# A CASE STUDY IN THE USE OF SATELLITE MAPPING AND GIS TO SUPPORT LARGE SCALE CONSERVATION AS PART OF THE CENTRAL AFRICAN REGIONAL PROGRAM FOR THE ENVIRONMENT

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## I. Introduction

Establishing a reliable baseline of forest extent and monitoring forest cover change across the Congo Basin is critical to evaluate the progress of CARPE towards meeting its strategic objective of reducing the rate of forest degradation and loss of biodiversity. Satellite-derived maps and geographic information systems provide spatial information and analytical tools essential for large scale conservation planning and effective monitoring of Congo Basin forests. Analytical tools, such as geographic information systems (GIS) help conservation planners integrate geospatial data on land cover, population centers and ecology to inform planning and policy decisions. Remote sensing provides the capacity to monitor the impacts of conservation initiatives on land cover and land use, which in turn relate directly to forest resources and biodiversity.

The United Nations Food and Agriculture Organization (FAO) compiled the Africover geospatial database in response to the lack of information on land cover for Africa and in recognition that this deficit limits planning, development and sustainable management of renewable natural resources. Africover includes feature datasets and land cover classifications that are derived from the visual interpretation of high resolution satellite imagery acquired between 1994 and 2001 . These data are a significant mapping contribution, but they are not available for all CARPE countries, and they are inadequate for CARPE's landscape planning purposes. The FAO Forest Resource Assessments (FRAs) provide statistics on forest cover, derived primarily from 'best estimate' information provided by national forest ministries, although those published for 1990, 2000 and 2005 are supplemented by analysis of samples of multi-temporal satellite data to estimate deforestation rates. Variability in forest categories and methodologies between assessments makes it difficult to make statistical comparisons. The FRA data are not spatially explicit, making them less useful for baseline assessments, monitoring rates of deforestation on sub-regional scales or evaluating the effect of specific programs to reduce the rate of deforestation within the CBFP landscapes.

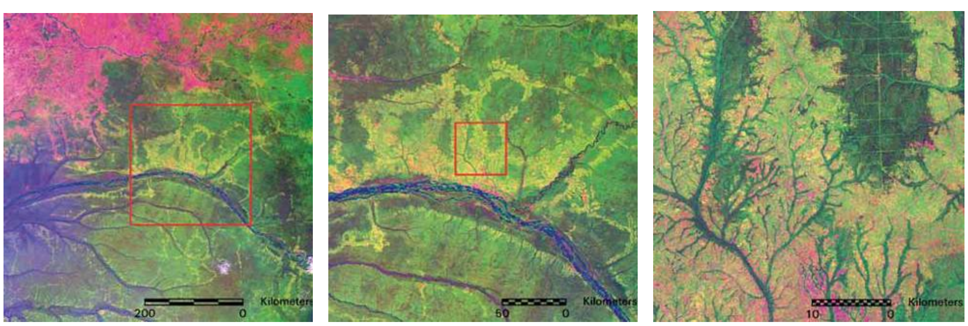
In order to address these shortfalls and produce the detailed and spatially explicit information necessary to support CARPE's conservation initiatives in the CBFP landscapes, CARPE has supported satellite mapping of forest cover in the Congo Basin and worked with CARPE partners to utilize geospatial data. The geospatial datasets produced under CARPE have broader applications beyond the program's objectives.

The following sections summarize land cover mapping using remote sensing in the Congo Basin, and describe recent developments in forest monitoring at the Basin level, including a discussion on the availability of remote sensing data. There is an overview of GIS applications within CARPE and the development of GIS/RS capacity in the region. Finally, lessons learned regarding the importance of GIS/RS for CARPE as a Basin-wide regional conservation initiative are summarized.

## II. Satellite Mapping for Central Africa

Since the 1970s, earth observing satellites have provided data suitable for mapping land cover. These remotely sensed data have become the predominant means of mapping humid tropical forest on global and regional scales. Remote sensing data offer numerous advantages over ground based data: large area coverage; collection over remote, inaccessible areas; internally consistent and repeatable measurements; systematic and continuous data acquisition; and relative to labor intensive field data collection, low data cost. When coupled with corroborative ground based data and improved geolocation methods, remote sensing data provide the means to produce vegetation maps of unprecedented precision and accuracy. Because remote sensing data captures biophysical and structural vegetation traits, the derived thematic classes are more general relative to the floristic detail that can be collected in ground based surveys.

There are two classes of satellite[1] optical data used for global, continental and regional land cover monitoring: moderate (200 - 300 meters) to coarse (1 kilometer) spatial resolution data with daily/frequent global coverage, e.g., AVHRR, MODIS, SPOT VEGETATION, and high (15 - 30 meters) spatial resolution data, e.g., Landsat and SPOT HRVIR, with repeat cycles of 2 to 3 weeks. The frequent acquisitions of the low resolution data increase the likelihood of collecting cloud-free data, which is particularly important for monitoring Central Africa due to persistent cloud cover in the western Congo Basin. Frequent data acquisitions enable depiction of vegetation phenology (seasonal effects) which can be very useful in discriminating vegetation types. However, moderate and coarse spatial resolution data with daily coverage cannot capture the fine scale changes in the forest domain resulting from shifting agriculture, a predominant driver of deforestation in the Congo Basin. Likewise, logging roads are often only detected in high resolution imagery and may be the only indication of selective commercial logging activity. Thus, both low and high spatial resolution data have information of value in monitoring forest cover within an environment such as the Congo Basin.




A. B. C.

Figure 1. Examples of satellite data used for vegetation mapping at different spatial resolutions. A. SPOT VEGETATION (1 km) B. MODIS (250 m) C. Landsat (30 m).

A number of land cover characterizations of Central Africa have been derived primarily from satellite optical data, either specifically for the Congo Basin, or as part of larger mapping projects. A global tropical forest inventory, the Tropical Resources and Environment monitoring by Satellites (TREES), was undertaken by Joint Research Center (JRC) and European Space Agency (ESA) in support of the International Geosphere-Biosphere Program (IGBP). That project produced a 1:5,000,000 vegetation map of Central Africa from 1 km (Local Area Coverage) and 5km (Global Area Coverage) AVHRR data acquired in 1992 and 1993 (Mayaux et al.,1999). In support of CARPE,

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[1] A table of earth observing satellites that provide data for vegetation mapping is provided in Appendix 1.

a similar land cover map was also prepared from multi-temporal, multi-resolution AVHRR data acquired during the 1980s and early 1990s (LaPorte et al., 1998). The Global Land Cover (GLC) 2000 project of the JRC produced a 1 km land cover map of the entire African continent from SPOT VEGETATION year 2000 data, supplemented by radar data to map flooded forests and a Digital Elevation Model to identify montane forests (Mayaux et al., 2004). The *Université Catholique de Louvain* (UCL) produced a more detailed land cover classification for the Democratic Republic of Congo also based on SPOT VEGETATION data from the year 2000 (Vancutsem, et al., 2004). A 300 meter resolution global land cover map (GlobCover 2005) derived from Envisat MERIS data, produced by ESA in partnership with UNEP, FAO, JRC, the European Environmental Agency (EEA) and GOFC-GOLD, will be released in 2008.

