive field and remote sensing testing of methods for classifying each class should be completed before full scale inventory and mapping is undertaken.

In CREL's example of canopy density, recommendations for improved SOPs could include guidance for field staff to avoid taking densiometer measurements in areas with extensive underbrush that obscures tree canopy. Such a modification would have resulted in better agreement in the identification of forested areas between mapping and field sampling activities.

6. FOREST INVENTORY– ESTABLISHING EMISSION FACTORS

R-PP Section 4.3: The National Forest Inventory will provide information that show the condition of forests across wide areas within the country. It will provide the relevant data to support national forest policy and provide the data to support the preparation of the GHG inventory to report for REDD+ under the UNFCCC. Field measurement will be used in order to collect the necessary data to assess the emission factors (EFs).

The purpose of this Section is to establish emission factors and other biophysical change factors that result from the conversion of forest to other non-forest or plantation land cover types. These data are intended for CREL to report on their GHG and biophysical baselines, and to inform REDD+ actors in Bangladesh on preliminary emission factors that could be used as a basis for larger scale national analysis. This section is also intended to provide insights to other REDD+ actors on development of emission factors in Bangladesh.

6.1. Sampling Design

R-PP Section 4.3.2: … Adequate sampling design and strategies are necessary to allow the development of a cost-efficient NFI and provide the adequate data with the targeted accuracy. The design will take into consideration IPCC guidelines to ensure that the outputs from the NFI will be in line with the UNFCCC reporting requirements.

The purpose of sampling is allow for the extrapolation from a subset to the whole population. This is done by 1) establishing a sufficient number of plots to meet a statistical level of precision, and 2) distributing those plots following accepted scientific methods to enable an unbiased sampling. The result being adequate data on forest and post-deforestation carbon stocks within targeted uncertainty levels. A sampling design should follow accepted scientific methods, as outlined in GOFC-GOLD (2010)11, to meet UNFCCC requirements.

The goal of the CREL forest inventory sampling design was to: 1) integrate the methods of past forest inventories, 2) estimate forest and post-deforestation carbon stocks for the eight CREL PAs with acceptable levels of uncertainty, and 3) establish metrics on forest and post-deforestation biophysical conditions that can be used to assess the environmental health and resiliency of different land cover.

To integrate past forest inventories, a thorough review of previous sampling designs was conducted. As described in Section 2, the two forest carbon inventories that appeared to meet UNFCCC reporting requirements were the Forest Carbon inventory in the Sundarbans Reserve Forest (SRF) (2009), and the IPAC inventory in hill forest protected areas (2010). Both of these inventories used a systematic sampling design laying out plots at predefined coordinate intervals. For the SRF the interval was a 1x1minute interval with cluster plots at each location. For the IPAC inventory the interval ranged from 50 to 15 second interval determined based on the area of forest (to ensure enough plots fell in the forest), and again used cluster plots at each location. The sampling designs met the criteria because they established a sufficient number of

11http://www.gofc-gold.uni-jena.de/redd/sourcebook/Sourcebook_Version_Nov_2010_cop16-1.pdf plots within the target land cover types (in this case forest), and they distributed the plots following accepted scientific methods.

Remaining consistent with previous inventories the CREL inventory followed a systematic sampling design. To determine the number of plots that should be inventoried for the CREL sites, an assessment of the 2009 IPAC plots was conducted. This assessment looked at the variability of forest carbon stocks between plots to estimate how many plots would be needed to reach a statistical measure ±10% of the mean at a 90% confidence interval. The assessment indicated that approximately 400 plots would be required to reach a certainly of ±10% of the mean at a 90% confidence interval for the 8 PAs.

Unlike past forest carbon inventories the CREL inventory also sought to include plots in common post-deforestation land covers: agriculture, tea, settlements, plantation forest, rubber and village forest. This is an important new contribution, because quantifying emissions (and other biophysical changes) requires data on both forest and post-deforestation land cover types. If less than three plots fell in anyone land uses the field teams were instructed to take extra points along the sampling design grid lines12. This helped to ensure that across the 8 PAs a reasonable number of sample points would be taken in the most common post-deforestation land cover types. However, the sampling design remained focused on forest lands and therefore did not make any other effort to meet statistical targets for post deforestation land cover types.

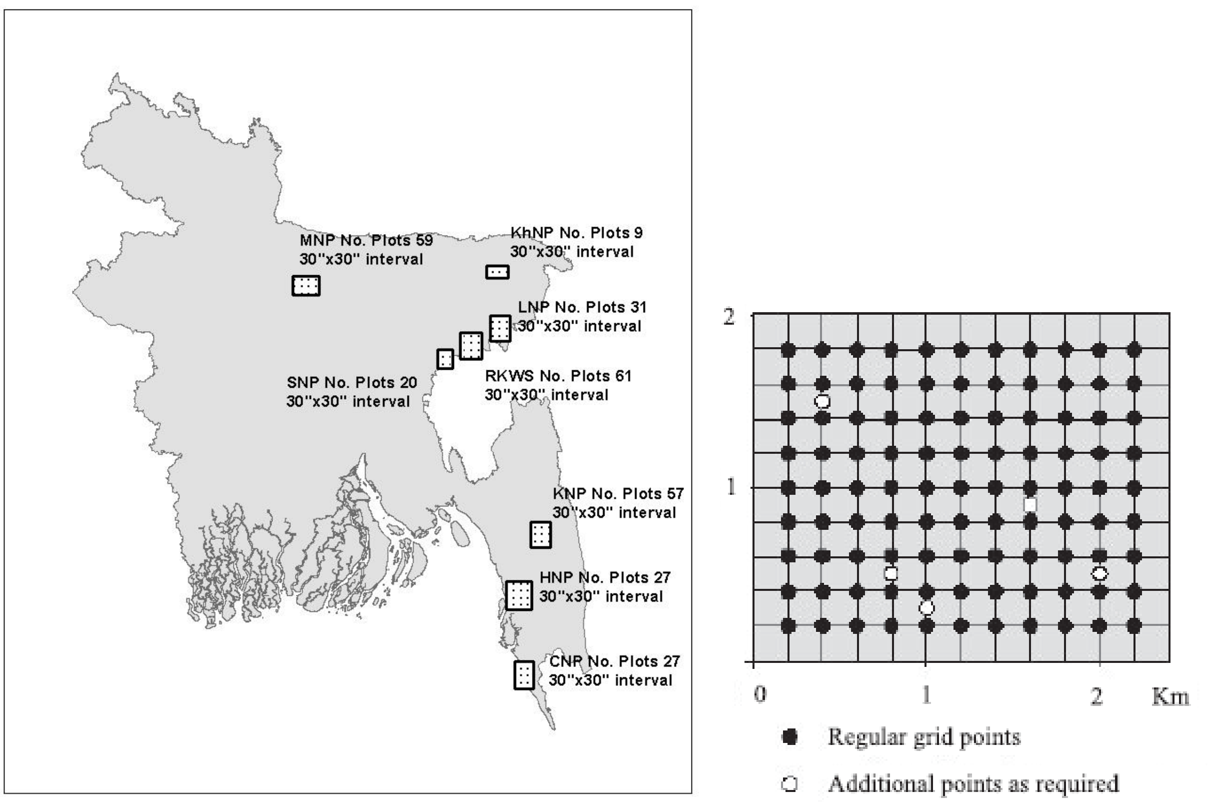


Figure 8. a) location and sampling interval for CREL inventory. b) Theoretical representation of the sampling design used for the CREL inventory

12 These extra points were randomized by maintaining the grid intervals but extending the transect to capture other land cover types.

This sampling design, along with the general methods used, enabled the CREL inventory to be comparable with both the SRF (2009) and IPAC (2010) inventories. This is possible because forest carbon inventories like these are designed to generate a single mean carbon stock for a given land cover/land use that captures the natural variability, therefore is assumed to be stable over time. In other words, once the mean carbon stock for a forest like the Sundarban mangroves is identified with acceptable statistical confidence, there is no need to remeasure it in the near future, as we assume the inventory in 2009 captured the natural variability. Following this logic an NFI in Bangladesh could assume the Sundarbans have been inventoried and focus efforts on other areas that have not been adequately sampled. Similarly an efficient NFI could leverage the data from CREL and IPAC inventories and develop a sampling design that does not resample these areas, thereby significantly reducing the time and effort required if the NFI was started from scratch. Although stocks in each stratum should be reassessed at a defined interval (perhaps every 10 years).

6.2. FIELD METHODS CARBON POOLS & BIOPHYSICAL

The objectives of the present carbon inventory was to develop a carbon and biophysical baseline of selected PAs that can be used under a REDD+ framework. A detailed Standard Operating Procedure (SOP) was developed, "Standard Operating Procedures (SOP) for Forest Carbon Inventory, Bangladesh" (2014). Also a detailed report on the forest inventory and the methods and results is provided in Latif, Chowdhury and Netzer, 2014[13]. General methods are described below.

The plot locations from the sampling design were superimposed on Google Earth and the plots were manually classified according to their land cover type. This enabled field teams to have a better understanding of whether they had a sufficient distribution of plots in the desired land cover types before the inventory began. The plot locations (latitude and longitude) of the plots for each PA were uploaded to each team's GPS. The team members navigated to the plots with the help of the map and GPS.A set of field data collection forms were designed for data collection See SOP (2014).

The starting points for access to the plots were marked as waypoints by signs on trees or by recording the GPS coordinates. After reaching the plot, the plot center was marked with a PVC pipe or a stake driven into the soil.

Plots were designed as concentric circles with radii of 2m, 4m, 10m and 17.84m. The plot layout is shown in Figure 9.The parameters that were recorded/measured from different sample plots are given in Table 8. For detailed description of the methods see the SOP 2014.

The carbon pools that were measured were trees (above and below ground), seedlings and saplings, non-tree vegetation (shrubs and bamboo), herbaceous, litter, standing deadwood, and lying dead wood. The sum of these pools made up the total carbon stock estimates. Soil carbon was also measured but was reported separately.

Biophysical measurements relied on a number of metrics. First on tree recruitment assessed through the number of seedling, sapling and tree present per hectare. A healthy natural forest has recruitment at all ages of forest growth. Second, tree species "richness" as defined by

[13] Latif, M. A.; Chowdhury, R. M. and Netzer, M. 2015: Forest Carbon Inventory 2014: Eight Protected Areas in Bangladesh. CREL Project Bangladesh Forest Department and Winrock International. (Mimeograph).

