ABSTRACT

Title of Document:	DETERMINING CONSERVATION PRIORITIES AND PARTICIPATIVE LAND USE PLANNING STRATEGIES IN THE MARINGA-LOPORI-WAMBA LANDSCAPE, DEMOCRATIC REPUBLIC OF THE CONGO
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Deforestation and forest degradation driven largely by agricultural expansion are key drivers of biodiversity loss in the tropics. Achieving sustainable and equitable management of land and resources and determining priority areas for conservation activities are important in the face of these advancing pressures. The Congo Basin of Central Africa contains approximately 20% of the world's remaining tropical forest

area and serves as important habitat for over half of Africa's flora and fauna. The Government of the Democratic Republic of the Congo (DRC) is currently laying the foundation for a national land use plan for conservation and sustainable use of its forests. Since 2004, the African Wildlife Foundation (AWF) has led efforts to develop a participatory land use plan for the Maringa-Lopori-Wamba (MLW) Landscape located in northern DRC. The landscape was recognized in 2002 as one of twelve priority landscapes in the Congo Basin targeted for the establishment of sustainable management plans. This dissertation focuses on the development of geospatial methods and tools for determining conservation priorities and assisting land use planning efforts in the MLW Landscape. The spatio-temporal patterns of recent primary forest loss are analyzed and complemented by the development of spatial models that identify the locations of 42 forest blocks and 32 potential wildlife corridors where conservation actions will be most important to promote future viability of landscape-wide terrestrial biodiversity such as the bonobo (*Pan paniscus*). In addition, the research explores three scenarios of potential agricultural expansion by 2050 and provides spatially-explicit information to show how trade-offs between biological conservation and human agricultural livelihoods might be balanced in land use planning processes. The research also describes a methodological approach for integrating spatial tools into participatory mapping processes with local communities and demonstrates how the resulting spatial data can be used to inform village-level agricultural land use for resource planning and management. Conclusions from the work demonstrate that primary forest loss is intensifying around agricultural complexes and that wildlife corridors connecting least-disturbed forest blocks are

most vulnerable to future forest conversion. Conservation of these areas is possible

with the development of land use plans in collaboration with local communities.

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DETERMINING CONSERVATION PRIORITIES AND PARTICIPATIVE LAND

USE PLANNING STRATEGIES IN THE MARINGA-LOPORI-WAMBA

LANDSCAPE, DEMOCRATIC REPUBLIC OF THE CONGO

By

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Foreword

Chapters 2-4 are comprised of jointly authored work of which Janet Nackoney is the primary author. All methods were developed and executed by Janet Nackoney. In addition, all results and findings are the outcome of her own work. Janet also led the development of all written content featured in this dissertation.

Dedication

For my family: Demian, Mom, Dad, and Sue.

Thank you all for your constant encouragement, support, and enthusiasm.

Acknowledgements

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Chapter 1: Introduction

1.1 Background to the research

1.1.1 Threats to biodiversity in the Congo Basin

The Congo Basin spans approximately 2 million km^2 in Central Africa and is the

second largest tropical rainforest in the world after the Amazon (CBFP, 2005). It

serves as important habitat for over half of Africa's total flora and fauna and contains

approximately 20% of the world's remaining tropical forests (Mayaux *et al*., 2004).

Pressures on terrestrial biodiversity in the Congo forests stem from a variety of

human activities, including commercial and subsistence-based hunting (Fa *et al.,*

2002), habitat fragmentation from shifting agriculture (CBFP, 2005), logging (Ruiz

Perez *et al.,* 2005) and road construction (Wilkie *et al.,* 2000; Blake *et al.,* 2007).

Habitat fragmentation from deforestation is one of the greatest threats to biodiversity

worldwide (Ehrlich, 1988). Fragmentation, the process of breaking up previously

intact forests into smaller, disconnected patches, causes isolation of wildlife habitats

and affects the process of genetic exchange between wildlife populations (Botequilha

& Ahern, 2002). Mitigating the negative effects of forest fragmentation and

deforestation through sustainable development and land use planning will be crucial

for the future conservation of terrestrial biodiversity in the Congo Basin as

competition for land resources increases (CBFP, 2009).

Comprising approximately 60 percent of forest coverage in the Congo Basin,

the Democratic Republic of the Congo (DRC) contains a wide array of natural resources (including timber and minerals) and serves as important habitat for a unique assemblage of vertebrates and terrestrial mammals. It has a human population of 71 million inhabitants (CIA, 2010). Approximately 66% of the DRC's population is rural (FAO, 2010) and relies heavily on its forests for the provision of natural resources and livelihood subsistence (Klaver, 2009). Accordingly, slash-and-burn methods for subsistence agriculture and fuelwood collection comprise the majority of deforestation in the DRC.

Between 1996 and 2003, the DRC suffered two devastating wars that collapsed its formal economy and resulted in increased social unrest and poverty. Human tolls were enormous; displaced persons numbered in the millions and fatalities exceeded five million in just the second Congo war alone (Bavier, 2008). War and civil conflict have been shown to contribute directly to increased wildlife poaching and environmental degradation (Blom *et al.,* 2000; Yamagiwa, 2003; Westing, 1992). Draulans & Van Krunkelsven (2002) noted the particular environmental consequences of the DRC's two wars and examined their impacts on terrestrial biodiversity. They observed soldiers possessing live monkeys, parrots, baby gorillas and bonobos for the animal pet trade, increased wildlife poaching to feed refugees and militia troops, and illegal and unsustainable logging. They also observed human populations fleeing their natal villages (traditionally located along the road axes) to take refuge in interior forests and escape conflict with soldiers. This particular type of human displacement can put substantial pressure on surrounding natural environments; examples include increased hunting to meet demands for

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sources of protein (Yamagiwa, 2003) and deforestation and habitat fragmentation

resulting from the creation of small-scale agricultural clearings and temporary camps.

Although the war ended in 2003, recovery in the DRC has been slow. As of

2011, the DRC's GDP per capita, at $300/person, was the second lowest in the world

(CIA, 2010). Today, the population growth of the DRC is around 2.6% (2011 est.),

though the average rate for 2000-2010 was around 3% (Barrientos & Soria, 2011).

Much of the country's infrastructure has not been rebuilt since the war, hampering the

DRC's formal economy and its overall productivity, including production of food. In

addition, the DRC's most recent presidential elections, held in November 2011, were

heavily criticized for a lack of transparency and possibly fraudulence (Nossiter,

2011). These factors indicate many future challenges for the people of the DRC.

From a conservation perspective, the combination of high poverty rates and the

DRC's limited capacity to modernize its food production raise concern that substantial

pressure will be exerted on the DRC's forests, posing challenges for human welfare

and biodiversity conservation in future generations.

1.1.2   Land use planning for conservation of biological diversity: a DRC perspective
Sustainable and equitable management of land and natural resources will be

increasingly important to mitigate effects of deforestation in the Congo Basin and to

promote human well-being for local populations who depend on the forests for their

livelihoods (UNEP, 2007). Land use planning and zoning provide an approach to

resolving conflicts between competing needs for land and determining appropriate

trade-offs (Halpern *et al.,* 2008), as well as planning for the sustainable use of

physical, biological and cultural resources (Ahern, 1999). Linking conservation and

livelihood objectives into sustainable development practices can be difficult, and

many studies have reflected the fact that these objectives are often at odds with each

other (e.g., Agrawal & Gibson, 1999; Barrett & Acrese, 1995). Contemporary

discourses on conservation and development, however, identify a transformation in

conservation thinking and practice, recognizing people and their livelihoods as being

key ingredients in building sustainable development strategies (Blaikie & Jeanrenaud,

1997; Hulme & Murphree, 1999).

Most, if not all, national land-use plans in the Congo Basin have focused

primarily on the establishment of logging concessions and protected areas (Sidle *et

al.,* 2012). This is starting to change, however. Together, the Central African Forests

Commission (COMIFAC) and the Congo Basin Forest Partnership (CBFP) provide

an institutional means to promote regional cooperation in forest conservation and

rural development within Congo Basin countries. In 2002, forestry ministers in

participating COMIFAC countries endorsed a Convergence Plan pertaining to the

conservation and sustainable management of the Congo Basin forests through

implementation of land use planning in twelve priority CBFP landscapes chosen for

their biological importance (the Maringa-Lopori-Wamba Landscape, which is the

focus of this dissertation, is one such landscape). The aim is to establish community

forest areas and other land use zones through a participatory process involving

multiple stakeholders, including national governments, local communities, and

members of the private sector (including logging companies and non-governmental

organizations) (Usongo & Nagahuedi, 2008). It is hoped that many of the COMIFC-

CBFP supported zoning activities will serve as a basis for the development of future land-use plans at the national level.

In the DRC, certain steps have been taken during the past ten years to set a foundation for forest governance and future sustainable land use planning. In 2002, the Government of the DRC developed a Forest Code that mandated an array of new requirements for logging operation titles (Counsell, 2006) and issued a moratorium on the issuance of new logging concessions until a multi-stakeholder legal review of existing titles was undertaken (Klaver, 2009). After review by the Interministerial Commission, only 65 out of 156 titles submitted to the DRC Government were granted legal conversion, leaving 12 million hectares subject to cancellation (Rainforest Foundation, 2009). Despite these advances, however, there is still much criticism of forest governance in the DRC. A report published by the Rainforest Foundation (UK) states,

> "However, the decrees as they presently exist relate exclusively to industrial logging; important issues such as community forestry, management of non-timber forest products, relationships between communities and logging companies – all of which are likely to affect the lives of millions of Congolese people – remain, as yet, in a legal vacuum." (Hoare, 2007)

There is no formal system of land tenure in the DRC. Legally, the forests and other natural resources (including minerals, timber and wildlife) belong to the State, while rural communities occupying land regarded as theirs by ancestry are granted the right to live there (Usongo & Nagahuedi, 2008). Lack of tenure is problematic both for local communities who depend on forests for the provision of goods and services for their economic well-being (i.e., collection of fuelwood and other non-timber forest

products), as well as for conservation of biological diversity. In more recent years, however, the Government of the DRC has acknowledged a need to develop a national land-use plan for conservation and sustainable use of its forests and in 2009 formed a national-level Steering Committee, *Comité National de Pilotage du Zonage Forestier* (CNPZF) for its oversight (USAID, 2010). DRC law now requires adherence to a set of guidelines for forest zoning, including extensive public participation (MECNT, 2011). Consequently, implementing land use planning in the DRC will require the use of participatory methods that involve representation of local communities at multiple political and administrative levels in order to ensure their involvement in making localized land use planning decisions.

