Land Use Policy 75 (2018) 102–115

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Anticipating social equity impacts in REDD+ policy design: An example from the Democratic Republic of Congo

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ARTICLE INFO

Keywords:
Equity
Reducing emissions from deforestation and forest degradation
Benefit sharing
Customary system
Democratic Republic of Congo

ABSTRACT

Equity is a sensitive topic discussed under the REDD+ mechanism. This study focuses on the impact of prevailing social and ecological conditions on the potential equity outcome of REDD+ intervention at the local level. Working at a REDD+ pilot project site in the Democratic Republic of Congo, we present a quantitative framework to assess contextual equity at the village level. We conducted a full community census on household characteristics and livelihood practices to evaluate current social conditions. We used participatory mapping and remote sensing analysis of a time series of very high resolution imagery over a 10-year period within the village boundaries to examine the ecological context of land use. We identify important differences between 379 households in terms of social characteristics and livelihoods practices. Social differentiation strongly relates to customary land rights as well as gender, ethnicity and origin. Using this case study, we find REDD+ activities that can be implemented under the prevailing ecological conditions could impact community members differently, by reducing access to land for a segment of the population that is already under stress, and therefore have implications on equity in both space and time. We identify important risks for sectors of the population that do not have the contextual features necessary for benefitting from REDD+ implementation and may be impacted, directly and indirectly, by decisions linked to benefit-sharing. We argue that such quantitative assessment is valuable to inform REDD+ policy design on the way livelihood practices and social characteristics are interlinked and how they affect forest cover change. This information can be used to anticipate potential equity issues that may arise with REDD+ implementation. We suggest that contextually informed definitions of the benefits and costs are critical for achieving equity in benefit-sharing. A flexible adaptive management and equity conscious approach is recommended from the policy design to implementation, by anticipating and mitigating potential risks of REDD+ interventions in order to promote equitable outcomes at the local level.

1. Introduction

Concerns have been raised globally about the potential impacts of policies aimed at Reducing Emissions from Deforestation and forest Degradation (REDD+) in developing countries at the local level, particularly on indigenous and forest dependent communities (Angelsen et al., 2012; Cotula and Mayers, 2009; Luttrell et al., 2013; Isyaku et al., 2017). Depending on their design and implementation, REDD+ interventions present risks since they have the potential to affect rural people's livelihoods by imposing new restrictions on access to valuable resources, by removing decision-making autonomy on resource use and by undermining long-established traditional forest management regimes (Peskett, 2011; Ribot and Larson, 2012).

Discussions to avoid harm and create co-benefits in communities where poor and vulnerable people depend on forestland for their livelihoods is among the most sensitive topics linked to REDD+ activities (Brown et al., 2008; Peskett et al., 2006). Concerns about its potential impacts have led to the adoption of REDD+ social safeguards that recognize the need for the full and effective participation of indigenous peoples and local communities, for respecting their knowledge and rights, and for the enhancement of social benefits (UNFCCC, 2010).

Trade-offs have been identified in the REDD+ context between the environmental effectiveness in reducing carbon emissions, the cost-efficiency of mitigation activities implemented, and equity between those

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https://doi.org/10.1016/j.landusepol.2018.03.011
Received 20 October 2017; Received in revised form 5 March 2018; Accepted 5 March 2018
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who benefit and those who assume the costs, (known as the 3E criteria: for effectiveness, efficiency, and equity) (Angelsen et al., 2009). If maximizing the reduction of emissions at the lowest cost possible is a valuable goal for addressing climate change, the potential consequences of REDD + interventions in terms of social equity cannot be ignored.

McDermott et al. (2013) provide a conceptual framework that identifies three dimensions of equity: distributional, procedural, and contextual equity.

Distributional equity refers to the distribution of benefits and costs of REDD + program among stakeholders through the creation of benefit-sharing mechanisms in REDD + participating countries. It focuses on the fairness of the REDD + outcome. Benefit-sharing mechanisms encompass the institutions and governance structures that deal with the distribution of REDD + costs and benefits (financial and non-financial). It is of crucial importance in the design of REDD + intervention as a means to incentivize behavioral change that will address the drivers of deforestation and forest degradation, leading to climate change mitigation benefits (Weatherley-Singh and Gupta, 2015). Different goals and rationales have been proposed about who should benefit from REDD + and why they should receive incentives, highlighting the perception that equity is taking shape differently among actors (Schroeder and McDermott, 2014). Previous studies have categorized different rationales for the distribution of benefits and have analyzed their potential consequences in case-study countries (McDermott et al., 2013; Luttrell et al., 2013; Pascual et al., 2010; Pham et al., 2013).

Procedural equity, on the other hand, addresses the perceptions of fairness and legitimacy of the political processes that lead to decision-making (Tyler, 2011) and relates to representation, participation, inclusion, and recognition in decision-making processes. This dimension of equity focuses on the fairness of the process. Procedural equity has been discussed in the REDD + context in relation to the establishment of standards that respect the principle of free, prior and informed consent (FPIC) (Colchester and Ferrari, 2007; Brown et al., 2008) and the participation of indigenous and local communities to the design and implementation of REDD + interventions (Holmes and Potvin, 2014).

The third dimension, *contextual equity*, concerns the pre-existing conditions that enable or restrain participation in decision-making processes, the access to resources and the resulting benefits. Rarely addressed, this structural dimension invites policy makers to take into account the social and political context at the root cause of inequality when designing REDD + interventions at the local level (Di Gregorio et al., 2013; Pasgaard et al., 2016).

Important linkages between these three dimensions of equity exist. For instance, the way decisions are made can also have an impact on outcomes, namely the distribution of benefits. Democratic, interactive and deliberative processes for local participation have been identified as central to help understand the needs and aspirations of the rural poor, define benefits and in the design of benefit-sharing mechanisms (Gebara, 2013; Ribot and Larson, 2012) so that the outcomes can be perceived as fair. Experiences in community forest management show that fair representation and active participation of the poor, indigenous and women is an essential component to promote equitable outcomes at the local level (Mahanty et al., 2009; Schreckenberg and Luttrell, 2009; Pelletier et al., 2016).

Despite being identified as an essential component of REDD + success (as one of the 3E criteria), quantitative assessments of equity at the local community level has been lacking. Furthermore, the question of how to evaluate contextual equity and link it to policy tools to address distributional equity has not been answered.

Expanding on the notion of contextual equity, this paper proposes a framework to quantitatively assess contextual equity of the socio-ecological system using mixed methods. Under this framework, the social and ecological prevailing conditions are quantitatively assessed, without resorting to prior assumptions. For the social context, we use multivariate statistical analysis on a full household census to answer three main questions: (1) Can we identify differences between households based on social characteristics and on livelihood strategies at the village level? (2) What are the factors implied in this social differentiation? (3) Is there a relation between social characteristics and livelihood strategies? To assess the ecological context, we use participatory mapping and a time series of remote sensing images to assess forest cover change and the agricultural dynamics inside the village boundaries. This framework was tested at a REDD + pilot project site in the Democratic Republic of Congo (DRC), but it can also be applied to other areas.

Using the results from this case study, we examine how prevailing ecological and social conditions could potentially affect the equity outcome of a REDD + intervention, *inter alia* by examining different options for benefit-sharing already developed in the literature. We argue that these prevailing conditions can be assessed, even quantitatively, and that this contextual information is important in REDD + policy design to prevent unintended consequences in benefit sharing at the village level. We wish to clarify that the REDD + mechanism is not prescriptive on how emission reductions can be achieved. The REDD + intervention that we evaluate with this study, with a village-level pilot project, is only one type of policies and measures that developing countries can implement to reduce emissions or increase absorptions.

Here we provide an overview of forest governance in the DRC, a key player in the REDD + climate change mitigation efforts. We set the stage of the REDD + pilot project case study and describe the field data collection methodology as well as the statistical and remote sensing analysis performed in the Materials and Methods section. Results from our replicable quantitative approach are presented for both social and ecological conditions and followed by a discussion of the potential equity impacts of those assessed conditions under different benefit-sharing options.

1.1. Forest governance and REDD + in the DRC

The DRC hosts about half of the second largest tropical humid forest in the world (de Wasseige et al., 2014) and has experienced a historically low annual rate of deforestation of 0.2% (Duveiller et al., 2008; de Wasseige et al., 2010), with gross forest cover loss of 37,118 km^2 for the 2000–2010 period (Potapov et al., 2012). Forest degradation could however affect up to three times more area than deforestation alone (Shapiro et al., 2016; Tyukavina et al., 2013). Shifting cultivation drives the current patterns of forest cover loss (Defourny et al., 2011; Molinario et al., 2015). Future land-use scenarios project increased deforestation driven by population growth and expansion of commercial agriculture, timber and minerals extraction driven by global demand (Galford et al., 2015; Mosnier et al., 2014; Phelps et al., 2013).

