TECHNICAL REPORT: MAPPING CURRENT AND HISTORIC LOGGING ROADS IN CAMEROON

AUTHORS:

Maria Jacoba VAN DE POL (Central Africa advisor to WRI-GFW, now a researcher for Wageningen University and Reseach Centre Alterra)

Susan MINNEMEYER (GIS Manager, WRI-GFW)

Lawrence NSOYUNI (GIS/RS Officer at LBZG, now GIS Trainer for WRI-GFW)

Jay MEEHL (GIS consultant and technical Adviser at LBZG, now with Saint Mary's University of Minnesota)

TABLE OF CONTENTS

1 ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	German Technical Cooperation (*Gesellschaft für Technische Zusammenarbeit*)
INC	National Institute of Cartography (*Institut National de Cartographie*)
ETM	Enhanced Thematic Mapper (Landsat satellite)
LBZG	Limbe Botanical and Zoological Garden
MINEF	Ministry of Environment and Forests
NASA	National Aeronautics & Space Administration (USA)
NASA-INFORMS	NASA Integrated Forest Monitoring System for Central Africa
SPOT	Earth Observation Satellite (*Satellite Pour l'Observation de La Terre*)
TREES	Tropical Ecosystem Environment observations by Satellite
FMU/UFA	Forest management unit (*unité forestière d'aménagement*)
SSV/VC	Sale of standing volume (*vente de coupe*)
UMD GLCF	University of Maryland Global Land Cover Facility
WRI-GFW	World Resources Institute – Global Forest Watch

2 EXECUTIVE SUMMARY

Forest roads were mapped as indicator of the location and extent of historic and current industrial logging for the Interactive Forestry Atlas of Cameroon (CD Version 1.0). This roads dataset was produced by a partnership between the Cameroon Ministry of Environment and Forests (MINEF) and the World Resources Institute – Global Forest Watch (WRI-GFW). The use of remotely sensed data such as Landsat ETM+ satellite images offers a reasonably-priced and efficient alternative to potentially time-consuming and expensive ground surveys. We processed and interpreted Landsat ETM+ images to map over 40,000 km of roads in the forest zones of Cameroon, including nearly 10,000 km of logging roads. The roads captured were characterized (attributed) on the basis of their date of origin (defined as the registration date of the image on which the road was first observed). For logging and forest roads, we also recorded the intensity of use of the road per logging season from 1999 to 2003. To validate and estimate the precision of roads digitized, a proportion of the corresponding roads digitized were field surveyed and tracked using a Global Positioning System (GPS). A statistical analysis was conducted (comparing the tracked roads with the corresponding section of the digitized roads) to estimate the precision of the digitized roads.

Mapped forest roads were prepared along with forest management data for Cameroon including concessions, reserves, and protected areas to inform decision making about forest resources. The roads and forest management datasets have been made available on a CD titled the Interactive Forestry Atlas of Cameroon. The CD contains all GIS datasets, a map viewing application, and a summary report, *The Interactive Forestry Atlas of Cameroon: an Overview*, that describes the atlas and potential uses by policy makers (available from Global Forest Watch, http://www.globalforestwatch.org).

3 INTRODUCTION

The extent of road access into forests is the basis for timely and accurate assessment of current and historical environmental changes resulting from industrial logging and other forest related development (Matricardi et al. 2003). In this report, we rely on multi-temporal mapping of logging roads from Landsat ETM+ imagery validated by ground surveys to provide information required for monitoring the location, extent and intensity of historic and current logging activities. Detailed information is provided on the methodology used to create and assessed the accuracy of the road datasets developed.

Logging roads were derived and will be updated annually from the interpretation of remotely sensed images integrated with extensive ground surveyed information and published with other datasets in the Interactive Forestry Atlas of Cameroon. The Limbe Botanical and Zoological Garden (LBZG), a unit of Cameroon's Ministry of Environment and Forests (MINEF) and a Global Forest Watch partner, led the road digitizing and data collection efforts.

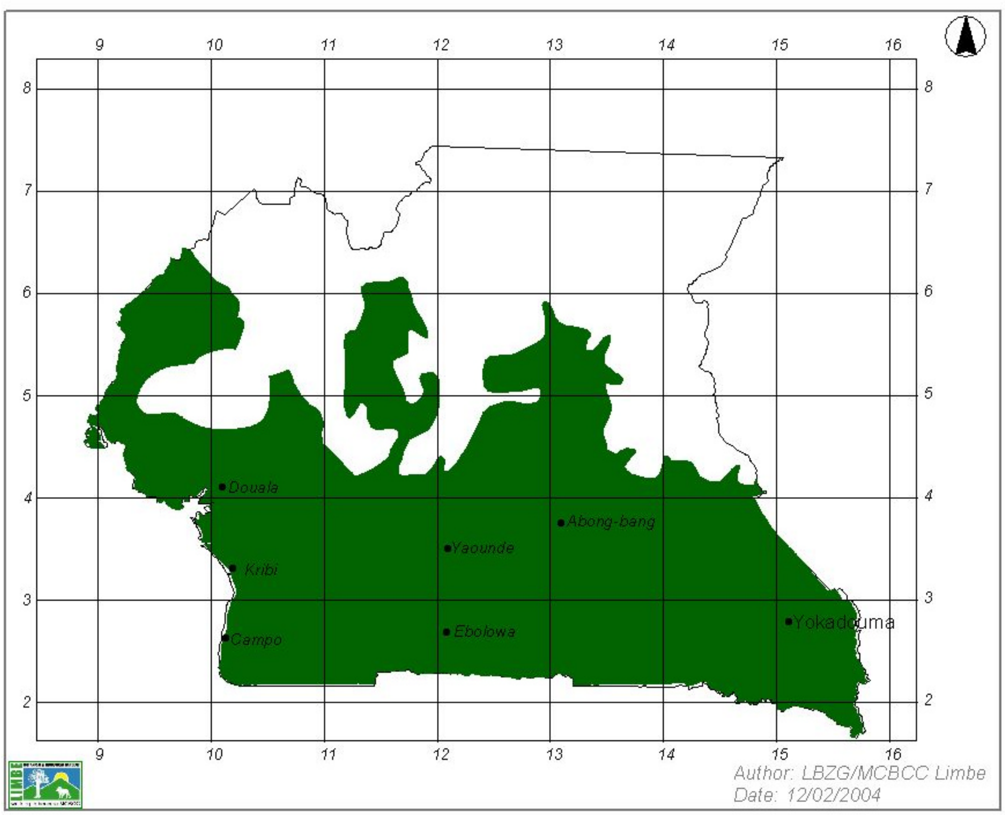
Landsat ETM+ images were chosen for this study because their resolution (28.5m), extent (185km by 170km), spectral characteristics, and relatively low cost were ideal for tracking road development over a large study area (Wilkie and Laporte, 2001). This effort was facilitated by the low cost of Landsat imagery and lack of copyright that allow for sharing of images by many organizations (e.g., NASA's Global Orthorectified Landsat Dataset, Tucker et al., 2004). Spectral bands in the visible to mid-infrared range allow for contrast in the visibility of vegetation in comparison to bare ground and the clear detection of linear road features (de Wasseige and Defourny, 2004).