1.1.3 Geospatial tools for land use planning

Including a spatial dimension in landscape planning is crucial (Forman, 1995). Sustainable land use planning requires information about biological conservation priorities and their geographic relationship to human livelihoods and natural resource use; combining these data in spatially-explicit, mapped form can help determine where land use planning might be most needed. The use of maps and Geographic Information Systems (GIS) to identify and quantify threats to biodiversity for conservation prioritization and planning have been widely evaluated and promoted within the literature (Margules & Pressey, 2000; Myers *et al.,* 2000; Sanderson *et al.,* 2002; Brooks *et al.,* 2006). Systematic conservation planning (Margules & Pressey, 2000; Groves *et al.,* 2002; Pressey & Bottrill, 2008) has been widely applied to

conservation priority-setting, combining measures of anthropological threat and biological significance to identify sites where wildlife are undergoing phenomenal losses of habitat (Myers *et al.,* 2000; Sanderson *et al.,* 2002; Moilanen *et al.,* 2005; Didier & LLP, 2006; Wilson *et al.*, 2007; Trombulak & Baldwin, 2010). Threat-based models are most useful for conservation prioritization when species-specific information is not available. Consequently, threat-based models have been developed and applied in several conservation prioritization and planning studies; these include Sanderson *et al*. (2002), Mattson and Angermeier (2007), Woolmer *et al.* (2008), and Paukert *et al.*(2011).

Decision support systems, usually consisting of both a computer-based knowledge system and a problem-solving system (Holsapple, 2003), can be used in land use planning processes to assist decision-makers be better informed about zoning options given a set of criteria and stakeholder preferences. Regional managers are integrating decision support systems with GIS to produce spatially-explicit maps of land use planning decision options and their implications (Crossland *et al.*, 1995; Jankowski *et al.,* 2001). Systematic conservation planning is often facilitated by heuristic-based optimization tools that are mathematically programmed to find alternative solutions to meeting well-defined targets. Optimization algorithms provide a set of directions for computations which aim to produce an optimal solution (Haith, 1982). There is a wealth of literature demonstrating the use of heuristic-based optimization tools for systematic conservation land use planning; these include McDonnell *et al.* (2002), Klein *et al.* (2009), Meinke *et al.* (2009), Esselman & Allan (2011), and Schneider *et al.* (2011).

With the growing recognition that local knowledge is critical to land use

planning, participatory approaches have become widely accepted for contributing to

the development of strategies for collaborative forest management within forest-

dependent indigenous communities (Craig *et al.,* 1990; Robiglio *et al.,* 2003; Johnson

et al., 2004; McCall & Minang, 2005; Chambers, 2006). Accordingly, studies have

shown that direct participation of local stakeholders in planning processes is essential

to establishing lasting conservation strategies (Fisher *et al.,* 2005; Zimmerer, 2006;

Velázquez *et al.,* 2009). As technological capacities have improved, especially with

advances in GIS coupled with an increased availability of satellite imagery, mapping

capabilities have become progressively more rich and participatory methods more

diverse, encompassing a variety of methods and facilitation approaches. Participatory

mapping methods have been used as tools for landscape land use planning (Wang *et

al.,* 2008; Hessel *et al.,* 2009; Valencia-Sandoval *et al.,* 2010; Bourgoin *et al.,* 2012),

management of natural resources (Patrick, 2002; Kalibo & Medley, 2007; Cronkleton

et al., 2010), and addressing tenure rights and mediating land conflict (Peluso, 1995;

Forbes, 1999).

1.2   Study area

The Maringa-Lopori-Wamba (MLW) Landscape, recognized in 2002 by the CBFP

for its conservation importance, covers a 72,000 km^2 swath of land in remote

Equateur Province in northern DRC. The landscape comprises a number of land

cover and land use types, including 68% moist dense forest, 25% swamp forest, and

5% agriculture (Figure 1.1). It harbors an array of threatened terrestrial species,

including the bonobo (*Pan paniscus*)—listed as Endangered since 2007 (Fruth *et al.,*

2008), the Congo peafowl (*Afropavo congensis*)—listed as Vulnerable since 2006

(Birdlife International, 2008), and the forest elephant (*Loxodonta cyclotis*)—listed as

Vulnerable since 2004 (Blanc, 2008). The human population density of the landscape

is relatively low with approximately 3-5 inhabitants per square kilometer (CBFP,

2006). Settlements and villages occur along rivers and road axes, and agricultural
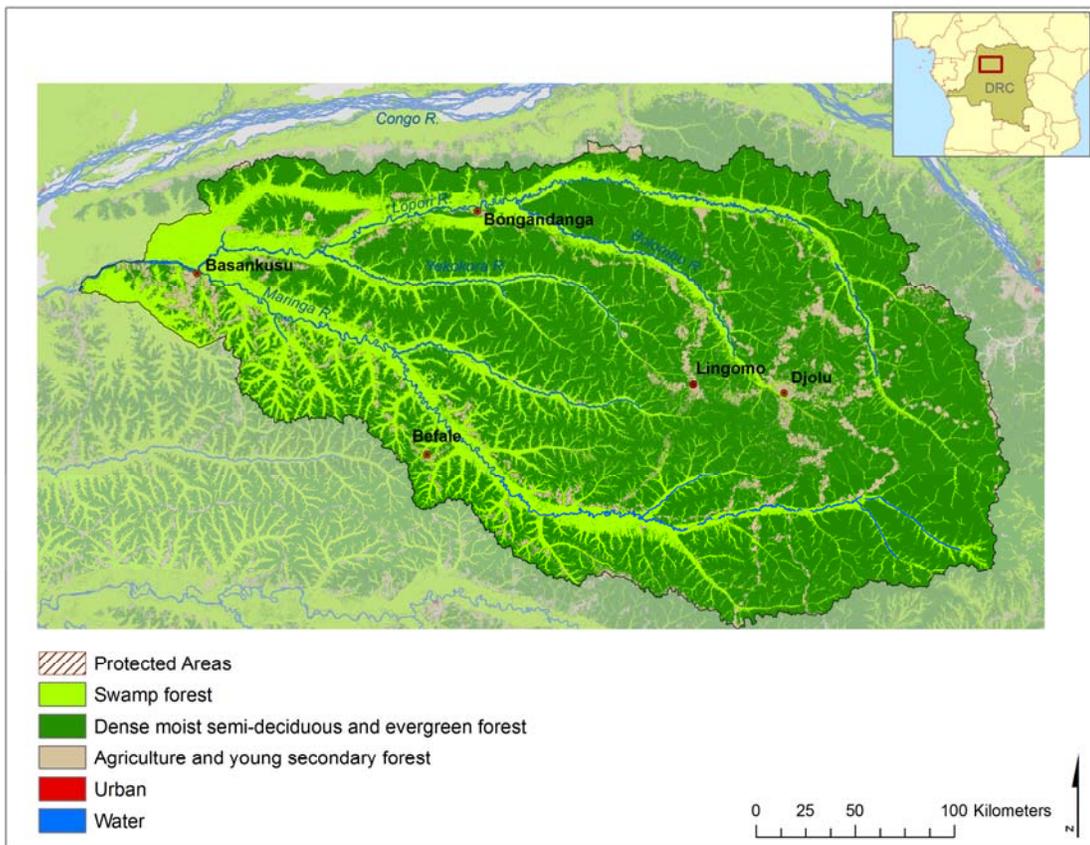
Figure 1.1 A land cover/land use map of the Maringa-Lopori-Wamba Landscape. Data sources: Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC), South Dakota State (SDSU) and University of Maryland (UMD) (2012).

areas extend outward from the roads into the forest. Agricultural activities and collection of non-timber forest products (including fuelwood, food and medicine) in the landscape are primarily for subsistence. Inhabitants use slash-and-burn practices to cultivate crops such as cassava, maize, and peanuts. Road infrastructure in the MLW Landscape is very poor, and passage is feasible only by foot, bicycle and motorbike. Motorbike use is constrained by high levels of poverty, limited motorbike ownership, and the prevalent scarcity of gasoline and parts. As overland transport is constrained, rivers are commonly used to ferry both people and goods and are navigated by wooden pirogues (canoes) made from dug-out tree trunks and houseboats made from wood and thatch. The landscape contains one abandoned logging concession, vacant since 1999, and is not currently subjected to large-scale logging. A few active and inactive palm and rubber plantations exist in the landscape, although specific numbers are not known. These plantations were active before the DRC's war; the majority of them are now inactive with some exceptions, including three or four large-scale commercially-owned plantations (ranging between 25 km^2 and 53 km^2) that currently operate in the western and northern parts of the landscape.

Historically, due to its remoteness and relative inaccessibility, the MLW Landscape has experienced a relatively low deforestation rate. From 1990 to 2000, forest loss in MLW was just 0.86% (Dupain *et al.,* 2009). The absence of commercial logging and small prevalence of plantations indicate that deforestation is due mostly to small-scale agricultural activities. The landscape therefore maintains large tracts of intact forests that sustain a wealth of terrestrial species. An increasing

human population will escalate demand for bushmeat and agricultural land within the landscape, however, and subsequent hunting pressure and habitat fragmentation will continue to be principal threats to areas of high conservation value.

Since 2004, the African Wildlife Foundation (AWF) and several partner institutions have been working with the Government of the DRC toward the development of a participatory landscape-wide land use plan for the MLW Landscape (CBFP, 2005). Threat-based conservation prioritization and on-the-ground participatory mapping combined with human livelihood improvement strategies have formed the basis for the landscape's planning activities. In September 2009, the Government of the DRC formally recognized the MLW land use planning activities as a pilot model for the creation of a national-level planning strategy for the DRC (Sidle *et al.,* 2012). Lessons from both the plan's development and initial implementation steps continue to inform national and regional planning policy frameworks (Dupain *et al.,* 2010).