In the DRC, forests are owned by the state, which recognizes local communities' customary user rights to land and forest resources (German et al., 2009; Mpoyi et al., 2013). The 2006 constitution recognize customs as source of rights and is used to rule and regulate human relationships, as long as the local customary rules do not contradict statutory law and conform with public order, right and equity (Mashini Mwatha, 2011). While the state claims ownership of all forestland, in rural areas, customary institutions govern forest and land resources in practice (Debroux et al., 2007; Bernard and Gélinas, 2014). These customary institutions differ widely across the DRC but generally land rights are transferred through patrilineal inheritance and confirmed by clearing a piece of forest for agriculture under customary law (Samndong and Nhantumbo, 2015). In many areas, women cannot hold land rights independently of their husbands and other male relatives (Gouzou et al., 2009; Stiem and Krause, 2016) and restrictions also apply to Batwa[1] indigenous people, though information differs among

[1] The Batwa is an ethnic group more commonly referred to as "Pygmy" in the region. They are also referred to as *Peuples Autochtones* (PA) in French, which means indigenous people.

sources (Mashini Mwatha, 2011). Those who do not have land rights, including internal migrants or *allogènes*, can rent land through different types of compensation agreement (Samndong and Nhantumbo, 2015). The land right-holders or *ayant-droits* are those who possess customary land rights and non-right-holders (*non ayant-droits*) those who access land through renting agreements.

Over the last decade, the DRC has been very active in the ongoing international climate negotiations and has accomplished several milestones towards readiness for the implementation phase of REDD+ (MECNT, 2010; Aquino and Guay, 2013). The country has attracted pilot investments in the region, including from multilateral and bilateral donors as well as from international NGOs, while also receiving technical and financial support of the Forest Carbon Partnership Facility (FCPF) and the UN-REDD program (Fobissie et al., 2014), as well as the Congo Basin Forest Fund (CBFF) of the African Development Bank. It is the first African country to launch a national forest monitoring system and a REDD+ National Registry for the monitoring of REDD+ projects. DRC has also adopted a National REDD+ Framework strategy in 2012, including a REDD+ National Fund and National REDD+ social and environmental standards. The latter were established "*to enable the management, monitoring, reporting and evaluation of the implementation of social and environmental measures for all REDD+ activities*" (République Démocratique du Congo, 2012), and are focused on increasing and sharing potential social and economic benefits.

Despite these important advancements, REDD+ governance in the DRC may be limited by several structural shortcomings and deficiencies in state institutions, characteristic of what has been described as a 'fragile state' (Mpoyi et al., 2013; Karsenty and Ongolo, 2012). Challenges for effective implementation of REDD+ in the DRC include the limited capacity of the Congolese government to implement sectoral reforms due to low levels of technical and institutional capacity, foreign interventions in policy processes, corruption, and lack of state control in portions of the national territory (Aquino and Guay, 2013).

One particular area of potential tension that may hinder the implementation of REDD+ is related to benefit-sharing mechanisms between different levels of government, between the state and local communities, and inside communities themselves (Balderas Torres and Skutsch, 2012). Previous experiences reveal conflicts in the sharing of tax revenue from the exploitation of natural resources between the central and local governments (Aquino and Guay, 2013). However, Fobissie et al. (2014) argue that the true tension and challenge in terms of REDD+ benefit sharing in the DRC is at the local community level, taking into account customary rules and local idiosyncrasies. Equity at the local community level is the focus of this study.

2. Materials and methods

2.1. Study area

This case study was conducted as a contribution to a REDD+ pilot project "*Projet Équateur*" located in the Équateur Province of the DRC. Équateur is one of the most forested areas of the DRC, with 87.9% forest cover[2] (Potapov et al., 2012), but it also has about 90% of its population living below the poverty level (PNUD Mars, 2009). The project was conducted in collaboration with DRC's Ministry of Environment and broadly aims to generate knowledge on how REDD+ can be designed at the local level in order to protect forests, improve livelihoods and promote sustainable development in the DRC. The project is implemented under a predominantly customary system of land and forest management. Our study focused on the village of Buya I in the sector *Les Élangas*, Bikoro territory located at 42 km South of Mbandaka, the Province's Capital. The village is characterized by two main ethnic groups, Bantu and Batwa (pygmy). The Batwa ethnic group is considered indigenous in the DRC. Livelihoods are predominantly based on shifting cultivation activities, and supplemented by hunting, fishing, and non-timber forest products (NTFP) collection. Residents are highly dependent on land and forests for their livelihoods. Using this case study, we assess equity from a socio-ecological system perspective, acknowledging the role of both the ecological system of this rural complex and the social system at the village level as well as their feedbacks in determining the potential equity outcome.

Previous studies at the same pilot site have addressed other contextual factors that may limit access to decision-making processes and participation (Stiem and Krause, 2016). These are the political, cultural and social norms context associated to the existing power dynamics and participation in decision-making at the local level (Ribot and Larson, 2012). Gender inequality is a contextual feature previously discussed in which factors that limit women's participation in decision-making at many levels are identified (Samndong and Kjosavik, 2017) and where empowerment is considered at the essence of democratic participation (Stiem and Krause, 2016). These aspects are related to the difficulties of some marginalized groups to be represented in local decision-making processes and gain access to opportunities and benefits. Other actors from outside the village however, are able to use different spheres of influence, inside or outside the customary norms, taking advantage of the legal pluralism surrounding forest resources authority and management in the DRC to access forest resources (Samndong, 2015).

2.2. Field data collection

Field data collection was performed between November 2013 and February 2014 and included a household survey and participatory mapping. Additional details on methods and analysis are provided in Appendix A in Supplementary material.

2.2.1. Household survey

A household survey was administered using Open Data Kit (ODK) tools on e-tablets and on paper to one representative of each of the 379 households found in Buya I to gather information on the demography, social characteristics, customary land rights as well as land use and livelihood practices. The survey was designed in French with inputs from Project Équateur DRC team. Congolese partners and local field assistants received training on the survey and methods. These hired and trained surveyors consensually agreed to the proper translation in Lingala and in the local language, Mongo. A pre-test phase and modifications were performed before the large deployment. Completed E-survey were uploaded to the server from Mbandaka after each day of work and cross-checked for accurate entry.

2.2.2. Participatory mapping

A participatory mapping exercise was organized to elicit participant views on customary land and forest resources as well as map out primary physical and cultural features (including village boundaries). The mapping workshop was led in the village with the participation of about 60 villagers, including representative from neighboring villages. It was conducted in French by the lead author with the assistance of one co-author on this paper and trained Congolese partners who provided translation and facilitation. To represent different user groups and favor free and open discussions, five interests groups were formed: Hunters and fishermen, Women, Youth, Pygmy and local authority (clan chiefs, customary chief). Groups used the ground and sticks to draw and discuss the first maps and then re-copied these onto paper maps. Results were presented in assembly and, after deliberations, a final representation was drawn onto a base map, a very high resolution (< 2m) DigitalGlobe GeoEye satellite image to help geo-localize the main features in the village and surroundings.

[2] The percentage of forested area was calculated based on forest area for the former Équateur Province based on (Potapov et al., 2012) on its total area. This former Equateur Province is now split into five provinces including Équateur, Tshuapa, Mongala, Nord-Ubangi and Sud-Ubangi provinces.

GPS point collection for geo-referencing the maps was performed by selected villagers after training. GPS points and accompanying field information were used to create the different features identified (points, lines and polygons) in a digital geographic information system (ESRI ArcGIS).

2.3. Data analysis

2.3.1. Statistical analysis of household survey data

Statistical analysis was performed on the household survey data (see Table 1A in Appendix in Supplementary material for description of variables). We performed a series of univariate and multivariate statistical tests to unveil relationships between household characteristics and livelihood practices. We normalized quantitative variables if they departed from the normal distribution using the square-root transformation or log transformation prior to analysis.

To test for the presence of a statistical relationship or dependence between univariate variables, we used the following tests depending on variables' mathematical type: (1) one-way analysis of variance (ANOVA) with permutation test (Legendre, 2007) with Tukey Honestly Significant Difference (HSD) post hoc test; (2) Pearson's Chi-square (X^2) test with Freeman-Tukey (FT) deviates post hoc test (Legendre and Legendre, 2012) and (3) Ordinary Least Square regression with permutation tests. For example, we examined households characteristics that would explain differences in the area cleared in 2013 (including primary, swamp and secondary forest and fallow) per household, using ANOVA with permutation tests.

