CHAPTER 6

TOWARDS AN OPERATIONAL FOREST MONITORING SYSTEM FOR CENTRAL AFRICA

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1 Introduction

Characterizing and mapping land cover and land use change in the rain forests of Central African is a complex process. This complexity is marked by the diversity of land use practices across six different countries (Cameroon, Central African Republic, Democratic Republic of Congo, Equatorial Guinea, Gabon, and Republic of Congo), the lack of full and continuous cloud-free coverage by any single optical remote sensing instrument, and the limited institutional capacity to implement mapping and monitoring activities.

As part of the NASA Land Cover Land Use Change Program (LCLUC) and the Central Africa Regional Program for the Environment (CARPE), an "Integrated Forest Monitoring System" (NASA-INFORMS project; http://www.whrc.org/africa) was established in close collaboration with national forest services, private logging companies, and conservation organizations. This project has been focused on developing remote sensing products for the needs of forest conservation and management, insuring that research findings are incorporated in the forest management plans at the national level.

In this chapter, we will describe how multi-temporal and multi-sensor remote sensing observations and techniques have been integrated with *in-situ* data for habitat mapping, logging monitoring, and biomass estimation. Using time-series of Landsat imagery, for example, we have mapped the expansion of logging activities in the northern Republic of Congo, providing a new monitoring tool for the national forest service. Indices for estimating the intensity of timber harvesting are also in development. Maps of forest types, as well as deforestation assessment around population centers, have been produced in collaboration with different stakeholders in order to promote better forest management practices in the region.

While these results suggest promise for mapping and monitoring Central Africa's forests using Landsat imagery, additional data sets and development of new data processing approaches are needed to improve land cover characterization and forest monitoring. We will provide examples of such techniques—one that used a hybrid method combining radar and optical remote sensing to describe vegetation types in Gabon and another that attempted to discriminate different levels of above-ground forest biomass in southern Cameroon using radar data alone.

G. Gutman et al. (eds.), Land Change Science, 97–110.

2 The Central Africa Region

Central Africa contains the world's second largest block of tropical rain forest (*c.* 1.8 million km^2) after the Amazon (Laporte et al., 1998). While rain forests in West and East Africa already have been reduced to fragments (Brou Yao et al., 2000; Riitters et al., 2000), Central Africa still contains the largest tracks of old-growth forest in the continent (Laporte et al., 1998). The history of deforestation in West and East Africa provides an important lesson for forest conservation and management in Central Africa. Between mid-1970 and mid-1990, total wood production in Ivory Coast had decreased by 50% (Durrieu de Madrone et al., 1998). During the same period, deforestation rates had also increased due to attractive market prices for cacao, unlimited cheap labor from neighboring countries, and a stable political situation that promoted the agricultural sector (Durrieu de Madrone et al., 1998). Today, Ivory Coast's old-growth rain forests are found only in parks, reserves, and few plantations (Brou Yao et al., 2000); the same situation is true in Ghana and Uganda (Laporte et al., 2002). Under the combined pressure of increased population and favorable economic markets, the future of the Central African rain forest could follow a similar path if the national governments do not adequately plan for the long-term management of their rich forests.

Central Africa is the largest carbon reservoir on the continent (Faure and Faure, 1990). It is also a center of biological diversity, harboring over 400 mammal species, more than 1,000 species of birds, and at least 10,000 plant species, of which about 3,000 are endemic (IUCN, 1992). Recent studies suggest that, after disturbances, species richness and ecosystem resilience of the forest are dependent on the presence and/or abundance of keystone animal species (*e.g.* Kellman et al., 1996). Many tree species depend on animals for seed dispersal; for example, the role of elephants and primates in seed dispersal is well documented (White 1994a; Wrangham et al., 1994; Hawthorne and Parren, 2000). However, hunting pressure on wildlife populations is strong as Central Africa is one of the poorest regions in the world. Morever, industrial logging opens up previously remote parts of the forest to human access and thus commercial hunting (Robinson et al., 1999).

