Guyana Forestry Commission

Guyana REDD+ Monitoring Reporting and Verification System (MRVS)

Accuracy Assessment Final Report

22 March 2011

EXECUTIVE SUMMARY

This report was commissioned by the Guyana Forestry Commission in support of a system to Monitor, Report and Verify (MRV) for forest resources and carbon stock changes as part of Guyana's engagement in the UN Collaborative Programme on Reducing Emissions from Deforestation and forest Degradation plus (REDD+). The scope of the work was to conduct an independent assessment of forest area and forest area change estimates for the period 1990 to 2010. Specifically, the terms of reference asked that confidence limits be attached to forest area estimates.

The methods used in this report follow the recommendations set out in the GOFC-GOLD guidelines to help identify and quantify uncertainty in the level and rate of deforestation in Guyana over the period 1990 to 2009 (Benchmark Period) and 2009 to 2010 (Interim Measures Period – Year 1). High spatial resolution imagery combined with low altitude photography and field visits are used to assess the wall-to-wall mapping of Guyana undertaken by Pöyry Management Consulting Ltd and Guyana Forestry Commission. In particular, imagery from the German RapidEye satellite constellation system, the UK-led DMC satellite constellation and IKONOS provided excellent sources for assessment of the 2010 (Year 1) mapping. A stratified sampling approach was adopted to help provide precise estimates of forest area. Two strata were selected according to "risk of deforestation", that is, land proximal to settlements, roads, logging concessions and mining areas, and other low risk land area. A 10 km by 10 km grid square was overlaid on the country and using available GIS data, grid squares containing any of the risk variables were tagged as high risk and the remainder as low risk. Interpretations of deforestation drivers followed the procedures documented in the Poyry Mapping and Satellite Image Interpretation Guide that should be read in conjunction with this report.

For the 1990 Forest – Non-forest map, the results show a correspondence (prevalence) between reference image interpretation and Pöyry/GFC mapping of 97.1% for all the 28,680 one hectare plots sampled from both strata. The same correspondence analysis for the Year 1 map yields a prevalence statistic of 98.3%. This demonstrates a very high level of agreement between the MRV maps and the reference data.

	Forest 1990 (ha)	Forest 2009 (ha)	Forest Year 1 (ha)	Δ 1990-2010 (ha)	Benchmark Rate %	Year 1 Rate %
Durham Estimate	17,916,980	17,816,927	17,805,317	111,663	0.029	0.065
Pöyry - GFC Estimate	18,473,394	18,398,497	18,388,190	85,204	0.021	0.056

The estimate of 1990 forest area, based on the stratified sampling design is 5,933,659 ± 17,609 hectares the High Risk stratum and 11,983,321 ± 55,695 hectares the Low Risk stratum. The estimate of forest area for Year 1, based on the stratified sampling design is 5,835,059 ± 15,376 hectares the High Risk stratum and 11,970,258 ± 28,845 hectares the Low Risk stratum. The differences between the model-based estimates and the maps are shown the table above. The deforestation rate over the 20 year period from 1990 to 2010 is 0.023% for the Pöyry-GFC maps and 0.031% based on the model-assisted estimator method. It is not possible to calculate a 2009-2010 rate directly from our results but if we spread the difference between our estimate and the Pöyry-GFC mapped results in the same proportion as Pöyry-GFC reported their deforestation data, then we estimate a Year 1 rate of 0.065% compared with 0.056% cited in the Interim measures Report (Pöyry, 2011). The main source of disagreement in the area estimates derives from deforestation due to Agriculture that was not detected in the 1990 Forest – Non-forest maps, mainly due to areas where Landsat TM and ETM+ imagery was obscured by persistent cloud cover.

TERMS OF REFERENCE

Overall objective

To conduct an independent accuracy assessment of area change estimates, the types of change mapped, and the deforestation rate as outlined in the Bid 1 MRVS report, and assessing their error margins/confidence bands.

Specific areas of activity

1. To develop an outline methodology for accuracy assessment including an outline of the (1) sample design, (2) response design, and (3) analysis design.[1]
2. Provide an accuracy assessment using IPCC GPG on LULUCF on 1990 Forest/Non Forest Mapping.
3. To report on REDD+ interim measures and national estimates, including initial interim results, and specifically focusing on the deforestation rate (i.e change over time) and assessing their error margins/confidence bands, and providing verification of the deforestation rate figures provided in the Bid 1 Report.
4. To provide an accuracy assessment on the area changes, an error assessment on the quality of attribution of types of changes mapped, an examination of why changes were mapped well or not, and accompanied by recommendations that can be used to improve efforts in the future. This assessment should be done with the recognition that for historical periods, “best efforts” will have to be applied in situations where there is a challenge in terms of availability of reference data and will have to entail field verification.

[1] GOFC GOLD Sourcebook Section 2.6.

1 AREA REPRESENTATION

The total land area for Guyana at the Benchmark period 2009[2] is reported in the Interim Measures Report to be 21.1 million hectares. This figure is based on GIS polygon data of Guyana's National boundary and is used when calculating area based statistics. The digital maps contained in the report were obtained from the Guyana Forestry Commission (GFC), the Guyana Land and Surveys Commission and Pöyry Consultants. All maps use the WGS 84 datum and are projected to UTM Zone 21N. For mapping, the GFC uses ArcGIS v.10 software although data were exported to Shapefiles for data analysis.

1.1 Forest Area

Land classified as **forest** by GFC follows the definition from the Marrakech Accords (UNFCCC, 2001). Under this agreement forest is defined as: a minimum area of land of 0.05-1.0 hectares (ha) with tree crown cover (or equivalent stocking level) of more than 10-30% with trees with the potential to reach a minimum height of 2-5 m at maturity in situ.

In accordance with the Marrakech Accords, Guyana has elected to classify land as forest if it meets the following criteria:

Tree cover of minimum 30%

At a minimum height of 5 m

Over a minimum area of 1 ha.

The forest area was mapped by Pöyry for GFC by excluding non-forest land cover types, including water bodies, infrastructure, mining and non-forest vegetation. The first epoch for mapping is 1990, and from that point forward land cover change from for forest to non-forest has been mapped and labelled with the new land cover class and the change driver (e.g. mining, agricultural concession, see table 1). GFC have conducted field inspections and measurements over a number of non-forest sites to verify the land cover type, the degree of canopy closure, the height of the vegetation and its potential to regenerate back to forest. The mapping was based on manual interpretation of Landsat TM and ETM+ imagery at approximately 1:25,000 using ArcGIS software. Mapping was conducted for the following epochs: 1990, 2000, 2005, 2009 and 2010. The 2009 epoch represents the Benchmark period for the Interim Measures and eventually for the MRVS.

In developing the MRVS it is vital that the 1990 and 2009 deforested areas are mapped accurately and forest area is estimated as precisely as possible. These data define 1990-2009 deforestation rate for the benchmark reporting period. The first task will be to quantify the precision of the estimate of forest area in 1990 since all subsequent mapping of deforestation builds upon the 1990 map. The second task is to validate the Year 1 deforestation area estimate using as well as GFC have mapped forest and non-forest land cover classes so that deforestation can be closely monitored but GFC also wishes to use a more refined map of forest types in order to assign to each class a potential carbon storage capacity and a level of risk of release into the atmosphere. The process of stratification will be informed by the forest type mapping, forest inventory data and modelling undertaken by Winrock for GFC.

The preliminary classification schema used by GFC is shown in Table 1 below. This conforms to the six broad land use categories in accordance with IPCC reporting guidelines.

[2] The precise area edited to account for coastal erosion between 1990 and 2009 is given as 21,129,348.5 ha.

Table 1: Land Use and Land Cover Classification

Class	Land use Category	Land use type	Comment	Change Drivers
Forest Land	Forest Land	Mixed forest	Grouped as forest for Interim measure reporting with Guyana's definition of forest applied for quantification within categories	Mining Shifting cultivation Selective and illegal harvesting of timber Shifting cultivation Fire
		Wallaba/Dakama/Muri Shrub Forest		
		Swamp/Marsh forest		
		Montane forest		
		Mangrove		
		Savannah >30% cover		
		Plantations		
Non forest	Grassland	Savannah <30% cover Grassland	Grouped as Non forest for Interim measure reporting with Guyana's definition of forest applied for quantification within categories	For the purpose of this exercise, no changes were mapped in the non-forest categories – this is a subsequent activity
	Cropland	Cropland		
		Shifting Agriculture		
	Wetland	Wetland open water		
		Herbaceous wetland		
	Settlements	Settlements		
	Other land	Other land		

2 INTERIM MEASURES MAPPING

2.1 Changes in Guyana's Forested Area 1990-2010

The Interim Measures Report (Pöyry, Jan 2011) estimated the area converted from forest to non-forest between 1990 and the Benchmark period (September 2009) as 74,917 ha. The estimate includes all forest to non-forest change including clearance for mining, road infrastructure, agricultural conversion and burning events that result in deforestation. The definition of deforestation specifically excludes forest degradation caused by selective harvesting, fire or shifting cultivation.

The area of deforestation for the Year 1 period (2009 to 2010) reported in the Interim Measures Report is 10,280 ha.

Table 2-1: Area Deforested 1990 to 2010 (after Poyry 2011)

Period	Forest Area ('000 ha)	Change ('000 ha)	Change (%)
Initial forest area 1990	18,473.39		
Benchmark (Sept 2009)	18,398.48	74.92	0.41%
Year 1 (Sept 2010)	18,388.19	10.28	0.06%

The rate of change statistic reported in the Interim Measures Report [Change (%)] is calculated from Equation1 (Puyravaud, 2003) and has been used to calculate annual rates of change.

Equation 1: Rate of Forest Change

$$q = \left(\frac{A_2}{A_1}\right)^{1/(t_2-t_1)} - 1$$

Taken from the Interim Measures Report (Pöyry, 2011), provides a breakdown by forest change drivers for the benchmark and year 1 periods.

Table 2-2: Forest Change Area by Period & Driver from 1990 to 2010 (after Poyry 2011)

Driver	Benchmark Period			Year 1
	1990 to 2000	2001 to 2005	2006 to 2009	2009-10
	Area (ha)			
Forestry	6,094	8,420	4,784	294
Agriculture	2,030	2,852	1,797	513
Mining	10,843	21,438	12,624	9,384
Infrastructure	590	1,304	195	64
Fire (deforestation)	1,708	235		32
Area Deforested	**21,267**	**34,249**	**19,400**	**10,287**
Total Forest Area of Guyana	18,473,394	18,452,127	18,417,878	18,398,478
Total Forest Area of Guyana Remaining	18,452,127	18,417,878	18,398,478	18,388,190
Deforestation %	0.01%	0.04%	0.02%	0.06%

Table 2-3: Annualised Rate of Forest Change by Period & Driver 1990 - 2010 (Poyry 2011)

Change Period	Change Period (Years)	Annualised Rate of Change by Driver — Forestry	Agriculture	Mining	Infrastructure	Fire	Annual Rate of Change (ha)
		Annual area (ha)					
1990-2000	10	609	203	1,084	59	171	2,127
2001-2005	5	1,684	570	4,288	261	47	6,850
2006-2009	4.8	1,007	378	2,658	41		4,084
2009-2010	**1**	**294**	**513**	**9,384**	**64**	**32**	**10,287**

Feedback from Norway and the US Forest Service on the data contained in tables 2-1, 2-2 and 2-3 taken from the Pöyry / GFC Interim Measures Report included the following comments:

1. The classification was based on the relationship between forest canopy cover and the Enhanced Vegetation Index (EVI).
2. Data from the preliminary accuracy assessment showed a certain bias in the estimates, although not statistically significant. Such biases could be reduced or eliminated by using the random sample of validation points as part of the estimation.
3. High resolution satellite images should be selected according to a statistically rigorous sampling design.
4. Do you plan to validate the accuracy of classification of historical images (i.e. by using historical high res. images), or assume that accuracy is the same when analyzing images from different points in time?
5. No presentation of uncertainties in area estimates, which might impact on conclusions drawn from the deforestation figures in the historical periods and for the first reporting period. There are obvious reasons to expect that the error margins could be considerable.
6. Given the importance that a change of deforestation rate will have in calculating Norway's economic contribution to Guyana, it would be of great interest to have data on the certainty of reported increase from 0.02% to 0.06% annual deforestation. Is it possible that these figures fall within each other's margin of error?

The approach taken in the sampling design seeks to address these questions by providing a rigorous approach using all of the available high spatial resolution imagery and providing standard errors to quantify the variability of the area estimates for the 1990 forest area map and the Year 1 deforestation map in particular. Providing rigorous estimates for the 2000, 2005 and 2009 epoch deforestation maps is severely limited by lack of suitable reference data for these periods (i.e. question 5 above). The other questions will be addressed by a rigorous accuracy assessment based mainly on newly available high spatial resolution imagery from 2010/11 as reference data.

3 SAMPLING DESIGN FOR VERIFYING FOREST AND FOREST CHANGE MAPPING

3.1 Maps to be validated

The problem here is to assess the accuracy of two countrywide thematic maps digitized primarily from Landsat TM and ETM+ imagery. The first depicts **Forest / Non-Forest** area for 1990 and a second map of **forest change** that contains attributes recording the data or epoch of change and interpretation of the cause of change. The maps were interpreted with a minimum mapping unit (MMU) of 1 ha and digitized manually at 1:25,000 scale using ArcGIS software. One Landsat scene was classified into forest / non-forest using an EVI threshold approach and afterwards checked and the digitizing edited manually (Pöyry, pers. comm.).

The task is to verify the thematic accuracy of the maps and our approach follows well established procedures:

1. Select the thematic criteria to be assessed and identify the data to be used for validation;
2. Determine the number of sample areas to be assessed;
3. Select the sample areas using an appropriate random or stratified sample;
4. Prepare a sampling grid and decision tree for thematic assessment;
5. Conduct sampling.

The desired goal of this validation is to derive a statistically robust and quantitative assessment of the uncertainties associated with the forest area and area change estimates.

As part of the external verification process the DNV assessment team asked the contractors to re-interpret and re-digitize forest change in a random sample of fifty 10km by 10km squares. This represents a check on the quality assurance process, especially where it pertains to the precision and care associated with digitizing. We note that *best efforts* are made when making interpretations from Landsat TM and ETM+ data and so we expect to see generalized lines when compared with what can be seen in the high resolution imagery.

Several factors potentially impact on the quality of forest mapping (GOFC GOLD, 2009), namely

- The spatial, spectral and temporal resolution of the imagery
- The radiometric and geometric pre-processing of the imagery
- The automated and manual procedures used to interpret the forest map category
- Cartographic and thematic standards (i.e. minimum mapping unit and land use definitions)
- The availability of field reference data for evaluation of the results.

