Monitoring Logging in the Tropical Forest of Republic of Congo with Landsat Imagery

Toward an Integrated Forest Monitoring System

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***Abstract*: Selective logging is the most extensive land use in the Congo Basin, with more than 40% of the forest allocated to timber concessions. Little information is available to monitor the spatial expansion of timber extraction and its impacts on tropical forests. As part of the INFORMS[1] project, "An Integrated Forest Monitoring System for Central Africa," we have developed a simple system to monitor the extension of logging roads using multi-temporal Landsat imagery. We also tested the utility of Landsat imagery in estimating logging intensity. This system is being used within the national forest services of the Republic of Congo and Cameroon to monitor logging expansion .**

Keywords: land use, mapping, landsat, logging, Congo, Africa

I. INTRODUCTION

Northern Republic of Congo has one of the most pristine tropical forests in the world. It encompasses part of the Sangha Tri-National Park (Figure 1) and is known for an exceptionally high concentration of large mammals and quality timber. Since the l960s, this forest has been selectively logged and slowly fragmented. Timber extraction is accelerating as over 3 million hectares of forest have been allocated or re-allocated for logging in the last decade. Currently, nine international logging companies are present in northern Congo. Due to the remote location of the concessions, transportation cost is estimated to be as high as $120 per m^3 of wood [1]. Consequently, greater than 70% of the timber harvested consists of two valuable species of African mahogany—*Entandrophramga cylindricum* (sapelli) and *E. utile* (sipo) [1]. This high-grading process has a lasting effect on the stem density and canopy composition of the forest; it could also lead to an irreversible impoverishment of *Entandropohragma* species if adequate silvicultural practices are not developed and implemented [2]. Furthermore, large-mammal populations are being threatened with the encroachment of poachers [3] and small-mammal communities altered with the increase of edge habitat [4]

African national forest services need quick and reliable methods to monitor timber extraction at the landscape scale. Remote sensing is a powerful tool for mapping industrial logging [5, 6] and for assessing its impacts on forest canopy [7]. However, most national forest services and conservation field offices in central Africa only have basic GIS software such as Arcview and limited access to image processing software. Thus, operational monitoring approach using remote sensing must not involve complex procedures and expensive or unsupported software.

II. METHODS

To monitor the expansion of logging bordering Republic of Congo, Central African Republic, and Cameroon, we mapped primary and secondary roads for four contiguous Landsat tiles using a series of multi-temporal Landsat imagery from the 1970s to the 2000s (Table 1). First, all images were co-registered to the Earthsat Corp. GEOCOVER ortho-rectified products[2]. Then, multiple RGB false-color composites were created for each image using different spectral combination and contrast stretching to optimize the visual detection of roads. All composite images were prepared in GeoTIFF format using PCI Geomatica 8.2 software[3]. This was followed by the manual digitization of roads in ESRI Arcview 3.2 software.

Table 1. Time series of Landsat imagery used to monitor logging in the Sangha Tri-National Park complex from the 1970s to the 2000s.

Path-Row	***181-58***	***181-59***	***182-58***	***182-59***
1970s	n/a	n/a	1979-03-18	1976-04-20
1980s	1986-01-16	1984-09-07	1986-12-09	1986-12-09
1990s	n/a	1999-11-12	1990-11-26	1990-12-28
				1999-02-12
2000s	2000-03-03	n/a	2001-02-09	2000-09-18
	2002-01-20		2002-04-01	2001-02-09
				2001-05-16

The entire road network mapped using the above data sets was stored in the ESRI shapefile vector format. Separate files were created for each of the 11 active UFA (Unit Forestière d'Aménagement) in northern Congo[4]. These files can be

[1] http://luci.umd.edu/lcluc/; http://www.whrc.org

[2] http://www.geocover.com/

[3] These operations can be performed in any available image processing software or in ESRI Arcview Image Analyst Extension.

[4] Logging companies can operate in more than one UFA.

updated regularly as new high resolution and very high resolution imagery is made available (Landsat, SPOT, ASTER, IKONOS, etc.). The 2001-2002 annual rate of expansion for logging roads was also established for active concessions surrounding the Nouabalé-Ndoki National Park[5]. Estimates from the CIB logging company (Congolaise Industrielle du Bois) were used where the 2002 imagery was not available.

We also tested the utility of Landsat imagery in estimating logging intensity 2 years after harvesting. Number of trees removed per 50-ha harvesting parcel were obtained from CIB for a 9,000 ha area in the Kabo UFA. For each parcel, the total number of trees harvested was correlated with the proportion of various Landsat-derived land cover types mapped using Landsat-7 ETM+ imagery (Path 182-Row 59; 2001-02-09) [8].