One-third of the total population of Central Africa lives in the tropical rain forest. Of the 24 million people, estimated 3 million from 150 different ethnic groups depend strictly on the forest ecosystems for their livelihoods (Bahuchet et al., 2000). These forest hunter-gathers—commonly referred to as pygmies—entertain cultural and commercial exchange with the dominant ethnic groups—diverse populations of Bantu and Ubanguians who traditionally rely on swidden agriculture, fishing, and trapping. Since colonization, most Bantu have been living along the road network, resulting in a relatively high and localized population density (*c.* 50 inhabitants per km^2). The 'mutual economic dependency' between the forest hunter-gathers people (providing bushmeat and medicinal products) and the sedentary Bantu (producing crops) is ancient (Joiris and Bahuchet, 1993). However, with the arrival of industrial logging, the hunter-gathers are spending increasingly more time working for the logging companies and/or providing cheap labor for commercial hunting. Coupled with timber extraction, the growing of sedentary population and land use practice around logging towns also increases the overall rate of deforestation in the region.

In Central Africa, farmers clear between 0.5-3.0 ha of forest per family every year, creating a mosaic of degraded vegetation in which new fields are intermingled with older fields of 2-3 years old, fallows, secondary forest, and mature forest. This complex agro-system mosaic, with an average size of clearing in the order of one hectare, is difficult to monitor using low-resolution satellite imagery. Recent estimates of deforestation using 8-km AVHRR data underestimated the rates of change due to the patchiness of forest loss in this region (Defries et al., 2000). Utilizing 1990 1-km AVHRR satellite images, it was estimated that farmers had converted more than 12% of the original forest in Central Africa (Laporte et al., 1998). Today, the most extensive land use in the region, however, is commercial logging. Currently, 41% of the rain forests in Central Africa have been allocated for timber extraction. While most of the forests in Cameroon and Gabon have been logged at least once (Reitsma, 1988; White, 1994b), the Democratic Republic of Congo and the Republic of Congo still contain extensive amounts of unlogged forests. Table 1 summarizes statistics on population and land use per country. These statistics are, however, uncertain and in need of improved accuracy. In the following sections, we will provide some case studies on the utility of high-resolution imagery, including Landsat optical and JERS-1 radar data, for mapping land cover and monitoring land use change associated with farming and logging.

Table 1. Statistics on the forest, population, and road network of Central Africa.

	Population (millions) (1)	Population Density (per km²)	Deforestation Rate 1980s-1990s 1990-2000s(2)	Road Density (km/km²) (3)	Forest Cover (%) (4)	Agriculture & Fallow (%) (4)	Logging (%) (5)
Cameroon	15	27.5	0.6, 0.9	5	37	14	31
Central African Republic (CAR)	3.5	5.2	0.4, 0.1	3	10	10	6
Dem. Rep. of Congo (DRC)	51	18.3	0.6, 0.4	3	48	4	18
Equatorial Guinea	0.35	15.6	0.4, 0.6	11	65	23	61
Gabon	1.2	4.9	0.6, n.s	3	80	9	48
Rep. of Congo	2.8	7.3	0.2, 0.1	3	66	11	61

(1) From CARPE CD-ROM and based on 1990 population
(2) Annual rate in percent from FAO Tropical Forest Assessment (http://www.fao.org/forestry/fo/fra/index.jsp)
(3) From CARPE CD-ROM (http://carpe.umd.edu)
(4) Derived from AVHRR analyses of the 1990s (Laporte *et al.*, 1998)
(5) From the most recent national forest service databases (changes are underway in Gabon, DRC, and Congo)

3 Habitat Mapping and Land Cover Change Assessment for Forest Conservation and Management: Sangha Tri-National Park Case Study

The needs for forest monitoring are urgent in Central Africa. National institutions in the region lack the most basic information to make land use decision and policy. Recent vegetation maps produced for the region were generated from low-resolution satellite imagery including AVHRR (Laporte et al., 1998), SPOT vegetation (Mayaux et al., 2003), and MODIS (Hansen et al., 2003). These coarse-scale maps are useful for monitoring land cover at the regional level, but they are poorly adapted to forest management needs at the landscape level (Demaze et al., 2001). In most of Central Africa, changes in land cover associated with agricultural expansion are occurring at such a fine scale that only high-resolution imagery can provide accurate estimates on the extent and the rate of land cover and land use change.