1.3   The role of the bonobo in the research

The bonobo, a great ape that is endemic to the DRC, has been listed as Endangered on the IUCN Red List since 2007 (Fruth *et al.,* 2008). The MLW Landscape comprises 17% of its 500,000 km^2 range, shown in Figure 1.2. Bonobos primarily use areas consisting of primary forest for sleeping and nesting, and swamp and secondary forests for foraging (Hashimoto *et al*., 1998). Their greatest threats consist of both habitat loss and hunting, the latter being the primary contributor to
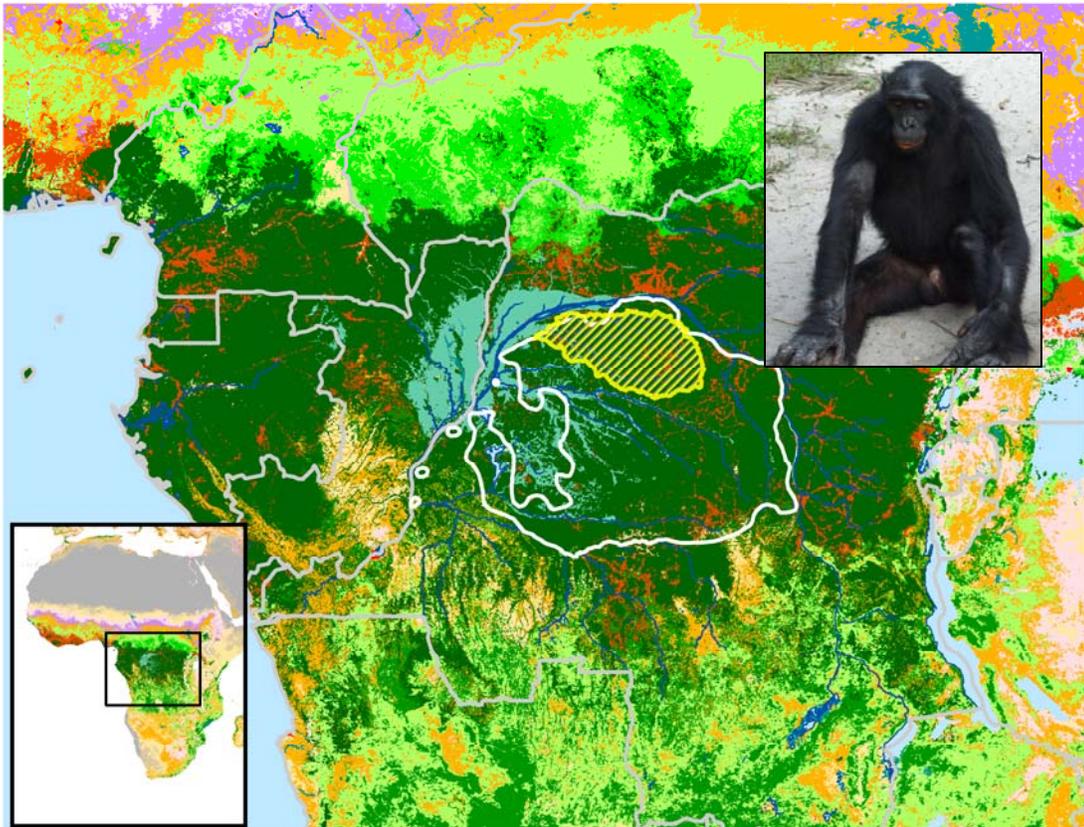
Figure 1.2 The bonobo's range is shown outlined in white in northern-central DRC. The MLW Landscape, shown as a yellow polygon with hatching, encompasses 17% of the bonobo range.

their endangered status (IUCN, 2010).

Bonobo populations were heavily affected by the DRC war (Furuichi *et al*., 2012). Particular impacts in the MLW Landscape were observed around Luo Scientific Reserve, located in the southeastern part of the landscape. Japanese researchers living and working at the reserve and studying Luo's bonobo populations noticed an increased prevalence of hunting camps located within the core forest areas, where human populations lived and cleared surrounding forests to grow small-

scale cassava crops. Hunting pressures during this time were substantially higher as local people were asked to hunt bonobos for soldiers, and likely for themselves as well as a source of income (Furuichi *et al.,* 2012).

Because spatial information on biodiversity is often limited, many studies have investigated the use surrogates and coarse-filter strategies for identifying conservation priorities such as better-known taxa or vegetation types (Noss, 1983; Rouget *et al.,* 2003; Coppolillo *et al.,* 2004; Klein *et al.,* 2009; Beier & Brost, 2010) based on the concept that the protection of diverse physical environments will promote high levels of biodiversity. The relatively remote and politically unstable characteristics of the MLW Landscape make it a difficult place to conduct long-term biological research, hindering the collection of range information for specific species and precluding the application of models driven by biological significance. The bonobo's endemism, vulnerability, and flagship species value argue for it being a focal species for conservation in the MLW Landscape. In addition, its requirement of large tracts of less-disturbed forest also lends it suitability as an umbrella species for other forest-dwelling taxa, such as monkeys and small duikers, in the landscape. Therefore, Chapters 2 and 3 give prominence to the bonobo as an umbrella species, featuring analyses and models that take the bonobo's habitat requirements into account with the goal of simultaneously accounting for similar terrestrial wildlife in conservation prioritization and planning in the MLW Landscape.

1.4 Research goals and objectives

This research integrates satellite-derived information with ground-based data that feed into geospatial methods for building and implementing conservation planning strategies in the MLW Landscape. The methods and findings resulting from the work can contribute directly to the development of land use plans in other tropical forested landscapes located in the Congo Basin. The research builds on an increasing literature on biodiversity conservation from a land use and land cover perspective; it provides an increased understanding of recent patterns of land use and land cover change in the MLW Landscape and identifies where conservation prioritization activities should occur in order to help safeguard the landscape's terrestrial biodiversity, including the bonobo. It also uses land use and land cover data as a direct input to a set of spatially-explicit optimization models that determine relative suitability for future agricultural expansion in the MLW Landscape given different scenarios driven by human population growth and natural resource use. Finally, the research contributes methods coupling participatory mapping, interpretation of satellite imagery and GPS data collection for micro-scale agricultural zoning at the village level. It provides both observations on the methodological process as well as recommendations for future application of the methods established, and analysis of village-level land use dynamics that inform agricultural planning in the landscape.

      Approaches to this research are as follows:

1. Use primary forest loss data derived from remote sensing to assess spatial patterns of land use and land cover change in the MLW Landscape from 2000 to 2010.

2. Devise a spatially-explicit threat-based model to identify key areas for conservation prioritization in the MLW Landscape, including least-disturbed forest blocks and wildlife corridors.

3. Assess the relative vulnerability of the least-disturbed forest blocks and wildlife corridors to land use and land cover change in order to target further conservation prioritization for planning.

4. Design a set of spatially-explicit optimization models that explore potential trade-offs between conservation and livelihood scenarios in the framework of land use planning in the MLW Landscape.

5. Develop a method that integrates participatory mapping, analysis of satellite imagery and GPS data collection for village-level agricultural planning.

6. Use in-situ information collected describing village-level agricultural surface area and human population size to analyze village-level agricultural land use dynamics in a portion of the MLW Landscape.

1.5   Dissertation organization

This dissertation consists of three research components detailed in Chapters 2-4. Although these chapters were originally written in a self-contained format prepared for journal submission, they have been condensed in the dissertation to avoid redundancy. Chapters 2 and 3 describe landscape-scale planning models that then inform the implementation of land use planning processes at the local level described in Chapter 4 (Figure 1.3). As such, Chapters 2 and 3 focus on coarser, macro-scale

analyses while Chapter 4 focuses on micro-scale implementation. A feedback loop is shown in Figure 1.3 to communicate the flow of the research; results of the analyses conducted at the macro-scale inform the activities at the local scale, and those local-scale activities then help inform the macro-scale analyses.

Chapter 2 analyzes the spatial and temporal patterns of land use and land cover change occurring in the MLW Landscape over the past decade (2000-2010) and identifies the spatial patterns of the most common scenarios of primary forest loss. It also assesses how the findings might relate to human migration patterns following the conclusion of the DRC's war in 2003. The chapter also shows the results of a spatially-explicit threat-based model that helps identify conservation priority areas in the MLW Landscape, tailored to the habitat requirements of the bonobo, a focal species for conservation. The definition of conservation priority areas used in the chapter include large forest blocks that are least threatened by human activities and that serve as relatively undisturbed habitat for bonobos as well as the potential corridors connecting them. Finally, the chapter assesses primary forest loss occurring in the modeled potential conservation priority areas and evaluates their relative vulnerability in order to help further prioritize sites for conservation action and intervention.
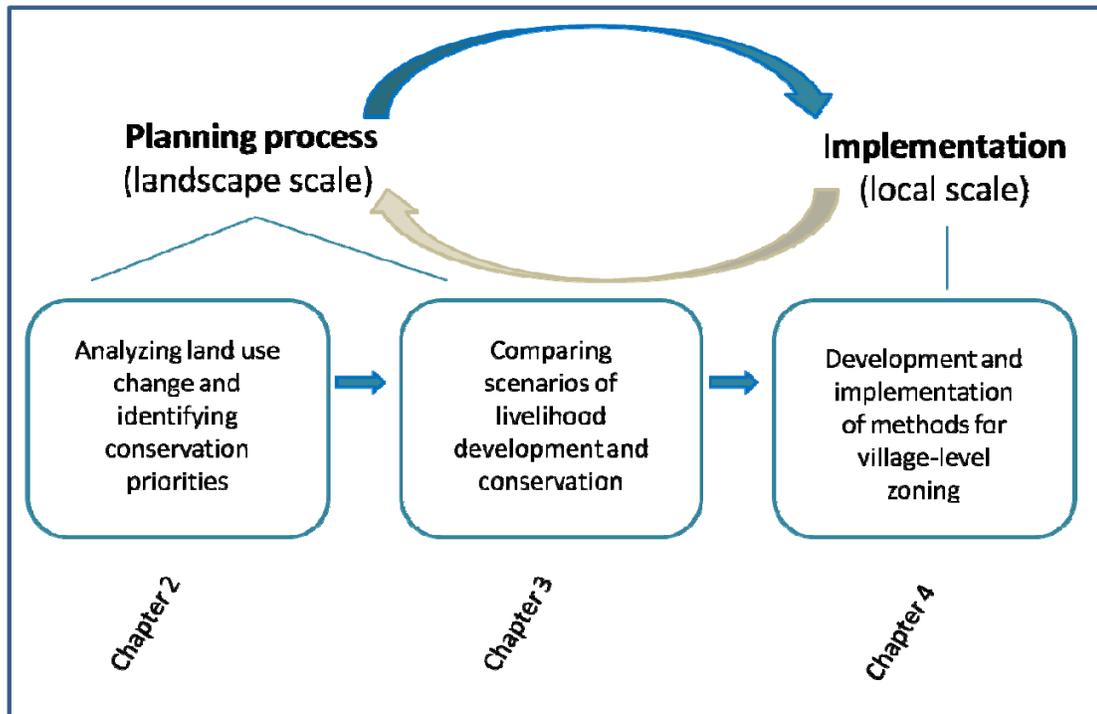
Figure 1.3 Flow of the dissertation research for Chapters 2-4.

Chapter 3 focuses on the development of a set of spatially-explicit optimization models that can be applied to aid land use planning in the MLW Landscape. Outputs from chapter 2 serve as direct inputs into the models. Based on three scenarios utilizing different assumptions about agricultural expansion and natural resource use, the models illustrate how competing needs in planning for both livelihood expansion and biological conservation in the MLW Landscape might be balanced. Given the spatial extent of current land used for sustaining agricultural livelihoods, as well as recent agricultural expansion rates from 2000-2010, the model identifies areas to encourage future agricultural expansion for a 40-year period (to 2050) while simultaneously conserving areas important for wildlife habitat and

connectivity. For this, a spatial allocation decision support tool called Marxan (Ball

& Possingham, 2000; Possingham *et al.,* 2000), one the most widely employed tools

for systematic conservation planning, was used.

Chapter 4 develops a participatory mapping method utilizing satellite image

interpretation and GPS data collection for the delineation of agricultural zone

boundaries for 16 villages in a 2,000 km^2 study site in eastern MLW Landscape. The

method contributes directly to the implementation of agricultural zoning in the

landscape and is significant in that it is the first time such community zoning has been

undertaken in MLW. The chapter highlights certain methodological experiences and

provides recommendations for other practitioners who may wish to implement

participatory methods that utilize geospatial technologies. The chapter also shows the

results of tabulating the resulting agricultural zone data and analyzing it alongside

corresponding population information in order to inform land use dynamics in the

immediate region.