The logging road dataset with annual updates reveals the extent of traffic access into forests and, together with up-to-date information on logging permits and other relevant information, forms the basis for timely and accurate assessments of environmental changes resulting from industrial logging and other forest related development. The dataset is also expected to benefit MINEF staff charged with monitoring and controlling logging activities, to identify areas where recent logging is taking place, to track the development of logging roads and related infrastructures (e.g., log yards), and to indicate whether road building and logging is occurring inside legally designated areas. Indicators of recent road building and/or logging will assist MINEF to prioritize field monitoring and control missions.

4 STUDY AREA

The study area extents across Cameroon's forested zone, stretching between longitude 9° - 16° east of the Greenwich Meridian and latitude 2° - 6° north of the Equator. The area below termed "Cameroon Forested Zone" is approximated from TREES (EC Joint Research Centre) 19992 -93 AVHRR imagery derived land cover map and combines dense moist forest and degraded forest classes.

Figure 1: Cameroon Forested Zone (derived from TREES Land cover Map, Mayaux et al., 1997).



5 MATERIALS

A variety of input data types, hardware and software were used to process imagery and to detect, map and verify logging roads. Extensive use was made of existing road datasets considering their source, quality, date of publication, etc. Hardware and software requirements for using the road dataset by a wider audience were also considered prior to deciding on the dataset format.

5.1 Data used for digitizing and verification

The input data types that were used to digitize, cross-check and validate roads dating the roads after production are summarized in the following paragraphs.

5.1.1 Landsat 7 ETM+ satellite imagery

A total of 46 medium-to-high resolution (28.5m) orthorectified[1] Landsat 7 Enhanced Thematic Mapper (ETM+) satellite images were obtained through the World Resources Institute - Global Forest Watch (WRI-GFW) and used for the study. See Annex 1 for the list of images used. Landsat ETM+ Satellite imagery has a spatial resolution of 28.5 meters per pixel (channels 1-5 and 7) and 14.5 meters per pixel (panchromatic channel) and a view range of 183km x 170km. Spectral and geometric correction was performed by EarthSat (Earth Satellite Corporation; Rockville, MD, USA). The images were orthorectified and georeferenced by EarthSat's to their GeoCover dataset (http://www.geocover.com), a commonly used and available system. The images were referenced by EarthSat using geodetic and elevation control points as tie-points within the overlap between adjacent scenes that corrected for differences in terrain or satellite viewing perspectives (Tucker et al., 2004). The image correction also improved edge-matching between scenes, allowing for road connectivity across scenes and thus facilitating road mapping.

The ETM+ scanner measures the sun's reflectance in seven spectral channels known as bands. These include the visible spectrum (bands 1-3), near infrared (bands 4 and 5), thermal (band 6) and medium infrared (band 7). These bands were selectively combined into color composite images to enhance roads visibility. Different band combinations were used to maximize the visibility of roads under a range of conditions and ages; the prominent band combinations used included; 7-5-3, 7-5-4, and 5-4-3. To improve the detection of narrow roads, the panchromatic band (14.5m resolution) was merged with the other bands (28.5m resolution) to create a "pan-sharpened" image. This image enhancement greatly improved the visibility of older, infrequently used, or abandoned logging roads.

5.1.2 Topographic maps of Cameroon

In the absence of large scale (1:25,000 or 50,000) topographic maps covering the entire study area, scanned 1:200,000 topographic maps produced by the National Institute of Cartography in Cameroon were used for road category verification, which was not possible through direct observation from the imagery. Instead, to assign road type, the digitized roads were overlaid on the scanned and georeferenced maps. This allowed the identification of national, provincial and departmental roads as well as most airstrips. (See paragraphs 6.3.3 and 6.3.4).

5.1.3 CARPE road data set for Central Africa

In addition, the digitized roads were compared with the road datasets made available by the Central Africa Regional Programme for the Environment (CARPE, 2000). The CARPE road

[1] Orthorectification was done by Earth Satellite Corporation, Rockville, MD, USA.

data set allowed the identification, especially in cloud covered areas, of any omission of public roads. The CARPE roads datasets were created by digitizing the 1:200,000 scaled topographic maps of Cameroon and have limited or no data on logging roads.

5.1.4 MINEF zoning plan data

The digital forest zoning plan of the Ministry of the Environment and Forestry (MINEF) was used to verify, validate, and in some cases categorize roads digitized from Landsat ETM+ imagery.

5.1.5 GPS Field Road Data

Three field trips were strategically planned to collect field data for verification across all the different Landsat ETM+ scenes in the study area. GPS points were collected in the field using hand-held Global Positioning System (GPS) units mounted on vehicles while driving roads. GPS data (points and tracked roads) were also obtained from various forestry and environmental conservation projects including Tropenbos in Kribi, the Mount Cameroon Project in Limbe and GTZ South East in Yokadouma. These GPS points were used to validate the accuracy of all the geo-referenced imagery used in the study. Tracked roads were used in assessing the spatial accuracy and completeness of the digitized roads data.

5.2 Software, preliminary image processing and GPS Units

Next, ERDAS Imagine 8.6 software (Leica-Geosystems, Inc., Atlanta, GA, USA) was used to create color composite and resolution-enhanced ("pansharpened") images. Color composite images combined bands 1, 2, 3, 4, 5 and 7 and pan-sharpened images including bands 3, 4, 5, 7, and the panchromatic band 8 were created for all Landsat ETM+ imagery. The 14.5m panchromatic band was used to enhance the detail of the 28.5m resolution color composite images.