In this section, we will describe how the NASA-INFORMS project produced crucial information for the forest management of northern Republic of Congo. These results include a new land cover map for the Sangha Tri-National Park (section 3.1); the monitoring of logging road progression (section 3.2); and, deforestation rates around major population centers (section 3.3).

Table 2. Time series of Landsat imagery used to monitor logging in northern Republic of Congo from the 1970s to the 2000s. * denotes images used for land cover mapping of the Sangha Tri-National Park.

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 2002-01-20	n/a	*2001-02-09 2002-04-01	2000-09-18 *2001-02-09 2001-05-16

For this case study, we used fourteen images of the Landsat Thematic Mapper (Table 2). These images were geographically co-referenced to the GEOCOVER products, which are orthorectified Landsat scenes produced by the Earth Satellite Corporation (EarthSat). Ground control points collected at road intersections or other land features were used to assess the accuracy of geo-referencing. The highest locational error was in the order of 1-pixel (*c.* 30 meters).

3.1 FOREST HABITAT MAPPING

Biodiversity conservation depends strongly on the management of both protected areas and their buffer zones. Unfortunately, in most of Central Africa, very little is known about the distribution of vegetation types and associated threats, such as deforestation, forest degradation, and forest fragmentation. While forest covers roughly 45% of Central Africa, only 10%, or 180,000 km^2, is currently protected (Laporte et al., 1998). Moreover, the park system is very fragmented. The viability of wildlife populations is not likely to be sustainable if the parks are connected by corridors (*e.g.* Oates, 1996). As part of the USAID-Central Africa Regional Program for the Environment (CARPE), a new landscape approach has been adopted to reduce forest loss by increasing natural resource management capacity and by creating corridors between parks.

In collaboration with CARPE partners (Wildlife Conservation Society, "Projet de Gestion des Ecosystèmes Périphériques au Parc National Nouabalé-Ndoki), a new vegetation map was produced for the Sangha Tri-National Park. Given the presence of heavy cloud cover and atmospheric haze in most of the Landsat scenes, various combinations of spectral bands were used to generate land cover maps from "semi-unsupervised" classification. Although the two Landsat scenes were classified

independently, the general procedures remained the same. The first step consisted of masking of clouds, cloud shadow, and water using mainly band 3, 4, and 5 and an ISOCLUS algorithm. The second step consisted of running unsupervised classification on the cloud-free data using various combinations of bands 2, 3, 4, and 5. Several iterations were performed to separate different forest types, and the clustering results were aggregated into 18 classes based on spectral separability and contextual information. Then, the aggregated image was filtered using a 4-pixel sieve filter, where clusters of less than 4-pixels were merged with the largest nearest neighboring cluster. Finally, each cluster was assigned to a thematic class based on a pre-defined legend established with end-users (park managers and forest service). In some cases, manual editing was performed when two habitats important for wildlife management could not be differentiated based on their spectral signatures.

The resulting map, with 18 different land cover & land use categories, is a significant step towards better characterization of wildlife habitats in the area. Distribution, structure, and phenology of vegetation are the most important determinants of wildlife population distribution and density (White, 1994a). This map is thus useful for modeling the distribution of wildlife populations. It also provides important baseline information for comparing the extents of different habitats across the Sangha Tri-National Park (Table 3). For example, while the semi-evergreen mixed species forest is the dominant habitat in all three sections of the park complex, the evergreen monodominant *Gilbertiodendron devewrei* forest occurs in large patches mainly in the Nouabalé-Ndoki National Park. The distribution and extent of this prime seasonal foraging habitat for wildlife lays on a south-to-north gradient, with the highest percent cover and the largest stands found in the Nouabalé-Ndoki National Park (Republic of Congo), the Loundoungou concession, and the Lobeké Reserve (Cameroon). Conversely, savanna habitat is found only in the Dzanga-Sangha Special Reserve (Central African Republic).

Table 3. Percent land cover of the Sangha Tri-National Park complex.

