Intermediate report on Work Package 3: A detailed work plan for remotely-sensed forest degradation assessment in Congo and Gabon

REDDiness

Support C-Africa in EO driven forest monitoring for REDD

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1 Introduction

International agreements on Reducing Emissions from Deforestation, and forest Degradation (REDD+) aim at reducing deforestation, reducing degradation, forest enhancement, sustainable forest management, and forest conservation. National forest monitoring systems are needed that accurately measure, report and verify (MRV) carbon stocks, sinks and emissions. Up-to-date earth observation (EO) techniques are an essential input to such MRV systems. Countries aiming to participate in REDD+ negotiations and receive REDD+ benefits must develop methods for forest cover monitoring. REDDiness aims to support development of regionally-relevant EO techniques and to transfer expertise in forest monitoring. EO monitoring techniques are required that take into account the specific REDD+ and Central African contexts. This report illustrates the direction that REDDiness has defined to contribute to this specific context. Based on a contextual and scientific state-of-the-art analysis carried out in the initial phase of the project (WP2), REDDiness aims to assist Gabon and the Republic of Congo in developing EO forest monitoring services (WP3) and building national capacity (WP4).

Section 2 of this report summarizes the results of the analysis of current EO REDD+ projects active in Congo and Gabon. In addition the section provides results of an extensive survey carried out in both countries with regard to current capacities and perceived priorities for MRV (WP2). This section provides the justification for the current work plan of WP3. The survey aimed to identify which EO products are considered of highest importance by local institutions. These include the monitoring of forest change (deforestation and degradation) and the estimation of carbon stocks. A contextual analysis revealed that other national and regional initiatives and projects are active on forest change monitoring and carbon stock estimation. Hence, together with all partners, scientific experts, and agreed to by the European Commission, REDDiness has decided to focus on forest degradation monitoring using remote sensing data. This focus is challenging given the small spatial size of expected changes and the persistent cloud cover in Gabon and Congo. In addition no generally agreed definition of forest degradation exists, and REDDiness will still need to establish a working definition with relevance for the analysis of EO data.

As indicated above, WP2 was of prime importance for setting the scene for WP3 and defined the work programme for WP3. As WP2 suffered some delays, WP3 as a consequence started later as well. The main focus of this intermediate report is to give a detailed account of the choices made for WP3 (section 2), show how study sites were selected (section 3), give an overview of remote sensing archive data for both sites and indicate what is planned as new acquisitions (section 4), give a broad overview of the methods we intend to apply in WP3 (section 5), and present the final work plan as agreed by all project partners (section 6).

2 Thematic focus

The REDDiness user requirements analysis followed two approaches: (i) a literature and contextual review of REDD+ MRV methods, projects and initiatives in Central Africa, and (ii) a quantitative survey carried out through a questionnaire. These two approaches are separately described in sections 2.1 and 2.2. In addition, section 2.3 presents the results of the REDDiness progress meeting, which took place in Kinshasa in October 2011. At this meeting, participants (partners and scientific advisors) reviewed items (i) and (ii) to decide on the focus for REDDiness regarding the specific EO monitoring and capacity building objectives. Section 2.3 provides also the overview of the proposed scope for WP3.

2.1 Outcomes WP2: other REDD+ related initiatives and projects in the Congo Basin

Before performing the user requirements analysis, an analysis of international and regional agreements, actors and ongoing projects in relation to REDD was performed to identify potentially relevant interactions for REDDiness. This analysis refers specifically to the current status of negotiations, actors and pilot projects in the two countries covered by REDDiness (Congo and Gabon). The existing methods, data and projects which can be related to REDDiness are described in a number of reports recently delivered to the EC Research Executive Agency (REA). After approval by the EC administration, these reports will be publicly available on REDDiness website (www.reddiness.eu).

Table 1 below summarizes the projects or programs which participate directly or indirectly to the definition of national REDD strategies. It highlights design and implementation projects which monitor land use changes as requested by MRV systems. The definition of REDD strategies is the responsibility of countries but they receive technical assistance through the Forest Carbon Partnership Facility (FCPF: Table 1c).

REDDiness aims to operate in close collaboration and synergy with existing or planned initiatives. Our contextual analysis indicated that two first pilot projects exist in Congo, which are led by the Congolese National REDD Coordination in collaboration with the German GAF and with the World Resources Institute (WRI)[1]. These projects develop EO systems for two essential REDD products i.e. (i) forest change estimation (rate of deforestation and degradation) and (ii) biomass estimation. The two projects started before REDDiness with higher budget envelopes but similar objectives. The collaboration with the WRI project is guaranteed by the presence of its coordinator in the REDDiness advisory board. The link with the GAF project is supported by the participation of IRD in both consortiums. Moreover, the Congolese CN-REDD who is responsible for coordinating all REDD initiatives in the Republic of Congo is the local partner of REDDiness (CNIAF). REDDiness aims to reinforce the ongoing REDD activities in the countries by avoiding duplication.

[1] Coordination National REDD, 2011. Proposition pour la Préparation à la REDD+ (RPP) République du Congo

Table 1: National and regional initiatives in forest monitoring and Carbon emissions

(a) Regional Initiatives

Project	Leader	Partners	Funder	Duration	Synergy	Coverage
CEOFAC (ex-FORAF)	CIRAD	CIFOR, FRM, JRC, UCL	EU	Phase 2 2011-2013	Capacity building, Data access, experience sharing	Countries of COMIFAC
CoForChange	CIRAD	CNRS, FRM, IRD, JRC, ABDN, FSUAGx, Oxford University, IRET, MNRST, Université de Bangui, Université Yaounde 1, Universié Marien Ngouabi and private companies	ANR, NERS	2009-2012	Research on forest dynamics & capacity building	Congo, Cameroun, Gabon, CAR
FACET	UMD	UMD, NASA, OSFAC	CARPE (USAID)		Forest monitoring and capacity building	DRC, Congo
FRA 2010 / TREES 3	FAO/JRC	UCL	FAO/JRC		Forest monitoring and capacity building	Tropics
UN-REDD	FAO, PNUD, PNUE					RDC, Congo
Projet regional de renforcement de capacités REDD	BM		GEF	2011-2013	Capacity building, research network	COMIFAC

(b) National initiatives

Project	Leader	Partners	Funder	Duration	Synergy	Coverage
GSE-FM Cameroon	GAF	MINFOF, MINEP, KfW, ESA, GTZ-COMIFAC	ESA	2007-2010	forest monitoring and capacity building	Cameroun
GSE-FM Congo and gabon	GAF	SIRS, Cemagref, IRD, JR, AGEOS-Tech, Gabon, MDDEFE-RoC	ESA	2009-2012	forest monitoring and capacity building	Congo, Gabon
REDD Alert	MLURI	UCL, VU, UGOE, ICRAF, CIFOR, IITA, CIAT, IRAD			forest monitoring	Cameroun
Quantifying carbon stock in Congo	WRI	SDSU, Winrock, IMAZON, OSFAC, CNIAF	CBFF	2010-2013	forest monitoring and capacity building	Congo
CANOPY	IRD/AMAP	FRM			forest dynamics supported with VHR data	Cameroun
REDDiness	Eurosense	ITC, IRD, MEF (Gabon), CNIAF (Congo)	UE	2011-2013	forest monitoring and capacity building	Congo, Gabon
REDDAF	GAF	University of Bangui, GTG-Cameroon, Joanneum Research, Cesbio, Mesa-Consult, SIRS	UE	2010-2012	forest monitoring and capacity building	Cameroun, RCA
SEAS Gabon	AGEOS	IRD, INPE	Gabon	2010-2012	Data access and sharing, forest monitoring and capacity building	Gabon, with regional dimension

(c) CBFF projects

Project	Leader	Partners	Funder	Duration	Synergy	Coverage
Development of National MRV Systems with a Regional approach for the Congo Basin countries	FAO	INPE Points focaux Climat et administration en charge des forêts/environnement	CBFF	3 years	MRV system and capacity building	COMIFAC
Inventaire forestier multi ressources en vue de l'élaboration du plan d'affectation des terres	CNIAF		CBFF	30 months	Mapping, data collection and geo- processing	Congo
Elaboration du plan d'affectation des terres et inventaire multi ressources des aires protégées prioritaires en vue de produire les plans d'aménagement	MEF		CBFF	3 years		Gabon

2.2 User requirements survey

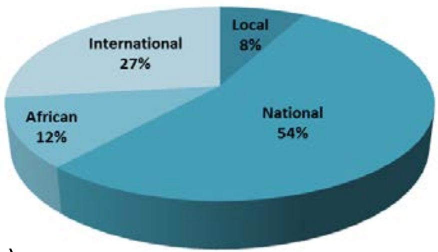
A quantitative survey was conducted in the framework of REDDiness with two main objectives: (i) to assess the level of knowledge regarding REDD and EO techniques of relevant stakeholders, (ii) to understand what local users perceive as their main needs in terms of MRV. This survey confirmed that the internal coordination for REDD and REDD-awareness are still at an initial stage in Congo and Gabon. Both countries have limited technical and human resources to develop a forest monitoring system meeting UNFCCC requirements. The set up of the survey and the main results are described in the following 4 sections: (i) questionnaire structure and survey implementation, (ii) presentation of participants, (iii) methodology used for analysis, and (iv) results.

2.2.1 Questionnaire structure

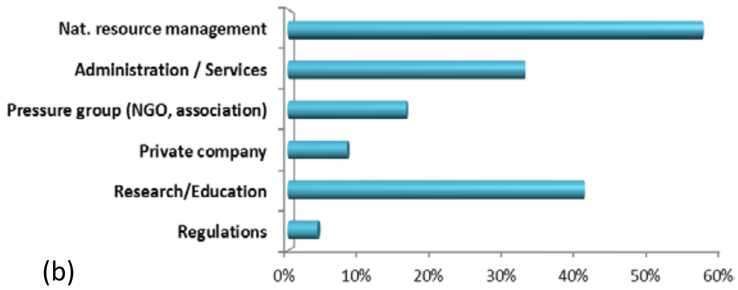
To analyze and compare stakeholder's responses in an objective way, REDDiness conducted a quantitative survey. In addition, the survey contained several open questions to gather general information about the survey participants and their involvement in REDD initiatives or projects. The questionnaire's body includes multiple choice questions about geomatics (data used, expertise, hard and software resources) and the participants' knowledge regarding the REDD mechanism (political and scientific knowledge, interesting products and definitions or parameters which are useful in setting up a MRV). A total of 26 surveys were received corresponding to a 59% response rate. The involvement of the local and regional project partners (CNIAF, MEF, OSFAC) was key in obtaining this satisfactory response rate.

2.2.2 Participant institutions

The majority of the responding institutions have a national status (54%) and to a lesser extent an international one (27%) (Figure 1a). They mainly represent research and administration (58%) in the fields of natural resource management, forestry or environment (Figure 1b). Only 32% of the institutes are involved in REDD projects and a mere 13% report having a good knowledge of the REDD process.



(a)



(b)

Figure 1: (a) Management level of the 26 institutions surveyed in REDDiness. (b) Domain of application.

In the REDD MRV context, the survey questions particularly focused on the types of spatial data and tools used by REDD stakeholders. Nearly all institutions (91%) produce and use thematic maps. A majority of participants make direct use of optical satellite imagery (70%) and aerial photographs (61%) while radar imagery (including satellite radar) is used only by 39%. LIDAR data acquired by satellite or airplane is relatively unknown (4 and 9%). The survey also provided information on existing software and technical expertise. ArcGIS / ArcView and MapInfo, the most well-known GIS/mapping software programs, are available in most institutions (87% and 65% respectively). Remote sensing software (e.g. ENVI and ERDAS Imagine) is available in only 26% of the institutions. Concerning technical expertise, most institutions are able to create geo-referenced databases (70%)

but less than 50% are able to perform basic image processing, such as unsupervised classifications (48%). Hence, although a large part of the organizations report a direct use of satellite imagery, in many cases software (and knowledge) for advanced analysis of these data seems unavailable.