Road digitizing was done in an ArcGIS Environment (ArcGIS 8.3 was used for the development of the Geodatabase, initial digitizing and attribution while ArcView 3.2a was used to hasten the digitizing process). The ArcGIS and Image Analyst environment offer several advantages over other GIS platforms, including the ability to toggle rapidly between data and image layers while digitizing, enhancement features such as histogram equalization and standard deviation stretches that enhance the visibility of roads under varying conditions.

For fieldwork, three different types of handheld Global Positioning System Units (Garmin 12XL, Garmin GPS 76 and Garmin Etrex Vista GPS) were used for road tracking (Garmin International, Inc., Olathe, KS USA). A laptop loaded with Arc View 3.2a (including a GPS data extraction extension) and a GPS data downloading cable were used for real-time on the spot comparison with digitized roads.

6 METHODOLOGY

6.1 Preparation of the geodatabase

To reduce possible data attribution errors, increase the speed of data capture, and facilitate efficient data creation, road information was captured and stored in a geodatabase using ESRI ArcGIS 8.3 software. A geodatabase represents geographic features and attributes as objects and is hosted inside a relational database management system (ESRI, Inc.) Using the geo-database model for digitizing permitted the following operations: (a) definition and control of database topology, (b) limitation of attribute values to a specified selection to prevent the introduction of unacceptable attribute values or typographical errors, and (c) the assignment and control of default and null values.

6.2 Road digitizing

6.2.1 Introduction

Skidding trails and log transportation roads created during industrial logging are visible on satellite images with medium to high spatial resolution (Ikonos, SPOT, Landsat ETM+ etc). According to field measurements, the forest roads that were most clearly visible as linear features on the satellite images were those that measured at least 7–15m wide, those with clearings on both sides, and/or those that had no overhead forest canopy cover. Roads in heavy use at the time of image registration were the most clearly visible, followed by recently created roads (relative to the date of image registration), and last, by less intensively used or abandoned roads.

6.2.2 Digitizing process

Landsat ETM+ bands were selectively combined (7-5-3, 7-5-4, and 5-4-3) and different spectral enhancement techniques were applied to clearly visualize and detect roads for digitizing. Roads were digitized scene-by-scene at a viewing scale of 1: 30,000 with a snapping tolerance of 30m. Road digitizing for each Landsat ETM+ path and row started with the oldest image and proceeded to the most recent. All visible roads were digitized with the exception of those too faint to distinguish from temporarily dry stream valleys or those largely obscured by clouds. Upon completion of the digitizing exercise, all road datasets were combined and cleaned, using ArcGIS 8.3 software, to assure correct topology. Datasets were frequently reviewed and verified throughout the digitizing process. A detailed description of the digitizing methodology is given in Annex 2.

6.2.3 Attributing digitized roads

In line with the objectives of the study and use of the dataset, digitized roads were attributed following the criteria given below and using a set of pre-selected values. In some cases the choice of attribute value was subjective based on the interpretation of the technician (for example, in distinguishing between lightly and heavily used roads).

6.2.3.1 RoadID: Unique numeric code automatically assigned by the ArcGIS software.

6.2.3.2 Origin: The registration date of the Landsat TM 7 image from which the road is first observed and digitized given in the format YYYYMMDD. When images with multiple dates were available, the date was attributed to the oldest scene on which (parts of) the road was (were) visible.

6.2.3.3 Type: To standardize road classification, a list of road type criteria was developed.

1. Public roads:
   - All classes of public roads occurring on 1:200,000 topographic maps;
   - All roads highly visible on the images that connect settlements and are away from logging concession areas. These include major public roads created after the publication of the topographic maps in 1971 and minor roads that were later improved (sometimes indicated by dashed lines on the 1:200,000 topographic maps); and

- Distinguished from the straight-line high-voltage electricity rights-of way connections, which also exhibited a slightly different spectral reflectance.

2. Primary Logging roads:
   - Within logging concessions;
   - Similar in appearance to public roads with cut-backs on the sides;
   - Branch off from public roads with other logging road types diverting from them;
   - Are often intensively used by heavy traffic for several years within active concessions; and
   - May be indicated by dashed lines on the national 1:200,000 scanned topographic maps.
3. Secondary logging roads and skidding trails:
   - Inside logging concessions, sales of standing volume (called sales of standing volume (SSV) (*ventes de coupe/VC*) in Cameroon) and other areas with a logging permit;
   - Roads diverting from primary logging roads;
   - Sometimes narrow in width compared to primary logging roads,
   - May branch off from a public road;
   - Are generally short in length;
   - Are in general used by heavy traffic for one or two years; and
   - Generally come to a dead end in forest.
4. Private roads in plantations;
   - Inside industrial agricultural plantations;
   - Branch off from public roads or other private roads;
   - Narrow in width compared to primary logging roads.
5. Forest roads:
   - Roads in forested areas that do not meet any of the above criteria.
6. Airstrips/Airport:
   - Short, intensively used straight lines with an average length of 500m, connected to other roads and close to a settlement or industrial complex.

6.2.3.4 <u>Traffic intensity:</u>

The use of heavy traffic on digitized roads was judged subjectively by the size and clarity of the road on each image. In addition, intensively used roads outside logging concessions tend to have many settlements bordering them, as confirmed by field observations. To monitor traffic intensity over time, three attribute fields were developed that corresponded to the three logging seasons from which imagery was available. Field names were assigned as a 4-digit number corresponding to logging season (for example, 1999-2000 was recorded as 9900). The date of the Landsat ETM+ scene from which the road was observed to be heavily used was recorded for the road in question in the format YYYYMMDD. If heavy use was not observed, the record was left blank. When use intensity could not be assessed due to cloudiness, the word ‘Cloudy’ was entered for the record in question. And finally if no image was available for a certain logging season ‘No data’ was entered. Below, the specifications for the field names (9900, 0001 and 0102) are described:

- 9900: Season beginning the 1st of July 1999 and ending the 30th of June 2000.
- 0001: Season beginning the 1st of July 2000 and ending the 30th of June 2001.
- 0102: Season beginning the 1st of July 2001 and ending the 30th of June 2002.