Land Cover Type	**Nouabalé-Ndoki**	**Dzanga-Sangha**	**Lac Lobeké**
Semi-evergreen mixed species forest	73	89	85
Evergreen *Gilbertiodendron dewevrei* forest	23	5	9
Swamp and marsh	3	3	5
Savanna (include forest-savanna transition)	0	2	0
Others	1	1	1

3.2 LOGGING MONITORING

Until recently, the Sangha Tri-National Park was one of the most remote places on Earth, with a large population of Aka and Baka forest people (Moukassa, 2001). Since 1970s, industrial logging has been attracting migrant workers from across Central Africa, resulting in demographic change and population booms in logging towns. Nine logging companies are active in northern Congo, and an extensive network of logging roads now surrounds the Sangha Tri-National Park (Figure 1). Today, this increase of access into the intact forests is recognized as one of the most critical factors leading to large-scale biodiversity loss.

Figure 1. Road network mapped using Landsat imagery two years post-harvesting from the 1970s to 2001. Base map was created using Landsat-7 ETM+ images of 1999, 2000, and 2001 (RGB-543).

Monitoring the expansion of logging roads is an important part of wildlife conservation in Central Africa. Road access into remote forest is often followed by an increase in commercial hunting that, if not properly managed and controlled, can threaten wildlife populations (Robinson et al., 1999). Using a time-series of Landsat satellite imagery (Table 2), roads were digitized to monitor the progression of logging in northern Congo and to identify areas potentially threatened by poaching. Currently, new roads are being built at a rate of more than 100 km per year per logging company. Between 2001 and 2002, the road network had increased by 176 km in the Lopola concession and 165 km in the Mokabi concession. We also tracked the total extent of roads constructed since the beginning of industrial logging in the 1970s. To date, this amounts to more than 5,000 km of logging roads—twice the total length of the primary roads in the entire country (Laporte and Lin, 2003).

The intensity of logging, in terms of number of trees harvested per unit area, was also estimated using Landsat imagery. Number of trees removed per 50-ha harvesting parcel was obtained from CIB (Congolaise Industrielle du Bois) for a 9,000 ha area in the Kabo concession, logged between 1998 and 1999. For each parcel, the total number of trees harvested was correlated with the proportion of various land cover types mapped using a dry season Landsat ETM+ imagery of 2001. (Refer to Section 3.1 for details on the vegetation mapping.) Of all land cover types, we found that logging intensity was most strongly correlated with the total amount of exploitable forest, with "exploitable" being defined by the logging companies as the extent of *terra firma* semi-evergreen mixed species forest (Figure 2).

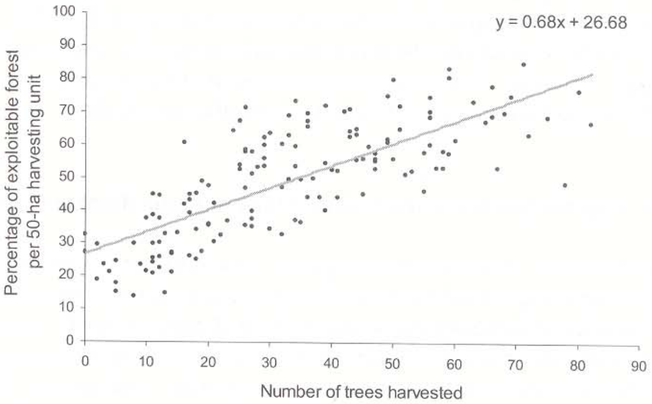


Figure 2. Estimating logging intensity with Landsat imagery two years post-harvesting (n = 143; $r^2 = 0.59$; $p < 0.01$).

3.3 MONITORING DEFORESTATION

Northern Congo has been undergoing various degrees of deforestation. Little is known on the current rate and extent of land cover conversion from forests to agro-systems. In this case study, we focused on comparing deforestation in the last decade around four major population centers—Ouesso, Pokola, Kabo, and Ngomb—in the vicinity of the Nouabalé-Ndoki Nation al Park. Ouesso, with a population of approximately 18,000, is an old administrative town and a center of bushmeat trade (Thuret, 1997). Pokola, Kabo, and Ngombe are logging towns located along the Sangha River, which remains the main communication network between settlements. Until the 1970s, Pokola was a small fishing village with only a few hundred inhabitants. It is now the headquarters of CIB, one of the largest industrial logging companies in the region. With a logging-driven economy, the population in Pokola has increased to over 7,000 (Moukassa, 2001). Managing more than 1.5 million hectares of forests, CIB also operates from Kabo, a town of *c.* 1,400 (Moukassa, 2001). Ngombe, the operation center for the Danzer logging company, has an unknown population size but is considerably smaller than Pokola.