Chapter 5 presents a discussion of research findings and the overall

conclusions of the doctoral research. It summarizes the findings from the three main

research components and their significance to conservation planning in the MLW

Landscape. In addition, the chapter highlights the contributions of spatial data and

geospatial tools to land use planning. Policy-relevant implications of the

dissertation's results for building sustainable land use plans in the DRC are examined.

The chapter concludes with a discussion of directions for future research.

Chapter 2: Conservation prioritization and planning with limited wildlife data in a Congo Basin forest landscape: assessing human threats and vulnerability to land use change[1]

2.1 Introduction

Over the approximate past decade and a half, spatially-explicit models have been used for the identification of areas best representing the native species and ecosystems of a given region and the underlying ecological processes sustaining them. Considering accelerating and irreversible losses of global biodiversity (Pimm *et al.,* 1995; Jenkins, 2003), the need to set geographically-focused conservation priorities is ever important. This is especially true for the world's tropical forests where deforestation rates are high due to expansion of agriculture, commercial logging and resource extraction (Laurance, 1999; Archard *et al.,* 2002).

A critical component of the systematic conservation planning framework (Margules & Pressey, 2000; Groves *et al.,* 2002) targets areas of high conservation priority and accounts for measures of vulnerability and anthropogenic threat (Wilson

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[1] The presented material has been previously published in part in Nackoney J, Williams D (2012) Conservation prioritization and planning with limited wildlife data in a Congo Basin forest landscape: assessing human threats and vulnerability to land use change. *Journal of Conservation Planning* **8**: 25-44.

et al., 2005; Brooks *et al.,* 2006; Pressey & Bottrill, 2008). The distribution and

relative influence of human threats can be spatially modeled using multi-criteria

decision analysis (MCDA), the process in which several criteria, or factors, are

evaluated in order to meet a specific objective or assessed for their combined

suitability for a particular purpose (Buckley, 1984; Eastman *et al.,* 1993; Malczewski,

1999). Some threat-based criteria that are independent of a particular species might

include measures of human settlement (such as population density or presence of

urban areas), measures of human access (such as proximity to transport routes),

presence of electrical power infrastructure, or other measures that may account for

other human land uses, such as agricultural development. MCDA methods

employing these criteria have been applied to several conservation prioritization and

planning studies; these include Sanderson *et al.* (2002), Mattson & Angermeier

(2007), Woolmer *et al.* (2008), and Paukert *et al.* (2011).

Analysis of past and present land use changes can elucidate the relative

vulnerability of areas of high conservation priority to anthropogenic pressure and

habitat fragmentation. In the tropics, land use trends such as forest conversion for

agriculture and road construction result in increased human encroachment into

forests, causing greater incidences of hunting and forest fragmentation (Trombulak &

Frissel, 2000; Fa *et al.,* 2002; Laurance *et al.,* 2006). Fragmentation of natural

habitats can cause isolation of wildlife habitats, causing "habitat islands," resulting in

potential loss of biodiversity and reduced genetic exchange among populations from

different habitat patches (Botequilha & Ahern, 2002). Providing connectivity zones

between these habitat islands, therefore, facilitates several critical conditions: feeding

across multiple habitat types (Kozakiewicz, 1995), re-colonization of extirpated patches (Brown & Kodric-Brown, 1977; Thomas, 1994), reduction of inbreeding (Richards, 2000), and pollination and seed dispersal—vital plant-animal interactions that sustain forest health (Tewksbury *et al.,* 2002; Crooks & Sanjayan, 2006). Least-cost modeling is one of the most widely used approaches for designing connectivity zones or corridors and is found to be relatively robust when compared to other methods (Adrianensen *et al.,* 2003; Beier *et al.,* 2009). Locations of the corridors can then serve as direct inputs for land use planning processes to ensure the future conservation of areas that contribute directly to maintaining biological connectivity and function within a landscape.

This chapter has multiple objectives. One is to assess the spatial and temporal patterns of land use and land cover change occurring in the MLW Landscape over the past decade (2000-2010) and identify the spatial patterns of the most common scenarios of primary forest loss in the landscape. During the DRC war (1996-2003), human populations migrated into interior forests to escape conflicts with soldiers in settled areas along roads (Draulans & Van Krunkelsven, 2002). As we were particularly interested in analyzing how these specific human migration patterns might have affected forest degradation and fragmentation in MLW throughout the 2000-2010 decade, we quantified the extent of primary forest loss in relation to distance from roads (where settled and subsistence-based agricultural areas occur) and determined its spatial-temporal patterns. A second objective of this chapter is to show the results of a spatially-explicit threat-based model that helps identify conservation priority areas in the MLW Landscape. The definition of conservation

priority areas used here includes a.) large forest blocks that are the least threatened by human activities and that serve as relatively undisturbed habitat for wildlife (heretofore referred to as "wildland blocks"), and b.) potential wildlife corridors connecting them. A third objective is to assess primary forest loss occurring in the modeled conservation priority areas and evaluate their relative vulnerability in order to help further prioritize sites for conservation action and intervention.

The MLW Landscape encompasses approximately 17% of the range of the bonobo; because the bonobo's endemism, vulnerability, and flagship species value argue for it being a focal species for conservation, we designed this particular analysis for it. Of course, this analysis can be changed to accommodate different species according to conservation objectives, if such data become available.

2.2   Methods

2.2.1   *Assessing recent patterns of land use and land cover change*

Using primary forest loss data for DRC derived from remote sensing and provided by OSFAC (2010) for 2000-2010, we analyzed the spatial and temporal distribution of primary forest loss in the MLW Landscape. The FACET dataset (OSFAC, 2010; Potapov *et al.,* in press), mapped at 60-meter resolution and covering the entire country of DRC, offers a spatially-explicit profile of primary forest loss for 2000-2005 and 2005-2010. Using FACET, we calculated the area of primary forest loss in the MLW Landscape for each half of the decade. In addition, we identified the spatial patterns of the most common scenarios of primary forest loss in the landscape

and conducted a decadal analysis of primary forest loss in relation to distance from roads. Lastly, after modeling the locations of wildland blocks and wildlife corridors (explained in the next section), we used FACET to calculate the rate of primary forest conversion occurring in the identified areas of high conservation potential. We demonstrate how this information can be used for conservation targeting and planning.

2.2.2   Development of a multi-criteria threat-based model to identify areas of highest conservation potential

We developed a spatially-explicit threat-based model to identify areas of highest conservation potential for maintaining terrestrial biodiversity across the MLW Landscape. The model was built and executed in a GIS using a simple additive weighting (SAW) process within a spatially-explicit MCDA. We followed Malczewski (1999), by first selecting a set of evaluation criteria, standardizing each criterion across multiple map layers so that scores range between 0 and 1, defining criteria weights explaining their relative importance, performing an added overlay of all criterion in a GIS, and ranking the output.

The conceptual diagram of the model developed is shown in Figure 2.1. The model considered: 1) Hunting pressure (including human accessibility and relative population demand for bushmeat), and 2) Habitat degradation (including the influence of agricultural and higher-density settled areas as well as large-scale plantations). The inputs to the model were spatially-explicit raster grids mapped at 90 meter resolution, detailed in Table 2.1.

The hunting accessibility sub-model and its underlying concept are based on an open-access model of hunting accessibility built by the Wildlife Conservation Society (WCS) (Didier & LLP, 2006) and altered for this analysis. First, using a gridded surface of land use and land cover for the MLW Landscape (see Table 2.1), we assigned a relative ranking to each grid cell according to relative ease or difficulty of travel across a given land surface (land surfaces that are easier to traverse across, such as roads and navigable rivers, are assigned a lower ranked score than say, swamp forest). These rankings are detailed in Table 2.2 (note that in other parts of DRC, slope can be a factor in determining hunting accessibility. With an elevation gradient of under 300 meters, the MLW Landscape is fairly homogeneous from a relief standpoint, hence, we eliminated slope from this particular model).
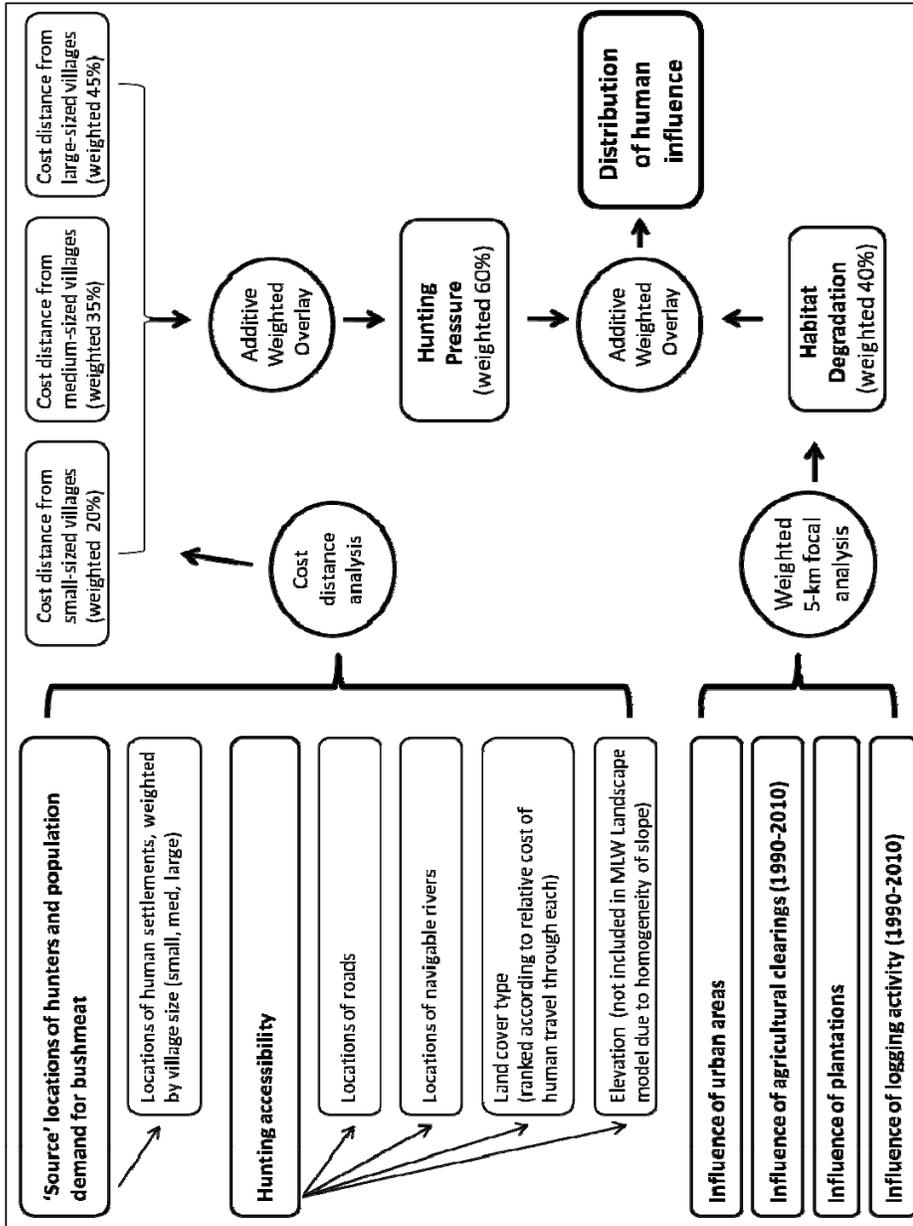
Figure 2.1 A conceptual diagram of the spatially-explicit threat-based model developed for identifying the spatial distribution of human influence in the MLW Landscape. The major components of the model include factors relating to potential hunting pressure and habitat degradation in the landscape.

