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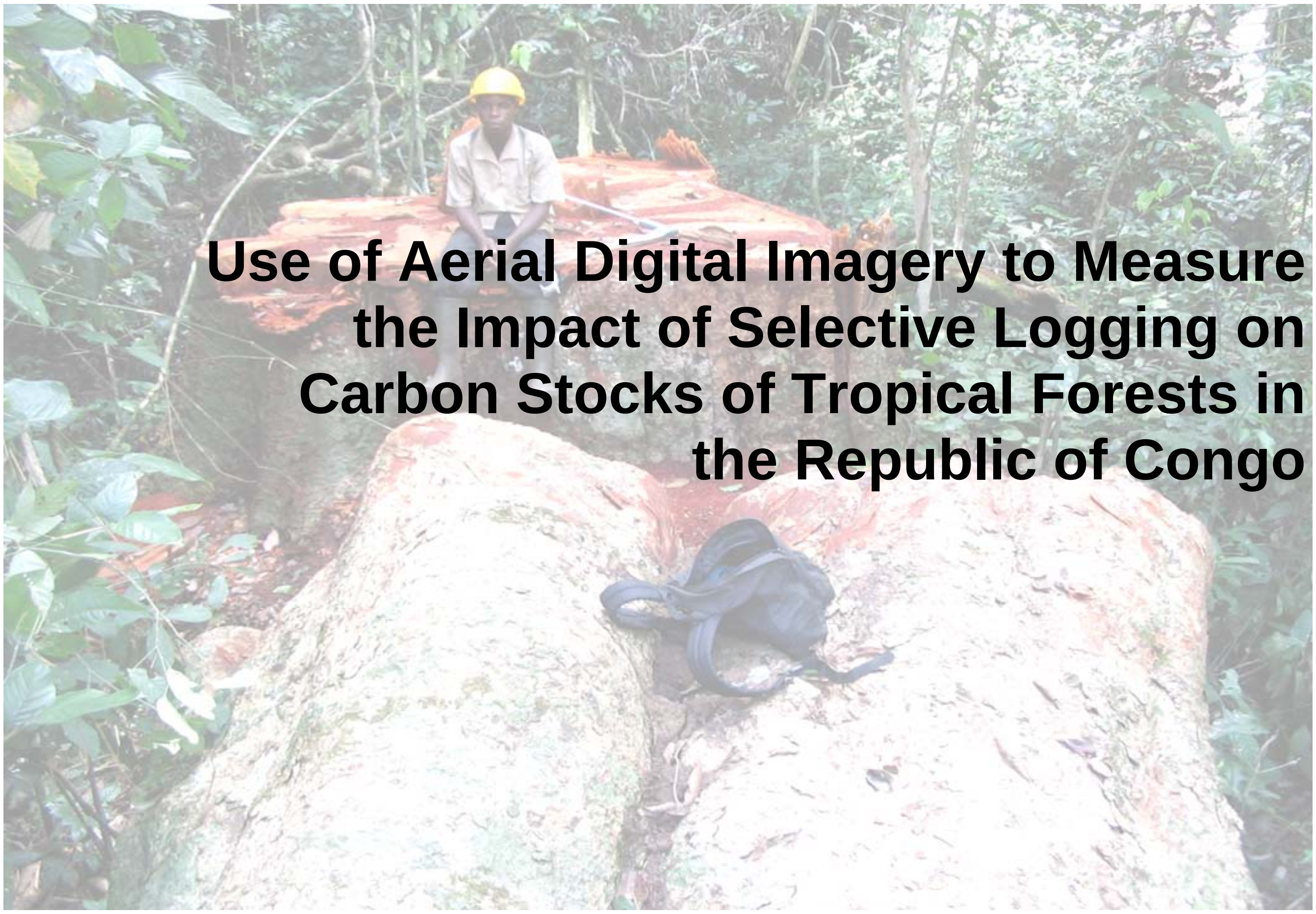

Use of Aerial Digital Imagery to Measure the Impact of Selective Logging on Carbon Stocks of Tropical Forests in the Republic of Congo

Deliverable 9: Aerial imagery analysis of logging damage

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EXECUTIVE SUMMARY

This report describes the use of the M3DADI (multispectral three-dimensional aerial digital imagery) technology that we have used with corresponding ground measurements to assess the impact of logging on the carbon stocks of tropical forests in the Republic of Congo.

M3DADI uses three-dimensional images to visualize the forest beneath. Transects were flown over more than 10 % of the 2004 logging area belonging to Congolaise Industrielle du Bois (CIB) near the town of Ndoki 2 in the Republic of Congo. In the interpretation process the area of gaps, the length of skid trails and the area of logging roads were recorded. These data were then combined with carbon estimates from ground data to derive estimates of the total impact of logging on forest carbon stocks.

Of the 11,798 hectares of 2004 CIB logging area, 1,473 ha, or 12.5%, were examined in the aerial imagery. The results showed highly selective logging, with only 31.9 ha of logging gap (2.2%) in the area surveyed, and about 18.4 km of skid trails created. The roads totaled 11.5 ha, or 0.78% of the mosaic area.

Our analysis resulted in an estimated timber extraction of 14,150 ± 870 m^3 (mean ± 95 % confidence interval), which is equal to 9.6 m^3 per hectare of concession ± 0.59 (mean ± 95 % confidence interval. The estimated number of trees extracted is equal to 0.5 per hectare.