Between 1990 and 2001, the greatest forest loss occurred around the two larger towns of Ouesso and Pokola. However, marked differences exist in the pattern of deforestation between the two. In 1990, Ouesso was already surrounded by a large area of young secondary forest (*c.* 30 km^2), which probably had been cleared previously or was highly degraded. This "degraded" or "regrowth" forest is typically preferred for shifting cultivation or housing conversion, consequently reduces the pressure of creating new forest clearings. Pokola, on the other hand, had limited area of young secondary forest. Most of the conversion to farmland and "urban" land cover in the last decade was, therefore, from old secondary forest that had only been selectively logged in the past. New forest clearings were created as the amount of 15-20 year-old young secondary forests was limited around Pokola. Furthermore, note that, in Ouesso, the area of increase in agriculture almost equals that in bare soil, but the increase in farmland in Pokola is only a third of the increase in "urban" build-up. This observation corresponds to the fact that more people in Ouesso rely on farming for their livelihood than in Pokola, of which nearly all inhabitants are employed by CIB. The spatial pattern of land cover also differs between the administrative town and the logging towns, with more "diffuse" land cover conversion in Ouesso and more "compact" conversion in the immediate vicinity of Pokola, Ngombe, and Kabo.

4 Testing New Approaches for Land Cover Mapping and Biomass Estimation

Central Africa, similar to many tropical regions, lacks full and continuous cloud-free coverage by any single high-resolution optical remote sensing instrument (*i.e.* Landsat). Therefore, it is crucial to develop multi-sensor hybrid approaches to characterize land cover types and to monitor human pressure on the forests. In the following sections, we will describe pilot studies of habitat mapping using radar and optical data combined (section 4.1) as well as biomass estimation using radar imagery (section 4.2).

4.1 FUSION OF SAR AND OPTICAL DATA FOR LAND COVER MAPPING OF THE LOPE RESERVE

Figure 3 illustrates the idea where the fusion of high-resolution radar data and low-resolution optical data is able to yield land cover maps of equivalent or better quality than those created by high-resolution optical data alone. Such an approach, if successful, could compensate for the lack of good Landsat coverage in the coastal region of Central Africa where heavy cloud cover traditionally limits the use of high-resolution optical data. While our future work will involve comparing land cover classification using JERS and MODIS data combined with that using Landsat data alone, we tested this concept of data fusion using 6-m SAR data and 30-m Landsat imagery in the pilot study.

The objective was to map eight different vegetation types for the Lopé Reserve in Gabon: 1) *Montane Forest*; 2) *Mixed Forest*—pluri-stratum stand with at least 3 different tree heights, including riparian and Marantaceae forest; 3) *Okoumé Forest*—mono-stratum stand with trees of similar diameters and heights; 4) *Savanna* in the range of 1 to 1.5 meters in height; 5) *Fern Savanna* of less than 1 meter in height; and, 6) *Burnt Savanna.* The higher resolution data (6-m) was extracted from a SAR image acquired from the "Mission Aéroportée radar SAR" flown in 1994; the lower resolution data (30-m) was a subset of the Landsat TM imagery of Path 185-Row 60, acquired on May 1, 1988. The Landsat data set was resampled to 6-m resolution since it was used as the reference image and as part of the fusion.