It is clear that accepted approaches were used to minimize these sources of error following IPCC and GOFC-GOLD good practice guidelines as appropriate.

The representativeness of sample selection of the original Interim Measures Report was significantly compromised by the restricted availability, cloud cover, temporal specificity and uneven spatial distribution of high resolution reference imagery over Guyana. This situation has improved with the acquisition of RapidEye, Ikonos and DMC data in late 2010 and early 2011.

The verification process used follows recognised design considerations in which three distinctive and integral phases are identified: response design, sampling design, and analysis and estimation (Stehman and Czaplewski, 1998).

3.2 Response Design

In this section we explain the criteria used to validate the 1990 Forest / non-Forest maps and the Forest Change map product for 2009-2010. Table 3.1 summarises the data available to validate the boundaries and attribute labels for each map polygon. Figure 3-1 illustrates the areas covered by the Very High Resolution (VHR) imagery that will be used to validate the Year 1 deforestation mapping, and figure 3-2 illustrates the area covered by the medium resolution imagery used to supplement the VHR imagery for the 1990 forest / non-forest mapping.

The image data are described according to information we received from GFC and Pöyry, and according to existing documentation and metadata.

A critical component of any accuracy assessment is the need for accurate reference data (Herold et al, 2006; Powell et al 2004). It is often the case that reference data itself contains errors and is not a gold standard and at least one study reports large differences of the order of 5-10% between field-based and remotely sensed reference data (Foody, 2010; Powell et al. 2004). Therefore, a key aspect of the response design is to use reference data that allow forest / non- forest land cover to be classified with certainty. In this case the spatial resolution of VHR imagery is higher than the Landsat TM and ETM+ data used for the forest and deforestation mapping. The mapping and change detection was done by Pöyry team through manual interpretation and digitizing by a small team (4 persons). For consistency, the VHR imagery will also be manually interpreted by a small team (also 4 persons) with knowledge of the landscape and land cover types. It is also the case that typical land cover change events that lead to deforestation occur on a scale considerably larger than the resolution of the VHR imagery. Any misinterpretation or labelling error is most likely to arise from human error or interpretation using poor quality imagery (e.g. lack of contrast in CBERS panchromatic data) or areas in partial cloud shadow. For this reason the response design allows these areas to be coded as *Omitted*. It is helpful that the classification is binary in nature and the verifying team are not faced with the more complicated task of assessing forest or land cover type where spatial, spectral and radiometric resolution can be limiting factors (Khorram, 1999).

Table 3-1: Data sources used for validation

Application	Dataset used	Provider	Sensor	Spectral Range	Date of Acquisition	Pixel size (m)	Area (ha)	% of Guyana
Forest Change	CBERS_2B_HRC	INPE	CBERS HRC	Pan	Aug-Oct 2009	2.7	869596	4.12
	IKONOS Geo	GeoEye	IKONOS	MS	June-Dec 2009	4	575032	2.72
	RapidEye	RapidEye	RapidEye constellation	MS	Dec 2010 - Jan 2011	5	17533060	8.30
	Overflights	Durham University	Digital Camera	Colour	16/02/2011	Variable	225000	1.06
Total for forest change (notice that there are no overlaps)							3422688	16.20
1990 Forest / non-forest	CBERS_2B_HRC	INPE	CBERS HRC	Pan	Aug-Oct 2009	2.7	869596	4.12
	IKONOS Geo	GeoEye	IKONOS	MS	June-Dec 2009	4	575032	2.72
	RapidEye	RapidEye	RapidEye constellation	MS	Dec 2010 - Jan 2011	5	17533060	8.30
	DMC	DMC International	DMC MS	MS	Aug-Dec 2010	22-32	10992522	52.02
	SPOT	SPOT Image	SPOT XS HRV	MS	2006-2009	20	3443997	16.30
	ASTER	JAXA	VNIR	MS	June 2010	15	389177	1.84
	RADAR	JAXA	ALOS - Palsar	Pan	Various	Variable		
Total for 1990 Forest / non-forest (notice that there are overlaps)							18023384	85.30

LANDSAT

The two map products *to be validated* were derived from Landsat TM and Landsat ETM+ data. The selection criteria and image processing used to derive these data for the five time epoch used in the Interim Measured Report are documented in the report in chapter 4 and chapter 5 respectively. We note that orthorectified Landsat data were not available for all areas of Guyana and for all time epochs but that care was taken to ensure a good visual match between the underlying Landsat mosaics, the maps being validated and the imagery used for verification. Landsat will not be used for map validation but will be useful to help identify the period to which deforestation omitted from the Year 1 change maps should be attributed to.

The 1990 Landsat data is generally of good quality but the North of Guyana is cloud covered partially obscuring some areas. Therefore, the validation team ordered an additional set of georectified imagery from the USSG in February 2011. These data were different from the Pöyry-GFC data and had less cloud cover in the North and North-east. These data were used to assist with interpretation of the 1990 Forest-Non-forest map.

CBERS

The China Brazil Earth Resources Satellites CBERS 2B carries a panchromatic high resolution camera (HRC) with 2.7 m resolution 27 x 27 km extent. CBERS HRC images were acquired by GFC from INPE, Brazil. These data were automatically projected from satellite ephemeris data but on inspection were offset in latitude. For this, a manual correction was applied using a number of ground control points (GCPs) and polynomial model to realign the CBERS data to UTM coordinate system so that they overlay on the 1990 Forest cover map and the Year 1 deforestation map. Thirteen (13) CBERS HRC images cover the sample design area and are relatively cloud free (less than 10% cloud cover). This imagery was acquired in 2009, thus it was only used as a support to the DMC and Landsat ETM+ 2010 so as to help the valuators with its higher spatial resolution to be more precise in their interpretation.

RAPIDEYE

RapidEye is a constellation of five high resolution visible and near infrared satellites. These acquire five band multispectral imagery at 6.5 m nominal ground pixel size. These data were provided to GFC as a Level 3A orthorectified image product using a Landsat orthorectified mosaic for horizontal control and SRTM v4.1 for height control (total accuracy 30m CE90 at worst; February 2011 Product Guide; www.rapideye.de). The imagery was resampled by cubic convolution. The RapidEye data contain clouds for which an unusable data mask (udm) file was produced and delivered by RapidEye. This mask highlights the areas of unusable data within an image but it fails to detect small clouds, haze and cloud shadows. However the data are of good quality and remain useful for validation purposes.

IKONOS

Three sets of multispectral IKONOS data are available. There was no metadata available however at worst these data are IKONOS Multispectral Geo™ products (15m CE90). The data available for validation purposes are 3 band (red, green and blue) 4m pixel size. This imagery was acquired in 2009, thus it was only used as a support to the DMC and Landsat ETM+ 2010 so as to help the valuators with its higher spatial resolution to be more precise in their interpretation.

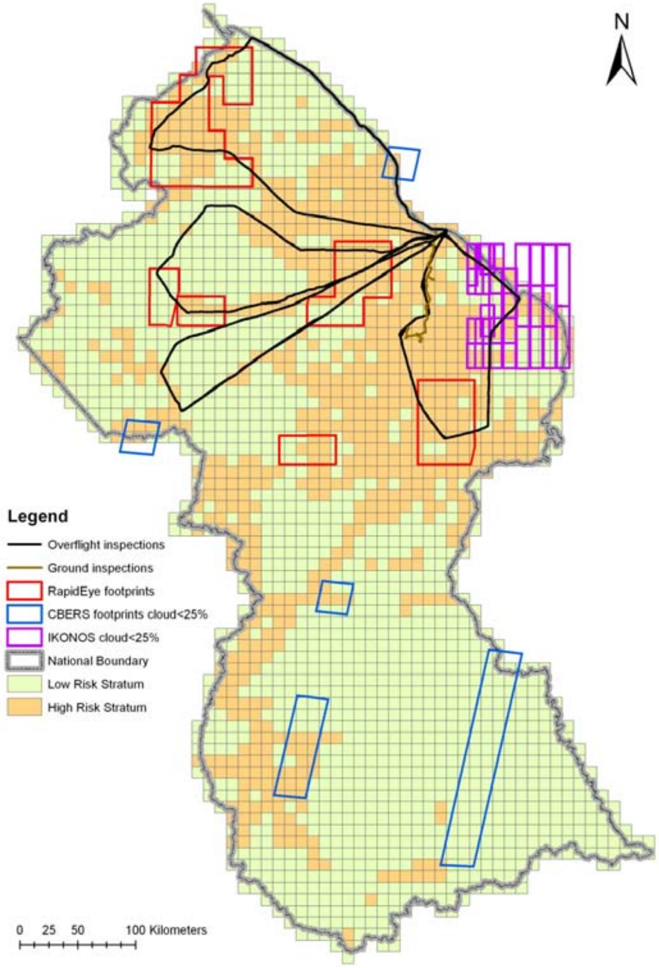


Figure 3-1: High Resolution Data available for validation

DMC

GFC tasked DMC to acquire multispectral imagery using the constellation of DMC satellites from September 2010 to February 2011. DMC provided both the raw imagery and orthorectified products. The resolution of the mosaic shown in Fig 3-2 varies from 22 m to 32 m depending on which of the three satellites was used to acquire the data (UK DMC-2 and Deimos-1: 22 m or Beijing-1: 32 m). The target cloud cover threshold is set to 10% however very few areas are cloud-free and so the data are used to validate the 1990 Forest cover map only.

SPOT

One hundred and eleven SPOT scenes are available for Guyana spanning a period of acquisition from 2006 to 2008 (World Wildlife Foundation). This dataset includes images from SPOT 2, 4 and 5 satellites and so the spatial resolution ranges from 10 to 20 m. These images were processed to level 2A meaning geo-referenced not ortho-corrected. The Interim measures Report 2011 states that there was an offset observed between the SPOT images and geo-referenced Landsat mosaic and that manual referencing was needed to reference these images to the 1990 Landsat base.

Eleven (11) scenes were selected to assist with the verification of the 1990 Forest / non Forest map on the criteria of cloud cover less than 25%.

ASTER

GFC through Pöyry recently purchased ALOS (10 m) and ASTER 15 m data. The ALOS is cloud covered but one ASTER data set for the south of Guyana is useful. The ASTER data is a Level 1A multispectral data product (visible and near infrared spectral bands) with 15 m pixel size from 25th July 2009. The data were georeferenced to the Landsat mosaic.

RADAR

Several radar datasets exist over Guyana. Historical coverage 1995-96 is available from Japanese Earth Resources Satellite (JERS-1). These images cover the wet and dry season and have previously been used by FRIU to assist in the production of the 2001 national forest cover map. The individual tiles (100 m resolution) were mosaicked and the two time periods combined to create a single composite image.

Additional data are available via the Forest Carbon Tracking Portal (www.geo-fct.org) and include 2008-2009 RADARSAT 2 images and PALSAR (Phased Array type L-band SAR) images. GFC has received 22 multi-temporal (12/10/2010) single and dual polarised (50 m resolution) PALSAR scenes that provide partial coverage of central Guyana. These scenes span from 2008 to the end of the 2009 benchmark period.

The spatial resolution, as well as the nature of the backscatter product, is not of sufficient quality to allow interpretation of forest change and forest change drivers and so these RADAR data were not used in the verification process. In future, it may be possible to use fine beam-mode RADAR products to assist with change detection analysis.

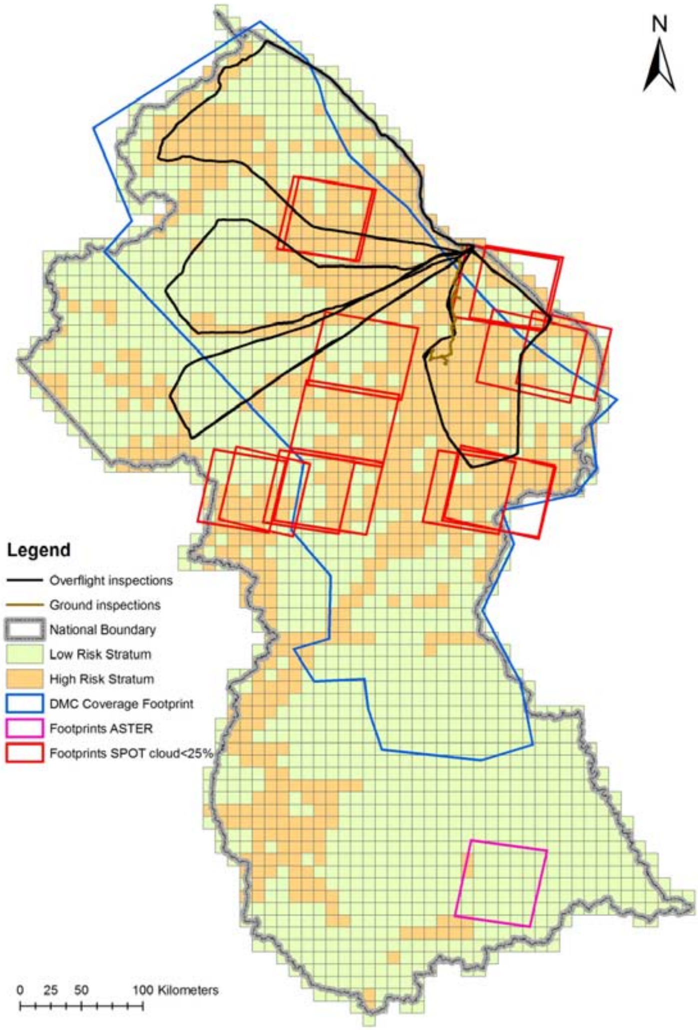


Figure 3-2: Medium Resolution Data available to help validate 1990 Forest / non forest map

3.3 Additional Verification Datasets

The difficulties posed in acquiring timely, cloud free, high resolution satellite imagery (5 m resolution or better) limit, to some extent, the spatial extent of the sample used to verify the Year 1 deforestation map.

Four overflights were undertaken using a Cessna 172 high wing light aircraft to provide high resolution photography of the ground from at altitude of 1,000-1,500 ft (see figure 3-3). GPS tagged oblique pictures were taken using digital cameras from both sides of the aircraft using 5 megapixel digital cameras. We estimate that each photograph captured an image of a 100 ha area every 1.5 km providing near total coverage of an area of 225,000 ha in total from four flights (see figure 3-4). We had access also to historical vertical aerial photography flown between the 1950 and 1970s. Selected photos from this coverage were used by the original mapping team to help map non-forest in inaccessible areas that have not undergone change or were persistently cloud covered.

Figure 3-3: The Cessna 172 and the pilot and observation team.