Multiple regressions with a forward selection procedure were used to identify household variables that contributed to best explain the variation in reported forest area cleared in 2013. We used distance-based redundancy analysis in order to explain variation between household variables and the types of crops or the types of forest products used (both binary variables) (Borcard et al., 2011).

Clustering methods were used to search for and identify discontinuities in the data (Legendre and Legendre, 2012), in order to distinguish: (1) social groups based on household characteristics (hereafter *household clusters*) and (2) livelihood strategies based on land use and subsistence practices (hereafter *livelihood clusters*). We used Ward's minimum variance clustering method that defines groups minimizing the within-group sum of squares (Borcard et al., 2011) on transformed data using Gower's similarity measure (S_{15}). Seven household clusters were defined based on household characteristics. Seven livelihood clusters were defined based on livelihood practices. Each group created under the household clusters and under the livelihood clusters was examined using summary statistics in order to highlight the key defining characteristics of each group. We then looked at relationships between the household clusters and livelihood clusters using Chi-square tests. We tested the relationship between the cleared forest area with household clusters using ANOVA and the reported economic status with the livelihood clusters using Chi-square tests. All statistical analyses were performed in R open source software version 3.2.2 (R Core Team, 2016).

2.3.2. Land-use/cover change analysis

We used a time series of four very high resolution (< 5m) GeoEye and Ikonos satellite images to assess land-use dynamics over a 10-year period starting in early 2002 and finishing at the end of 2011 (Table 2A, in Appendix in Supplementary material). First, we digitized recent clearings on each image independently to identify the number and the area of clearings for each year inside the village boundaries. We then performed a temporal change analysis to determine land-use change over time, after image pre-processing (radiometric, atmospheric and geometric corrections). From 2002–2011, it became obvious that a very limited area of primary forest (mainly swamp forests) was cleared. To maximize accuracy of the classification, we performed a first classification to distinguish Forest/Non-forest classes using the 2002 and the 2011 images. Deforested area was identified during post-classification using visual interpretation. Afterwards, we performed a second classification of the Non-forest area using the four images to tract the agricultural land dynamics, namely the transitions from agriculture to fallow, fallow to agriculture and no change. These classifications were performed using a four-step mean-shift segmentation algorithm applied to normalized difference vegetation index (NDVI) images, using Monteverdi Orfeo ToolBox software (Horning, 2013b). Statistics on segment features were collected as well as training data for each classes. Image classification was performed using *RandomForest* algorithm, which is a machine learning approach that makes use of regression tree model ensembles (Breiman, 2001). *RandomForest* was applied to the segmented image using segment feature statistics and the training data collected (Horning, 2013a). The classification for each period was verified and validated through visual interpretation and any inconsistencies were corrected with post-classification segment edits. Area of change and other statistics on classification outputs were calculated for each period.

3. Results

3.1. Household characteristics and land-use practices

Using the household survey data we unveiled relationships between social characteristics and land-use practices. We found a significant difference in cleared area between land right-holders and non-right-holders ($F_{\alpha=0.05(2),1,377} = 27.26$, $p = 0.001$), with right-holders clearing significantly more (2.5 ha) compared to the non-right-holders (1.5 ha). We also found a significant difference in terms of area cleared between ethnic groups ($F_{\alpha=0.05(2),1,376} = 48.32$, $p = 0.001$), with Bantou ethnic group clearing more area than Batwa (pygmies), who represent less than 20% of the adult population (Table 1). We obtained a significant difference in terms of clearing area between those born in Buya I and those born elsewhere ($F_{\alpha=0.05(2),1,377} = 9.00$, $p = 0.002$), with a mean of

Table 1
Demographic characteristics of the Buya 1 village inhabitants.

Characteristics	Sub-categories	Count	%
Total number of inhabitants		2235	
Adults > 15 yrs old and% of total population		1030	46.1
	Number of men (adults) and% of adults	524	50.9
	Number of women (adults) and% of adults	506	49.1
Total nb of children (< 15yrs old) and% of total population		1205	53.9
	Children from 0 to 5 yrs old	589	26.4
	Children from 6 to 10 yrs old	390	17.4
	Children from 11 to 15 yrs old	226	10.1
Total nb of adults by ethnic group and% of total population			
	Bantou	837	81.3
	Batwa	188	18.3
	Other	5	0.5
Total nb of adults by clan and% of total population			
	Djipanga	107	10.4
	Ekole	288	28.0
	Esangele Nkoy	273	26.5
	Other	361	35.1
Average nb of children per Bantou family		9.6	
Average nb of children per Batwa family		7.3	

2.2 ha and 1.7 ha respectively, and a significant difference in terms of land holding ($F_{\alpha=0.05(2),1,377} = 64.36$, $p = 0.001$), with the *Allogènes* or alien having significantly less land rights. We identified a significant difference in area cleared by economic status ($F_{\alpha=0.05(2),3,372} = 6.94$, $p = 0.001$), between Average and Very Poor and between Poor and Very Poor households, with richer households clearing more land. There was also a significant relationship between the primary occupation of the head of household and the cleared area ($F_{\alpha=0.05(2),6,370} = 19.89$, $p = 0.001$), with cultivators clearing more than laborers, merchants, and timber company employees working for forest companies outside Buya I. Laborers and sellers also clear less than people with 'Other' primary occupation and students, who practice agriculture as a secondary occupation.

A significant positive relationship was also observed between the area cleared and years of education (Adjusted $R^2 = 0.063$, p=$4.444e^{-07}$),between the area cleared and the number of children (Adjusted $R^2 = 0.082$, p= $8.707e^{-09}$), and between the area cleared and the number of adults in the household (labor force) (Adjusted $R^2 = 0.069$, p= $1.364e^{-07}$), although less than 10% of the variation was explained in any of these models. More than half of the village population is younger than 15 years old, with Batwa having on average fewer children (7.3) than Bantou (9.6) (Table 1). We found a significant relation between landholding area and the deforested area, which indicates land right holders with more land also clear more area (Adjusted $R^2 = 0.078$, p= $1.638e^{-08}$), but again little of the variation was explained. The multiple regression models, combining both quantitative and qualitative variables, followed by forward variable selection, explained 31% of the variation in cleared area (Adjusted $R^2 = 0.312$, p= $< 2.2e^{-16}$), with the primary occupation, the number of animals owned, the number of children and the right-holding area explaining the variation in cleared area.

In terms of social patterns between household characteristics, we found a significant relationship between the ethnic group and the economic status, with Bantou disproportionately representing comfortable and average economic status while Batwa were dominantly represented in the poor and very poor categories ($X^2 = 61.582$, $df = 2$, $p = 4.242e^{-14}$). There was also a significant dependence between the economic status and the land right-holder status, with Very poor having disproportionately less land right and the richer economic group having more land rights ($X^2 = 23.14$, $df = 3$, $p = 3.772e^{-05}$). A significant relationship was also obtained between the economic status and the primary occupation of the head of household ($X^2 = 41.87$, $df = 12$, $p = 3.49e^{-05}$), with people having 'Other' occupation, including people working in the service sector (e.g. teachers) or specialized workers (e.g. mechanics), showing higher economic status and found significantly less in very poor category. As expected, laborers are significantly more categorized as 'very poor' and significantly less in higher economic status. Right-holders also significantly more often own animals ($X^2 = 9.728$, $df = 1$, $p = 0.002$).

We found no significant relationship between gender (of the household head) and the cleared area, or the size of landholding or economic status. We found no significant relationship between the place of birth (in Buya I or elsewhere) and economic status. Using linear discriminant analysis, household characteristics and livelihood variables could not be clearly separated on the basis of the economic status. Using distance-based redundancy analysis, household characteristics did not explain much of the variation in the type of crops and/or forest products used. These results indicate that relations between household characteristics and livelihood strategies are complex and/or more stochastic, and that household characteristics are not strong predictors of livelihood decisions.

