Khasi Hills Community REDD+ Project: Restoring and Conserving Meghalaya's Hill Forests through Community Action

REDD+ and ANR Technical Specifications

Submitted to Plan Vivo, UK by

Community Forestry International on behalf of

Ka Synjuk Ki Hima Arliang Wah Umiam,

Mawphlang Welfare Society

Mawphlang, Meghalaya, North Eastern India

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Community Forestry
INTERNATIONAL

SUMMARY OF PROJECT

PROJECT TITLE	Khasi Hills REDD+ Project: Restoring and Conserving Meghalaya's Hills Forests through Community Action
PROJECT LOCATION	Khasi Hills, Meghalaya, India
PROJECT SIZE	27,139 ha.
PROJECT DESIGN ORGANIZATION	Community Forestry International (CFI)
PROJECT IMPLEMENTER	Ka Synjuk Ki Hima Arliang Wah Umiam ("FEDERATION")
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TECHNICAL SUPPORT	Technical Advisory Committee (Federation TAC)
	CFI, BioClimate, Rainforest Alliance

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ACRONYMS

ANR	Assisted Natural Regeneration
IGA	Income Generating Activities
LWC	Local Working Conditions
NRM	Natural Resource Management
NTFPs	Non-timber Forest Products
REDD	Reducing Emissions from Deforestation and Forest Degradation
VNRMPs	Village Natural Resource Management Plans

VERSION CONTROL

This version 3.0 of the Technical Specification (January 2017) provides an update to, and follows Version 2.0 (August 2015). The following changes have been made:

- Revised estimates of carbon stocks in dense and open forest, and updated tables to reflect changes to estimates of emissions and removals, as a result of:
  - Adding below-ground woody biomass as an accounted carbon pool
  - Updating volume equations used to estimate individual tree biomass, to use species specific equations when available
  - Applying a more conservative interpretation of mean biomass values by adopting the lower 90% confidence interval
- Revised baseline scenario: correction of a minor error in the interpretation of the satellite analysis. However, the revised values make use of the same analysis as that used for the initial version of the Technical Specification.
- Revised effectiveness of project activities using an analysis of deforestation and degradation observed in an analysis of satellite images from 2010 and 2016. The effectiveness values are applied for the period 2017 to 2021 to give a more conservative estimate of project effectiveness in this period.
- Revised estimated uptake from Assisted Natural Regeneration in 2017 to 2021 to reflect the annual area that will be planted in this period.

1. INTRODUCTION

The Khasi Hills project will slow, halt, and reverse the loss and degradation of forests in North-eastern India. It is India's first community REDD+ project to be certified under an international standard.

Restoration of degraded forests are being achieved by supporting communities in land management and forest regeneration activities in order to yield livelihood benefits. The project supports the development of community natural resource management (NRM) plans for the management of forests and micro-watersheds. Where possible, the project aims to link forest fragments to enhance hydrological and biodiversity services, especially on major and minor riparian arteries of the Umiam River

2. APPLICABILITY

The project represents an innovative approach to community-based forest conservation and restoration that has broad application in the neighboring watersheds in the Khasi hills, as well as more broadly across Meghalaya. The project also seeks to build community institutional capacity to monitor changes in forest cover, hydrological conditions, and biodiversity. The project is located on the traditional forest lands of the Khasi people, which are recognized by the Government of India as community forests under the Sixth Schedule of the Constitution.

This technical specification for reducing emissions from deforestation and forest degradation (REDD+) and assisted natural regeneration (ANR) has been developed for community forests in Meghalaya, India. REDD+ is applicable to dense or open forest under threat of deforestation or degradation. ANR is applicable to open forest. Definitions for dense and open forest are taken from the Indian Forest Survey. Dense forest has canopy cover from 40-100%, while open forest has canopy cover from 10- 40%

3. GEOGRAPHICAL AREA

The REDD+ project is located in the East Khasi Hills District of Meghalaya in Northeast India. The project boundary is the boundary of the Umiam River sub-watershed plus a one-kilometer belt. The project area includes the traditional territories of the nine participating Khasi governments (Hima). The project area is 27,139 hectares. The Umiam sub-watershed is in the Central Plateau Upland region of Meghalaya, India. The altitude of the plateau varies from 150 m to 1,961 m above mean sea level. The plateau has steep regular slopes to the south where Meghalaya borders Bangladesh. The Umiam sub- watershed has rolling uplands, rounded hills and rivers. The River Umiam, which flows through the project area, is a major river in Meghalaya and an important source of water for the capital city of Shillong. Figure 1 shows the Meghalaya Plateau between the Eastern Himalayas and the Arakan Mountains and the locations of the initial 15 community conservation areas.

Figure 1: Meghalaya in Northeast India

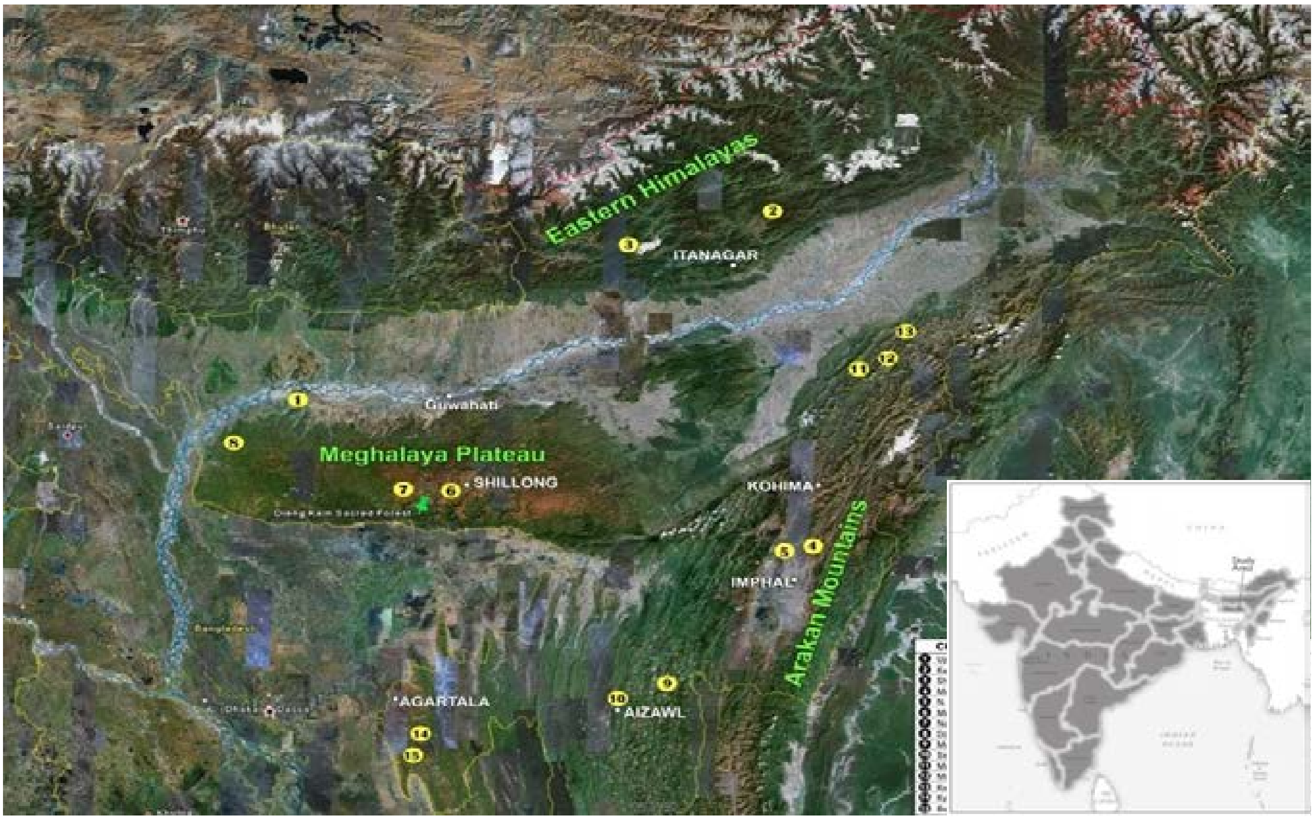
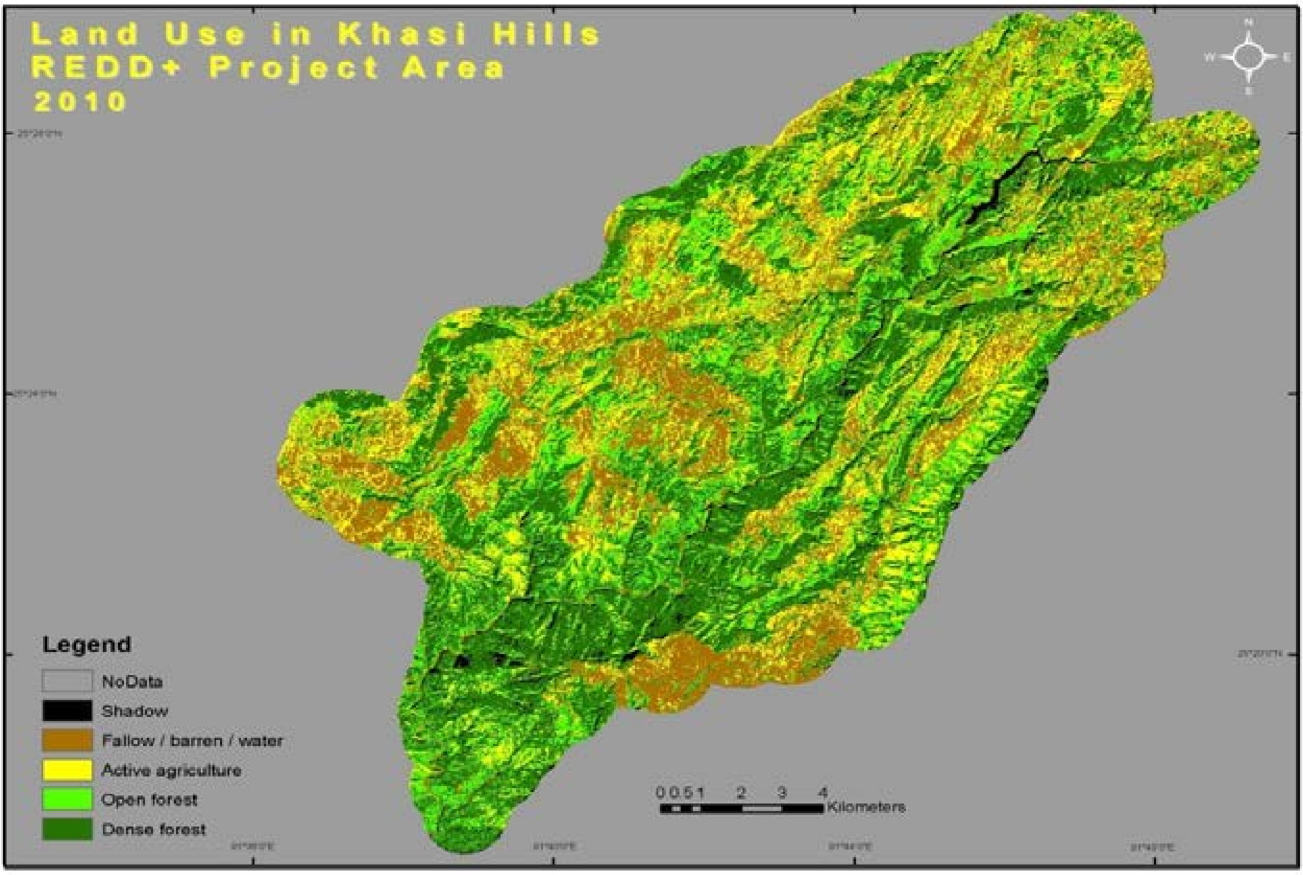


Figure 2: Project Area



3.1. Climate

The climate of the Central Plateau Upland region is influenced by its topography and has high seasonal rainfall. There are four seasons: 1) a cool spring from March to April; 2) a hot rainy summer (monsoons) from May to September; 3) a pleasant autumn from October to mid-November and; 4) a cold winter from mid-November to February. The mean maximum temperature ranges between 15◦C to 25◦C and the mean minimum temperature ranges between 5◦C to 18◦C.

3.2. Land Cover Types

In the Umiam sub-watershed, there are pine forests, small areas of mixed evergreen cloud forest, barren land, active agricultural land, fallow land and settlements. Forest on community land is mainly pine forest, which is a secondary forest type. Mixed broadleaved and pine forest is found in valleys.

Pure broadleaved forest remnants are confined to gullies, steep slopes and sacred groves. Fragments of mixed evergreen cloud forest remain in the project area as sacred groves. The Mawphlang Sacred Forest is one of the most famous sacred groves in the Khasi Hills (Meghalaya Tourism, 2012). The project area is stratified into four land cover types; 1) dense forest 2) open forest 3) barren or fallow lands and 4) agricultural land (see Table 1).