Figure 3-4: Example over flight photography (TL: clearance for agriculture; TR secondary road almost invisible; BL mining; BR zoom of mining camp / dredge)

3.4 Data provided by Guyana Forestry Commission

The Forest Resource Information Unit (FRIU) holds a range of operational spatial data that were used to assist in the stratification into areas of high and low risk of deforestation. A summary of the spatial layers is provided in Table 3.2.

Table 3-2: GFC GIS Datasets

Data Group	Layer Name	Created/ Update freq	Description
Admin	guyana_boundary	August 2010	Updated country boundary for Guyana.
Hydro	Waterbody	August 2010	Waterbodies layer, digitised from geocorrected Landsat imagery. Layer integrated into the 1990 forest / non-forest map
Managed Forest Areas	State_Forest_2006	2006	Layer showing the extent of the state forest boundary.
	TSA_WCL_Merged	6 monthly	A merged layer showing all active Timber Sales Agreements (TSA) and Wood Cutting Leases (WCL) (large forest concessions)
	PropSFEP_Merged	6 monthly	A merged layer of all proposed State Forest Exploratory Permits
	activeSFEP_Merged	6 monthly	A merged layer of all active State Forest Exploratory Permits.
	activeSFPs_Merged	6 months	All active State Forest Permits (small forest concessions). Merged by Division – Demerara, Essequibo, Berbice, North West
	logging_Camps	NA	Point location of logging camp sites, based on the Annual Operating plan.
	harvest_Areas	NA	Polygons showing extent of harvest activities (pre 2008, 2008 & 2009)
Roads	gps roads_dd	3-6 months	All GPS roads and trails as at August 2010.
Agricultural Leases	GFCAGleases	Upon titling	Agricultural leases that fall within the State Forest Estate (Administrative Regions: 1, 2, 3, 6, 7, 8 and 10)
Mining Areas	LRG_Scale-Aug2010_region, MED_Scale-Aug2010_region, Mining_dredges	Upon granting of mining permit/licence/claim	Large and Medium scale mining areas including dredge locations.

3.5 Sampling Design

The sampling design refers to the methods used to select the locations at which the reference data are obtained.

To assess the 1990 forest/non-forest map and the Year 1 deforestation map a two phase sampling strategy was adopted. In the first phase, a square grid of 10km by 10km in size was created within the spatial extent of the country's national boundary[3]. This resulted in 2296 squares; note that squares intersecting the boundary are also selected (figure 3-5).

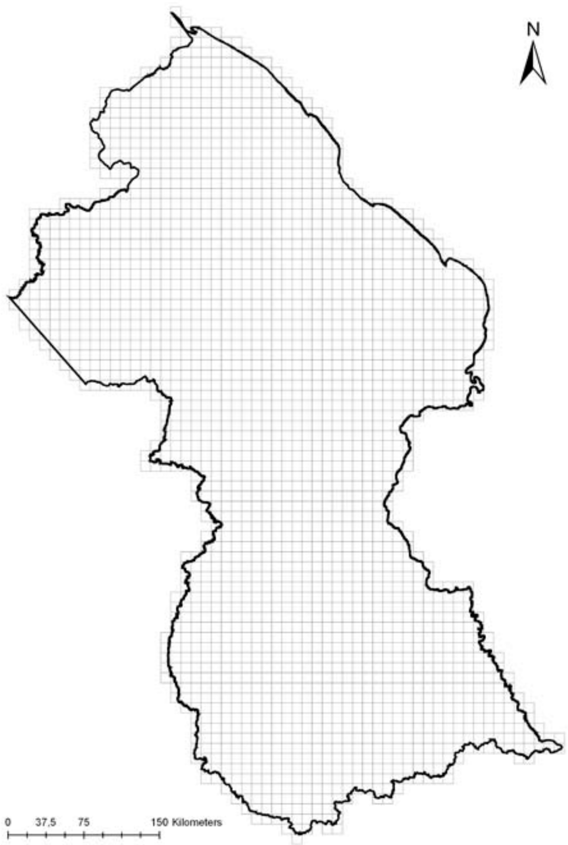


Figure 3-5: A grid of 10km by 10km in size was created within and intersecting the national boundary of Guyana.

As the area of the country is large, and deforestation is observed to be clustered around relatively small areas of human activity, it is more efficient to adopt a stratified sampling framework than use simple random or systematic sampling (Gallego, 2000; Foody 2004; Stehman, 2001). For each stratum, sample means and variances can be calculated; a weighted average of the within stratum estimates is then derived, where weights are proportional to stratum size. In this case, the goal is to improve the precision of the forest (or deforestation) area using a stratum-based estimate of variance that will be more precise that using simple random sampling (Stehman and Czaplewski, 1998; Stehman, 2009b). Based on geographical data provided by GFC, grid squares were stratified according to factors closely associated with risk of deforestation. In particular, data about the location of logging camps, mining dredges, settlements, and the existing road

[3] According to the Interim Measures Report January 2011, the national boundary was defined by following information received from the GL&SC and with the aid of Landsat imagery.

network were used (see Table 3-3). This way, all grid squares that satisfied the following criteria were selected.

Contain at least one of: logging camps, mining dredges, or settlements,
OR
Intersect with at least one road.

This resulted in the classification of grid squares into two strata. The ones that satisfied the criteria (named "High Risk") and the ones that did not satisfy the criteria (named "Low Risk"). This resulted in 806 "High Risk" squares and 1490 "Low Risk" squares (see figure 3-6).

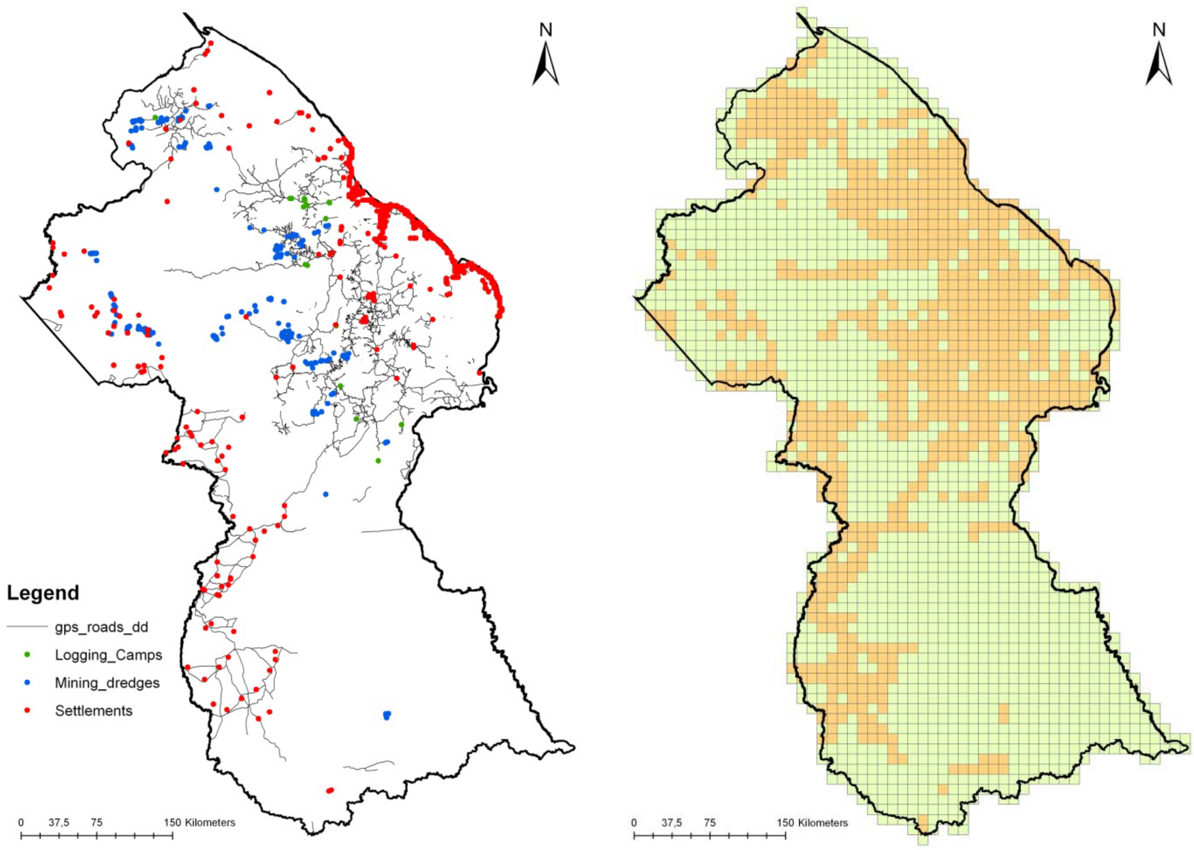


Figure 3-6: Criteria for the stratification of the sampling (left image), and the two strata created along with the fit with deforestation layer (right image).

Figure 3-7 shows an overlay in red colour of the deforestation data (for all years 190-2010) on the sampling stratification map. It demonstrates that about 85% of the deforestation (all years – 1990-2010) falls within the "High Risk" stratum with the remaining 15% falling within the "Low Risk" squares. Note that these figures are based on the area of deforestation present within each grid square not differentiated by time period at this stage. The map suggests that there is a low probability of sampling deforestation in the Low Risk stratum and so, in order not to under sample and miss deforestation events in this stratum, a weighting was applied when randomly selecting grid squares to analyse in detail. The method used was to randomly sample 70% of the High-Low Risk squares and 30% of the Low Risk grid squares. This resulted in a random sample of 564 "High Risk" squares and 447 "Low Risk" squares (see table 3-4).

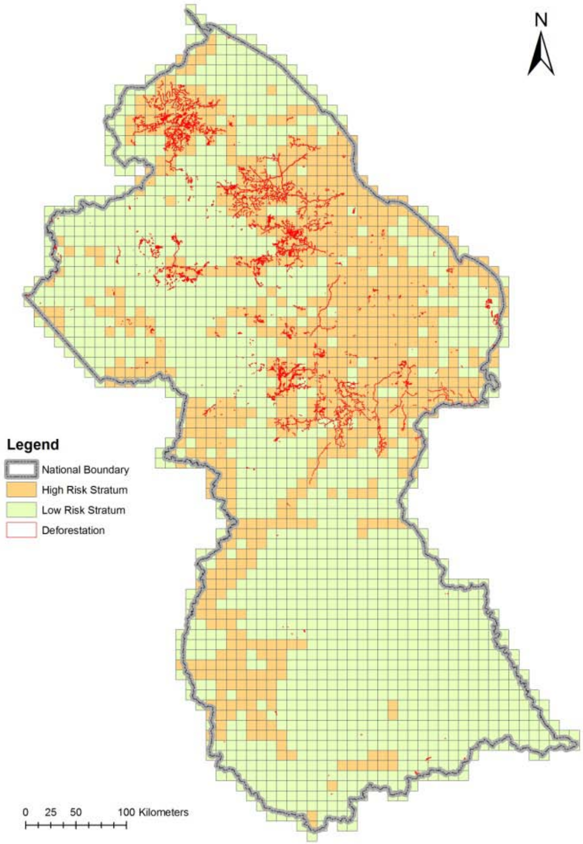


Figure 3-7: The mapped deforestation appears 85% within the "High Risk" and 15% within the "Low Risk" sample squares.

Table 3-3: Spatial data used to help stratification

Data Group	Layer Name	Created/ Update freq	Description
Admin	guyana_boundary	August 2010	Guyana Boundary Digitised from waypoints and instructions received from GL&SC, and Landsat imagery.
Managed Forest Areas	logging_camps	N/A	Point location of logging camp sites, based on the Annual Operating plan.
Roads	gps roads_dd	3-6 months	All GPS roads and trails as at August 2010.
Mining Areas	mining_dredges	Upon granting of mining permit/licence/claim	Mining Dredge sites normally found in/around rivers
Population	settlements	N/A	An extraction of a number of larger settlements from the placenames point feature class.

The assessment of deforestation in particular relies upon the availability of VHR (Very High Resolution) imagery in order to make reliable judgements about the nature of any change observed. The response design details the type and distribution of VHR data available for the accuracy assessment. Therefore, the second phase of the sample design selects a sub set of the grid squares from the first phase that fall within the footprints of the VHR data. This resulted in 117 “High Risk” squares and 46 “Low Risk” squares (see figure 3-8).

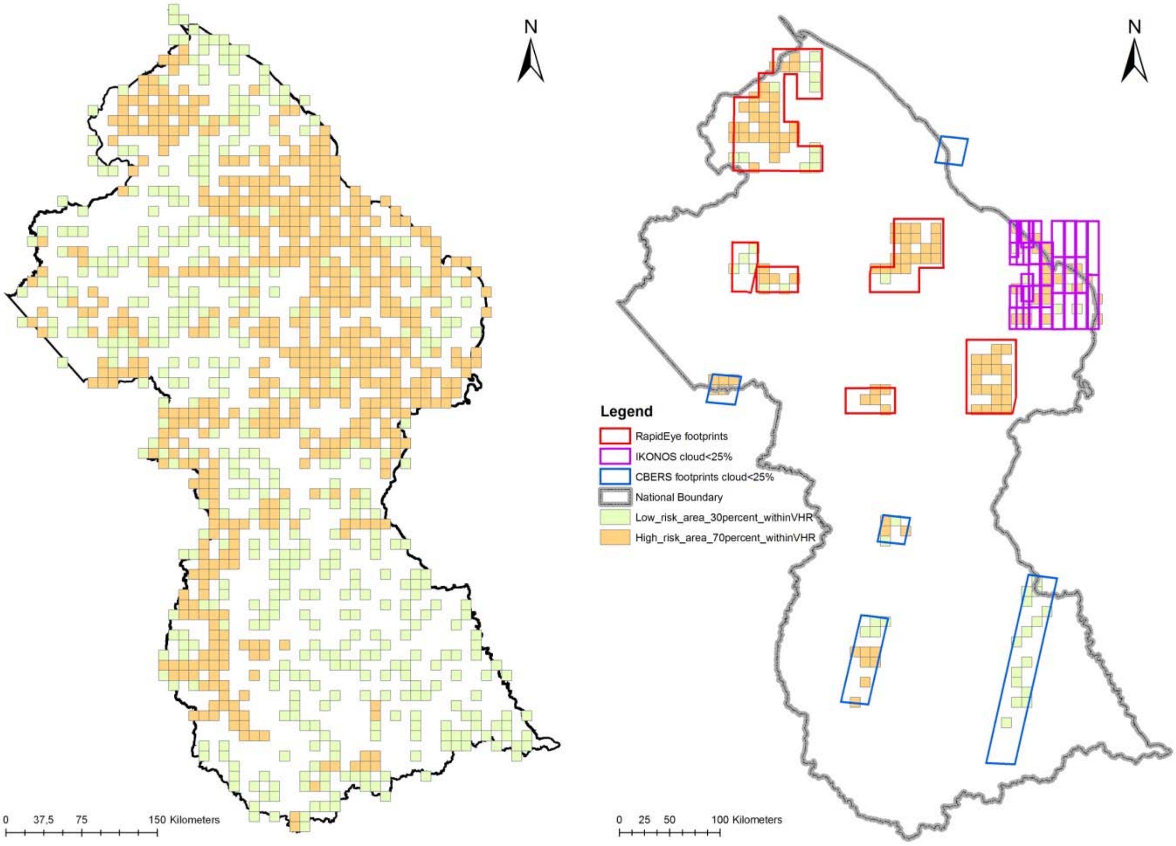


Figure 3-8: Phase 1: Random sampling of the High Risk (70%): Low Risk (30%) strata (left image). Phase 2: sample squares that fall within the coverage of available very high resolution (VHR) imagery (right image).