Although subjective, use intensity classification was observed to be of acceptable accuracy following fieldwork verification. However, visibility of roads on images was observed to be influenced by the time of registration of the imagery. For instance roads may be more clearly visible during the rainy season when the infrared reflectance (band four) of healthy vegetation increases relative to that of paved or un-paved roads. Heavily used roads may also be difficult to distinguish in forest areas where a closed canopy borders closely on roadsides (i.e., no roadside clearings).

6.3 Verification and validation of digitized roads

The digitized roads and their attributes were verified internally at LBZG during the digitizing process and corrected by exchanging and reviewing the data between the GIS/RS specialists. After digitizing, the road dataset was verified, corrected and validated in four steps with backstopping from WRI-GFW.

6.3.1 Step one: verification of digitizing quality

Each satellite image (for each scene treating them from the oldest to the most recent) was scanned systematically and thoroughly for missing roads, roads that were not digitized precisely, and roads digitized in error. Errors were often roads that were poorly visible on the image or difficult to distinguish from other similar features, such as temporarily dry stream valleys. Verification was performed using the pan-sharpened images. At the same time the date of origin (the date of the image on which the road was first visible) was verified. This was specifically necessary along the scene margins, where neighboring images overlap.

The topology of the road data set was verified and corrected to remove any overlapping roads or pseudo nodes (points where a continuous road was broken into separate lines). Pseudo nodes were tolerated where road segments represented a meeting point of two different roads or road segments; for example, where one part was an old road and the other newly constructed.

6.3.2 Step two: verification of spatial accuracy

To ensure the spatial accuracy of road datasets, verification was done using field-collected data. Three field visits were conducted during which 2,585km of roads (representing 7% of the total length of roads that were digitized) were tracked using handheld GPS units. Field-tracked roads extended across most of the Landsat ETM+ scenes covering the study area (see Annex 3). GPS waypoints characterizing these roads segments were registered during fieldwork. Additional GPS waypoints points and tracked roads were obtained as well from several other forest or environmental conservation projects including the GTZ-South East, Mount Cameroon Project and Tropenbos, to complete the sample coverage for the other scenes. The GPS-tracked roads were imported into the ArcView3.2.

To assess the spatial accuracy, a total of 25,850 sampled points were generated randomly using an Arc view script (approximately 10 points per kilometer) from the GPS tracked roads. These sampled points were overlaid with the digitized roads in Arc View GIS software and using statistical techniques, road comparison analysis were performed to calculate the proximity of each sampled points on the GPS tracked road to its corresponding point on the digitized road. A detailed description of the field verification method is given in Annex 3.

6.3.3 Step three: verification of use intensity

When digitally enhanced, roads that were intensely used during the time of image registration displayed distinctive reflectance in comparison with those less intensely used or abandoned. Heavily used roads appear with a very intense and different color in comparison to surrounding vegetation, whereas the color of lightly used roads is more difficult to distinguish from the surrounding forest. Abandoned logging roads appear slightly brighter than the surrounding forest and become less visible with age. These differences in the reflectance of heavily and lightly used roads were confirmed with field visits. It was also noted that heavily used roads as narrow as 5m-7m could still be adequately identified. In some cases, however, heavily used roads bordered with closed canopy were confused with less intensely used roads. Road surface type (paved, gravel etc) had very minor influence on characterizing use intensity. Beginning with the oldest image for a particular scene, all the images pertaining to that scene were scanned, verifying and characterizing annual use intensity on the basis of brightness and contrast. Examples of intensively used and abandoned roads are given in Picture 1, 2 and 3.

6.3.4 Step four: verification of road types

Because public roads can cross industrial plantations and logging concessions, first the public roads were verified and divided into primary- and secondary roads using the INC 1:200,00 topographic maps. Verification of railways was done using the topographic maps as a reference, and field collected GPS data.

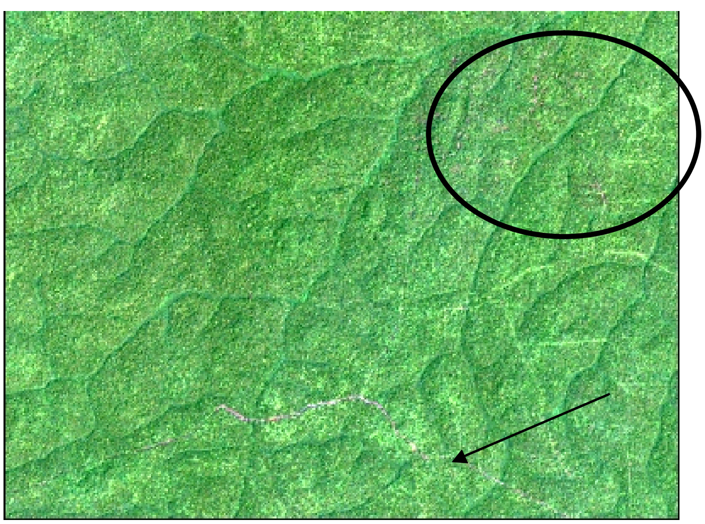
After this the logging and plantation roads were distinguished using the MINEF digital forest zoning plan. All roads (except the public roads) that occurred within industrial plantations in this zoning plan were labeled as plantation roads. All roads (except the public roads) within logging concessions, called FMUs (UFAs) in Cameroon, or other logging permit areas (i.e. sales of standing volume (SSV), called *vente de coupe* (VC) in Cameroon), and within other areas identified as production forests in the zoning plan were labeled logging roads. These logging roads were afterwards subdivided into three types, as define in "Normes de Cartographie Forestière Numérique" (Bélanger et al 2001). These included primary logging roads, secondary-logging roads, and abandoned logging roads.

Primary logging roads are the main access roads leading into attributed logging concessions. Continuous and annual usage of these roads helps in distinguishing them from the secondary logging roads, which in most cases occur within annual logging areas (called Assiettes de Coupe in Cameroon) that are usually only exploited for one season or cycle of a concession's duration (30 years in Cameroon). Several logging companies collaborated in the verification of the classification of primary and secondary logging roads[2] within their concessions by commenting on printed drafts road maps delivered to them by WRI-GFW. For roads observed within non-attributed concessions, or outside any of the production forests, we verified whether these roads occurred within an area previously designated as a logging license prior to the establishment of the current UFA concessions and observed their traffic intensity during the past three logging seasons. If roads overlapped a former logging license and were not intensively used during the three-year study period, they were labeled abandoned logging roads. If on any image during the three–year study period the road was intensively used it was labeled a forest road. Some roads fell both outside old logging licenses areas and the current concessions or other logging permits and could not be identified as public or logging roads without field verification. Thus, those roads were also labeled as forest roads.