Table 1: Land Cover Types (Source: Satellite image analysis - see Appendix 3) [1]

LAND COVER	AREA IN 2010 (Ha)
Dense forest	9,270
Open forest	5,947
Barren or fallow	6,330
Agriculture	4,777
Other (shadow/water/no data)[1]	814
Total Area	27,139

3.3. Deforestation and Degradation

The East Khasi Hills have experienced rapid, unplanned deforestation and forest degradation due to social and economic forces. A recent forest survey of India showed that the deforestation rate is 3.6% for dense forest and over 6.8% per year for open forest in the East Khasi Hills District (FSI, 2006) (see Table 2 below).

Table 2: Forest Cover in the East Khasi Hills District: 2001 and 2005. [Source: FSI (2006)]

YEAR	DENSE FOREST	OPEN FOREST	TOTAL
2001	997	1,553	2,550
2005	817	1,019	1,836
Percentage Loss over 5 years	18 %	34 %	28 %
Percentage Loss per year	3.6 %	6.8 %	5.6 %

[1] In the satellite image analysis some areas could not be classified due to water, shadows, or insufficient data. These areas have been grouped into the category called “other” and are treated as non-forest land.

3.3.1. Drivers of Deforestation and Degradation

The key drivers of deforestation and forest degradation in the project area are: 1) forest fires; 2) unsustainable fuel wood collection; 3) charcoal making; 4) stone quarrying; 5) uncontrolled grazing; and 6) agricultural expansion.

With many of the drivers above, it is difficult to estimate the specific contribution of each driver to overall emissions from the project area, due to the limited availability of quantitative data. Firewood consumption, however, lends itself best to such an exercise as virtually all households use firewood with estimated consumption around 10 to 20 kg per household per day. With 4,400 households this means around 15,000 to 30,000 tons of fuelwood are burned each year.

The project estimates that the adoption of fuel-efficient stoves can reduce fuelwood consumption by 30 to 50%, however the project conservatively estimated actual reductions at 15% in the first 5 years and 25% in the second five years. In addition, NRM plans will include rotational fuelwood harvesting and the establishment of fast growing plantations that should increase fuelwood supplies, reducing the rate of forest degradation and accelerating natural regeneration by reducing pressure on the natural forests. Plantations may generate around 4,000 to 6,000 tons of fuelwood a year once they are productive (year 5) which would meet approximately 30 to 40% of the demand in the project area.

The Federation will be monitoring changes in forest conditions and the drivers of forest loss and degradation. Feedback on forest loss will be communicated by LWC members to the Federation on an annual basis. In addition, every five years, updated satellite images of the area will be analyzed to identify where forest loss is occurring. Based on this information the Federation will identify the causes and appropriate mitigation measures. Risk from natural hazards appears low at the present time. This upland region is not in a flood zone, nor is it subject to landslides or frequent earthquakes.

3.3.2. Forest Fires

Fires occur during dry months when the forest floor is covered with a thick layer of dry leaves and needles. In recent years, ground fires are estimated to burn approximately 25% of the project area each year. Fires are often set by discarded cigarettes, children playing with matches and escaping fires from agricultural burning. CFI's earlier pilot project demonstrated that community awareness-raising with community imposed prohibitions on smoking and carrying matches into the forest have significantly reduced the incidence of fire. Building fire-lines and hiring village firewatchers also contributed to reductions in ground fires. In addition, the establishment of fines for those who cause fires also creates an incentive to be careful. Incidence of fire will be monitored by the LWC as burn areas are highly visible. Rewards to communities that prevent fire may be given at the end of the fire season. Training in fire safety and control is also important as communities may use fire to establish fire-lines (sanding) as well as for agricultural clearing.

3.3.3. Unsustainable Firewood Collection

Over 99% of the rural community uses firewood as their sole source of fuel. Being situated in a relatively cold region, firewood consumption per household in the area is high, averaging 10 to 20 kg per household per day. Firewood is collected from nearby forests. If dead trees are not available, people resort to felling live trees and saplings. While some villages have regulations guiding fuelwood collection, many do not or these systems have broken down. The establishment of an NRM (plan vivo) planning process will help communities re-establish sustainable firewood production systems.

3.3.4. Charcoal Production

There is a significant demand for charcoal in Meghalaya. Charcoal is used by iron-ore smelting industries and it is also used for heating homes and offices in urban centers such as the city of Shillong. Charcoal making and its purchase by industries is illegal in Meghalaya. Charcoal making is concentrated in a few villages with limited alternative income generating opportunities.

3.3.5. Stone Quarrying

There is a large demand for stone, sand and gravel for construction in Shillong city. Many stone quarries exist in the project area. Quarries are usually on steep slopes and they lead to erosion and landslides. Hima governments will be asked to place a moratorium on leasing land for quarries and not extend existing leases wherever possible.

3.3.6. Uncontrolled Grazing

The rural communities allow cattle, goats and sheep to graze in nearby forest areas. Grazing causes forest degradation as young seedlings and saplings are grazed or trampled. Grazing animals are reported to have little economic value with communities often eager to switch to stall feeding and higher quality livestock.

3.3.7. Agricultural Expansion

Communities or clans own most of the forests in the project area. However, when community and clan forests are privatized they are often permanently cleared for agriculture. Forest clearance is also practiced for extensive and shifting agriculture (*jhum*) on steep slopes.

Agricultural expansion is taking place in several Hima in the southern part of the project area where businessmen are providing loans to families to clear forests and plant broom grass for markets in other parts of India. Slowing and halting this process will require consultations with farmers involved in this activity to discuss alternative agricultural and other economic activities which could be supported both through the project as well as under Government of India schemes and projects.

3.4. Legal Status and Community Rights

There are no legally designated or protected conservation areas within, overlapping or adjacent to the project area. Communities own their land through a legally recognised land-tenure system. In this system, *Dorbars* are the administrative heads of territorial units, and decisions regarding community land are made by consensus by male community members over 21 years of age.

4. PROJECT ACTIVITIES

REDD+ and ANR are the Plan Vivo project interventions covered in this technical specification. REDD+ is the protection of dense or open forest threatened by deforestation and forest degradation. ANR is the protection, management, and regeneration of open forest.
In addition to REDD+ and ANR interventions, other income-generating activities (IGAs) are designed to improve local livelihoods. IGAs have been designed by the communities and are facilitated by the project team.

4.1. Reducing Emissions from Deforestation & Degradation (REDD+)

REDD+ intervention addresses the key drivers of deforestation and forest degradation in the project area. It consists of the following activities: 1) forest fire control, 2) sustainable firewood plantations, 3) reducing uncontrolled grazing and 4) agricultural containment.

4.1.1. Forest Fire Control

Damage from forest fires will be reduced through fire prevention and early fire detection. Activities to control forest fires include:

- Creating firebreaks around forests
- Appointing firewatchers to detect and extinguish fires in the dry season
- Community fire awareness programmes to improve fire safety

4.1.2. Sustainable Firewood

Sustainable firewood plantations will be established close to settlements and firewood gathering will be organized around a rotational system of harvesting with guidelines for fuel collection during years 1 to 5 as the fuelwood plantations grow and mature. Fuelwood collection areas are associated with specific villages, so that there is limited likelihood of displacement or leakage from other communities outside the project area. With the project, fuelwood access is more regulated based on emerging NRM plans. Where possible, fast growing woodlots comprised of native coppicing species such as Himalayan alder (*Alnus nepalensis*), will be grown on vacant community land.

Project woodlots will take 4-5 years before annual harvesting of coppice shoots takes place. Of the 15,000 ha of forest in the project area, woodlot plantations will likely cover approximately 300 ha (5 ha for each village), depending on funding availability. According to the phytomass files (Duke, 1981b), annual productivity of other *Alnus* species ranges from 5 to 26 Mt/ha. Used for nitrogen fixation and slope stabilization alder is also used for firewood and might be considered for the generation of electricity. Heat content of *Alnus rubra* is about 4,600 kcal/kg. This temperate species may yield 10–21 m3/ha/yr. The wood dries rapidly and burns evenly (Little, 1983 and Duke, J.A. 1981b), (Little, E.L. Jr 1983).

4.1.3. Reduce Uncontrolled Grazing

Through animal exchange programs, communities will be encouraged to replace cattle with stall-fed livestock such as pigs and broiler chickens. The Mawphlang Pilot Project demonstrated that participating families were able to transition from open forest grazing with low value goats and cows to stall fed pigs, reducing pressure on the forests while generating additional income from pig sales.

4.1.4. Sustainable Farming Systems

The project will support the adoption of sustainable agricultural practices. Sustainable agriculture refers to farming systems that are likely to be practiced for extended periods without damage to forests and soils. This would include organic vegetable cultivation and orchards, stall fed livestock, and aquaculture. Unsustainable systems such as broom grass, pineapples requiring the clearing of vegetation on steep slopes, and valley bottom potatoes requiring high use of chemical fertilizers and pesticides will be phased out where possible. The project is building partnerships with the Indian Council for Agricultural Research that provides training and materials for exploring new agricultural practices. Project funded micro-finance groups provide capital for small farmers to adopt sustainable farming practices.

4.1.5. Alternatives to Charcoal Making

Charcoal making is concentrated in two of the 10 Project Hima. In those areas, meetings are being planned with charcoal-making households to identify alternative livelihood activities including pig and poultry raising. Funds will be allocated to provide support to these families to help them transition their household economy.

The core project strategy begins with a community dialogue followed by an agreement on the part of all member households to attempt to reduce the impact of drivers of deforestation activities and build mitigation activities into their NRM plan (Plan Vivo). As mentioned above this approach has been implemented with considerable success in two villages in the project area from 2005 to 2009. The project has a successful approach to replacing low value cows and goats with stall fed chicken and pigs (see PDD) reducing grazing pressures.

Fire control efforts of the community were very successful through 5 fire seasons. Agricultural expansion is most threatening where forests are cleared for cash crops, especially broom grass. Areas where this is occurring have been identified and targeted discussions with practitioners are planned to find more sustainable crops outside the forests. Reducing charcoal making will again target the charcoal making households to help them find alternatives. Involving female members in micro-finance self-help groups and providing technical training and low interest loans to establish piggeries and poultry operations.

4.2. Assisted Natural Regeneration (ANR)

ANR activities will take place in open forest. There are two ANR phases. The initial phase of “advanced closure” involves “closing” the area to fire, grazing, and firewood collection. The second “ANR treatment” phase involves weeding, thinning, and enrichment plating. No exotic species will be used in the ANR areas. Some limited gap filling and enrichment planting will take place using native Khasi pine saplings (*Pinus khasiana*) as well as oak (*Quercus griffithi*), chestnut (*Castanopsis purpurella*) and myrica (*Myrica esculenta*).

A long term goal of the project is to improve the soil fertility, soil moisture, biomass, and species diversity of the open forests through ANR treatment. Past experience from the Mawphlang pilot project (2005-2009) indicated that with protection through advanced closure, forest regrowth was quite rapid. Open forests tend to be dominated by pioneering Khasi pine seedlings that grow quickly in many sites once grazing, hacking and fire pressures are removed. Over time, a growing number of native broadleaved and evergreen species of shrubs and trees emerge creating more diverse forest ecology. In sites, with no seed sources, enrichment planting of native oaks and chestnuts will be encouraged to facilitate this process.

ANR advance closure will be implemented in 50% of the open forest in the first implementation phase (2012-2016), expanding to 75% of the area in the second implementation phase (2017-2021) (see Table 3).

Table 3: ANR Area

ANR TREATMENT TYPE	IMPLEMENTATION PHASE 1 2012-2016 (Ha)	IMPLEMENTATION PHASE 2 2017-2021 (Ha)	TOTAL 2012-2021 (Ha)
ANR advance closure	1,500	1,000	2,500
ANR treatment	500	500	1,000
Total ANR area	1,500	1,000	2,500

5. PROJECT PERIOD

The initial project phase is 5 years. At the end of this phase (2016) and following verification, the project was extended and the baseline and technical specifications duly updated.

The total project period is 30 years. For the carbon benefit calculation, the project period is divided into five-year crediting periods.

5.1. Project Timeline

From 2005 to 2009, CFI organized REDD+ and IGA pilot activities in two communities in Mawphlang (Appendix 1). Following the success of the Mawphlang pilot project, the design process for the Khasi Hills REDD+ project took place in 2010-2011. In 2011-2012, early REDD+ activities including institution building, awareness campaigns, field activity development, and the design of monitoring systems began. The first implementation phase of the project took place from 2012 to 2016. At the end of the first implementation phase, the Technical Specifications were revised and the expected climate benefits have been updated prior to the second implementation phase of the project from 2017 to 2021.