Table 3-4: Area represented on each stratum

	Total number of squares	Area (hectares)	Percent of Guyana area
Total Grid	2296	22,960,000	108.6%
High Risk	1490	14,900,000	70.5%
Low Risk	806	8,060,000	38.1%
70% random	564	5,640,000	26.7%
30% random	447	4,470,000	21.2%
HR within VHR imagery	117	1,170,000	5.5%
LR within VHR imagery	46	460,000	2.2%

Within each grid square, a systematic sample of points at regular 500m intervals was created, yielding 361 points in each sample square. These points were then buffered to create a circular sampling area of one hectare in size corresponding to the minimum mapping unit (MMU), see figure 3-9. Each of the grid squares is assigned an ID according to its centre point location, and each of the sampling circles has an ID according to its respective centre point location. In total, 58843 one hectare sampling areas are available for accuracy assessment.

For each sample area, the land cover class (e.g. Forest or Non-Forest) is determined for both the 1990 Forest / Non-Forest map and the 2009-2010 Year 1 deforestation map. The assessment follows a systematic procedure where the GIS table for the samples is populated using the ArcGIS toolbar shown in figure 3.10. For the **1990 Map** the interpretation proceeds as follows:

1. Is the area **mapped as Forest in 1990**? If **yes**, then is it interpreted as forest in the 1990 epoch Landsat imagery? If **yes**, then sample is classified as **Forest1990-Correct**.
2. Is the area **mapped as Non-Forest in 1990**? If **yes**, then is it non-forest in the 1990 epoch Landsat imagery? If **yes**, then is it non-forest in the high resolution validation from 2009/2010 (i.e. between 1990 and 2010 never mapped as either non-forest or deforested)? If yes, then sample is classified as **NonForest1990-Correct**.
3. Is the area **mapped as Forest in 1990**? Is the area seen in the 1990 epoch Landsat data as forest? If **no**, is it interpreted as deforested at any epoch between 1990 and 2010? If **no**, then sample is classified as **Forest1990-Incorrect**.
4. Is the area **mapped as Non-Forest in 1990**? Is the area seen in the 1990 epoch Landsat data as forest OR is it seen as forest in the high resolution validation from 2009/2010? If **yes**, is it interpreted as forest or has returned to forested following degradation and classified as **NonForest1990-Incorrect**.
5. Is the area seen in 1990 / 2010 is obscured from view? If so then mark as omitted from analysis. This is normally because of cloud or cloud shadow.

Specifically the tools used to interpret and validate the 1990 map data included Pöyry 1990 Landsat data, additional 1990 Landsat data obtained by Durham from USGS and imagery from post-1990 where appropriate (see table 3-1). We also had made available to us historic air photos mainly pre-dating 1990, land use maps and GIS data indicating forestry and agricultural concessions.

For the Year 1 (2010) map the interpretation proceeds as follows:

1. Is the area **mapped as forest in 2010 (Year 1)**? If **yes**, then is it forest in the high resolution validation from 2010 imagery? If **yes**, then sample is classified as **Forest-Correct**. No driver label is needed and a confidence label on a 0-4 scale is given.

6. Is the area **mapped as non-forest in 2010 (Year 1)**? If **yes**, then is it non-forest in the in the high resolution validation from 2010 imagery? If **yes**, then the sample is classified as **NonForest-Correct**. No driver label is needed and a confidence label on a 0-4 scale is given.
7. Is the area **mapped as forest in 2010 (Year 1)**? Is the area seen in the high resolution validation from 2010 imagery as forest? If **no**, has it been interpreted as deforested at any epoch between 1990 and 2010 (GIS check)? If **no**, then sample is classified as **Forest-Incorrect**. A **Driver label** is needed (e.g. Agriculture, Settlement, Road, Mining, Burning) and a **Confidence label** on a 0-4 scale is given.
8. Is the area **mapped as non-forest in 2010 (Year 1)**? Is the area seen in the high resolution validation from 2010 imagery as forest? If **no**, has it been interpreted as deforested at any epoch between 1990 and 2010 (GIS check)? If **no**, then sample is classified as **NonForest-Incorrect**. A **Driver label** is needed (e.g. Agriculture, Settlement, Road, Mining, Burning) and a **Confidence label** on a 0-4 scale is given.
9. Is the area obscured from view by missing data or cloud or outside the national boundary (e.g beyond coastline)? If so then mark as omitted from analysis. This is normally because of cloud or cloud shadow.

Note that in applying the above procedure the interpreters were trained in, and followed, the mapping rules specified in the Pöyry Mapping and Satellite Image Interpretation Guide (Pöyry 2011b).

When assessing the Year 1 map, any areas seen to be incorrect were labelled with a deforestation driver or marked as afforested. The approach to interpreting the correct driver relied on following the Mapping Rules that include identifying the cause of deforestation and field and air survey experience (see figure 3.4 and Pöyry 2011b).

The most important points to note are:

1. Areas of forest degradation are treated as 'unchanged' forest as only deforestation is being assessed.
2. Areas of shifting cultivation are generally small in size (under 5 ha) and are treated as forest as these have the potential to return to canopy closed woodland.
3. Areas of infrastructure including settlements are classified as non-forest as are water bodies.
4. Areas cloud and shadow or missing data are labeled as *Omitted*.
5. Areas representing Year 2 change were also omitted from the analysis as this change postdates the Year 1 reference imagery. These areas are labeled as Year 2 in the GIS database.

The rules for validating each point account for small discrepancies between the original mapping that was digitized at 1:25,000 scale from Landsat TM and ETM+, and the VHR data that can normally be interpreted at 15,000 scale. Minor discrepancies might include digitizing error due to map generalization and map-to-image misregistration. These are distinct from factors that might explain misclassification or mislabeling in the mapping or indeed in the validation of the mapping. Misclassification can occur due to poor radiometric quality of imagery, spectral overlap among classes, scale / resolution of imagery and human error.

Furthermore, where a discrepancy between the mapping and the validation data is detected, an interpretation will be made of the correct assignment for the sample point. A toolbar was created by Pöyry and modified by the Durham team so that both errors of omission and commission could be tagged; that is each label A,B,C,D in table 3-5 could be selected. For errors of omission, the interpreter could assign the correct land cover class and, if the area has been deforested in the 2009-10 period, make an assessment of the driver causing the change (see Figure 3-10). The toolbar also included a confidence label on a 0-4 scale. This allows for uncertainties in interpretation to be removed from the estimation and validation process if required.

The two-phase stratified sampling strategy adopted uses a large sample size that will allow for assessment of the true extent of false positives and negatives in accordance with the GOFC-GOLD (2006) recommendations. Note that the right hand side of the interpretation toolbar contains a dropdown database entry to represent the confidence or certainty of the interpretation. Uncertainty, in this case refers to doubt in the interpreters mind about the nature of the change observed not the classification between forest and non-forest. The uncertainty will refer to confidence in interpreting the driver for change and is recorded on a four interval percentage scale

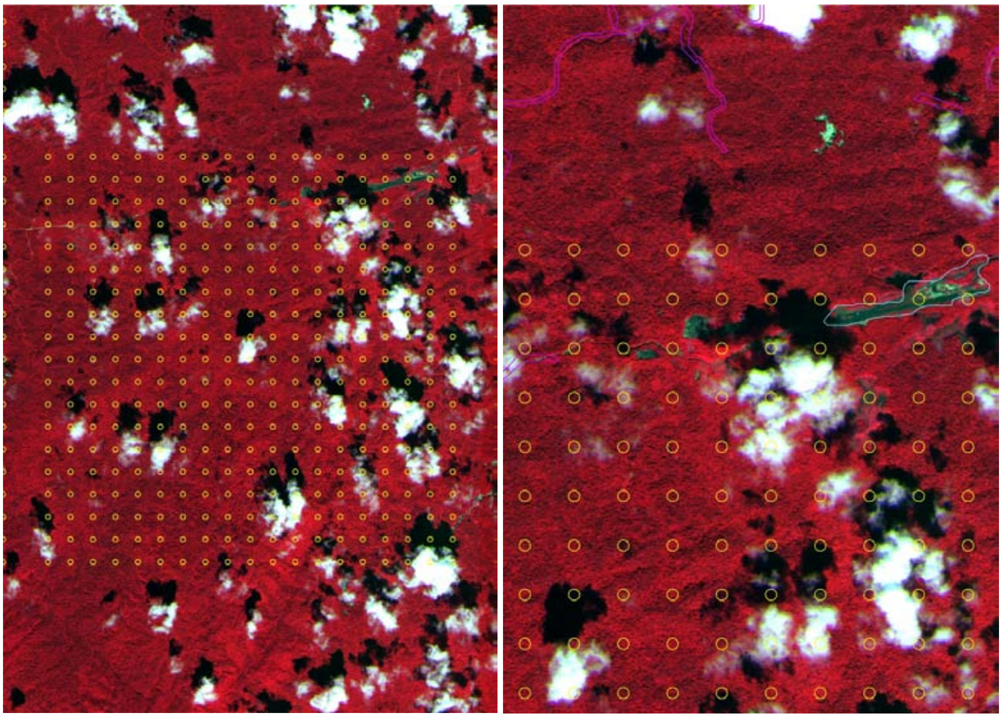


Figure 3-9: Systematic sampling showing 361 one hectare sample points superposed on a false colour 5 m resolution Rapid Eye image (left image). Zoomed in systematic sample grid showing the deforestation later added to the view frame (right image)

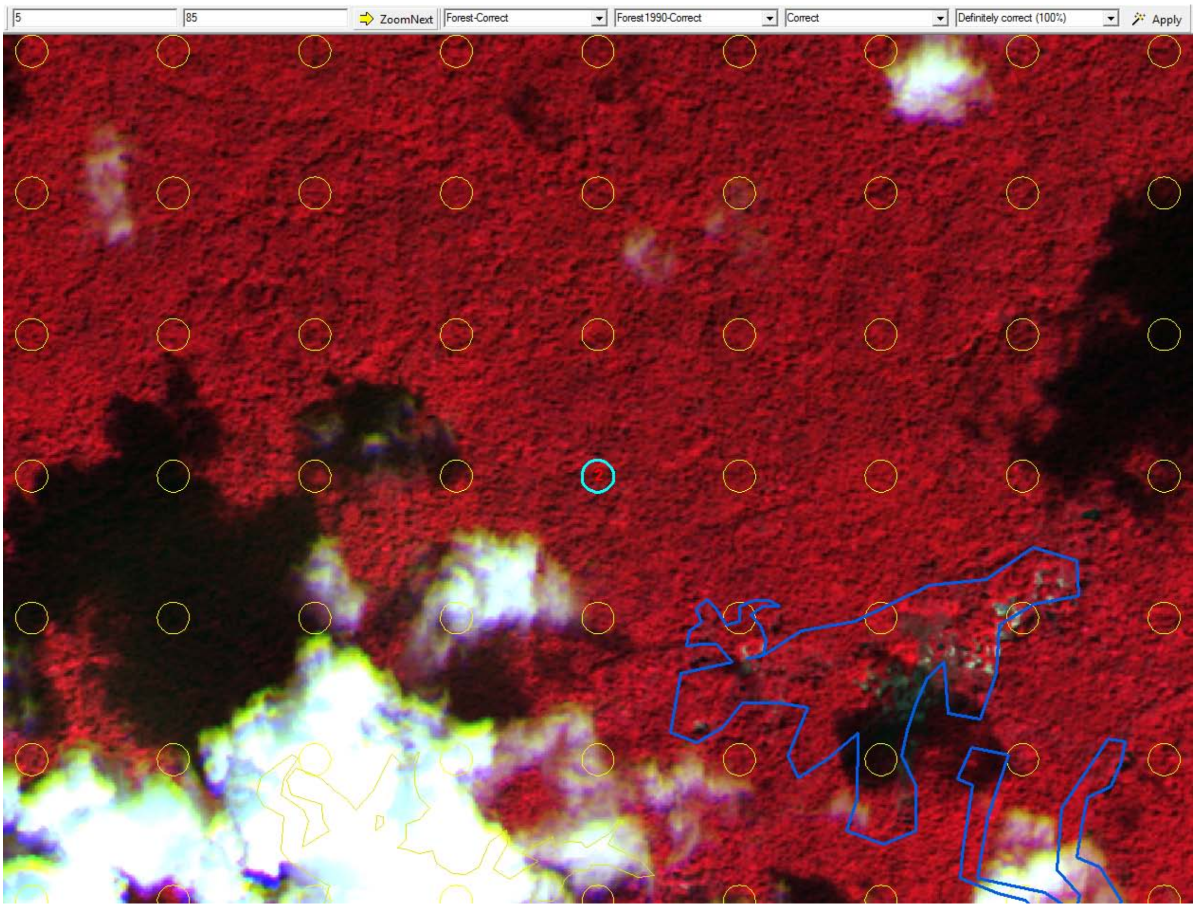


Figure 3-10: The interpretation toolbar (top of image)

3.6 Analysis and Estimation

The analysis procedure, assisted by the toolbar will proceed to validate the points within each sample grid square. These data will be recorded in a database, one for each stratum, and used to generate a cross tabulation between reference data and the maps. The structure of the tabulation, sometimes called a confusion or error matrix is shown in table 3-5. This matrix is widely used to quantifying the quality of the classification and characterizing the error (Foody, 2002; Story and Congalton 1986; Van Oort 2007). The labels assigned to sample points in the reference data are cross-tabulated against the mapped classes for each sampling frame.