The understanding of questions was unequal among participants. Unanswered or incomplete answers demonstrate a limited level of knowledge about REDD and MRV implementation. This confirms the need for capacity building on REDD/REDD+ and forest monitoring in the countries involved[2]. REDD projects have a role in strengthening the dissemination of information on the objectives and implementation of REDD, in Africa in general, and in the Congo Basin in particular.

2.2.3 Methodology

The number of questionnaires received (26) did not allow for a reliable statistical analysis. For the quantitative analysis, we selected the surveys containing the most comprehensive responses. These included the potentially relevant partners for REDDiness in the implementation of these MRV systems in Congo and Gabon. Three selection criteria were used (Figure 2) i.e. (i) knowledge of REDD, (ii) completeness of responses, (iii) consistency of responses evaluated by two sub-criteria, compliance with instructions and logical link between two specific responses. A threshold of 79% in the sum of these criteria identifies eight institutions, four per country, for which the quantitative responses on REDDiness products and data were analyzed in detail (Figure 2).

	REDD knowledge		Completeness *23 questions)*	Consistency		Total (%)	REDD project
	Pol. *(/5)*	Scient. *(/5)*		Compliance *(/2)*	Link *(/1)*		
Congo							
CNIAF Centre National d'Inventaire et Aménagement des Ressources Forestières - Fauniques	3	3	23	2	1	87%	OUI
OCDH Observatoire Congolais des Droits de l'Homme	5	4	22	1.5	0.5	79%	OUI
CERGEC Centre de Recherche Géographique et de Production Cartographique	3	4	23	1	1	85%	NON
CIB Congolaise Industrielle des Bois	2	3	23	2	1	87%	NON
CNIAF							
DG-Wood General Directorate of industries, timber trade and exploitation of forest products from the Ministry of Forestry (mapping service)	2	3	22	2	1	85%	OUI
DG-Aqua General Directorate of aquatic ecosystems of the Ministry of Forestry (mapping service)	3	3	23	2	1	87%	NON
IRET Institut de Recherche en Ecologie Tropicale	3	3	23	2	1	87%	NON
IRSH-CNDIO Institut de Recherche en Science humaine - Centre National de Données et d'Information Océanographique	4	5	23	2	0.5	92%	NON

Figure 2: Selection criteria and selected institutions.

For Congo, we selected four REDD actors, which include government body - CNIAF, Non-Governmental Organization - OCDH, research centre - CERGEC and private actor - CIB. For Gabon, this quantitative analysis includes two governmental services: DG-Aqua and DG-Wood and two research centres: IRSH –CNDIO and IRET. In addition to these institutions, our local partner in Gabon

[2] Herold, M., 2009. An assessment of national forest monitoring capabilities in tropical non-Annex I countries, Recommendations for capacity building, GOFC-GOLD Land Cover Project Office, Friedrich Schiller University Jena

(MEF) identified a number of other potential stakeholders, such as LAGRAC (Laboratoire de Graphique et Cartographie of geographic department of the University Omar Bongo) and DG Forests. For those, filled questionnaires were received but did not meet our selection criteria for the quantitative analysis.

2.2.4 Survey results

This survey assisted in defining needs of EO data and products to be developed in both countries. Regarding the perceived need in the framework of REDD monitoring, there is no clear consensus between the participants on EO data types to be used. However, most of them point out high-resolution satellite imagery (Landsat) as their first choice (5 out of 8). There was more consensus regarding the relevance of potential EO products to be developed (Figure 3): forest change estimation (rate of deforestation and degradation) and biomass estimation. Spatially-explicit forest degradation monitoring is seen as the third important element to be addressed by the national REDD strategy. The contextual analysis indicated that other projects such as the two first pilot projects led by the Congolese National REDD Coordination in collaboration with GAF and WRI (CN-REDD, 2011[3]) develop the first two products. To avoid overlap and increase significance of the project, REDDiness proposes to focus on EO techniques for the third product, i.e. spatially-explicit forest degradation monitoring.

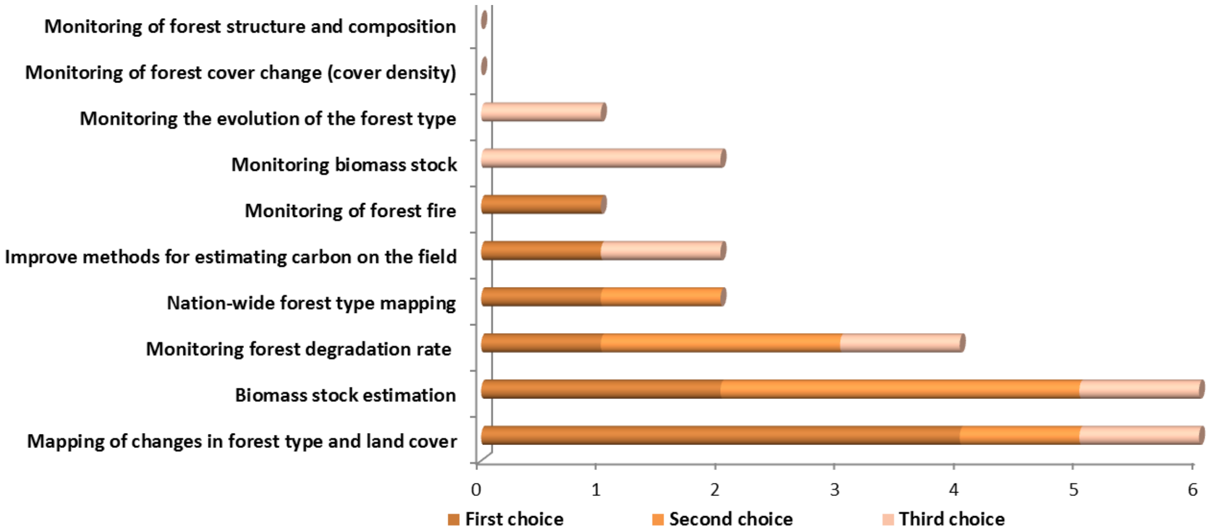


Figure 3: Order of importance in the three most useful products for REDD strategy and forest monitoring

2.3 Advise scientific experts and proposed scope of WP3

Many REDD issues still need to be addressed and EO techniques need to be tailored to local conditions before effective implementation of MRV systems in both countries. The user survey and the knowledge acquired on other projects in the region clearly pointed to a topical focus for REDDiness, i.e. forest degradation assessment and monitoring. This priority was reinforced during the project progress meeting that took place in Kinshasa in October 2011. At this occasion, project partners and scientific advisors discussed the results of the user requirements study and set directions for the way forward for REDDiness. A consensus was achieved between the participants on the main objective of the EO development part of REDDiness. To support the meeting decisions,

[3] Coordination National REDD, 2011. Proposition pour la Préparation à la REDD+ (RPP) République du Congo

several technical and methodological choices faced by REDD projects (or participating country) were identified, i.e. principal theme (deforestation/degradation/carbon), study zone and sampling, and the spatial and temporal resolution to be used. Figure 4 shows the different options that were discussed for REDDiness during the meeting. Several options in this figure are related: for example it was agreed that assessing forest degradation is impossible with low spatial resolution or infrequent observations, especially for the Congo Basin.

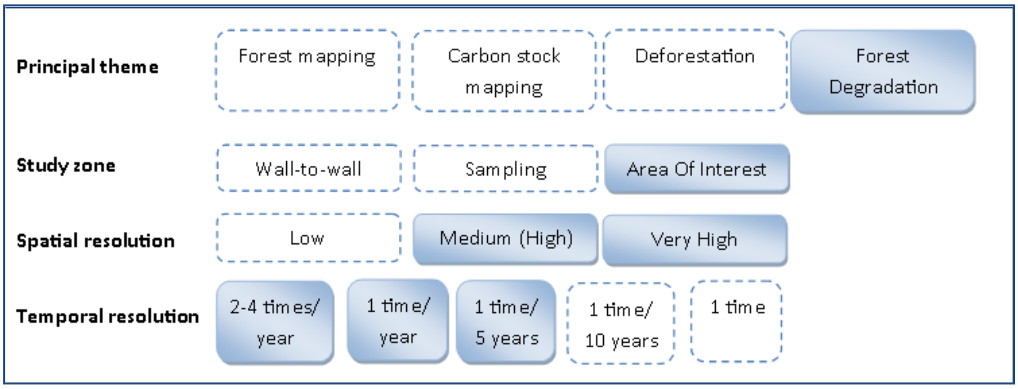


Figure 4: Selection of REDDiness focus by surveying 4 main questions within the consortium.

The agreed research and development objective for REDDiness is to evaluate the effectiveness of different types of satellite imagery in detecting and monitoring forest degradation. Such an evaluation is urgently needed given 1) the importance of forest degradation in REDD which is currently not addressed in detail especially in Central Africa, 2) the difficulty to assess forest degradation due to spatial size and pattern of the process - in the Congo Basin forest degradation is often characterized by small scale changes in forest cover-, 3) the limited time frame in which to detect degradation given the potential quick regeneration of vegetation, and 4) the frequent cloud cover in both countries limiting optical image acquisition. The defined priority objective is supported by the European Commission (EC). The EC requested to avoid overlap with other existing projects to optimally use EC resources. Because REDDiness is a research project, EC encourages the testing of new options and techniques regarding REDD+. The project intends to evaluate a variety of satellite image types, including optical and radar data of high (30m) to very high (<1m) resolution. Given the short duration of the project, existing archive data will be an essential element of the analysis, but a number of new acquisitions are essential and foreseen. The focus will be on two study areas of limited extent, one in Congo and one in Gabon. In addition based on current commercial costs and planned satellite missions, we intend to provide a future outlook of how forest degradation may be included in an MRV system for countries in the Congo Basin.

3 Study site selection

3.1 Forest sector and condition in Congo and Gabon[4]

3.1.1 Republic of Congo

Congo covers 342,815 km^2 and has an estimated population of 3.6 million, corresponding to a relatively low population density of 10.5 inhabitants per km^2. This population is mostly urban, with more than half of all Congolese living in the six largest cities. Population growth remains high, although in slight decline to 2.9% per annum. There are strong regional disparities, the forest area in the north being very sparsely populated with less than 1.5 persons/km^2 in the departments of Sangha and Likouala. This population is distributed along the main communication axes, leaving vast areas uninhabited. The forests in the south are more populated and there are more serious threats to resources: subsistence farming, hunting, intensive logging for many years without any management planning to date.

The forestry sector contributes significantly to the national economy, although in relative terms less than the period up to the early 1970s. In 1974, timber generated 85% of export earnings and accounted for 10% of GDP. The rise of oil has diminished the importance of the forestry sector. Production of timber and processed products represents the major part of the formal sector's contribution to the economy. In 2006 forestry products made up only 5.6% of the GDP. This figure masks the fundamental role played by the forest sector in terms of job creation and regional development in the most disadvantaged rural areas.

Forests occupy a prominent place in the Congo, with area estimates ranging from 22.4 million hectares (CNIAF, 2008) to 25.9 million hectares[5]. The most recent remote sensing based forest cover estimate is 18.5 million hectares[6]. The Congolese forest covers two thirds of the Congolese territory.

The estimated annual rate of deforestation is very low, with a net rate of 0.02%. Gross deforestation is a little higher, at 0.07% per year, but this is off-set by reforestation of 0.05%[7]. The deforestation rate is almost zero in the north of the country. Figures for the south are less known because of the lack of available satellite images, which can lead to an underestimation of national deforestation rates. Shifting cultivation is the main cause of deforestation. This can be observed on satellite images around the main cities (Brazzaville, Pointe-Noire, Nkayi, Dolisie, Ouesso) and along roads. Human activities such as logging, firewood harvesting and bush fires can cause forest degradation (a reduction in biomass) and potentially affect biodiversity, without having a major effect on the evolution of forest cover and without compromising forest sustainability. At present, mining and agro-industry have no marked impact on Congo's forests. But many mineral operations are currently underway (approximately 60,000 km^2 in 2005, 17.5% of the forest estate is designated for mining permits). These could result in future extraction of the identified deposits. A revival of agro-industrial activities is possible.