6. CARBON POOLS

Above- and below-ground tree biomass are the carbon pool used to calculate carbon benefits for both REDD+ and ANR (see Table 4). Other carbon pools are omitted for three reasons: simplicity, cost of measurement and conservativeness.

Including only tree biomass leads to simple and less resource- intensive monitoring, measurement, and analysis. The resulting carbon benefit estimate is also conservative as the storage and sequestration in soil and, deadwood and litter, are not being claimed as credits by the Project. Consequently this represents a buffer that may help reduce project risk.

Explanations for carbon pool selection are:

- Above- and below-ground tree biomass comprise the main carbon pools - these are included
- Biomass stored in leaf litter and dead wood will increase as a result of tree-planting activities, but is unlikely to be a large proportion of the total carbon and is therefore

excluded

- Non-tree vegetation is unlikely to be a large proportion of the total carbon stock and is excluded
- Soil carbon is expected to increase but the cost of measuring it is high, so it is excluded
- Dead wood is likely to increase during forest conservation, but this is not included to allow a conservative estimate of carbon benefit

Table 4: Carbon Pools

CARBON POOL	LIKELY IMPACT ON CARBON STOCK	MEASUREMENT LIMITATIONS	DECISION
Above-ground woody biomass	Increase	Minimal	Include
Below-ground woody biomass	Increase	Minimal	Include
Non-tree biomass	Small increase	Time-consuming	Exclude
Dead wood	Increase	Minimal	Exclude
Leaf litter	Small increase	Time-consuming	Exclude
Soil	Increase	Expensive	Exclude

7. BASELINE SCENARIOS

7.1. Initial Carbon Stocks

Initial carbon stocks in the project area were determined by carrying out a biomass survey and a satellite image analysis (see Table 5).

Table 5: Carbon Stock in 2010

LAND USE	AREA (Ha)	TOTAL CARBON STOCK (tC)	TOTAL CARBON STOCK (tCO_2e)
Dense forest	9,270	878,193	3,220,042
Open forest	5,947	71,761	263,123
Non-forest	11,921	0	0
Total	27,139	949,954	3,483,165

Source: Biomass Survey (see Appendix 2)

Biomass Survey

The project team carried out a biomass survey of 21 plots in dense forest and 19 plots in open forest (Appendix 2) in 2010 to assess initial carbon stock. Dense and open forest areas were identified on a land cover stratification map based on remote sensing data from the Forest Survey of India (2004), contour maps and path network maps. Most of the forestland is relatively inaccessible, far from roads or tracks or on steep slopes and plateaus cut by gullies and cliffs. For this reason, sample plots were selected randomly along transects that follow the existing local path network running east- west and north-south. Dense forest plots were 10 square meters (0.02 ha), and open forest plots were 20 square meters (0.04 ha). In each plot, the tree species and diameter at breast height (DBH) were recorded as well as top heights of three trees at the lower, middle, and upper canopy (Table 6).

To calculate biomass from sample plot measurements for dense forest plots, species-specific volume equations (FSI 1996; Table 7) were used to estimate stem volume of individual trees. The Forest Survey of India – based on measurements of the tree dimensions during past fellings of thousands of trees over two decades – developed these equations. If species-specific equations were not available a generic equation for north-east Indian tree species was used. Stem volume was converted to stem biomass by multiplying the volume estimate by species-specific wood density values for trees in India from the Global Wood Density Database (Zanne 2009). If species-specific wood density values were not available a values of 0.652 g/cm3 was applied, which is the average of all Indian species in the Global Wood Density Database.

A biomass expansion factor (BEF) was then applied to convert stem biomass estimates to estimates of whole tree biomass was applied. Biomass expansion factors recommended by Brown (1997) were applied:

- When inventoried biomass was >190 t/ha a BEF of 1.74 was applied;
- When inventories biomass as <190t/ha a BEF = EXP(3.213-0.506*LN(BV)), was applied where BV=inventoried volume;
- For plots dominated by pines a BEF of 1.3 was applied.

Below-ground biomass was estimated by assuming a root:shoot ratio of 0.15 for all species. FSI (1996) reports a range of root-shoot ratios, with values up to 0.32. Other studies in Punjab (e.g. Rawat et al. 2015) report lower values however, ranging from 0.15 to 0.19 depending on tree age. To avoid overestimating below ground biomass, the most conservative value from the literature was selected.
Since there is some uncertainty in estimated biomass from tree inventories, related to the variation in biomass between sample plots in the same forest type, the lower 90% confidence interval of mean values was adopted to estimate biomass for each forest type. Estimated biomass was therefore 12.1 tC/ha for open forest and 94.7 tC/ha for dense forest. It was assumed that carbon stock for barren or fallow land and agricultural land was zero. Inventories of sample plots will be taken again at the end of the initial 5-year phase in 2016.

Table 6: Biomass Survey Values.

Open Forest		Dense Forest	
Plot No.	tC/ha	Plot No.	tC/ha
3	16.9	1	170.5
6	3.3	2	97.1
7	10.3	4	86.7
8	6.3	5	57.9
12	19.5	9	160.2
13	8.5	10	108.9
15	28.4	11	100.1
16	54.1	14	144.8
17	44.3	21	87.4
18	12.7	22	151.7
19	8.9	24	125.9
20	5.9	25	21.1
23	8.2	28	75.8
26	24.8	29	140.2
27	35.0	30	209.9
31	10.5	33	63.0
36	11.9	34	119.8

39	22.2	35	53.8
40	4.4	37	213.2
		32	63.5
		38	142.3
Mean	**17.7**	**17.6**	**114.0**
90% CI	**5.6**	**5.3**	**19.3**

Source: Biomass Survey (see Appendix 2)

Table 7: Local volume equations for different species for Meghalaya state.

SPECIES	VOLUME EQUATION *	NOTE
Castanopsis hystix	$V=0.13937-0.35988\sqrt{D}+6.81318D^2$	
Castanopsis indica	$\sqrt{V}=0.22234+4.90695D+1.5124\sqrt{D}$	
Engelhardtia spicata	$Log_eV=2.47635+2.51046\ Log_eD$	
*Pinus kesiya***	$V=0.0232-0.011613D+0.0011549D^2$	(diameter in cm)
Quercus fenestrata	$V/D^2=0.000295/D^2-0.0079835/D+0.00086$	(diameter in cm)
Quercus glauca	V/D2=0.000295/D2-0.0079835/D+0.00086	(diameter in cm)
Quercus griffithii	$V/D^2=0.000295/D^2-0.0079835/D+0.00086$	(diameter in cm)
Rhododendron arboreum	$V=0.08934+0.70730D+2.13941D^2$	
Schima wallichii	$V=0.27609-3.68443D+15.866870D^2$	
Symplocus theaefolia	$V=0.03754+0.000587D^2$	(diameter in cm)
Others	$V=0.11079-1.81103D+11.4132D^2+0.38528D^3$	

Source: FSI 1996. Note: Equations selected were those derived from measurements of trees in closest proximity to the project site.

*** V=Volume in m^3; D = Diameter in m (unless specified otherwise)**

**** If the dbh of the pine trees are <10 cm, the generic volume equation was applied, as the species specific equation was not intended for use on trees <10 cm diameter.**

7.2. REDD+

A SPOT satellite image analysis was carried out to determine the land-use types and areas present in 2006 and 2010 (Table 8) as well as the recent rates of forest degradation and deforestation (Table 9). See Appendix 3 for a detailed description of the satellite image analysis.

Table 8: Land Use and Land Cover in 2006 and 2010.

LAND USE	2006 (Ha)	2010 (Ha)
Dense forest	10,446	9,270
Open forest	5,908	5,947
Barren or fallow	5,794	6,330
Agriculture	3,179	4,777
Other (shadow/water/no data)[1]	1,812	814
Total Area	**27,139**	**27,139**

Source: Satellite Image Analysis (see Appendix 3)

From 2006 to 2010, dense forest changed to non-forest land at a rate of 2.7% per year; dense forest changed to open forest at a rate of 4.5% per year; and open forest changed to non-forest at a rate of 6.4% per year (Table 9).

Table 9: Forest Degradation and Deforestation from 2006 to 2010.

LAND USE CHANGE (2006 TO 2010)	AREA (HA)	CHANGE PER YEAR
Dense forest changed to non-forest	1,136	2.7%
Dense forest changed to open forest	1,860	4.5%
Open forest changed to non-forest	1,510	6.4%

Source: Satellite Image Analysis (see Appendix 3)

For the REDD+ baseline scenario we assume recent rates of deforestation and degradation would continue over the next ten years in the absence of project activities, resulting in 1,845 ha of dense forest being changed to non-forest; 3,700 ha of open forest changed to non-forest; and 3,021 ha of dense forest being changed to open forest in the project area. This results in 1,720,050 tCO_2 emissions (Table 10).

Table 10: REDD+ Baseline

Year	Dense forest changed to non-forest (ha)	Open forest changed to non-forest (ha)	Dense forest changed to open forest (ha)	C stock change from conversion of dense forest to non-forest (tC)	C stock change from conversion of open forest to non-forest (tC)	C stock change from conversion of dense forest to open forest (tC)	Total C stock change (tC)	Total emissions (tCO_2)*
2012	252	380	413	23,875	4,585	34119	62,578	229,453
2013	234	382	383	22,163	4,610	31672	58,445	214,298
2014	217	382	356	20,574	4,611	29401	54,585	200,146
2015	202	380	330	19,098	4,590	27293	50,981	186,931
2016	187	377	306	17,729	4,552	25335	47,616	174,592
2017	174	373	284	16,458	4,497	23519	44,473	163,069
2018	161	367	264	15,277	4,429	21832	41,539	152,309
2019	150	360	245	14,182	4,350	20267	38,798	142,260
2020	139	353	228	13,165	4,261	18813	36,239	132,877
2021	129	345	211	12,221	4,164	17464	33,849	124,114
Total	**1,845**	**3,700**	**3,021**	**174,742**	**44,648**	**249,715**	**469,104**	**1,720,050**

Source: See tables 5 and 9.

*** Assuming all reductions in C stock result in instantaneous emission of CO_2**

7.3. Assisted Natural Regeneration (ANR)

ANR activities will be implemented in open forest areas. In the absence of project activities, it is assumed that open forests would continue to degrade due to periodic forest fires, unsustainable fuelwood extraction, agricultural expansion and grazing, gradually loosing biomass, rootstock, and top soil. Typically, under the without project scenario, new shoots are hacked for firewood, seedlings are trampled by cattle and goats, and ground fires retard or destroy seedlings and saplings. This pattern has been observed throughout the project area leading up to the initiation of the project. Carbon stocks in open forest are therefore expected to decline in absence of project interventions, but the rate of decline is not known. We therefore adopt the conservative assumption that carbon stocks in open forests would remain constant at 12.1 tC/ha in the absence of project interventions.

8. PROJECT SCENARIO

8.1. REDD+

There are two initial implementation phases. In the first implementation phase (2012-2016), activities were started, and in the second implementation phase (2017-2021), activities will be intensified in terms of participation.

At the start of the project it was estimated that the overall rate of deforestation and forest degradation without the project would be reduced by 33% at the start of the first implementation phase, increasing to 57% by the end of the second implementation phase (see Table 11 and Appendix 4). Under the original REDD+ Project scenario, emissions would be 971,548 tCO_2e over 10 years (see Table 12). The estimated 33% decrease at the start of the first five years was based on impacts achieved between 2005 and 2010 in the original pilot project area where ground fires were dramatically reduced, as were grazing and fuelwood collection pressures. The expected effectiveness of community mitigation measures was due to the consensus decision taken by the indigenous government (Hima Mawphlang) and the participating village durbar meetings and discussions. This REDD+ project has adopted the same approach and is being developed at the request of 10 neighboring indigenous governments that have seen the results of the pilot activities.

Table 11: Original REDD+ Project Scenario (2010).

Year	Reduction in deforestation and degradation %	Dense forest changed to non-forest (ha)	Open forest changed to non-forest (ha)	Dense forest changed to open forest (ha)	C stock change (dense forest to non-forest) (tC)	C stock change (open forest to non-forest) (tC)	C stock change (dense forest to open forest) (tC)	Total C stock change (t C)	Total emissions (t CO_2)*
2012	33%	169	255	277	15,996	3,072	22,859	41,927	153,734
2013	36%	150	245	245	14,184	2,950	20,270	37,405	137,151
2014	38%	135	237	221	12,756	2,859	18,229	33,843	124,091
2015	41%	119	224	195	11,268	2,708	16,103	30,079	110,290
2016	44%	105	211	172	9,928	2,549	14,188	26,665	97,771
2017	46%	94	201	154	8,887	2,428	12,700	24,016	88,057
2018	49%	82	187	135	7,791	2,259	11,134	21,185	77,677
2019	52%	72	173	118	6,807	2,088	9,728	18,623	68,285
2020	54%	64	162	105	6,056	1,960	8,654	16,670	61,123
2021	57%	55	148	91	5,255	1,791	7,510	14,555	53,369
Total		**1,044**	**2,044**	**1,710**	**98,929**	**24,664**	**141,375**	**264,968**	**971,548**

Source: Appendix 4, Tables 5 and 10.