Menhinick's index (known as D). Species richness is a measure of the number of species found in a sample population.

Equation: $D = \frac{s}{\sqrt{N}}$

Where D= Menhinick's index (unitless),s=number of species in sample and N=the total number of individuals

Last, the different carbon pools were reported as an indication of a forest that has a decent distribution of live biomass and dead decomposing biomass. High soil carbon is a good indication of biophysical health as it is a key component of potential for plant productivity, healthy decomposition, and limited soil loss from erosion that is predominant in areas with low vegetation cover.

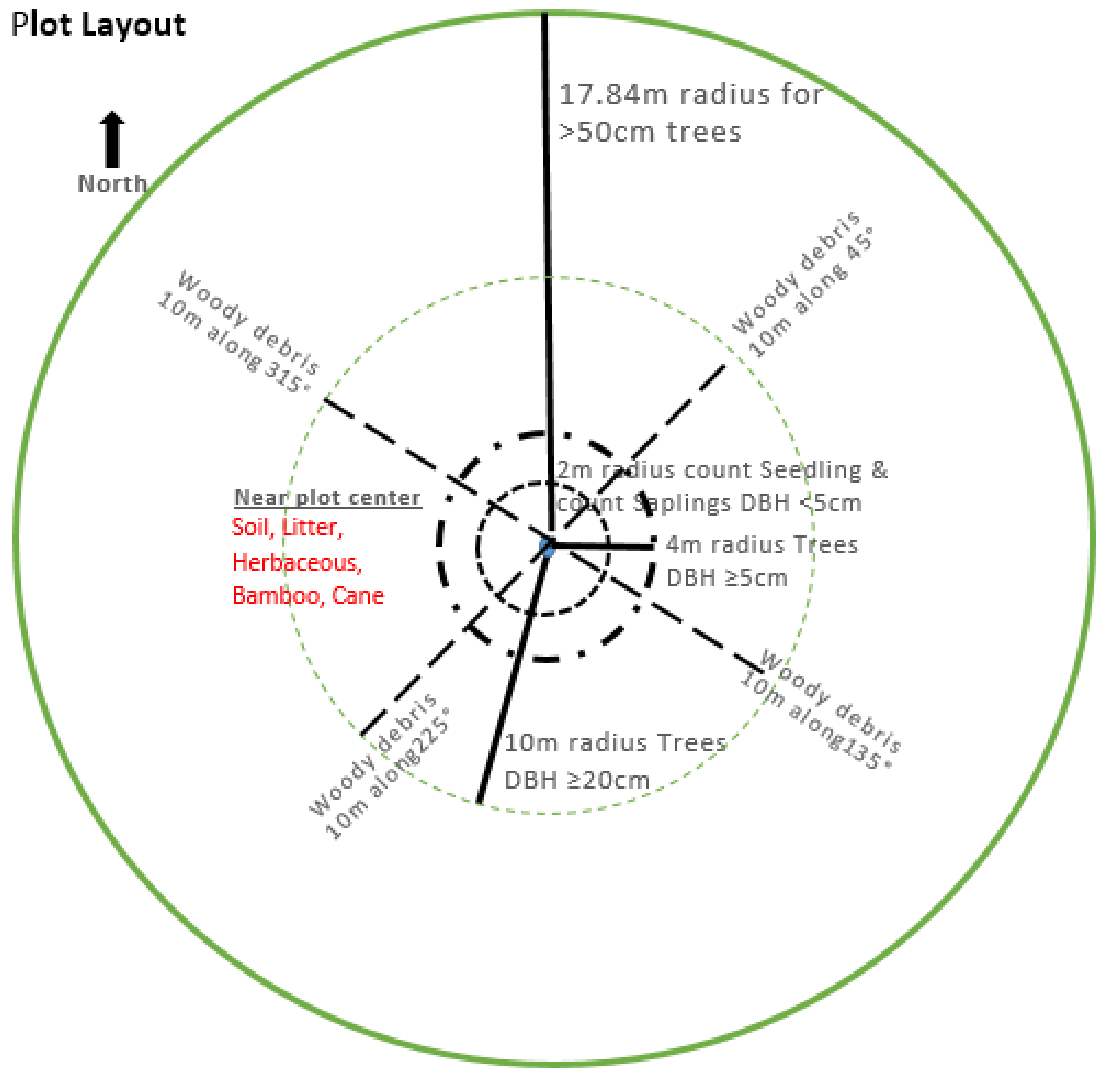


Figure 9. Plot layout for Carbon Inventory 2014 at 8 PAs in Bangladesh

Table 8. Forest carbon plot dimensions for data collection from different pools

Plot size	Parameters	Activities
BIOMASS		
2 meter radius	Seedling count	Counted the number of live seedlings ≤1.3 m tall for all species.
	Sapling 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.
	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.
4 meter radius	Tree DBH	Measured DBH of all trees (including standing dead trees) with DBH ≥ 5.0cm with species name Measured stumps (≥10 cm base diameter) diameter
	DBH, heights & counts of Cane and Bamboo (non-tree woody plants)	Recorded data on Count the number of clump, stem or culm/clump and weight of one representative culm/stem
10 meter radius	Palm DBH & height	Measured the height of all palm species, and DBH
	DBH of trees	Measured DBH of all trees (including standing dead trees) with DBH ≥ 20.0 cm with species name Measured the stump base diameter ≥ 10.0 cm
17.84 meter radius	Trees DBH	Measured DBH of trees ≥50 cm (including standing dead trees), with species name;
	Stumps basal D	Measured Stumps (≥10 cm base diameter)
17.84 meter radius	Trees height	Measured heights of three co-dominant trees
4 transects, 25m long each	Lying deadwood	Measured all lying dead wood≥10cm diameter, if it is ≥50% above the ground. Measured along transect line from plot center to 25m at each cardinal direction (45, 135, 225 & 315 degrees)
50cm Square clip plot	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.
	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.
SOIL		

Plot size	Parameters	Activities
Sample depth 30cm	Soil Organic Carbon	Soil Samples for estimation of organic carbon were taken using soil sampler/pit method at 4 locations (covering valley, slope and flat) to 0-30cm depth. All 4 samples were mixed thoroughly and then took a sub sample (200-300g) for laboratory analyses.
Sample depths:0-15 cm & 15-30 cm	Soil Bulk Density	Soil samples for estimation of bulk density (BD) were taken from two depths (0-15 cm and 15-30 cm). Each bulk density sample was placed in an individual air-tied sample bag for lab analyses.
CANOPY COVER		
At the end of 10 m	Canopy cover	Took canopy cover with Densiometer at 10 meters from the plot center at four cardinal directions at due north, east, south & west.

6.3. Field inventory results

The CREL forest inventory sampled 377 plots in eight PAs across Bangladesh (Table 9).

According to the definition used, forests were identified as areas with tree cover ≥10% canopy cover, and tress >5m in height over 0.5ha. Natural forest was classified as Hill, Sal and Mangrove. Non-natural forest was stratified into rubber, plantation and village forest. Degraded forest shrubland, is dominated by high shrubs with a few trees (See Section 6.3.2 for discussion on forest degradation). Although this degraded forest shrubland does not meet the "forest" definition, it maintains the degraded forest distinction because this is Forest Department land and given proper management could return to forest14. Degraded forest that maintains a forest canopy (i.e. meets the forest definition) but has had trees extracted for things like fuelwood or timber is discussed in Section 6.3.2. Non-forest areas sampled included agriculture, settlement, and tea garden.

Table 9. Number of plots taken in different land cover types in each of the eight CREL PAs.

Land cover types	CWS	HNP	KhNP	KNP	LNP	MNP	RKW	SNP	Total No. plots in each land use
Agriculture	4			1		3	3	1	12
Degraded forest shrubland	56	20	2	17	3		1	3	102
Forest (Hill & Sal)*	21	1	6	17	12	30	46	5	138
Plantations	26		1	24	12	12	13	11	99
Rubber plantations						7			7
Village forests	4	6		2	1	3			16
Tea Gardens					1				1
Total No. plots in each PA	111	27	9	61	31	55	63	20	377

14 Under a REDD+ system these areas would be termed "non-forest." This would be an important distinction under a REDD+ system as they will need to be monitored differently than areas that are actually "degraded forest" (i.e. an area that maintains a forest definition but is reduced in carbon stock)

* This included degraded forest that maintains a canopy cover. This type of degraded forest and non-degraded forest were not able to be spatially distinguished.

The primary objective of this forest inventory was to establish forest carbon stock for the eight CREL PAs. Figure 10 shows the forest CO_2 stocks per hectare for each of the PAs sampled in this inventory along with error bars representing 90% confidence intervals. HNP only had one plot in forest, therefore there are no error bars. Confidence intervals for the different PAs ranged from ±14-50% of the mean (Figure 10). Recommended targets from the UNFCCC are ±10% of the mean at a 90% confidence interval, therefore at an individual PA level forest carbon stocks had relatively poor precision.