The total impact is estimated to be 8.9 t C/ha of which 29 % is from the extracted log and 26 % from the combined impact of skid trails and logging roads. The great majority of the impact arises from the logging gaps (74 %), and 61 % of this impact (or 45 % of the total impact) is in the stump and crown of the felled tree and in the incidentally damaged surrounding trees.

Finally new estimation factors are developed using the aerial data, which allow the calculation of total carbon impact based solely on extracted volume. We use the extracted volume as the variable of interest in these calculations as this is a commonly reported forest statistic. These numbers can, however, only be applied to forest entities harvesting in forests similar in structure to those in ROC.

INTRODUCTION

Given the interest in implementing land-use change and forestry projects for mitigating carbon dioxide emissions, there is potentially a large demand for a system to measure carbon stocks accurately and precisely in a cost-effective manner. As terrestrial ecosystems tend to be heterogeneous, a large number of sample plots could be needed to attain desired levels of precision, thus resulting in a costly process. Additional costs can be incurred when sites are remote or difficult to reach. A potential way of reducing costs of measuring the carbon stocks and condition of forests is to collect the key data remotely. We have designed a multispectral three-dimensional aerial digital imagery system that collects high-resolution overlapping stereo imagery (≤ 10 cm pixels) from which we can distinguish individual trees, shrubs and the gaps left after their removal. In essence, we created a virtual forest that we can use to measure trees, forest gaps, skid trails, roads, and other carbon-relevant factors.

This system has been successfully tested in settings as disparate as a pine savanna in Belize, tropical forests in Puerto Rico, Peru, and Costa Rica and bottomland temperate hardwoods in Mississippi. In Belize (Brown et al. 2004, 2005), we flew transects over savanna vegetation, and analyzed the imagery using 77 aerial-imagery plots. Biomass was measured with a 95 % confidence interval equal to 16 % of the mean. It was calculated that 3 x more person hours would be required to collect the same data on the ground in the field.

As part of Winrock International's larger effort to determine the impact of logging on carbon stocks, high resolution aerial digital imagery was collected in the North of the Republic of Congo. Using this imagery we identified logging gaps in areas logged by CIB (Congolaise Industrielle du Bois) in 2004. Used in combination with ground data, these gaps can be used to determine the amount of carbon in trees removed, as well as in those damaged in the felling and extracting processes.

DESCRIPTION OF AERIAL DIGITAL IMAGERY SYSTEM

The essential goal of the M3DADI system is to obtain imagery of the ground at a scale at which individual trees, gaps and damage can be identified and measured; from experimental analysis we found that a scale of 10-cm resolution meets this goal. The components of the Aerial Digital Imagery system are a Duncantech high definition video camera, a profiling laser, an inertial measurement unit, a real-time differential correction geographic positioning system, a laptop computer, and a data collection computer (Figure 1). All incoming data for each exposure are time stamped in the computer. This allows for all data to be associated with all other pieces of data and to integrate them into a position report for each exposure.

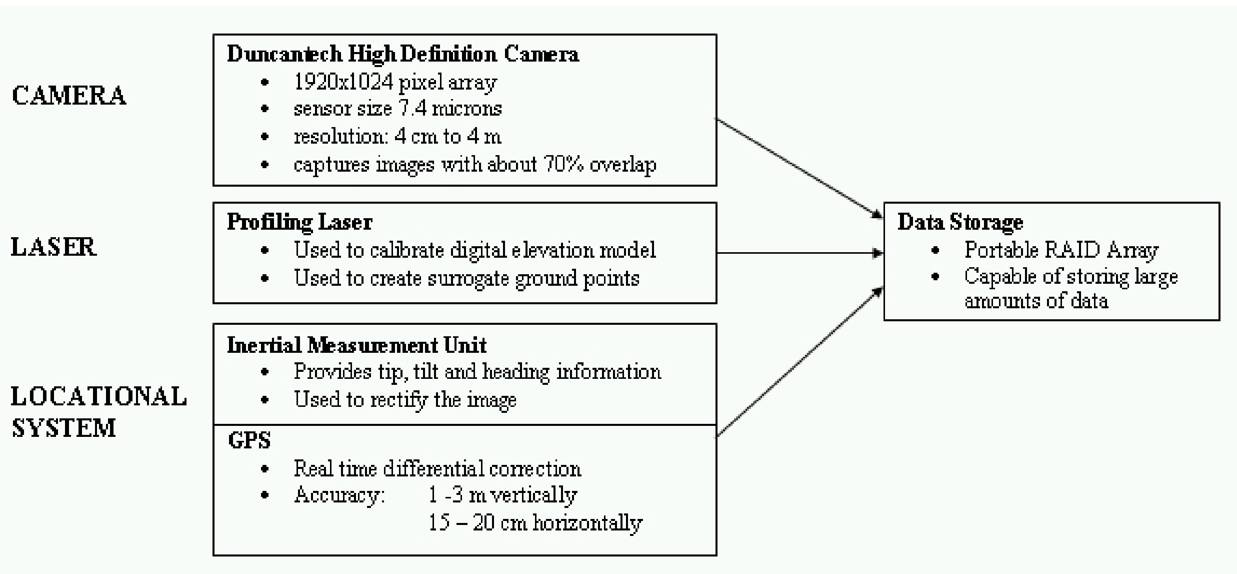

Figure 1. Overview of the multi-spectral Aerial Digital Imagery system. The system can be installed in most small aircraft, and draws power from the aircraft.