*** Assuming all reductions in C stock result in instantaneous emission of CO_2**

At the end of the first implementation phase, in 2016, analysis of remote sensing data was carried out to describe the change in land cover that occurred in the period from 2010 to 2016 (see Appendix 6). The estimated effectiveness of the project was revised for the second implementation period (2017 to 2021). The results suggest that, relative to the baseline scenario, project activities in the first project implementation period reduced deforestation of dense forest by 20.2%, reduced deforestation of open forest by 28.5% and reduced degradation of dense forest to open forest by 35.0% (see table 12).

Table 12: Forest Degradation and Deforestation from 2010 to 2016.

LAND USE CHANGE (2010 TO 2016)	TOTAL AREA (Ha)	ANNUAL AREA (Ha)	CHANGE PER YEAR	EFFECTIVENESS RELATIVE TO BASELINE
Dense forest changed to non-forest	1,328	221.4	2.2%	20.2%
Dense forest changed to open forest	1,770	295.1	2.9%	35.0%
Open forest changed to non-forest	1,029	171.4	4.6%	28.5%

Source: Satellite Image Analysis (see Appendix 6), and Table 9.

For the revised REDD+ project scenario, for the second project implementation period (2017 to 2021), it is assumed that the project activities will result in the same level of effectiveness achieved during period from 2010 to 2016 (see Table 12). This is expected to provide a conservative estimate of project effectiveness for two reasons. Firstly because the estimated effectiveness from 2010 to 2016 includes two years during which project activities were not fully operational, and secondly because this does not factor in the expected increase in effectiveness as the project progresses that was included in the original project scenario.

The revised estimate of emission reductions from REDD+ achieved during the first phase of the project, and expected during the second phase of the project, are summarized in Table 13. The revised project scenario has higher total emissions than expected with the effectiveness assumed in the original project scenario.

Table 13: Revised REDD+ Project Scenario (2016)

Year	Dense forest changed to non-forest (ha)	Open forest changed to non-forest (ha)	Dense forest changed to open forest (ha)	C stock change (dense forest to non-forest) (tC)	C stock change (open forest to non-forest) (tC)	C stock change (dense forest to open forest) (tC)	Total C stock change (t C)	Total emissions (tCO_2)*
2012	252	380	413	23,875	4,585	34,119	62,578	229,453
2013	187	273	249	17,697	3,294	20,580	41,571	152,426
2014	173	273	231	16,428	3,294	19,105	38,827	142,364
2015	161	272	215	15,250	3,280	17,735	36,264	132,968
2016	149	270	199	14,156	3,252	16,463	33,871	124,194
2017	139	266	185	13,141	3,213	15,282	31,637	116,001
2018	129	262	172	12,199	3,165	14,186	29,550	108,349
2019	120	258	159	11,324	3,108	13,169	27,601	101,204
2020	111	252	148	10,512	3,044	12,225	25,781	94,531
2021	103	247	137	9,758	2,975	11,348	24,082	88,299
Total	**1,524**	**2,752**	**2,107**	**144,340**	**33,210**	**174,212**	**351,761**	**1,289,791**

8.2. Assisted Natural Regeneration (ANR)

Assisted natural regeneration (ANR) will take place in open forest. ANR activities begin with “advance closure” to protect the area from fire and grazing and to allow the trees to regenerate. Following advance closure, some areas also receive “ANR treatment” which is weeding, thinning and enrichment planting.

All ANR activities have the same initial advance closure stage and therefore the same carbon benefit. Based on our observation of rapid forest regeneration in the Mawphlang project (Appendix 1), we assume that open forests can regenerate into dense forest in 30 years. Assuming open forests can regenerate into dense forests in 30 years, the average annual carbon sequestered would be approximately 1.95 tC/ha/yr; however, we make the conservative assumption that open forest with ANR will sequester carbon at a rate of 1 tC/ha/yr for the first 10 years and a rate of 1.5 tC/ha/yr for the following 20 years.

The ANR sequestration rates estimated for the project compare well with findings from studies of similar open pine forests. Open pine forests can sequester carbon at a rate between 1.07 and 1.6 tC/ha/yr (Table 14). The related studies from central Nepal are based on degraded Chir pine forests that are very similar to the khasi pine (*Pinus khasiana*) that dominates the open forest landscape in the project area. Further, elevation is similar, though rainfall in the project area is considerably higher than western Nepal, suggesting that growth in the project area may be more rapid.

Table 14: Carbon Sequestration in Open Pine Forests

REFERENCE	OPEN PINE FOREST (tC/Ha/Yr)
Shrestha, R. (2010)	(1.6 pine + 1.37 poor condition)/2 = 1.5
Baral et al, (2009)	1.35 (pine)
Jina et al, (2008)	1.07 to 1.27 (degraded pine)

Between 2013 and 2016 the project worked with communities to bring 1,500 hectares under ANR with plans to bring an additional 1,000 hectares under ANR between 2017 and 2021. The climate benefits from ANR achieved during the first phase of the project, and expected during the second phase, are summarized in Table 15.

Table 15: Estimated Carbon uptake achieved during Phase 1 and expected during Phase 2.

Year	Area Planted (Ha)	Cumulative Area Planted (Ha)	Carbon Uptake (tC)	Emissions Reductions (tCO_2)
2012	0	0	0	0
2013	0	0	0	0
2014	500	500	500	1,833
2015	500	1,000	1,000	3,667
2016	500	1,500	1,500	5,500
2017	200	1,700	1,700	6,233
2018	200	1,900	1,900	6,967
2019	200	2,100	2,100	7,700
2020	200	2,300	2,300	8,433
2021	200	2,500	2,500	9,167
Total			**13,500**	**49,500**

8.3. Leakage

For each risk of leakage, the project includes leakage mitigation measures for both REDD+ and ANR (See Table 16). With leakage mitigation measures in place, activities causing emissions are unlikely to be displaced outside the project area. Therefore, we assume the risk of leakage risk to be low and have applied a 5% leakage deduction to the overall benefit calculations for both REDD+ and ANR.

Table 16: Leakage Mitigation Measures

Drivers of Mitigation	Activity	Mitigation Measures
Firewood Collection	REDD+, ANR	Village Natural Resource Management Plans (VNRMPs) will be designed to ensure that firewood requirements are met from community land. VNRMPs will include the establishment of plantations close to villages to supply firewood. This wood will be harvested sustainably using rotational harvesting systems.
Charcoal making	REDD+	Charcoal-making is a driver of deforestation and forest degradation in one of the nine Himas in the project area, Nonglwai Hima. Charcoal making and its purchase by industries are illegal in Meghalaya. Assistance from administrative authorities will be obtained to help to check illicit movement of charcoal to ferro-alloy factories in and around the project area.
Agricultural expansion	REDD+, ANR	The project will introduce sustainable agricultural practices to replace unsustainable swidden farming. This will lead to agricultural containment in the project area, and agricultural expansion will not be displaced outside the project area.
Grazing in forest	REDD+, ANR	Cattle and goats will be exchanged for stall-fed livestock through an animal exchange program. This will reduce grazing in the project area and will not increase the risk of grazing outside the project area.

8.4. Sustainability

REDD+ and ANR activities are designed to be sustainable and to supply benefits after the project period. Firstly, the project team is working to reduce financial, management, and technical risks. Secondly, political, social, land ownership, and opportunity cost risks will be addressed. Thirdly, the risks of fire will be minimized. Please see appendix 5 for a detailed analysis. The risk table attempts to quantify the risk for a range of risk factors including socio-political, institutional, financial, and natural events.

The formula is based on giving a score to the likelihood the risk factor will occur (.05 = unlikely, and .1 = likely) multiplied times the severity of potential impact to the project (1= low, 2= medium and 3= high). This provides a composite score that would suggest a buffer of 20%. Overall the project is comparatively low risk in the South Asia context due to very strong tenure security, active and democratic indigenous governments, high literacy in the project communities, and a strong local commitment to restoring forests in the watershed.

8.4.1. Risk Buffer

The risk buffer is a proportion of carbon benefits that are not sold. It is based on the risk of non-sustainability of the project. We estimate that a 20% risk buffer is appropriate for project activities where Plan Vivo certificates are sold ex-post and in accordance with the Plan Vivo guideline for REDD+ projects. The project design relies on a conservative estimate of carbon stocks and benefits in order to reduce the risks of over-estimating carbon credits generated by the project. Potential carbon offsets from below ground biomass, litter and deadwood are also not included and can be viewed as an additional risk buffer.

9. CARBON BENEFITS

9.1. REDD+

Over 10 years, the expected REDD+ net benefit expected is 408,745 tCO_2 (See Table 17).

Table 17: REDD+ Emissions Reductions

Year	Baseline scenario emissions (tCO_2)	Project scenario emissions (tCO_2)	Leakage (tCO_2)	Emissions Reductions (tCO_2)
2012	229,453	229,453	0	0
2013	214,298	152,426	3,094	58,778
2014	200,146	142,364	2,889	54,893
2015	186,931	132,968	2,698	51,265
2016	174,592	124,194	2,520	47,878
2017	163,069	116,001	2,353	44,715
2018	152,309	108,349	2,198	41,761
2019	142,260	101,204	2,053	39,004
2020	132,877	94,531	1,917	36,429
2021	124,114	88,299	1,791	34,024
Total	**1,720,050**	**1,289,791**	**21,513**	**408,745**

9.2. Assisted Natural Regeneration (ANR)

Over 10 years, the expected ANR benefit is 47,025 tCO_2e (see Table 18).

Table 18: ANR Emissions Reductions

Year	Baseline scenario emissions (tCO_2)	Project scenario emissions (tCO_2)	Leakage (tCO_2)	Emissions Reductions (tCO_2)
2012	0	0	0	0
2013	0	0	0	0
2014	0	-1,833	92	1,742
2015	0	-3,667	183	3,483
2016	0	-5,500	275	5,225
2017	0	-6,233	312	5,922
2018	0	-6,967	348	6,618
2019	0	-7,700	385	7,315
2020	0	-8,433	422	8,012
2021	0	-9,167	458	8,708
Total	**0**	**-49,500**	**2,475**	**47,025**

9.3. Total Benefits

Table 19 below shows the projected carbon benefits for the first ten years of the project that are estimated to result from all planned Project activities. These estimates have been reviewed in 2016 during the first 5-year verification.

Table 19 shows the annual Project benefit from both REDD+ and ANR over the whole 10-year period. The final column shows the total benefits (per year) with a 20% risk buffer subtracted. The table also reflects the additional 500 ha treated under ANR each year beginning in 2014 with an average sequestration rate of 1tC per ha per year.

Table 19: Total project carbon benefits

Year	Net REDD+ benefit (tCO_2)	Net ANR benefit (tCO_2)	Overall project benefit (tCO_2)	20% Buffer (tCO_2)	Net Total (minus buffer) (tCO_2)
2012	0	0	0	0	0
2013	58,778	0	58,778	11,756	47,022
2014	54,893	1,742	56,634	11,327	45,307
2015	51,265	3,483	54,748	10,950	43,799
2016	47,878	5,225	53,103	10,621	42,482
2017	44,715	5,922	50,636	10,127	40,509
2018	41,761	6,618	48,380	9,676	38,704
2019	39,004	7,315	46,319	9,264	37,055
2020	36,429	8,012	44,440	8,888	35,552
2021	34,024	8,708	42,732	8,546	34,186
Total	**408,745**	**47,025**	**455,770**	**91,154**	**364,616**

10. MONITORING PLAN

The Project has developed a comprehensive monitoring plan based on the requirements of the Plan Vivo Standard (2013). This plan will enable the Project to monitor performance (assessed by achievement of annual targets and five year goals), validate assumptions used for calculating the carbon benefits and ensure community involvement. The monitoring plan also includes monitoring of indictors to assess the effectiveness of Project activities to mitigate the key drivers of deforestation and forest degradation and of indicators to assess the socio-economic impacts and environmental impacts of the Project to ensure that these aspects of the Plan Vivo Standard are met. The monitoring Plan is summarized in the following three tables including Table 20: Ecosystems Service Benefit Indicators, Table 21: Socio-Economic Monitoring Indicators, and Table 22: Environmental and Biodiversity Monitoring Indicators.