Satellite radar data are also useful for mapping humid tropical forests because of the ability of the radar signal to penetrate cloud cover, to discriminate inundated forest from *terra firma* forest and to estimate forest biomass from radar interferometry. Processing and analysis of radar data are considerably more complex than for optical data. There have been two efforts to collect, process and derive forest maps from satellite synthetic aperture radar (SAR) data across the Congo Basin. The ESA /European Commission Central Africa Mosaic Project (CAMP), used C-band (3 cm wavelength) data from the European Remote Sensing (ERS) satellites, and the National Space Development Agency of Japan (NASDA) Global Rain Forest Mapping (GRFM) project relied on L-band (23 cm) data from the Japanese Earth Resources Satellite (JERS-1). Both of these mosaic datasets were used to produce vegetation map*s* for Central Africa that distinguished periodically and permanently flooded forest from lowland forest (Mayaux, et al., 2002).

In recognition that discrete categorical depictions of forest cover in the maps described above can vary depending on forest definition, a global map of proportional tree cover at 1 km was produced from AVHRR data (DeFries, et al., 2000). A similar approach was subsequently applied to MODIS data to produce a 500 meter resolution global percent tree cover map (Hansen et al., 2003). This Vegetation Continuous Fields (VCF) method was modified to create a 250 meter resolution percent tree cover map specifically for the Congo Basin (Hansen et al., 2008). This map was consolidated with the GLC 2000 map to provide an initial survey of the Central African forest for the State of the Forest 2006 (CBFP 2007).

Detection and mapping of the fine scale forest cover changes that are characteristic of the Congo Basin requires imagery with a spatial resolution of less than 100 meters. The NASA Landsat Pathfinder Humid Tropical Deforestation Project was a collaborative effort by the University of Maryland, the University of New Hampshire and NASA Goddard Space Flight Center to map deforestation using Landsat data (30 meter resolution) for three epochs (1970s, 1980s and 1990s) in Southeast Asia, the Amazon Basin and Central Africa. Production of forest cover maps from these data was time consuming and labor intensive, but the primary limitation for mapping deforestation was a lack of sufficient cloud-free data for each time period. Nonetheless, the data archive compiled by the Pathfinder Humid Tropical Deforestation Project has been essential for subsequent high resolution mapping efforts.

An alternative approach to exhaustive, i.e., ‘wall to wall’, forest cover change mapping is to employ a sample-based method such as the systematic sampling scheme developed by JRC/UCL for estimating forest cover change. This approach used 10 km x 10 km subsets of Landsat data from 1990 and 2000 distributed every ½ degree across the Central African forest domain to derive rates of deforestation, reforestation, forest degradation and forest recovery (Duveillier et al 2008). The FAO has proposed to use this sampling strategy for future global FRAs. For this method to be effective in a region like the Congo Basin where forest cover change is relatively rare, a large number of samples must be obtained in order to produce estimates with reasonable levels uncertainty. For the purposes of CARPE, where the areas of interest, the landscapes or macrozones, can be relatively small, estimates of change derived by this method would not be sufficient.

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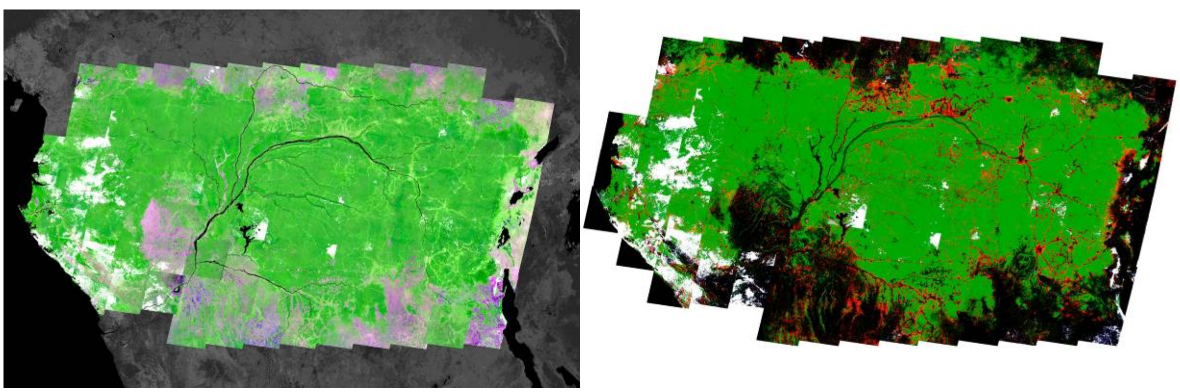
**III. Recent Congo Basin Forest Cover and Change Mapping under CARPE: Methods and Results**

CARPE has supported the development of a sophisticated, innovative method to map forest cover and forest cover change exhaustively across the Basin which combines a consistent regional characterization of forest derived from MODIS data with spatially detailed forest cover and change derived from Landsat data (Hansen et al 2008). The Decadal Forest Change Mapping (DFCM) project automatically maps a forest likelihood variable and forest cover change[2] across the Congo Basin at 57 meters, a resolution that is adequate to capture the small scale changes in forest cover that are characteristic of this biome.

A 250 meter resolution land cover map was produced from multi-temporal (years 2000 to 2004) MODIS data for the Congo Basin. The MODIS land cover map provides training data to automatically derive land cover characterizations from Landsat imagery. Multiple Landsat acquisitions are included for each path/row tile [3] to compensate for cloud cover. Two epochs of Landsat data, circa 1990 and circa 2000, are used to produce a forest likelihood map and map of forest cover change between the two time periods. The result is a consistent high resolution depiction of forest cover and forest cover change for the entire Congo Basin. It is the first spatially explicit representation of forest cover change ever produced for this region.



A. B.

Figure 2. A. DFCM multi-spectral 1990s – 2000 Landsat composite image for the Congo Basin superimposed on a gray-scale MODIS image. B. Forested area of the Congo Basin derived from Landsat imagery using the DFCM algorithm (green is forest, black is non-forest). Areas of forest cover change detected between the 1990s and 2000s epochs are shown in red, enhanced for easier viewing. White areas within each mosaic were obscured by cloud cover in either or both of the time periods and not included in the analysis

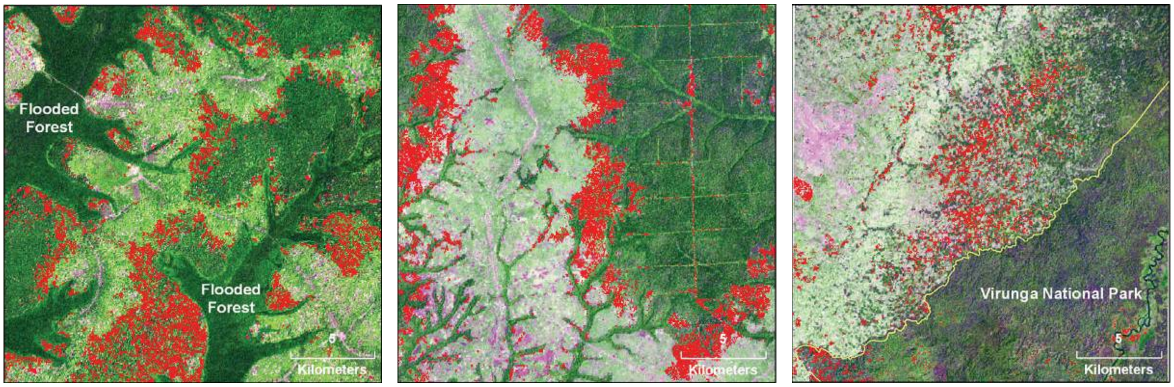
[2] Forest likelihood is a measure of the probability, from 0 to 100%, that a given mapping unit, in this case a 57 meter square pixel, meets the definition of closed canopy forest. A continuous variable, rather than a categorical depiction, allows the data user to delineate subsets of forest based on user defined thresholds. Forest cover change, on the other hand, is defined by a DFCM algorithm and is assigned a unique value. The forest cover data presented here are based on a forest likelihood value of greater than 50%.