Table 3-5: Structure of accuracy assessment matrix

<table>
<tr><th rowspan="5">Map</th><th rowspan="2">Class</th><th colspan="4">Reference Data</th></tr>
<tr><th>No change</th><th>Change</th><th>% of Total Area</th><th>User Accuracy</th></tr>
<tr><th>No change</th><td>A</td><td>B</td><td>X</td><td></td></tr>
<tr><th>Change</th><td>C</td><td>D</td><td>Y</td><td></td></tr>
<tr><th>Total</th><td>x’</td><td>y’</td><td>100</td><td></td></tr>
<tr><th colspan="2">Producer Accuracy</th><td></td><td></td><td></td><td></td></tr>
</table>

Cells **a** and **d** represent map areas that have been validated as correct. Counts in cell **b** are false negatives and those in cell **c** false positives. Interpretation of these data assumes that the reference data are error free, that the sampling is unbiased and of sufficient size. Nevertheless, the confusion matrix provides a simple and convenient method to illustrate the nature of any disagreement between the map and the reference data.

The accuracy of a class is expressed in two ways, as a user's and producer's accuracies (Story and Congalton 1986; Van Oort, 2005). The user's accuracy indicates the probability that land classified into a given land cover class by the map is actually that class on the ground. It is also referred to as the error of commission as sample points that are incorrectly classified are commissioned into another class (i.e. forest misclassified as non-forest or the reverse).

The producer's accuracy provides a measure of accuracy of the classification scheme. The producer accuracy is also known as the error of omission because areas that have been incorrectly classified are “omitted” from the correct class. This accuracy indicates how well the sample points falling on a given land cover type are classified, i.e., it is the probability of how well the reference data fitted the map.

For a simple random sample the user's accuracy is calculated by dividing the number of correctly classified sample points in each class by the total number of sample points classified in each class (row total). The producer's accuracy value is calculated by dividing of the total number of correctly classified plots in each class by the total reference data plots in each class (column total).

Unlike a simple random sample, raw counts in a stratified sample cannot be directly used to make unbiased statistical estimates. For stratified random sampling, each cell must converted into an estimated joint probability (the proportion of total class counts per percentage class area) before the assessment statistics are derived.

3.7 Precision of area estimates for Forest / Non-forest and Year 1 Deforestation maps

The two-phase stratified sampling design optimises the probablitiy of sampling deforestation in Year 1 when the are mapped as deforestation represents only 0.06% of the national land area. There are several factors such as cloud cover, accessibility, safety and cost that limit the availability and quality of reference data. However, it is vital to provide a very percise estimate of the uncertainty attached to the area statistics provided in the Interim Measures Report.

A key consideration is minimising the risk of intoducing any possible bias into the estimates. Bias may arise from sampling, from cloud cover patterns and perhaps from the distribution and coverage of the reference data. Sampling bias can be assessed from the joint probabliity matrices. The distribution of cloud cover has been assessed qualitatively from cloud cover masks but this can be quantified more formally from the sample area data and from the cloud mask data derived from analysis of the VHR satellite imagery. A more subjective measure is the spatial coverage of the available reference data. Table 3-6 shows the distribution of sample grid on the 2010 Land Cover map of Guyana for each sampling stratum. This suggests that the sample covers all of the land cover classes (none are omitted) and that the most important land cover classes, the Mixed Tropical Forest and Montane & Steep Forest classes, are sampled most intensively.

Table 3-6: Intersection of sample grids on the 2010 Land Cover map

Location of Sample Grid Centre	High Risk Stratum	Low Risk Stratum
Savannah	2	0
Mangrove	0	1
Mixed Forest	55	23
Montane & Steep Forest	16	6
Swamp/Marsh Forest	8	8
Wallaba/Dakama/Muri Shrub Forest	6	2
Waterbodies	19	4
Non Forest incl 1990 infrastructure	3	1
Outside national boundary	8	1
TOTAL	117	46

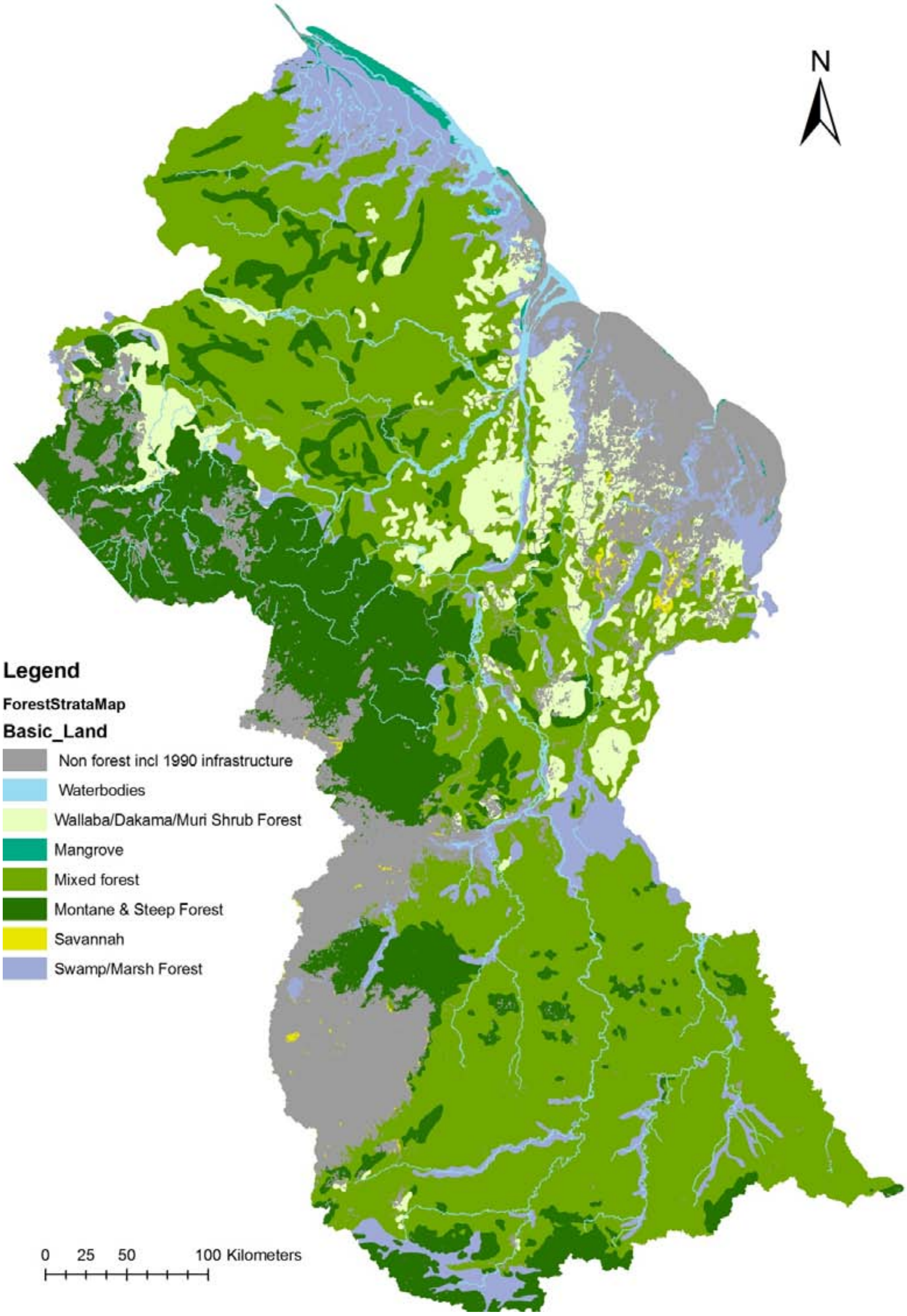


Figure 3-11: Forest strata map (notice that small areas disappear in this scale).

4 RESULTS

Results are organised into three sections. First, an assessment is made of the quality of the mapping undertaken by Pöyry-GFC based largely on interpretation of Landsat TM and ETM+ imagery. Secondly, we assess the consistency of the interpretations made by the validation team to ensure that the quality of the reference data is of a good standard. Thirdly, we present estimates of forest area for 1990 and 2010 based on the two-phase stratified sampling design. Finally, we assess the rate of deforestation over the Benchmark period and make an estimate of the Year 1 Deforestation Rate.

4.1 Quality of Mapping

The prevalence statistic is a good measure of overall correspondence between the map and reference data. We found that for both 1990 and for 2010, prevalence was greater than 0.96 or 96% agreement, see tables 4-1 and 4-2. This is a very high figure, better than one would expect from automated classification of multispectral remotely sensed data, and is almost certainly explained by the manual process of interpretation and on-screen digitizing. We also note that the reference data are not perfect, about 7% of the sample area could not be used because of missing reference data or because the ground was obscured by cloud or cloud shadow. Missing reference data were excluded from the analysis.

Table 4-1: Error matrix for Forest-Non-forest 1990 map

1990 Forest – Nonforest map	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
Map	Forest	22799	737	23536	96.9%
	Non-forest	106	5038	5144	97.9%
	Total	22905	5775	28680	
Producer Accuracy		99.5%	87.2%		97.1%

1644 Omitted.

Table 4-1 is not weighted by strata and should only be used to note the correspondence between Map and Reference data. Note, however, that 737 (12.8%) of sample areas that were mapped as forest were found to be non-forest. This is a notable finding that warrants further analysis because it represents a change in the total area of forest land cover in Guyana in 1990. The majority of these incorrect non-forest areas are attributable to areas of agriculture, rivers and, to a lesser extent, roads.

Figure 4-1 uses the GIS to illustrate the spatial distribution of areas seen as non-forest in the reference imagery that could be tracked back to the Landsat 1990 and confirmed as non-forest. Note also, that the Durham team acquired from USGS a second set of orthorectified 1990 Landsat TM data that had less cloud cover in the affected areas. Note the red locations in the NW and NE of the country that show areas of misclassification. The 1990 Forest – Non-forest map is derived from a two stage process where computer-based image processing used to automatically thresholding Landsat TM imagery using the Enhanced Vegetation Index (EVI). The second stage was one of manual interpretation and editing of the polygon boundaries generated from the EVI threshold (Pöyry 2011 and Pers. Comm.). The 1990 Forest – Non-forest map was verified by independent reinterpretation of the 1990 data over the sample areas since no high spatial resolution imagery is available from 1990. However, using independent reinterpretation it was possible to track forward in time from 1990 until 2010 to assess the persistence of deforestation. In 106 one ha sample plots (0.37% of sample) it was found that areas had been wrongly identified as deforested (or that reafforestation had occurred), whereas 737 sample plots (2.57% of sample) showed as deforestation not detected in the Pöyry-GFC 1990 map.

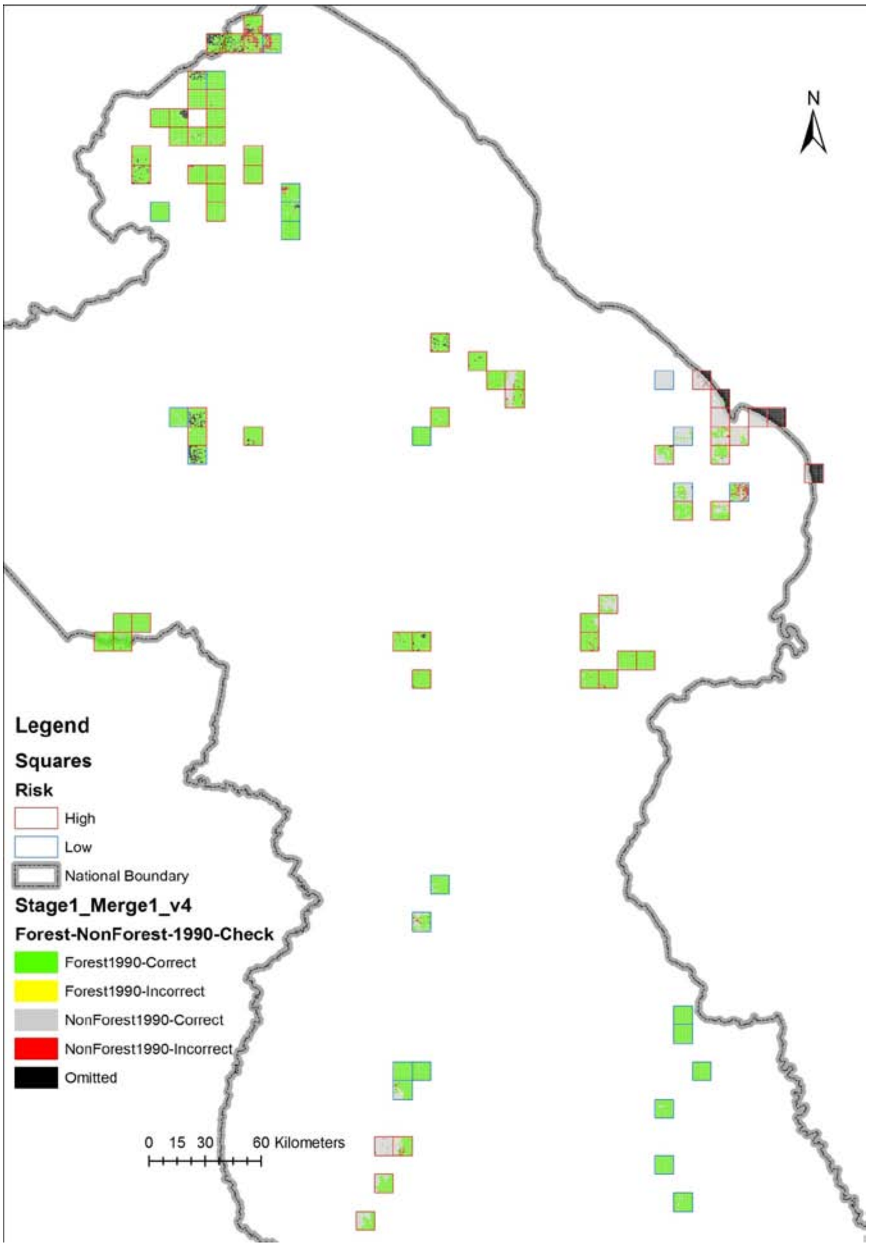


Figure 4-1: Distribution of errors in 1990 map plotted by sample grid square

Table 4-2: Error matrix for Year 1 Forest map

High & Low Risk strata combined	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
Map	Forest	21751	360	22111	98.4%
	Non-forest	101	5640	5741	98.2%
	Total	21852	6000	27852	
Producer Accuracy		99.5%	94.0%		98.3%

1406 Omitted

The error matrix for the assessment of the 1990 map (table 4-1) has a total of 28,680 sample points plus 1644 *Omitted* points giving a total of 30,324 one hectare plots analysed. The matrix for Year 1 (2010) has a total of 27,852 samples plus 1406 *Omitted* points giving a total of 29,258. The difference (1066) between the two totals occurs because we cannot account for deforestation twice in the analysis. Deforestation found in 1990 remains as deforestation in 2010 and so must be subtracted from the 2010 non-forest (incorrectly mapped) total. Note also, that when the 2010 map was validated any areas that had been missed in 1990 but subsequently mapped as deforestation over the benchmark period were removed from analysis. The difference (1066) between the two totals is divided up as follows:

737 circles/samples - deforestation missed in 1990 map;
106 circles/samples - incorrectly mapped as deforestation in 1990;
223 circles/samples - proportion of total area mapped as Roads from VHR imagery.