III. Results

In northern Congo, the total length of logging roads established between in the last 30 years was estimated to be more than 6,000 km—two times the total length of primary roads in the entire country (Figure 2). Between February 2001 and April 2002, primary and secondary roads increased by more than 500 km in active concessions surrounding the Nouabalé-Ndoki National Park. In the Mokabi UFA (operated by Rougier) and in the Lopala UFA (BLP-BITAR), 166 km and 176 km of roads were built during this time period, respectively (Figure 3). This translates into an annual rate of 0.05 to 0.09 km of logging road constructed per km^2 of forest.

We observed two distinct patterns of road construction in concessions owned by different logging companies. In the two CIB-owned UFAs south of the Nouabalé-Ndoki National Park, secondary roads were constructed in irregular network with lesslength of road per unit area. In contrast, many companies with concessions north of the park have a dense parallel network of secondary roads that are as little as 850 m apart. We believe that the first is a result of the company's efforts to reduce total length of roads constructed—due to economic factors and intent toward the implementation of Reduced Impact Logging practices (RIL). The latter, on the other hand, could be a function of the lack of sufficient machinery for skidding. Differences in topography, soil and the presence of swamps also influence the pattern of secondary road construction.

In the pilot study of estimating logging intensity, we found that the number of trees harvested was most strongly correlated with the total amount of exploitable forest mapped using Landsat imagery (Figure 4). The land cover type described as "exploitable forest" is defined as the extent of *terra firma* semi-evergreen mixed species forest[6].

IV. Discussion

Although a considerable amount of secondary roads have been abandoned, construction of new logging roads pose a potential threat to the ecosystem of northern Congo by allowing the penetration of poachers into remote forests [3, 9]. Hence, the monitoring of road network associated with logging is an important contribution to tropical forest management and conservation [4].

To monitor industrial logging, road networks should be mapped on a regular basis with annual coverage of satellite imagery. A minimum of two consecutive years of data sets are required to estimate with precision the progression of roads.

Access to free imagery and training is critical for the implementation of forest monitoring program in most of the central Africa countries. Landsat images used in this study were made available as part of the NASA Science Data Purchase and the NASA Land Use Land Cover Change Program[7]. These data sets, adequately processed and interpreted, allow national forest services to monitor logging expansion and accurately revise the limits of concessions. At CIB, the images were also used to optimize road construction across swamps to reduce the total length of roads built.

Figure 1. Study area: Sangha Tri-National Park in Central Africa

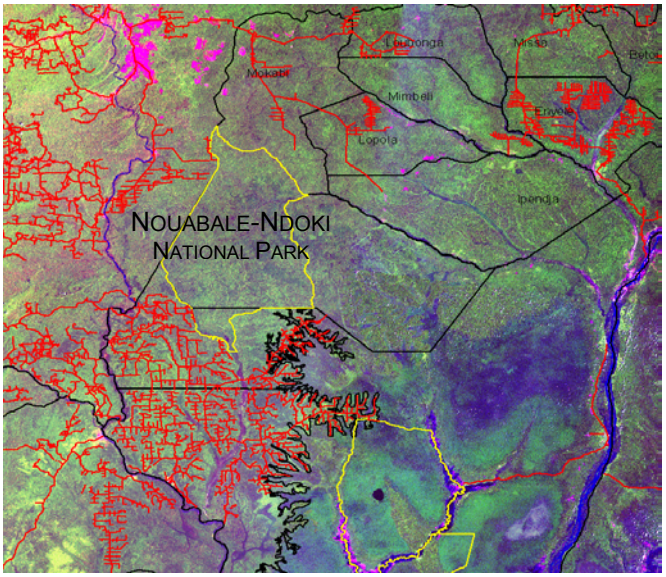

Figure 2. Logging roads constructed between the 1970s and the 2000s in the Sangha Tri-National Park region.

[5] Extension of the Sangha Tri-National Park in northern Congo

[6] Evergreen monodominant forest of *Gilbertiodendron dewevrei* is not being logged in northern Congo due to its low market value.

