Case study 3 - The Use of Satellite Mapping and GIS to Support Large Scale Conservation : Lessons Learned from the Carpe Program

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Introduction

Establishing a reliable baseline of forest extent and monitoring forest cover change across the Congo Basin is critical to evaluating the progress of CARPE towards meeting its strategic objective of reducing the rate of forest degradation and loss of biodiversity. Satellite-derived maps and geographical information systems (GIS) provide spatial information and analytical tools essential for large-scale conservation planning and effective monitoring of Congo Basin forests. Analytical tools, such as GIS, help conservation planners integrate geospatial data on land cover, population centres and ecology to inform planning and policy decisions. Remote sensing (RS) 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 Food and Agriculture Organization of The United Nations (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, nor can they at present provide rates of forest cover change. 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 subregional scales or evaluating the effect of specific programmes in reducing the rate of deforestation within the Congo Basin Forest Partnership (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 use geospatial data. The geospatial datasets produced under CARPE have broader applications beyond the programme'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.

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, compared to labour-intensive field data collection, low 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 capture 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 m) to coarse (1 km) spatial resolution data with daily/frequent global coverage, e.g., AVHRR, MODIS, SPOT VEGETATION; and high (15–30 m) spatial resolution data, e.g., Landsat and SPOT HRVIR, with repeat cycles of 2–3 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 spatial 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 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 Satellite (TREES), was undertaken by the European Commission Joint Research Centre (JRC) and the European Space Agency (ESA) in support of the International Geosphere-Biosphere Programme (IGBP). That project produced a 1:5,000,000 vegetation map of Central Africa from 1 km (Local Area Coverage) and 5 km (Global Area Coverage) AVHRR data acquired in

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

A. SPOT VEGETATION (1 km) **B.** MODIS (250 m) **C.** Landsat (30 m)

Figure 1. Examples of satellite data used for vegetation mapping at different spatial resolutions

1992 and 1993 (Mayaux et al., 1999). In support of CARPE, 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 (DRC) also based on SPOT VEGETATION data from the year 2000 (Vancutsem et al., 2004). A 300 m resolution global land cover map, (GlobCover 2005) derived from Envisat MERIS data, is being produced by ESA in partnership with UNEP, FAO, JRC, the European Environment Agency (EEA) and GOFC-GOLD (Global Observation of Forest and Land Cover Dynamics).

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 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 maps 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 m 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 State of the Forest 2006 (CBFP 2007).

Detection and mapping of the fine-scale forest cover changes that are characteristic of the Congo Basin require imagery with a spatial resolution of less than 100 m. The NASA Landsat Pathfinder Humid Tropical Deforestation Project was a collaborative effort by the University of Maryland (UMD), the University of New Hampshire, and the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center to map deforestation using Landsat data (30 m 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 labour-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 (Duveiller et al., 2008). The FAO has proposed using 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 of 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.

Recent Congo Basin forest cover and change mapping under CARPE: methods and results