[3] Landsat data is acquired in a fixed pattern of tiles across the earth's land surface. Each tile is referenced by path (the orbital ground track) and row (image segment).

Table I. Forest cover and forest loss between circa 1990 and circa 2000 for the 12 CBFP landscapes. Included is the percent of each landscape area not surveyed due to cloud or cloud shadow for each time period. Forest cover and forest cover loss for those landscapes with persistent cloud cover may be underestimated.

| CBFP Landscape | 1990 Forest Cover ($km^2$) | 1990 Not Surveyed (%) | 2000 Forest Cover ($km^2$) | 2000 Not Surveyed (%) | Forest Cover Loss ($km^2$) | Forest Cover Loss (%) |
|---|---|---|---|---|---|---|
| Dja - Odzala - Minkebe Tri-National | 155,606 | 7 | 155,267 | 4 | 339 | 0.22 |
| Lac Tele - Lac Tumba | 100,158 | 0 | 99,169 | 1 | 989 | 0.99 |
| Salonga - Lukenia - Sankuru | 97,214 | 1 | 96,851 | 1 | 363 | 0.37 |
| Maiko - Tayna – Kahuzi - Biega | 86,488 | 1 | 85,259 | 1 | 1,229 | 1.42 |
| Maringa - Lopori - Wamba | 68,670 | 0 | 68,067 | 0 | 603 | 0.88 |
| Ituri - Epulu – Aru | 41,431 | 0 | 41,143 | 1 | 288 | 0.70 |
| Sangha Tri-National | 35,632 | 0 | 35,571 | 0 | 61 | 0.17 |
| Lope - Chaillu - Louesse | 22,873 | 19 | 22,695 | 23 | 178 | 0.78 |
| Gamba - Mayumba - Conkouati | 17,596 | 43 | 17,375 | 22 | 221 | 1.26 |
| Monte Alen - Monts de Cristal | 17,233 | 7 | 17,143 | 30 | 90 | 0.52 |
| Leconi - Bateke - Lefini | 3,540 | 26 | 3,478 | 57 | 62 | 1.77 |
| Virunga | 2,315 | 23 | 2,136 | 13 | 179 | 7.74 |

The consistent Basin-wide characterization of forest cover and forest cover change permits the derivation of comparable statistics at regional, national and local levels. The spatially explicit data enable analysis of forest cover change processes at different scales, including investigations of local drivers of deforestation which are important for land use management decisions. For example, in the Democratic Republic of Congo, nearly 98 percent of all forest change took place within 2 kilometers of a pre-existing forest clearing and approximately 50% of all forest clearing occurred within 6 km of a major road. These preliminary results reflect what is visually apparent in the data: most of the deforestation is the result expansion of the rural complex (the mosaic of settlements, fields and degraded forest which exist along the road networks) into the forest.




A. B. C.

Figure 3. Examples of forest cover loss from circa 1990s to circa 2000, shown in red, overlaid on a multi-spectral Landsat composite from the same time period. A. Agricultural expansion into upland forest areas; flooded forest is avoided. B. Expansion of the rural complex and logging roads north of Bumba. C. Forest loss near Virunga National Park; as forest is lost outside the park, pressure on forest resources within the park increases.

Regional analysis of the DFCM data shows a 1.7 percent overall decrease in forest cover in the Congo Basin from the 1990s to the 2000s epoch. This corresponds to a loss of 27,718 km$^2$ of an original forested extent of 1.6 million km$^2$ at a rate of 0.17 percent per year (Lindquist et al., unpublished data). This estimate is very similar to the sample-based change estimate of Duveiller (2008) of 0.22 percent per year from 1990 to 2000. Given the very different methodological approaches, and the heterogeneous, fine scale nature of change within the Congo Basin, the relative agreement of the two estimates is an encouraging sign for monitoring within this environment. In the Democratic Republic of Congo, 21,668 km$^2$ of forest was converted from an original extent of 1.1 million km$^2$. This represents a 2 percent decrease in forest cover from the 1990s to 2000s epoch.

Table II. Forest cover and forest loss between circa 1990 and circa 2000 inside and outside of protected areas in the Democratic Republic of Congo.

| Forested Region | 1990 Forest Cover (km$^2$) | 2000 Forest Cover (km$^2$) | Forest Cover Loss (km$^2$) | Forest Cover Loss (%) |
|---|---|---|---|---|
| DRC | 1,088,092 | 1,066,423 | 21,668 | 1.99 |
| Inside Protected Areas | 147,004 | 146,006 | 998 | 0.68 |
| Outside Protected Areas | 941,088 | 920,418 | 20,670 | 2.20 |

*Mid-decadal Landsat Composites and Change Detection*

Because the DFCM method is an automated procedure, the maps can be updated as additional data become available. Work is currently underway to produce forest cover change maps for 2000 to 2005 from recent Landsat imagery, despite the Scan Line Corrector (SLC) failure of the ETM+ sensor which causes significant gaps in the data. While many researchers have purposely avoided using the

Landsat SLC-off data, the DFCM approach generically handles the data gaps to create products for the 2000 to 2005 epoch.

Mid-decadal Landsat mosaics have been completed for over 20% of the Basin representing an area of more than 600,000km$^2$. Landsat path/rows for which multiple acquisitions are available produce more consistent results (e.g. free of scan gaps and scan line artifacts) than path/rows without such data richness. Figure 3 shows the current extent of the mid-decadal forest cover map for the Congo Basin with an example of forest cover change as detected using the automated DFCM algorithm. Quantitative estimates of Basin-wide mid-decadal forest change are currently being developed.

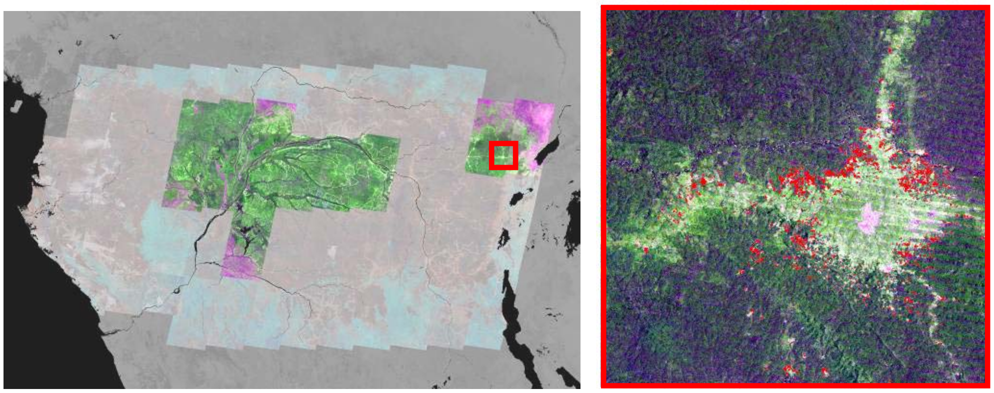


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Figure 4. A. DFCM multi-spectral 2005 Landsat composite for path/rows processed to date using the DFCM algorithm. The 2000 Landsat DFCM mosaic is in the background to show the total extent of the study area. A MODIS map of central Africa provides the backdrop. B. Example of forest cover loss (in red) detected between 2000 and 2005 for a site in eastern DRC (red box on larger map).

*Additional forest characterizations – degraded and flooded forest*

The distinction of degraded (secondary) forest from mature (primary) forest is an important one for habitat conservation, biodiversity, and estimation of carbon stocks. Since the DFCM forest cover is represented as a continuous variable, it is theoretically possible to initiate characterization of a degraded forest class based on thresholds of forest likelihood values. Forest likelihood values were compared for field plots classified as forest, non-forest or degraded forest as from an FAO National Forest Inventory of Cameroon. There was a clear separation of forest likelihood values for forest and nonforest plots, but degraded forest plots comprised a wide range of values which overlap the forest plot values. Work is continuing on the characterization of a degraded forest class.