3.2. Household groups and livelihood strategies

Seven groups based on demographic and household characteristics were created and interpreted on the basis of the defining characteristics that they embody (Fig. 1). Gender is one key differentiating factor amongst groups, as well as the ethnic group. Two female head of

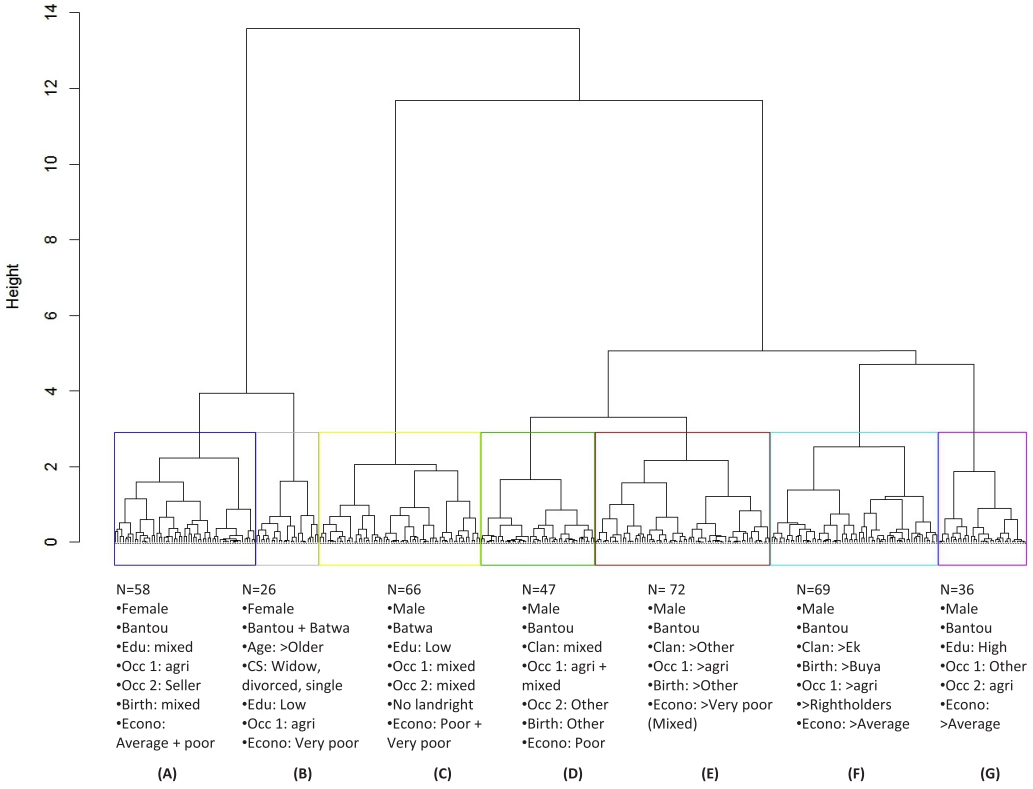

Fig. 1. Clusters dendrogram of household social variables with the key characteristics defining each group. The sample size is given by N. The sign > signifies a dominance of the key characteristics mentioned. 'Mixed' indicates that we identified no dominant characteristic. Agri = agriculture; Occ 1 = Primary occupation; Occ 2 = Secondary occupation.

household groups were formed. The first cluster includes female heads of households from the Bantou ethnic group, that have on average more years of education, who sell part of their harvest, and have poor and average economic level (group A). The second one includes Bantou or Pygmy women (group B) that share the following social characteristics: low education, older average age and in majority widow, divorced or single. Five male head of household groups were obtained: (1) a pygmy group without land-rights, with low education as well as low and very low economic level (group C); (2) a Bantou group with high level of education, working outside the agricultural sector or studying (group G); (3) a Bantou group born in Buya I and holding land rights, with agriculture as primary occupation (Group F); 4) a Bantou group born elsewhere and with many head of household from other clans than the typical ones found in Buya I, with very poor and mixed economic status (Group E); 5) a Bantou group, born elsewhere, with 'Other' secondary occupation and generally poor (Group D). The village is represented by three main clans but about 35% of the inhabitants are from other clans (Table 1). This clustering approach allowed us to differentiate socio-economic groups, including the most well off economically (group G) and the most vulnerable (group B and C). Among the most vulnerable, we find members of the pygmy ethnic group (C) and also a subset of women head of household.

We used the same methods to identify and typify different livelihood strategies (Fig. 2). We found that all groups make use of the land or of forest products. Two groups do not base their livelihoods on subsistence cultivation, with one characterized by a 'hunting & gathering' livelihood (group I) while the other shows very limited use of the land and of forest products (group V). This livelihood group having very limited land use activities present mixed household characteristics but is mostly represented by households without land rights, with a high proportion of women head of household and in pygmy ethnic group, along with very poor and poor households. Other livelihood groups use manioc as a staple and produce more clearings for agriculture. Group VII is the most diversified in terms of the type of crops cultivated and livelihood activities compared to other groups including raising animals, charcoal and timber production as well as fishing. In terms of diversity, they are followed by Group II, which have less varied types of crops but supply their livelihoods by hunting and charcoal production. Groups III, IV and VI show difference in land use practice but have generally a less diversified set of subsistence activities.

We used Chi-square tests to search for the presence of relationships between household social clusters and livelihood groups. We found the male pygmy group C is significantly more represented in the 'hunters and gatherers' livelihood group and significantly less in the 'most diversified agriculture livelihood' group VII. Households in Group D, represented by Bantou mostly born elsewhere, are significantly less represented in the diversified livelihood cluster. Group D also has the largest average clearing area. Group E and F, that are represented by Bantou, right holders and/or with higher economic status, were significantly less represented in the 'hunters and gatherers' livelihood group. The female Bantou + Pygmy group B was significantly less represented in livelihood group II and III, and more in IV, indicating that they rely less on animal raising, hunting, and fishing than cultivation of staple crops.

We also found a significant difference between household social clusters and the area cleared with group B and C, representing the most socio-economically vulnerable groups, having smallest average area of clearings. There is a significant difference of cluster C (male Pygmy group) with all the other household groups except for B, and for group B (female Bantou & Pygmy group) with group D, E, and F.

Finally, using Chi-square tests, we found a significant dependence between the livelihood strategies and economic status, with higher economic status households being more represented in the most diversified livelihood group VII, and very poor households significantly less represented in that group. Also, households of higher economic status were found significantly less often in the 'hunters and gatherers' livelihood group.

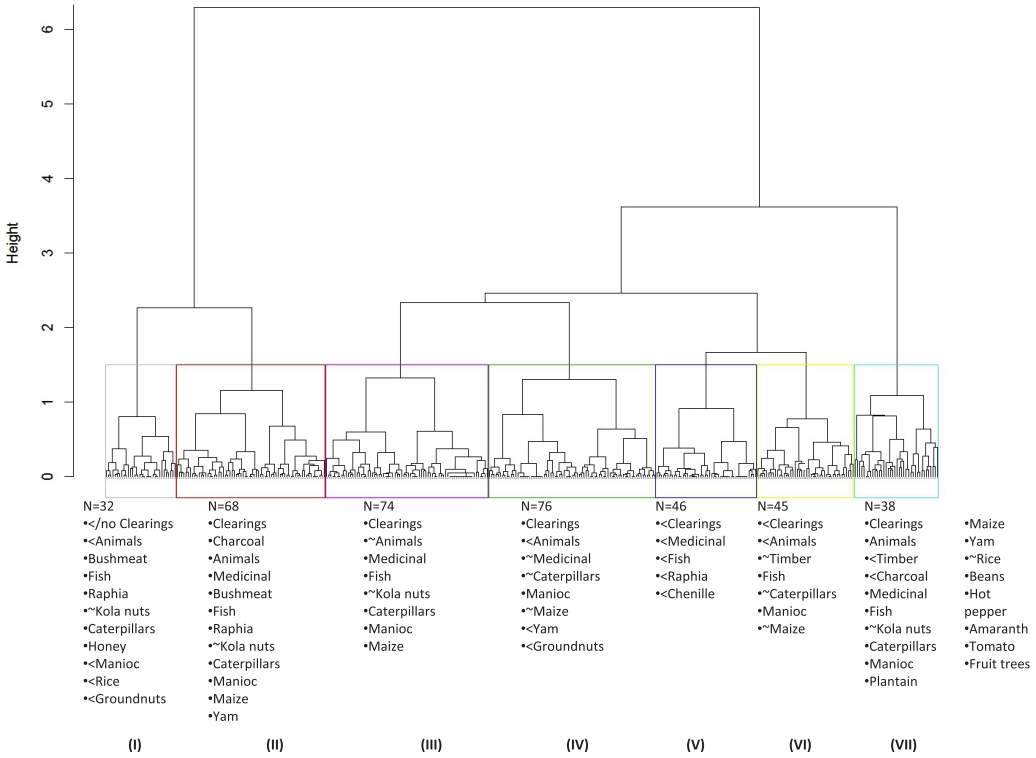

Fig. 2. Land use and livelihood strategy clustering dendrogram. The sample size is given by N. The sign < signifies that only a small number of household perform this practice while ' ~ ' indicate that about half of households in the group are practicing. Animals refer to domestic animals such as goats and chickens. This is in contrast to bush meat which is obtained by hunting. Fish include only those caught by the household, not purchased. Manioc is also known as *Cassava*.