Table 2.1 A list of spatial data and sources used in the multi-criteria model.

Data Category	Data Type	Source
Hunting pressure	Landcover rankings	University of Maryland (UMD) and South Dakota State University (SDSU). 2009. Landcover categories for the Maringa-Lopori-Wamba (MLW) Landscape.
Hunting pressure	Roads: Transport	World Resources Institute (WRI) and the Ministry of the Environment, Conservation of Nature and Tourism of the Democratic Republic of Congo (MECNT). 2010. Atlas forestier interactif de la République Démocratique du Congo - version 1.0. Washington, D.C.: World Resources Institute. Downloadable at: http://www.wri.org/publication/interactive-forest-atlas-democratic-republic-of-congo
Hunting pressure and Habitat Degradation	Roads: Logging	World Resources Institute (WRI) and the Ministry of the Environment, Conservation of Nature and Tourism of the Democratic Republic of Congo (MECNT). 2010. Atlas forestier interactif de la République Démocratique du Congo - version 1.0. Washington, D.C.: World Resources Institute. Downloadable at: http://www.wri.org/publication/interactive-forest-atlas-democratic-republic-of-congo
Hunting pressure	Navigable rivers	CARPE database, University of Maryland. Downloadable at: ftp://congo.iluci.org/CARPE_data_explorer/Products/drc_rivr.zip
Hunting pressure	Human settlements	United Nations Organization Mission in the Democratic Republic of Congo (MONUC) and the NGA GEOnet Names Server (GNS). 1999. United Nations Office for the Coordination of Human Affairs (http://ochaonline.un.org/) Downloadable from: https://gistdata.itos.uga.edu/
Habitat Degradation	Agricultural areas	University of Maryland (UMD) and South Dakota State University (SDSU). 2009. Landcover categories for the Maringa-Lopori-Wamba (MLW) Landscape.
Habitat Degradation	Urban areas and Plantations	Food and Agriculture Organization of the United Nations (FAO). 2000. Africover Multipurpose Land Cover Databases for Democratic Republic of Congo. Rome: FAO. Downloadable at: http://www.africover.org/system/africover_data.php
Habitat Degradation	Agricultural clearings 2000 - 2010	Observatoire Satellital des forêts d'Afrique central (OSFAC). 2010. Forêts d'Afrique Centrale Évaluées par Télédétection (FACET): Forest cover and forest cover loss in the Democratic Republic of Congo from 2000 to 2010. Brookings, South Dakota, USA: South Dakota State University. Downloadable at: http://osfac.umd.edu/facet.html

Table 2.2 Relative rankings were used to describe potential hunter travel accessibility through each land cover and land use type.

Data Type	Rank (1= lowest travel cost, 4= highest travel cost)
Roads	1
Navigable rivers	1
Urban areas	1
Agricultural areas and clearings	2
Forest: Dense moist evergreen and semi-deciduous	3
Forest: Inundated (swamp forest)	4

Second, we assigned all human settlements in the landscape a relative size ranking in three categories to reflect the relative potential number of hunters in each village and the approximate relative population demand for bushmeat. We determined our size categories using a combination of human settlement data provided by WRI and MECNT (2010) and field knowledge. Next, we used the Cost Distance tool in ESRI ArcGIS 9.3 software to create three separate cost-distance grids, assigning each grid cell a final score of relative travel accessibility from the nearest settlement for each of the three size categories. We combined the three resulting grids using the ArcGIS Weighted Overlay tool where we assigned weights to each grid based on its relative contribution to hunting pressure (20% was assigned to the cost-distance surface generated from small-sized settlements, 35% from medium-sized settlements, and 45% from large-sized settlements). The assignment of weights was based on the assumption that larger settlements have a larger relative "source" of hunters as well as a larger relative demand for bushmeat, and thereby have an overall higher potential influence on hunting accessibility. The output of this sub-model was a mapped index of hunting accessibility from all settlements in the

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landscape weighted by relative size. An important caveat (which also applies to the original WCS model on which this sub-model is based) is that the index provides a relative assessment of potential hunting accessibility only, and does not attempt to model relative bushmeat availability (which in reality would influence a hunter's decisions about where to hunt). Second, the model assumes that hunting activity is linearly related to the amount of time it takes to access a particular location from each village, which might be false.

The habitat degradation sub-model considered the relative influence of a variety of factors affecting the degradation of terrestrial wildlife habitat (including bonobo habitat, a flagship species) in the MLW Landscape. These factors included the presence of densely settled areas, agricultural complexes, large-scale palm plantations, logging roads, and small clearings in remote forested areas. With the help of AWF biologists stationed in the landscape, we subjectively assigned a ranking score to each factor to reflect its relative contribution to habitat degradation. We assigned densely settled areas and large-scale palm plantations a higher degradation score of 2, while agricultural areas, old logging roads and small clearings were assigned a lower degradation score of 1. We then used a circular moving window to calculate the sum of all grid cells within a 5 km radius to produce a spatially-explicit continuous surface of the relative intensity of these factors across the landscape. The model therefore assumes that forests proximate to densely settled areas are subject to more degradation from a combination of cultivation and non-timber forest product collection than forests in more remote areas.

Finally, we added together the hunting accessibility and habitat degradation

surfaces. Because we agreed that hunting poses a greater immediate threat to

terrestrial biodiversity in MLW (especially to the bonobo, cited in IUCN 2010), we

assigned it a weight of 60%, versus 40% for habitat degradation (refer to Figure 2.1).

2.2.3   Identification of wildland blocks and corridors

We followed the methods outlined in Sanderson *et al.* (2002) and Mcpherson *et al.*

(2008) to identify systematically locations of the least-disturbed forest blocks in the

MLW Landscape. We summarized and extracted the average human influence value

derived from the threat-based model into a grid of 1 km^2 planning units. The

planning units falling below the medium mean threshold of human influence were

designated as wildland blocks important for conservation prioritization. To reflect the

authors' decision to tailor the analysis to meet the needs of the bonobo, an umbrella

species, all wildland blocks not meeting a minimum size requirement of 20 km^2 (the

size of the bonobo home range according to Hashimoto *et al.* (1998)) were

eliminated.

After identifying the locations of the wildland forest blocks, we modeled the

potential connectivity areas linking them using the Corridor Designer extension for

ArcGIS (Majka *et al.,* 2007). We chose this particular software package for its

usability, reputation, and applicability for decision-making support in habitat

conservation and landscape planning. Corridor modeling is usually performed on a

species-specific basis, incorporating biological needs for a set of focal species,

including preferred dispersal distances, links to ecological processes, and mobility

preferences (Beier *et al.,* 2008). We parameterized our analysis to meet the minimum

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home range area of 20 km^2 and a breeding patch size of 10,000 km^2. This breeding

patch size was five times larger than the minimum habitat patch size, per the Corridor

Designer recommendations. We used the output of the threat-based human influence

model detailed in the previous section as our "cost" surface to depict the ecological

conditions promoting or discouraging bonobo movement through each grid cell in

order to identify the most permeable travel routes between wildland blocks. Because

bonobos do not cross major rivers, we extracted a subset of the largest rivers (defined

as at least 30 meters across and detected by Landsat satellite imagery) using a

combination of satellite imagery and expert knowledge, and then applied them in the

corridor suitability model as a constraint to bonobo connectivity.

2.3 Results

2.3.1 Assessing decadal patterns of primary forest loss

Although the overall loss of primary forest in the MLW Landscape during 2000-2010

was relatively low (the FACET data revealed a decadal primary forest deforestation

rate of 0.45% for MLW versus 1.03% for DRC), nearly two-thirds of the total 2000-

2010 primary forest loss occurred during the second half of the decade (35.4 % of all

primary forest loss in MLW took place in 2000–2005, and 64.6% occurred in 2005-

2010, see Figure 2.2). A closer look at the mapped FACET data in a GIS shows that

deforestation sites are dispersed (there are no active logging concessions nor large-

scale agricultural activities in the MLW Landscape) and therefore can be attributed

primarily to small-scale, subsistence-based agriculture. Only one commercially-
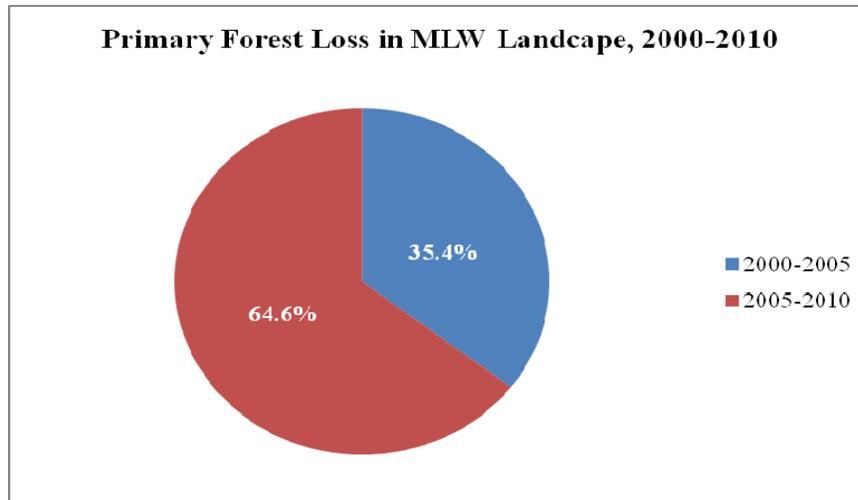
Figure 2.2 Percent primary forest loss in the MLW Landscape, 2000-2005 and 2005-2010.

owned palm plantation significantly expanded into the primary forest (approximately 2 km^2).