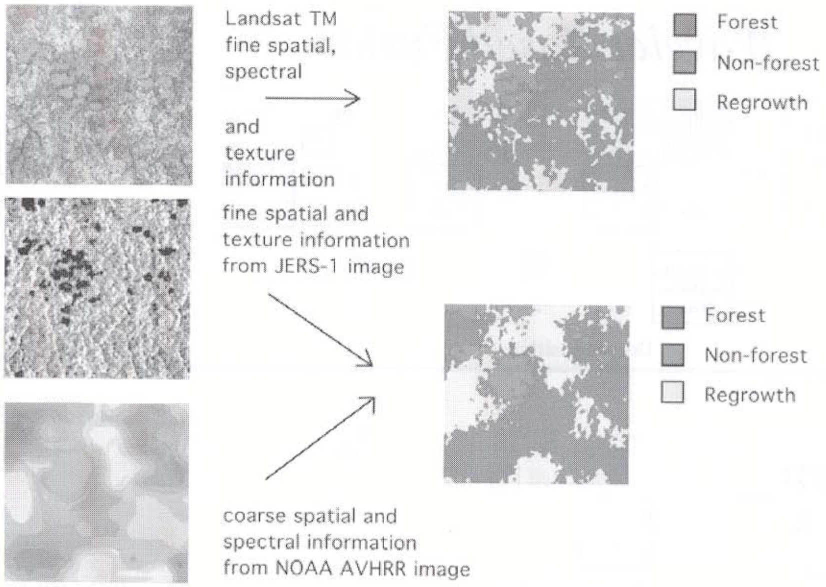


Figure 3. Fusion of fine-resolution radar and coarse-resolution optical imagery enables the creation of a land cover map with quality equivalent to a map created based on fine-resolution optical data alone.

Multi-sensor data fusion may be performed either before the classification step with a pixel-level image fusion technique, or as a post-processing by combining multiple classification results at the feature- or decision-level (Pohl et al., 1998). In this experiement, we performed the fusion before the classification and used a number of hybrid fusion techniques. The results described here are based only on the use of a wavelet transform, which describes images in the frequency domain at multiple spatial resolutions using Multi-Resolution Analysis (MRA). Figure 4 illustrates the wavelet-based fusion idea, where high- and low-resolution data are independently decomposed using the MRA scheme. Briefly, a wavelet decomposition of any given signal (1-D or 2-D) is the process which provides a complete representation of the signal according to a well-chosen division of the time-frequency (1-D) or space-frequency (2-D) plane. Through iterative filtering using low- and high-pass filters, it provides information about low- and high-frequencies of the signal at successive spatial scales. Performing image fusion within a wavelet framework enables the user to fuse data selectively at various frequency components in the lower spatial resolutions while preserving spectral information of higher spatial resolutions. During the reconstruction phase, components from both decompositions are combined to create the new fused data. In our experiments, we used a Daubechies filter size 4 (Daubechies, 1991) and a Mallat MRA (Mallat, 1989) for both decomposition and reconstruction and for both types of data. Low-frequency information of the lowest spatial resolution data (*i.e.*, Landsat) were combined with high-frequency information of the highest resolution data (*i.e.*, SAR) in order to take simultaneous advantage of the higher spatial and spectral resolutions. However, one can imagine using different filters for decomposition and reconstruction as well as for high- and low-resolution data that would better preserve the spatial, spectral and textural properties of the data.