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[4] The Forests of the Congo Basin - State of the Forest 2008, Editors : de Wasseige C., Devers D., de Marcken P., Eba'a Atyi R., Nasi R. and Mayaux Ph., 2009, Luxembourg: Publications Office of the European Union

[5] Mayaux P., Bartholomé E., Massart M., Van Cutsem C., Cabral, A., Nonguierma A., Diallo O., Pretorius C., Thompson M., Cherlet M. et al., 2003. A Land Cover Map of Africa, Joint Research Centre, EUR 20665 EN (European Commission, Luxembourg).

[6] The Forests of the Congo Basin - State of the Forest 2008

[7] Duveiller G., Defourny P., Desclée B., Mayaux P., 2008. Deforestation in Central Africa: Estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts. Remote Sensing of Environment, 112 (5), pp. 1969-1981.

3.1.2 Republic of Gabon

Gabon covers 262,090 km^2. In 2005 Gabon was reported to have 1.3 million inhabitants giving an average population density of 5 inhabitants per km^2. For the period 2005 to 2010, the average rate of demographic growth was estimated at 1.48%. There is strong disparity between the rural environment, which is lightly populated and the urban zones, where most of the population is based (85 % of the total). Urban population is currently growing at a rate of 2.2%.

The rural zones are sparsely populated and traditional agriculture and agro-industry are under-developed. The population ratio per hectare of arable and cultivated land is 0.9. This figure is the lowest in Central Africa (with an average of 2.02 for the Congo Basin countries). Cropped areas represent about 5% of national surface area.

Gabon has dense forest covering some 21 million ha, more than 80% of the national territory. This coupled with low population density results in Gabon having the highest rate of forest surface per capita in Africa. Between 1990 and 2005, the recorded loss of forest surfaces remained very limited, 0.15 million hectare (less than 1%). Natural resource exploitation is the cornerstone of the Gabonese economy: oil, forests and mining make up half of the GDP. The oil sector alone accounts for 42.4% of GDP. The forest sector is in second place (6.0%) followed by mining (1.9%).

Gabon has a dense forest covering more than 80% of its surface area. Three main types of dense rain forest can be distinguished, coastal forests (0-300 m): 32.6%, intermediary forests (300-1000 m): 66.7%, and flooded forest and mangrove: 0.7%. The rest of the country is made up of forest-savannah mosaic, swampy zones and mangrove. Recent analysis of satellite data[8] estimated the change in forest cover over all countries in the Congo Basin region. In terms of deforestation rate, Gabon, the Republic of Congo and the Central African Republic, are among those countries where the deforestation dynamic is still relatively low with an annual rate of 0.09% for a regional average of 0.21% per year (± 0.05%). In the framework of the GSE Forest monitoring initiative, measured statistics on deforestation rate indicate even lower figures: the annual rate of deforestation for Gabon was estimated to 0.02% for the period 1990-2000, and 0,004% for the period 2000-2010[9]. As for the net rate of degradation of forest cover, Gabon has a rate of 0.08% for a regional average of 0.15% per year (± 0.03%). However, in the authors' view, a certain margin of interpretation should be maintained given the low volume of data available for the country.

3.2 Study site selection criteria

To evaluate the potential of different sensors to detect when and where forest degradation occurs, it was decided to select one site in each country: i.e. one in Congo and one in Gabon. Given the limited resources and timeframe of the project, and the small scale of the forest degradation process, this was agreed as the optimal solution by all partners. The two study sites are defined in a nested way: the broader area covers 40x40 km and will be analyzed with high resolution data (optical and radar). For very high resolution, partly for economic (quota) reasons we define within each site, two focal areas of 10x10 km. These focal areas will be studied in more detail using also very high resolution data. The 40x40 km regions were selected based on several criteria:

[8] Idem 7

[9] Sannier, C., Massard, E., Fichet, L.-V., Mertens, B., Huynh, F. 2011. Monitoring of forest cover change in the Republic of Gabon between 1990, 2000 and 2010 following IPCC guidelines, International Symposium on Remote Sensing of the Environement.

- The areas should not have been extensively studied by other projects and experience persistent cloud cover thus imposing a constraint on RS solutions (South of Congo, Gabon).
- Forest degradation should likely have occurred in the past 5 years, or is likely to occur in the coming 6 months according to information from local expert (local partners or references).
- The area should be accessible because this:
    - ➢ determines an external pressure (demand for fuel wood from the village, town, or near road) which can cause uncontrolled use of forest resources (and consequent degradation)
    - ➢ is needed for the validation fieldwork.
- A forest concession is present in part of the area (possible data availability on wood extraction).
- Otherwise data are available which relate to forest degradation (concessions, statistics from the ministry, studies performed).
- The areas have a limited terrain slope to facilitate radar analysis.
- At least a basic availability of optical very high resolution data (satellite or aerial photography).

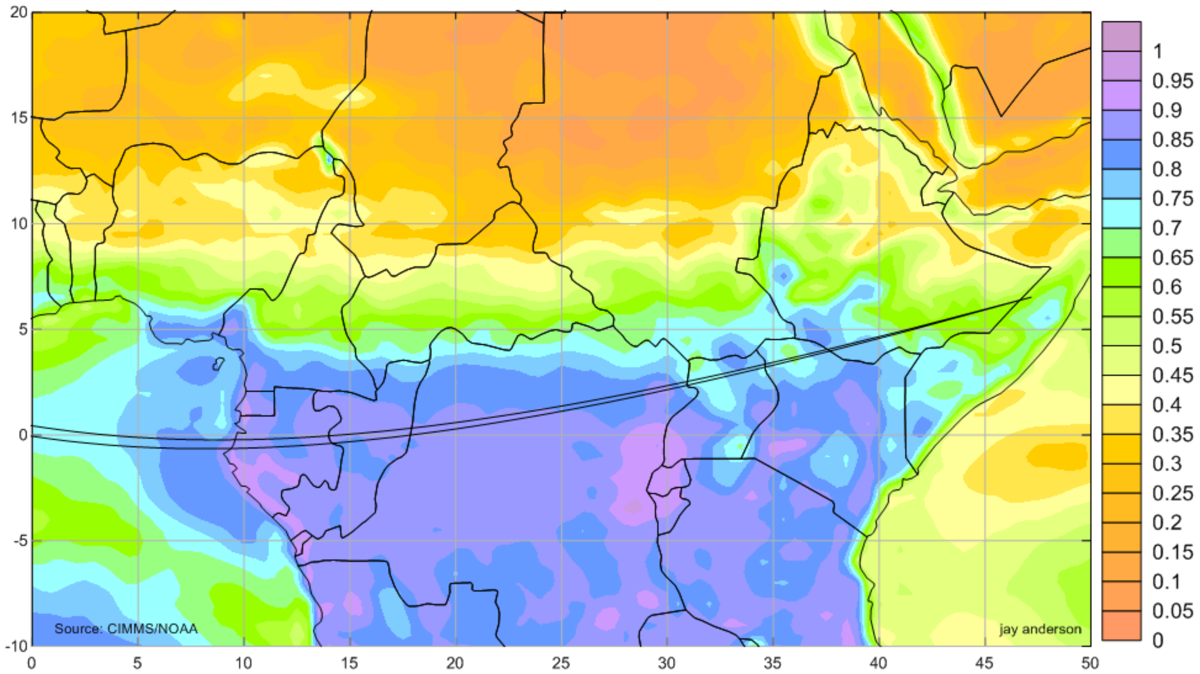

Figure 5: Average cloud cover in tenths across Africa, based on 24 years of satellite measurements. Data CIMMS/NOAA

3.3 Options and applying criteria

This section describes the process for the final selection of study sites in Congo and Gabon. The process took place in three stages:

1. Local partners proposed regions of interest where forest degradation is likely to occur.
2. Based on the criteria (see 3.2), we selected the best area in which we set the study site of 40x40 km.
3. Within the 40x40 km, two focal areas of 10x10 km were chosen according to the availability of archive VHR images (see 4.1).

3.3.1 Study site in Congo

Local partners identified three areas of forest degradation: Youbi, Ngoua, and the Saras (Figure 6). These are located in two departments, i.e. Kouilou and Niari. During the evaluation of these areas, local partners proposed two additional areas (Mila Mila forest and Mapati forest). However, this proposal came late when the selection procedure had already been largely performed. Moreover, the Youbi area met all selection criteria described in section 3.2 (see Table 2) and resulted already as the best candidate study site in Congo. We decided therefore not to extend our analysis to the additional proposed areas.

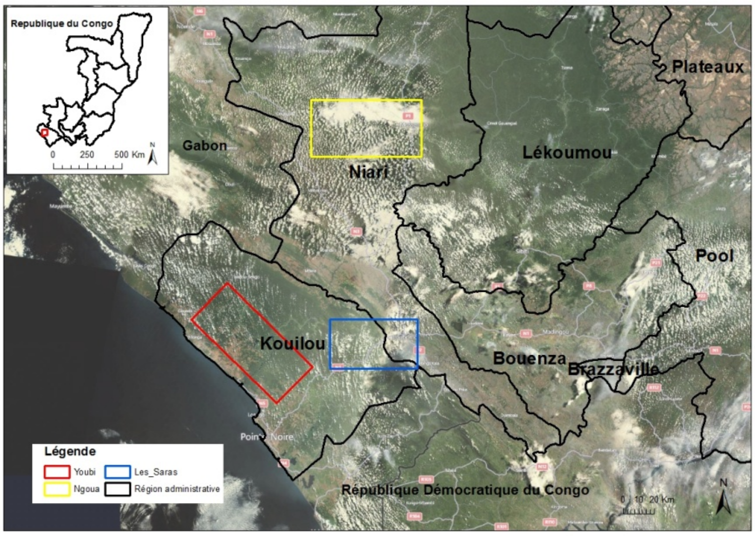

Figure 6: Location of three areas of forest degradation identified by local partners in Congo

Table 2: Applying the selection criteria to the Youbi area

#	Selection criteria (see 3.2)	Youbi	References
1	Frequent cloud cover	OK	Figure 5, Fabing et al., 2001[10].
2	Forest degradation	OK	Confirmed by local partner and several studies (Fabing et al., 2001[10]; Missamba-Lola, 2005[11]; Yembé Yembé, 2007[12]).
3	Accessibility	OK	Area near Youbi village and crossed by a national road (N6).
4	Forest concession	OK	Forest concession of Nanga (see Figure 7).
5	Degradation data	OK	Several studies on degradation were conducted in the region (see #2). Missamba-Lola gathered perceptions of local people on forest conditions in the villages Youbi and Koutou[11]. According to local partners, as the site belongs to the UFA Sud 2-Kayes (Unité forestière d'aménagement), statistical data should be available at the Ministry.
6	Limited slope	OK	
7	VHR data	OK	Aerial images of Winrock (2007) and Quickbird, Worldview (4.1).

[10] Fabing A., 2001 – Bilan spatial et structurel de l'antagonisme « Préssion Anthropique/Dynamique forestière naturelle» en zone de forte croissance urbaine. Le cas de Pointe Noire et de sa Région R. du Congo. Thèse d'université, Biogéographie. Faculté de Géographie, 46 Université de Strasbourg I. France, 321 p.

[11] Missamba-Lola, A.-P. 2004. Typologie et méthodes de réhabilitation des forêts secondaires et dégradées de Youbi (Région du Kouilou-Congo). Mémoire de maîtrise. Université Marien Ngouabi. Laboratoire de géographie physique. Biogéographie et restauration forestière. 68p.