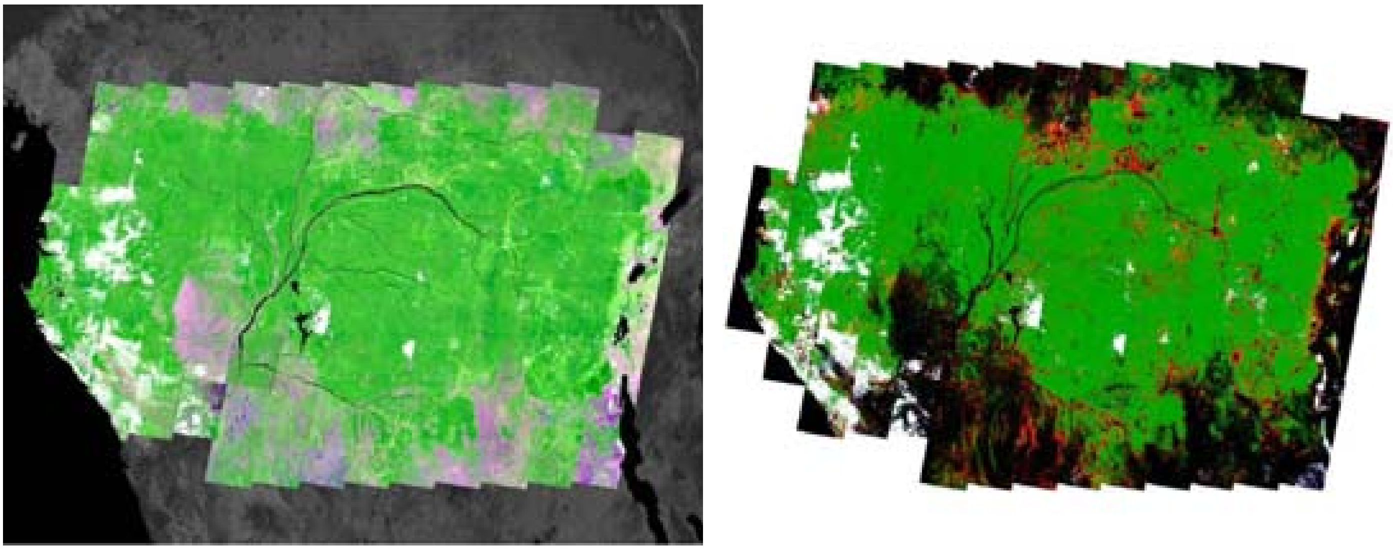
CARPE has supported the development of a sophisticated, innovative method to map forest cover and forest cover change exhaustively across the Basin which combines a consistent regional characterization of forest derived from MODIS data with spatially detailed forest cover and cover change derived from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

A 250 m resolution land cover map was produced from multi-temporal (2000–2004) MODIS data for the Congo Basin. The MODIS land cover map provides reference data to automatically derive land cover characterizations from Landsat imagery. Multiple Landsat acquisitions are included for each image tile 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 high resolution representation of forest cover change ever produced for this region.
kelihood value of greater than or equal to 50 percent. Forest cover change is determined by a specific DFCM algorithm. Where persistent cloud cover obscured the Landsat mosaic, MODIS forest cover data were used to augment the calculation of forest cover area and loss. The landscape boundaries available as of 5 September, 2008 were used for these calculations.

The consistent basin-wide characterization of forest cover and forest cover change permits the derivation of comparable statistics at regional,

[2] Forest likelihood is a measure of the probability, from 0–100%, that a given mapping unit, in this case a 57 m 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 or equal to 50 percent.

[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).



A. DFCM multi-spectral 1990s to 2000s Landsat composite image for the Congo Basin superimposed on a grey-scale MODIS image

B. Forested area of the Congo Basin derived from Landsat imagery using the DFCM process (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.

Figure 2. Forest cover and forest cover change in the Congo Basin (1990s–2000)

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 DRC between 1990 and 2000, nearly 98 percent of all forest change took place within 2 km of a pre-existing forest clearing and approximately 50 percent 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 of expansion of the rural complex (the mosaic of settlements, fields and degraded forest which exists along the road networks) into the forest.

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

Figure 3. Examples of forest cover loss from circa 1990 to circa 2000, shown in red, overlaid on a multi-spectral Landsat composite from the same time period

CBFP Landscape	Landscape area (km^2)	1990 Forest cover (km^2)	2000 Forest cover (km^2)	1990–2000 Forest cover loss (%)	2005 Forest cover (km^2)	2000–2005 Forest cover coss (%)
Monte Alén-Monts de Cristal	26,725	26,229	26,101	0.49	NA	NA
Gamba-Mayumba-Conkouati	46,549	29,153	28,709	1.52	NA	NA
Lopé-Chaillu-Louesse	34,925	33,845	33,647	0.59	NA	NA
Dja-Odzala-Minkébé Tri-National (TRIDOM)	192,403	186,065	185,729	0.18	NA	NA
Sangha Tri-National (TNS)	44,134	42,820	42,743	0.18	42,607	0.32
Léconi-Batéké-Léfini	36,077	7,073	6,968	1.48	NA	NA
Lac Télé-Lac Tumba	131,292	100,285	99,366	0.92	99,177	0.19
Salonga-Lukenie-Sankuru	104,670	101,570	101,198	0.37	100,034	0.26
Maringa–Lopori-Wamba (MLW)	72,693	68,756	68,162	0.86	67,938	0.33
Maiko-Tayna-Kahuzi-Biega	106,210	92,376	91,404	1.05	90,600	0.88
Ituri-Epulu-Aru	41,045	39,663	39,449	0.54	39,310	0.35
Virunga	17,465	3,480	3,279	5.79	3,143	4.14