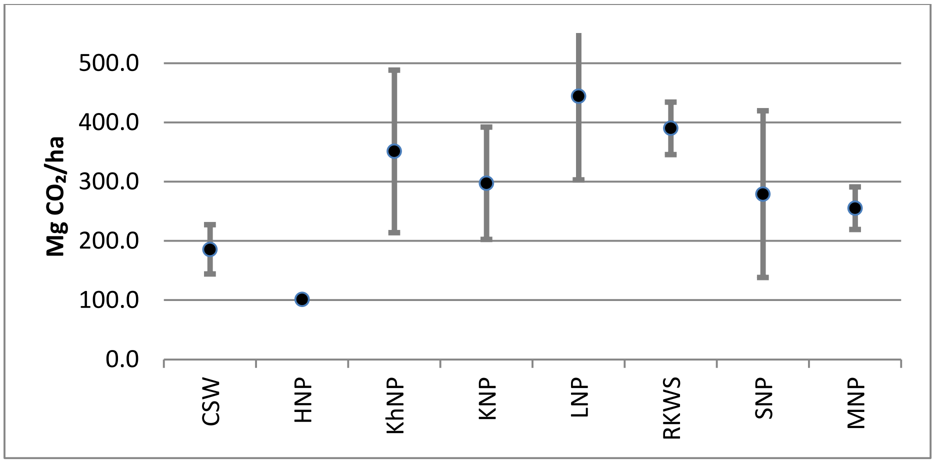
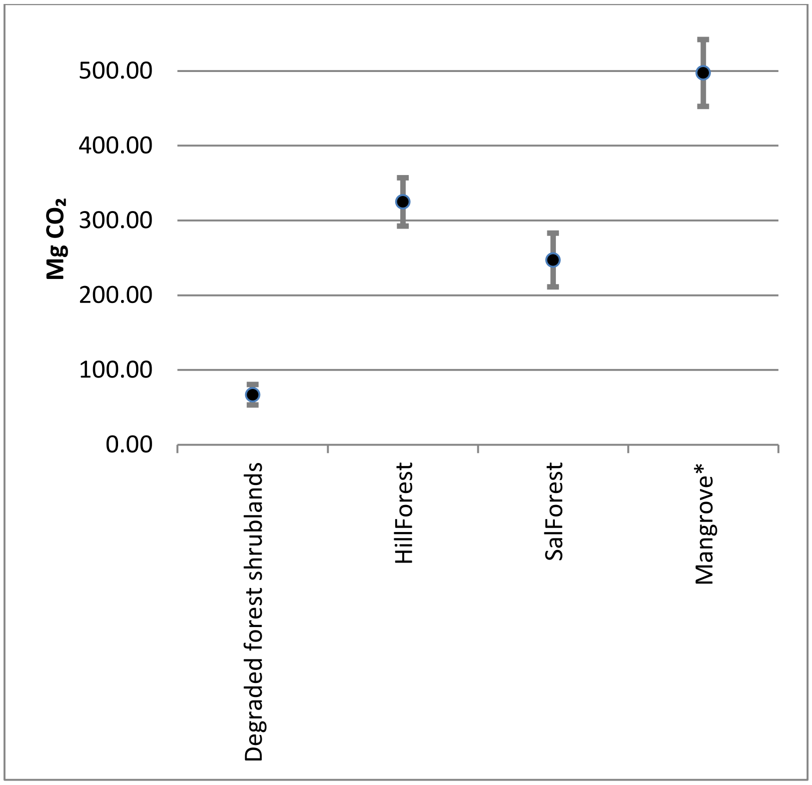


Figure 10. Mean CO2 stocks for forest in each of the eight CREL PAs with error bars showing 90% confidence intervals.

To improve the precision, plots were combined based on those that were in Hill forest, and Sal forest. These are common forest types in Bangladesh and were classified in the 2009 FAO National land cover map. A third class, “degraded forest shrublands,” was identified by field crews during the inventory. These degraded forest lands are common across many of the CREL PAs, often dominated by shrubs, with very sparse tree cover but has the potential to regenerate into forest if human activities (e.g. cutting of saplings trees and other wood extraction) were abated15.The degraded forest shrubland class in Figure 11 are shrubland and do not maintain a “forest” definition (See Section 6.3.2 for information). Also, plots from the 2009 survey in the Sundarbans were included as a fourth stratum. The results for mean forest CO_2 in Hill, Sal, degraded and Mangrove forest are shown in Figure 11 with 90% confidence interval error bars.

15 These areas often do not meet the forest definition of >10% canopy cover over 0.5ha, however they are considered forest lands in Bangladesh as they have the ability to reach those thresholds in situ.



* Based on 2010 Sundarban Inventory

Figure 11. Results for mean CO_2 stocks with error bars showing 90% confidence intervals for Hill, Sal, degraded and Mangrove forest (not including soil carbon).

The stratification of these four forest types is important when forests are of significantly different biophysical condition and therefore have different average carbon stocks. By stratifying these forest types we are able to estimate the average carbon stocks, and therefore CO_2, for four major forest types recognized in Bangladesh. By grouping the CREL inventory plots into these four strata we are also able to improve the precision of our estimated mean CO_2 ha^{-1} (Table 10). Hill forest and Mangrove have a confidence interval below 10% of the mean, while Sal forest remained above 10% of the mean (14.5%). Degraded forest (shrub dominated), despite 102 plots, had relatively poor confidence levels. This is due to the high variability in this land cover type, where one plot may have a number of big trees and another no trees and just shrubs. To improve confidence levels there are two options, 1) take more plots with the hopes that uncertainty is reduced, 2) identify a way to stratify degraded lands into multiple classes that have less variability. Stratifying can be a good option, however, the difficulty lies in being able to identify and map those degraded lands across the landscape. While field crews may be able to distinguish between different degraded land types, it can be very difficult to do the same using remote sensing which is used to map and monitor these land cover types. The degraded forest in Table 10are those lands dominated by shrublands. This is an important distinction because these shrubland areas that were able to be mapped using remote sensing while forest that are degraded but maintain a significant canopy were not able to be mapped and therefore establishing a set mean ton of carbon per hectare is not feasible (See Section 6.3.2. for more information).

Table 10. Results for mean natural forest CO_2 stocks not including soil. SD=Standard Deviation, n= number, SE= Standard Error.

Land Cover Type	Mean Mg CO_2 ha^{-1}	SD	n	SE	Confidence Level (90.0%)	Confidence as % of mean
Degraded forests shrubland	66.9	83.08	102	8.23	13.66	20.4%
Hill forests	324.9	201.75	108	19.41	32.21	9.9%
Sal forests	247.1	115.54	30	21.09	35.84	14.5%
Mangroves*	497.4	332.02	150	27.11	44.87	9.0%

* Based on 2010 Sundarban Inventory

Other lands inventoried during the field campaign were plantation forest, rubber, village forest, agriculture, settlement/bare land and tea garden. Tea garden only had one plot from LNP. Settlement/barren had no plots and is assumed to be zero (not including soil carbon) (Table 11). Confidence levels were very high for most of these areas, mostly due to the few number of plots in each class. Given the high uncertainty in agriculture it is advised that IPCC default factors be used for all permanent agriculture areas (not shifting agriculture). These default factors are published by the IPCC16 for globally common land cover types and are accepted under UNFCCC accounting frameworks. Agricultural defaults are reported in Chapter 5 Croplands 2006 report. For perennial crops with no fallow the mean biomass is 2.9Mg ha^{-1} which equates to 5.3Mg CO_2 ha^{-1} 17.

Table 11. Results for mean CO_2 stocks for plantation, rubber, village forest, and non-forest, not including soil. SD=Standard Deviation, n= number, SE= Standard Error.

Land Cover Type	Mean Mg CO_2 ha^{-1}	SD	n	SE	Confidence Level (90.0%)	Confidence as % of mean
Plantation forests	231.5	200.5	99	20.2	33.5	14.5%
Rubber plantations	210.4	57.4	7	21.7	42.1	20.0%
Village forests	141.8	122.3	16	30.6	53.6	37.8%
Tea Gardens	36.9		1			
Agriculture lands	5.8	12.0	11	3.6	6.6	88.0%
Settlements/bare lands	0.0					

The results presented above provide estimation for the carbon and therefore CO_2 stocks for most of the common land cover types in the CREL PAs, and although the sampling design was not developed for national or region levels they also represent a substantial step forward for the estimation of forest and non-forest carbon stocks for the country of Bangladesh. It is thought that these results could be used as a basis for further regional or national inventories.

6.3.1 Emission Factors from Deforestation

The development of emission factors for land use change is a fundamental component of completing any regional or national GHG accounting. Emission factors are calculated as the difference between the forest CO_2 stocks before land use change and after land use change

16http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

17 To convert biomass to CO_2: 1) convert biomass to carbon (carbon=biomass x 0.5), 2) convert carbon to CO_2 (CO_2 = carbon x 44/12)

(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 regrow into forest, or an agricultural area is planted with trees. Table12shows the emission factors developed from the CREL inventory, including mangroves from the 2010 Sundarbans inventory. Red numbers represent an emission in Mg CO_2 ha^{-1}, and green numbers represent sequestration in Mg CO_2 ha^{-1}.

Table12.Emission factor table, units areMg CO_2 ha-1

		Converted to:								
		Mangrove	Hill Forest	Sal Forest	Plantation	Rubber	Degraded forest (shrub)	Tea Garden	Agriculture	Bare land
Converted from:	Mangrove	N/A	N/A	N/A	265.9	287.0	430.5	460.5	491.6	497.4
	Hill Forest	N/A	N/A	N/A	93.4	114.4	257.9	288.0	319.1	324.8
	Sal Forest	N/A	N/A	N/A	15.6	36.6	180.1	210.2	241.3	247.1
	Plantation	N/A	N/A	N/A	N/A	21.0	164.6	194.6	225.7	231.5
	Rubber	N/A	N/A	N/A	N/A	N/A	143.5	173.6	204.7	210.4
	Degraded forest (shrub)	N/A	(257.9)	(180.1)	(164.6)	(143.5)	N/A	30.0	61.1	66.9
	Tea Garden	N/A	N/A	N/A	N/A	N/A	N/A	N/A	31.1	36.9
	Agriculture	N/A	(319.1)	(241.3)	(225.7)	(204.7)	N/A	(31.1)	N/A	5.8

Example of how to use Table 13: if 1 hectare of hill forest is converted to degraded forest there is an emission of 257.9 Mg CO_2. If ten hectares of hill forest was converted to degraded forest then the emissions are 2,579 Mg CO_2. If 1 ha of Sal forest is converted to agriculture there is an emission of 241 Mg CO_2.

6.3.2. Forest Degradation

In Bangladesh the term “degraded forest” has a few definitions. Based on the CREL inventory, the most common reference to degraded forest are areas with very sparse tree cover, dominated by shrubs and other primary growth bamboo, and herbs. These areas are maintained in this state of degradation by continuous extraction from local and immigrant agents. By most accounts, degradation pressure is so severe that trees are often cut as saplings for garden poles and fences. This is the same with cane and bamboo. It is uncommon for a tree to grow above 5cm DBH, and when it does it is likely to be cut for fuel wood or timber. It is so uncommon for trees to grow above 5cm that stumps are not common, indicating that these areas have been degraded for a long time (depending on stump decomposition rate). Because these degraded forests are quite distinct from canopy forests they can be mapped using remote sensing and the emissions that result from forest going to shrubland degraded forest can be calculated as the difference in CO_2, as was done above in the emissions factor table (Table12). It must be noted that these areas often do not meet the forest definition. They are termed degraded forest because they are under the Forest Department jurisdiction and if managed could return to forest. However, under a REDD+ program these areas would need to be defined appropriately, because if they do not meet a forest definition they will need to be managed and accounted for very differently from areas maintaining >10% canopy cover. For example, if they do not meet a forest definition they do not need to be monitored for deforestation, and they are available for reforestation.