[2] *The logging companies that collaborated in this verification are HFC, LOREMA, Pallisco, SFID, SIBAF, VICWOOD-Thanry and Wijma.*

Picture 1 Intensively used public road with agricultural fields on both sides.

Picture 2 Abandoned logging roads.



Picture 3 Active logging area with intensively used logging road.

7 RESULTS

A total of 40,565 kilometers of roads were mapped. Persistent cloud cover, a natural phenomenon common in the tropical rainforest, prevented complete mapping of many roads. As a result, roads digitized from such areas appear as broken segments that will be filled as new data is acquired either from new imagery or field checks. Based on field observations, we estimate that abandoned or infrequently used roads remain lightly visible (faint) on satellite imagery for a maximum period of approximately 5–10 years and can thus be mapped. Similar results were found in a study using Landsat TM imagery to map logging roads in the Central African Republic. Images were obtained at the time of logging and again five year later; results showed approximately 50% of logging roads still visible 5 years after logging (de Wasseige and Defourny, 2004). Table 1 lists the extent of roads of various types; the field "Indicatif" in this table is the official MINEF codification for roads (Bélanger et al 2001).

Table 1 Road categories and the total length of roads digitized for each.

Indicatif	**Explanation**	**Nr. of segments**	**Length (km)**
031000101	National road	532	4,418
031000102	Provincial road	385	2,284
031000103	Department road	295	1,753
031000104	Other public roads	3240	14,065
031000201	Railway	64	480
031000901	Plantation road	232	410
031001001	Primary logging road	629	2,157
031001002	Secondary logging road	3187	7,228
031001200	Abandoned logging roads (in old licenses)	2085	5,234
031001201	Abandoned forest roads (outside old licenses)	528	1,419
031001202	Forest roads (outside of attributed FMU and VC, but active)	414	1,061
090101301	Paved airstrip	8	14
090101302	Airstrip	25	41
TOTAL		**11624**	**40,565**

7.1 Roads used by heavy traffic

Intensively used roads are main transportation routes, and inside logging concessions, indicate where logging is active. Intensity of use was determined only for the following road types: primary logging roads, secondary logging roads, forest roads (active roads outside valid FMU or VC permit areas), and abandoned logging and forest roads. A summary of the roads being observed active during the past three logging seasons is given in Table 2.

Table 2 Total length (km) of intensively used roads since 1999 per category

Category	**1999-2000**	**2000-2001**	**2001-2002**
Plantation road	943	55	20
Primary logging road	1,177	1,324	1,469
Secondary logging road	402	756	1,006
Abandoned logging roads (in old licenses)	295	53	51
Abandoned forest roads (outside old licenses)	2	28	12
Forest roads (outside of attributed FMU and VC, but active)	17	502	457

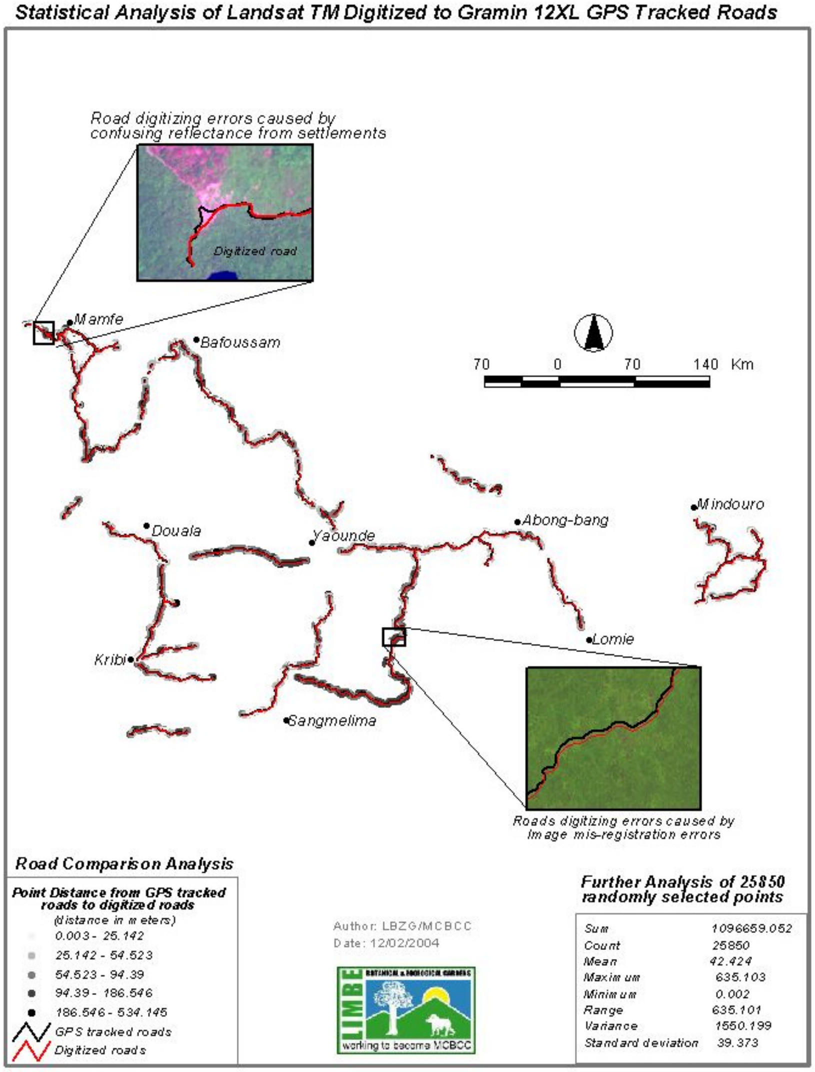
The primary- and secondary logging roads that were observed for the first time on images of season 2001-2002 and were also intensively used in that season were estimated to be new logging roads. The total amount of km of these new roads is: 729km. The forest roads (non-public roads outside of attributed FMU and VC) that were observed for the first time on images of 2001-2002 and were intensively used during that logging season have a total length of 729km. The origin of these roads is undetermined and some may indicate illegal activity; additional information or field checks by MINEF would be required to determine legality.