Flooded forest is a crucial cover theme for modeling regional hydrology, assessing habitats and biodiversity and understanding human impacts on the forest environment. Most deforestation occurs within *terra firma* forests, due to greater agricultural suitability and easier access. Flooded forests can be difficult to discriminate from *terra firma* forests on the basis of optical (reflected) data alone. A method currently being implemented, with support from CARPE, employs Landsat image mosaics, elevation data and derived hydrographical parameters from Shuttle Radar Topography Mission (SRTM) data, and radar data to map wetlands, including forested wetlands, across the Basin at 57 meters.

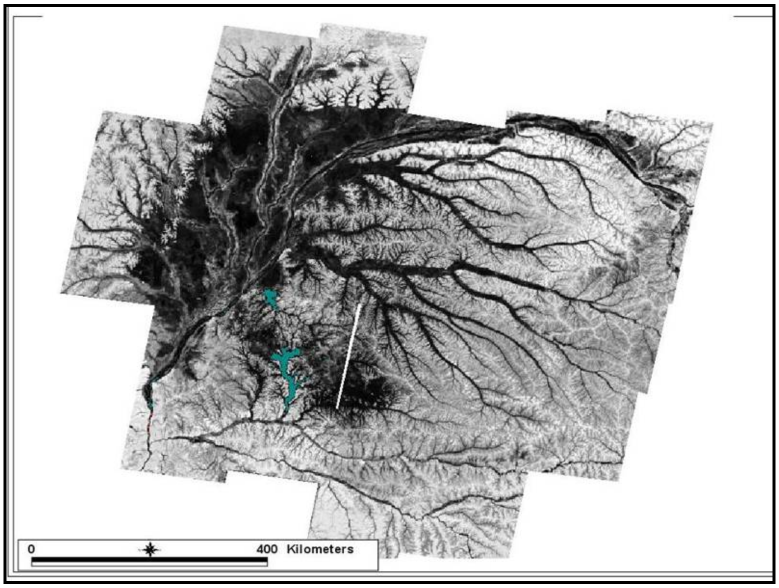



Figure 5. Preliminary wetland mask for the central Congo Basin. Dark values indicate high likelihood of wetland occurrence, bright values are low likelihood. Lakes Tumba and Mai Ndombe are overlain.

As a suite of products, the forest cover, forest cover change, degraded forest and flooded forest maps will be valuable inputs for land use planning, regional policy decisions, carbon accounting initiatives and climate modeling. They will also help to meet the goals of international monitoring programs, such as the United Nations Framework Convention on Climate Change (UNFCCC) Reducing Emissions for Deforestation and Degradation (REDD) initiative.

**IV. Remote Sensing Data Access**

The success of remote sensing based forest mapping efforts has demonstrated the utility of satellite data for land cover mapping in Central Africa. Recent technological advances have made it easier to process large amounts of data and methodologies for deriving vegetation characterizations continue to improve. Limitations to the derivation of more timely and accurate forest cover characterizations are primarily related to data access. Researchers typically use the data they can afford, not the data they truly need for implementing rigorous monitoring schemes. Therefore, it is paramount that future data policies ensure the regular delivery of the data required to meet policy goals. While some recent developments hint at a more liberal era of data access, the major hurdle to producing new satellite based maps to date has been the cost of acquiring remotely sensed data.

NASA provides MODIS datasets for free through the USGS Land Processes DAAC and NOAA AVHRR derived NDVI is freely available via the Global Land Cover Facility. SPOT VEGETATION data that have been archived for 3 months or longer are also available free of charge. However, as mentioned previously, higher spatial resolution data are required to map the forest cover changes that occur in the Congo Basin.

The NASA/USGS Landsat series of satellites have been the work horses for high resolution forest cover mapping since 1972. Landsat 5, launched in 1984, is still operational, but data must be directly downlinked to ground stations in view of the satellite, i.e., there is no on-board storage of data. Currently, due to the absence of a ground station in the region, there has been no collection of Landsat 5 data over most of the Congo Basin since 1999. The NASA/USGS Mid-Decadal Global Land Survey (MDGLS) proposed to begin Landsat 5 data downlinking to an ESA ground station in Malindi. However, this ground station will most likely not operate continuously due to technical challenges and the fact that the Landsat 5 sensor is likely to fail due to its advanced age. Landsat 7 was launched in 1999 and produced well calibrated, high quality images until May 2003 when the sensor Scan Line Corrector (SLC) failed. As a result, there are linear gaps in the images which cause a 22% loss of data in any given image. Aside from the data gaps, the image quality remains unaffected, but additional images are required to compensate for the gaps. Meanwhile, the NASA/USGS Landsat Data Continuity Mission is striving to have a new Landsat satellite in launched in 2011.

Landsat data are not generically free, and pricing and distribution policies have varied over the duration of the program. CARPE and its partners have benefited from NASA funded acquisitions of Landsat data, under the Pathfinder project and the Science Data Purchase for the production of the GeoCover datasets. The GeoCover data consist of select, orthorectified Landsat scenes for the 1970s, circa 1990 and circa 2000, with near global coverage for each epoch, that are made freely available. The MDGLS is producing another global orthorectified Landsat data set, the Global Land Survey 2005 (GLS 2005), from Landsat 7 and Landsat 5 data. Production of GLS 2005 will include select reprocessing of GeoCover datasets to assure continuity and compatibility. The new and reprocessed datasets will be available free of charge. GLS 2005 data for Central Africa will be available in early 2008. Additionally, there are plans to open the archive beyond the GLS and GeoCover data. No confirmed dates for such an implementation yet exist.

Cloud cover will always be an issue for the Congo Basin, and full access to the entire Landsat archive would greatly facilitate the production of a mid-decadal forest change map for Central Africa. Other optical data can supplement the Landsat data. ASTER data has been acquired over the Congo Basin by UMD through the NASA Science Data Purchase, and will be used for filling data gaps for the DFCM method. ASTER scene footprints are approximately 1/9 the size of a Landsat scene and data acquisition is not systematic. Although thousands of scenes have been acquired over the Congo Basin since the sensor was activated in 2000, large areas remain for which there is no useable ASTER data. The Indian Remote Sensing Resource-1 Satellite (IRS) and SPOT HRV(IR) provide data that are suitable for forest mapping but the data are currently prohibitively expensive. IRS data at 50m also offers the added advantage of obtaining several acquisitions per month. China and Brazil announced in November 2007 that they would make CBERS data available to African countries, but the mechanism for data acquisition and transfer for central Africa has not been established.

To meet the needs of CARPE, radar data may provide the best opportunity for monitoring CBFP landscapes in persistently cloudy regions. SAR C-band instruments are on two ESA satellites: Envisat and ERS-2. A radar instrument with multiple polarization capability, PASLAR,is on board the Japanese satellite, ALOS, launched in January 2006. A systematic observation strategy is planned for PALSAR in order to produce a consistent, global time-series data set. The ESA and Japanese data can be made available to researchers on a limited basis. A commercial SAR satellite, RADARSAT-2, was launched in December 2007.

**V. GIS and CARPE**

The integration of remote sensing products with other geospatial data in a Geographic Information System (GIS) can provide useful information for conservation and natural resource management. Within CARPE, GIS has been used to compile, model, analyze and disseminate geospatial data. Outputs in the form of digital and hard copy maps are used for orientation, education, community discussion and mapping, visualizing land cover and land use, highlighting areas of forest change, and land use planning.