The system can be loaded onto nearly any single engine aircraft that can fly at low altitudes (approximately 200 m above ground level) and at relatively slow speeds for image acquisition (a Cessna 207 was chartered for this project). The imagery system can be flown under cloud cover, flown at high temporal frequency, and viewed as automatically georeferenced strips and stereo pairs in a standard computer with GIS (Geographic Information System) software.

STUDY SITE

The study area was the 2004-harvest forest zones operated from the Ndoki 2 logging camp of Congolaise Industrielle des Bois (CIB), a Swiss-German timber company, in Sangha Province in the northern Republic of Congo (hereafter referred to as Congo)(Figure 2). The elevation of the area is approximately 450 meters above sea level, with gentle to flat topography. The mean annual rainfall is about 1300 mm with a mild dry season of 2-3 months. The forest concession contains trees as large as 3.5 m diameter at breast height, reaching heights in excess of 50 m. Trees, with a dbh of between 80 and 220 cm, of up to 20 timber species are felled. The 2004 harvest-forest zones total an area of 11,798 ha (Figure 2).

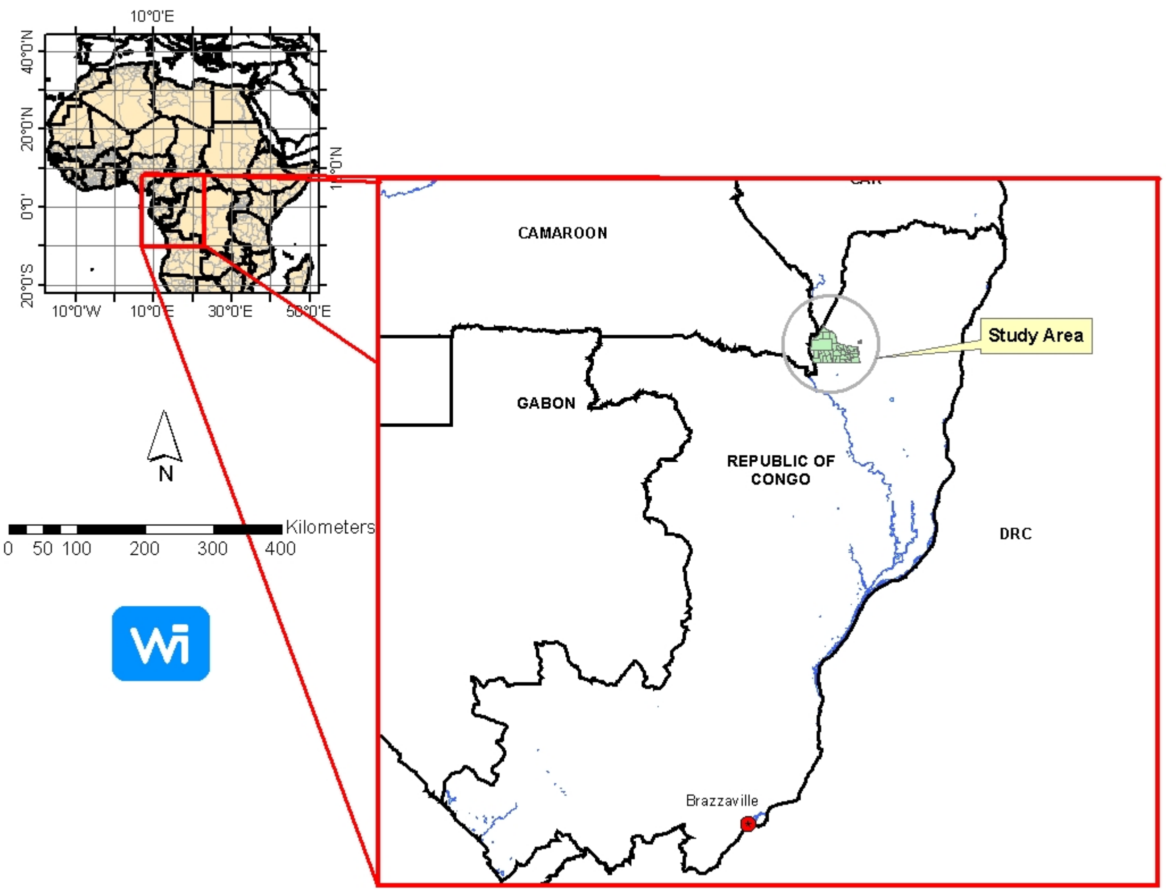

Figure 2. Location of the study area: CIB logging concessions in the Republic of Congo

METHODOLOGY

The imagery was collected between December 16 and 19, 2004 in Northern Congo (Figure 3), and consists of 10 cm per pixel resolution digital photos flown in transects 2 km apart, to yield a 10% sample of the areas logged by CIB in 2004. Additional lines were flown to give additional coverage of sites visited on the ground by the field team. A total of 336 km of transects were flown over CIB concessions. (Coverage was focused on areas selectively logged by CIB in 2004; some additional coverage was conducted of areas logged in 2003 and areas scheduled for logging in 2005 but these areas fall outside the scope of the present analysis). All imagery was collected in the visible bands (red, green, blue) as well as in the near-infrared, which makes more in-depth analysis of vegetation health and moisture possible using false-color composites or NDVI (Normalized Differenced Vegetation Index) based tools (Figure 4). Imagery was collected from an aircraft approximately 640 feet (195 meters) above the ground, at a rate of about 2 images per second. This high rate of collection yields overlap of 70-80% between each image and its neighbors, making stereo interpretation possible.