3.3. Customary land rights

Through the household survey, we obtained a snapshot of the effective implementation of customary lands rights in Buya I, including information about the landholding of the land right holders as well as about the access to agricultural land by those without customary rights. Forming about only 32.7% of the households, most of the right-holders have acquired land through inheritance, some by marriage, purchase or renting (Table 2). Only 4% (5 of 124 right holders) have obtained their arable land through forest clearing. A majority of right-holders have customary rights on one undivided plot of land; only five right-holders have more than 5 plots of land. The median landholding size is 4 ha, while the minimum is 0.4 ha and the maximum 210 ha. This shows that even among right-holders, the landholding size in Buya I is highly skewed. Some right-holders have plots of land in Buya I and elsewhere, while a few have land rights outside Buya I.

Forming the majority of the population (255 of 379 households), those without customary right to land, mostly gain access to agricultural land by renting (80.9% of non-right-holders), in majority to right-holders that they know (38.3%) or to friends (33.1%) (Table 3). Land rental arrangements are paid through monetary compensation (63.5% of the cases) at a median value of 20,000 Congolese francs equivalent to US$22 per year. Some of those landless people (10.3%) compensate the right-holder by providing a fraction of the harvest (between 40 and 60%), namely by sharecropping. Others compensate with a raised animal (goat or pork) or receive a daily wage as laborers. More than 100 right-holders were mentioned as renting land. Out of the 157 plots rented, 15 of them were rented by women. The median plot size is 1 ha, with a maximum area of 50 ha, provided to the landless by a family member who receives compensation for the land. Most of those having land through an employer are pygmies, whom generally work as laborers and give in-kind compensation from crops harvested to their employer. Only one employer in the village was mentioned by multiple laborer respondents. Some right-holders rent land to many landless; one of them is the customary Chief (16 plots) and the others are those with the largest landholdings.

Table 2
Characteristics of the land right holders and their landholdings.

Characteristics	Categories	Frequency	%
Household land rights			
	Land right-holders	124	32.7
	No land right-holders	255	67.3
Number of plots for land right-holders			
	1	69	55.2
	2	25	20.0
	3	14	11.2
	4	9	7.2
	5	3	2.4
	> 5	5	4.0
Location of plots			
	Buya	197	81.4
	Buya and Outside	36	14.9
	Outside	9	3.7
Acquisition procedure of the land owned			
	Inheritance	141	63.8
	Marriage	27	12.2
	Purchase	17	7.7
	Renting	12	5.4
	Attribution by the clan and inheritance	8	3.6
	Forest clearing	5	2.3
	Donations	4	1.8
	Other	4	1.8
	Attribution by the clan	3	1.4
Plot area statistics		***Area (in hectares)***	
	Mean area	10.5	
	Median	4	
	Minimum	0.4	
	Maximum	210	

Table 3
Land access conditions for inhabitants without customary land rights.

LAND ACCESS VARIABLES	Category/statistics	Frequency	%
Type of land access	Rental	127	80.9
	Through Employer*	21	13.4
	Loan	6	3.8
	No land access	3	1.9
	Community land	0	0.0
Relationship to the right holder	Known person	60	38.2
	Friendship	52	33.1
	Employer	23	14.6
	Family	20	12.7
	Other	2	1.3
Arrangement with right holder	choice 1	99	63.5
	choice 2	16	10.3
	choice 3	15	9.6
	choice 4	6	3.8
	Other	20	12.8
Customary right holders	Number of right holders providing land	109	
	Number of plots	157	
	Held by Female right holder	15	
	Held by Male right holder	142	
Area cultivated/acquired (ha)	Median	1	
	Mean	1.86	
	Maximum	50	
Monetary Compensation (in Congolese Franc)**	Median	$20,000	
	Mean	$22,308	
	Maximum	$60,000	

* The respondent works as a laborer.
choice 1 = You pay the rental with money.
choice 2 = You give a compensation to the right holder (share of the harvest or other).
choice 3 = The right holder pay you with money to cultivate its land.
choice 4 = The right holder compensate you with a share of the harvest or other.
** In November 2013, 1 USD was equal to approximately 900 Congolese Francs.

3.4. Land use and land-use change in the rural complex

Based on participatory mapping, we obtained information about the village history, land use practices and changes over time (Fig. 3). The village was founded in 1922, with the land provided by the neighboring village of Bongonde Djole. It was relocated along the road axes during the colonial period. Batwa arrived in the 1970's, and a portion of land was ceded to them. The participants noted the decline in primary *terra firme* forest, which has almost completely disappeared and is replaced by fallow (some of them dominated by grass), agricultural land and some isolated patches of secondary forests. The mapping participants explained this decline in primary forest to be the result of demographic expansion, poverty, and slash-and-burn agriculture. Shortened fallow period was noted. Sacred forest area (*Djembo*) and the cemetery (*Ngelo*) are primary forest patches that remain untouched for cultural purposes. The swamp forest was noted to have mostly been preserved by the community.

Our remote sensing assessment illustrated the trend in agricultural land usage, in forest clearings and in the agriculture-fallow dynamics. Recent clearings were digitized for each year where very high resolution imagery was available (Fig. 4). Inside the village's limits obtained via participatory mapping, we compared statistics on the number of clearings and size in each year (Table 4). We observe a clear increase in the number of agricultural clearings from 55 in 2002–232 in 2011, and in the area covered by clearings from 16.2 ha in 2002–28.4 ha in 2011. There is also a decline in the minimum, mean and maximum size of the clearings for cultivation, as well as a lower variation between clearing size over time.

For the forest cover change analysis executed for the 2002–2011 period, we obtain 40.4 ha deforested area, equivalent to −0.004 annual

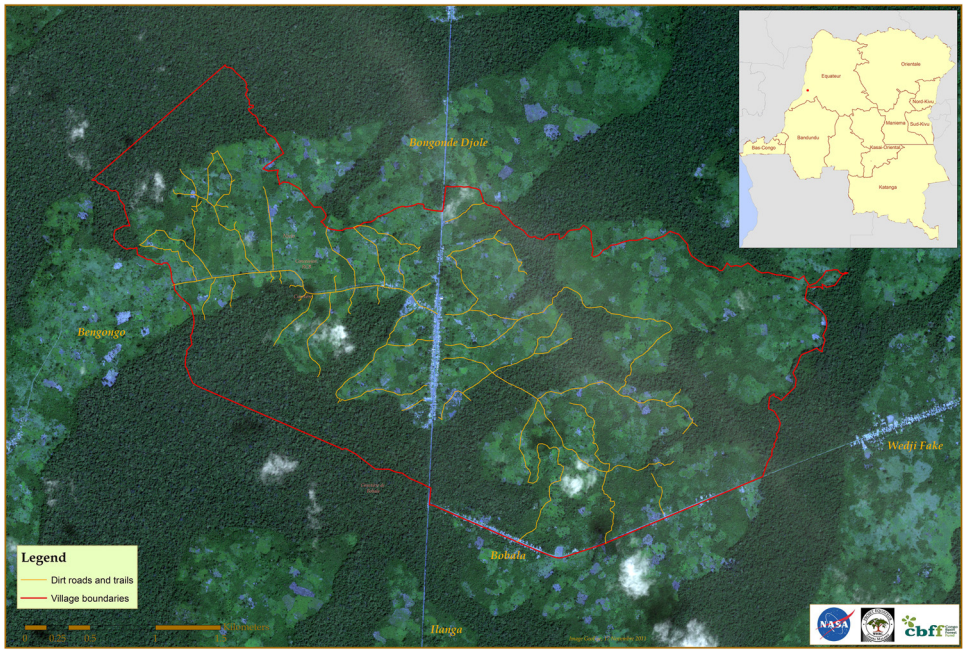

Fig. 3. Participatory map of the Buya I village, Province Équateur, Democratic Republic of Congo. Village boundaries are indicated in red and village trails are identified in yellow. The forest observed is swamp forest. Human settlements are located along the main roads. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

deforestation rate or −0.39% (Puyravaud, 2003), which is similar to the national rate (Hansen et al., 2013; Potapov et al., 2012). Swamp forests occupy 51.4% of the village territory and non-forest land 46.7%, including agriculture and fallow. The total village territory estimated through this study covers an area of 2175 ha.

The dynamics of shifting cultivation or agriculture-fallows are complex to interpret (Fig. 5). The five-year time gap between the 2005 and 2010 images most likely led to some loss of information about changes in this dynamic agricultural system. However, we observed more land converted from fallow to agriculture than agriculture going to fallow (Table 5). If we ignore the middle period (2005–2010), we see an overall increase in the annual area of fallow cleared for agriculture from the early period (2002–2005) to the latest period (2010–2011).