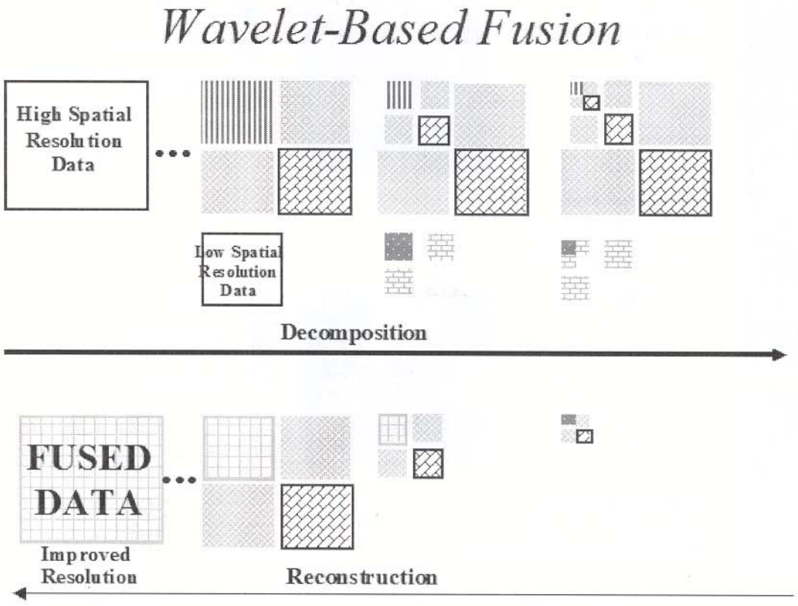


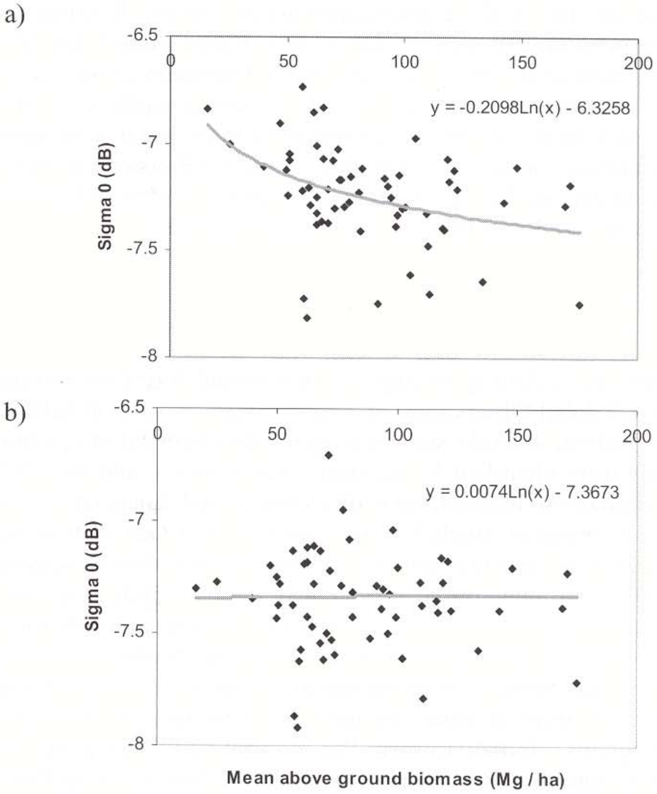
Figure 4. Principle of the wavelet-based fusion.

Due to the lack of reliable training data sets at the time of the experiment, unsupervised classification was used to obtain a vegetation map from the Landsat data alone and from the fused data. With the targeted number of clusters set to 10 and all other parameters being equal, unsupervised classification using the ISOCLUS algorithm returned 9 clusters for both data sets. These clusters then were regrouped thematically into the six vegetation types described earlier. Although qualitatively similar, the fused clustering shows more localized details with differentiation of the three savannas types and a different clustering of the *Montane Forest* versus *Mixed Forest*. This pilot study, although incomplete, illustrates that a wavelet-based fusion of radar and optical data can augment a forest monitoring system for applications at the local and regional scales. Our ongoing work involves data fusion of JERS and MODIS imagery compared to Landsat and to MODIS data alone; investigation of different types of wavelet filters; improvements to the clustering scheme; and, quantitative evaluation of results using *in-situ* data.

4.2 ASSESSING FOREST BIOMASS USING JERS-1 RADAR MOSAICS

Studies on changes in above-ground biomass under different land use scenarios have been focused primarily on the Amazon (*e.g.* Fearnside and Guimaraes, 1996). In Central Africa, however, very little is known about the impacts of agricultural conversion and logging on carbon stocks or cycling. Many studies have shown positive correlation of radar backscatter to total above-ground biomass in different forest types in the Northern Hemisphere (*e.g.* LeToan et al., 1992; Ranson and Sun, 1994). Radar backscatter from forest canopies depends on wavelength, incidence angle and polarization, as well as canopy structure and wetness. Generally, longer wavelength

(L-band) SAR imagery such as JERS-1 may be used to discriminate between different levels of forest biomass up to a certain saturation point. Additionally, there is evidence that cross-polarized backscatter is more sensitive to changes in biomass (Tiangco and Forester, 2000). The potential for mapping forest biomass using SAR data is, however, limited when the forest structure is complex and the biomass level is high, as in the case of most tropical forests in Central Africa.



Figures 5a, 5b. Estimating above-ground biomass with JERS-1 normalized backscatter: a) February 1996, dry season ($r^2 = 0.15$; $p < 0.05$); b) November 1996, wet season ($r^2 < 0.01$; $p > 0.05$).