7.2 Spatial accuracy

The spatial accuracy of the road dataset is determined by the quality of the imagery ortho-rectification and by the digitizing quality. Results obtained showed that 76% of the sample points fell within the target range determined at the outset of this project (+/- 60m which corresponds to 2 pixels on a Landsat ETM+ image).

Points Distances	- Less than 60 Meters	75.7% of points
GPS to Digitized	- 60 to 100 Meters	17.2% of points
Road Segments	- Greater than 100 meters	7.06% of points

Statistical Analysis of Landsat TM Digitized to Gramin 12XL GPS Tracked Roads



The average spatial difference in between the digitized roads and GPS registered roads sampled was found to be ±41.7m, which is largely satisfactory based on the methodology (satellite interpretation) and data source type used (Landsat ETM+) for the study. This level of error is also sufficient at the scale (1: 200,000) at which the data will be used. Statistics for the sampled road segments and the calculated spatial differences are presented in Table 3.

Table 3 Statistics of spatial accuracy calculation

Sum	1079346.230
Count	25850
Mean	41.754
Maximum Minimum	534.145 0.003
Range	534.142
Variance	1420.429
Standard Deviation	37.689

As can be observed from the statistics, spatial differences in between the digitized roads and GPS registered roads amounting up to 534m could be observed. Such very high error rates were investigated and observed to have originated from roads digitized in areas showing one of the following features:

- Roads passing through settlements having wide cleared areas on one or both sides of the roads, thus making it difficult to determine the exact course of the road on satellite imagery.
- Roads bordered on both sides by dense forest canopy thus blocking direct reflectance from the road and making it difficult to correctly digitize along the road course. This tendency was most apparent in areas where the road was narrow with no cutbacks. Most logging roads, however, did not share these features and were digitized with less error.
- Roads where small clouds or cloud shadows occasionally obscured road visibility, thus causing errors when attempts were made to digitize in such areas.
- Roads intersections with high voltage power lines, railroad crossings, pipeline crossings, etc. In some cases the road course in intersections was clearly visible while in other areas large clearings around intersections caused digitizing errors of up to hundreds of meters.

Orthorectification errors were observed on two Landsat ETM+ images: p185r058 (located in the area of Ebolowa, there was a slight non-uniform shift of 100m to 150m on the image) and p187r056 (in the North-West province, which has a non-uniform shift in between images of two different dates of about 70m).

The roads and their attributes can be viewed in the Interactive Forestry Atlas of Cameroon published by MINEF and WRI-GFW. The Interactive Forestry Atlas and accompanying GIS data are freely available (see www.globalforestwatch.org for more information).

8 RECOMMENDATIONS

8.1 Field verification of undefined forest roads

One thousand and sixty-one (1,061) kilometers of the roads were classified as undefined forest roads some of which were actively used within one or all the three years studied. These roads are not public roads and appear outside of attributed FMU (forest management unit or *unité forestière d'aménagement*) and SSV (sale of standing volume or *vente de coupe*). The roads of this category that were intensively used in logging season 2001-2002 have a total length of 729km. These are high priority areas for MINEF field monitoring to identify whether illegal activity is taking place. In addition, the boundaries of some non-FMU permit areas such as community forests and sales of standing volume were unavailable. The development of more complete data on the total valid permit areas would better enable timely evaluation of forest roads.

8.2 Improvement of the spatial accuracy and completeness of digitized roads

The spatial accuracy analysis proves that logging roads can be digitized from Landsat ETM+ imagery to acceptable spatial accuracy. Improving imagery orthorectification and careful digitizing avoiding attempts at digitizing roads under the following circumstances can enhance spatial accuracy:

1. Settlement areas including urban areas, villages, areas with wide clearings along roadsides, etc.
2. Road segments (especially narrow sections) bordered closely by dense forest canopy.
3. Cloudy sections of images where roads may be partially obscured.

Such areas where roads could not be accurately digitized using satellite imagery can later be tracked using a GPS and integrated with the digitized roads. Over time, GPS tracks of most public roads will be acquired, eliminating the need to map these roads from Landsat imagery.

8.3 Use of the road data set

Taking into consideration the fact that the roads were mapped from satellite imagery with just 7% of them field-verified, considering as well irregularities that may results from digitizing under the above mentioned conditions, we expect that some areas of misinterpretation may remain in the dataset. Roads may have been missed due to persistent cloud cover, closed forest canopy cover bordering narrow or infrequently used roads, and the difficulty of mapping old or abandoned logging roads. While GFW continues working to improve the quality and completeness in future versions of the road dataset, we encourage collaboration among local field initiatives and encourage constructive feedback from the use of this road dataset by colleagues in other organizations. Importantly, we are interested in conducting field verifications particularly in specific problem areas identified to improve our methodology and understanding of the limitations of mapping logging roads and estimating road use intensity from medium-to-high resolution satellite imagery such as Landsat ETM+.

8.4 Future use of other satellite image sources

Due to the partial failure of the Landsat ETM+ satellite data capturer in May 2003 (NASA, 2004), which limits the use of its imagery, other types of imagery including ASTER and the IRS (Indian Remote Sensing) satellite are being investigated as possible alternatives. High-resolution imagery, such as IKONOS or Quickbird, may be useful tools for verifying datasets derived from Landsat ETM+ (or other medium to high resolution imagery) though their high costs are a limiting factor. Low-cost copyright-free Landsat imagery has facilitated monitoring projects such as this one, and finding a suitable replacement with similar cost and ease of use will be a challenge.

9 REFERENCES

Bélanger, L. Juin 2001. *Gestion Durable des Forêts Camerounaises*. Normes de Cartographie Forestière Numérique, Saisie et structuration des données, Edition 2. TECSULT.

CARPE. CARPE data CD-ROM (2000). World Wildlife Fund, World Resources Institute, World Conservation Monitoring Centre, and the European Union's Joint Research Center. http://carpe.umd.edu.

Mayaux, P. E. Janodet, C. Blair-Myers and P. Legeay-Janvier. 1997. Vegetation map of Central Africa at 1:5,000,000. European Commission, Joint Research Centre, Space Applications Institute, Tropical Ecosystem Environment Observation by Satellites (TREES).

Matricardi, E. 2003. *Multi-temporal assessment of selective logging using remotely sensed data in the Brazilian Amazon*. M. A Thesis. Michigan State University, U.S.A.