However, degradation does not always result in the loss of canopy cover, but occurs commonly under the canopy through the cutting and extraction of small to medium sized trees. It is uncommon for large trees to be extracted from existing forest areas, as it is illegal and the work requires considerable time, chainsaws, and other equipment that make the likelihood of confiscation high[18]. Therefore, existing forests in some of the CREL PAs are often maintained by the presence of large canopy trees, but understory trees are under high pressure from local agents to be extracted for fuel and construction. To quantify this type of degradation, stumps were measured in each of the CREL PAs. To estimate the amount of biomass extracted, a relationship was developed correlating stump basal diameter to tree DBH (Figure 12). By estimating the DBH we can calculate the biomass, therefore carbon (multiply by 0.5), and CO_2 (multiply carbon by 3.67 or (44/12)).

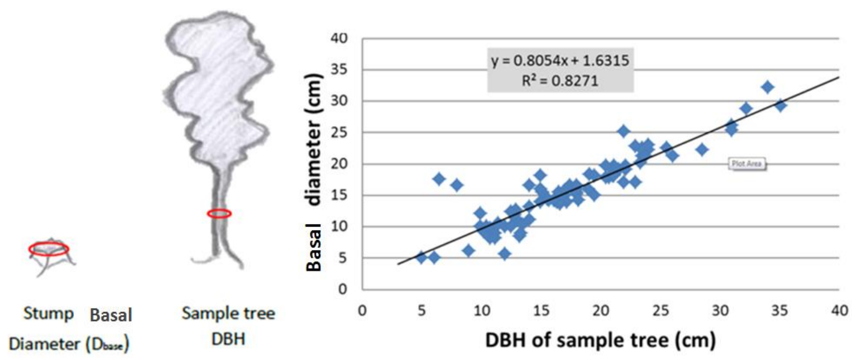


Figure 12. Example of the field methods and quantification for estimating the biomass of trees extracted based on the presence of stumps.

If we know the biomass of the stump, and we know the biomass of the tree that has been extracted, the difference is the total biomass/carbon/CO_2 extracted. In this way the total biomass extracted can be calculated from inventorying the stumps, resulting in an estimation of forest degradation.

$$\text{Biomass extracted (Mg ha}^{1}) = \text{Biomass stump(Mg ha}^{1}) - \text{Biomass of sample tree(Mg ha}^{1}) =$$

The results for CO_2 emissions from forest degradation that does not result in a shrub dominated environment are presented in Figure 13 and Table 13. It must be noted that these results are limited for accurate accounting of GHG emissions because: 1) this type of degradation is highly variable across the forest and we can’t get accurate areas of different degradation intensities; 2) stumps can remain present for many years so there is no information on the timing of the event;

18From discussions with local experts, the extraction of large timber trees does still occur in cases when local officials that are above the law decide to or are pressured to cut timber trees.

and 3) it is unknown the fate of the wood products (are they burned for fuel wood or used for construction?).

For this work we are assuming all wood extracted from the forest was burnt. There were no results for HNP because there was only one plot in forest, and that plot had no stumps (Figure 13). CSW, LNP, and MNP all had average emission of 2 Mg CO_2 ha^{1}, 6 Mg CO_2 ha^{1}and 4 Mg CO_2 ha^{1}. The relatively low forest degradation may be a result of: 1) effective protection of the forest, 2) lower threat based on things like community activities or lower population, or 3) the area was degraded long ago and no stumps remain. SNP, RKWS and KhNP had much higher average emission from 18-27 Mg CO_2 ha^{1}, with some areas having more than 100-150 Mg CO_2 ha^{1} extracted, which is 30-40% of the total forest CO_2 stocks. KNP was the outlier with extremely high emission that were on average 49 Mg CO_2 ha^{1} (17% of the total forest CO_2 stocks), with higher areas at over 200 Mg CO_2 ha^{1} (>50% of forest CO_2 stocks).

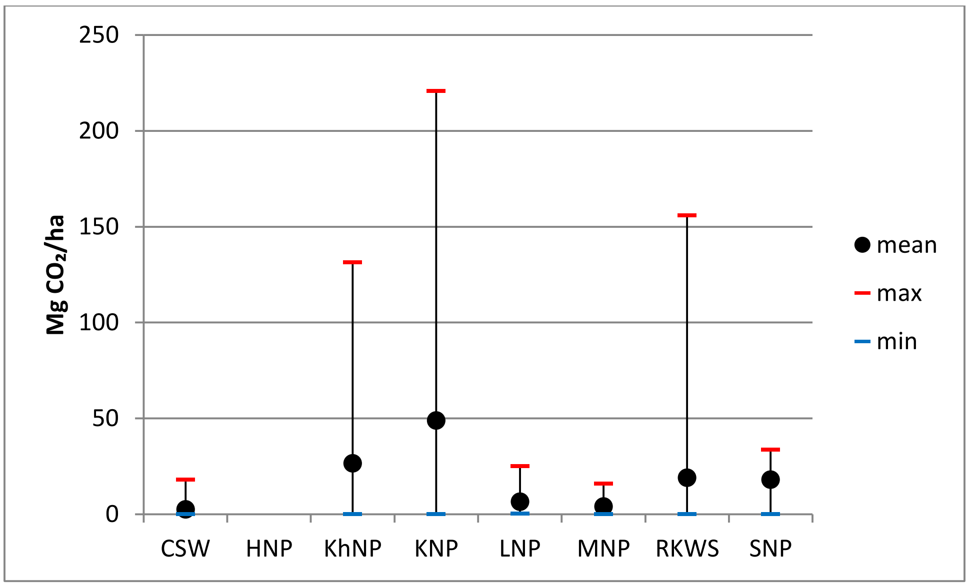


Figure 13.Results for emissions from forest degradation (Mg CO_2 ha^{1}) from each CREL PA based on quantification of stumps.

The average emission per hectare from forest degradation for each PA is presented in Table 13. By multiplying the average emissions per hectare by the total area of forest an estimate of total emission from forest degradation is presented (Table 13). While these estimates can prove useful for estimating impacts from forest degradation in different CREL PAs, the results are not applicable for national GHG accounting because 1) this type of degradation can be highly variable from site to site and cannot be mapped to estimate actual area of degradation; and 2) there is no estimate of time relating to this degradation as stumps may remain present for years after cutting (depending on stump decomposition rates).

Table 13. Results for emissions from forest degradation (Mg CO_2 ha^{1}) from each CREL PA based on quantification of stumps.

Name of PA	Area of forest (ha)	Ave. No. stumps per ha	Ave. wood biomass	Ave. emissions from extraction	Percent of total forest CO_2 stocks	Total emissions from extraction

			extracted (Mg C/ha)	of trees (Mg CO2/ha)		of trees (Mg CO_2)
CWS	507	26	0.91	2.51	1.6%	1,272
KhNP	479	15	4.74	26.44	9.1%	12,663
KNP	3,786	65	17.81	48.89	17.0%	185,085
LNP	1,911	30	2.35	6.43	1.7%	12,281
RKWS	5,613	19	6.92	19.00	5.0%	106,639
SNP	222	40	6.56	18.02	7.7%	3,994
MNP	2,232	19	1.34	4.03	1.7%	9,004
ALL sites	14,749	31	5.80	17.90	6.3%	330,938

The results in Table 13 can be an indication of forests that are under high threat and therefore where CREL activities could have the biggest impact. Figure 13 indicates KNP, KhNP and RKWS are PAs where CREL activities could have the biggest impact, because of high emissions from forest degradation (forests remaining as forests).

The next step is to identify areas within the PAs where forest degradation (i.e. tree extraction) is most prevalent. Figure 14 shows a density map for plots with high to low emissions from forest degradation related to stumps in PAs. The emissions from high to low are relative for each PA, with high emission (red) in Lawachara being equivalent to 25Mg CO_2 ha^{-1} and in Kaptai 220.8Mg CO_2 ha^{-1}. These density maps could provide important information for where threat of forest degradation in highest and therefore where interventions could be most effective.