[12] Yembé-Yembé, R. 2007. Étude de l'organisation de la filière bois-énergie en zones forestières au Congo : étude du cas des villages de la périphérie du parc national Conkouati Douli. Université Marien Ngouabi. IDR. 52p. in http://www.fao.org/docrep/013/i1973f/i1973f00.pdf

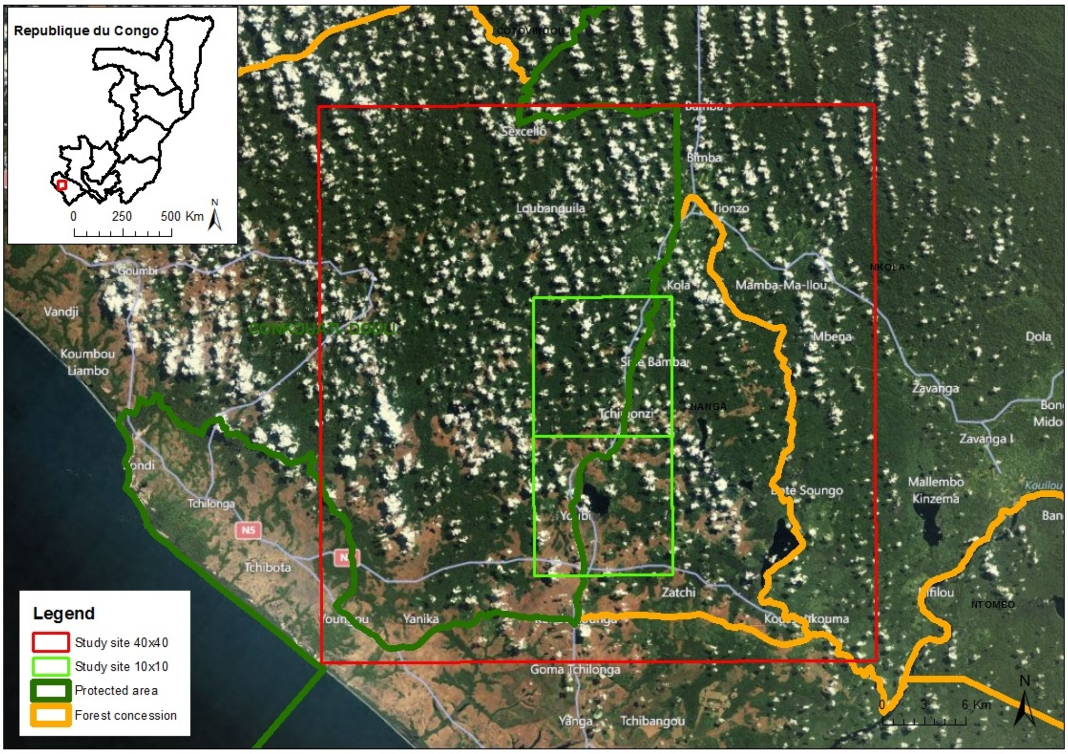

Figure 7: Location of the study site for REDDiness in the area of Youbi.

The location of the two focal areas of 10x10km was determined by:

- the location of aerial photography and a VHR satellite image (see 4.1).
- the location of the city of Youbi
- the national road
- the overlap with the forest concession and the protected area.

3.3.2 Study site for Gabon

Based on current knowledge and potential collaboration with ongoing research projects, IRD and local partners proposed three areas of degradation: Oyem (Wloleu Ntem) and the areas around forest concessions of CBG (Ogooué Maritime province) and SBL near Koulamoutou (Ogooué Lolo province: Figure 8).

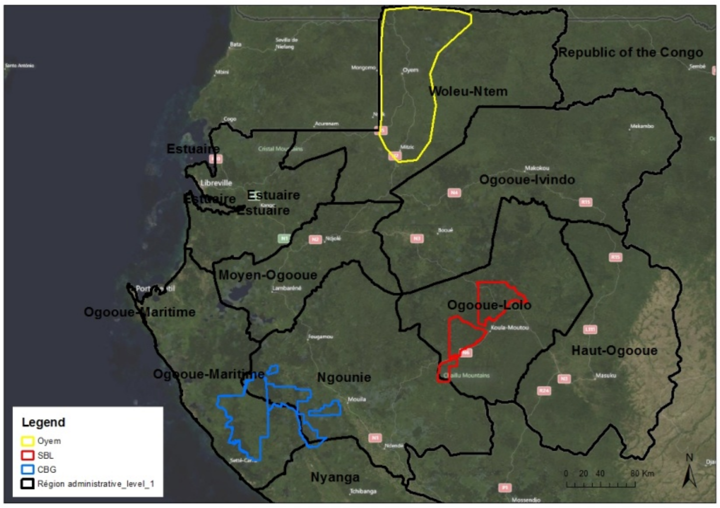

Figure 8: Location of the areas identified by local partners in Gabon

The area of Koulamoutou fully meets the selection criteria of selection (see table 3). Therefore the Gabon study site was placed in this area.

Table 3: Comparison of the characteristics of the Koulamoutou area with the selection criteria

#	Selection criteria (see 3.2)	SBL	References
1	Frequent cloud cover	OK	Figure 5
2	Forest degradation	OK	Presence of forest exploitation (2008-2012) and small scale agricultural expansion
3	Accessibility	OK	Area near the town of Koulamoutou and Lastourville and crossed by a major national road (N3 and N6).
4	Forest concession	OK	SBL Forest concession
5	Degradation data	OK	Collaboration with ongoing PhD research carried out in partnership with forest companies (SBL, CBG) and Ministry of Forest. Access to statistical data on forest exploitation and management.
6	Limited slope	OK	
7	VHR data	OK	Satellite images: Quickbird, Worldview (see 4.1)

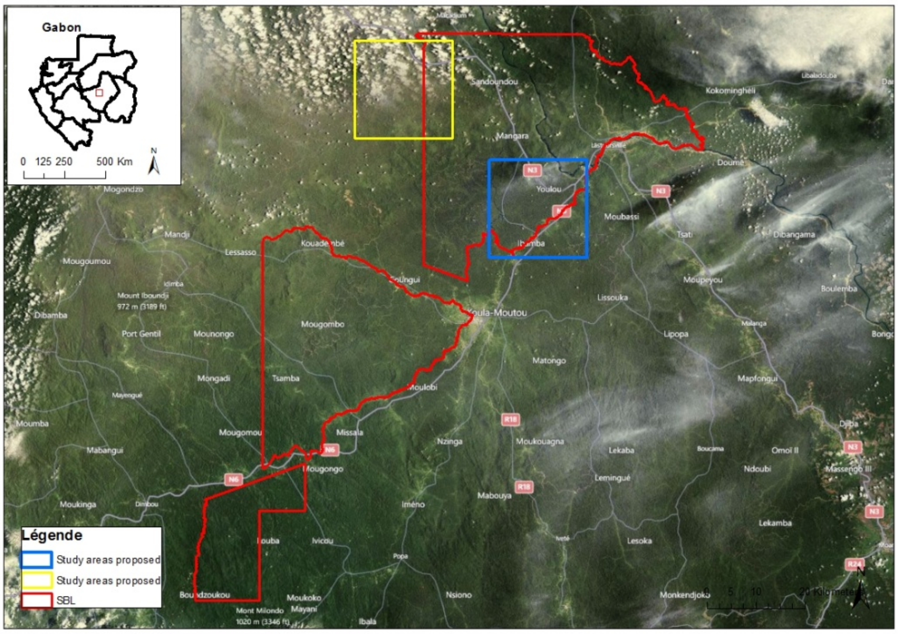

Figure 9: Study areas considered by local partners within the concession of SBL

Within the area, two potential study areas were proposed by IRD and local partners (see figure 9).

The **area 1** (see figure 9 in blue) theoretically concentrates logging areas, with annual cutting areas from 2008 to 2012. However, this is not very visible (only a few openings tracks) on Landsat data observed between 2000 and 2011. This is also characterized by the presence of agricultural areas and the national road linking Lastourville (where is located the wood industry) to Koulamoutou.

The **area 2** (see figure 9 in yellow) overlaps two concessions owned by SBL. Regarding the observation of Landsat images available between 2000 and 2011, this area looks intensively exploited (opening of many forest tracks). It seems that SBL has focused its business operations in this area.

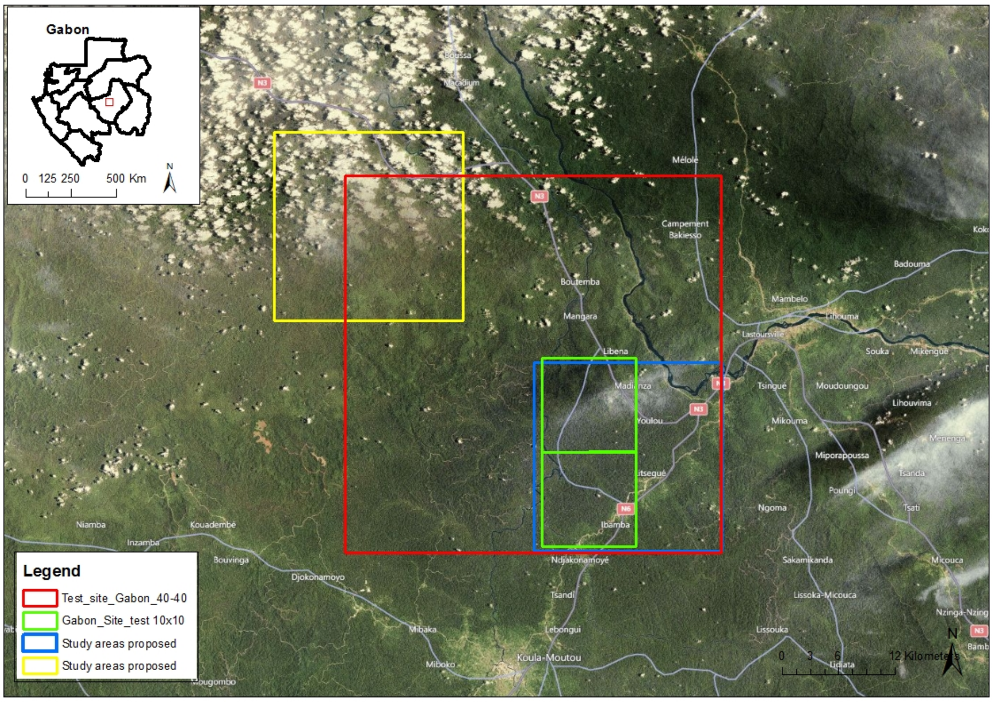

Figure 10: Location of the study site of REDDiness in the forest concession of SBL

To maximize our chances of observing forest degradation we decided to place our study site of 40x40 km on both areas (see figure 10). The location of the two focal areas of 10x10km was determined by the availability of archive VHR data in the 40x40 km site (see 4.1) and the position of the area 1.

3.4 Short description of selected study sites

3.4.1 Youbi (Congo)

Youbi is a village located 90km north-west of Pointe-Noire and part of the district of Kayes Madingo. This district is one of the least populated of the Department of Kouilou with a density of 1.4 persons/km^2. According to census figures (1996), Youbi has about 500 inhabitants. The density of the area around Youbi is much higher (10.7 persons/km^2) than the entire district of Madingo-Kayes. This is related to a concentration of population along the lines of communication, allowing the flow of food, wood and charcoal.

The forest of Youbi is part of the Forest Management Unit Sud-2[13]. This Unit includes the Conkouati Reserve and the Nanga forest concession, attributed for production in 2004 to CITB. This area suffered from deforestation and degradation during its history caused mainly by forest logging and shifting cultivation agriculture[14]. In southern Congo, as in southern Gabon, there is a natural trend towards reforestation observed in forest-savannah transition areas[15].

[13] The Congolese permanent forest domain is divided into Forest Management Unit (FMU). FMU have specific management objectives, which can be production (forest concession) or conservation (national park and other types of natural resources protection areas). Some FMU, such as the FMU Sud 2, can be further subdivided into smaller units with specific management objectives.

[14] Missamba-Lola, A.-P. 2004. Typologie et méthodes de réhabilitation des forêts secondaires et dégradées de Youbi (Région du Kouilou-Congo). Mémoire de maîtrise. Université Marien Ngouabi. Laboratoire de géographie physique. Biogéographie et restauration forestière. 68p.

[15] Bigot, 1996. Stabilité de la variation pluviométrique de l'Afrique tropicale entre 1951 et 1988, Dynamique à long terme des écosystèmes intertropicaux, CNRSI Orstom : 13-16.