Baselines were established at the start of the Project in 2011 covering (a) forest cover (b) carbon stock and (c) socio-economic indicators. As a REDD+ project, annual monitoring (and reporting) is largely based on monitoring of activities supported by the project with impact monitoring taking place every 5 years and with the resulting information being used to revise this technical specification.

Indicators measured and recorded annually (see Tables 20, 21, 22 below) will be submitted in the Project Annual Reports submitted to Plan Vivo. Results from five-year indicators will be used during preparation of project verification reports.

10.1. REDD+ Monitoring

The primary methodology used to monitor changes in forest cover is an analysis of a time series of satellite images of the project area. For the baseline, SPOT images from 2006 and 2010 were used to determine that the rate of deforestation was 2.7% per annum. For forest areas that have moved from the dense forest category (40% canopy closure or more) to non-forest, the rate of degradation was 0.1%. For forest areas that have moved from the dense forest category to open forest (10 to 40% canopy closure). Actual changes in forest cover were determined at the end of 2016 through the analysis of satellite image done in 2017 and will be reassessed every 5 years (i.e. 2021, 2026, 2031, etc.).

Data from a biomass survey of sample plots and photo monitoring is used to assess the actual carbon stock. The annual biomass survey includes 20 permanent sample plots that were surveyed for the baseline in April 2011 and will be used for the long term monitoring of carbon stock changes in the dense forests that comprise the REDD+ project area. This method allows an annual assessment of changes in carbon stock for dense forests to be made.

It is estimated that the rate of forest loss will gradually be reduced over the project period from an initial 33% reduction in the deforestation/degradation rate to a 57% reduction after the end of the initial two 5-year phases compared with the baseline (without project) scenario. By 2025, it is projected that forest cover will stabilize and begin to expand as open forests recover. As actual rates are monitored, the estimated project benefits will be recalculated and technical specifications revised accordingly.

The Federation has identified on current SPOT images 'hot spots' where dense forest loss is occurring and is meeting with local communities to discuss how to reduce forest loss. Specific drivers are associated with certain 'hot spots' and special attention will be given to monitoring forest clearing for broom grass cultivation as well as charcoal making with discussions with households participating in these activities to find alternative income generating activities. Each Local Working Committee will report annually on forest losses due to specific drivers of deforestation such as broom grass cultivation, charcoal making and others.

In addition to the analysis of remotely sensed data to monitor forest cover, the Project will conduct annual field-level inventories of 60 forest plots to assess changes in biomass and carbon stock. The measurements are conducted at the end of each calendar year. The forest plot sample includes 20 dense forest plots (10m x 10m), 20 open forest plots (20m x 20m), and 20 plots under Assisted Natural Regeneration (ANR) (20m x 20m). The data is collected in November each year and analyzed to assess changes in biomass. The plot locations are marked with paint and identified using GPS coordinates. This will include both the dense forest plots and the open forest/ANR plots. Resources required for monitoring include a forestry professional guide, the community facilitator team that works for the Federation, and members of the LWC who are trained in forest inventory techniques. Equipment includes plot and tree measuring tapes, clipboards and data collection forms, cameras, GPS units, plot lines, and paint. The data will be analyzed by the Federation and the project's REDD+ Technical Support Unit (RTSU) using and EXCEL and ACCESS data base system.

Annually, at the end of the rainy season, monitoring photo will be taken from a known fixed point in the plot. The project has established these photo monitoring positions throughout the project area. Photos will be taken and compared with the previous photo to assess changes in forest structure and rate of regrowth. Since the longitudinal methods described above require a minimum of 5 years elapsed project time to reveal meaningful changes in forest cover or stocking levels, the project also monitors ongoing activity and event indicators to capture the impact of community mitigation measures. In designing the project strategy community leaders and members identified a number of drivers of deforestation and mitigation measures including: controlling forest fires, closing forests to grazing, closing some forests to fuelwood collection while they regenerate, limiting the conversion of forest lands to quarries and for agriculture, and reducing charcoal making.

Table 20: Ecosystem Service Benefit Indicators

Activity	Activity Indicator (measure annually)	Annual Targets		
		Full Target Achievement	Partial Target Achievement	Missed Target
Fire Control	Number of Hectares Burned during Dry Season by Hima	< 50 ha	51-100	> 100 ha
	Length of fire lines constructed by Hima	> 60 km	40-59 km	< 40 km
Forest Restoration	Number of Hectares with ANR Advance Closure Treatment	> 200 ha	100-200 ha	< 100 ha
	Number of hectares with ANR Silvicultural Treatment	> 50 ha	25-49 ha	< 25 ha
Impact (after 5 years)	**Impact Indicator**	**Means of assessment**	**Baseline (2016)**	**Target (2021)**
Forest Condition	Average C-stock in dense forest monitoring plots	Plot measurements	157 tC/ha	200 tC/ha (equivalent to C-stock annual increment of c.8 t/C/ha)
	Average C-stock in open forest monitoring plots	Plot measurements	26 tC/ha	34 tC/ha
Fire damage	Area burnt by wildfires during year	GIS data & project records	64 ha	32 ha

Annually, the activities contributing to REDD+ will be monitored (see Table 20 above). These indicate that the planned REDD+ activities have taken place. Community facilitators (CFs) from each of the 18 micro-watersheds are responsible for collecting this data and reporting the findings to the monitoring officer. The annual monitoring indicator report provides information on changes in carbon stock in the monitoring plots the total area burned by forest fire, and the length of fire lines created to protect forests. This in turn provides an overview of community capacity to limit forest loss and carbon emissions. Annual reporting to the Plan Vivo Foundation will include monitoring results from biomass surveys and photo monitoring for certificate issuance as well as annual activity reports.

10.2. ANR Monitoring

To monitor regeneration in ANR areas, biomass surveys will be carried out annually. At least one plot will be measured and photographed in each ANR area. At least ANR 20 20x20m plots will be established for monitoring purposes over the first three years of the project to assess changes in carbon stock in areas that are being protected by the community through social fencing. In addition, another 20 plots of open forest will be monitored to maintain a baseline. The project also reports on any additional degraded forests that have been placed under "advanced closure" by communities and the area receiving silvicultural forest restoration treatment. Every five years, ANR areas will also be monitored using satellite image analysis as for REDD+. To detect forest regeneration or a lack of change in ANR areas, the perimeters of ANR areas will be marked on maps and satellite images using GPS data

10.3. Environmental & Biodiversity Indicators

The project seeks to address the heavy reliance of project communities on fuelwood by reducing consumption and shifting project families to LPG cooktops. This will take pressure off local forests while improving health conditions within the homes by reduced smoke pollution. Table 21 presents annual indicators to be used to assess project impact. In addition, the project is working with local governments (hima and durbar) to encourage the reduction of area under open pit mining operations. The project will monitor the total area currently being mined in each village to assess how this environmental awareness program is progressing. Finally, the project team will collect data on the observation of key indicator species that are threatened or endangered. Siting data gathered by youth volunteers and community facilitators will be analyzed at the end of each year and included in the annual report to Plan Vivo.

Table 21: Environmental & Biodiversity Indicators

Activity	Activity Indicator (measure annually)	Annual Targets		
		Full Target Achievement	Partial Target Achievement	Missed Target
Fuelwood saving devices	No. of fuel efficient stoves installed	> 250 stoves	150-249 stoves	< 150 stoves
	Number of LPG Units Installed	> 200 units	100-199 units	< 100 units
Biodiversity	Number of biodiversity surveys conducted by CF and youth volunteers	> 2 surveys	1 survey	0 surveys
Quarrying	Number of reports and lobby advocacy meetings reports held	4 reports/ lobbying meetings	2-3 reports/ lobbying meetings	1 or less reports/lobbying meetings
Impact (after 5 years)	**Impact Indicator**	**Means of assessment**	**Baseline (2016)**	**Target (2021)**
Fuelwood consumption	Households using fuel efficient stoves (number)	Baseline survey/resurvey	6% of households	At least 25% of all households using fuel efficient stoves
	Households using LPG (number)	Baseline survey/resurvey	1.5% of households	At least 15 % of households using LPG
	Level of household fuelwood consumption (tonnes/year)	Baseline survey/resurvey	2.5 t/yr.	Fuel wood Consumption reduced by an average of 50% across all participating households
Biodiversity	Number of observations of endangered mammal species	Records from surveys conducted by Youth volunteers	42 No. of observation during 2016	50% increase over baseline
Quarrying	% of villages with active quarrying	Baseline assessment	15 % of villages with active quarrying	> 12% of villages with active quarrying

10.4. Socio-Economic Monitoring

The monitoring plan includes socio-economic monitoring to ensure that the project is delivering benefits to participants that enhance their livelihoods and quality of life in accordance with the Plan Vivo Standard. The project seeks to distribute benefits and share them with communities through the provision of annual community development grants (CDG) to each participating village. The village members decide what project they wish to implement and submit proposals to the Federation for funding. Each year, the Federation compiles a report on the type of project, amount spent, and impact of the activity. The Federation also assesses how many community families benefited directly from the project. In addition, the project seeks to build the capacity of community institutions including the Local Working Committees, Self-help groups, and farmer's clubs. Training sessions are held by the Federation to build awareness regarding forest conservation and management, bookkeeping, technical skills in agriculture, animal husbandry, and other income generating activities. The number and results of the trainings are reported each year as an annual indicator (see Table 22 below).

Table 22: Socio-Economic Monitoring Indicators

Activity	Activity Indicator (measure annually)	Annual Targets		
		Full Target Achievement	Partial Target Achievement	Missed Target
Benefit sharing and participation	Number of villages with community Development Grants	> 50 villages	30-49 villages	< 30 villages
	Number of families accessing CDGs	> 600 households	400-599 households	< 400 households
Institutional capacity	Number of training programs	> 10 programs	6-9 programs	< 6 programs
	Number of families participating in income Generating Activties	> 200 families	100-200 families	< 100 families
Impact (after 5 years)	**Impact Indicator**	**Means of assessment**	**Baseline (2016)**	**Target (2021)**
Knowledge and awareness	Knowledge of the federation & project	Baseline survey/resurvey	75 % of households	85% of all households with knowledge of the Federation and Project activities.
Livelihoods benefits	% of all project households receiving benefits from community grants	Baseline survey/resurvey	30 % of households	60 % of households receiving benefits from community development grants
	% of households with livelihoods activities reflecting conservation of forests and natural resources	Baseline survey/resurvey	20 % of households	60% of all households with expansion of livelihood activities that also reflect conservation of forests and natural resources

10.5. Satellite Monitoring

Satellite image analysis will be carried out as described in Appendix 3. The Federation will use the land use change map to identify areas with reduced rates of deforestation, restoration, and problem areas with continuing deforestation and degradation (see Table 23).

Table 23: Satellite Image Monitoring Indicators

TARGETS	REDD+	ANR
	The rate of deforestation and forest degradation will be assessed by comparing SPOT imagery from the baseline 2010 image with that the most recent images available. Extent of deforestation will be determined by shifts in land use classes, especially between dense, open, and barren areas.	In the ANR areas, rates of forest regrowth will be assessed by comparing forest cover change from the SPOT baseline 2010 period to the most recent image available. Extent of canopy closure (crown cover) will be a primary indicator of forest cover change.
Green target	Reduced by the target percentage or more.	Regeneration in ANR sites is identifiable in the satellite image analysis after year 4.
Amber threshold	Reduced by less than the target percentage, but more than the baseline.	Regeneration is not identifiable in the satellite image analysis after year 4, but a field visit shows some regeneration and there is evidence that an effort has been made to reduce grazing and to implement fire lines.
Red threshold	Same as the baseline or greater.	No change or has been deforested.

10.6. Verification of Targets and Thresholds

REDD+ targets are annual reductions in the rate of deforestation and forest degradation in the project area. In the baseline, dense forest changes to non-forest at a rate of 2.7% per year and dense forest changed to open forest at a rate of 0.1% per year. The annual targets for the reduction in the rate of deforestation and degradation start in 2012 at 33% and increase to 57% by 2021. If there is a reduction in the rate of deforestation and degradation, but it is less than the target, the amber threshold has been met. In this case, the project team and the Community Management Federation will work with communities to improve the implementation of fire lines, sustainable fuel wood collection, reducing charcoal making, reducing grazing, and reducing agricultural expansion.

The ANR target is to achieve identifiable forest regeneration. Forest regeneration should be identifiable in a satellite image analysis after an ANR area has been protected for four years.

If there is regeneration, but there is also evidence of grazing and only partially implemented fire lines, the amber threshold has been met. In this case, the project team and the Community Management Federation will work with communities to improve the implementation of fire lines and to reduce grazing.