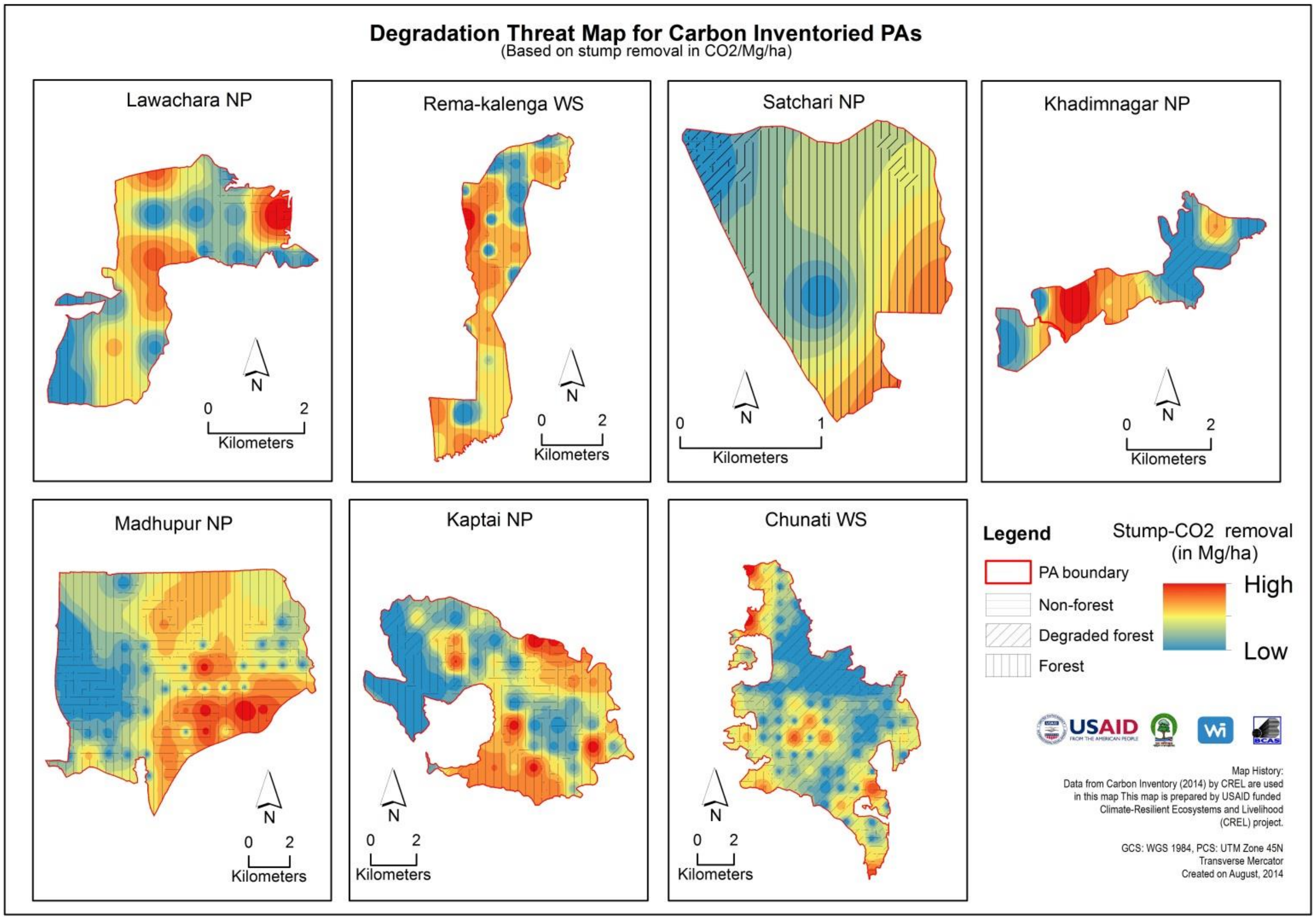


Figure 14. Threat of degradation, PAs with high threat shown on the top row, and low threat in bottom row. Within each PA threat is mapped based on plots with high (red) to low (blue) CO_2 extracted.

6.3.3 Forest biophysical indicators

For the CREL project, improving forest biophysical condition is a key goal. Forest biophysical condition was measured in the eight CREL PAs as the average seedlings, saplings, live trees, tree species richness and carbon pools present in each land cover type.

The presence and quantity of seedlings, saplings and live trees are an indication of forest recruitment across multiple growth stages, and therefore a sign of forest health. Tree species richness[19]is represented as an index, with low values indicating a low number of species to total trees, and high values high number of species to total trees (zero indicates no trees). Higher tree species diversity is an indication of a healthy natural forest that can, in turn, support a more diverse natural assemblage of plants and animals. This can be an indication of habitat health, and livelihood potential for those that rely on products from the natural forest. Carbon

19Species richness is a measure of the number of species found in a sample population. This species richness index is Menhinick's index (known as D). Equation $D=s/\sqrt{N}$, where s=number of species in sample and N=the total number of individuals pools are also a good indication of forest biophysical condition as they provide an indication of the relationship between trees, non-tree vegetation, dead wood, litter and soil. These relationships provide insights into general vegetation structure, decomposition (through litter and dead wood), and soil organic matter (an important indication of soil fertility).

The results in Table 14 show that the recruitment of different age class trees is highest in forest areas, followed by, plantation forests, village forest, degraded forest then rubber (Results for each CREL PA are presented in Appendix 1). Tea, settlement and agriculture result in almost complete absence of tree recruitment. Species diversity follows a similar trend. This data could be used to estimate relative changes in biophysical condition of an area that is converted from one land use to another (similar to emission factors). For example, for every hectare of forest converted to a plantation forest there is a drop in the recruitment of seedlings and saplings by 73% and 33% respectively. The abundance of live trees drops by 19% along with the overall diversity of tree species.

Table 14. Results for biophysical condition for different land cover types based on data from eight CREL PAs

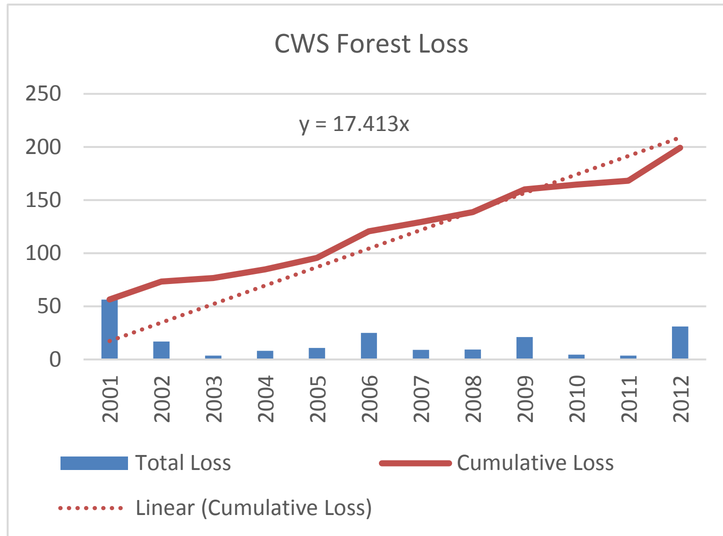
Land cover type	**Ave. Seedlings**	**Ave. Sapling**	**Live trees**	**Spp. Richness index**	**Trees (above and below ground)**	**Dead trees**	**Non-Tree**	**Litter**	**Soil**
	(ha)			**Ratio**	**Mg CO_2/ha**				
Forest	17,804	3,800	1,700	0.10	293.9	1.2	3.2	8.6	35.3
Plantation	4,815	2,556	1,376	0.07	222.2	0.6	7.1	7.2	29.7
Rubber	455	0	1,204	0.02	201.5	0.0	2.5	6.8	35.8
Village forest	1,393	746	929	0.06	136.3	1.1	1.0	3.2	15.9
Tea Garden	0	0	381	0.04	105.1	0.0	0.6	3.8	50.7
Degraded forest	1,178	1,763	447	0.03	57.1	0.2	4.1	4.9	26.2
Settlement/bare land	0	0	113	0.00	27.8	0.0	2.3	10.5	40.1
Agriculture	0	0	46	0.01	23.7	0.0	0.9	2.6	27.7

7. BASELINE RESULTS

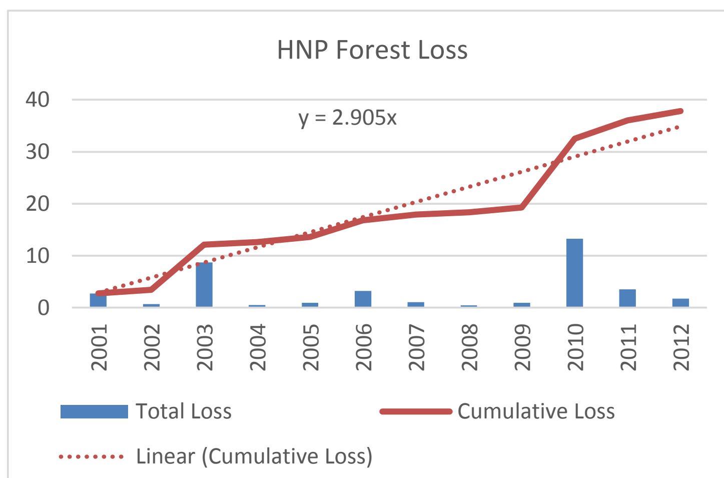
7.1. Historic land cover change in 8 PAs

The tables and figures below show the baseline rate of deforestation for each of the CREL PAs. The rate of deforestation was derived from the Hansen et al. (2013) data set overlaid with the CREL 2013 land cover maps. Because the CREL land cover maps classified areas of degraded forests, plantation forests, rubber plantations, agriculture lands and settlements in 2013, an estimation of how many hectares of forest was lost to each of these classes over the last 12 years could be established. These area estimates are called "activity data."

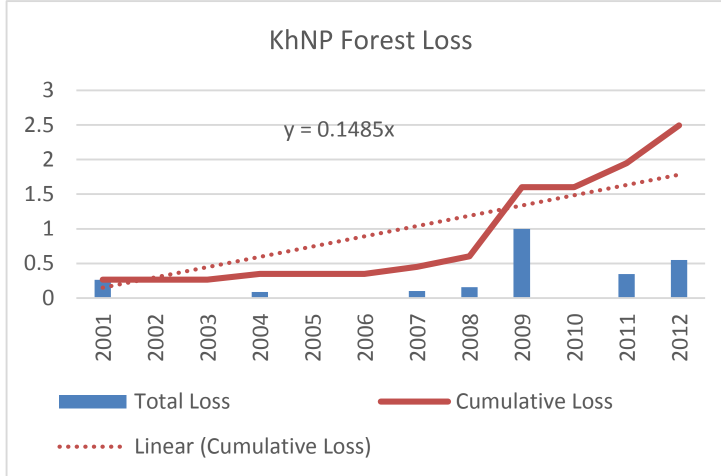
CSW had 1067 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Degraded forest shrublands	169.0	14.1	1.32%
Settlements	20.8	1.7	0.16%
Agriculture	8.5	0.7	0.07%
Wetlands	1.0	0.1	0.01%
Total	199.3	16.6	1.56%



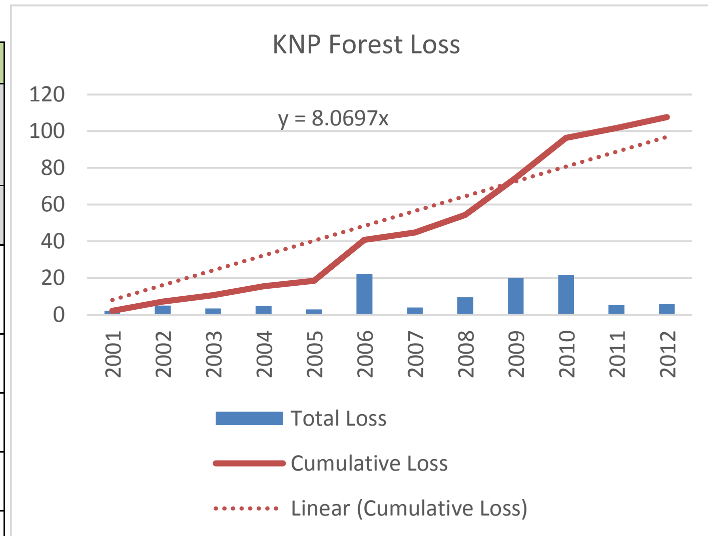
HNP had 182 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Degraded forest shrublands	30.6	2.6	1.40%
Bare lands	2.8	0.2	0.13%
Settlements	2.3	0.2	0.10%
Agriculture	2.0	0.2	0.09%
Total	37.9	3.2	1.74%