NASA. 2004. NASA Landsat 7 Program update: Fall/Winter 2004. http://landsat.gsfc.nasa.gov/main/PDF/program_handouts/program_update_nov04_lr.pdf.

Tucker, Compton J., Denelle M. Grant, and Jon D. Dykstra. 2004. NASA's Global Orthorectified Landsat Data Set. *Photogrammetric Engineering & Remote Sensing*, 70(3): 313-22.

Wasseige, Carlos de, and Pierre Defourny. 2002. Remote sensing of selective logging impact for tropical forest management. *Forest Ecology and Management*, 188(2004):161-173.

Wilkie, D. and N. Laporte. 2001. Forest area and deforestation in Central Africa: current knowledge and future directions. In: Weber, W., W. Vedder, S. Morland, and L. White (Eds.), African Rainforest Ecology and Conservation. Yale University Press, New Haven, pp. 119-138.

ANNEX 1 LIST OF SATELLITE IMAGES

PathRow	1999	2000	2001	2002	2003
p182r058		26-Mar**	9-Feb**	1-Apr*	15-Feb**
p182r059		18-Sep**	9-Feb**	1-Apr*	15-Feb**
p183r057		14-Dec**		2-Jan*	5-Feb**
p183r058		1-Mar** 14-Dec**	7-May**	2-Jan*	5-Feb**
p183r059			7-May**	2-Jan*	5-Feb**
p184r056			7-Feb**	30-Mar*	
p184r057			7-Feb**	25-Jan* 27-Dec**	
p184r058		24-Mar**		31-Mar* 27-Dec**	
p185r056			14-Feb** 31-Dec*		
p185r057			14-Feb**	16-Jan*	
p185r058			18-Mar**	1-Feb*	
p186r056			5-Feb**	15-May*	
p186r057			26-Apr** 19-Oct*		
p186r058			26-Apr** 21-Feb**		27-Feb**
p187r056	12-Aug**	10-Dec**		30-Jan*	
p187r057	12-Aug**	10-Dec**		30-Jan*	

*Images marked were purchased and donated by the NASA-INFORMS project.
**Images purchased by WRI-GFW.
All images were orthorectified by the Earth Satellite Corporation (Rockville, MD USA) to their Geocover dataset (http://www.geocover.com). All images regardless of source are available online at the University of Maryland Global Land Cover Facility (UMD GLCF), http://glcf.umiacs.umd.edu and the University of Michigan's Landsat.org project http://www.Landsat.org/dataservices/GFW_WRI. Images are also available on CDrom through partners in Cameroon (MINEF, Cameroon Environmental Watch and Limbe Botanical and Zoological Garden.
The yearly variability of satellite coverage can be attributed to variation in cloud cover.

ANNEX 2 ROAD DIGITIZING METHOD IN DETAIL

The following data creation steps were developed in ArcGIS editing environment.

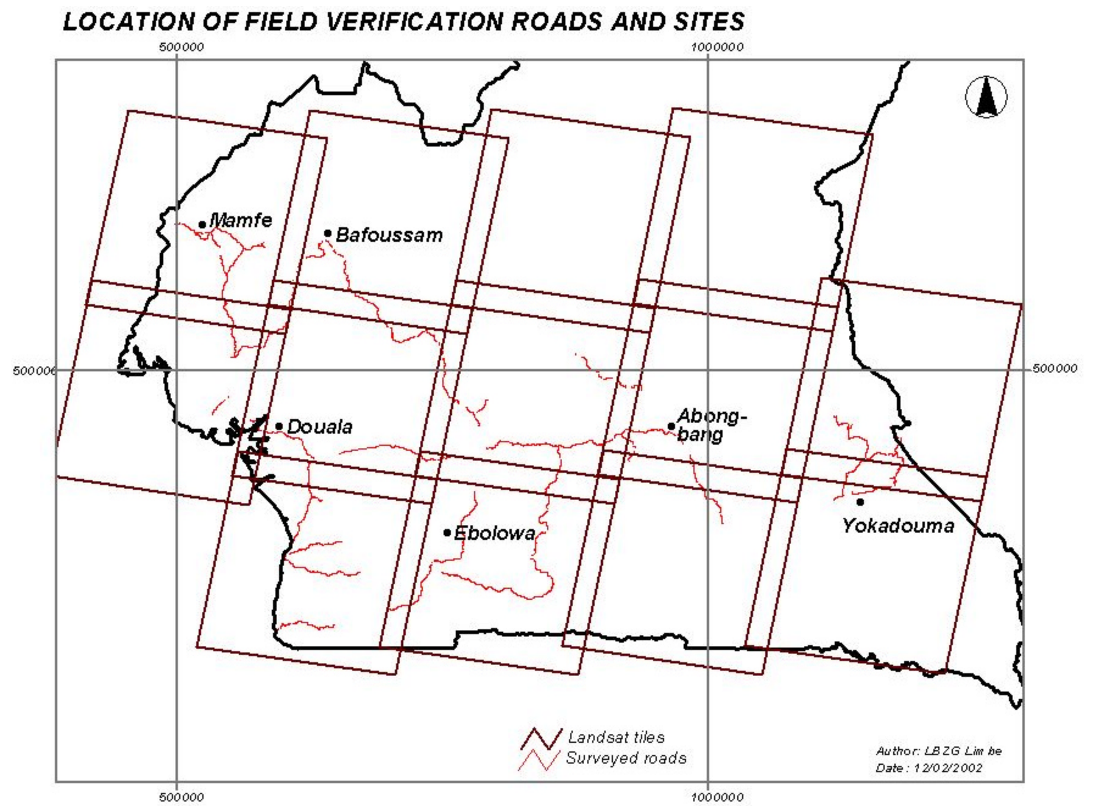
1. Set up data view window with data layers which include:
   - Display master road layer with road type classified;
   - Overlaid image tiles for the current editing area in chronological order (oldest on top);
   - Set image display with the optimal band combination for road visibility.
2. Set snapping environment and scale:
   - Set snapping tolerance to 30 map units (meters); set snap environment to End and Edge;
   - Set and save view display scale to 1: 30,000. In areas where more detail is needed, a larger scale (approximately 1:20,000) may be used;
   - Initial vertices are snapped to existing road segments before digitizing takes place.
3. While editing be aware of the following:
   - All roads intersecting on the imagery should be snapped together;
   - Road segments should be ended at any change in road type, date, cloud occurrence or when in doubt if the line feature on the image is a road;
   - Digitize roads beginning with the oldest image and move progressively to the most recent. Making sure to add date in Origin Field appropriately;
   - When all roads have been collected from one image tile turn it off and inspect the next tile (more recent) for new roads and missing road parts that were previously covered by clouds;
   - Save edits often;
   - Note any problems in the field verified column.