The consequence of the demographic explosion and the rural exodus is an urban concentration, which comes with environmental effects. These include an increase of human pressure on areas up to 100-km around the urban centres (here Pointe-Noire). In these areas forests are frequently replaced by degraded formations, which have no time to develop into a secondary forest stage. This depends on many factors: shifting cultivation (reduced fallow time), fuel wood extraction (firewood and charcoal exploitation to supply the Pointe-Noire agglomeration). Even along the road network, the human settlements and the associated agricultural extension impose constraints on the forest resource (degradation in a belt of 5 to 10 km around the villages).

On the other hand, areas that are far away from the agglomeration became human deserts in which forest expands with only bush fires potentially stopping this expansion. In these areas, logging does not lead to forest degradation in the case where logging is not followed by agriculture.[16]

3.4.2 Koulamoutou (Gabon)

Koulamoutou is located 350km south-west of the capital city Libreville, and is the capital (chef lieu de province) of the Ogooué Lolo province in central Gabon. The estimated population of the city is 15,000 inhabitants, corresponding to one of the smallest provincial capitals of the country, mainly because of its isolation from the main transportation network and low accessibility. Koulamoutou lies at the confluence of the rivers Lolo and Bouenguidi, and the N6 road. The area is located at 50km of the town of Lastourville (6,000 inhabitants), which is linked with Libreville by railway. The Ogooué Lolo province is one of the lowest populated areas in Gabon (1.7 persons/km^2).

The study site covers a part of the SBL (Société des Bois de Lastourville) forest concession (Concession forestière sous aménagement durable, CFAD). Rural population around the SBL forest concession is estimated to 9,000 inhabitants, mainly located along the road axes[17]. The forest company is installed in Lastourville since 1986, mainly exploiting the forest concessions attributed alongside the creation of the railway (ZACF: zone d'attractivité du chemin de fer). Since the end of the 1990s, SBL has implemented a transformation unit in Lastourville. A management plan for the forest concession is approved since 2003.

[16] Fabing A., 2001 – Bilan spatial et structurel de l'antagonisme « Préssion Anthropique/Dynamique forestière naturelle» en zone de forte croissance urbaine. Le cas de Pointe Noire et de sa Région R. du Congo. Thèse d'université, Biogéographie. Faculté de Géographie, 46 Université de Strasbourg I. France, 321 p.

[17] SBL (2004). Plan d'aménagement de la CFAD SBL/TRB.

4 Remote sensing data

4.1 Optical image availability

As mentioned in section 2.3, REDDiness concentrates on forest degradation which generally occurs at a small scale in the two countries. Therefore, the availability of optical images was evaluated through an extensive search in the archives of very high and high resolution data. Coarse resolution data (>50m) such as MERIS, MODIS and SPOT VEGETATION is considered irrelevant for our project.

The availability of archive VHR optical imagery was used as a basis to define the location of the two focal areas of 10x10km for Congo and Gabon. This availability was evaluated through an extensive search in the archives from 2007 to present of several data providers (EROS B, Worldiew-1 and -2, QuickBird-2, IKONOS, GeoEye-1, ALOS-Prism and SPOT-5). We queried the archives for both study sites of 40x40 km using a maximum cloud cover percentage of 20%. The number of images available for both study sites in Gabon and Congo is low.

The availability of HR data from 2007 to present has been analyzed for three sensors: DMC-constellation (22m), Landsat-7 (30m) and SPOT-4 (20m). The query for SPOT-4 used a maximum cloud cover percentage of 40% (option not available for others sensors).

4.1.1 Congo optical image availability

The results of the VHR archive data search for the 40x40km study site are illustrated in table 4. Within the 40x40km study sites, the placement of the 10x10 km focal areas was partly based on the availability of very high resolution imagery (7th criteria in section 3.2). The archives spatial analysis was carried out in two steps: (i) mapping the location of the VHR scene outlines (table 4) and (ii) discussion and agreement with partners on the relevant study site based on this availability.

Table 4: List of available VHR archive data within the 40x40km test site in Congo

Archive VHR			
Sensor	**Resolution (m)**	**Number of images**	**Comment**
Eros B	0.7	0	
Worldview-1	0.5	0	
Worldview-2	0.5	1	
QuickBird-2	0.6	1	
IKONOS	1	2	
GeoEye-1	0.5	0	
SPOT-5	2.5	0	
Kompsat-2	4	6	
ALOS-Prism	2.5	2	Cloud cover more than 20% in AOI

In Congo, the number of available images is higher than in Gabon (see table 4 and 5) but their placement is not ideal for the 40x40km study site and their quality is overall low (cloud cover more than 20% in the area of interest). The focal areas of 10x10km are fully covered by only one image: a WorldView-2 image of 29th Augustus 2011 (Figure 11). Although the cloud cover percentage of the entire image is low (3%), the cloud cover in the focal areas is higher (around 20 %). The focal areas are thus not completely covered and an adaptation of image processing to mask clouds, haze and shadows will be necessary. A multi-temporal analysis could be carried out in combination with a Kompsat-2 image of 8th March 2009. The Kompsat-2 image seems of good quality but this data type is not included in the GMES Space Component Data Access Portfolio. Discussions with the administrator about GMES data sharing agreement are foreseen to address this issue. On the downside, Kompsat-2 offers significantly lower spatial resolution than WorldView-2 (4m versus 0.6m), which reduces its usefulness in for example the detection of individual trees. To complete and facilitate the multi-temporal analysis, we plan to request new acquisitions at the same resolution of the WorldView-2 (see section 4.3).

In addition to the available VHR satellite images for the focal areas of 10x10km, aerial photography of 2007 received from Winrock partially covers these areas (Figure 11).

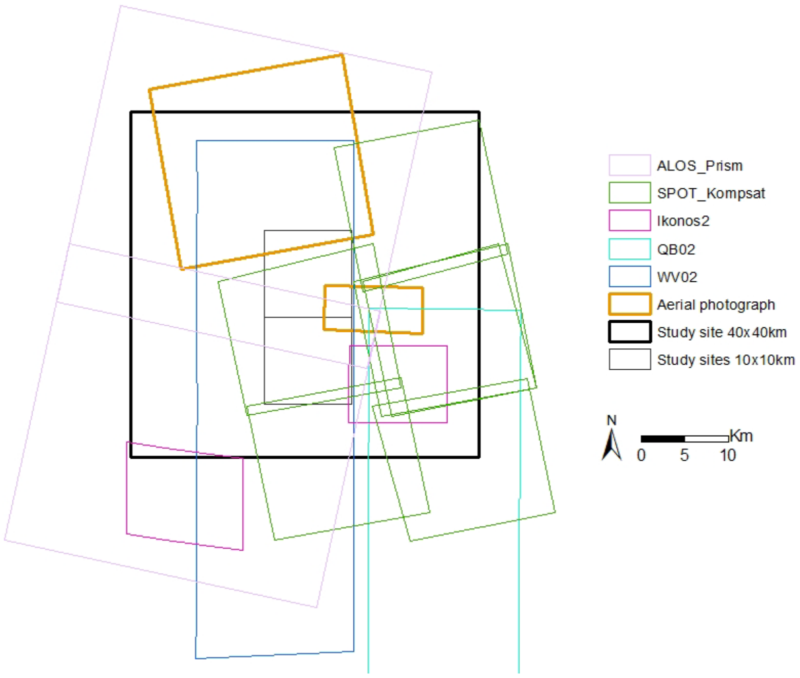

Figure 11: Availability of archive optical images in a 40x40km defined as the test site for The Republic of Congo

For high resolution, 45 DMC images are available on archive but none of these has a reasonably low cloud cover. The Landsat archive provides images of good quality (low cloud cover) even when taking into account the SLC-off (Scan Line Corrector Failure) since May 2003. Table 5 shows the available Landsat images for the 40x40km site.

Table 5: Landsat image dates available for the 40x40 km test sites Congo

Dates	Cloud cover
12/03/2007	37.50%
20/07/2008	1.40%
08/04/2011	8.95%

A multi-temporal analysis can be executed based on these images. Only one SPOT image is available under the cloud cover threshold of 40% (for 4 February 2011 with 8% cloud cover). This SPOT image could perhaps be used in combination with Landsat data, for example to address the problem of Landsat SLC-off but the SPOT image quality is not certain: the quicklook provided in the archive search tool does not provide clear evidence.

4.1.2 Gabon optical image availability

The results of the VHR archive data search for the 40x40km study site of Gabon are illustrated in table 6. For Gabon, as described in 3.3.2, our partner IRD proposed two specific area of interest (see two yellow zones on Figure 12). Figure 12 illustrates that archive imagery is not available in the area located in the north-west part of the 40x40 km. Therefore we selected two contiguous 10x10km sites as focal areas in the southwest area proposed by IRD (see figure 12). A QuikBird-2 image of 25 December 2010 covers both of these 10x10km test sites. This image seems to be of sufficient quality for effective analysis of forest degradation. To carry out a multi-temporal analysis, a new acquisition of a very high resolution image is planned (see section 4.3).

Table 6: List of available VHR archive data within the 40x40km test site in Gabon

Archive VHR			
Sensor	**Resolution (m)**	**Number of images**	**Comment**
Eros B	0.7	0	
WorldView-1	0.5	1	40x40 area not well covered (Figure 12)
WorldView-2	0.5	0	
QuickBird-2	0.6	1	
IKONOS	1	0	
GeoEye-1	0.5	0	
SPOT-5	2.5	0	
Kompsat-2	4	2	
ALOS-Prism	2.5	3	40x40 area not well covered (Figure 12)

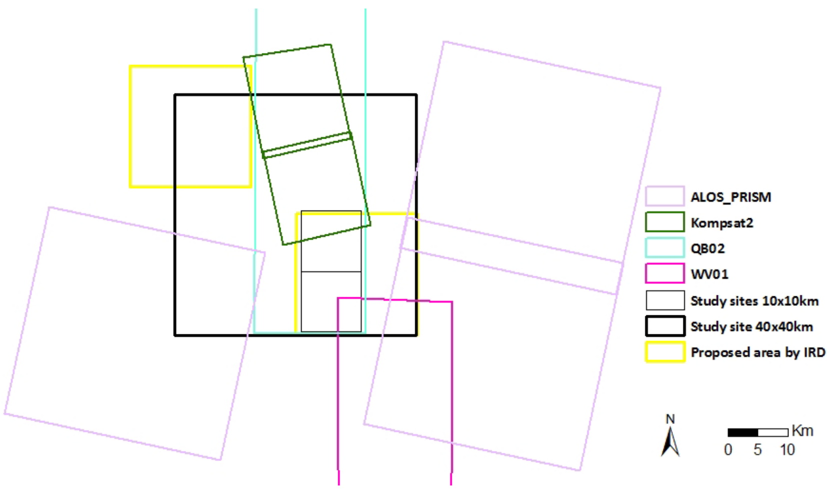

Figure 12: Availability of archive optical images in the 40x40km study area of Gabon

As for Congo, the analysis of high resolution images shows that DMC has archive imagery (44 images) but none of them with a reasonably low cloud cover percentage. The Landsat archive has better availability of cloud-free imagery even when taking into account the SLC-off (Scan Line Corrector Failure) since May 2003. Table 7 shows the available Landsat images for the two 40x40km sites. A multi-temporal analysis can be executed based on these images. The analysis of the SPOT archive (10 and 20m resolution) with a maximum of 40% cloud cover showed that we can partly use 3 images but their cloud cover percentage is relatively high (see table 8). As indicated before, the quick looks provided before acquisition do not show clear evidence about the image quality. These SPOT images could perhaps be used in combination with Landsat data, for example to address the problem of Landsat SLC-off.

Table 7: Landsat images available on the 40X40 km test sites in Gabon

Dates	Cloud cover
20/05/2009	9.42%
04/03/2010	37.73%
26/07/2010	20.80%
08/04/2011	0.65%

Table 8: SPOT images available on the 40X40 km test sites in Gabon

Dates	Cloud cover
20/12/2010	28%
19/01/2011	30%
24/01/2011	30%

4.2 SAR image availability

A detailed analysis was executed to establish SAR satellite data availability (HR and VHR) for both study areas during the past 10 years. The availability of archive data is also a key factor in determining which additional data may need to be acquired (section 4.3). We do not provide an extensive list of all images that are available, but focus on those that we would plan to use within the project. Several of the current SAR systems offer multiple resolutions by imaging in different modes. For example COSMO-SkyMed archives are investigated. In principle COSMO-SkyMed offers very-high resolution SAR (up to 1m). However, for both sites (and generally also over large parts of the country) the archives only contain data in wide mode (i.e. 30 m resolution). Below we separately summarize the results for Congo and Gabon.