Coincident with the imagery collection, GPS, tip and tilt, and laser range data were collected to better orient the images in space. This also allows the creation of surrogate ground points, making processing to georeferenced imagery possible without extensive ground work along the course of the flight lines. Upon completion of the data collection phase, all data was integrated into a collection of Erdas Imagine Leica Photogrammetry Suite-format block files. The block files use the location, tip and tilt information in combination with the surrogate ground points to project the digital images to the ground, georeferencing them for use in any GIS. The georeferenced images can then be used to create a seamless mosaic of the photos.

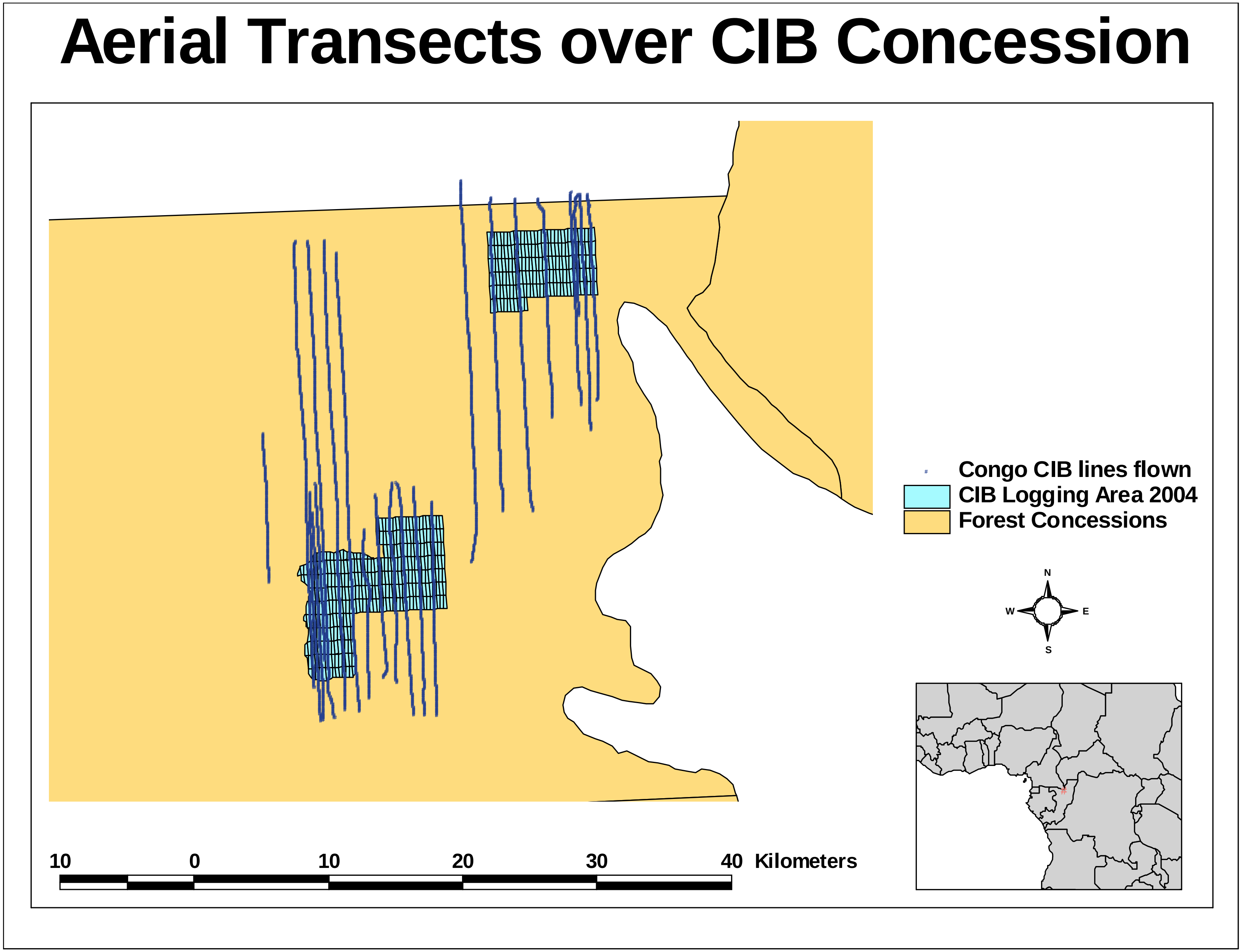

Figure 3. Flightlines over CIB concession in the north of the Republic of Congo, approximately 50km north of Pokola.