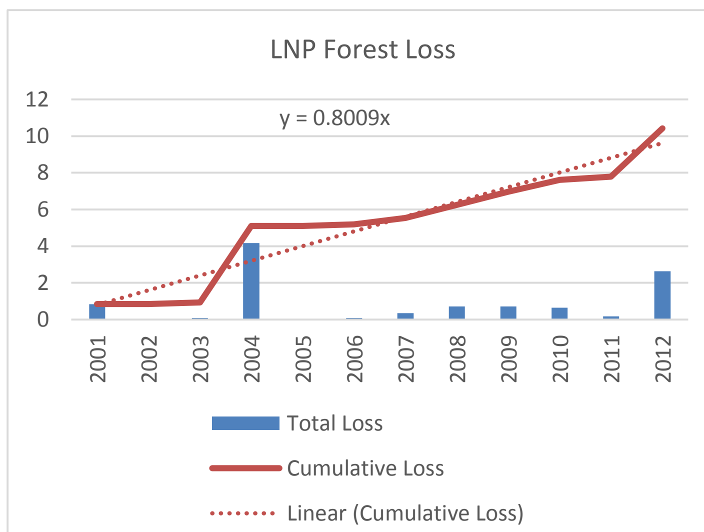
KhNP had 481 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Degraded forest shrublands	2.5	0.2	0.04%



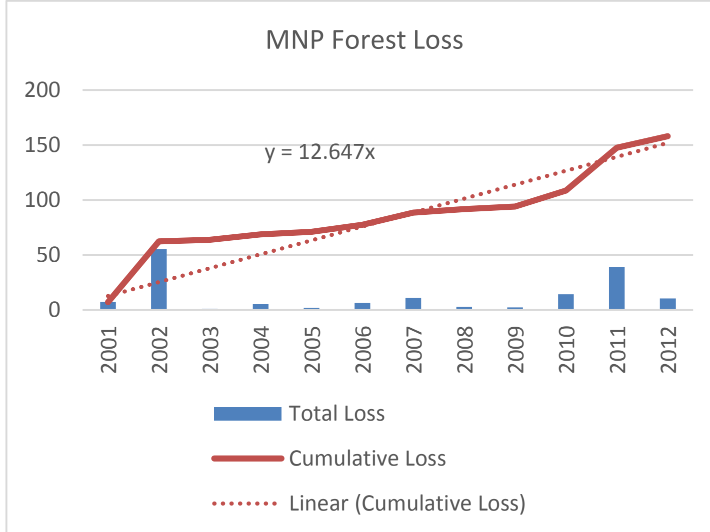
KNP had 5,755ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Degraded forest ~~shrublands~~	94.6	7.9	0.21%
Water bodies	6.0	0.5	0.01%
Agriculture	4.1	0.3	0.01%
Settlements	3.0	0.3	0.01%
Total	107.7	9.0	0.23%



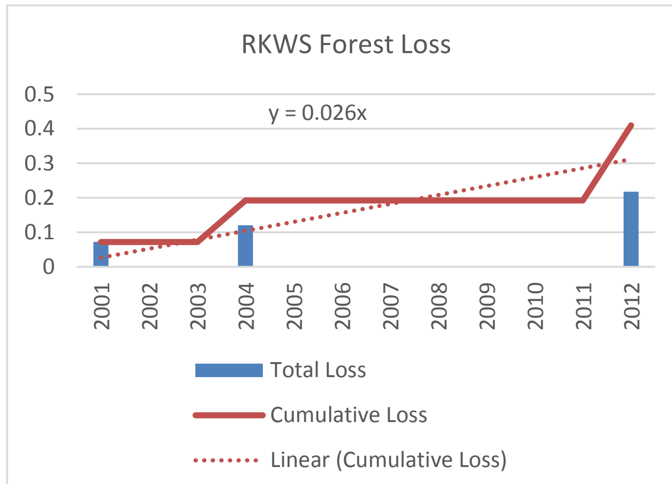
LNP had 2,149 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Agriculture	7.6	0.6	0.03%
Settlements	2.8	0.2	0.01%
Total	10.4	0.9	0.04%



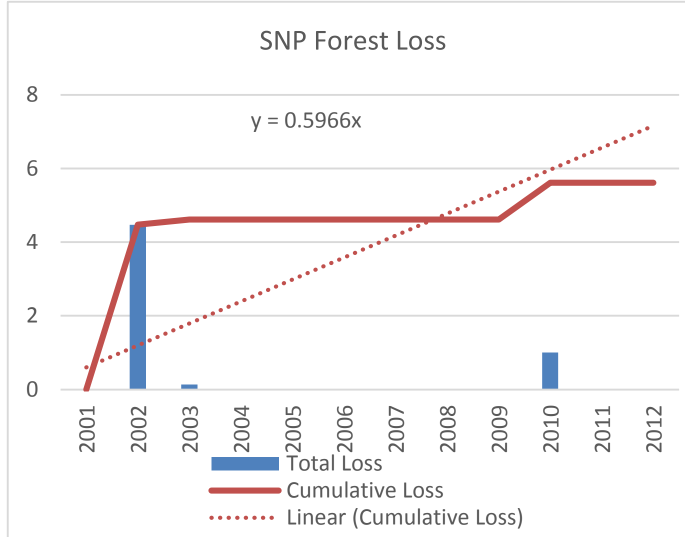
MNP had 2,389 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Agriculture	110	9	0.38%
Settlements	47	4	0.17%
Total	158	13	0.55%



RKWS had 5,755ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Agriculture	0.4	0.0	0.00%



SNP had 229 ha of forest in 2001			
Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation
Forest to:	ha	ha/y	%
Degraded forest ~~shrublands~~	5.0	0.4	0.18%
Water bodies	0.6	0.1	0.02%
Total	5.6	0.5	0.20%



7.2. GHG EMISSIONS AND BIOPHYSICAL CONDITION

By combining the results from the area of change (hectares) with the emissions factors and biophysical factors historical baselines can be established for each of the CREL PAs. If we assume that the historical rate of change is the baseline rate of change that would have continued into the future in the absence of the CREL project, then the annual area of change or rate is the baseline that the CREL project should measure its success against. For example, if the baseline rate of change in CSW is 16.5 ha per year resulting in 4,422Mg CO_2 yr^{-1}(see

Table15) and during the life of the CREL project the rate drops to 14ha per year with a corresponding decrease in CO_2 emissions then the CREL project may be able to say that it has been successful reducing GHG emission from deforestation by around 15%. To monitor any changes in the deforestation rate there are two options for CREL, 1) wait for the Hansen dataset to be updated (this is expected annually starting in 2015), 2) use the USAID AFOLU Carbon Calculator Tool to estimate using a subjective question and answer approach.

Table15 shows the results for baseline annual emissions for each of the CREL PAs. The total baseline annual emissions for each PA are what CREL should use to monitor is success against.

Table15.Results for baseline annual emissions for eight CREL PAs.

PA	Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation	Emission Factor	Baseline Annual Emissions
	Forest to:	ha	ha/yr	%	Mg CO_2 ha^1	Mg CO_2 yr^{-1}
CWS	Degraded Forest Shrubland*	169.0	14.1	1.32%	258	3,632
CWS	Settlement	20.8	1.7	0.16%	325	564
CWS	Agriculture	8.5	0.7	0.07%	319	227
CWS	Total	198.3	16.5	1.55%		4,422
HNP	Degraded Forest Shrubland*	30.6	2.6	1.40%	258	658
HNP	Bare soil	2.8	0.2	0.13%	325	75
HNP	Settlement	2.3	0.2	0.10%	325	61

PA	Land cover change	Total area of change (2001-2012)	Annual area change	Rate of Deforestation	Emission Factor	Baseline Annual Emissions
	Forest to:	**ha**	**ha/yr**	**%**	**Mg CO_2 ha[1]**	**Mg CO_2 yr^{-1}**
HNP	Agriculture	2.0	0.2	0.09%	319	52
HNP	Total	37.6	3.1	1.73%		847
KhNP	Degraded Forest Shrubland*	2.5	0.2	0.04%	258	54
KhNP	Total	2.5	0.2	0.04%		54
KNP	Degraded Forest Shrubland*	94.6	7.9	0.21%	258	2,033
KNP	Agriculture	4.1	0.3	0.01%	319	109
KNP	Settlement	3.0	0.3	0.01%	325	81
KNP	Total	102	8	0		2,224
LNP	Agriculture	7.6	0.6	0.27%	319	203
LNP	Settlements	2.8	0.2	0.10%	325	76
LNP	Total	10.4	0.9	0.37%		278
MNP	Agriculture	110.2	9.2	0.38%	241	2,215
MNP	Settlements	47.4	4.0	0.17%	247	977
MNP	Total	157.6	13.1	0.55%		3,192
RKWS	Agriculture	0.4	0.0	0.00%	319	11
RKWS	Total	0.4	0.0	0.00%		11
SNP	Degraded Forest Shrubland*	5.0	0.4	0.18%	258	107
SNP	Total	5.0	0.4	0.18%		107

* In this study the shrubland degraded forest is a distinct land cover type that is dominated by shrubs. In most cases these lands do not meet the forest definition (>10% canopy cover over 0.5ha), however are called "degraded forest shrublands" because they are forest department lands and eligible for reforestation. This is in contrast to other areas where there is forest (i.e. it meets the forest definition) and it has been degraded, these land s are called "degraded forest." This distinction would be critical under a REDD+ system as these two land cover types would be monitored and reported in very different ways (See Section 6.3.2)

8. DISCUSSION

This report provides the results from the CREL forest inventory and land cover mapping in 2014. The analysis of the results also provide important recommendations and contributions to Bangladesh's National REDD+ development.

The forest inventories resulted in carbon stocks estimates for Sal forest and Hill forest. Data from the 2009 Sundarbans Inventory[2] was used to establish Mangrove carbon stocks. 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.

[1] Standard Operating Procedures (SOP) for Forest Carbon Inventory, Bangladesh (2014)

[2] Forest Carbon inventory in the Sundarbans RF (2009)

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 eight 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 shrubland 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 eight forest protected areas based on an inventory of tree stumps. This helps to quantify the threat and impact of forest degradation 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. From our experience higher resolution data is not the best solution and it is advised to look at other data sources like Radar.