Regional analysis of the DFCM data shows a 1.4 percent overall decrease in forest cover in the Congo Basin from the 1990s to the 2000s. This corresponds to a loss of 25,720 km2 of an original forested extent of 1.8 million km2 at a rate of 0.14 percent per year (Lindquist et al., in preparation). This estimate is smaller than but close 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 DRC, 19,575 km² of forest was converted from an original extent of 1.1 million km². This represents a 1.83 percent decrease in forest cover from the 1990s to the 2000s.

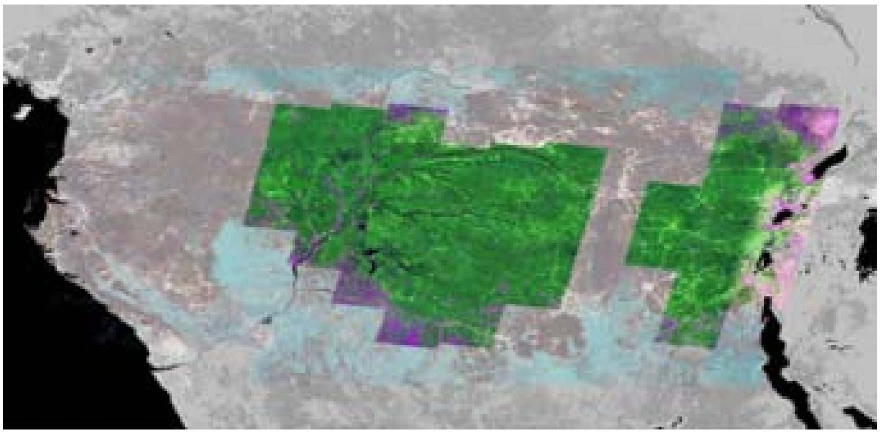
Table 2. Forest cover and forest loss between circa 1990 and circa 2000 inside and outside protected areas in the Democratic Republic of Congo

Forested region	1990 forest cover (km2)	2000 forest cover (km2)	Forest cover loss (km2)	Forest cover loss (%)
DRC	1,110,092	1,090,517	19,575	1.83
Inside protected areas	147,004	146,006	998	0.68
Outside protected areas	941,088	920,418	20,670	2.20

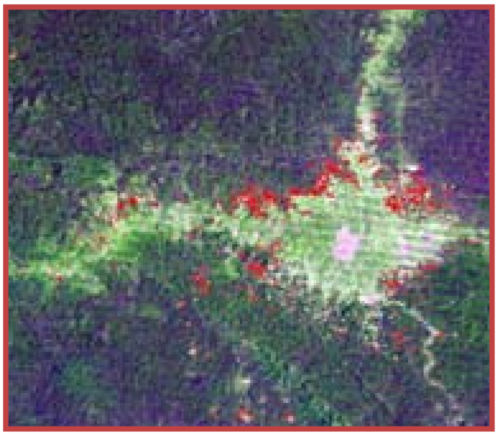
Mid-decadal Landsat composites and change detection

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 2000–2005 from recent Landsat imagery, despite the Scan Line Corrector (SLC) failure of the ETM+ sensor which causes significant gaps in the data rendering about 22 percent of each image unuseable. 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 2000–2005 epoch.

Mid-decadal Landsat mosaics have been completed for over 60 percent of the Basin and seven of the 12 CBFP Landscapes. Landsat image tiles for which multiple acquisitions are available produce more consistent results (e.g., free of scan gaps and scan line artifacts) than tiles without such data richness. Figure 4 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.



A. DFCM multi-spectral 2005 Landsat composite for image tiles 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).

Figure 4. Mid-decadal forest cover map for the Congo Basin with an example of forest cover change

Additional forest characterizations – degraded and flooded forest

Distinguishing degraded (secondary) forest from mature (primary) forest is important 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 non-forest 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 modelling 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 m.