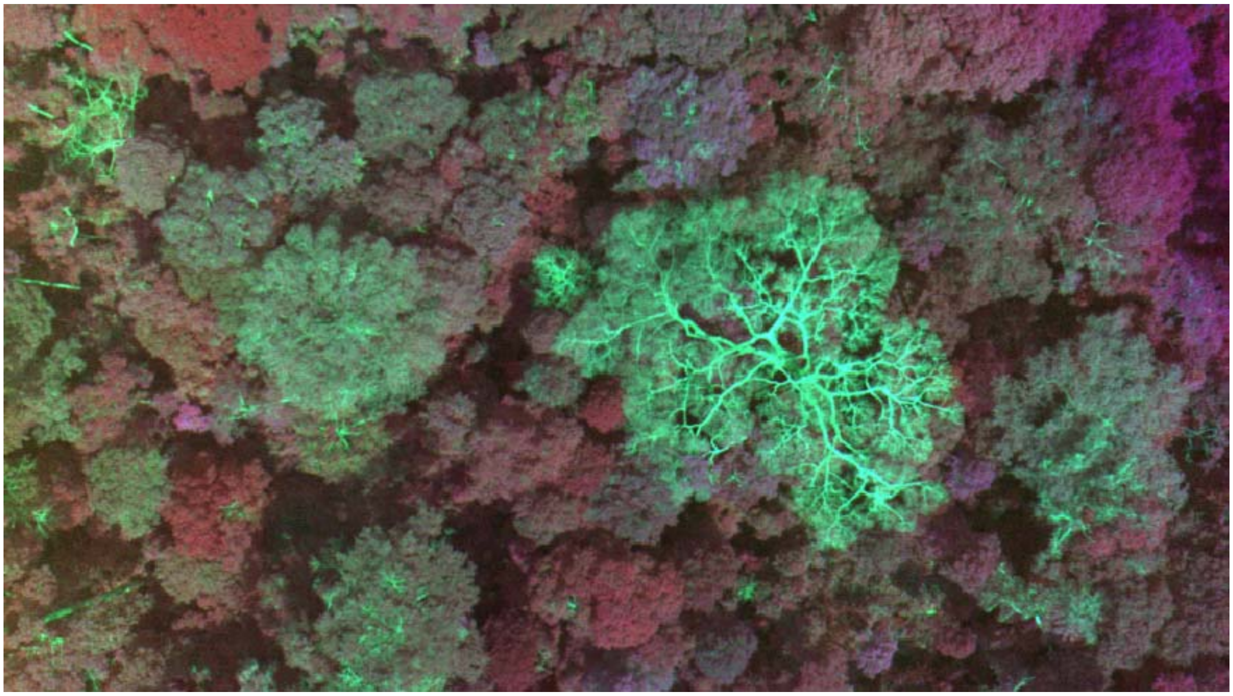

Figure 4. Comparison of Visible and False Color Imagery. The upper image displays the Red, Green, and Blue bands of the visible spectrum (RGB), while the lower image display the same photo in the Green, Red, and Near Infrared (GRIR or False Color). The infrared band reflects much more from surfaces with high levels of moisture, making it a good tool for evaluating plant health or activity. Darker shades of red have higher moisture levels while shades approaching purple are less active.

After creating blocks in Leica Photogrammetry Suite, work moves to the Stereo Analyst module of the Erdas Imagine software. This software allows true 3D viewing on a computer monitor, using special shutter glasses which are synchronized with the monitor, alternately blocking the vision of each eye 100 times a second, tricking the brain into seeing depth on a flat screen, through precise overlapping of neighboring images. A trained user of the software can easily measure tree heights, delineate tree crowns, and identify other features in the imagery.

For this project, we identified logging gaps (e.g. Figure 5) by digitizing polygons that completely enclosed the resulting areas of bare ground, visible slash and other debris, and low, scrubby growth. The skid trails used for log extraction were often visible beneath the forest canopy (Figure 6), and these trails were digitized as simple line features everywhere that they were visible. When the location could be confidently interpolated, it was digitized (visible on either side of a large tree, for example). The third category digitized was roads and loading areas (Figure 7), which were delineated as polygons and were free of any type of vegetation.

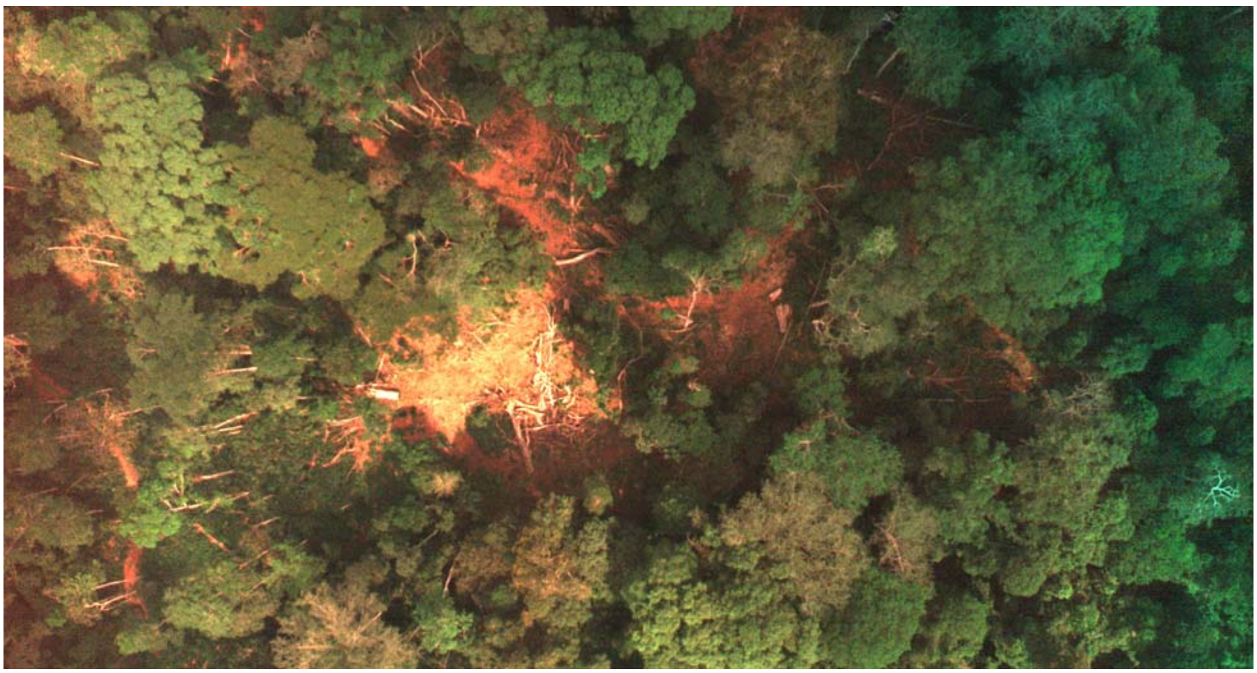

Figure 5. Logging gap. Note the felled tree on the left side of the clearing.