With regards to estimating the area of deforestation due to Roads, we examined a large number of 1 hectare samples containing roads and observed that roads crossing through our sample area never occupied more that 20% of the 1 ha area. We noted also that the Pöyry-GFC mapping team applied a 20 m buffer around roads when digitising. Therefore, we calculated that a road deforestation will never occupy more that 45% of the 1 hectare and so scaled the number of Road-deforestation sample points accordingly. This will still overestimate the amount of deforestation due to roads in all cases. It does however provide a less biased estimate since Roads were identified in the mapping process if any part of the sample circle touched any part of a road. This validation rule was different from other mapping polygons where the interpretation of land cover was assessed at the location of the sample centroid because of the linear nature of roads. Figures 4-2 and 4-3 show the distribution of the errors by driver and geographically.

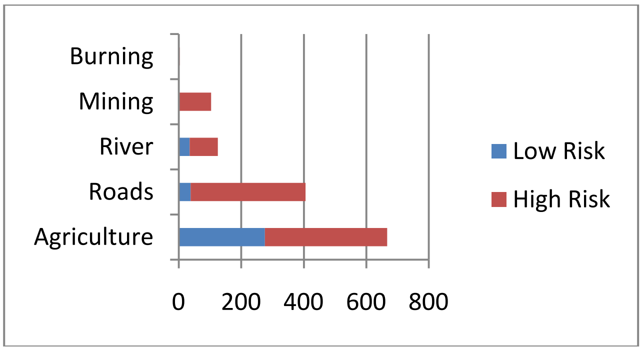


Figure 4-2: Distribution of the incorrectly mapped samples from the Year 1data before adjustment for areas missed in the 1990 Non-forest map

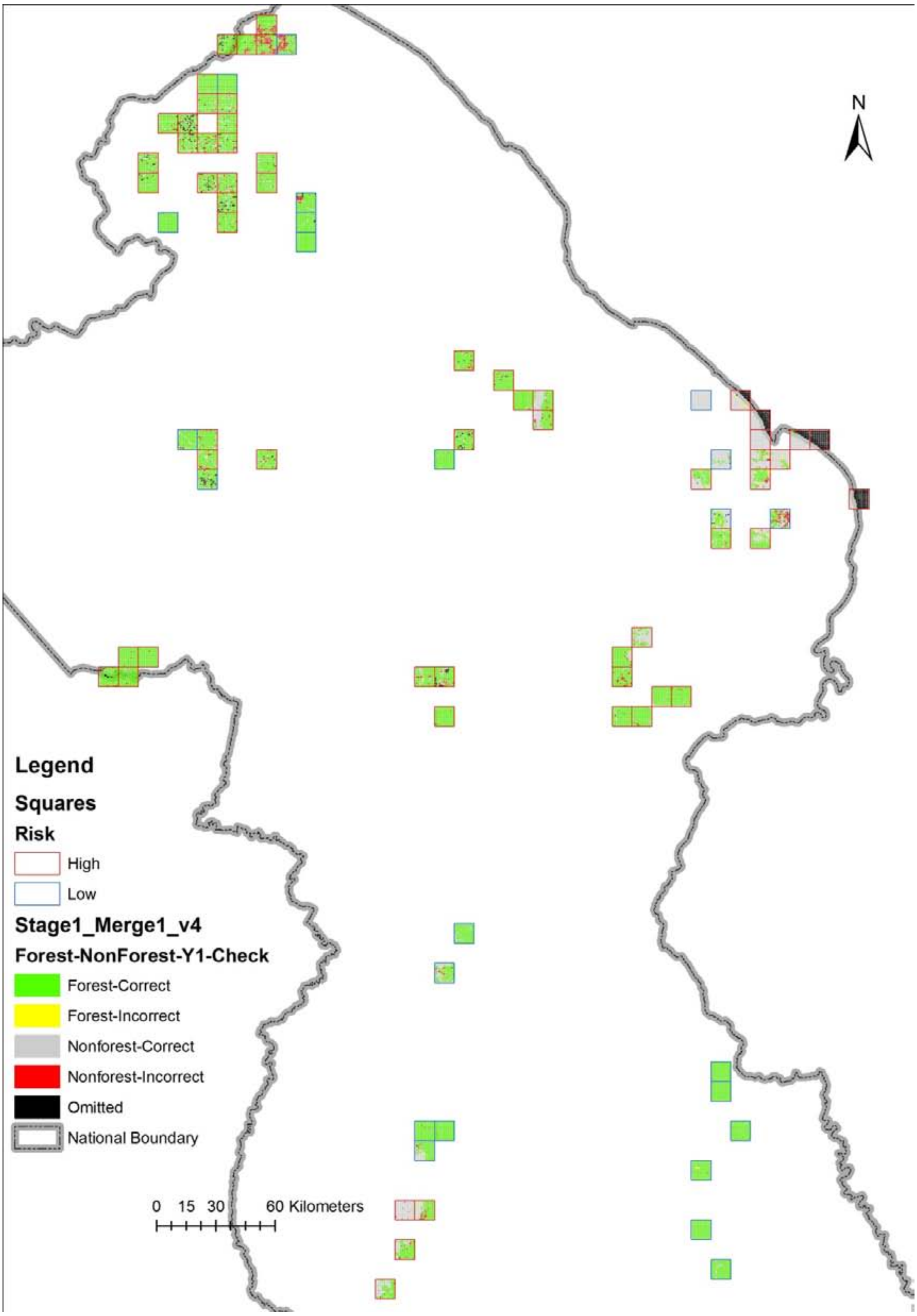


Figure 4-3: Distribution of errors in 2010 map plotted by sample grid square

4.2 Consistency

The validation team consists of four well qualified and experienced image interpreters, two of whom visited Guyana and participated in field visits and overflights. They acted as mentors for the other two interpreters. Every effort was made to inform the team validating the mapping about the geography of Guyana, forest types, definitions of land cover, definitions of deforestation, the processes driving deforestation and the rules that were followed by the original mapping team. The validation team very familiar with satellite imagery, particularly Landsat TM, ETM+ and DMC; they were less familiar with RapidEye and CBERS data and took time to learn about how best to use image processing to enhance these data.

The analysis reported here l used scenes from three different high resolution sensors covering a total of 8.5% of Guyana's land area. Approximately 30,000 hectares were scrutinised. Assessment also included information for field inspections and aerial over-flights conducted in good conditions in February 2011. The geo-positioned aerial imagery provides valuable evidence that helped confirm the interpretations of the validation team, particularly with regard to the drivers for deforestation.

Two experiments were conducted to ensure that the data used to validate the mapping was as precise as possible. The first involved blind replication of four sample grids (1444 sample plots). Each interpreter analysed the same four grids, three of which were in the High Risk stratum and one in Low. The grids were purposely selected to include areas of high activity (mining, forest roads, agriculture etc) and used RapidEye, IKONOS and the Brazilian CBERS data. The results are shown in table 4-3 and demonstrate that with initial training the team were consistent over 95% of the time.

Table 4-3: Agreement among interpretation team members

	Interpreter A	Interpreter B	Interpreter C
Interpreter A			
Interpreter B	95.70		
Interpreter C	95.98	95.36	
Interpreter D	96.96	95.98	95.43

However, this exercise was followed by analysis of the disagreements and discussion among the team about how to follow the Pöyry MRVS Image Interpretation Guide (Pöyry 2011). Following a further training session, a second experiment was conducted over one sample grid square from the high risk stratum using RapidEye imagery and the same interpretation methods. This time each sample area was analysed by the group to come to an agreed *Master* coverage and then the independent interpretations were compared against this master. The results are presented in table 4-4 below.

Table 4-4: Comparison of interpretation by team members with *Master* data

	Master	Interpreter A	Interpreter B	Interpreter C
Interpreter A	97.21			
Interpreter B	94.12	94.74		
Interpreter C	95.05	92.36	93.50	
Interpreter D	94.43	92.26	91.64	91.33

The results are very similar to the first experiment and demonstrate that it is difficult to achieve a level of image interpretation that is better than 95% correct. Foody (2010) discusses the impact of imperfect ground reference data and demonstrates the impacts it can have on reported Producer's accuracy. This study of consistency does not allow us to conclusively attribute an error value to the reference data. However, it demonstrates that there is no interpreter bias and that the level of error is unlikely to exceed 5%. It is beyond the scope of this contract, but it would be interesting to model the effect the reference data error on the estimates of forest area and their confidence limits for given confidence levels.

4.3 Forest Area Estimates

The Interim Measures Report used a model-assisted difference estimator, McRoberts (2010), to derive a Confidence Interval (CI) of 18.008 to 18.807 million ha at a 95% Confidence Level (CL) for the 1990 forest area. This was based on the assumption that the (albeit very small sample) was randomly selected and unbiased.

The reference data consisted of 84 of the original 163 sample grids; the 84 grids were stratified into High and Low risk areas as described in the sampling design (section 3.5) and randomly sampled within each stratum. This design allows a probability-based inference approach to be applied. This approach assumes (1) that samples are selected from each stratum randomly; (2) that the probability of sample selection from each stratum can be estimated; (3) the sampling fraction in each stratum is proportional to the total population and that the relative sample size reflects, in this case, a ratio of 70:30 between High and Low Risk stratum respectively. Note that the probability of encountering deforestation in each stratum can be estimated from the map data by query to the GIS; 85% of deforestation is located in the High Risk Stratum and 15% in the Low Risk stratum. However, it was important not to under-sample the Low risk stratum as the drivers for deforestation are not known with absolute certainty. Therefore, despite randomisation, there are several possible sources of bias that include:

1. Selecting sample grids, from the random sample within each stratum, by availability of suitable reference data, because the reference data are themselves selected randomly and do not cover the whole population.
2. The reference data may be of variable quality and that quality may be distributed unevenly between strata.
3. The maps were produced from manual image interpretation and the validation also used manual interpretation based on a 1 ha minimum mapping unit. Operator bias could be present either in the distribution of errors in the maps and also in the interpretation of the reference data.

Although, the expectation is that probability-based estimators are unbiased, this cannot be assumed. An elegant approach that combines the advantages of simple random sampling with model-based estimators is the model-assisted difference estimator (McRoberts 2010; McRoberts *et al*. 2010a; McRoberts *et al*. 2010b). A model-assisted estimator used map data to make an initial inference but uses the probability-based sample to validate the result. In this analysis the model-assisted difference estimator has been applied separately to each stratum since forest area can be calculated easily from the GIS. Bias and Variance are estimated from the probability-based sample within each stratum.

At the 95% confidence level, the estimate of 1990 forest area, based on the model-assisted stratified sampling design is 5,933,659 ± 17,609 hectares the High Risk stratum and 11,983,321 ± 55,695 hectares the Low Risk stratum. Combined, this gives a model-assisted estimate of 17,916,980 hectares for Guyana for 1990 compared with a figure of 18,473,394 hectares from the Pöyry-GFC map.

At the 95% confidence level, the estimate of forest area for 2010 (Year 1), based on the stratified sampling design is 5,835,059 ± 15,376 hectares the High Risk stratum and 11,970,258 ± 28,845 hectares the Low Risk stratum. Combined, this gives a sample-based estimate of 17,805,317 hectares for Guyana for 1990 compared with a figure of 18,388,190 hectares from the Pöyry-GFC map.

The differences between the model-based estimates and the maps are shown in table 4-5. Note that the Durham and Pöyry estimates of forest area differs mainly because of apparent misclassification of areas in the 1990 map. The differences observed in 1990 project forward in time although the amount of deforestation estimated from the sampling and the map are very similar indeed; the observed difference of 26,459 ha (over the 1990-2010 period) from the two estimation methods does not appear to be statistically significant.

Table 4-5: Summary of forest area estimates (in hectares) comparing mapped areas and areas estimated from a model-assisted difference estimator

Area in ha	1990	2009	2010 (Year 1)	Difference 1990-2010 (Y1)
Durham Estimate	17,916,980	17,816,927	17,805,317	111,663
Pöyry Estimate	18,473,394	18,398,497	18,388,190	85,204
Difference	556,414	581,570	582,873	-26,459

Tables 4-6 to 4-9 list the error matrices and the statistics used to estimate the forest area and confidence limits for the 95% and 99% confidence levels. Only the 95% confidence level data is reported in the conclusion and executive summary. Figure 4-4 shows the confidence limits for each stratum for 1990 and 2010 graphically.