We explored the utility of 100-m JERS-1 radar imagery for above-ground biomass estimation across a range of 1-ha plots in 61 study sites throughout southern Cameroon. The field biomass measurements, collected in 1995, were compared with the normalized backscatter of the 1996 JERS-1 mosaic produced by the NASA Jet Propulsion Laboratory (http://trfic.jpl.nasa.gov). We found poor relationships between the above-ground biomass measurements and backscatter for both low and high water mosaics (Figures 5a & 5b). These findings suggest limited utility of JERS-1 radar imagery for biomass estimation across tropical Africa. Similar limitations have been noted in the Amazonian forests (Salas et al., 2002). There are, however, several possible factors for the poor results. Locational errors of the field sites and geographic mis-registration of the images could negatively affect the backscatter-biomass relationship. The pre-processing of the JERS-1 mosaic could also have been a factor, particularly owing to resolution loss due to the resampling of the data. Morever, forest structure in these areas is highly variable, especially in disturbed sites. Comparison of 1-ha plots with the 100-m JERS-1 mosaic therefore could have been negatively influenced by the high spatial heterogeneity of above-ground biomass. However, we believe that the site heterogeneity was adequately characterized since the sampling method was based on that of the Cameroonian forest service designed for biomass estimation and has been proven accurate for related studies using 1-km AVHRR data (Boyd et al., 1999; Lucas et al., 2000). Finally, JERS-1 normalized backscatter is likely to underestimate biomass of disturbed forests where a collection of numerous regenerating small trees may have the same level of biomass as a mature stand with few big trees. This limitation was also noted in boreal forests (Ranson and Sun, 1994). In the future, we plan to explore the use of LIDAR waveform models, which should allow improved estimates of both forest biomass and canopy structure.

5 Conclusions

International efforts are underway to improve operational forest monitoring. At the first Central Africa "Global Observation of Forest Cover" workshop held in February 2000 in Libreville, Gabon, several issues limiting the development of operational forest monitoring systems were identified by national forest services and their international partners. These limitations included lack of technical and financial resources, poor access to data and information (including the internet), and lack of training facilities and opportunities. It was also unanimously recognized that remote sensing is a key component to any forest monitoring system and that, at each stage of scientific understanding, there be transfer of relevant information to policy and decision makers.

While information derived from remote sensing products can help natural resource managers to determine optimal management practices for maintaining healthy forest ecosystems, few tropical countries have the resources to develop their own remote sensing programs. Initiatives from the NASA/LCLUC program, the CARPE program, and GOFC can, therefore, help to facilitate the transfer of technology to the national forest services in Central Africa. Ultimately, these activities must contribute to the better management of natural resources for the present and future generations by the residents of the region. Our development of an integrated forest monitoring system, where remote sensing technology is combined with *in situ* data from commercial logging and biodiversity inventories, allowed us to provide crucial information for the management of the northern Congo forest ecosystem and to explore the utility of new approaches to land cover mapping. We continue to pursue these activities in a region that is one of the least known yet most productive and biologically diverse on earth.

Acknowledgments. This research was supported by the NASA Land Cover Land Use Change Program and the Central Africa Regional Program for the Environment (CARPE). It would not have been possible without the logistic support of the Wildlife Conservation Society (Paul Elkan and Fiona Maisels) and the Congolaise Industrielle des Bois (Olivier Desmet, Dominique Paget). We want to thank the following individuals for generous donation of their time and their work dedicated to preserving these unique ecosystems: Steve Blake, Brian Curran, Bourges Djoni-

Djimbi, Sarah Elkan, Mike Fay, Steve Gulick, Richard Malonga, Antoine Moukassa, and Chris Wilks. We also thank Yves Dubois, Leon Embon, Patrick Geffroy, Frederic Glannaz, Jackie Glannaz, Patrice Gouala, Christian Guyonvaro, Gregoire Kossa, Tom van Loon, Alfred Tira, and Luca van Der Walt for field assistance and working towards the sustainable use of the region's forest resources. Scott Goetz provided editorial assistance; Debra Fischman and Jeremy Goetz assisted with compiling the road network.

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