In Figure 8 there is a strip of forest with (A) and without (B) the gaps, trails and road delineated.

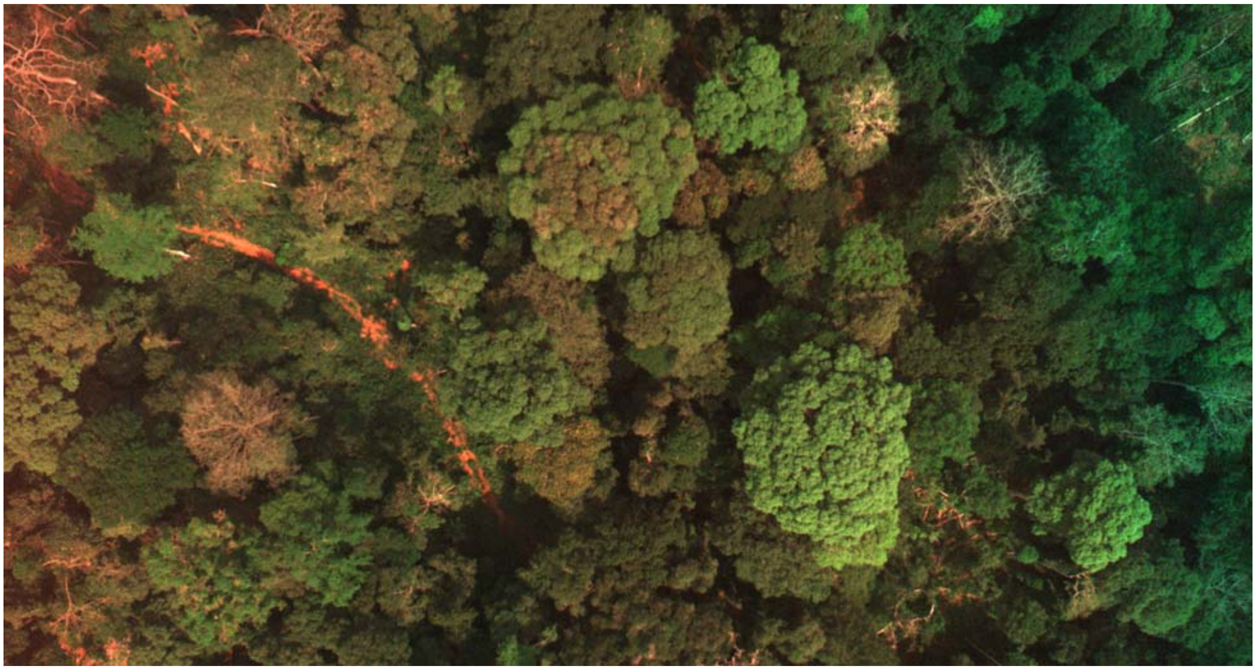

Figure 6. Visible skid trail. This example of a skid trail is wider than most in this logging concession, yet still disappears into the forest and shadow on the lower edge of the image