$\boldsymbol{\phi}$ = area to be estimated

x_i = random sample element

E = Expected value

$$\text{Bias}(\Phi) \quad = E[\Phi] - \Phi = \frac{predicted\ positive - predicted\ negative}{n}$$

$$\text{Variance}(\phi) = \frac{1}{n(n-1)} \sum_{i=1}^{n} (\bar{x}_i - x_i)^2$$

Table 4-6: Error Matrix used for Forest Area Estimates for High Risk stratum 1990

High Risk	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
1990 Map	Forest	15934	449	16383	97.26%
	Non-forest	82	3699	3781	97.83%
	Total	16016	4148	20164	
Producer Accuracy		99.49%	89.18%		97.37%

Bias (ϕ)	0.018201	Sensitivity	0.994880	Producer's accuracy (Forest)
		Specificity	0.891755	Producer's accuracy (Non-Forest)
Forest	6073880	Predicted positive	0.972594	User's accuracy (Forest)
Total land	7704138	Predicted negative	0.978313	User's accuracy (Non-Forest)
		Prevalence	0.973666	Correspondence
ϕinit (from model)	0.788392			
ϕ	0.770191			
Variance(ϕ)	1.31E-06	Area estimate		
		Upper	Lower	**CI Range**
95% CL	0.002286	5951268	5916050	35218.06
99% CL	0.003428	5960072	5907245	52827.08
ϕ init 95%	0.002286	6091489	6056271	35218.06

Table 4-7: Error Matrix used for Forest Area Estimates for Low Risk Stratum 1990

Low Risk	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
1990 Map	Forest	6865	288	7153	95.97%
	Non-forest	24	1339	1363	98.24%
	Total	6889	1627	8516	
Producer Accuracy		99.65%	82.30%		96.34%

Bias (ϕ)	0.031	Sensitivity	0.996516	Producer's accuracy (Forest)
		Specificity	0.822987	Producer's accuracy (Non-Forest)
Forest	12399509	Predicted positive	0.959737	User's accuracy (Forest)
Total land	13425210	Predicted negative	0.982392	User's accuracy (Non-Forest)
		Prevalence	0.963363	Correspondence
ϕinit (from model)	0.923599			
ϕ	0.892598			
Variance(ϕ)	4.3E-06	Area estimate		
		Upper	Lower	**CI Range**
95% CL	0.004149	12039016	11927626	111390.5
99% CL	0.006223	12066864	11899778	167085.8
ϕ init 95%	0.004149	12455204	12343814	111390.5

Table 4-8: Error Matrix used for Forest Area Estimates for 2010

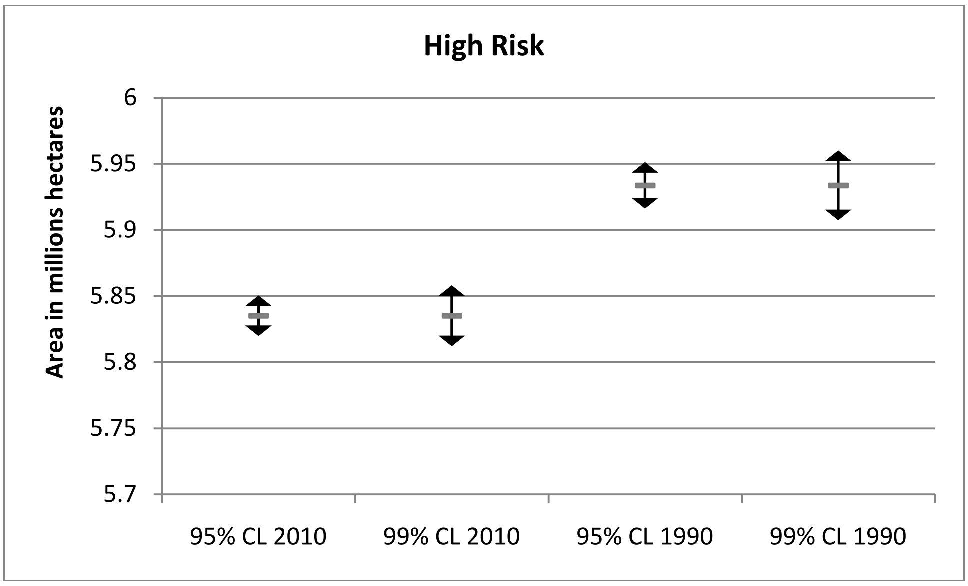
High Risk	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
Year 1 Map	Forest	14910	317	15227	97.92%
	Non-forest	66	4319	4385	98.49%
	Total	14976	4636	19612	
Producer Accuracy		99.56%	93.16%		98.05%

Bias (**ϕ**)	0.01279829	Sensitivity	0.995593	Producer's accuracy (Forest)
		Specificity	0.931622	Producer's accuracy (Non-Forest)
Forest (ha)	5933658.881	Predicted positive	0.979182	User's accuracy (Forest)
Total land (ha)	7704138	Predicted negative	0.984949	User's accuracy (Non-Forest)
		Prevalence	0.980471	Correspondence
ϕinit (from model)	0.770191			
ϕ	0.757393			
Variance(**ϕ**)	9.96E-07	Area estimate		
		Upper	Lower	**CI Range**
95% CL	0.001996	5850435	5819683	30752
99% CL	0.002994	5858123	5811995	46128
ϕ init 95%	0.001996	5949035	5918283	30752

Table 4-9: Error Matrix used for Forest Area Estimates for High Risk Stratum 2010

Low Risk	Class	Reference Images			
		Forest	Non-forest	Total	User Accuracy
Year 1 Map	Forest	6841	43	6884	99.38%
	Non-forest	35	1321	1356	97.42%
	Total	6876	1364	8240	
Producer Accuracy		99.49%	96.85%		99.05%

Bias (**ϕ**)	0.00097087	Sensitivity	0.995593	Producer's accuracy (Forest)
		Specificity	0.931622	Producer's accuracy (Non-Forest)
Forest (ha)	11983321.18	Predicted positive	0.979182	User's accuracy (Forest)
Total land (ha)	13455210	Predicted negative	0.984949	User's accuracy (Non-Forest)
		Prevalence	0.980471	Correspondence
ϕinit (from model)	0.890608261			
ϕ	0.889637388			
Variance(**ϕ**)	1.15E-06	Area estimate		
		Upper	Lower	**CI Range**
95% CL	0.002143761	11999103	11941413	57689.52
99% CL	0.003215642	12013525	11926991	86534.28
ϕ init 95%	0.002143761	12012166	11954476	57689.52



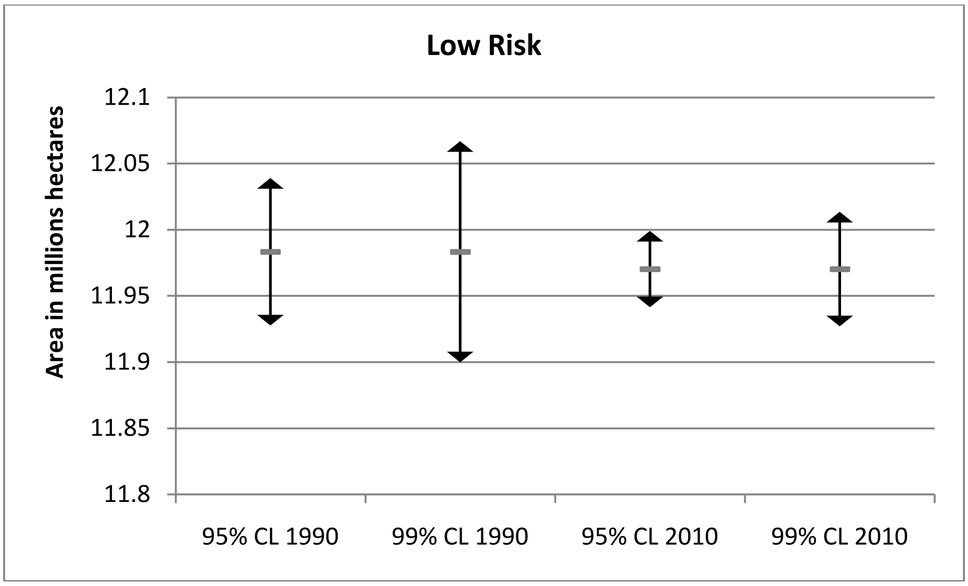


Figure 4-4: Confidence Limits

Deforestation rate

The Pöyry-GFC maps show a deforestation rate over the 20 year period from 1990 to 2010 of 0.023%. The model-assisted deforestation rate over the same 20 year period of 0.031%. It is not possible to calculate a 2009-2010 deforestation rate directly from the results of the sampling because the 2009 map was not validated independently from the 2010 map. However, if we spread the difference between our estimate and the Pöyry-GFC mapped results in the same proportion as Pöyry-GFC reported their deforestation data, then we estimate a Year 1 rate of 0.065%. This compares with 0.056% cited in the Interim measures Report (Pöyry, 2011a).

	1990 (ha)	2009 (ha)	Year 1 (ha)	Deforestation Rate %	Benchmark Period Deforestation Rate %	Estimated Year 1 Deforestation Rate %
Durham Estimate	17916980	17816927	17805317	0.031	0.029	0.065
Pöyry Estimate	18473394	18398497	18388190	0.023	0.021	0.056

The deforestation rate over the 20 year period from 1990 to 2010 is 0.023% for the Pöyry-GFC maps and 0.031% based on the stratified sampling. It is not possible to calculate a 2009-2010 rate directly from our results but if we spread the difference between our estimate and the Pöyry-GFC mapped results in the same proportion as Pöyry-GFC reported their deforestation data, then we estimate a Year 1 rate of 0.065% compared with 0.056% cited in the Interim measures Report (Pöyry, 2011). The main source of disagreement in the area estimates derives from deforestation due to Agriculture that was not detected in the 1990 Forest – Non-forest maps, mainly due to areas where Landsat TM and ETM+ imagery was obscured by persistent cloud cover.

The 1990 forest area map (Pöyry-GFC) and the estimate from this study differ by 556,414 hectares. This figure is predominantly due to areas of agriculture and rivers missed due to persistent cloud cover, spatial resolution or mislabelling of agriculture as shifting cultivation. It is recommended that areas labelled as shifting cultivation are visited on the ground to confirm the labelling. The GIS data containing all of the sample areas is available and can be used to help cross check interpretations from high spatial resolution imagery with field-based interpretation and government records on agricultural concessions.

We conclude that the GOFC-GOLD handbook provides a widely accepted set of good practice guidelines for the use of satellite imagery in support of Monitoring, Reporting and Validating (MRV) forest resources and carbon stock changes. The methods used by Pöyry and GFC and reported in the Interim Measures Report (Pöyry 2011a) and in this report follow the good practice recommendations set out in the GOFC-GOLD guidelines to help identify and quantify uncertainty in the level and rate of deforestation in Guyana over the period 1990 to 2009 (Benchmark Period) and 2009 to 2010 (Interim Measures Period – Year 1).

5 DISCUSSION

The results divide into three important areas that warrant further discussion i) reliability of the procedures used to identify deforestation and attribute the correct driver (reason for the change) from satellite imagery; ii) representativeness of the sample used to estimate bias and precision of the forest area mapping; iii) assessment of the process to help validation and verification in future years.

5.1 Reliability

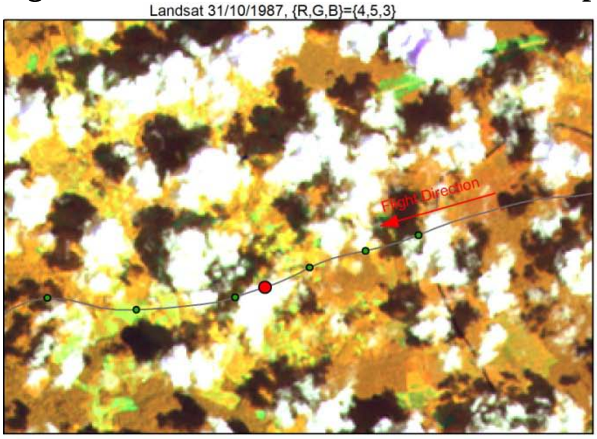
There is a large literature highlighting the difficulties associated with mapping and verifying deforestation rates in the world's humid tropical forests (e.g. Achard et al. 2002; Grainger 2008; Hanson et al 2008; Hanson et al 2010). Any approach that uses satellite imagery to overcome the lack of reliable forest inventory data will need to account for errors caused by areas obscured by clouds (and cloud shadows) and low spatial resolution imagery. In addition to errors where deforestation has been missed, there is also the difficulty of interpreting and accounting for areas of degradation that do not constitute deforestation.

The approach taken by GFC to develop a wall-to-wall mapping exercise is ambitious but will generate very precise, location specific data. Once established in a GIS the data can be updated relatively easily but adding to the map units when new deforestation is identified from new imagery or fieldwork. The approach also allows Carbon modelling to be developed to a high level of precision by linking land cover, forest and soil type and in a dynamic model. The validation exercise, although a small sample of the total land area suggests that the maps correspond well to actual land cover and the forest area is mapped very precisely.

Figure 5-1 shows two examples of areas of agriculture missed in the 1990 map. In this figure, our 1990 image is displayed because it provided better view of the agriculture missed. This highlights the level of cloud cover in the Pöyry-GFC Landsat TM image that prevented this agriculture from being recognized either from the EVI threshold method or manual interpretation. The field patterns are extensive and can clearly be seen from the air today (Feb 2011).

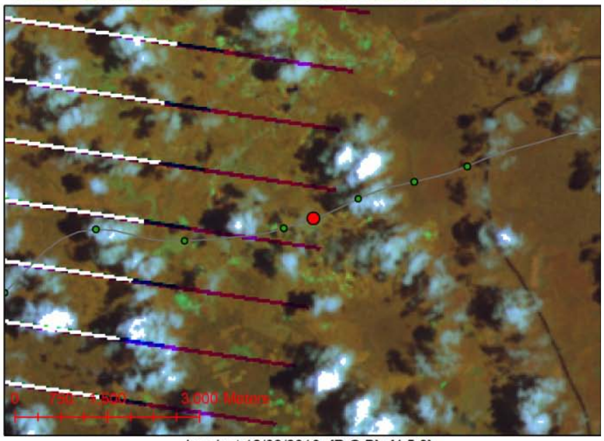
Figure 5-2: Areas of missed in the 1990 map due to agriculture and mining activity

Landsat 31/10/1987, {R,G,B}={4,5,3}



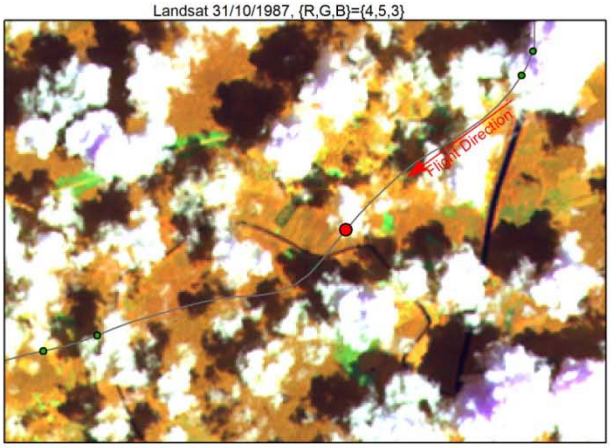
Picture from point towards the right side of the airplane (16/02/2011)

Picture from point towards the left side of the airplane (16/02/2011)