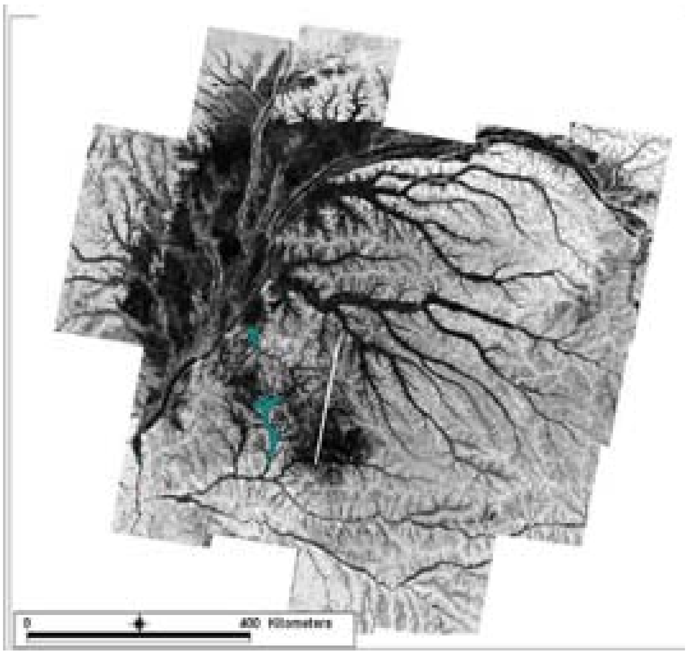


Figure 5. Preliminary wetland mask for the central Congo Basin
Key : Dark values indicate high likelihood of wetland occurrence, bright values are low likelihood. Lakes Tumba and Mai Ndombe are overlain.

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 modelling. They will also help to meet the goals of international monitoring programmes, such as the United Nations Framework Convention on Climate Change (UNFCCC) Reducing Emissions from Deforestation and Degradation (REDD) initiative.

Remote sensing data access

The success of RS-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 suggest 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 United States Geological Survey (USGS) Land Processes Distributed Active Archive Center, and the National Oceanic and Atmospheric Administration (NOAA) AVHRR-derived Normalized Difference Vegetation Index (NDVI) is freely available via the Global Land Cover Facility. SPOT VEGETATION data that have been archived for three 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 workhorses 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) initiated two limited Landsat 5 data acquisition campaigns which included part of the Congo Basin in 2008, 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 SLC failed. As a result, there are linear gaps in the images which cause a 22 percent 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 launched in 2011.

Until very recently, Landsat data have not been generically free, and pricing and distribution policies have varied over the duration of the programme. 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. These data sets are being reprocessed, with improved geometric and topographic inputs, under the USGS GLS project. In addition, the MDGLS is producing another global orthorectified Landsat dataset, the Global Land Survey 2005 (GLS 2005), from Landsat 7 and Landsat 5 data. Both the GLS 2000 and the GLS 2005 datasets for Africa are freely available for download from the USGS Glovis website (http://glovis.usgs.gov) as of March 2008. As of December 2008, the USGS is providing Landsat 7 archival data (both SLC-off and SLC-on) and Landsat 4 and 5 archival data at no charge through the Glovis website. New Landsat 7 and Landsat 5 images are also made available shortly after they are acquired This is a significant positive development for forest cover monitoring under the CARPE programme.

Cloud cover will always be an issue for the Congo Basin, and full access to the entire Landsat archive will greatly facilitate the production of a mid-decadal forest change map for Central Africa. Other optical data can supplement the Landsat data. Advanced Spaceborne Thermal Emission and Reflection Radiometer (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 HRVIR provide data that are suitable for forest mapping but the data are currently prohibitively expensive. IRS data at 50 m also offers the added advantage of obtaining several acquisitions per month. China and Brazil announced in November 2007 that they would make China Brazil Earth Resources Satellite (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 (Phased Array type L-band Synthetic Aperture Radar or PALSAR) is on board the Japanese Advanced Land Observing 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.

GIS and CARPE

The integration of remote sensing products with other geospatial data using 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 datasets
- UNEP-WCMC (World Conservation Monitoring Centre) and IUCN (International Union for Conservation of Nature) World Database on Protected Areas
- UN FAO Africover
- UCL maps of the 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 metadata, 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 afterthought 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

Key datasets 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.

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 MOV (means of verification) documents.