6. Plantation forest is also an important component of Bangladesh's forests. These can be very hard to map with RS therefore manual digitization should be considered as a viable option.

7. Wetlands are an important aspect of the Bangladesh landscape and there are significant drivers that are converting wetlands, therefore any national GHG accounting should include wetlands. This would require conducting wetland inventories and mapping wetlands so that wetland conversion can be monitored.

Appendix 1 CREL forest biophysical results by PA.

PA	Land cover type	Area	Ave. Seedlings	Ave. Sapling	Live trees	Spp. Diversity index	Trees (above and below ground)	Dead trees	Non-Tree	Litter	Soil	Total (ex. soil)
		(ha)				Ratio	Mg CO_2/ha					
CSW	Forest	507	8,412	3,752	1,321	0.13	146.3	0.0	8.1	28.1	22.0	185.8
CSW	Plantation	361	9,886	4,989	1,745	0.07	135.4	0.3	4.8	17.6	17.1	162.1
CSW	Settlement	981	1,393	1,790	1,278	0.10	131.6	0.5	5.3	13.6	20.6	152.0
CSW	Degraded forest	5,871	810	441	655	0.06	75.1	0.2	5.2	14.8	27.1	95.6
CSW	Agriculture	600	0	0	0	0.00	0.0	0.0	1.5	9.7	13.0	11.1
HNP	Settlement	No Class	133	133	387	0.05	114.4	1.7	0.0	0.0	3.8	116.2
HNP	Forest	No Class	3,183	0	1,027	0.12	100.4	0.0	0.0	0.0	16.2	101.1
HNP	Degraded forest	No Class	2,546	3,939	60	0.01	9.9	0.0	0.5	0.5	17.2	12.8
KhNP	Forest	479	1,326	531	1,017	0.07	330.2	0.0	1.9	18.7	21.5	351.2
KhNP	Plantation	No Class	0	0	1,768	0.04	313.4	0.0	1.0	15.4	29.0	329.8
KhNP	Degraded forest	198	0	1,989	360	0.04	39.5	0.0	0.1	0.0	39.4	40.4
KNP	Plantation	42	862	199	1,359	0.30	329.9	2.0	1.0	5.0	27.1	324.8
KNP	Forest	3,786	1,966	328	1,298	0.40	275.0	8.4	4.1	8.0	27.3	297.3
KNP	Settlement	210	398	398	828	0.20	123.1	2.9	2.2	1.7	26.4	130.3
KNP	Degraded forest	966	140	187	316	0.12	57.8	0.3	1.4	2.6	27.2	62.3
KNP	Agriculture	23	0	0	0	0.00	0.0	0.0	0.0	0.0	27.1	0.0
LNP	Forest	1,911	4,775	3,382	1,976	0.28	409.4	3.3	1.9	28.3	44.2	444.5
LNP	Settlement	310	796	0	1,903	0.28	308.6	0.0	0.0	0.0	41.8	308.8
LNP	Plantation	No Class.	2,255	4,178	1,319	0.08	239.9	0.3	4.3	19.8	40.7	265.5
LNP	Tea Garden	227	0	0	381	0.08	105.1	0.0	1.1	9.5	50.7	115.8
LNP	Degraded forest	No Class.	2,918	18,568	284	0.05	21.1	25.3	9.7	15.9	37.0	76.8
LNP	Bare Land	No Class.	0	0	113	0.04	27.8	0.0	5.7	26.1	40.1	59.5
MNP	Forest	2,232	53,184	7,666	2,500	0.08	239.8	0.0	0.9	15.5	30.5	255.0
MNP	Rubber	496	455	0	1,204	0.05	201.5	0.0	3.1	13.5	35.8	218.1
MNP	Plantation	578	4,509	2,785	1,135	0.05	174.8	0.0	0.5	8.6	37.1	156.2
MNP	Settlement	2,873	4,775	1,061	1,290	0.11	137.9	0.0	0.7	11.8	18.3	151.1
MNP	Agriculture	2,083	0	0	0	0.00	0.0	0.0	3.3	2.6	34.0	5.9
RKWS	Forest	5,613	12,118	3,321	1,602	0.22	375.8	0.0	0.7	10.3	47.0	390.1
RKWS	Plantation	93	6,366	1,347	1,195		198.8	0.0	1.6	8.5	41.1	212.3
RKWS	Agriculture	74	0	0	53	0.01	37.5	0.0	0.0	0.0	42.9	12.5
RKWS	Degraded forest	No Class.	11,141	10,345	0	0.00	0.0	0.0	0.3	4.6	44.0	5.9
SNP	Forest	222	5,093	2,706	1,059	0.15	256.0	0.4	2.2	17.1	39.3	279.1
SNP	Plantation	0	3,183	1,592	1,045	0.11	244.8	0.3	2.0	16.0	31.5	265.3
SNP	Agriculture	2	0	0	393	0.08	128.6	0.0	8.9	3.6	22.4	141.1
SNP	Degraded forest	19	531	1,061	236	0.04	78.5	0.0	3.4	6.3	38.1	89.3
FkWS	Dense Forest	483	1,971	3,969	313	No data	553.1	0.1	No Data	5.7	No Data	558.8

PA	Land cover type	Area	Ave. Seedlings	Ave. Sapling	Live trees	Spp. Diversity index	Trees (above and below ground)	Dead trees	Non-Tree	Litter	Soil	Total (ex. soil)
		(ha)				Ratio	Mg CO_2/ha					
	Plantation	No Class	1,309	2,971	82		334.9	0.0	No Data	4.9	No Data	339.8
	Settlement	18	371	1,662	101		114.9	0.0	No Data	4.5	No Data	119.5
	Degraded Forest	692	891	1,878	50		88.5	0.4	No Data	5.4	No Data	94.3
DDWS	Dense Forest	2,618	6,465	1,746	262	No data	329.9	1.8	79.6	4.4	No Data	415.7
	Plantation	58	4,562	1,450	263		345.2	1.0	6.5	4.8	No Data	357.4
	Degraded forest	1,468	3,566	986	216		128.9	2.1	50.4	4.7	No Data	186.1
	Settlement	192	0	0	19		3.2	0.0	0.0	3.4	No Data	6.6

Appendix 2: Confusion Matrix of LC Classification

Confusion Matrix of Satchari National Park

		Observed (ground truth)									
	Class	Agriculture	Degraded Forest	Forest	Rubber	Settlements	Tea	Water	Grand Total		
Predicted (mapped as)	Agriculture	21	2		3	1	2		29	72%	User's Accuracy
	Degraded Forest		14	6	3	1	6		30	47%	
	Forest		3	24			2		29	83%	
	Rubber				30				30	100%	
	Settlements			2		26	1		29	90%	
	Tea	1					29		30	97%	
	Water	1				1	2	26	30	87%	
	Grand Total	23	19	32	36	29	42	26	207		
		91%	74%	75%	83%	90%	69%	100%			
		Producer's Accuracy									

Class Name	Producer's Accuracy	User's Accuracy
Agriculture	91%	72%
Degraded Forest	74%	47%
Forest	75%	83%
Rubber	83%	100%
Settlements	90%	90%
Tea	69%	97%
Water	100%	87%
Overall	**82%**	

Confusion Matrix of Chunati National Park

		Observed (ground truth)								
		Agricul ture	Degra ded Forest	Hill Forest	Planta tion	Settle ment	Wetla nd	Grand Total		
Predicted (mapped as)	Agriculture	18	1			5	1	25	72%	User's accuracy
	Degraded Forest	3	20	1	1			25	80%	
	Hill Forest		13	7	5			25	28%	
	Plantation	2			21	2		25	84%	
	Settlement	4	2		4	13	2	25	52%	
	Wetland	6	1			3	15	25	60%	
	Grand Total	33	37	8	31	23	18	150		
		55%	54%	88%	68%	57%	83%			
		Producer's accuracy								

Land use/cover class	Producer's accuracy	User's accuracy
Agriculture	55%	72%
Degraded Forest	54%	80%
Hill Forest	88%	28%
Plantation	68%	84%
Settlement	57%	52%
Wetland	83%	60%
Overall	**63%**	

Confusion Matrix of Dudhpukuria Wildlife Sanctuary

		Observed (ground truth)								
	Class	Degraded land	Hill forest	Irrigated Agriculture	Non-native plantation	Settlement	Water bodies	Grand Total		
Predicted (mapped	Degraded land	21	4					25	84%	User's accuracy
	Hill forest	8	13	3	1			25	52%	
	Irrigated Agriculture	6	2	13		2	2	25	52%	
	Non-native plantation	6	1	2	16			25	64%	
	Settlement	7	1	8		8	1	25	32%	
	Water bodies	4	1	9	1	1	11	27	41%	
	Grand Total	52	22	35	18	11	14	152		
		40%	59%	37%	89%	73%	79%			
		Producer's accuracy								

Landover	Users accuracy	Producers accuracy
Degraded land	84%	40%
Hill forest	52%	59%
Irrigated Agriculture	52%	37%
Non-native plantation	64%	89%
Settlement	32%	73%
Water bodies	41%	79%
Overall	**54%**	

Confusion Matrix of Fasiakhali National Park

		Observed (ground truth)								
	Map	Degraded Forest	Forest	Irrigated Agriculture	Saltpan	Settlement	Wetland	Grand Total		
Predicted (mapped as)	Degraded Forest	37	7	6				50	74%	User's accuracy
	Forest	5	36	6		2	1	50	72%	
	Irrigated Agriculture		2	36	1	7	4	50	72%	
	Saltpan			2	41		7	50	82%	
	Settlement	1	1	7		39	2	50	78%	
	Wetland			5		3	42	50	84%	
	Grand Total	43	46	62	42	51	56	300		
		86%	78%	58%	98%	76%	75%			
		Producer's accuracy								

Land use/cover	Producer's accuracy	User's accuracy
Degraded Forest	86%	74%
Forest	78%	72%
Irrigated Agriculture	58%	72%
Saltpan	98%	82%
Settlement	76%	78%
Wetland	75%	84%
Overall	**77%**	