When CARPE was first authorized in 1995, there was a dearth of geo-referenced data for the Congo Basin. Initial data collection efforts focused on collating and digitizing the locations of towns and settlements, as well as road features from paper maps or Landsat images. Currently, there are many more sources of geospatial data for Central Africa (Box 1), but these datasets are not always compatible, and depending on the scale of the application, datasets may be too coarse or imprecise. To help users determine what data are available, and whether they are suitable for a specific application, CARPE II placed more emphasis on the collection and sharing of geospatial data from and between CARPE partners. UMD established CARPE Data Explorer to facilitate this process (see Box 2).

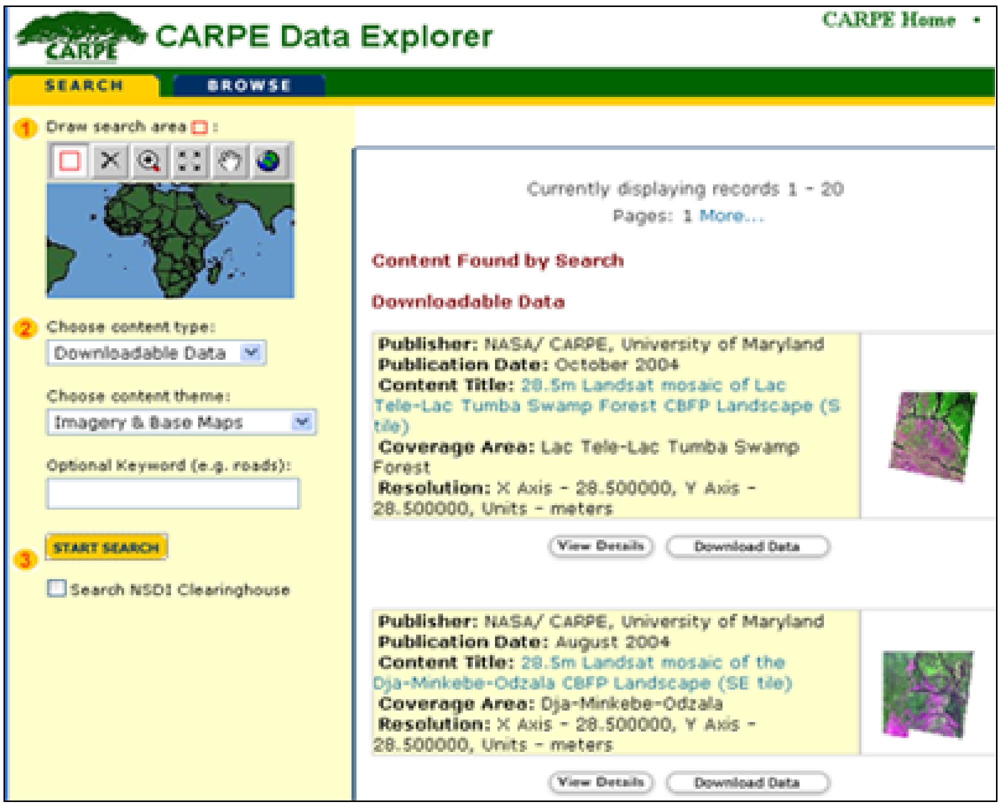
**Box 1. Geospatial datasets** currently available for Central Africa:

- ESRI (Environmental Systems Research Institute) global data sets
- IUCN World Database of Protected Areas
- UN FAO Africover
- *Université catholique de Louvain* maps of Democratic Republic of Congo
- World Resources Institute (WRI) Forestry Atlases for Cameroon, the Republic of Congo and Democratic Republic of Congo (coming soon)
- Data at the landscape level from NGOs and in situ projects, including ECOFAC (*Ecosystèmes Forestiers d'Afrique Centrale*)

An on-line central data repository allows users to easily determine if geospatial data is available and suitable for their needs, and provides data access. For geospatial data to be of real value, ancillary information, or meta-data, must accompany the geospatial data. Metadata, at a minimum, should include: spatial extent, projection, datum, information on when and how the data was created, and an explanation of attribute fields. Metadata is often compiled as an after-thought when data collection is completed and unfortunately, when resources are limited, the creation of adequate metadata is not a priority. Partners may be reluctant to contribute geospatial data through the CARPE Data Explorer due to a lack of adequate metadata, or the datasets are incomplete or partners are waiting to publish results. Datasets are sometimes revised by partners but not re-submitted in a timely fashion. The end result is that many GIS datasets held at CARPE are out of date or do not reflect new information. USAID has encouraged more sharing of GIS data within CARPE, requiring that geospatial data (e.g., shape files) be submitted as part of the MOVs (means of verification) documents.

Key data sets are those that relate directly to CARPE activities; they include priority landscape boundaries, population centers, hunting camps, roads, rivers, protected areas, logging and oil concessions, flora and fauna inventories, habitat assessments, and more recently delineations of the land use management zones.

**BOX 2. CARPE Data Explorer** is a customized version of ESRI's GIS Portal Toolkit. Geospatial data and mapping services are organized to enable map-based or keyword searches for geospatial data. These data can be viewed and download over the Internet.
In our experience users unfamiliar with geo-portals have found that the search function is not very comprehensive. Alternative solutions for accessing data are currently being assessed for improved functionality.




**Box 3. CARPE Mapper** is web-based mapping service for viewing and querying geospatial data over the Internet without requiring access to GIS software. Map services are available for each of the 12 priority landscapes. Each contain data specific to that landscape provided by the NGOs working there. Four of the 12 landscapes contain Forest Elephant telemetry data, provided by the Wildlife Conservation Society (WCS).
CARPE Mapper provides a useful overview of the landscapes and allows users to select and query a range of data layers Using CARPE Mapper does however require reasonable Internet access and user feedback from has shown that when internet access is intermittent or bandwidth is low, the performance of CARPE Mapper can be prohibitively slow. CARPE Mapper was developed approximately 4 years ago using ESRI ArcIMS software. Since it was developed there have been a number of advances in internet mapping software; alternative mapping services are being considered but noticeable improvements in performance are unlikely without improving bandwidth in the region.

GIS integrates remote sensing data and results with other geospatial datasets, which is critical for CARPE monitoring and reporting. Using GIS it is possible to analyze changes in forest cover by, for example, landscape, protected area, administrative area, watershed or distance from roads. An examination of the spatial variability of forest cover change helps to understand drivers of land cover change such as human population distribution, land use practices, resource management policies, and socio-economic factors.

One of the most useful outputs from GIS are maps that integrate satellite imagery, forest change and local feature data to provide users with a birds-eye view of the landscape. These maps have proved to be a powerful tool for interpreting land cover and land use dynamics, as images reveal detail that cannot possibly be represented by strictly cartographic elements. The maps have been used for field work, engaging local communities and have provide focal points for discussion. An example of such a map produced for CARPE is shown in Figure 6.

Spatial modeling with GIS is also making significant contributions to CARPE. Simulating how natural resources (such as wildlife population distributions or socio-economic impacts on forest resources) would be affected under different land use scenarios is useful for guiding land use planning. An example of spatial modeling used in land use planning for a CBFP landscape is presented in Box 4.


Figure 6. A poster for the Maringa-Lopori-Wamba landscape which incorporates a Landsat composite and forest cover change map from the DFCM along with information provided by the landscape partner.