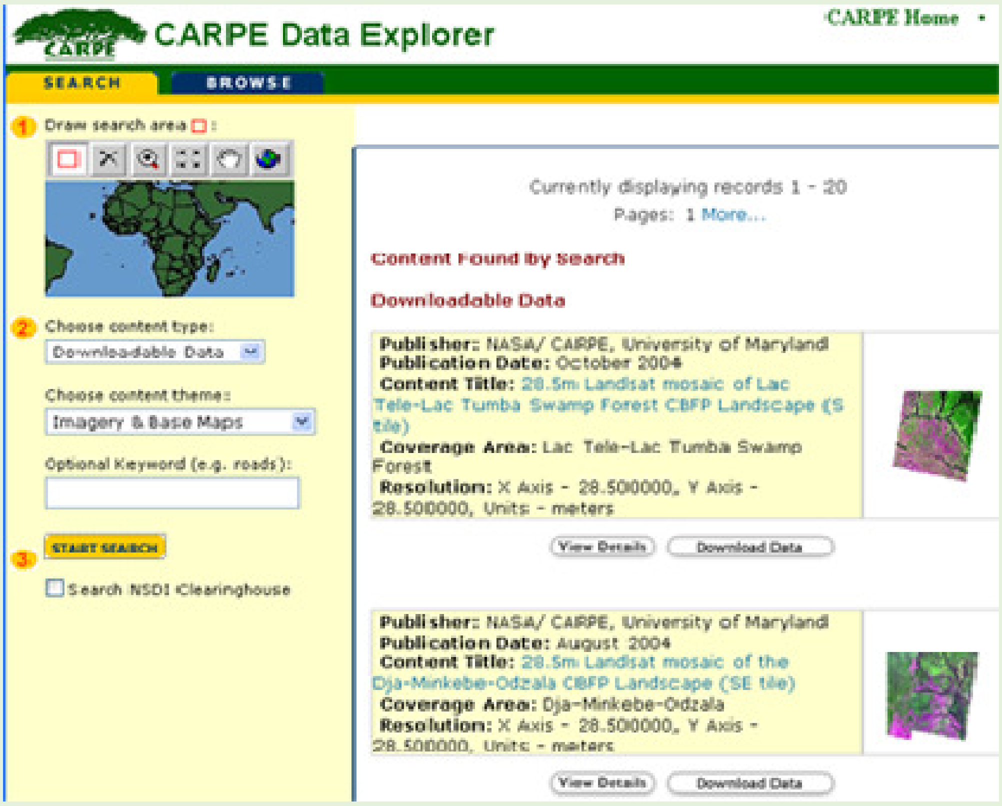
GIS integrates RS data and results with other geospatial datasets, which is critical for CARPE monitoring and reporting. Using GIS it is possible to analyze changes in forest cover by, for example, landscape, protected area, administrative area, watershed or distance from roads. An examination of the 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 bird's-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 provided focal points for discussion. An example of such a map produced for CARPE is shown in Figure 6.

Spatial modelling 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 modelling used in land-use planning for a CBFP landscape is

BOX 2. CARPE DATA EXPLORER

CARPE Data Explorer is a customized version of ESRI's ArcIMS (Arc Internet Map Server) Metadata Explorer. Geospatial data and mapping services are organized to enable map-based or keyword searches for geospatial data. These data can be viewed and downloaded 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.



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presented in Box 4.

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 CARPE Phase II, 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 producing this information efficiently and on a regular basis, but no critical mass of experts in this field existed in the Congo Basin. Capacity was limited to several individuals

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, UMD, in partnership with the African Wildlife Foundation (AWF), 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 MLW landscape, located in northern Democratic Republic of Congo. Modelled 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 DFCM satellite-derived forest change products have been used to predict land cover change in the landscape over the course of the next 50 years. To contribute directly to land-use zoning initiatives, the team will use a spatially-explicit site selection modelling tool to identify areas most suitable for future human expansion, taking into account conservation and human needs.

and site-specific projects scattered across the region and no appropriate infrastructure existed to support a regional initiative on forest mapping.
In 2000, stakeholders concerned with using spatial data in forest management met in Libreville, Gabon for a GOFC-GOLD Central Africa regional workshop, co-sponsored by TREES, NASA (through the Global Change SysTem for Analysis, Research and Training initiative, START), and USAID-CARPE. A panel of the Global Terrestrial Observing System, GOFC-GOLD 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 2000 GOFC-GOLD workshop was to create a Central African GOFC-GOLD chapter that would link national agencies and the user community with producers of this information.