We identified four common spatial patterns of primary forest conversion occurring in the MLW Landscape (Figure 2.3): conversion in areas around roads where there previously were no clearings (shown in map subset #1), conversion along the outermost edges of existing agricultural areas fanning out from the roads (shown in map subset #2), conversion alongside major navigable rivers most likely due to expansion of fishing communities (shown in map subset #3), and conversion in remote forested areas most likely due to expansion of hunting camps and isolated pockets of small-scale agriculture (shown in map subset #4). As mentioned previously and explained in Draulans & Van Krunkelsven (2002), we attribute the conversion patterns detected and shown in map subset #4 to the particular human
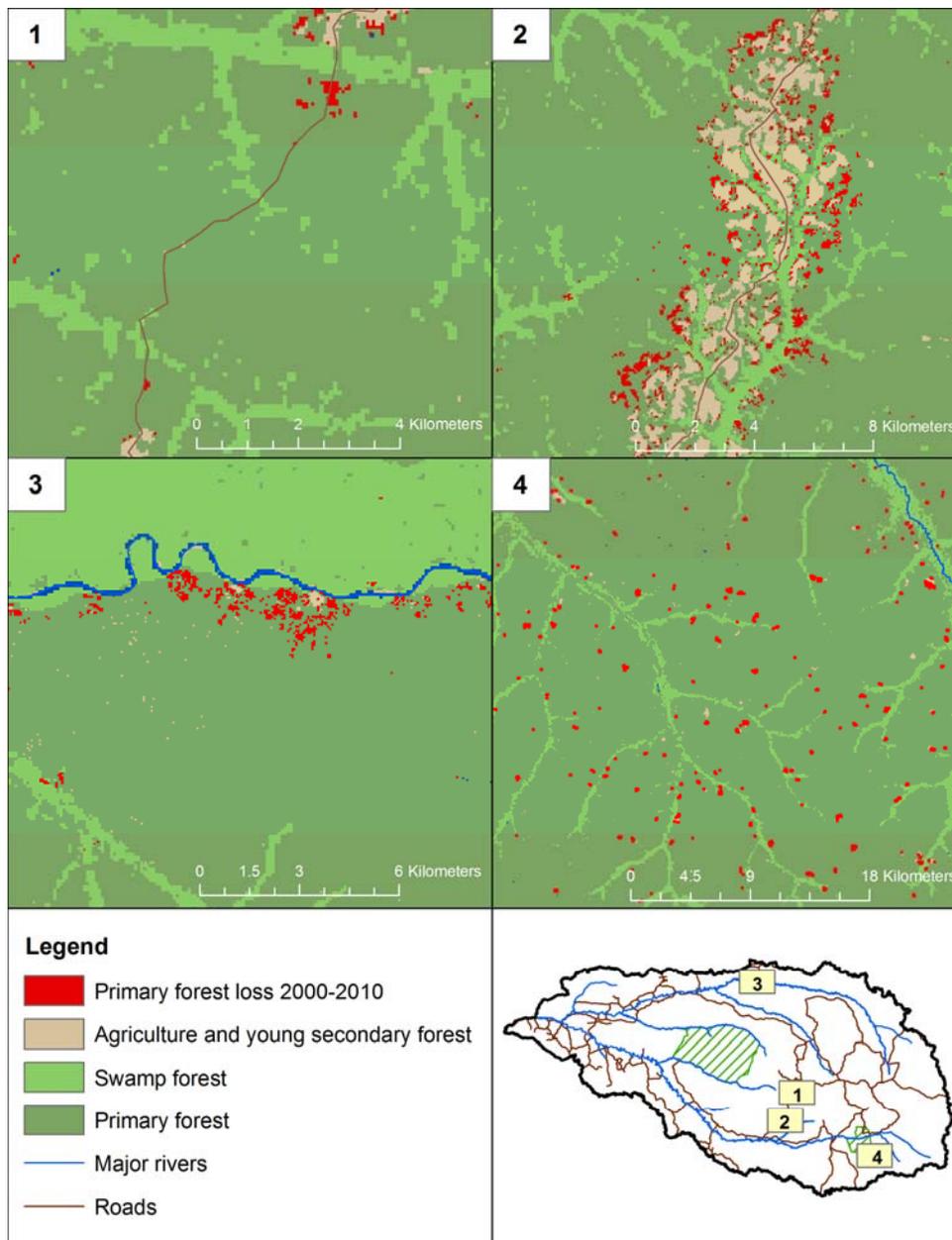
Figure 2.3 Four distinct spatial patterns of forest conversion in the MLW Landscape are illustrated: 1) conversion in areas around roads where there previously were no clearings, 2) conversion along the outermost edges of existing agricultural areas fanning out from the roads, 3) conversion alongside major navigable rivers most likely due to expansion of fishing communities, and 4) conversion in remote forested areas most likely due to expansion of hunting camps and isolated pockets of small-scale agriculture (note: for #4, primary forest loss pixels were buffered by 90 meters to enhance visual clarity).
migration patterns that happened during the DRC war.

We found that roughly 66% of forest loss for 2000-2010 occurred within 3 kilometers of roads, suggesting that the majority of it can be ascribed to slash-and-burn agricultural activity around human settlements located along road and river axes. This is illustrated in the bar graph in Figure 2.4, which shows the relative proportion of decadal rates of forest loss in the MLW Landscape and corresponding spatial relationship to roads. Here, we discovered that the proportion of forest conversion occurring in the second half of the decade relative to the first half was 5% higher in locations within 1 kilometer from roads. For locations between 1 to 10 kilometers from roads, the proportion of primary forest loss was relatively consistent between the two halves of the decade (although slightly lower in the second). In remote forested locations greater than 10 kilometers away from roads, we found that the proportion of forest conversion taking place in the second half of the decade decreased by approximately 2.5% relative to the first.

2.3.2   Determining locations of high conservation potential

Figure 2.5 presents the mapped result of the threat-based model of human influence at 90 m resolution. Values range between 0 (low human influence) to 1 (high human influence). As expected, the areas of highest human influence are clustered around roads where settlements occur.
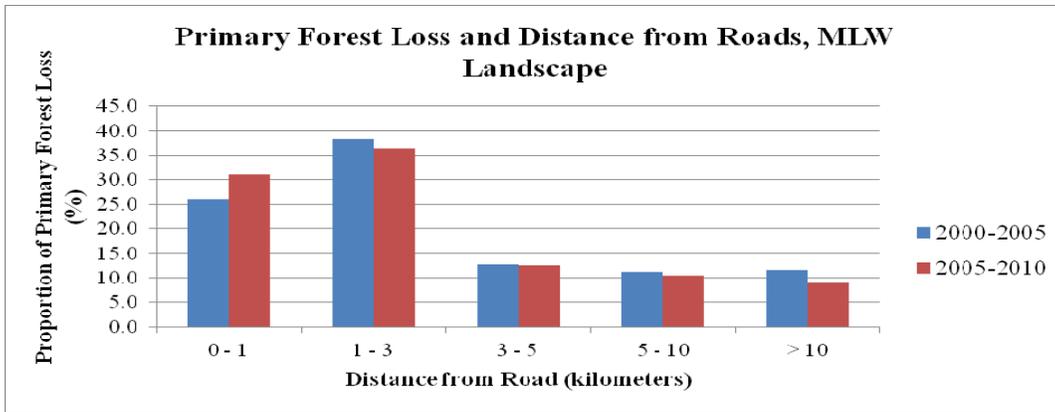
Figure 2.4 The proportion of forest loss in the MLW Landscape in relation to distance from roads is shown for 2000-2005 and 2005-2010.
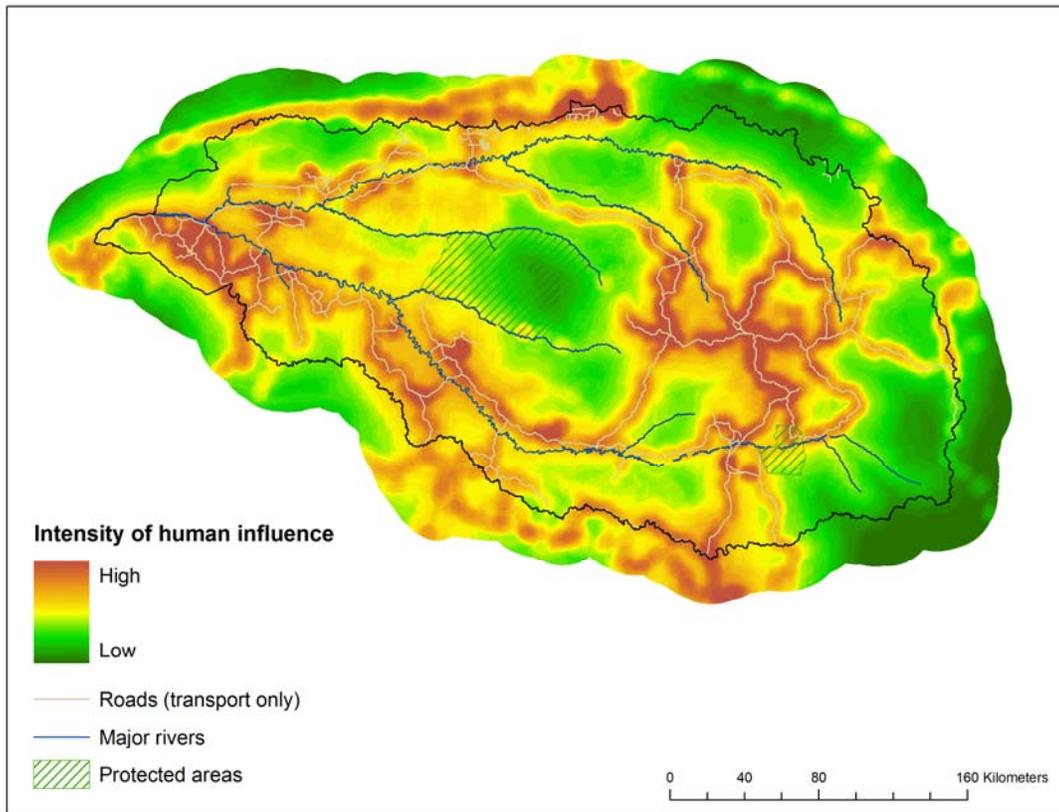
Figure 2.5 A map of the final result of the threat-based multi-criteria model determining the spatial distribution of the intensity of human influence in the MLW Landscape. Areas of highest human influence, shown in the graduated color scale in oranges and browns, are clustered around roads where settlements occur.

The maps in Figure 2.6 show the result of aggregating the average human influence scores to a grid of 1 km^2 planning units to determine locations of high-priority wildland blocks. The map at the top of the figure reveals the 1 km^2 planning units falling above (shown in orange) and below (shown in green) the threshold of "medium" mean human influence. The map at the bottom of the figure shows the planning units with a human influence score falling below the threshold and that were identified as least-disturbed wildland blocks. We identified 42 wildland blocks, occupying 60% of the MLW Landscape, that had an area of at least 20 km^2, the home range of the bonobo. The largest identified wildland block extends almost 13,000 km^2. While the wildland blocks smaller than 20 km^2 may be insufficient to support a bonobo population's home range, they may still offer value for dispersal and connectivity.