11. REFERENCES

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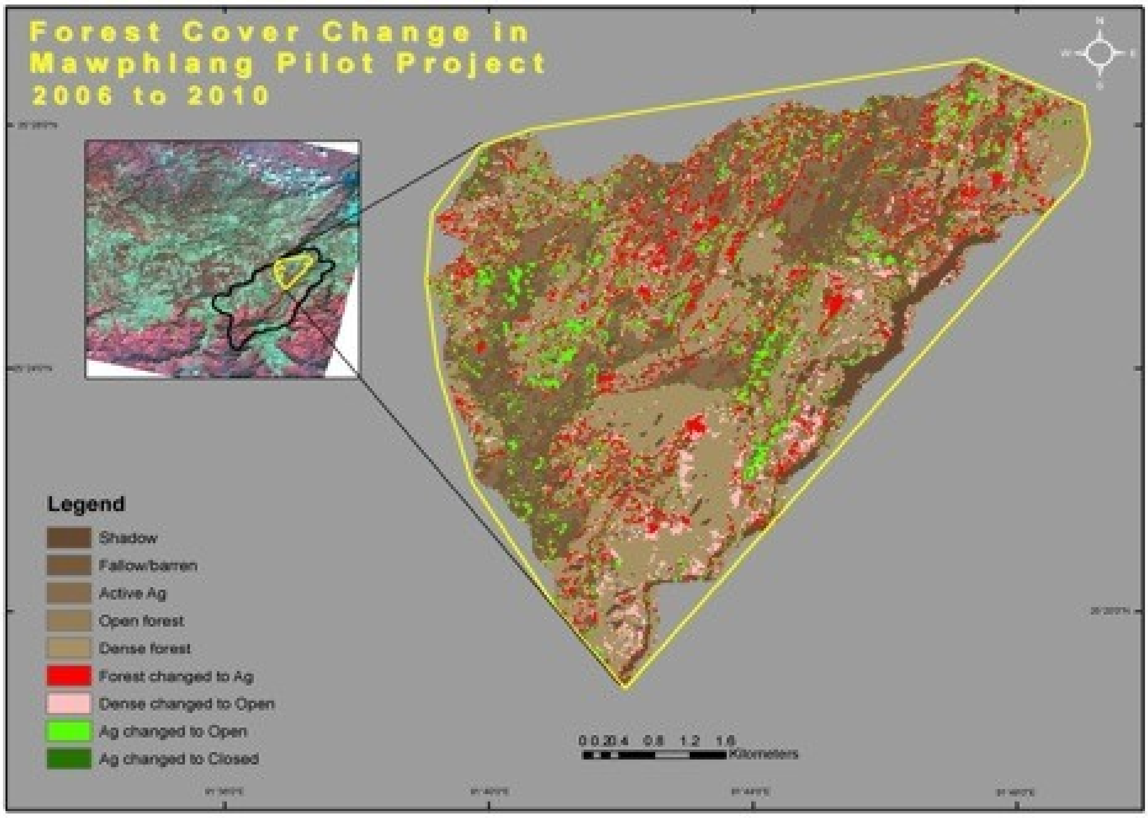
APPENDICES

Appendix 1: Mawphlang Pilot Project

Pilot project activities have been successful in Mawphlang. From 2006 to 2010, REDD+ and ANR activities have taken place in Mawphlang. Fire has been reduced by fire lines and fire watches, and assisted natural regeneration has led to forest regrowth.



Appendix 2: Biomass Survey

The biomass survey annex shows the biomass survey steps and a sample data collection form (see Table A).

Biomass survey steps:

1. Get equipment
2. Produce sample plot sheets
3. Stratify site
4. Confirm sampling intensity
5. Select sampling transects
6. Do training
7. Start sampling
8. Record data
9. Transfer data from data sheets to Excel documents
10. Calculate the sample variance
11. Determine sampling intensity to achieve 95% CI with 10% error
12. Name documents
13. Save documents

Table A: Biomass Survey Form

Plot No.		**Name of Team Leader**			**Forest Type**		**Location**				
Date		**Slope (^{0})**		**Elevation (mt)**		**Accuracy (mt)**		**Photo Number**	3		
GPS Coordinates		**Access Instructions**							**DBH (cm)**	**Top Height (mt)**	**Comments**
				Tree Species							
Sl.No.	1	2	3	4	5	6	7	8			
1											
2											
3											
4											
5											
Total											
Comments											

Appendix 3: Satellite Image Analysis

A total of three SPOT images were received from 3 points in time: 1990, 2006, and 2010. The images were processed from level 1A to ortho-rectified normalized reflectance ready for image analysis. The images were then analyzed for change and classified into simple land cover classes for further assessment.

Image Processing Methodology

The imagery from the earliest data set of 1990 was at a spatial resolution of 20m and contained 3 bands; green, red, and NIR. The other two images from 2006 and 2010 had a native resolution of 10m and 4 bands of data that were consistent with the 1990 data but included the middle infra-red band at 20m. For initial image processing well-developed methods were employed to first ortho-rectifiy the imagery to the ground then to reduce the later data sets both spatially and spectrally to match the data from the earliest time period. This was done to make comparison between years as consistent as possible. All image processing steps were done using ERDAS Imagine 9.3. The steps were as follows:

a) Image geometric correction. The SPOT specific model within ERDAS was used along with a 90m DEM from SRTM (NASA). The DEM required recalculating height values to WGS84 from the SRTM standard of EGM96.

b) The 1990 and 2006 imagery were rectified in the same manner but had an added step of co- registration to the 2010 image for consistency. A minimum of 12 points per imager was necessary for a .9 pixel co-registration accuracy.

c) All imagery was re-projected from the native geographic projection to UTM WGS84 Zone 46 using cubit convolution to match the existing polygons for project boundaries.

d) Both the 2006 and 2010 images were up-sampled to 20m in order approximate the resolution of the 1990 image using cubic convolution and rigorous transformation.

e) Each image was then clipped to the boundary of the project area including a 1km buffer to reduce loss from positional error.

f) An added step of splitting the area in to three illumination categories was also performed due to the excessive amounts of slope and sun angle that resulted in over and under illumination problems with this imagery. Each of the three area categories were analyzed separately to reduce the error and overlap in spectral response from illumination differences.

g) Each image was assessed for sun angle properties and a subsequent mask was created to depict those areas with more than 30 degrees of slope and a sun angle that would either cast shadow or over illuminate.

h) The mask for each of the two conditions was applied to the whole image to separate out those areas and classify them separately.

Image Classification Methodology

A hybrid approach to change analysis was used to attempt to capture the most change over time while limiting the error from yearly variability. An initial change analysis comparing strictly pixel values and magnitude of change was done to assess the amount of change and distribution to expect. While this process does yield a change map, it does not identify what is changing. This approach also has limitations due to variability in spectral response from year to year. It does however, give an initial understanding of what to expect and the magnitude of change over the landscape. The second step was to do a simple unsupervised classification of all three data sets. Because we have limited knowledge of the ground as well as limited spectral data it is more consistent to allow the classifier to make the decisions about spectral separability and probable number of classes. The land cover classes of interest are simple classes but can and do have spectral overlap under certain conditions. The classes of interest are:

- Dense forest (greater than 40% canopy closure)
- Open forest (10% to 40% canopy closure)
- Fallow / barren
- Active Agriculture
- Shadow or Water

An initial assessment looking at a histogram of values over the entire image indicated that approximately 25 unique separable classes were extractable from the data. An iso-clustering routine was used for the unsupervised classification and a total of 25 classes extracted. This was done for each of the images.

Visual Interpretation

Using both ground based data and high resolution satellite data from Digital Globe (60cm), each of the 25 classes was grouped into one of the four classes of interest (fallow, agriculture, open, and dense forest). This process was relatively simple for the 2010 image that closely matched the digital globe data available for that area. In this case each of the 4 classes was easily identified visually from that resolution data.

Assessment of the 2006 data was slightly different. There were numerous sites that had not shown any change from the initial reflectance change analysis and so were used as areas of consistent land cover. The 25 iso-cluster classes were assigned to the four landcover classes using direct comparison with the 2010 image classes where change was known to have not occurred. At times the pan- sharpened version of the 2006 image at 2.5 meters was used for assessment as well as the 60cm Digital globe data.

For the 1990 image the approach was similar to the 2006 image. Areas that had little to no change were used for class identification and consistency. There was no pan-sharpened version of the 1990 image available or any other higher resolution imagery to use as ground truth so the assessment from later images was the main interpretation tool.

Change Analysis of Remotely Sensed Data

To assess the change from one time step to the next a direct class change analysis was done. Two points in time were chosen and those land cover maps were assessed for which classes had changed state. For the purposes of this project classes that changed between active agriculture and fallow/barren were ignored as these classes are somewhat ambiguous between them. The change of interest was when forest pixels changed to non-forest pixels, i.e. forest cover loss. Two types of forest cover change were identified; dense forest changing to open forest and any forest cover (dense or open) changing to agriculture or fallow/barren. A third type of change was also captured, that of forest regrowth. Only those pixels that changed from Ag or fallow in time one to dense forest in time two were considered real regrowth. All other change was ignored or considered classification error.

Some changes that should also be noted were:

- When changes from fallow/barren to active agriculture or the convers occurred the class from the time two image was chosen as the land cover type. This change was not consistent nor was it of main interest.
- When a grid cell was classed as shadow in either time one or time two it was classed as shadow for the change analysis. This resulted in a gross loss of grid cells available for change analysis.
- Changes from open forest to dense forest were also ignored and considered to be classification error. While this change may be real it was decided that a more conservative approach to change assessment should be taken.
- For the purposes of reducing error from image co-registration, seasonal effects, etc., a majority filter was applied to the change map. This reduces the number of single grid cells of change occurring in the middle of a consistent landscape that are frequently error. Therefore, some small amounts of change may be unaccounted for but classification error is also reduced. This process was done for 1990 to 2006 and 2006 to 2010.

Known Problems

With any image analysis project there is some error. Due to the nature of this type of analysis there are few ways to conduct any sort of classification accuracy assessment. This is mostly a function of the time when the satellite data was collected. The 2006 and 1990 image classifications cannot be consistently assessed for accuracy other than a visual interpretation of the original data. The 2010 classification can be performed using the 60cm Digital globe data as the source of information for distinguishing between obviously forested areas to barren fallow or agriculture areas, very much in the same way that the original classification was done. Some error was assessed at the time of classification and could not be dealt with at that time.

Due to the topographic relief in this region, there are extensive areas with steep slopes. These slopes tend to be either over or under illuminated when the sun is not directly overhead at the time of image collection.

The resulting effect is termed topographic shadow. Under some conditions this inconsistent illumination can be corrected for as was done in this project. However, areas that were under illuminated were still difficult to assess properly due to a basic lack of spectral response from shadow. Therefor in those areas of under illumination we can expect there to be some areas that underwent change that was undetectable. In most if not all misclassification cases dense forest was over estimated in areas of under illumination.

Appendix 4: REDD+ Project Effectiveness

The project team worked together to estimate the effectiveness of REDD+ project activities. For each of the drivers of deforestation and degradation, we considered the likely impact of mitigating project activities. From this exercise, we estimate that the rate of deforestation and degradation will be reduced by 33% as project activities start (2012-2016). Once project activities are established and expanding, we estimate that the rate of deforestation and degradation will be reduced by 57%.

Table B: Effectiveness of REDD+ Mitigation Measures.

DRIVERS OF DEFORESTATION AND DEGRADATION	CONTRIBUTION TO DEFORESTATION	CONTRIBUTION TO FOREST DEGRADATION	MITIGATION IMPACT (2012-2016)	REDUCTION IN RATE OF DEFORESTATION AND DEGRADATION (2012-2016)	MITIGATION IMPACT (2012-2021)	REDUCTION IN RATE OF DEFORESTATION AND DEGRADATION (2017-2021)
Forest Fire	High	High	50% reduction in the area affected by forest fire	15%	75% reduction in the area affected by forest fire	23%
Firewood collection	High	Med	15% reduction in firewood use by volume	5%	25% reduction in firewood use by volume	8%
Charcoal Making	Med	Med	25% reduction in charcoal making	6%	50% reduction in charcoal making	12%
Agricultural land clearing	Med	Low	25% reduction in new area cleared for agriculture	4%	50% reduction in new area cleared for agriculture	8%
Grazing	Low	Med	15% reduction in the area affected by grazing	3%	30% reduction in the area affected by grazing	6%
Quarrying	Low	Low	25% reduction in the impact from quarrying	1%	50% reduction in the impact from quarrying	2%
Total impact				**33%**		**57%**

Appendix 5: Minimizing the Risks of Non-sustainability

Project activities are designed to be sustainable. However, where required, we use a risk buffer of 20% based on this analysis of the risks of non-sustainability (see Table C).