Participants of the workshop agreed that the network would be coordinated from Kinshasa, and that it 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 17 September 2005, OSFAC was granted authorization to function in the DRC by the Ministry of Justice and on 6 February 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 began, 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 UMD 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 (SDSU) and UMD. UMD has maintained a full-time technical consultant for OSFAC in the DRC since 2005. OSFAC has also established a close relationship with the national university system in the 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 programmes to develop scientific expertise and introduce new satellite and information technology to OSFAC staff.

In 2005, OSFAC began offering basic and more advanced training courses to outside agencies (see Box 5). Over 400 individuals (see Table 3) have participated in technical courses in GIS and RS at the OSFAC lab and ex-situ sites in the DRC, Gabon and the Republic of Congo. Courses typically last 1–4 weeks and are designed to increase capacity in GIS software such as ArcView, ArcGIS and/or the RS image-processing software, ENVI. 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 programme. This programme incorporates both professional and academic degree-seeking interns who work with the OSFAC staff for up to 12 months.

OSFAC's programme to build higher-level capacity continues to evolve. 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. Since 2005, OSFAC has successfully promoted the studies of three students from the region in doctoral programmes in the US and Europe. OSFAC is also working to establish a pool of regional experts capable of generating functional products for decision makers and managers, using 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 programme in the DRC.

Currently OSFAC's capacity for GIS is high and it 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

BOX 5. INSTITUTIONS AND PROTECTED AREAS THAT HAVE RECEIVED TECHNICAL TRAINING FROM OSFAC

- AWF
- 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)
- 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 (Faculté d'agronomie)
- Garamba National Park, DRC
- ICCN (Institut Congolaise pour la conservation de la nature)
- IPS (Inspection provincial de la santé)
- 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 forêts)
- SNR/MECNEF (Service national de reboisement)
- MECNT (Ministère de l'environnement, conservation de la nature et tourisme)
- MEFE (Ministère de l'économie forestière et l'environnement, République du Congo)
- MINEF (Ministère de l'économie 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
- WRI
- WWF (World Wildlife Fund)

OSFAC to prioritize conservation areas in the DRC. Throughout the workshop, OSFAC provided technical support to create maps of priority areas.
- An initiative by the United Nations Educational, Scientific and Cultural Organization (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 World Bank PRO-ROUTES project.
- Partnering with WWF and WCS for a month-long field and lab-based GIS training centred on inventorying and mapping the Bombo Lumene Hunting Zone.
- A project to produce posters of all the RAPAC (Réseau des Aires Protégées d'Afrique Centrale) sites.
- Projects to map the Kisantu and Kinshasa Botanical Gardens.
- An inter-university project to map erosion in Kinshasa.
- A CTB 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 (Environmental Information Systems)-Africa. The initiative aims to create a catalogue of available fundamental geospatial datasets and do a country gap analysis. Within the DRC, OSFAC is an active member of 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 on 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 Observatory for the Forests of Central Africa (OFAC).

Table 3. Total number of individuals trained by OSFAC (June 2005–February 2008)

	Men	Women	TOTAL
Trainees	383	60	403
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

Lessons learned in the use of satellite mapping and GIS

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

Reaching a consensus on rates of forest cover change across the Congo Basin amongst different practitioners requires good communication. 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 the Central African Forest Commission[4] 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 RS 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 programmes.

There is an urgent need in the Congo Basin to transfer 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. Transferring 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 programme.

One of OSFAC's primary goals is to work with national forest monitoring agencies to use 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 use of satellite data and support the development of sustainable forest monitoring systems in the Congo Basin Region.

Long-term forest cover monitoring requires insti-

[4] The Commission des Forêts d'Afrique Centrale (COMIFAC), which consists of the forestry ministers of participating Central African countries, coordinates decisions, actions and initiatives pertaining to the conservation and sustainable management of the Congo Basin forests.

tutional 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-used 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[5].

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 RS 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 CBFP and to the State of the Forest reports in particular. The data, products and results need to be made available to CARPE partners, and to the wider community, in a timely manner.

The regional dissemination of RS 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 RS data, there is a need to ensure that geospatial data is shared among CARPE partners. There should be a routine transfer of satellite data to OSFAC and a systematic review of RS 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 RS 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 programmes, such as the UNFCCC's REDD initiative.