Confusion Matrix of Himchari National Park

		Observed (ground truth)														
		Agriculture	Aquaculture	Bare soil	Brick Field	Degraded land	Hill forest	Plantation	River	Sand bar	sea	Settlement	Wetland	Grand Total		
Predicted (mapped as)	Agriculture	22						1				2		25	88%	User's accuracy
	Aquaculture	6	10						1			2	6	25	40%	
	Bare soil	3		9		10		1				2		25	36%	
	Brick Field				25									25	100%	
	Degraded land					23	1	1						25	92%	
	Hill forest					2	20	2				1		25	80%	
	Plantation	2				1		22						25	88%	
	River	2							23					25	92%	
	Sand bar	2		2	2			2	2	11	2	1	1	25	44%	
	Sea									1	24			25	96%	
	Settlement	8						1				16		25	64%	
	Wetland	4				1	1	1		1		2	15	25	60%	
	Grand Total	49	10	11	27	37	22	31	26	13	26	26	22	300		
		45%	100%	82%	93%	62%	91%	71%	88%	85%	92%	62%	68%			
		Producer's accuracy														

Land use/cover class	Producer's accuracy	User's accuracy
Agriculture	45%	88%
Aquaculture	100%	40%
Bare soil	82%	36%
Brick Field	93%	100%
Degraded land	62%	92%
Hill forest	91%	80%
Plantation	71%	88%
River	88%	92%
Sand bar	85%	44%
Sea	92%	96%
Settlement	62%	64%
Wetland	68%	60%
Overall	73%	

Confusion Matrix of Inani

		Observed (ground truth)												
	Class	Agriculture	Brick Field	Degraded Forest	Forest	Industry	Plantation	Sand Bar	Sea	Settlement	Water Bodies	Grand Total		
Predicted (mapped as)	Agriculture	22		1			1				1	25	88%	User's accuracy
	Brick Field	1	23							1		25	92%	
	Degraded Forest	1		23	1							25	92%	
	Forest			7	18							25	72%	
	Industry	1				22	2					25	88%	
	Plantation						25					25	100%	
	Sand Bar	1					4	19			1	25	76%	
	Sea							2	23			25	92%	
	Settlement	6								19		25	76%	
	Water Bodies	4									21	25	84%	
	Grand Total	36	23	31	19	22	32	21	23	20	23	250		
		61%	100%	74%	95%	100%	78%	90%	100%	95%	91%			
		Producer's accuracy												

Land Cover/Class	Producer's accuracy	User's accuracy
Agriculture	61%	88%
Brick Field	100%	92%
Degraded Forest	74%	92%
Forest	95%	72%
Industry	100%	88%
Plantation	78%	100%
Sand Bar	90%	76%
Sea	100%	92%
Settlement	95%	76%
Water Bodies	91%	84%
Overall	86%	

Confusion Matrix of Khadimnagar National Park

		Observed (ground truth)									
	Map	Agriculture	Degraded land	Forest	Plantation	Settlement	Tea	Water bodies	Grand Total		
Predicted (mapped as)	Agriculture	22				1	2		25	88%	User's accuracy
	Degraded land	1	17				7		25	68%	
	Forest		2	23					25	92%	
	Plantation	1	1		23				25	92%	
	Settlement	7	3			13	2		25	52%	
	Tea	3	2				20		25	80%	
	Water bodies	1				1		23	25	92%	
	Grand Total	35	25	23	23	15	31	23	175		
		63%	68%	100%	100%	87%	65%	100%			
		Producer's accuracy									

Land use/cover class	Producer's accuracy	User's accuracy
Agriculture	63%	88%
Degraded land	68%	68%
Forest	100%	92%
Plantation	100%	92%
Settlement	87%	52%
Tea	65%	80%
Water bodies	100%	92%
Overall	81%	

Confusion Matrix of Kaptai National Park

		Observed (ground truth)									
	Map	Agriculture	Degraded land	Forest	Industry	Plantation	Settlement	Water bodies	Grand Total		
Predicted (mapped as)	Agriculture	19	3	1			2		25	76%	User's accuracy
	Degraded land		20	5					25	80%	
	Forest		4	19				2	25	76%	
	Industry				24			1	25	96%	
	Plantation				2	21	2		25	84%	
	Settlement		3	2	1	2	17		25	68%	
	Water bodies			2				23	25	92%	
	Grand Total	19	30	29	27	23	21	26	175		
		100%	67%	66%	89%	91%	81%	88%			
		Producer's accuracy									

Land use/cover class	Producer's accuracy	User's accuracy
Agriculture	100%	76%
Degraded land	67%	80%
Forest	66%	76%
Industry	89%	96%
Plantation	91%	84%
Settlement	81%	68%
Water bodies	88%	92%
Overall	82%	

Confusion Matrix of Lawachara National Park

	Observed(ground truth)										
Predicted(mapped as)		Agriculture	Bare	Forest	Rubber	Settlements	Tea	Water bodies	Grand Total		
	Agriculture	23				1	1		25	92%	User's accuracy
	Bare		17		7		1		25	68%	
	Forest	1		22			2		25	88%	
	Rubber	2			21		2		25	84%	
	Settlements	1				12	12		25	48%	
	Tea			1		4	19	1	25	76%	
	Water bodies	12			1	4		8	25	32%	
	Grand Total	39	17	23	29	21	37	9	175		
		59%	100%	96%	72%	57%	51%	89%			
		Producer's accuracy									

Land use/cover class	Producer's accuracy	User's accuracy
Agriculture	59%	92%
Bare	100%	68%
Forest	96%	88%
Rubber	72%	84%
Settlements	57%	48%
Tea	51%	76%
Water bodies	89%	32%
Overall	70%	

Confusion Matrix of Medhakachapia National Park

		Observed(ground truth)								
	Class	Degraded Forest	Forest	Irrigated Agriculture	Saltpan	Settlement	Wetland	Grand Total		
Predicted(mapped as)	Degraded Forest	43	1	6				50	86%	User's accuracy
	Forest	5	35	8		2		50	70%	
	Irrigated Agriculture	10	4	28		6	2	50	56%	
	Saltpan			1	45	1	3	50	90%	
	settlement			11		39		50	78%	
	Wetland			4		4	42	50	84%	
	Grand Total	58	40	58	45	52	47	300		
		74%	88%	48%	100%	75%	89%			
		Producer's accuracy								

Land Cover/Class	Producer's accuracy	User's accuracy
Degraded Forest	74%	86%
Forest	88%	70%
Irrigated Agriculture	48%	56%
Saltpan	100%	90%
settlement	75%	78%
Wetland	89%	84%
Overall	**77%**	

Confusion Matrix of Modhupur National Park

		Observed (ground truth)								
		Irrigated	Non-native Plantation	Rubber	Sal	settlement	Wetland	Grand Total		
Predicted (mapped as)	Irrigated	46					4	50	92%	User's accuracy
	Non-native Plantation	13	37					50	74%	
	Rubber	3		47				50	94%	
	Sal	1			49			50	98%	
	settlement	10		3	2	27	8	50	54%	
	Wetland	1			3		46	50	92%	
	Grand Total	74	37	50	54	27	58	300		
		62%	100%	94%	91%	100%	79%			
		Producer's accuracy								

Land use/cover class	Producer's accuracy	User's accuracy
Irrigated	62%	92%
Non-native Plantation	100%	74%
Rubber	94%	94%
Sal	91%	98%
settlement	100%	54%
Wetland	79%	92%
Overall	**84%**	

Confusion Matrix of Remakalenga Wildlife Sanctuary

		Observed (ground truth)									
		Agriculture	Forest	Plantation	Rubber	Settlements	Tea	Water	Grand Total		
Predicted (mapped as)	Agriculture	20	1	2		2			25	80%	User's Accuracy
	Forest	1	24						25	96%	
	Plantation	6	1	16		2			25	64%	
	Rubber	1			23		1		25	92%	
	Settlements	1	1	5		16	2		25	64%	
	Tea	4	1			3	17		25	68%	
	Water	1				1		23	25	92%	
	Grand Total	34	28	23	23	24	20	23	175		
		59%	86%	70%	100%	67%	85%	100%			
		Producer's Accuracy									

Land use/cover class	Producer's Accuracy	User's Accuracy
Agriculture	59%	80%
Forest	86%	96%
Plantation	70%	64%
Rubber	100%	92%
Settlements	67%	64%
Tea	85%	68%
Water	100%	92%
Overall	**79%**	

Confusion Matrix of Teknaf Wildlife Sanctuary

		Observed (ground truth)																	
	Class	Agriculture	Brick Field	Built-up	Cloud/Shadow	Degraded Forest	Dry/Bare Soil	Low-Mid Canopy Forest	Mangrove	Mid-High Canopy Forest	Mudflat	Plantation	Refugee Camp	Salt Pan	Sandbars	Settlements	Water Bodies	Grand Total		
Predicted (mapped as)	Agriculture	22					1	1								5		29	76 %	User's Accuracy
	Brick Field		29															29	100 %	
	Built-up			24													4	28	86 %	
	Cloud/Shadow	1			11			11		4						2		29	38 %	
	Degraded Forest	2				12	2	10				2				1		29	41 %	
	Dry/Bare Soil					1	18	10										29	62 %	
	Low-Mid Canopy Forest	1						19		8		2						30	63 %	
	Mangrove	5							17		1			4			1	28	61 %	
	Mid-High Canopy Forest							7		17		6						30	57 %	
	Mudflat									1	17			1	7	1	2	29	59 %	
	Plantation											30						30	100 %	
	Refugee Camp												30					30	100 %	
	Salt Pan	1												28				29	97 %	
	Sandbars								4		1				20		5	30	67 %	
	Settlements	3						1				1				25		30	83 %	
	Water Bodies	2												1			27	30	90 %	
	Grand Total	37	29	24	11	13	21	59	21	30	19	41	30	34	27	34	39	469		
		59 %	100 %	100 %	100 %	92 %	86 %	32 %	81 %	57 %	89 %	73 %	100 %	82 %	74 %	74 %	69 %			
		Producer's Accuracy																		

Class	Producer's Accuracy	User's Accuracy
Agriculture	100%	76%
Brick Field	100%	100%
Built-up	100%	86%
Cloud/Shadow	92%	38%
Degraded Forest	86%	41%
Dry/Bare Soil	32%	62%
Low-Mid Canopy Forest	81%	63%
Mangrove	57%	61%
Mid-High Canopy Forest	89%	57%
Mudflat	73%	59%
Plantation	100%	100%
Refugee Camp	82%	100%
Salt Pan	74%	97%
Sandbars	74%	67%
Settlements	69%	83%
Water Bodies		90%
Overall	**74%**	