Table C: Risks to Non-sustainability and Mitigation Actions

	RISK TYPE	INFLUENCE	SITUATION	ACTION	TIME-SCALE	WILL A PROBLEM HAPPEN?		SEVERITY		SCORE
A	Land ownership / tenure									0.15
A.1	Land tenure	Partial	Communally owned land	Assist registry of communally owned land	Short	Unlikely	0.05	High	3	0.15
A.2	Land tenure	Partial	External interests may attempt to take control of project land	Build a sense of ownership among district and state government officials, so that they will be committed to supporting the project goals and strategies.	Short	Unlikely	0.05	High	3	0.15
B	Financial									0.3
B.1	Project financial plan	Complete	Further funding needs to be secured	Develop a sliding scale of budgetary options, allowing available resource to be directed to the most critical project elements in times of funding scarcity. Diversify sources of funding for the project so that it is not entirely dependent on carbon sales or any other single source. This will include financial support from Government of India schemes and projects, sales of NTFPs or other forest products, PES sales to local government including exploring a watershed management contract with the Shillong Municipality, and carbon sales in markets.	Short	Likely	0.1	High	3	0.3
C	Technical									0.05
C.1	Coordinator capacity	Complete	Technical competence	Training	Short	Unlikely	0.05	Low	1	0.05
D	Management									0.1375
D.1	Ineffective management	Complete	Project management in place	Project managers and staff adequately trained	Short	Unlikely	0.05	High	3	0.15
D.2	Poor record keeping	Complete	Data management process in place	Robust procedures and keen oversight	Short	Unlikely	0.05	Medium	2	0.1
D.3	Staff with relevant skills and expertise	Complete	Staff selected	Careful selection of project staff and training	Short	Unlikely	0.05	Medium	2	0.1
D.4	Tree damage from browsing	Partial	Grazing in forest	Reduce forest grazing through project activities	Short	Likely	0.1	Medium	2	0.2

E	Opportunity costs									0.05
E.1	Returns to producer and implementer stakeholders	Partial	Opportunities for alternate livelihood activities with project	Development of business plans (reviewed periodically) for economically viable management	Short	Unlikely	0.05	Low	1	0.05
F	Political									0.3
F.1	Inter- community conflicts	None	Inter-community conflicts could undermine project management and implantation, especially related to REDD+ Activities.	The project has sought to support mediation mechanisms at the Durbar, Hima, Federation and Autonomous District Council levels to resolve resource and project related conflicts.	Short	Likely	0.1	High	3	0.3
G	Social									0.3
G.1	Disputes caused by conflict of project aims or activities with local communities or organisations	Partial	Consultation with communities planned over project lifetime	Participatory planning and continued stakeholder consultation over project lifetime	Short	Likely	0.1	High	3	0.3
G.2	Community coordination	Partial	Opportunity to strengthen community coordination	Establishment of an institutional framework originating at the village level, with coordination and support through LWC, Hima governments and the Federation.	Medium	Likely	0.1	High	3	0.3
H	Fire									0.3
H.1	Incidence of forest fire	Partial	Forest fires are common	Fire management plans including creation and maintenance of fire line, employment of seasonal firewatchers.	Short	Likely	0.1	High	3	0.3
I	Physical									0.05
I.1	Drought	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
I.2	Hurricane	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
I.3	Floods	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
I.4	Earthquakes	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
I.5	Landslides	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
I.6	Mudslides	None	Infrequent (<1 in 10 yrs)	Replanting of trees as required	Short	Unlikely	0.05	Low	1	0.05
	Overall Score (average of risk types)									0.18
	SUGGESTED RISK BUFFER									19%

Appendix 6: Satellite Image Analysis 2010-2016

Satellite remote sensing is employed to monitor the rate and spatial pattern of land cover change and deforestation within the project area for the duration of the project implementation between 2010 and 2016. Both the imagery and procedures used for this analysis closely follow those used for the baseline assessment undertaken for the period 1990 to 2010 (see Appendix 3) to make comparison between images as consistent as possible, minimizing differences in classification outputs that are not attributed to true changes in land cover. The following sections detail the imagery and procedures used, highlighting deviations from those used in the baseline assessment.

Imagery

High resolution imagery acquired by the Satellite Pour l'Observation de Terre (SPOT) was obtained for 2016 (Table D).

Table D: 2016 Satellite Image Metadata

ACQUISITION DATE	SATELLITE	RESOLUTION	PROCESSING LEVEL
09/11/2016	SPOT 6/7	1.5m Natural color and PSM	Level 3 (Ortho) *

*** Level 3 products are georeferenced and pre-processed using a digital elevation model to correct residual parallax errors due to relief. Geometric corrections consist in "orthorectifying" imagery using a resampling model that compensates for systematic distortion effects and performs transformations need to project the image in a specified map projection (UTM). Corrections are based on a model of the satellite's flight dynamics on GCPs and a DEM**

Image Processing Methodology

Ortho-rectification and co-registration:

- 2016 imagery is ortho-rectified prior to delivery. This differs to the 2010 imagery which is ortho-rectified to the ground using the SPOT specific model within ERDAS along with a 90m DEM from SRTM (NASA) by the image analyst (see Appendix 3: a).
- The 2016 image closely aligned with the 2010 image. Co-registration procedures applied to the 1990 and 2006 images (Appendix 3: b) were therefore not required.

Spatial and spectral resolution:

- The 2016 dataset was both spatially and spectrally altered to match the 1990 dataset using ERDAS Imagine 9.3 following the same steps applied to the 2010 dataset (Appendix 3: c – e).

Method for reducing terrain effect:

- Variations in radiance levels of spectral data are caused not only by variations in land surface characteristics but also by differences in surface slope angle and aspect of the terrain, in combination with solar zenith and azimuth angles (Holben and Justice, 1980). Consequently, a certain land cover/use type may not have the same spectral response at different topographic positions. This is known as topographic effect. The topographic effect is responsible for a large part of the spectral variation of the land cover in rugged terrain, such as the Khasi hills.

- To reduce the topographic effect in this analysis, the images were split into three illumination categories. Each category was then analyzed separately to reduce the overlap in spectral response from illumination differences. The same procedure was followed as documented for the 1990, 2006 and 2010 images in Appendix 3. Specifically, to create the separate illumination categories the following steps were taken:
    a) *Slope* (Figure 3a) and *surface aspect* (Figure 3b) rasters were derived from the SRTM Digital Elevation Model (DEM) using *DEM analysis* tools in ERDAS. The slope raster was re-classified into a binary raster of slopes either above or below 30 degrees (Figure 3c). The surface aspect raster was then reclassified to areas illuminated or in shadow at the given sun angle.
    b) The binary slope raster was combined with the sun angle product to create an illumination raster (Figure 3d) with the following three classes:
        I. Land where over illumination occurs and is over 30 degrees slope
        II. Land where shadowing occurs and is over 30 degrees slope
        III. Land where either over-illumination or shadow occurs and is under 30 degrees slope

    This product was then converted to vector format and the 2016 image was masked by illumination category to create three separate rasters for each year.

Figure 3: Processing steps taken to analyse SPOT imagery by illumination category; a) slope (degrees), b) Aspect (degrees), c) binary slope raster (below or above 30 degrees), d) illumination categories

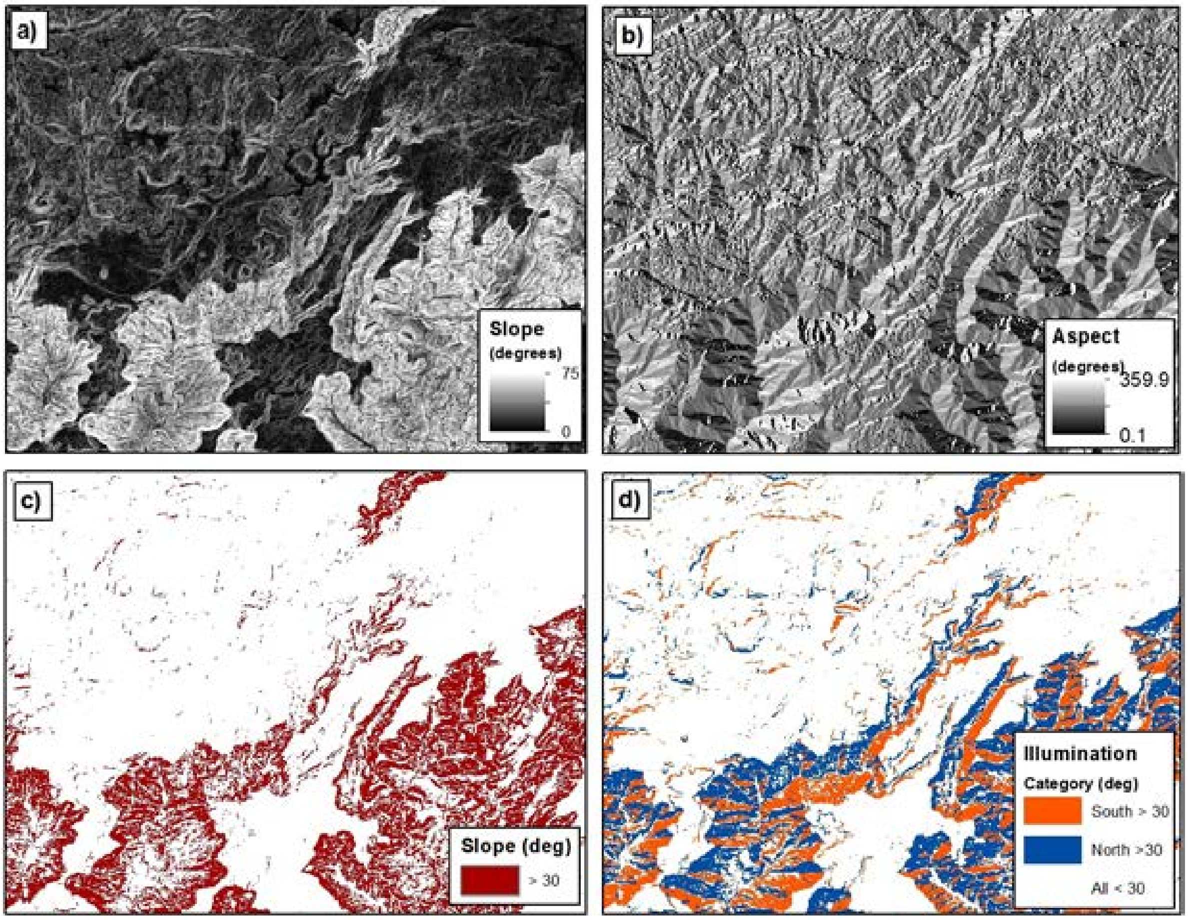


Image Classification Methodology

The procedure outlined in Appendix 3 for image classification was used to classify the 2010 and 2016 imagery into land cover classes (Figure 4) and calculate the areas for each land cover category (Table E).

Figure 4: Land Cover Map for Khasi Hills REDD+ Project Area in a) 2010, and b) 2016

a) b)

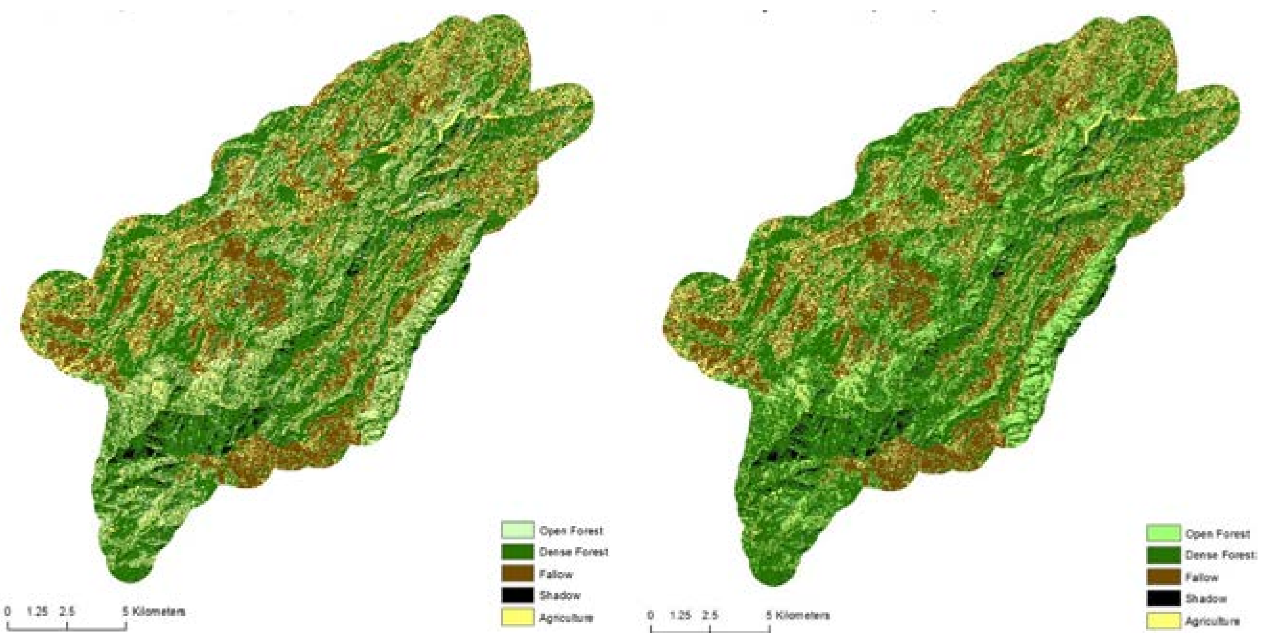


Table E: Land Cover Types (2016)