ANNEX 3 FIELD VERIFICATION OF DIGITIZED ROADS

3.1 INTRODUCTION

To assess the accuracy of imagery orthorectification and digitizing of roads, a number of field trips were organized to collect data including detailed characterized and attributed GPS waypoints and tracked roads segments. Field trips were planned with data collected from across the different Landsat ETM+ scenes within the forest zone (see map below). The collected data were integrated with datasets obtained from field projects.

3.2 FIELDWORK LOCATIONS



3.3 METHOD

GPS tracks measuring about 30-40km in length, were registered by driving 2,585km of roads (approximately 7% of the total length of roads digitized). Tracks were collected using Garmin 12XL, Garmin GPS76 and Garmin Etrex handheld GPS units. An antenna was attached to the Garmin 12XL and the Garmin GPS76 and mounted outside on top of the car, while the Garmin Extrex was held at a fixed position outside of the vehicle while driving. Data were collected over a variety of road surfaces (e.g., paved roads, gravel roads, dirt roads). Waypoints were also collected along these roads to record road attribute descriptions. Digital photographs, which were referenced to the GPS waypoints, were taken to visualize road conditions. Tracked roads were periodically downloaded onto a laptop computer in the field and imported into Arc View 3.2a GIS for a rapid crosscheck comparison with the digitized roads. This rapid analysis made it possible to identify and correct errors immediately, thus improving data quality during the preparation of the initial database. From information collected and lessons learned during the first field trip, an improved database attributing structure and data collection approach was created for subsequent field trips to better capture characteristics of observations made along the different roads segments. The following attributes were registered for each of the Waypoints:

IDENT	GPS Waypoint number used to join tables to waypoint shape file
LAT	GPS generated Latitude coordinate
LONG	GPS generated Longitude coordinate
RD_TYPE	Road Type (P-Public, MJ-Major Logging, MR-Minor Logging)
RD_USE	Road Use Classification (H-Heavy, L-Light, U-Unknown)
RD_SURFACE	Road Surface (P-Paved, G-Gravel, TK-Track, TL-Trail)
RD_WIDTH	General Road Width in Meters (measured at points)
RD_CUTBK	General Road Cutback in Meters (measured or approximated)
CANOPY	Canopy Cover (F-Full, P-Partial, N-None)
RD_STATUS	Road Status (N-New, C-Current, O-Old, A-Abandoned)
BREAKLINE	Indicator that tracks should be broken at a specific point (Y or N)
DIGITIZED	Indicator that the road was originally digitized (Y or N)
PHOTO	Photograph number associated with the point
RD_NAME	Road name or road end points for identification
FIELDNOTES	Field notes collected at the waypoint

The GOTO function in the GPS and Real time GPS tracking technique were used to navigate to questionable digitized roads or intersections for verification. Pictures were taken at sites to reference some of the irregularities noticed.

Villages, railroad crossings, high voltage power lines, pipelines and other features that seemed to cause confusion during digitizing were identified preliminary for field verification and characterized while in the field. Waypoints were also collected from significant sites such as road intersections, bridges and airstrips. The field data and photos were compiled in tables and analyzed (see example in Table 1).

Table 1 Example of sample data collected during a field visit.

IDENT	LAT	LONG	TYPE	USE	SURFACE	WIDTH	CUTBK	CANOPY	STATUS	LINE	DIGITIZED	PHOTO	RD_NAME	FIELDNOTES
001	3.78829837	10.14077783	P	H	P	10.0	10.0	N	C	Y	Y		Edea-Kribi	Edea/Yaounde/Kribi junction, Rd width 7.2/3.2 side pavement.
002	3.76817644	10.12810707	P	H	P	10.0	15.0	N	C	N	Y		Edea-Kribi	Larger cutback
003	3.67917001	10.10889173	P	H	P	10.0	5.0	N	C	N	Y		Edea-Kribi	Power lines parallel to road 300 m, increased cutback
004	3.65187585	10.11455655	P	H	P	10.0	10.0	N	C	N	Y		Edea-Kribi	Power line crossing over road
005	3.60924482	10.11279166	P	H	P	10.0	10.0	N	C	N	Y	Pt005.mov	Edea-Kribi	Movie taken along this section
006	3.56505811	10.10608613	P	H	P	10.0	20.0	N	C	N	Y		Edea-Kribi	Larger cutback, plantation area
007	3.55557382	10.11376798	P	H	P	10.0	10.0	N	C	N	Y		Edea-Kribi	Point taken at center of river for registration purposes
008	3.54788125	10.11496425	P	H	P	10.0	10.0	N	C	N	Y		Edea-Kribi	Power line crossing

The location accuracy was performed after every fieldwork trip as below.

1. The GPS tracked roads were converted to a linear shapefile using the DNR Garmin ArcView extension. A copy of corresponding digitized roads segments was made and visually checked to ensure that the two roads were of the same length, to avoid introducing statistical outliers that would confuse the results of statistical analysis

2. If roads were not the same length, the shorter segment was used to create the random points to avoid statistical outliers that may result if the longer segment is used.
3. The "a_random.ave" script (Avenue programming language) was loaded in ArcView.
4. Using the Xtools extension[3], the total length of the road(s) to be used for the analysis was calculated.
5. The number of random points to be generated from the roads was determined as a percentage of the total road(s) length. The point density used was 10 points per Km.
6. The road segment(s) for random point generation were selected and the script was run.
7. Once the points were generated and stored into a new shape file, the tile function was used from the menus to display both the point file table and the road table. Afterwards the SHAPE field for both themes was selected. With the points table active the JOIN button was selected and the two tables were joined together. This created a new field called DISTANCE in the point table.
8. The distance field was highlighted. The Statistics option in the field menu was used to show mean, range, and other statistics, which has been included in this report.
9. Afterwards the calculated distances were classified and displayed to see the general trend on maps.

[3] Xtools is a combined group of free Arc view extensions that facilitate some Arc view tasks.