Figure 7. Logging road and loading area

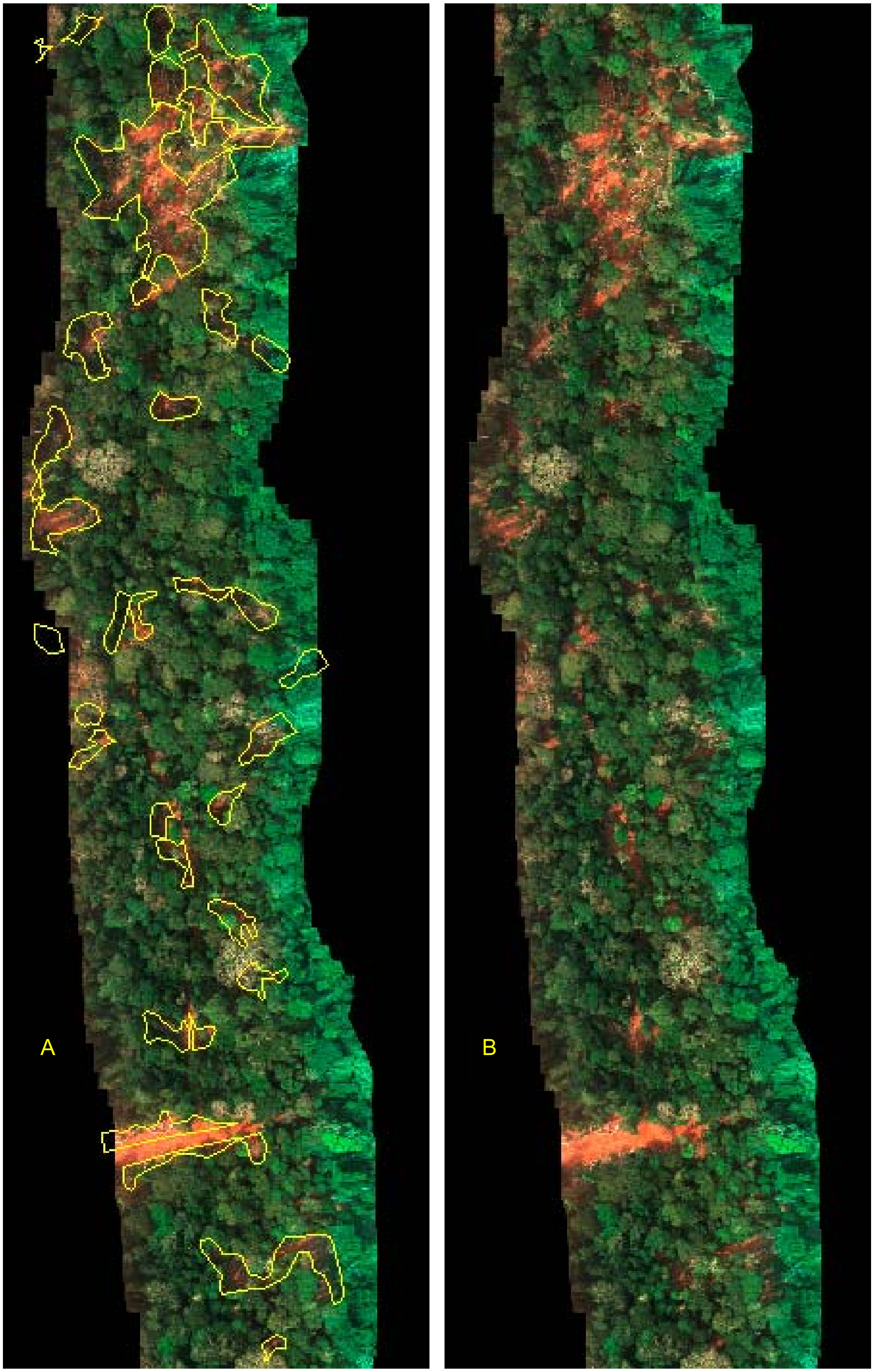

Figure 8. Strips of aerial imagery showing logging damage, in A the areas of damage are delineated. The imagery is designed to be seen in three dimensions and so some of the polygons are offset when seen in two dimensions.

Enhanced visualization of the imagery is possible using DEMs (Digital Elevation Models) and same scale (10cm) mosaics. Used in combination, the two give a much improved overview of the forest and it's components. In Figure 9, a mosaic has been draped over a DEM in the area of a road. This shows the vegetative variety (both species and height) between the areas adjacent to the road and those areas that are further away and have less of a history of disturbance.

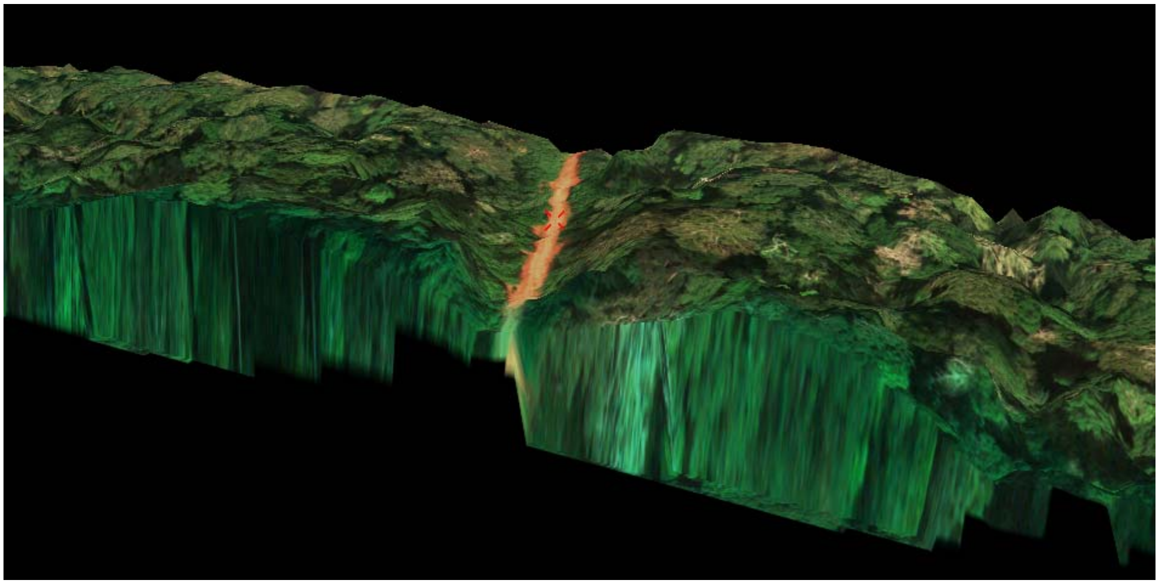

Figure 9. This image shows mosaicked 10cm imagery draped over a DEM (Digital Elevation Model) of the area, which is an additional product of the same data set. The two layers are at different resolutions, resulting in the slightly "melted" appearance of the mosaic.

Sampling Design

Data was collected along flightlines that were nearly north-south, paralleling the logging blocks in use by CIB. The lines were placed with the intent of flying along the center of the north-south oriented blocks every two kilometers, yielding a 10 percent sample. Additional lines with the same orientation were also flown over areas of known interest, especially those where ground plots had been placed and skid trail damage recorded.