LAND COVER	AREA 2010 (Ha)	AREA 2016 (Ha)
Dense forest	10,186	10,838
Open forest	3,752	4,418
Barren or fallow	6,387	5,763
Agriculture	4,999	5,054
Other (shadow/water/no data [1]	1,709	960
Total Area	**27,033**	**27,033**

Change Analysis of Remotely Sensed Data

The procedure outlined in Appendix 3 for change analysis was followed to create the 2010 to 2016 land cover change map (Figure 5). Table F details the area of change between each category

Figure 5: Land Cover Change Map (2010-2016)

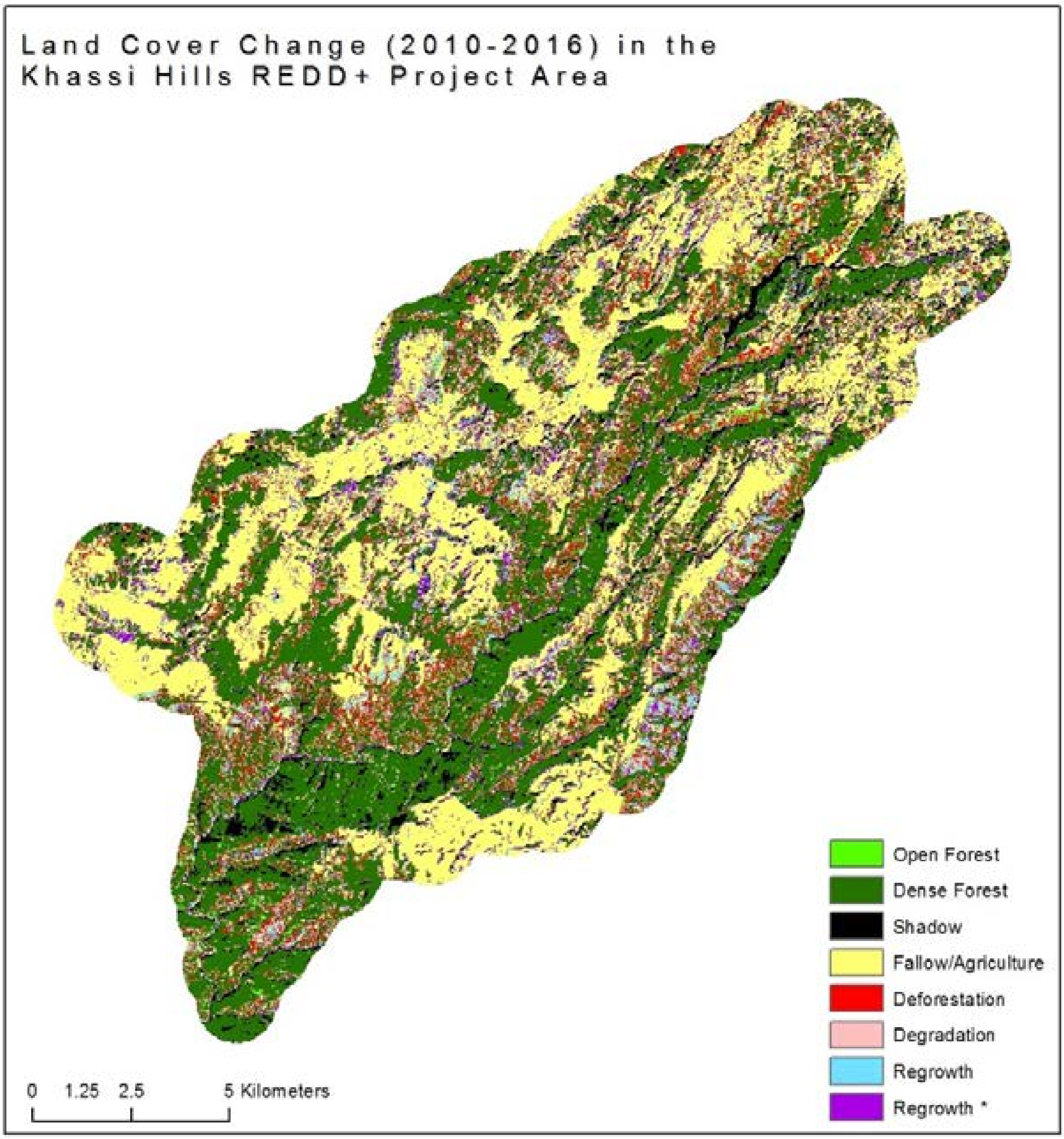


Table F: Land Cover Change Matrix (2010–2016)

2010 CLASS	2016 CLASS	CHANGE CLASS	AREA (Ha)
Open Forest	Open Forest	Open Forest	1,143
Open Forest	Dense Forest	Regeneration	1,501
Open Forest	Fallow	Deforestation	300
Open Forest	Shadow	Shadow	80
Open Forest	Agriculture	Deforestation	729
Dense Forest	Open Forest	Degradation	1,770
Dense Forest	Dense Forest	Dense Forest	6,480
Dense Forest	Fallow	Deforestation	333
Dense Forest	Shadow	Shadow	607
Dense Forest	Agriculture	Deforestation	995
Fallow	Open Forest	Regrowth	595
Fallow	Dense Forest	Regrowth	996

Fallow	Fallow	Agriculture/Fallow	3082
Fallow	Shadow	Shadow	59
Fallow	Agriculture	Agriculture/Fallow	1,654
Shadow	Open Forest	Shadow	121
Shadow	Dense Forest	Shadow	1,176
Shadow	Fallow	Shadow	72
Shadow	Shadow	Shadow	167
Shadow	Agriculture	Shadow	173
Agriculture	Open Forest	Regrowth	789
Agriculture	Dense Forest	Regrowth	685
Agriculture	Fallow	Agriculture/Fallow	1,976
Agriculture	Shadow	Shadow	46
Agriculture	Agriculture	Agriculture/Fallow	1,503
TOTAL			**27,032**

Limitations

It was not possible to remove all topographic effects on the classification, and no accuracy assessment was carried out, as appropriate ground-truthing data were not available. Potential sources of inaccuracy of land cover classifications therefore include:

- Remnant topographic effect on spectral signatures; and
- The classification approach – which relied on 'unsupervised' classification of the 2016 image.

It should also be noted that change maps produced using sequential classifications are likely to exhibit accuracies similar to the product of multiplying the accuracies of each individual classification (Lambin and Strahler, 1994).

The change map produced from this analysis (Figure 5) is intended to be used to assess project performance relative to the baseline scenario described from a previous analysis (Appendix 3). While every effort was made to replicate approaches and produce comparable land-cover change maps, some differences in imagery and processing methods between the two analyses were unavoidable. Since similar methods were used for both analyses, however, so systematic bias that could lead to a gross under- or over-estimate of project effectiveness is not expected.

The main limitations of the study are described in more detail below:

1. Topographic effect on spectral signatures

As outlined above, the Khasi Hills region is mountainous, meaning that some slopes are over-illuminated while others are under-illuminated. The resulting spectral signature recorded by the satellite is such that single land cover types have different signatures on different slopes and are not always identifiable as the same type of land cover. By splitting the image into three separate illumination categories, we reduced this error by analyzing land cover under different illumination conditions separately. However, within each illumination category considerable differences in slope and aspect still exist that are not accounted for. Prevalence of residual illumination effect is assumed to be equal between the different classifications and between class types, however, leading to similar levels of mis-classification of any land cover type.

Additionally, under different illumination conditions the amount of solar radiation that reaches the area (and therefor the amount reflected and detected by the sensor) differs. In areas of high illumination, land receives more solar radiation and consequently reflects and emits larger quantities back to the sensor, with the convers true for regions in shadow. It is difficult for the sensor to identify differences in spectral signatures for regions where very little radiation is reflected, creating potential for mis-classification in these areas. This seems to have two impacts on the Khasi Hills analysis:

a. The majority of land on North facing slopes is classified as dense forest, with minimal spatial variability within the class

b. Minimal land cover change is recorded on North facing slopes

While this effect highlights further uncertainty in the analysis of these under-illuminated areas, all land cover classes and class change are assumed to be affected equally (equally failing to detect deforestation, reforestation, degradation etc. in these under-illuminated areas), and systematic bias that could lead to a gross under- or over-estimate of project effectiveness is not expected.

2. Lack of ground-truthing data to supervise classifications and assess accuracy

After the automated iso-cluster classification was complete, the image analyst manually assigned each of the 25 'clusters' to one of the four land cover classes. For the 2010 imagery, this is done by looking at higher accuracy Digital Globe imagery to 'supervise' the classification but for 2016 no higher resolution imagery was available so was is done by assigning target areas that were assumed to have had no change from 2010 to a land cover class and surmising that the remaining area of that cluster is appropriately classified (original SPOT imagery as well as high resolution imagery from the Google Earth Server (12/2016) was consulted). Mis-classification of an iso-cluster can occur with this approach if either the 'static target' has in fact changed between sequential image acquisition, if in that particular image it has different spectral properties to other land of the same class, or if the cluster is meaningless to a single land cover type due to other conditions impacting the spectral response (e.g. illumination). Every effort was made to reduce the likelihood of these circumstances by taking care to identify static target areas that appeared representative of land cover spectral responses in that class and had not changed between successive images. Again we expect the likelihood of these errors affecting the mis-classification of land cover to be similar across all classes.

Unfortunately, forest inventory plots collected for both 2010 and 2016 cannot be used to supervise or assess the accuracy of the classification because not only does their coverage not extend across all illumination categories but their area is smaller than that of a single pixel. Because all optical imagery contains some speckle noise, ground-truthing polygons should cover a parcel of pixels to reduce the risk of supervising an image from an unrepresentative spectral signature. Without ground-truthing data/knowledge of an area, the reliance on a clustering algorithm to group pixels according to similar natural spectral responses is the most appropriate method of classification land cover.

3. Differences in imagery and processing

The aim of this analysis was to provide change estimates that are comparable to the estimates in the baseline scenario (Appendix 3). As a result of a) different acquisition years of imagery, and b) the timing of the different analyses (meaning that processing was completed by two different analysts) there are some unavoidable differences in imagery and processing techniques that are likely to cause some differences in classification that are not attributed to true land cover change, however. Table G highlights these differences and their potential impact.

Table G: Summary of key differences between sequential analyses

DIFFERENCE	IMPACT
Different satellite sensors	2010 imagery was acquired by the HRG 2 instrument on board SPOT-5. 2016 imagery was acquired from SPOT-6. The 2016 sensor has an additional 'blue' band (0.450-0.520 µm) and all band widths vary slightly between sensors. While the blue band for 2016 was removed for this analysis, the difference in bandwidths of the remaining bands could not be accounted for and will have varying capability of capturing spectral responses.
Differences in ortho-rectification	The process of ortho-rectification alters the spectral signature of any pixel depending on the pixel's topographic position (slope, aspect, height). The 2010 and 2016 images were ortho-rectified using different procedures and therefore the spectral signature for any given location for the two sequential time periods may be altered differently creating a difference that cannot be attributed to true change. The assumption is that both procedures used follow similar logic and that these differences are negligible.
Different extents of illumination categories	Despite following the written procedure for creating the extent of illumination categories, the extents of the 2010-2016 illumination categories differ from those created for the 1990-2006-2010 analysis. It is uncertain what additional step was taken in the earlier analysis. This will have had no effect on the 2010-2016 analysis that used the same illumination category extents, but may cause some differences between the successive change analyses where certain pixels in the 1990, 2006, 2010 analysis were clustered according to the population of pixels in the initial illumination extents, and then clustered differently in the 2010, 2016 analysis according to a different population of pixels. It can be assumed that this will impact all land cover change categories equally.
Different image analysts	The initial 1990, 2006, 2010 change analysis completed in 2010 was conducted by a different image analyst than that for the 2010 - 2016 change analysis. Despite documenting and sharing procedures used, remote sensing analyses will invariably differ between analysts wherever any manual procedure and opinion is required.