Figure 2.7 presents the result of the corridor suitability analysis parameterized to facilitate bonobo movement between wildland blocks. The 32 corridor sections identified occupy 3% of the landscape. Corridor Designer produced a nested set of increasingly wide "slices" comprised of the pixels with lowest cost distance between wildland blocks; here, we show the smallest 1% slices. Figures 2.5 - 2.7 demonstrate the pivotal role of spatial data and analysis in determining the spatial distribution of conservation priority areas in the MLW Landscape.
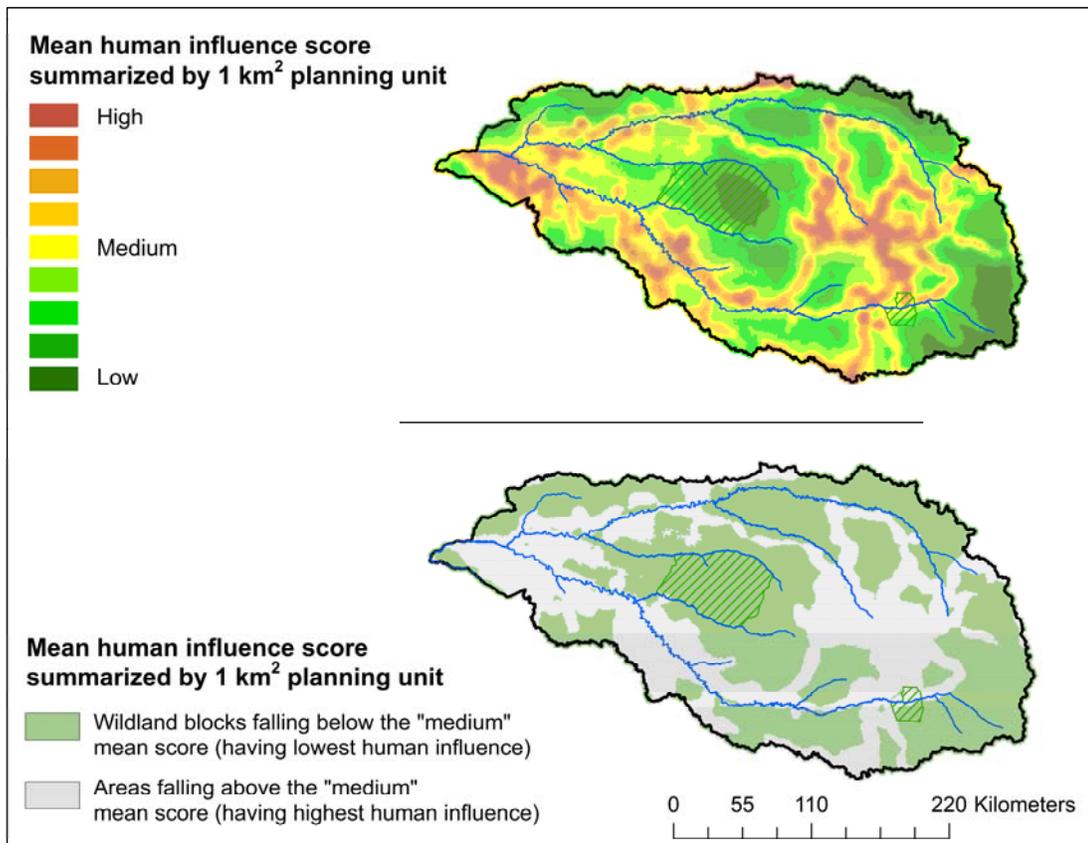
Figure 2.6 The map at the top of the figure reveals the 1 km² planning units falling above (shown in orange) and below (shown in green) the threshold of "medium" mean human influence across the MLW Landscape. The map at the bottom of the figure shows the planning units with a human influence score falling below the threshold and comprising the least-disturbed wildland blocks.
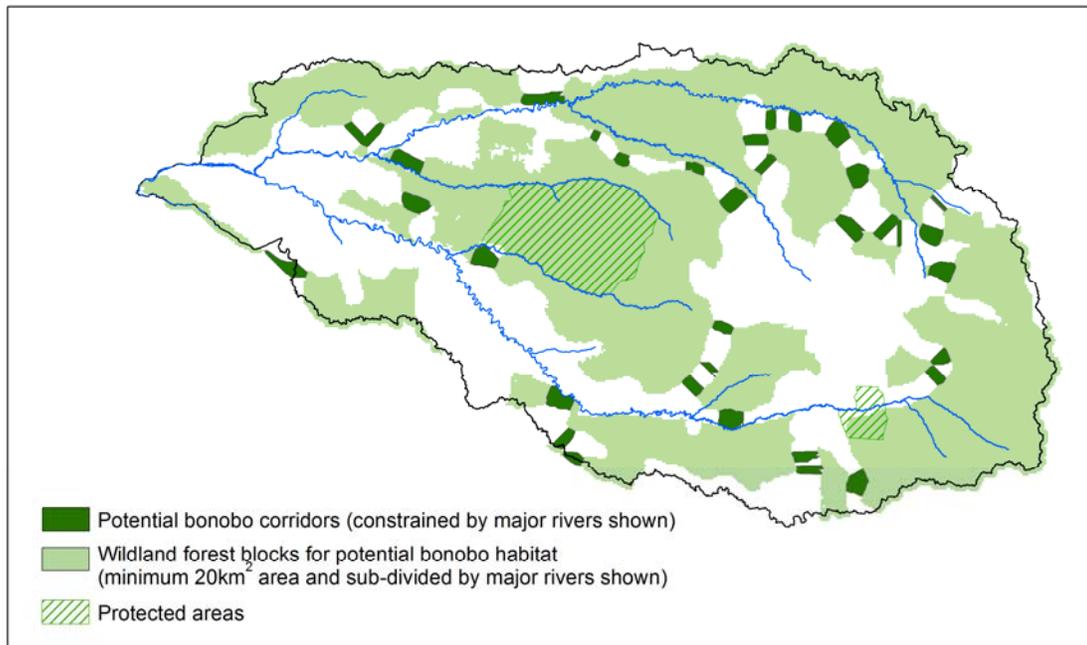
Figure 2.7 A map of the resulting corridor suitability analysis parameterized to facilitate bonobo movement between wildland blocks.

Using the FACET data, we found that 20.5% of all forest loss occurring in the MLW Landscape during 2000-2010 took place in the potential bonobo wildland blocks and 5% occurred in the potential corridors. Threading through agricultural areas, the corridors, however, are more threatened, having a decadal net loss of 0.59% versus 0.14% for the wildland blocks. Figure 2.8 provides an illustrative map of the relative vulnerability of the bonobo corridors to observed primary forest loss. The corridors shown in red experienced the highest rates of primary forest loss during the decade and are consequently most vulnerable to encroachment (loss of forest around the edges of the corridors) and interior fragmentation. We use the term "vulnerable" to communicate our assumption that recent forest conversion patterns are suggestive

of likely future conversion patterns. Therefore, we would expect that corridors that

have suffered from extensive encroachment in 2000-2010 will experience similar

levels of encroachment over the course of the next decade.
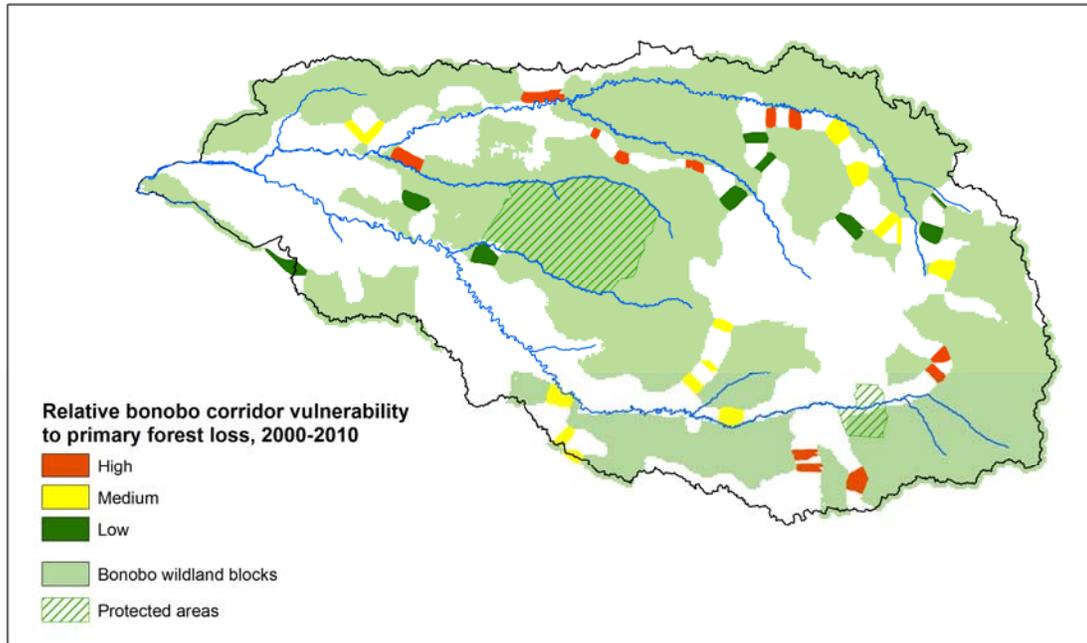
Figure 2.8 A map illustrating the relative vulnerability of the bonobo corridors to observed primary forest loss. The corridors shown in red experienced the highest rates of primary forest loss during the 2000-2010 decade and are consequently considered most vulnerable to human encroachment (loss of forest around the edges of the corridors) and interior fragmentation. Maps like this can be a useful tool for conservation practitioners to prioritize areas for conservation action in the face of past, current and future land cover and land use change.

2.4 Discussion

2.4.1 Patterns of land use change and primary forest loss

The majority of primary forest loss during the 2000-2010 decade occurred within 3 km from roads in existing rural complexes. During the second half of the decade, there was a 30% increase in primary forest loss from the first half; the largest proportion of this increase took place in locations within 1 kilometer from roads. We believe that this phenomenon might be linked to human migration patterns following the conclusion of DRC's war in 2003. It is likely that local populations returned to their natal villages (with possibly larger families) after the war and cleared new fields to revitalize and increase food production after escaping into interior forests to avoid wartime conflict as documented in Draulans & Van Krunkelsven (2002) and Furuichi *et al.* (2012). Because our analysis based on the FACET data does not consider forest regrowth, however, it is difficult to draw too many conclusions about potential human migration patterns. For example, we do not yet understand whether certain clearings, located farther away from roads and located in more remote forests, may have been abandoned after the war. An additional factor possibly influencing forest conversion patterns in MLW since the conclusion of the DRC war is that AWF and partners have implemented conservation programs in the landscape designed to boost the agricultural sector near river ports and central market areas. A more comprehensive time-series analysis of landscape land cover and land use dynamics that considers other time periods would be helpful to evaluate these speculations.