The imagery was analyzed in roughly the same order as it was captured. Analysis was also performed along the same flight lines, to be used for comparison or for future reference.

CARBON CALCULATIONS

As a result of fieldwork within CIB's 2004 harvest area, factors were created that linked gap area, skid trail length and road area with carbon impact (Table 1; Pearson et al. 2005, Brown et al. 2005). These factors were applied to the data derived from the aerial imagery to calculate carbon impact.

Table 1. Estimation factors for linking data facets derived from the aerial imagery with extracted volume and biomass carbon, and damaged biomass carbon from logging operations in the CIB concession, Republic of Congo.

	Factor	**95% CI**
m^3 extracted / m^2 of gap area	0.0444	*±0.0057*
Kg C extracted / m^2 of gap area	12.10	*±1.58*
Kg C damaged / m^2 of gap area	18.52	*±2.29*
Kg C damaged / m of skid trail	6.83	*±2.44*
Kg C damaged / m^2 of road area	27.67	*±10.39*

RESULTS

Of the 11,798 hectares of 2004 CIB logging area, 1,473 ha were examined in the aerial imagery. This is equivalent to 12.5 % of the total area. The results on area of gaps, area of roads and length of skidding trails were extracted for this imagery area. These results showed highly selective logging, with only 31.9 ha of logging gap (2.2%) in the area surveyed, and about 18.4 km of skid trails created. The roads passing through the area are used for access and timber extraction and totaled 11.5 ha, or 0.78% of the mosaic area.

From the analysis we calculated an extraction of 14,150 m^3 ± 870 (mean ± 95 % confidence interval), which is equal to 9.6 m^3 per hectare of concession ± 0.59 (mean ± 95 % confidence interval. The mean per tree volume calculated in the field from 120 felled trees was 20.67 m^3. The calculated extraction (from the aerial imagery) of 9.6 m^3 per hectare is therefore equal to 0.46 trees per hectare.

In Table 2 the total carbon impact on this area and the carbon impact per hectare of concession is presented. The total impact is calculated to equal 8.86 t C/ha of which 29 % is in the extracted log and 26 % is the combined impact of skid trails and logging roads. The great majority of the impact arises therefore in the logging gaps (74 %) and 61 % of this impact or 45 % of the total impact is in the stump and crown of the felled tree and in the incidentally damaged surrounding trees. The 9.3 m^3 /ha of timber removal thus causes a total carbon impact of 8.86 t C/ha (or a reduction in live biomass of 8.86 t C/ha); or 0.95 t C/m^3 of timber extracted.

Table 2. The total carbon impact and the carbon impact per hectare as calculated from aerial imagery analyzed from 1,473 ha of forest in 2004 concession area.

	Total carbon impact		**Impact per ha of concession**	
	t C	**95% CI**	**t C/ha**	**95% CI**
Extracted biomass carbon	3,824	± *248*	2.60	± *0.17*
Damaged biomass carbon in logging gap	5,698	± *343*	4.01	± *0.23*
Damaged biomass carbon in skid trails	126	± *10*	0.09	± *0.007*
Biomass carbon impact of logging roads	3,194	± *598*	2.17	± *0.41*
TOTAL	13,042	± *1,199*	8.86	± *0.81*

Additional Scaling Factors

The aerial data permit the calculation of factors that can give the estimated carbon impact from roads and skid trails based on the extracted volume. These factors will only apply for the logging intensity employed by CIB.

- 0.0089 t C impact on skid trails / m^3 extracted (95 % CI = 0.0007)
- 0.23 t C impact from logging roads / m^3 extracted (95 % CI = 0.04)

These can be added to the factors already derived for extracted biomass and damaged biomass in the logging gap (Pearson et al. 2005, Brown et al. 2005):

- 0.27 t C impact from extracted biomass / m3 extracted (95 % CI = 0.004)
- 0.46 t C impact from stump+crown+incidentally damaged biomass /m3 extracted (95 % CI = 0.05)
- 0.95 t C total impact /m^3 of timber extracted

With these factors it is possible to calculate the carbon impact of activities of CIB, or a company using similar practices, based solely on the reported extracted volumes. However, these impacts do not represent immediate emissions of carbon dioxide to the atmosphere. Dead wood in the forest will decompose over time gradually releasing carbon and a proportion of the extracted biomass will be converted into long term wood products and may remain sequestered in this form for very many years (c.f. Pearson et al. 2005, Brown et al. 2005).

REFERENCES

Brown, S, T. Pearson, N. Moore, A. Parveen, S. Ambagis and D. Shoch. 2005. Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study. Deliverable 6 to USAID, Cooperative Agreement No. EEM-A-00-03-00006-00.

Brown, S., T. Pearson, D. Slaymaker, S. Ambagis, N. Moore, D. Novelo, and W. Sabido. 2005. Creating a virtual tropical forest from three-dimensional aerial imagery to estimate carbon stocks. *In press*. Ecological Applications, pp 13.

Brown, S., T. Pearson, D. Slaymaker, S. Ambagis, N. Moore, D. Novelo, and W. Sabido. 2004. Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Tropical Pine Savanna. Report to The Nature Conservancy Conservation Partnership Agreement. Pp 22.

Pearson, T.R.H., S. Brown, R. Vaca, J. Quispe, S. Ambagis, and D. Shoch. 2005. Impact of selective logging on the carbon stocks of tropical forests: Bolivia and the Republic of Congo as case studies. Submitted to the Canadian Journal of Forest Research.