4.2.1 Congo SAR data availability

Like for Gabon, also the Congo study site has limited availability of very high resolution SAR data. COSMO-SkyMED data do not exist for the study site. The most interesting acquisition available is a single TerraSAR StripMap scene (3m resolution) dated 8 June 2010. We plan to complement this archive scene with a new acquisition request using the same imaging characteristics (section 4.3), i.e. HH polarization ascending with a 37.8° incidence angle.

More image availability in the archives exists for recent high resolution data. As for Gabon, we judged ENVISAT ASAR and ALOS PALSAR to be the most useful for their multi-temporal coverage with the same imaging characteristics. Access to data from these systems is warranted through the GMES arrangements. Table 9 shows details of the TerraSAR scene and summarizes the ENVISAT ASAR and ALOS PALSAR data that will be freely available and requested under the GMES arrangement. Figure 13 shows the location of these scenes in relation to the proposed study site. Note that for PALSAR we will try to get the scenes shifted slightly southward to better cover the 40x40km area (acquisitions continue in the same path). The figure shows that for PALSAR the selected scenes miss a small part of the 40x40 km area. Other scenes are available for those locations, but we will only request those if analyses with other image types indicate interesting developments in that region.

In addition a number of RADARSAT-1 and -2 scenes exist for recent years. These are not at very high resolution, but have somewhat higher resolutions than ASAR and PALSAR. They include RADARSAT-2 Multi-Look Fine (about 10m resolution) and RADARSAT-1 Fine (about 8m resolution). For RADARSAT-2 there are eight images available, all between 9 December 2009 and 25 March 2010. For RADARSAT-1 Fine resolution archive imagery after 2002 exists only for a short time frame as well with seven acquisitions between 17 May 2008 and 1 August 2008. An additional problem is that many of these images are recorded with different incidence angles and during ascending and descending passes. This complicates comparison between images. More detailed characteristics of RADARSAT imagery are not presented here, but section 4.3 shows which images we plan to use.

Table 9: Summary of SAR scenes of interest for the Congo study site.

Satellite	Sensor	Resolution	Band	Polarization	Dates	Details
TerraSAR-X	Idem	3m	X	HH	2010-06-08	StripMap 37.8° incidence angle
ENVISAT	ASAR	30m	C	VV	2006-04-21 2011-03-24	Image mode
ENVISAT	ASAR	30m	C	VV	2010-04-27	Alternating Polarization
ALOS	PALSAR	20m	L	HH+HV	2007-08-22 2008-08-24 2008-10-09 2009-07-12 2009-10-12 2010-05-30 2010-08-30	Fine Beam Dual 34.3° incidence angle ascending
ALOS	PALSAR	10m	L	HH	2007-02-19 2007-10-07 2008-04-08 2009-02-24 2010-04-14 2011-01-15 2011-03-02	Fine Beam Single 34.3° incidence angle ascending (2 additional descending scenes Mar & Apr 2007)
ALOS	PALSAR	+- 30m	L	HH+HV+VH+VV	2009-03-20 2010-11-08 2011-03-26	Fine Beam Polarimetric 21.5° incidence angle

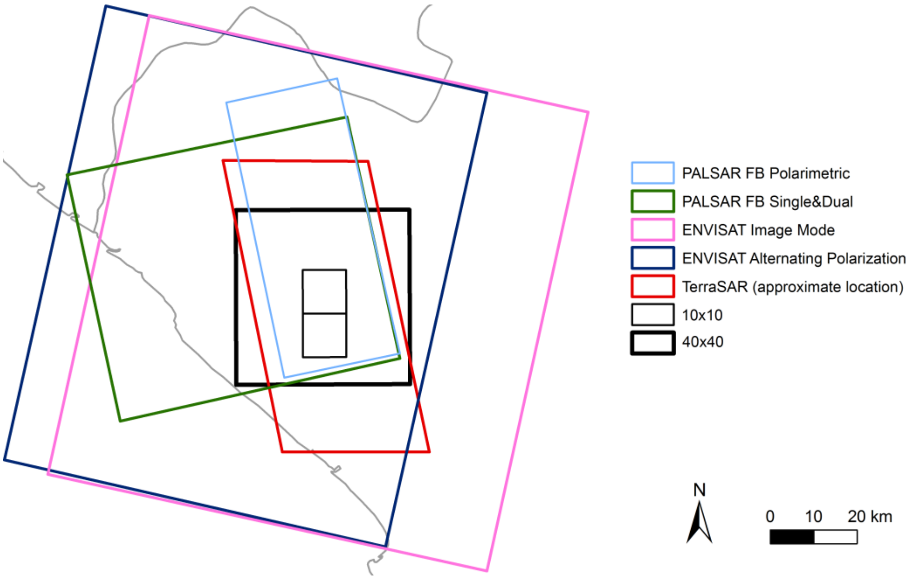

Figure 13: Location of the SAR (TerraSAR, ENVISAT, ALOS) scenes for Congo in relation to the 10x10 and 40x40km study sites.

4.2.2 Gabon SAR data availability

For very high resolution, the archives investigated include TerraSAR, RADARSAT-2, and COSMO-SkyMed. This investigation made clear that no data have been recorded at very high resolution for the study site. We plan to request new acquisitions however (section 4.3).

For recent high resolution data there is more availability. We judged ENVISAT ASAR and ALOS PALSAR to be the most useful because they have the best multi-temporal coverage. In addition the access to data from these systems is also warranted through the GMES arrangements. Table 10 summarizes the ENVISAT ASAR and ALOS PALSAR data that will be freely available and requested under the GMES arrangement. Figure 14 shows the location of these scenes in relation to the proposed study site.

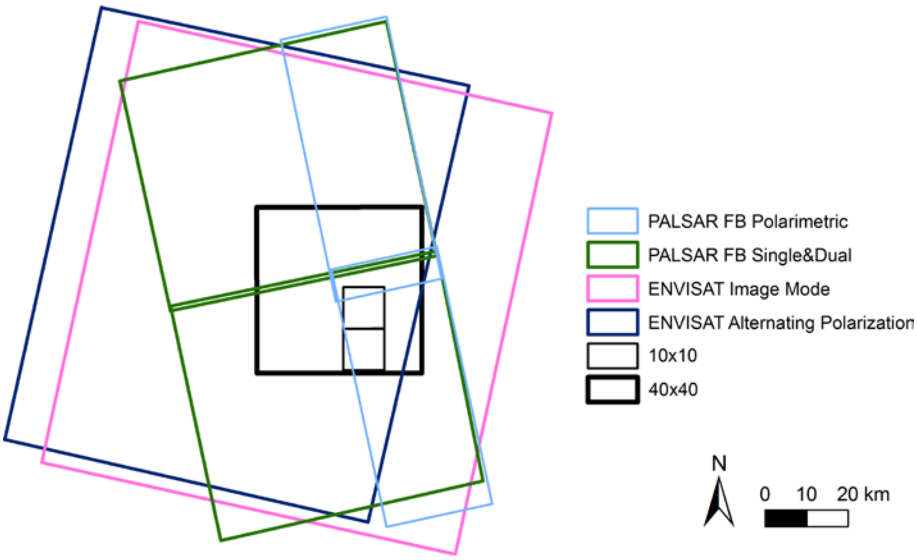

Figure 14: Location of the SAR scenes for Gabon in relation to the 10x10 and 40x40km study sites.

Table 10: Summary of SAR scenes of interest for the Gabon study site.

Satellite	Sensor	Resolution	Band	Polarization	Dates	Details
ENVISAT	ASAR	30m	C	VV	2005-08-19 2006-12-22 2011-03-24	Image mode
ENVISAT	ASAR	30m	C	VV	2010-04-27	Alternating Polarization
ALOS	PALSAR	20m	L	HH+HV	2007-08-17 2008-08-19 2008-10-04 2009-07-07 2009-10-07 2010-08-25 2010-10-10	Fine Beam Dual 34.3° incidence angle
ALOS	PALSAR	10m	L	HH	2007-02-14 2008-02-17 2009-02-19 2010-02-22 2010-04-09 2011-01-10 2011-02-25	Fine Beam Single 34.3° incidence angle
ALOS	PALSAR	+- 30m	L	HH+HV+VH+VV	2010-11-03	Fine Beam Polarimetric 21.5° incidence angle

4.3 Planned data acquisition

Based on our detailed analysis of archive data in sections 4.1 and 4.2 it is clear that the availability of archive imagery is relatively modest. This section shortly lists which archive images are planned to be requested. Imagery that is readily available through the GMES arrangements (i.e. GMES Space Component / Data Warehouse Mechanism) is not included in the tables. These include for example ENVISAT ASAR and ALOS PALSAR.

Table 11 shows the three archive VHR images that are planned to be ordered for Gabon and Congo. Table 12 gives an overview of the archive SAR images that are planned to be requested within REDDiness. Note that we only request archive SAR for Congo, due to non-availability of very high resolution SAR for Gabon. ALOS en ENVISAT data will be readily available through GMES arrangements and are excluded from this list. However, those data (as shown in section 4.2) will also be requested.

Table 11: Archive very high resolution optical imagery requested within REDDiness for both study sites

Sensor	Resolution	Date	Acquisition parameters	Catalog ID	Cloud percentage
			Gabon		
QuickBird-2	0.6m	25/12/2010	MS	101001000CC2F500	20%
			Congo		
WorldView-2	0.5m	29/08/2011	MS	103001000CCE0E00	2%
Kompsat-2	4m	08/03/2009	MS	MSC_090308095117_13936_00870969BP21_1A	20%

Table 12: Archive SAR imagery requested within REDDiness (ENVISAT ASAR and ALOS PALSAR are exluded as these are readily available through GMES arrangements). As a result archive request is only for Congo (due to limited availability in Gabon).

Satellite	Sensor	Resolution	Band	Polarization	Dates	Details
TerraSAR-X	idem	3m	X	HH	2010-06-08	StripMap 37.8° incidence angle
RADARSAT-2	SAR	10m	C	HH	2010-03-15 2009-12-09	Multi-Look fine 34.8° inc. angle
RADARSAT-1	SAR	8m	C	HH	2008-07-28 2008-06-10	Fine 40.7° inc. angle

We would like to complement the archive imagery with new acquisitions. This will still require a negotiation with ESA and EC to assign adapted quota. We have understood that possibilities for this exist, however the corresponding budget would need to be evaluated by EC. Because per country we plan to work on two sites of 100km² to study forest degradation, our request for most image types is 2x200 km². In addition we request high resolution images to cover the study site of 1600km². This is based on mono-temporal acquisitions. Multi-temporal would not make much sense considering the remaining time frame of WP3, because little changes can be expected (main changes during dry period: June-August). However, in combination with the archive imagery we intend to have multi-temporal acquisitions for various image types (for example QuickBird-2 and TerraSAR). To allow time for image analysis within the project, all images should have been acquired before 31 May 2012. Table 13 summarizes the requested imagery for optical acquisitions, and Table 14 for SAR acquisitions. Depending on potential budget constraints, we have the possibility to scale down our focal areas to only one 10x10 km area per country or reduce image types (e.g. TerraSAR). This will be clarified further with EC and ESA during January 2012.

Table 13: New acquisitions optical imagery requested within REDDiness (only one moment for all).

Satellite	Resolution	Acquisition parameters	Km² Gabon	Km² Congo	Km² total
Quickbird	0.6m	MS	200	200	400
DMC	22	MS	1600	1600	3200
SPOT 4	20	MS	1600	1600	3200

Table 14: New acquisitions SAR imagery requested within REDDiness (only one moment for all). We have included ENVISAT ASAR for completeness, although for this no negotiation is needed.