**Box 4. Land-Use Planning in the Maringa-Lopori-Wamba (MLW) Landscape**
As a pilot project for the CARPE Landscapes, the University of Maryland, in partnership with the African Wildlife Foundation (AWF), the *Université catholique de Louvain* (UCL), the US Forest Service (USFS) and others, are using GIS and products derived from remote sensing to build a suite of spatially-explicit land use models for the Maringa-Lopori-Wamba (MLW) landscape, located in northern Democratic Republic of Congo. Modeled outputs include human population distribution and human accessibility in the landscape, as well as identification of biodiversity hotspots and important wildlife corridors connecting existing protected areas. The Decadal Forest Change Mapping satellite-derived forest change products have been used to predict landcover change in the landscape over the course of the next 50 years. To contribute directly to land-use zoning initiatives, the team will utilize a spatially-explicit site selection modeling tool to identify areas most suitable for future human expansion, taking into account conservation and human needs.

## VI. Regional activities: Establishing the capacity and infrastructure to use geospatial data in forest management and monitoring in the Congo Basin

Prior to the implementation of the second phase of the Central Africa Regional Program for the Environment (CARPE) it was widely acknowledged that there was a paucity of reliable and updated information on forest cover and forest cover change. National institutions recognized that accurate mapping and remotely sensed data, in conjunction with in-situ data, were essential to efficiently producing this information on a regular basis, but no critical mass of experts in this field existed in the Congo Basin. Capacity was limited to several individuals and site-specific projects scattered across the region and no appropriate infrastructure existed to support a regional initiative on forest mapping.

In 2004, stakeholders concerned with using spatial data in forest management met in Libreville, Gabon for a GOFC Central Africa regional workshop, co-sponsored by EEC-TREES, NASA-START, and USAID-CARPE. A panel of the Global Terrestrial Observing System, GOFC-GOLD (Global Observation of Forest and Land Cover Dynamics) works at the global and regional scale to improve the quality and availability of forest observations and produce functional products for users of this data. The main agenda of the 2004 GOFC workshop was to create a Central African GOFC chapter that would link national agencies and the user community with producers of this information.

Participants of the workshop agreed the focal point for the network would be based in Kinshasa, Democratic Republic of Congo (DRC) and that the network would operate under the French acronym OSFAC (Observatoire Satellital des Forêts d'Afrique Centrale). As a regional GOFC-GOLD network, OSFAC's unique long term objective is to build regional capacity to use remotely sensed data and mapping techniques to produce reliable information on forest cover and forest cover change across Central Africa. Simultaneously, OSFAC works to tackle some of the obstacles to establishing and maintaining operational forest mapping in the region. These primary constraints have been identified by national agencies as: a lack of human and financial resources, poor access to data (imagery) and information, poor internet access, and a lack of local expertise.

In order to operate efficiently within the DRC and across Central Africa, OSFAC sought recognition as a Congolese NGO concerned with facilitating access to satellite data, building capacity and forest cover monitoring. On September 17, 2005 OSFAC was granted authorization to function in the DRC by the Ministry of Justice and on February 06, 2006 OSFAC established a technical agreement with the Ministry of the Environment. Currently, OSFAC operates as a legally recognized NGO under the direction of a seven member Board of Advisors. It supports six full-time professionals, including three high level GIS program officers and trainers. Day to day management is overseen by a small group of advisors. In addition to its technical and administrative departments in Kinshasa, OSFAC also works to reinforce their regional network through voluntary points of contact in countries across the Congo Basin.

When OSFAC was started the capacity to develop and implement a methodology for monitoring forest cover using remotely sensed data did not exist in Central Africa, however, the need to establish baseline information was critical. The decision was made to develop a methodology for monitoring forest cover within a scientific institution outside of the region while simultaneously building capacity within Central Africa to analyze and use the information generated. This approach made it possible for OSFAC to receive continued technical and financial support from the University of Maryland under the 'resource monitoring institutionalized' objective of CARPE. Within CARPE OSFAC provides technical support to implementing partners and is seen as the primary channel through which capacity to monitor forests using remotely sensed data can be transferred to the region.

As part of CARPE, OSFAC receives technical support from both South Dakota State University and UMD. UMD has maintained a full-time technical consultant for OSFAC in DRC since 2005. OSFAC has also established a close relationship with the national university system in DRC and since 2005 OSFAC has maintained and managed a GIS/RS lab within the School of Agronomy at the University of Kinshasa (UNIKIN).

**Building Capacity**

To build capacity for GIS and RS in Central Africa the OSFAC network predicted the need for two levels of training: (1) periodic basic training courses across the region and (2) more specialized and higher level training courses and exchange programs to develop scientific expertise and introduce new satellite and information technology to OSFAC staff.

In 2005 the OSFAC focal point began offering basic and more advanced training courses to outside agencies (See Box 5). Over 400 individuals (see Table III) have participated in technical courses in GIS and RS at the OSFAC lab and ex-situ sites in DRC, Gabon, and the Republic of Congo. Courses typically run from 1 to 4 weeks and are designed to increase capacity in ArcView, ArcGIS and/or ENVI software. Each course is adapted to its participants in order to prepare trainees to use spatial data in their area of implementation. OSFAC also provides a limited number of individuals the opportunity to participate in an internship program. This program incorporates both professional and academic degree-seeking interns who work with the OSFAC staff for up to 12 months.

OSFAC's program to build higher level capacity continues to evolve. Since 2005 OSFAC has successfully promoted the exchange of three students from the region into doctoral programs in the US and Europe. Remote sensing to monitor forest cover is a highly technical and scientific exercise. Long-term exchanges and partnerships with scientific institutions are the only means to develop the level of expertise necessary to develop original forest cover change datasets. OSFAC is also working to establish within its focal point a pool of regional experts capable of generating functional products for decision makers and mangers building off of methodologies developed by top level scientists. To meet this goal, OSFAC, UMD, and SDSU plan to transfer capacity for these activities to OSFAC through an extensive training program in the DRC next year.

**Box 5. Institutions and protected areas that have received technical training from OSFAC**

- **AWF** (African Wildlife Foundation)
- **Bombo Lumene Hunting Zone,** DRC
- **BCI** (Bonobo Conservation Initiative)
- **BEAU** (Bureau d'études et d'aménagement urbain)
- **CAMI** (Cadastre minier)
- **CENAREST** (Centre national de recherche scientifique et technologique)
- **CIB** (Congolaise industrielle des bois)
- **CICOS** (La commission internationale du bassin du Congo-Oubangui-Sangha)
- **CNIE** (Cadre national de l'information environnementale)
- **CNPN** (Conseil national des parcs nationaux, Gabon)
- **COHYDRO** (Congolaise des hydrocarbures)
- **Conkouati-Douli National Park,** Republic of Congo
- **CRGM** (Centre de recherche géologique et minière)
- **CTB** (Coopération technique belge-FSU, PU, RRBC, RIB, AILD-KIN
- **CTCPM (**La Cellule Technique de Coordination et de Planification Minière
- **DGF** (Direction de gestion forestière)
- **ECODED** (Economie et développement durable)
- **ERAIFT** (Ecole régionale d'aménagement intègre des forêts tropicales)
- **FACAGRO** (Faculte d'agronomie)
- **Garamba National Park**, DRC
- **ICCN** (Institut Congolaise pour la conservation de la nature)
- **IPS** (Inspection provincial de la sante)
- **IRM** (Innovative Resource Management)
- **ITTO** (International Tropical Timber Organization)
- **Kahuzi Biega National Park,** DRC
- **Lac Télé Community Reserve,** Republic of Congo
- **Lopé Reserve,** Gabon
- **MECNEF** (Ministère de l'environnement, conservation de la nature, eaux et forets)
- **SNR/MECNEF** (Service national de reboisement)
- **MECNT** (Ministère de l'environnement, conservation de la nature et tourisme)
- **MEFE** (Ministère de l'economie forestière et l'environnement, République du Congo)
- **MINEF** (Ministère de l'economie forestière, Gabon)
- **Mikébé National Park,** Gabon
- **Nouabale Ndoki National Park**, Republic of Congo
- **OCHA/UN** (Office for the Coordination of Human Affairs)
- **Okapi Faunal Reserve,** DRC
- **PAIDECO** (Programmes d'appui aux initiatives de développement communautaire)
- **PARCAFRIQUE**
- **PNLTHA** (Programme nationale de lutte contre la trypanosomiase humaine africaine)
- **PROGEPP** (Projet de gestion des écosystèmes périphériques du parc national de Nouabalé-Ndoki)
- **Salonga National Park,** DRC
- **SPIAF** (Service permanant d'inventaire forestier)
- **SYGIAP** (Système de gestion des aires protégées)
- **TRIDOM** (Dja-Odzala-Minkébé Tri-National)
- **UNICEF** (United Nations Children's Fund)
- **UNIKIN** (University of Kinshasa)
- **UNILU** (University of Lubumbashi)
- **Virunga National Park,** DRC
- **WCS** (Wildlife Conservation Society
- **WRI** (World Resources Institute)
- **WWF** (World Wildlife Fund)