Fig. 6 shows the total area that went into active cultivation, assessed by compiling the information obtained from the three periods for the village area. A field or land area was considered active if it was

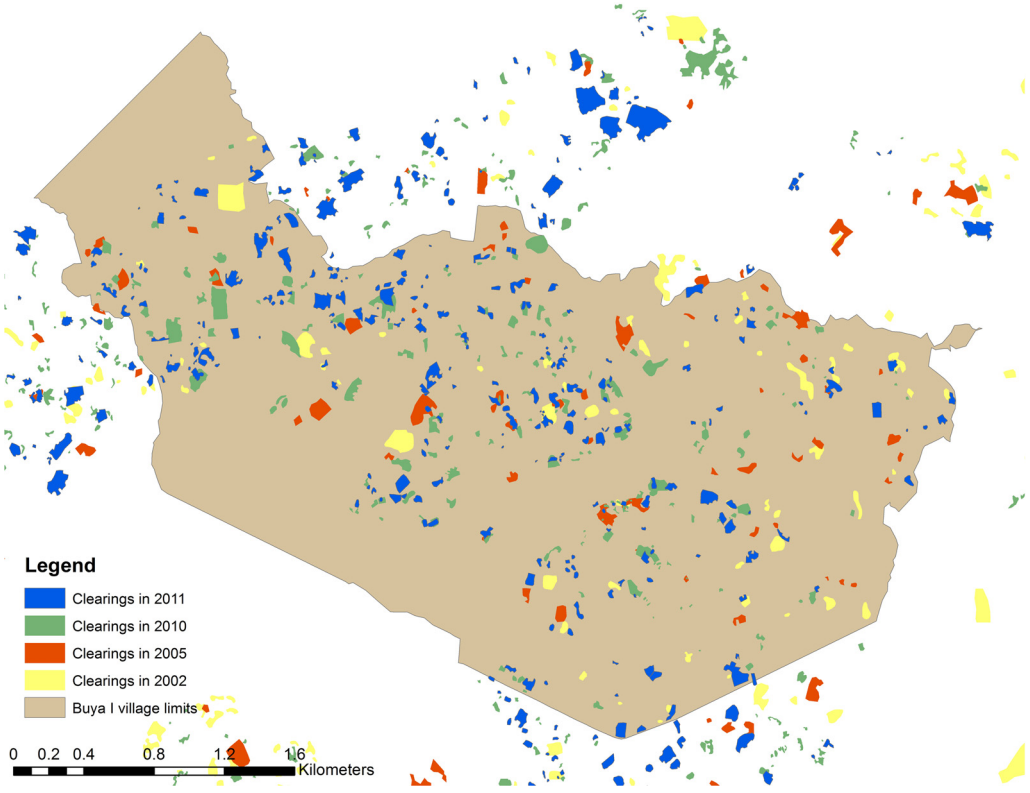

Fig. 4. Map of forest and fallow clearings throughout the time series of remote sensing images in and around Buya I village. The clearings were digitized for each year separately. The number and the size of clearings give an indication of the demand for cultivated land.

Table 4
Statistics on the number and size (in ha) of clearings from 2002 to 2011 in Buya I village based on digitization of clearings.

	2002	2005	2010	2011
Number Clearings	55	52	165	232
Minimum size (ha)	0.04	0.03	0.01	0.01
Maximum size (ha)	2.19	1.46	1.48	0.90
Sum of cultivated area (ha)	16.12	14.07	25.61	28.35
Mean size for cultivated area (ha)	0.29	0.27	0.16	0.12
Standard Deviation (ha)	0.38	0.28	0.23	0.14

Table 5
Statistics on the area of change in non-forest section for each time period in Buya I village, using change analysis based on segmentation and machine learning classification between images (in hectares). Annual change are reported to facilitate comparison between periods.

Time period	Total change area	Fallow to agriculture area	Agriculture to fallow area	Annual fallow to agriculture area	Annual agriculture to fallow area
2002–2005	135.4	85.5	49.9	28.5	16.6
2005–2010	179.7	96.3	83.4	19.3	16.7
2010–2011	60.0	40.8	19.2	40.8	19.2

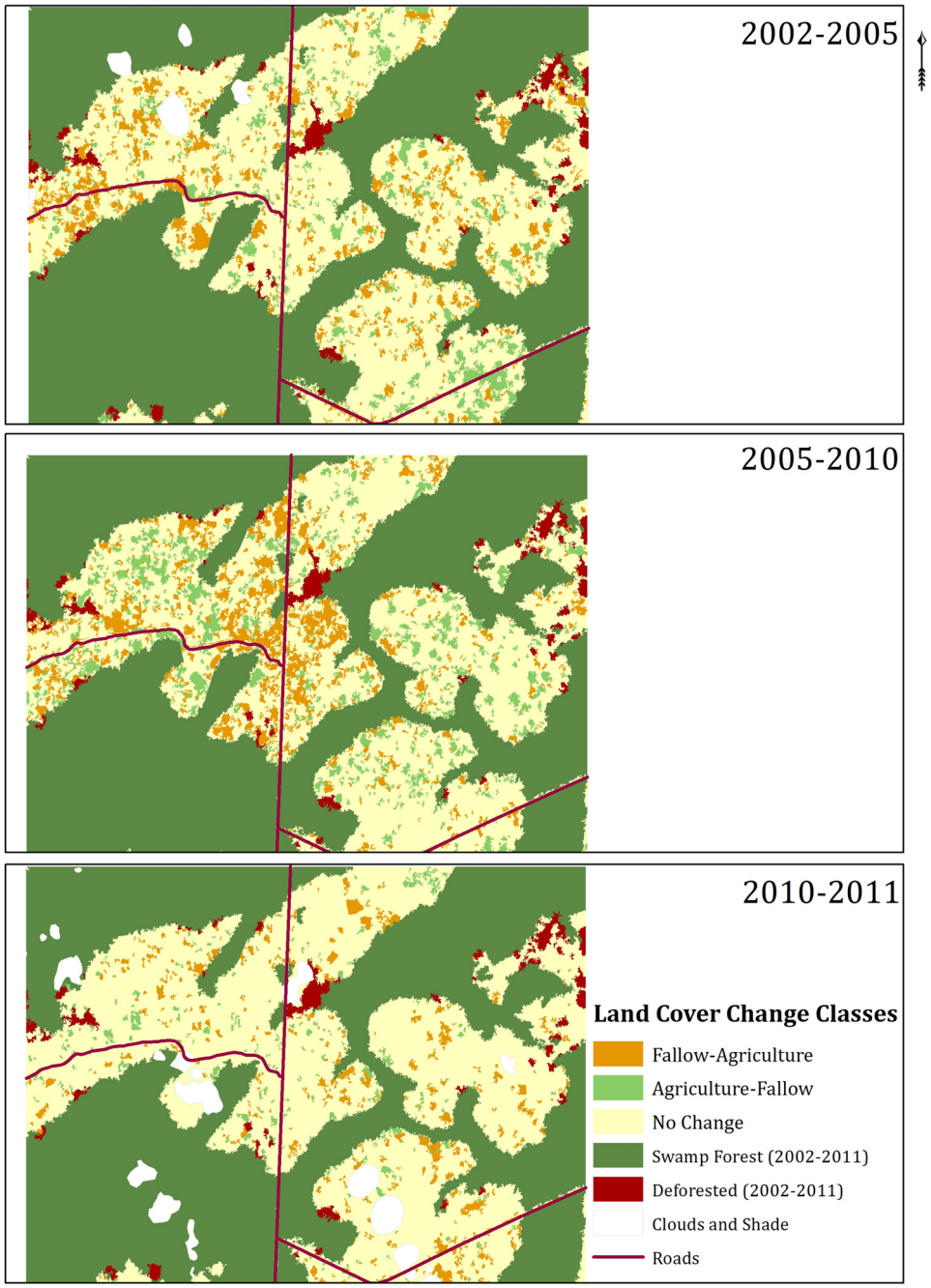

Fig. 5. Illustration of the land-cover change analysis performed for Buya I using very high resolution imagery. Change from 'Forest to Non-Forest' is quantified for the 2002–2011 period. Change in the agricultural system, in the non-forest area, is assessed for each the 2002–2005, 2005–2010 and 2010–2011 periods for 'Fallow to agriculture', 'Agriculture to fallow' and 'No change'.

Fig. 6. Map of the land-use dynamics for the 2002–2011 period. 'Active agricultural field' includes all fields that have been under cultivation at some point during the study period. 'Non Active' is the land in fallow during the whole period.

cultivated at some point during the time period (2002–2011). The active agricultural field area amounted to 308.5 ha for the 9-year period or 32% of the non-forest area.

4. Discussion

Equity concerns call for close attention to prevailing everyday realities that exist at the local level to examine the potential impacts of REDD+ interventions as well as other conservation and resource management activities. This study presents a rigorous analysis of land use change along with household and livelihood characteristics in a forest frontier village of the DRC. We show there are significant differences in household characteristics and in livelihood practices, and that the two are statistically related. Our analysis provides a complete overview of customary land tenure and of the land-use dynamics within the village boundaries. These quantitative results demonstrate existing disparities at the village level.