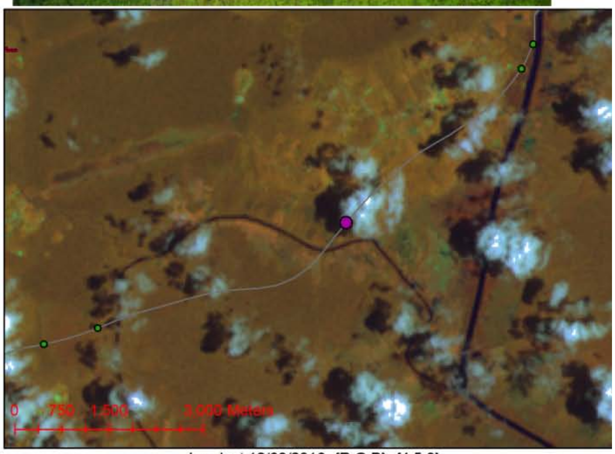
Landsat 12/09/2010, {R,G,B}={4,5,3}

Landsat 31/10/1987, {R,G,B}={4,5,3}

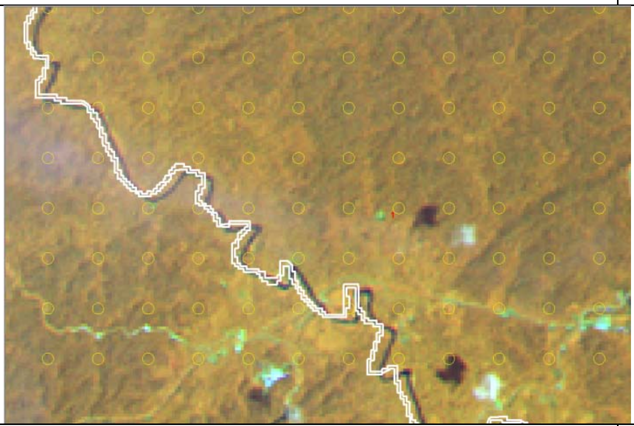
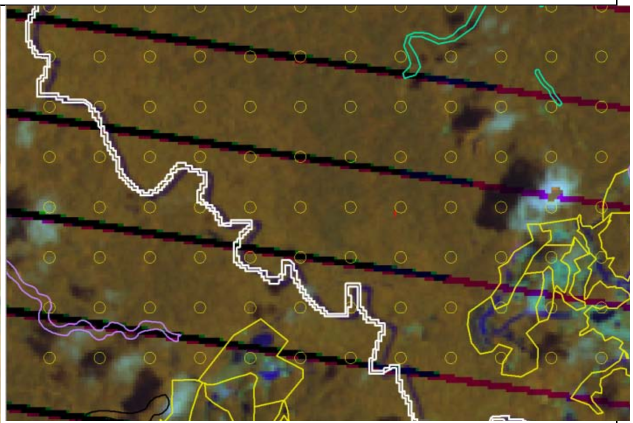
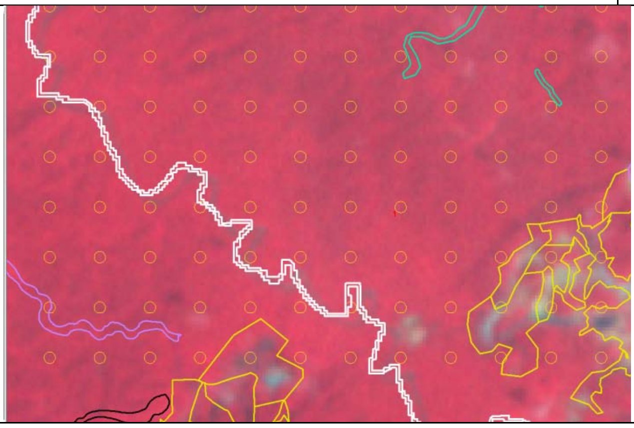
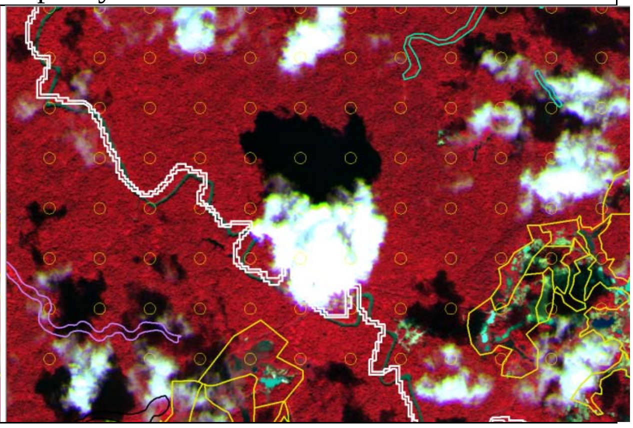


Picture from point towards the right side of the airplane (16/02/2011)

Picture from point towards the left side of the airplane (16/02/2011)



Landsat 12/09/2010, {R,G,B}={4,5,3}

Mining road missed in 1990; some areas yet to be mapped	
Landsat 1990	Landsat 2010
	
DMC 2010	RapidEye 2010
	

5.2 Drivers of forest change

The lack of suitable high resolution imagery has meant that it has not been possible to validate mapping for each epoch within the benchmark period. The results of the mapping in 2000, 2005 and 2009 are however captured in the 2010 map validation. This means that it not possible to comment on the temporal pattern of deforestation drivers. It would appear that mining and road construction for logging and mining are the principal drivers in year 1 but it is not possible to break down the statistics by period. That said, every sample point analysed now has a map label and validator’s interpretation attached to it. This means that a spatial analysis of deforestation drivers could be carried out to help predict the pattern of deforestation in the future. Given the uncertainty over causes and driving forces for tropical deforestation globally (Geist and Lambin 2002), the data held in the GFC-MRVS for Guyana presents an excellent opportunity to understand and perhaps better manage these processes in future.

5.3 Conclusions

In keeping with the results arising from the assessment of the 1990 forest- non-forest map it would be helpful to revisit areas mapped as shifting cultivation and reassess the mapping. If these areas are mapped as shifting cultivation, it would be a straightforward task to re-label these as agriculture and update the 1990 and subsequent maps accordingly.

Similarly, there are many roads that can be identified easily from the IKONOS and RapidEye imagery that are difficult to interpret using Landsat TM, ETM+ and DMC imagery. The sampling accounts for misclassifications due to roads, however, it would be prudent to use the RapidEye data that covers most of the areas of recent mining and logging activity to digitise these features. Otherwise, they will appear as deforestation in Year 2 and bias the deforestation rate.

The RapidEye imagery, despite a 20-25% level of cloud cover turned out to be of excellent radiometric quality and of a spatial resolution ideally suited to the task of deforestation mapping. The false colour infrared images were easily enhanced in spite of cloud cover. Recently cut roads and mining dredges stood out very clearly indeed. It was possible to identify roads of the type used for logging operations that were some years ago and where the canopy had closed over. These stood out through brightness differences in the near infrared mainly. RapidEye is a constellation of five satellites which means that it can revisit cloudy areas frequently and so we strongly suggest that these data are used to target the High Risk stratum to help validate the Year 2 REDD+ mapping. Before proceeding to year 2, we recommend that the existing high spatial resolution reference data is used to 1) enhance the quality of the Year 1 map, and, 2) help orthorectify any Landsat imagery that is misregistered.

6 SUMMARY AND CONCLUSIONS

We conclude that the quality of the mapping undertaken by Pöyry-GFC based largely on interpretation of Landsat TM and ETM+ imagery is of a good standard. The prevalence statistic is a good measure of overall correspondence between the map and reference data. We found that for 1990 and for 2010, prevalence was greater than 0.96 or 96% agreement. This is a very high figure, better than one would expect from automated classification of multispectral remotely sensed data, and is almost certainly explained by the manual process of interpretation and on-screen digitizing. We also note that the reference data are not perfect, about 7% of the sample area could not be used because of missing reference data or because the ground was obscured by cloud or cloud shadow. Missing reference data were excluded from the analysis.

1. We conclude that the GOFC-GOLD handbook provides a widely accepted set of good practice guidelines for the use of satellite imagery in support of MRVS for forest resources and carbon stock changes. The methods used by Pöyry and GFC and reported in the Interim Measures Report (Pöyry 2011a) and in this report follow the good practice recommendations set out in the GOFC-GOLD guidelines to help identify and quantify uncertainty in the level and rate of deforestation in Guyana over the period 1990 to 2009 (Benchmark Period) and 2009 to 2010 (Interim Measures Period – Year 1).

2. The 1990 Forest – Non-forest map show a correspondence (prevalence) between reference image interpretation and Pöyry/GFC mapping of 97.1%. This statistic is derived from 28,680 one hectare plots sampled from both strata and excludes areas of cloud cover and areas beyond the Guyana border and coastline.

3. The correspondence between reference image interpretation and Pöyry/GFC mapping for the Year 1 map yields a prevalence statistic of 98.3%. This statistic is derived from 27,852 one hectare plots sampled from both strata and excludes areas of cloud cover and areas beyond the Guyana border and coastline. This demonstrates a very high level of agreement between the MRVS maps and the reference data.

4. The 1990 Forest – Non-forest map is derived from a two stage process. In the first stage computer-based image processing was used to automatically threshold Landsat TM 1990 imagery by using the Enhanced Vegetation Index (EVI). The second stage is one of manual interpretation and editing of the polygon boundaries generated from the EVI threshold (Pöyry 2011 and Pers. Comm.). The 1990 Forest – Non-forest map was verified by acquisition and interpretation of extra Landsat scenes of the 1990 period, and also independent reinterpretation of the 1990 data over the sample areas since no high spatial resolution imagery is available from 1990. Through this method it was possible to track forward in time from 1990 until 2010 to assess the persistence of deforestation. In 106 one ha sample plots (0.37% of sample) it was found that areas had been wrongly identified as deforested (or that reafforestation had occurred), whereas 737 sample plots (2.57% of sample) showed as deforestation not detected in the Pöyry-GFC 1990 map.

5. The 1990 forest area map (Pöyry-GFC) and the estimate from this study differ by 556,414 hectares. This figure is predominantly due to areas of agriculture and rivers missed due to persistent cloud cover, spatial resolution or mislabelling of agriculture as shifting cultivation. It is recommended that areas labelled as shifting cultivation are visited on the ground to confirm the labelling. The GIS data file containing all of the sample areas is available and can be used to help cross check interpretations from high spatial resolution imagery with field-based interpretation and government records on agricultural concessions.

6. The estimate of 1990 forest area, based on the stratified sampling design is 5,933,659 ± 17,609 hectares the High Risk stratum and 11,983,321 ± 55,695 hectares the Low Risk stratum. Combined, this gives a sample-based estimate of 17,916,980 hectares for Guyana for 1990 compared with a figure of 18,473,394 hectares from the Pöyry-GFC map.

7. The estimate of forest area for 2010 (Year 1), based on the stratified sampling design is 5,835,059 ± 15,376 hectares the High Risk stratum and 11,970,258 ± 28,845 hectares the Low Risk stratum. Combined, this gives a sample-based estimate of 17,805,317 hectares for Guyana for 2010 compared with a figure of 18,388,190 hectares from the Pöyry-GFC map.

8. The Pöyry-GFC maps show a deforestation rate over the 20 year period from 1990 to 2010 of 0.023%. This study shows a deforestation rate over the same 20 year period of 0.031%. It is not possible to calculate a 2009-2010 deforestation rate directly from our results. However, if we spread the difference between our estimate and the Pöyry-GFC mapped results in the same proportion as Pöyry-GFC reported their deforestation data, then we estimate a Year 1 rate of 0.065%. This compares with 0.056% cited in the Interim measures Report (Pöyry, 2011a).

7 RECOMMENDATIONS

Assessment of tropical deforestation and degradation is a far from trivial exercise that requires a high level of experience in satellite image interpretation, GIS data handling, spatial analysis and statistical estimation. The MRVS GIS for Guyana contains many hundreds of satellite images and the vast majority of these are needed to undertake the assessment because single-period duplication helped circumvent cloud cover and multi-period imagery was needed to track changes as part of the interpretation process. The high spatial resolution imagery had large file sizes that made use of the GIS for map quality assessment a slow and painstaking process. The process of validation was based on 10 km^2 grid squares randomly distributed within high and low risk strata. It took approximately 2-3 hours to interpret the 361 one hectare sample plots in each square. Ideally, imagery was available to sample 163 squares giving approximately a 70% spatial sample of the high risk stratum and 30% of the low risk stratum. Time permitted a sample of 84 10 km^2 grid squares. What limited the work was time available within the Guyana-Norway Interim Measure Agreement and budget.

The sample grids were distributed equally among four interpreters; each interpreter was given a set of grids that contained the correct proportion (according to the 70:30 stratification) of High and Low Risk and examples of each of the high resolution satellite imagery reference data (RapidEye, IKONOS & CBERS). The 163 grid squares were split into two sets (84 and 79) in case it was not necessary to sample all 163 either because the estimates were sufficiently precise or time did not permit. In fact this was fortuitous because the estimates were precise after sampling 84 squares and there was not sufficient time available for all 163.

The interpreters underwent a training exercise designed to give a 'glimpse' of all the different satellite imagery and example of different types of deforestation driver. The group did a blind assessment of the same four grids so that any disagreements could be highlighted, discussed and any interpretation bias removed before the validation process began.

Two members of the validation team were able to visit Guyana and meet with GFC officials and the original mapping team. This helped a lot to: understand the protocols and definitions surrounding the Interim Measures Agreement; answer questions about MRVS methodology and interpretations; exchange data and knowledge about data sets. The Pöyry team developed at our request and extended MRVS Mapping and Satellite Image Interpretation Guide (Pöyry, 2011) and a toolbar for ArcGIS that was used to speed up the image interpretation process.

Despite the lack of time, the stratified sampling strategy has resulted in very precise estimates of deforestation as shown by the reported confidence intervals. The number of samples analysed was sufficient.

With regard to improving the validation process for Year 2 assessment, we make the following recommendations:

1. The RapidEye data are of excellent quality and ideally suited to for the task. We recommend that the existing RapidEye data are interpreted and deforestation digitized. That will enhance the quality of the Year 1 map. Some Year 2 deforestation was identified in the RapidEye and careful comparison with DMC and Landsat data will allow deforestation to be attributed to the correct year.

2. Use the existing set of high resolution data to “clean-up” the existing mapping, that is check areas identified in this study as incorrect so that the area estimates fall into line.
3. Identify and add the navigable water bodies to the GIS. Navigable water maps improve the ability to predict areas of forest at risk.
4. Default all samples to the mapping values. During assessment, only disagreements will be checked.
5. Ensure that GFC staff are familiar with the validation process and have powerful workstations to be able to undertake some of this work in house.
6. Allow sufficient time for the validation. The sample size used in 2011 appears sufficient for purpose. This information allows a realistic timescale of validation to be calculated.
7. Design the over-flights and field work to take place AFTER the photointerpretation to allow particular areas of ambiguity or uncertainty to be validated.
8. Acquire as much reference data as possible for the period of interest. If money is an issue, plan the reference data acquisition above areas of 'High Risk'/detected deforestation instead of areas of detected deforestation only.
9. We witnessed an effort from GFC to improve their standards of surveying and mapping and this GIS exercise presented a good opportunity for this. We recommend that GFC will continue the effort and define standards for spatial data acquisition as clearly as possible and apply appropriate quality control measures.

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