Currently OSFAC's capacity for GIS is high and its focal point maintains a reputation for delivering quality support and products. OSFAC engages in a wide variety of GIS and basic RS projects as part of its efforts to strengthen conservation and sustainable development initiatives by incorporating the use of spatial datasets. These initiatives build mapping capacity, provide OSFAC trainees with practical experience and contribute to OSFAC's long-term sustainability. Among the projects in which OSFAC has participated in are:

- A 2007 workshop co-hosted by WWF, the Minister of the Environment, ICCN, and OSFAC to prioritize conservation areas in DRC. Throughout the workshop, OSFAC provided technical support to create maps of priority areas.
- An initiative by UNESCO to establish a permanent GIS lab at ERAIFT.

- Developing a methodology for monitoring land cover change as part of an environmental impact assessment for the PRO-ROUTES project.
- Partnering with WWF and WCS for a month long field and lab-based GIS training centered on inventorying and mapping the Bombo Lumene Hunting Zone.
- A project to produce posters of all the RAPAC sites.
- Projects to map the Jardin Botanique de Kisantu and the Jardin Botanique de Kinshasa.
- An inter-university project (PIC) to map erosion in Kinshasa.
- A CTB (Coopération techniques belge) project to map numerous communes in Kinshasa.

**Data Accessibility**

Since its inception OSFAC has been committed to working with regional partners to assess and improve the state of spatial datasets in Central Africa as well as facilitate regional access to satellite data. OSFAC served as the sub-regional partner on the Mapping Africa for Africa (MAFA) initiative led by the Human Science Research Council and EIS-Africa. The initiative aims to create a catalogue of available fundamental geo-spatial datasets and do a country gap analysis. Within DRC, OSFAC is an active member the GIS working group established by the UN Joint Logistic Committee. The working group provides a platform for stakeholders collecting and using GIS data in the DRC, including government institutions, UN agencies and NGOs, to harmonize data.

Through its affiliation with UMD, OSFAC has obtained hundreds of satellite images and maintains a database cataloguing all distributable imagery. OSFAC disseminates these data free of charge upon request. Poor internet access in the region means that having data available locally greatly facilitates access for many users. In addition to physically distributing data and providing technical assistance to individuals or organizations interested in using satellite images, OSFAC also maintains a website that provides users with information on different types of satellite imagery, remotely sensed products and details on data coverage across the region.

## Future Objectives

Building off of its current capacity and ongoing activities, OSFAC remains focused on establishing its own sustainability and developing regional capacity to use satellite data in routine forest cover monitoring of the Congo Basin. OSFAC will be the primary conduit by which capacity for using the UMD/SDSU methodology is transferred to the region and hopes to establish itself as an independent organization with the capacity to monitor changes in forest cover. Once the capacity is established, OSFAC will work with local agencies to determine the accuracy of estimates and combine remotely sensed data with in-situ datasets. These data and derived products will be provided to forest managers and decision-makers directly and as part of the Forest Observatory for Central Africa (OFAC).

**Table III.** Total number of individuals trained by OSFAC (June 2005- February 2008)

| | Men | Women | Total |
|---|---|---|---|
| Trainees | 383 | 60 | 443 |
| Interns* | 19 | 9 | 28** |
| Total | 402 | 69 | **471** |

*includes both academic and professional interns
**16 were university students who worked with OSFAC to incorporate spatial data into their theses

## VII. Lessons Learned in the use of satellite mapping and GIS for CARPE

**Regional initiatives such as topic-specific networks and technical bodies are fundamental mechanisms for creating rigorous forest monitoring systems.**

Monitoring forests across an area as vast as the Congo Basin requires good communication amongst different practitioners of forest monitoring to assure that agreements can be reached on estimates of rates of change. Regional networks provide practitioners a means to communicate and compare different monitoring methodologies to achieve a general consensus on estimates of change.

An independent technical body is necessary to assess the veracity of national forest change estimates. To be effective the body will need to have the scientific capacity to develop accurate estimates as well as be officially recognized across the region as an independent assessor of forest change. In the Congo Basin one could imagine COMIFAC establishing an independent body to carry out forest change assessments in close collaboration with a university.

Satellite remote sensing provides a comprehensive means for regional monitoring of forest cover. The convergence of change estimates derived from different remote sensing methodologies demonstrates that a reliable representation of forest extent and forest change can be produced from satellite data. The wall-to-wall explicit mapping of forest cover change is more useful for CARPE's purposes than results obtained from a sampling methodology. However, it is useful to have simultaneous, overlapping monitoring activities to corroborate regional results.

Remote sensing provides a relatively low cost solution for monitoring forest cover, but ultimately the derived products must be validated with ground-truth data. Implementation of a statistically valid Basin-wide field data collection campaign would be logistically and financially infeasible, since much of the Congo Basin remains relatively inaccessible. Plans are underway to collect field data for the validation of the DFCM products in at least one landscape. This will provide an opportunity to test and refine a field data collection protocol which can be disseminated to landscape partners to implement along with their other field activities. Establishing a mechanism whereby field and forest plot data can be shared, such as through a regional network, would benefit the development of reliable forest monitoring programs.

**There is an urgent need in the Congo Basin to transition forest monitoring methods developed in the research domain into the operational domain.**

The institutionalization of methods such as the DFCM is a current CARPE objective. Porting these tools will require intensive long-term training to develop in-region technical capabilities. With increased capacity in the region, this method could be the foundation of an operational regional monitoring program.

One of OSFAC's primary goals is to work with national forest monitoring agencies to utilize monitoring methods developed in the research domain to create useful products for forest management and decision making. This will require continuing to build the OSFAC network across the region and significantly increasing efforts to work with government agencies to understand their needs and communicate potential implications and possible applications of monitoring data.

**Improved acquisition and free and open access to data would increase utilization of satellite data and support the development of sustainable forest monitoring systems in the Congo Basin Region**.