[7] http://lcluc.gsfc.nasa.gov

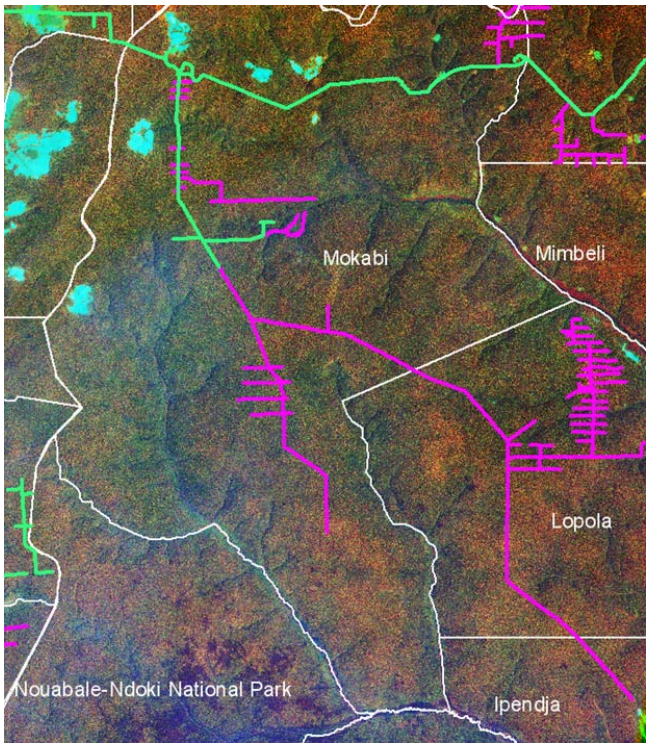

Figure 3. Mapping logging road expansion in northern Republic of Congo, Mokabi and Lopola UFA: in green, roads mapped using Landsat imagery up to February 2001; in pink, road progression mapped using Landsat imagery of April 2002.

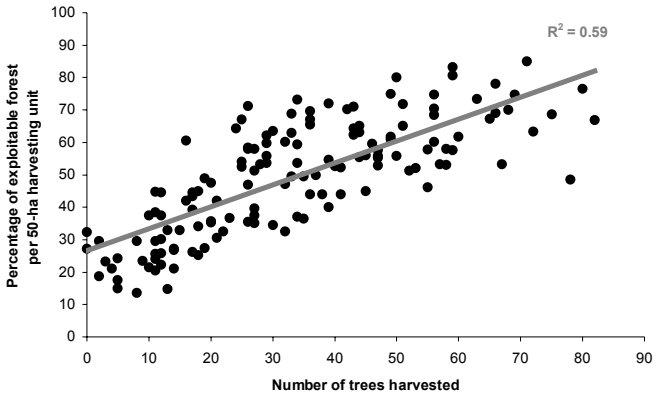

Figure 4. Correlating logging intensity with land cover type: number of trees harvest versus proportion of exploitable forest per harvesting unit ($n = 143$; $r^2 = 0.59$; $p < 0.01$)

V. Conclusions

Using Landsat imagery, we developed an operational monitoring system of industrial logging in the northern Republic of Congo. This approach is currently being implemented in Cameroon in collaboration with the World Resource Institute (WRI) and in Congo with the Centre National d'Inventaire et d'Aménagements des Ressources Forestières et Fauniques (CNIAF).

Remote sensing is a key component to any landscape-scale forest monitoring system, and it is important that baseline information be made available to forest ministries, private foresters, and natural resource managers for developing best forest management practices. Since few tropical countries have the resources to develop their own remote sensing activities, it is crucial that interdisciplinary programs such as the newly established Congo Basin Forest Partnesrship[8] and the existing NASA Land Use Land Cover Change Program continue to facilitate the use of these technologies for maintaining a healthy forest ecosystem.

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References

[1] Congolaise Industrelle du Bois, pers. comm.

[2] Hall, J. S., D. J. Harris, V. Medjibe, and P. M. S. Ashton. 2003. The effects of selective logging on forest structure and tree species composition in a central African forest: implications for management of conservation areas. *Forest Ecology & Management*, in press.

[3] Robinson, J. G., K. H. Redford, and E. L. Bennett. 1999. Conservation: wildlife harvest in logged tropical forests. *Science* 284(5414): 595-596.

[4] Malcom, J. R. and J. C. Ray. Influence of timber extraction routes on Central African small-mammal communities, forest structure, and tree diversity. *Conservation Biology* 14 (6):1623-1638.

[5] Laporte, N., S. J. Goetz, C. O. Justice, and M. Heinicke. 1998. A new land cover map of central Africa derived from multiresolution, multitemporal satellite observations. *International Journal of Remote Sensing* 19: 3537-3550.

[6] Laporte, N. T, T. S. Lin, J. LeMoigne, D. Devers, and M. Honzak. 2003. Toward an Integrated Forest Monitoring System for Central Africa. In: *Land Change Science: Observation, Monitoring, and Understanding Trajectories of Change on the Earth Surface*, Ed. G. Gutman. NASA-LCLUC Program, in press.

[7] Chan, J. C-W, N. Laporte, and R. S. Defries. 2003. Texture classification of logged forests in Tropical Africa using machine learning algorithms. *International Journal of Remote sensing* 24(6): 1401-1407

[8] Laporte, N. 2002. *Stratification Forestière des UFA Kabo, Pokola, et Loundoungou.* Rapport technique au Wildlife Conservation Society. New York, U.S.A. 32 p.

[9] White, L. J. T. 1994. The effects of commercial mechanised logging on forest structure and composition on a transect in the Lopé Reserve, Gabon. *Journal of Tropical Ecology* 10: 309-318.

[8] http://carpe.umd.edu