Map products in poster form are an effective means of communicating CARPE objectives and results. In particular, the maps based on RS image composites are useful for informing stakeholders, 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

[5] The NASA/USGS Landsat data distribution policy ensures that data products are available at no more than the cost of fulfilling user requests (COSUR), 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 programmes.

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 centres 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 Central Africa. Through CARPE, OSFAC has developed and maintained an active relationship with both UMD and SDSU in the USA. 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 RS 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 programmes.

Simultaneously, OSFAC has benefited by maintaining a close relationship with UNIKIN 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. Additional centres of excellence are necessary to meet the demand for high technical skills.

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

Since its inception, OSFAC has benefited 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 percent of OSFAC's operating costs. The aim is to increase this percentage but it is acknowledged that if OSFAC is to have a role in regional forest monitoring, it will continue to require additional sources of support, either through donor agencies or through a commitment from national agencies.

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Appendix I.

Acronyms

ALOS – Advanced Land Observing Satellite
ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR – Advanced Very High Resolution Radiometer
AWF – African Wildlife Foundation
CAMP – ESA/EC Central Africa Mosaic Project
CARPE – Central African Regional Program for the Environment
CBERS – China Brazil Earth Resources Satellite
CBFP – Congo Basin Forest Partnership
CTB – Coopération Technique Belge
DFCM – Decadal Forest Change Mapping
DRC – Democratic Republic of Congo
EC – European Commission
EEA – European Environment Agency
ERAIFT – Ecole régionale d’aménagement intègre des forêts tropicales
ERS – European Remote Sensing satellites
ESA – European Space Agency
ESRI – Environmental Systems Research Institute
ETM – Enhanced Thematic Mapper
FAO –Food and Agriculture Organization of The United Nations
FRA – FAO Forest Resource Assessment
GIS –Geographical Information System
GLC – Global Land Cover
GOFC-GOLD – Global Observation of Forest and Land Cover Dynamics
GRFM – Global Rain Forest Mapping
HRVIR – High Resolution Visible and Infrared
ICCN – Institut Congolaise pour la conservation de la nature
IGBP – International Geosphere-Biosphere Programme
IRS – Indian Remote Sensing Resource-1 Satellite
JRC – European Commission Joint Research Centre
MDGLS – NASA/USGS Mid-Decadal Global Land Survey
MERIS – Medium Resolution Imaging Spectrometer
MODIS – Moderate Resolution Imaging Spectrometer
NASA – National Aeronautics and Space Administration
NDVI – Normalized Difference Vegetation Index
NOAA – National Oceanic and Atmospheric Administration (USA)
OSFAC – Observatoire Satellital des Forêts d’Afrique Centrale
PALSAR – Phased Array type L-band Synthetic Aperture Radar
RED – Reducing Emissions from Deforestation and Degradation
RS – Remote Sensing
SAR – Synthetic Aperture Radar
SDSU – South Dakota State University (USA)
SLC – Scan Line Corrector

SPOT – Satellites Pour l'Observation de la Terre satellite series
TREES – Tropical REsources and Environment monitoring by Satellite
UCL – Université Catholique de Louvain (Belgium)
UMD – University of Maryland (USA)
UNEP – United Nations Environment Programme
UNFCCC – United Nations Framework Convention on Climate Change
UNIKIN – University of Kinshasa
USAID – United States Agency for International Development
USGS – United States Geological Survey
WCS – Wildlife Conservation Society
WRI – World Resources Institute
WWF – World Wildlife Fund

Earth Observing Satellites with Vegetation Mapping Applications

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

[6] For CARPE purposes, regional corresponds to the entire Congo Basin and local corresponds to the CBFP Landscape level.
[7] The primary purpose for this sensor is meteorological.
[8] High Resolution Charge-coupled Device (CCD) camera, Infrared Multi-Spectral Scanner, Wide Field Imager
[9] Linear Imaging Self Scanner, Advanced Wide Field Sensor
[10] Thematic Mapper/Enhanced Thematic Mapper
[11] High Resolution Geometric
[12] Advanced Land Imager
[13] Revisit frequency depends on mode and incidence angle.
[14] Advanced Synthetic Aperture Radar