In order to explore the relation between pre-existing conditions and the potential outcome from an intervention, we developed a framework amenable to quantitative assessment and statistical testing. This framework can be used to acquire relevant contextual information at the community level and link it to the different rationales that have been developed in the literature on REDD+ benefit-sharing. We use the results from our case study to anticipate the potential social equity impacts of REDD+ project implementation by generating hypotheses on the potential distributive outcomes of different options for benefit-sharing. We argue for the need to adopt an equity-conscious approach in policy development at the outset, based on a structured framework that allow to anticipate potential equity concerns and prevent or mitigate those risks.

4.1. Framework to link contextual equity to outcome

We built a framework that consist of a set of questions aimed to get relevant information about the socio-ecological context and to use this information to reflect on possible impacts of a set of options for REDD+ benefit-sharing (Fig. 7). With this framework, we look at what could happen with the distribution of the benefits and costs arising from the implementation of a REDD+ intervention. We used five different goals or rationales for benefit-sharing based on previous work by Luttrell et al. (2013), McDermott et al. (2013) and Pascual et al. (2010) about who should receive incentives. That is, benefits should go to: 1) actors with legal rights, statutory or customary; 2) actors achieving emission reductions or carbon sequestration; 3) low-emitting forest stewards; 4) compensating actors incurring costs; 5) the poor and vulnerable (pro-poor). Based on the existing conditions, we are interested in anticipating if the project implementation could increase social benefits or/and if it could increase the burden for some sectors of the population. Using this forward-looking approach, based on quantitative evaluation can help orient policy interventions to achieve desirable outcomes and limit unintended consequences. In the next sections, we look at these ecological and social conditions for our case study, to anticipate the potential outcomes.

4.2. Ecological conditions of the rural complex

Ecological conditions set the stage upon which resource users can act to develop their livelihood activities, and they condition opportunities for sustainable development (Coomes et al. 2016). Looking at land-cover change over time, we found that the village's land experienced little forest cover loss from 2002 to 2011, as it has been already deforested in the past and is currently in a system of rotating swidden-fallow agriculture. Current deforestation is inhibited by the swamp forest found in this region of the DRC, considered unsuitable to cultivation. However, in recent years, rice cultivation has been promoted in swamp forest area and might therefore be a potential threat to those forests for agricultural expansion in the future (Samndong and Bush, 2017), though no rice cultivation was practiced in the village at the time of the study. There is timber extracted from the swamp forest and

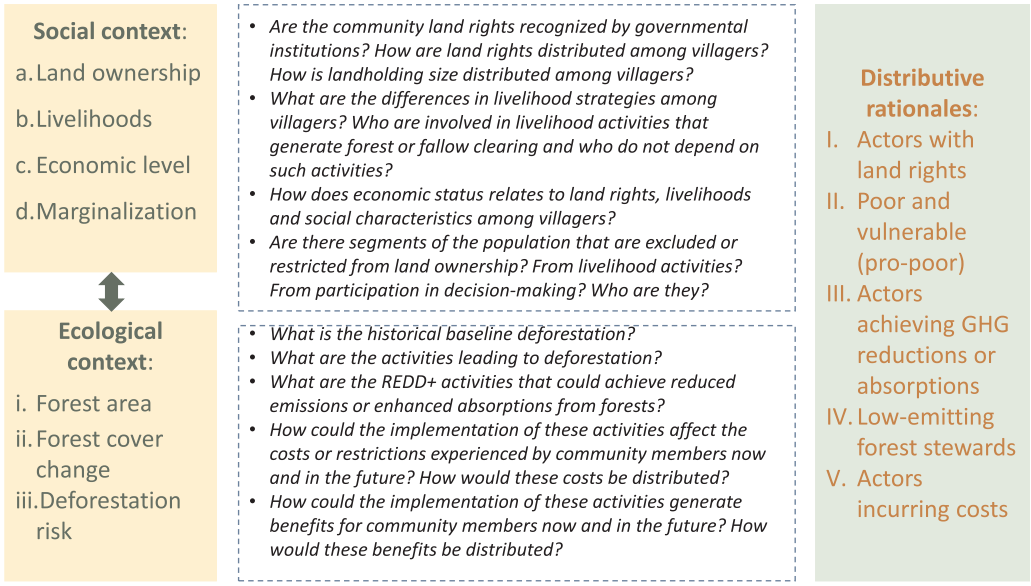

Fig. 7. Framework to link contextual equity to distributive outcome. On the left, we list key variables relevant to define the pre-existing social and ecological context. On the right, we identify five rationales for the distribution of benefits. In the core section, we propose a set of questions amenable to quantitative assessment and statistical testing, without being prescriptive on the statistical approach to be used. Our framework aims to provide a structured way to access information needed to link the context at the village level with the distributive rationales and to generate hypotheses on the possible consequences of each scenarios in terms of social equity. This framework is a decision-making tool that can be used by policy-makers and practitioners to analyze and to reflect on the context and potential outcomes of REDD+ implementation at the village level.

charcoal is produced in the swamp forest and different land-use types, with about 10% of households being engaged in those activities. The swamp forest is collectively managed by the local population for seasonal fishing, hunting, timber, and a source of non-timber forest products including medicinal plants.

These business-as-usual ecological conditions show that there are little emission reductions to be compensated for by reducing deforestation because there is little deforestation. Timber extraction and charcoal production may lead to forest degradation however we did not detect the impacts of these activities on forest cover. Relevant REDD+ activities would fall back on enhancing forest carbon stocks, sustainable management of forests and forest conservation. Yet, only forest carbon enhancement would produce additional carbon removals from the atmosphere compared to the business-as-usual context we observed. Additionality is a determination of whether a proposed REDD+ activity will produce some supplementary benefits in the future relative to a reference scenario or baseline (Gillenwater, 2012), a criterion which is important for REDD+ environmental effectiveness. Carbon stock enhancement could be achieved by agroforestry including enrichment tree planting, improved fallow, or fruit tree planting. All these activities depend on having land rights, providing benefits through direct payments and from tree planting to the right holders. In Buya I, it would benefit about a third of the households. REDD+ intervention could directly increase social disparity between right holders and non-right holders by providing more benefits to land right holders alone.

By planting trees on lands of customary right holders, REDD+ activities also have the potential to make a share of the right holder's land unavailable to other uses. This could eventually limit land availability for leasing to landless people who depend on renting for their livelihoods. Forest carbon stock enhancement through tree planting takes time for allowing trees to grow. Therefore, decisions taken now by right holders can affect the potential access to agricultural land to landless people but also reduce access for future generations. This brings to the fore the intergenerational equity for land right holders' families. By planting trees on agricultural lands or fallow, the right holder locks this piece of land for the future years, making a long-term land-use decision that may reduce options of their children who depend on inheritance for accessing agricultural lands. This risk makes tree planting often unattractive and has contributed to the limited impacts of afforestation and reforestation clean development mechanism projects for smallholders (Coomes et al., 2008; Benessaiah, 2012). The opportunity can, however, be attractive to right holders having large landholdings and on degraded.

These results show that the prevailing ecological conditions have implications in both space and time. The land use and ecological context is affecting the type of activities that can be realized under REDD+. These REDD+ activities can impact community members differently, including the majority of the population that do not have customary land rights, by reducing access to land now or in the future.

4.3. Prevailing social context

Existing social conditions are important to consider in order to foster equitable outcomes when developing REDD+ interventions at the local level. We were able to identify quantitative differences between households on the basis of household social characteristics and livelihoods. We found that different social groups rely on different livelihood activities, which can make them more or less susceptible to restrictions on land and forest use. The main factors implied in this social differentiation are customary rights to arable land, gender and ethnic group. Clearly, access is socially differentiated.

One of the key determinants of social disparity at the local level is related to customary rights to land. We find that customary right holders through their rights to land have more means and opportunities namely, more diversified livelihoods, a higher economic status, and a higher level of education, but they are also the ones that clear larger areas of forest or fallow on their land. Thus, those that clear more vegetation for agriculture are also those that are better off. The implementation of REDD+ in a context of unequal land distribution, as reported for a pilot project site in Kenya, can reinforce social disparities when the distributive policy does not take this pre-existing context into account (Chomba et al., 2016). Similar risks have been identified for other areas of the DRC (Bernard and Gélinas, 2014).

Women heads of household were found in two separate groupings, distinct from men based on our clustering results. The most vulnerable women groups depend more on agriculture of staple crops for their livelihoods, and less on other activities such as fishing, hunting, and animal husbandry. These women heads of household might be more impacted by restrictions in access to land for renting or increased land rental costs, as it may impact their main source of subsistence.