Satellite	Resolution	Band	Polarization	Details	Km² Gabon	Km² Congo	Km² total
TerraSAR-X	3m	X	HH	StripMap 37.8° incidence angle	200	200	400
TerraSAR-X	1m	X	HH	HighResolution Spotlight	200	200	400
RADARSAT-2	10m	C	HH	Multi-Look fine 34.8° inc. angle	-	200	400
ENVISAT ASAR	30m	C	VV	Image Mode	1600	1600	3200
ENVISAT ASAR	30m	C	VV	Alternating Polarization	1600	1600	3200

5 Methodology

5.1 General

Monitoring spatial and temporal changes in forest cover requires understanding of change processes in the context of space and time. The forest change processes in Central Africa are particularly hard to address by remote sensing due to (Duveiller et al 2008[18]): (i) small deforestation areas needing fine scale imagery, (ii) non-uniform distribution of deforestation, (iii) persistent cloud cover, and (iv) short time scales needed to effectively address the forest cover change processes (e.g. because of quick regeneration). Besides forest conversion (i.e. deforestation), forest degradation (for fuel wood collection, selective logging, wildfires, or slash and burn practices) should also be included in REDD+ MRV although it is seldom addressed in existing operational projects. Forest degradation is the loss of carbon stock in forest land that remains forest. Mapping forest degradation with remote sensing is challenging because degraded forests are generally a complex mix of various land cover types (vegetation, dead trees, soil, shade, and possibly crops) and the spectral signature of a degraded forest can change quickly[19]. Therefore monitoring forest degradation and selective logging needs high to very high spatial resolution. This is usually done either in a direct approach (detecting small clearings) or an indirect approach detecting disturbances like road networks and log decks. Direct methods vary in a trade-off between visual image interpretation and automated algorithms such as spectral mixture analysis (SMA) using sub-pixel classification methods or Normalized Difference Fraction Index (NDFI) both applied successfully in the Brazilian Amazon.

It should be noted that beyond methodology challenges to estimate degradation, there is an issue regarding definitions. An IPCC report suggested and analyzed five definitions of forest degradation but could not agree on one[20]. Congolese plans for REDD took the following suggestion from that IPCC report: "Degradation is a long-term loss (persisting for x years or more) of at least y% of forest carbon stocks since time T and not qualifying as deforestation, i.e. the conversion of "forest" land to another land-use category"[21]. However even if using this definition, x and y should be defined, while also the definition should be made workable for EO analysis. We envisage more in-depth discussion on a precise working definition of forest degradation in WP3.

Because of ease of visual interpretation and robust classifications methods developed since several decades, EO optical sensors provide the most accessible and straightforward data for forest monitoring. However, the study sites are situated just north and south from the equator. Here winds originating from the northern and the southern hemisphere join in the Intertropical Convergence Zone (ITCZ) resulting in persistent cloud cover. Up to 200 precipitation days per year are measured in this area. Because of the cloud coverage, a combined approach using optical and SAR sensors, which are able to penetrate through clouds, can be envisaged for forest monitoring on a regular basis.

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[18] Duveiller G, Defourny P, Desclée B, Mayaux P. 2008, Deforestation in Central Africa: estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts. Remote Sensing of Environment 112: 1969–1981

[19] Lambin, E. F. (1999). Monitoring forest degradation in tropical regions by remote sensing: some methodological issues. Global Ecology and Biogeography, 8: 191-198.

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5.2 High and Very-high resolution optical: semi-automated classification

EO data are a powerful tool to make quick land cover or forest assessments on large areas. Change detection involves the processing of multi-temporal datasets to quantitatively analyze the temporal effects of the phenomenon, here the forest degradations. Monitoring of land use (LU) conversion (forest to other land use) can be mapped at multiple scales using available EO data.

Several existing forest mapping approaches use high resolution EO (such as Landsat, DMC and SPOT) data to estimate forest cover for the entire Congo Basin[22,23]. The new generation of very high resolution (VHR) satellite images offers useful information to support the analysis of forest degradation in addition to deforestation. While the higher spatial resolution provides a better visibility of small-scale changes, the automated classification of VHR imagery is challenging. We propose to compare high resolution imagery (Landsat and SPOT data, see section 4.1) and VHR imagery (Quickbird, WorldView-2 below 1m resolution) to analyze the forest degradation process in two areas in Congo and Gabon.

Operational projects produced an historical mapping of forested areas which is called a “benchmark forest area map”. Existing forest monitoring projects in Gabon and Congo[24], including the GSE Forest Monitoring (GSE-FM) project supported by the European Space Agency (ESA) and the World Resources Institute (WRI) project supported by CBFF, use high resolution data to produce this benchmarking forest mapping for 1990, 2000, and 2010 in Congo and Gabon.

Forest cover maps can be derived in two ways: through visual interpretation by a human interpreter or through computer-based automated procedures. The former method has the advantage of using human pattern recognition, which is still far superior to any machine-based vision technique in terms of accuracy. Unfortunately, it is also tediously slow when compared to the processing speed of such automated procedures, while also differences may emerge between different interpreters. As stated by Duveiller et al.[24], no automated change detection method was found to be as efficient as visual interpretation. In WP3, we propose to test either an automated method proposed by Souza et al.[25] or a semi-automated image classification method combining the advantages of both visual and automated techniques[26]. The most common classification methods to quantitatively derive thematic maps from remotely sensed imagery are either pixel-based or object-based[27]. Object-oriented methods are potentially best suited to manage the increase in resolution and the complex content of VHR images[28] but also to propose accurate estimation of deforestation[24].

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5.2.1 Automated algorithms for forest degradation mapping

The Normalized Difference Fraction Index (NDFI) is a method successfully applied in the Brazilian Amazon to identify and distinguish forest degradation caused by selective logging and associated forest fires from other natural disturbances[29]. The NDFI combines the information of several component fraction images defined by Spectral Mixture Analysis (SMA). The interpretation of NDFI images are facilitated by a contextual classification algorithm (CCA). The CCA uses the location of log landings as contextual information and the NDFI as the spectral information sensitive to canopy damages. Tested in the Southern Brazilian Amazon, this method is currently being tested in the Congolese context within the WRI project. OSFAC has been trained to apply NDFI methods to map forest degradation in Congo. Within REDDiness, OSFAC will test the NDFI approach in our two study areas.

According to Souza et al.[30], the Spectral Mixture Analysis (SMA) overcomes some of the problems of visual interpretation and conventional image processing techniques. The soil fraction derived from SMA enhances the detection of the log landings and logging roads, which have been recognized as the spatial signature of mechanized logging in tropical forests. Green vegetation (GV) fraction is used to estimate forest canopy damage associated with selective logging. The non-photo-synthetic vegetation (NPV) fraction quantifies levels of forest degradation caused by burning. NDFI combines the GV, NPV, soil and shade fractions that were extracted through SMA (using Landsat imagery). NDFI showed a higher percent change between intact forest and forest degradation classes, when compared to the changes detected by any of the individual fraction images. However, the authors mentioned that detection of non-mechanized logging seems not possible with this technique. Given the general small-scale changes in the central African context (i.e. different degradation processes), the potential of NDFI for Congo and Gabon needs to be examined.

5.2.2 Semi-automated algorithms for forest degradation mappings

One motivation for object-based classification methods is the fact that, in many cases, the expected result of most image analysis tasks is the extraction of real world objects, proper in shape and proper in classification[30]. As an alternative to pixel-based classification with salt-and-pepper effect, segmentation approaches propose a mapping procedure that operates on groups of adjacent pixels that are assigned to the same land-cover or forest-cover class by the classifier. The most common image segmentation techniques are region growing algorithms, watershed segmentation, texture segmentation and the object-oriented approach of eCognition / Definiens[31].

The semi automatic classification proposed in this WP will be developed in eCognition v8.0. A set of rules, or module, will define each class ("forest-cover classification") in a specific order. The first discrimination will be done between "built-up areas" and "primary forest". Then the "cleared areas" can be subtracted from the "primary forest" class and the subsequently "rivers", "grasslands" and then "secondary forest" will be discriminated. A parameterized approach is proposed so that the developed methodology can be easily replicated on a new image.

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[30] Baatz, M. & Schäpe, A. 1999. Object-oriented and multi-scale image analysis in semantic networks. Proc. of the 2nd International Symposium on Operationalization of Remote Sensing, August 16th-20th 1999. Enschede. ITC

This methodology has been tested on a site in Republic Democratic of Congo (RDC). Eurosense processed and compared VHR and HR forest classification in the frame of the G-Mosaic project funded by the 7th Framework Programme of the European Commission. Figure 15 compares the VHR classification (1) with the FACET (Forest monitoring of Central Africa using remotely sensed data sets) classification produced by OSFAC (2). To quantitatively and visually compare these maps, the VHR object-oriented classification was degraded to the resolution of FACET (3), and all forest cover loss classes in the FACET classification were merged (4). The FACET dataset should be produced soon for the Republic of Congo. A similar process of comparison between HR and VHR forest classification is foreseen within WP3 of REDDiness to better understand the limitations of different sensor resolution for mapping and monitoring forest degradation processes in Congo and Gabon.

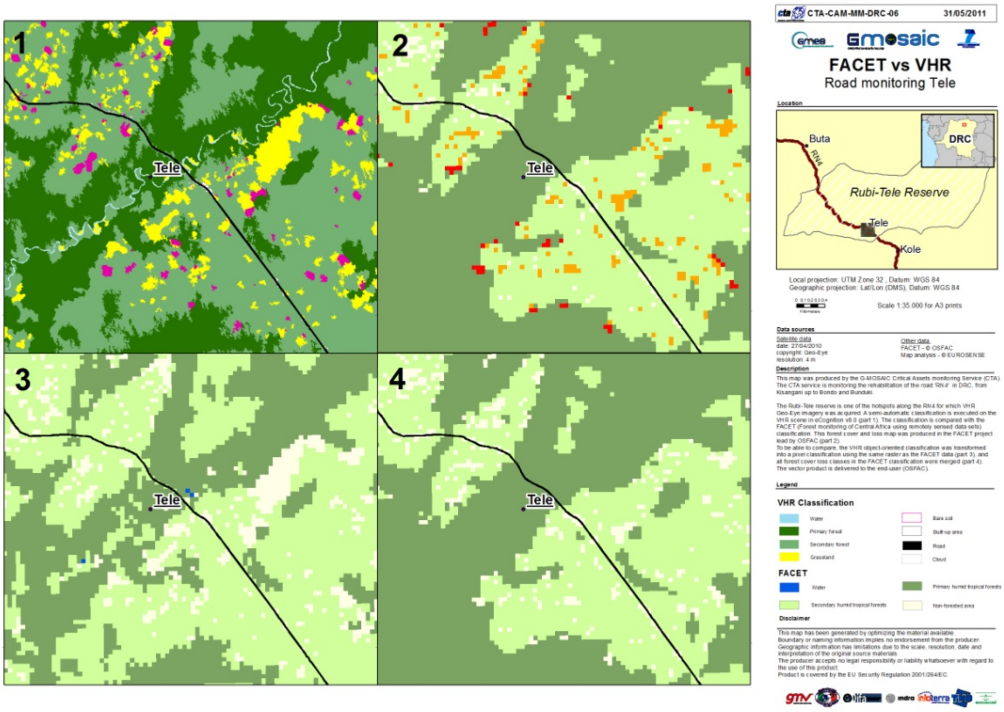

Figure 15: Comparison of G-Mosaic VHR classification and FACET HR in Rubi-Tele reserve, RDC

For this RDC test case, the HR classification "primary forest" occupies 76.8% while VHR map distinguishes the very dense from the secondary forest. The VHR classification identifies also more deforested areas (5km²) than FACET (2.7km²). The difference in classification shows that both in terms of deforestation and forest degradation, VHR data have important information to add. In WP3 we will assess in more detail what options HR offers vis-à-vis VHR, and what are the limitations of both.