Long term forest cover monitoring requires institutional support and access to a continuous data stream. While governments continue to support global and regional monitoring by developing and launching satellite borne sensors, data are still under-utilized due to prohibitive data costs. Even when individual scenes are relatively inexpensive, cumulative costs can be high when data needs are intensive. Progressive data policies are required so that operational mapping organizations need not worry about problematic data cost or access policies.[4]

The greatest return on investment in earth observing satellite assets comes as information derived from sensor data in the form of value-added products. Limited data access limits the development and improvement of methods to derive useful products, limits the capacity for monitoring and limits the information available for making sound resource management decisions. An international strategy should coordinate data acquisition from different sensors to maximize the potential for obtaining useful data (e.g. cloud-free in the case of optical sensors) over the Congo Basin, and this data should be made freely available.

In the current limited satellite data access scenario, researchers use the data they can afford, not the data they truly need. For example, the DFCM method is robust, repeatable and could be modified to work with data inputs other than Landsat, if the data were readily available. Significant gaps remain in the products largely due to a lack of cloud-free Landsat data. While it is not possible to overcome historical failures of data acquisition and archiving, other data sources exist today that can compensate for Landsat limitations, either by increasing the available pool of cloud-free optical data or by providing data from other modes, such as radar.

**The compilation and creation of geospatial data and products, as well as the results of geospatial analyses, contribute to CARPE's success. The dissemination of these data, products and results must continue to be fostered and improved.**

The geospatial and remote sensing data and the derived products compiled and created under CARPE are a significant contribution to forest management and planning for the Congo Basin, to the Congo Basin Forest Partnership and to the State of the Forest reports in particular. The data, products

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[4] The NASA/USGS Landsat data distribution policy ensures that data products are available at no more than the cost of fulfilling user requests, meaning that there is no effort to recover costs of satellites, ground systems or other capital assets. This COFUR policy could be a model for other satellite data distribution programs.

and results need to be made available to CARPE partners, and to the wider community, in a timely manner.

The regional dissemination of remote sensing data and derived products is problematic due to the large data volumes involved and limited internet capacity in the Congo Basin, therefore, OSFAC will continue to be an important regional node for data distribution. Internet dissemination of geospatial feature data is less of a problem, but for both feature and remote sensing data, there is a need to assure that geospatial data is shared among CARPE partners. There should be a routine porting of satellite data to OSFAC and a systematic review of remote sensing data available to CARPE partners. The ability to review, access and update geospatial datasets could be improved, perhaps by implementing an open source geoportal.

The geospatial and remote sensing data compiled and produced by CARPE are filling a regional data deficit and will have applications beyond their contribution to CARPE Strategic Objectives. The availability of these datasets should be brought to the attention of international environmental monitoring programs, such as the UNFCCC's Reducing Emissions for Deforestation and Degradation (REDD) initiative.

Map products in poster form are an effective means of communicating CARPE objectives and results. In particular, the maps based on remote sensing image composites are useful for informing stake holders, engaging local communities and for public education. Integrating the basic DFCM products with other geospatial datasets, such as national, landscape and protected area boundaries, conveys at a glance the forest cover and change dynamic within the Congo Basin. Maps of this type tailored to specific regional needs should be produced by OSFAC.

**Partnerships with academic institutions are essential to develop technical expertise and establish centers of excellence to meet the demand for high technical skills.**

One of the keys to OSFAC's success has been its close relationship with academic institutions both within and outside of Central Africa. Through the CARPE program, OSFAC has developed and maintained an active relationship with both the University of Maryland and South Dakota State University. Both universities are highly scientific institutions with long-term commitments to using remote sensing to monitor forest cover and working with OSFAC to create a critical mass of remote sensing experts in Central Africa. These partnerships have provided OSFAC with the day-to-day technical and financial support necessary to establish itself as a respected NGO concerned with mapping resources in the Congo Basin and have provided the best opportunity for OSFAC to continue to develop its capacity through a combination of higher-level training courses in the region and in academic exchange programs.

Simultaneously, OSFAC has benefitted by maintaining a close relationship with the University of Kinshasa and its School of Agronomy. This partnership is critical to assure that capacity building in remote sensing and GIS will be institutionalized within the region and has put OSFAC in contact with a continuous pool of motivated and skilled candidates for training. Working through the local university system has allowed OSFAC the opportunity to partner with supplementary initiatives to establish more permanent training institutions such as ERAIFT (Ecole régionale d'aménagement intègre des forêts tropicales). Additional centers of excellence are necessary to meet the demand for high technical skills.

**OSFAC will only succeed if OSFAC can attain a measure of sustainability, including establishing secure funding mechanisms and building management capacity.**

Since its inception, OSFAC has benefitted technically and financially from the support of USAID and partnering academic institutions. This support is critical in these initial stages; however, in its aim to establish itself as a local organization it is imperative that OSFAC continues to develop its own management capacity and financial sustainability. OSFAC supplements its USAID funding by engaging in short term income generating mapping projects, but this income covers less than 25% of OSFAC's operating costs and OSFAC will continue to require additional sources of support, either through donor agencies or through a commitment from national agencies.

Appendix I.

Table I. Earth Observing Satellites with Vegetation Mapping Applications

| Satellite | Sensor(s) | Spatial Resolution | Revisit Frequency | Application[5] |
|---|---|---|---|---|
| | Optical | | | |
| NOAA [6] | AVHRR[7] | 1 km | daily | Global NDVI[8] |
| SPOT [9] | VEGETATION | 1 km | daily | Global |
| Terra / Aqua | MODIS [10] | 250 m – 1 km | daily | Global, Regional |
| Envisat | MERIS [11] | 300 m – 1 km | 3 days | Global, Regional |
| CBERS-2 [12] | CCD, IRMSS, WFI [13] | 20 – 260 m | 5 / 26 days | Regional, Local |
| IRS-P6 [14] | LISS, AWiFS [15] | 5.8 – 56 m | 5 / 24 days | Regional, Local |
| Landsat 5 / 7 | TM / ETM+ [16] | 15 - 60 m | 16 days | Regional, Local |
| SPOT- 4 / 5 | HRVIR / HRG [17] | 10 – 20 m | 26 days | Regional, Local |
| Terra | ASTER[18] | 15 – 90 m | On demand | Local |
| EO-1 | ALI [19] | 10 – 30 m | 16 days | Local |
| | Radar | | Orbit overpass[20] | |
| ERS-2 [21] | SAR (C-band) | 30 m | 35 days | Regional |
| Envisat | ASAR[22] (C-band) | 30 m | 35 days | Regional |
| ALOS [23] | PALSAR [24] | 7 – 88 m | 46 days | Regional |
| RADARSAT | SAR (C and X-band) | 25 m | 24 days | Regional |

[5] For CARPE purposes, regional corresponds to the entire Congo Basin and local corresponds to the CBFP landscape level.
[6] National Oceanic and Atmospheric Administration satellite series
[7] Advanced Very High Resolution Radiometer – The primary purpose for this sensor is meteorological.
[8] Normalized Difference Vegetation Index
[9] *Satellites Pour l'Observation de la Terre* satellite series
[10] Moderate Resolution Imaging Spectrometer
[11] Medium Resolution Imaging Spectrometer
[12] China Brazil Earth Resources satellite
[13] CCD High Resolution, Infrared Multi-Spectral Scanner, Wide Field Imager
[14] Indian Remote Sensing Resource-1 satellite
[15] Linear Imaging Self Scanner, Advanced Wide Field Sensor
[16] Thematic Mapper / Ehanced Thematic Mapper
[17] High Resolution Visible and Infrared, High Resolution Geometric
[18] Advanced Spaceborne Thermal Emission and Reflection Radiometer
[19] Advanced Land Imager
[20] Revisit frequency depends on mode and incidence angle.
[21] European Remote Sensing satellite
[22] Advanced Synthetic Aperture Radar
[23] Advanced Land Observing Satellite
[24] Phased Array type L-band Synthetic Aperture Radar

Appendix II.

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