On the other hand, male pygmy headed households depend less on cultivation and more on a 'hunter & gatherer' livelihood strategy. Even if they are more often very poor and show clear vulnerability, REDD+ activities restricting land availability might have less costs or impact on their subsistence since they depend mostly on activities other than agriculture. So, unless forest access would be restricted by REDD+

project implementation – which is unlikely – there are limited impacts anticipated to their current livelihood.

Awareness of the flexible nature of customary rules is necessary in order to revisit assumptions related to the accessibility to land rights and the possibilities for social change. For example, some women and indigenous people that were supposedly prohibited from access to land rights according to custom were found as right-holders in the village studied. Some women were even identified to rent part of their holding to those without land. If women and indigenous people with land holding represent a small minority of the right-holders, it indicates that the possibility exists for social change toward enhanced access for these segments of the population in customary institutions.

Social change can also lead to negative impacts on democratic access to land and on forests too. Our study shows that internal migrants or *allogènes* have significantly less land rights and on average clear less land than customary right holders. Another study in the same area reports accounts that better-off internal migrants use social networks to gain access to land and forest by negotiating their way with customary authorities, by buying land in the village to right holders, or by using state authority to bypass customary rules and authorities to access forest resources (Samndong and Vatn, forthcoming).

The social differences related to gender, ethnicity and origin are reflected in the livelihood strategies adopted. The differential access to land for those groups, sanctioned by social norms, is linked to inequalities of power, status and wealth between right holders, indigenous people and migrants (Samndong and Vatn, forthcoming). Women also have less access to land in the area due to culturally sanctioned gender bias. These conditions of social disparities affect the potential access to benefits and the susceptibility to experience the costs or burdens of interventions aiming at mitigating climate change. The complexity of interactions between the resource users and the resource systems and how it affects behavior over resource use warns us from oversimplification of these linkages (Ostrom, 2009).

4.4. Linking contextual and distributive equity

Taking into account the socio-ecological conditions of our case study, we summarize what are the anticipated impacts of different options for the distribution of benefits (Table 6). This analysis assumes that some livelihood activities including firewood and non-timber forest products collection are not affected by REDD+ activities. These products would be harder to compensate and restrictions would create more potential impacts, as evaluated in Nepal (Poudel et al., 2015; Karky and Skutsch, 2010).

A mixed strategy can be contemplated that would incentivize right holders' behavior towards carbon stock enhancement and would provide development benefits for the majority, including marginalized groups. Based on our case study, where we identify important social disparities at the outset, this approach could lead to a broader distribution of benefits instead of benefitting to only a small subset of the population.

4.5. Social and ecological feedbacks

Recent research has underlined how the equity impacts of payment for environmental services (PES) scheme, including REDD+, can create positive and negative feedbacks that influence ecological outcomes (Pascual et al., 2014; Halpern et al., 2013; Miller et al., 2012) and that social and ecological outcomes are inter-connected. Causal links have been identified between social equity and ecological outcomes where negative equity feedbacks can reduce the legitimacy and participation, generate active resistance, noncompliance, manipulation of the rules and corruption (Pascual et al., 2014; Corbera and Pascual, 2012), transforming interested and cooperative participants into opponents (Halpern et al., 2013). In our case, it is easy to imagine that if renting land becomes too difficult for landless people as an indirect effect of REDD+ intervention, the DRC still offers ample opportunity for agricultural land expansion elsewhere through internal migration (i.e. leakage) – which is an outcome that would be undesirable from a social and ecological viewpoint. Pragmatically, overseeing equity concerns may also affect REDD+ effectiveness and sustainability over time by increasing the risk of conflicts and non-permanence (Luttrell et al., 2013). Therefore, decoupling conservation objectives from social equity and sustainable development goals in developing countries is not only ethically untenable, but it can also negatively influence the likelihood of conservation/climate change mitigation success (Halpern et al., 2013; Corbera and Pascual, 2012).

4.6. Equity-conscious adaptive management

Analyzing the potential consequences of REDD+ policy in terms of equity before implementation is critical. Adopting a systematic and adaptive approach needs to go much further than a trial-and-error approach because of the possible consequences for poor and marginalized people's lives. Policy decisions about equity objectives and rationales to provide compensation will likely differ based on societal values and cultural norms. It is crucial that policy-makers get involved in analyzing the possible outcomes of these choices by adopting an equity-conscious approach in the policy design at the outset (Pascual et al., 2014). This approach would consist of a flexible mechanism that would establish consultative and democratic processes at the local level. We highlight in this study the importance to foresee possible risks using contextually informed hypotheses about the implications of different options for benefit sharing in order to avoid negative impacts. Flexible mechanisms to monitor and respond to equity concerns throughout the implementation according to the goals formulated is essential, taking into

Table 6
Potential distributional outcomes of five different rationales for benefit sharing applied in the context of the case study village of Buya I in the DRC.

Rationales –Benefits should go to…	Potential impacts
Actors with legal rights	Assuming that customary laws are recognized, as specified in the 2006 Constitution, only right holders would benefit under this rational, representing about a third of the households in this case study.
Actors achieving emission reductions or removals	Right holders are those who clear the most area and who could participate in carbon stock enhancement as they hold right to the land. In this context, this incentive scheme would promote behavioral changes for those who have impacts on land-use decisions.
Low-emitting forest stewards	Benefits for conserving the swamp forests around the communities could be equally distributed among village residents. However, since the swamp forests are already conserved under BAU, there would be no additional environmental benefits. The potential of rice cultivation in swamp forests is however a deforestation threat that should be evaluated.
Actors incurring costs	A careful analysis of the types of costs would be required, with the direct costs more likely to be compensated. Indirect costs such as a decrease in land available for rent by non-right holders is unlikely to be compensated.
The poor and vulnerable people (Pro-poor approach)	This is the only scheme that could potentially address equity issues by creating compensation for non-right holders as well as indigenous, women and migrants.

account feedbacks between social and ecological outcomes, and to redress situations where there would be inequitable social impacts. Experiences of PES schemes have shown that robust cross-scale institutional frameworks are necessary to ensure objectives for equity and sustainable development are met, and that marginalized sectors of society are not excluded (Brown and Corbera, 2003). It is possible however that achieving equitable outcomes for REDD+ at the local level could be cost-prohibitive, especially where existing unequal conditions are important. Other types of policies and measures could be implemented by REDD+ participating countries, including at the macroeconomic level which may also have equity impacts (either positive or negative) and for which evaluations would be needed as well.

In conclusion, contextually informed definition of benefits and costs is critical for achieving equity in benefit-sharing at the local level. There is still much uncertainty surrounding benefit-sharing for REDD+ in the DRC, as well as in most developing countries participating in REDD+. We identified important risks for sectors of the population that do not have the contextual features necessary for benefitting from REDD+ implementation, and may be directly and/or indirectly impacted by the decisions related to benefit sharing. In the DRC, the sector of the population that may benefit most from REDD+, customary right holders, represent a minority of the total population, *inter alia* due to the social differentiation between gender, ethnic groups and *allogènes* (internal migrants). A flexible adaptive management and equity conscious approach is recommended, all the way from initial policy design through implementation, by anticipating and mitigating potential risks in REDD + interventions. This precautionary approach is important in order to achieve global climate change mitigation benefits as well as equitable social and ecological outcomes at the local level.

Acknowledgements

This work was supported by NASA/USAID Grant No. NNX12AL27G. We warmly thank the inhabitants of the Buya I village for their participation in this study. We thank Dauphin Mboka, Vinny Nkoso Lokul, Roger Ngange, Jean-Claude Lofete, Patrice Bondongo, Felly Baoto, Tipo Simba, Marie Boketshu, Bomuese Ixpoli, Pierre Basili, Igola Bofambaito, Epanda Bokeka, Kembo Inukia, Sumaili Ramazani, Angélique Epangonda for their contribution to the participatory mapping. We also thank Gédéon Boyo, Paul Itanga, Aboubakar Ikelemba, Petronel Andondo, Clément Botefa, Frido Bosulu, Gode Lompoko, Papy Ithambala, Nestor Betulu, and Crispin Bombito for their contribution on the household survey. We are grateful to Joseph Zambo and Melaine Kermarc for their support in coordinating the field team, organizing field logistics and their intellectual input. DigitalGlobe data were provided by NASA's NGA Commercial Archive Data (cad4nasa.gsfc.nasa.gov) under the National Geospatial-Intelligence Agency's NextView license agreement. We also thank the JGI and Google.org for making available electronic tablets for the household survey, and Yeon Su Kim for comments on the manuscript. We acknowledge support from Norway's Center for Global Development via the Congo Basin Forest Fund.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landusepol.2018.03.011.

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