5.3 SAR image analysis

The SAR part of the REDDiness project will focus on high resolution and very high resolution. Section 4.2 provided the overview of archive imagery, while section 4.3 listed the planned acquisitions. As for the optical, the main objective is to evaluate the potential and limitations for the detection of forest degradation with SAR satellite data. In this project we plan to concentrate on the following sources:

- TerraSAR: very high resolution at X-band

- ALOS PALSAR: high resolution at L-band (more sensitive to biomass) with multi-temporal coverage (more than annual) of both sites between 2007 and 2010 (2011 for Gabon).
- ENVISAT ASAR: high resolution at C-band, with a few archive images in time and the possibility to add a new acquisition in 2012.

Hence RADARSAT-1 and -2 archive data will not form a major input to our analysis for a number of reasons: 1) in Gabon they are not available and hence would not allow analysis at both sites, 2) the gain in resolution with respect to PALSAR is relatively modest while C-band is less-suited for forest studies, 3) for Congo all acquisitions for each satellite (1 and 2) are focused in a very short time of a few months only thus a large risk of little change in the time period(s) of acquisition. Given the last reason, if indications appear during the course of the coming months of strong changes in those periods, we may reconsider our focus. We do in any case envisage ordering a few RADARSAT-2 images to visually understand its potential in relation to the other image types.

All stakeholders (including scientific experts, local partners, and the European Commission Research Executive Agency) clearly indicated that inclusion of SAR in the analysis is essential (for these countries in particular due to persistent cloud cover). ITC has some experience and in collaboration with Eurosense will take on this task. The SAR field is generally dominated by technical experts who often work with highly advanced techniques or processing software. Within REDDiness we propose to evaluate with simple techniques what SAR seems to offer to forest degradation assessment. In the framework of a SICA project and in view of WP2 outcomes, this makes sense. For both countries WP2 showed that local technical knowledge on remote sensing in general is quite limited. Any outcome of REDDiness that should be transferred to increase the countries' capacities for building MRV systems, should build on the current available capacity. Having said this, we would certainly be open for collaboration with projects as REDD-FLAME in testing their methods or establishing best practices.

A main component of the SAR analysis will be the visual comparison of the imagery (and derived products) with evidence of forest degradation. This evidence includes very high resolution optical imagery and field evidence (including logging information from concessions). We expect that this part should provide a large part of the answer to whether SAR has potential in detecting forest degradation. Our assumption is that very high resolution allows for best detection of forest degradation, given the small spatial scale and patterns of the process. Likely coarser resolution will 'miss' out on subtle changes. Nonetheless, the larger wavelength of PALSAR is more sensitive to biomass, which may imply potential also on the high resolution front. Basic SAR pre-processing steps will be executed including precise co-registration of multi-temporal imagery and likely speckle filtering. We will use of the free package NEST (Next ESA SAR Toolbox) and IDL-ENVI for data processing. Regarding visual analysis we envisage the following:

- Mono-temporal display and comparison with other evidence. Particularly for very high resolution (TerraSAR StripMap and possible new SpotLight acquisitions) we expect that degradation processes (including logging of individual large trees) should be visible on a single image. For dual polarization images (PALSAR), also color displays can be created: because cross-polarized (HV) backscatter is sensitive to biomass spatial color differences could indicate more or less advance of forest degradation. However, we should note that the signal saturates at relatively low levels of biomass.

- Multi-temporal color compositing of images. For PALSAR and ASAR especially we have multi-temporal data sets of various dates. Hopefully we can also obtain a second acquisition of TerraSAR StripMap). Although speckle phenomena in the image can cause some random variation, overall in stable tropical forests we would expect relatively little change of backscatter to occur between different time periods. Multi-temporal composites are a useful approach to evaluate which regions are stable and which are subject to change. Certainly the analysis of such change would need a masking out of non-forest areas. Deforestation can be expected to show strong changes. However, the main question is whether the backscatter signal also varies over time in areas under degradation.
- Image differencing for multi-temporal images. This option relates to the previous, but enhances areas where change occurred by creating a new image highlighting differences between both dates.

We expect that the visual analysis as described above should result in identifying the most promising SAR data types for assessing forest degradation in Gabon and Congo. The inter-comparison between different SAR products and optical data should be highly informative in this respect. If we find one or more promising data types to detect (hence possibly monitor) forest degradation, a next step would be to classify areas under degradation. The classification approach would highly depend on the image type and the precise image characteristics of the areas to be distinguished. We foresee three possible approaches to classification:

1. Visual interpretation. This remains one of the most accurate methods for classifying remote sensing imagery. It is a simple and straightforward process although different classifications may emerge based on the interpreter. Nonetheless, it is a method that would be easy to transfer to the countries (locally visual interpretation is used most often). With respect to capacity building, knowledge on SAR imaging principles should increase in the countries.
2. Semi-automated classification. This combines advantages of visual interpretation with faster delineation of units (see section 5.2). Applying a semi-automated method for classifying SAR data could create good synergies between the optical and SAR part of REDDiness. The software eCognition is also well-suited for SAR data, and can include more typical SAR image characteristics such as texture.
3. Automated classification. Using a combination of texture and backscatter it may prove possible to automatically separate degraded forest from intact forests. A promising approach for multi-temporal data could be to use as an input to the classification the multi-temporal set or change images. For very-high resolution automatic tree delineation or gap detection could be interesting options to explore.

As we spoke in point 2 above about possible synergies between the optical and SAR part of REDDiness, one point should be added. To reiterate, the main aim of REDDiness is to compare different image sources for its potential in effective detection of forest degradation. Comparison in principle does not imply an integration of data sources, hence such integration is not a main aim. Nonetheless, we envisage (if time and resources permit) to select optimal data types in optical and SAR, and evaluate whether an integration (i.e. fusion) of both data sources could lead to improved detection of forest degradation.

5.4 Foreseen fieldwork activities

Part of the fieldwork will be carried out in close synergy with Work Package 4 (capacity building). Associated with the short-term technical training sessions, the project will build and improve the technical local expertise through the participation to fieldwork. Field campaigns will be carried out to support WP3 research actions, i.e. field observations and measurements will provide the required for the verification and validation process of the WP3 products. Field campaigns will be carried out by local partners (CNIAF, MEF) with technical support from OSFAC and EU partners.

The expected fieldwork activities include:

- Identification and characterization of the main forest degradation processes currently affecting the area, with a focus on the forest exploitation associated activities;
- Collection of information for the verification and validation of the preliminary image processing results, based on high and very high resolution data (GPS located observations);
- Collection of additional data and information, such as forest harvesting statistics and agricultural production figures;
- Interviews with key resource persons on forest degradation and deforestation processes and factors (to be carried out in the study area and in Libreville and Brazzaville).

6 Work plan

This section presents the work plan as agreed between all project partners. It consists of the objectives, the responsibilities and expected outcomes, and a planning of when which activity should be finalized.

6.1 Objectives

Main objective:

- To demonstrate for selected areas in Gabon and the Republic of Congo the potential of different satellite sensors for effective detection of forest degradation.

Specific objectives:

1. To provide an overview based on (local) literature and expert knowledge on forest degradation processes (extent and spatial scale) and drivers in Gabon and the Republic of Congo.
2. To gather field-based spatially and temporally explicit evidence on forest degradation for the 20*20 km study sites including an overview of local uses of forest and forest products.
3. To evaluate the effectiveness of high-resolution optical sensors (ASTER, Landsat) in detecting forest degradation based on existing techniques (e.g. NDFI, CLASLite).
4. To evaluate the effectiveness of very high-resolution (<5m) optical sensors (GeoEye, SPOT XS, etc) in detecting forest degradation.
5. To evaluate the effectiveness of very high- and high-resolution SAR imagery in detecting forest degradation.
6. To provide a future outlook on including forest degradation in MRV systems based on effectiveness of detection and (future) cost aspects.
7. To present the results of WP3 in a scientific peer-reviewed journal.

6.2 Responsibilities and expected output

The following table relates to the stated objectives under section 6.1.

Table 15: Responsibilities and expected results of WP3 for each specific objective

Specific objective	Responsible	Contributors	Expected results
1	IRD	OSFAC, CNIAF, MEF	Summary document (1-2 pages) including references on studies reporting on extent, scale, and drivers of forest degradation in both countries. Expert consultation may be included. Additional material to be delivered is (electronic) copies of the original studies, and names of persons consulted. Any statement in the summary should be well-referenced.
2	OSFAC, CNIAF, MEF	IRD	- Detailed statistics on forest concessions regarding when, where, and how much wood is extracted. - Terrain evidence on recent forest degradation within the 20*20 km zones (using GPS) - Specific information (literature, interviews with local key informants) regarding forest use and drivers for degradation in both zones. ➔ We envisage a link with WP4 by training staff in effective acquisition of relevant geo-referenced field data.
3	OSFAC	ES	For each site a degradation assessment based on NDFI (Souza, 2005) and/or CLASLite (Asner, 2009) using Landsat, SPOT, ASTER archive imagery (2000 to present) as input. Preferably focus on short time periods and recent years. To be delivered: original data (and meta-data) and output of approaches, a report describing what was done in detail.
4	ES	-	For each site a degradation assessment based on very high resolution data and semi-automatic classification. Resulting maps. To discuss: possibly first a visual evaluation, classification for promising cases. Report describing in detail the methods used, including references.
5	ITC	ES	Visual multi-temporal comparison of a variety of SAR scenes of different sensors. Likely a classification/change detection attempt for promising cases.
6	ES	ITC	Comparison of different methods under 4, 5 and 6 in relation also to field data of 3. Critical analysis of cost aspects, and future possibilities with planned sensors.
7	ITC	All	Integrating all information in a scientific article.

6.3 Planning

Table 16 shows the planning of the project, including the deadlines and responsibilities. Orange colors relate to deliverables to be sent to the European Commission. Pink colors are internal reports (part of which will be compiled in the final deliverable). Blue colors relate to other activities to be executed in the project. Only the journal article output is indicated in black. Although no formal EC-requirements, we include it here because the project strongly feels that this should be an important aim of WP3. We want to contribute to the science of forest degradation monitoring and share our findings in a peer-reviewed journal. Partly this activity can also be seen in the light of WP5 (dissemination).

Table 16: Planning of WP3 main activities

Objective	Action	Deadline	Responsibility	Contribution
0	Del 3.2. Consolidated report on processing chain combining operational and research methods	15-Aug-2012	ITC/ES	
1	Report (1-2 pages) based on literature and expert knowledge on forest degradation processes (extent and spatial scale) and drivers in both countries + delivery of meta-data	29-Feb-2012	IRD	OSFAC/CNIAF /MEF
2	Fieldwork planning finalized (dates + participants)	29-Feb-2012	OSFAC/CNIAF/ MEF	IRD
2	Fieldwork execution	31-May-2012	OSFAC/CNIAF/ MEF	IRD
2	Fieldwork report on specified topics, including delivery of organized data (GPS+description+photos), detailed concession statistics, and reporting on informant interviews	15-Jun-2012	OSFAC/CNIAF/ MEF	IRD
3	NDFI: first analysis (input fieldwork): provide base images and NDFI results to partners (+short report)	1-Apr-2012	OSFAC	ES
3	NDFI: consolidated analysis: same as above + report on method (and how applied) and results	1-Jul-2012	OSFAC	ES
4	Placement of data acquisition requests for optical VHR (to be recorded before 5/31/2012)	31-Jan-2012	ES	
4	Preliminary analysis (input fieldwork) on VHR optical (+short report)	1-Apr-2012	ES	
4	VHR+classification: consolidated analysis: provide results and base images + report on method (and how applied) and results	1-Jul-2012	ES	
5	Placement of data acquisition requests for SAR VHR (to be recorded before 5/31/2012)	31-Jan-2012	ITC	ES

Objective	Action	Deadline	Responsibility	Contribution
5	Preliminary analysis (input fieldwork) on SAR (+short report)	1-Apr-2012	ITC	ES
5	SAR: consolidated analysis: provide results and base images + report on method (and how applied) and results	1-Jul-2012	ITC	ES
6	Comparison of different methods under 4, 5 and 6 in relation also to field data of 3. Critical analysis of cost aspects, and future possibilities with planned sensors.	1-Aug-2012	ES	ITC
7	Submission ISI-journal article	15-Sep-2012	ITC	all