2.4.2   Spatially-explicit threat-based modeling for conservation prioritization

We identified 42 wildland blocks, occupying 60% of the MLW Landscape, large

enough to support the home range of a bonobo, and 32 corridor sections offering

connectivity between them. We also discovered that the corridors, which generally

thread through agricultural areas, were more vulnerable to primary forest loss than the

wildland blocks and therefore should be the focus of our conservation priorities. The

map shown in Figure 2.8 is an example of how this type of spatial information can be

used as a tool for conservation practitioners to prioritize areas for conservation action

in the face of past, current and future land cover and land use change.

Systematic conservation planning strategies have evolved to include multiple

steps including the identification of target species, stakeholder participation, and

detailed threats analyses. Determining where to do conservation, and how to achieve

it, are separate processes. Thus, the conservation prioritization methods that we

outline here should not be interpreted as a comprehensive approach for conservation

planning. Instead, we hope they can serve as a foundation of a workflow that

conservation practitioners could find useful in combination with other planning

activities. The methods have wide applicability for conservation prioritization and

land use planning in other areas of the Congo Basin (such as in other Congo Basin

Forest Partnership Landscapes), especially those areas that may be hampered by a

lack of biological habitat data. Because there are no precise rules for selecting threats

and assigning corresponding weights of influence, involving the knowledge of local

or regional experts is essential (Mcpherson *et al.,* 2008), and we therefore advocate

the use of participatory threats analyses (Beazley *et al.,* 2010) to complement these methods. Our work, for example, would benefit from the inclusion of stakeholder involvement to increase our understanding of the influence of palm plantations in the landscape, and how it might change in the future due to speculation about potential palm expansion in DRC (African Bulletin, 2011).

We also recommend the use of sensitivity analyses to address the subjectivity of certain weights used in the threat-based model (such as the relative weighting of small, medium and large settlements in the hunting influence model). We assigned our weights based on expert- and field- based knowledge, but this is not always ideal, as explained in Beazley *et al.* (2010). In addition, a great deal of time was invested in assessing the quality of all input data used in the model. We determined that spatial data in several categories, such as road and town locations, exhibited significant disagreement and variability in data quality as they were mapped by multiple data providers. We recommend careful inter-comparison and editing of datasets to find the best representation (perhaps derived from an eclectic combination of several datasets) of the phenomenon of interest. Overlaying datasets on top of satellite imagery is useful for accuracy evaluation or for digitizing new features when necessary.

Our corridor analysis utilized the Corridor Designer tool for mapping potential bonobo corridors between modeled wildland blocks. One advantage of this tool is that it produces a nested set of increasingly wide "slices" of corridors made up of the pixels with lowest cost distance between wildland blocks. Using this output, a graduated cost map of corridor potential can be created and presented to stakeholders

to offer added flexibility in the land use planning process. We recommend the use of this freely-available tool in conservation prioritization methods.

2.5   Conclusion

As carbon accounting programs and conservation incentive mechanisms such as REDD+ (UNFCC, 2010) improve deforestation monitoring efforts in the Congo Basin, spatial analyses of primary forest conversion patterns will be increasingly important in order to develop land use planning strategies in areas most vulnerable to habitat loss and fragmentation. Datasets like FACET consequently will have real value for targeting and planning. Efforts to move forward with national-level strategies for conservation land use planning in DRC will likely be challenged by limited data collection for target species due to issues of inaccessibility and high costs of implementing data collection procedures. Planning strategies that take into account identification of core areas achieving representation of native species and ecosystems and their inter-connectivity, therefore, will be crucial. The design and implementation of conservation planning methods should take place in conjunction with local communities in order for sustainable future development to benefit both people and wildlife.

Chapter 3: A comparison of scenarios for rural development planning in the Democratic Republic of the Congo[1]

3.1 Introduction

Systematic conservation planning (Margules & Pressey, 2000; Groves *et al.,* 2002) is often facilitated by heuristic-based optimization tools that are mathematically programmed to find solutions for meeting well-defined targets (Possingham *et al.,* 2000; Klein *et al.,* 2010). Heuristic (non-exact) algorithms are generally preferred over exact algorithms for planning, as they are more efficient at working with large datasets typically involved in planning (Ardron & Klein, 2008) and provide a set of near-optimal solutions for planners and stakeholders to consider (Possingham *et al.,* 2000; McDonnell *et al.,* 2002; Cabeza, 2003). There is a wealth of literature demonstrating application of heuristic-based optimization tools for systematic conservation land use planning; these include McDonnell *et al.* (2002), Klein *et al.* (2010), Meinke *et al.* (2009), Wilson *et al.* (2010), Esselman and Allan (2011), and Schneider *et al.* (2011).

We employed a spatial allocation decision-support tool called Marxan (Ball & Possingham, 2000; Possingham *et al.,* 2000) to generate potential options for

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[1]The presented material is in preparation to be submitted to *Biological Conservation:* Nackoney J, Williams D (in prep) A comparison of scenarios for rural development planning in the Democratic Republic of the Congo.

delineating the most suitable land for inclusion in a proposed Rural Development Zone (RDZ) in the MLW Landscape. The RDZ is a macro-level zone designated for the sustainable expansion of agricultural activities under a management plan (Sidle *et al.,* 2010). It is intended to contain deforestation from slash-and-burn methods so that surrounding forests are protected for the collection of non-timber forest products such as bushmeat, fuelwood, fruits and medicinal plants, as well as for provision of ecosystem services and the overall conservation of biological diversity. Other macro-zones being defined for the MLW Landscape are community-based natural resource management areas (CBNRMA), protected areas, and logging concessions.

Given a set of assumptions about population growth and agricultural expansion, we used Marxan to develop a series of potential scenarios for future human and agricultural expansion for 2050 to guide stakeholders and assist decision-makers for future macro-level planning activities for MLW. We used data describing current patterns of human activity, land cover suitability for agricultural activity, and presence of important wildlife connectivity zones and protected areas to identify locations suitable for agricultural expansion considering both human preferences and conservation priority areas. The resulting options inform further refinement of the landscape's Land Use Plan (Dupain *et al.,* 2010) and illustrate how competing needs might be balanced in planning for both livelihood expansion and terrestrial biological conservation in the MLW Landscape.

3.2 Methods

3.2.1 2050 Rural Development Zone design

Numerous studies have employed optimization models for rural land allocation (e.g.,

Raja *et al.,* 1997; Meyer-Aurich *et al.,* 1998; Roetter *et al.,* 2005; Sadeghi *et al.,*

2009) using linear programming and employing various agricultural data (labor,

fertilizer use, productivity, etc.). Due to the absence of these spatially-explicit data

for MLW, our methods are derived from a purely land cover and land use perspective

based on human population growth and historical rates of primary forest conversion.

Marxan was developed to inform the selection of new conservation areas and

facilitate the exploration of trade-offs between conservation and socio-economic

objectives (Ardron & Klein, 2008). The tool, which is freely available, is widely used

by conservation practitioners for many reasons, including its flexibility (it can be used

within a variety of different graphical front-end software packages, including ESRI

ArcGIS), its accommodation of spatially variable data, its use of a powerful simulated

annealing algorithm that arrives at alternative solutions relatively quickly (even for

large problem sets), and users can learn it fairly easily thanks to training programs

and free online support (Ball *et al.,* 2009). Although our particular application of

Marxan is somewhat unconventional (we are not using it for the identification of

protected areas), we chose it for this research for the above reasons and for its direct

relevance to our optimization problem.

First, one or more conservation objectives, or "targets" is defined by the user.

Our *target* was a projected future amount of agricultural land needed for the RDZ to

satisfy agricultural livelihoods in the landscape by 2050 based on our assumptions.

Marxan's simulated annealing algorithm then selects an optimal configuration of

planning units that meet the defined target(s) at minimum "cost." *Cost* is a relative

term that describes any number of measures, including socio-economic costs or land

protection opportunity costs (Wilson *et al.,* 2005; Richardson *et al.,* 2006) and

represents a range of values assigned that are to the planning units by the user to

control their relative suitability for site selection. Our costs were based on the

prevalence of factors determining relative suitability for future agricultural expansion,

such as the intensity of human activity, or the locations of conservation priority areas

in the landscape. Outputs were potential agricultural zoning designs that can assist

stakeholders in determining the spatial extent of the landscape's RDZ.

The mathematical basis of Marxan is described by an objective function that

minimizes a linear combination of the planning unit costs as well as penalties for not

meeting defined targets. At the same time, the objective function accounts for a

measure of fragmentation so that planning units making up the final solution are

clustered and not scattered. Because a more fragmented reserve network will have a

greater overall boundary length (Game & Grantham, 2008), this component of the

objective function is achieved by minimizing the outer boundary length of the

solution portfolio. Therefore, planning units are selected for inclusion in the RDZ if

they are assigned high suitability (i.e., low cost) for agricultural expansion, if their

configuration promotes a smaller overall outer boundary (i.e., a more compact, not

scattered, agricultural zone that minimizes the amount of forest fragmentation in the

landscape), and if they represent adequate coverage to meet the defined target amount

of agricultural land needed for 2050.

Minimize the objective function (Ball & Possingham, 2000):

$$\sum_{PUs} Cost + BLM\sum_{PUs} BoundaryLength + \sum_{ConValue} CFPF \times Penalty + CostThresholdPenalty$$

'*Cost*' is a relative measure assigned to each planning unit ('*PU*') that determines its suitability for inclusion in the RDZ. '*BoundaryLength*' is the total length of the outer boundary of the planning units selected for the RDZ. *BLM* (a constant) is the boundary length multiplier that regulates the length of the RDZ boundary relative to the total cost of the planning units within the RDZ system. '*CFPF*' is the conservation feature penalty factor unique to each conservation feature. This last group of terms represents a penalty factor that is assigned to each conservation feature for failing to achieve target representation and controls the priority that each conservation feature receives. Accordingly, these last terms of the objective function are increasingly important for planning problems that need to accommodate several conservation features and targets. '*CostThresholdPenalty*' is an optional penalty assigned for exceeding a preset cost threshold (often used when planning unit costs are monetized; it was not used in this research). For more detailed information on Marxan's objective function, refer to Ball and Possingham (2000).

3.2.2   Defining potential scenarios of agricultural expansion

Our models were designed to be run multiple times with varied inputs to create a set of optimized scenarios based on a set of diverse objectives incorporated from multiple stakeholders. Proposing multiple scenarios allows for incorporation of sensitivity analyses of model inputs (Ardron *et al.,* 2010). Our scenarios were designed to illustrate possible options for future agricultural expansion while considering both human preferences and conservation objectives. Resulting options and trade-offs can then be evaluated by stakeholders in the RDZ planning process.

1. Land cover/land use scenario: This business-as-usual scenario, a least-biased "control" scenario of agricultural expansion, reflects where agricultural expansion might occur based upon land use and land cover type. This scenario accounts for only basic human preferences for settlement and agricultural expansion as revealed by the locations of land cover types that may be suitable (agriculture or forest) or not suitable (swamp forest and water bodies) for settlement and agricultural activity.

2. Human preference scenario: In addition to the above land cover suitability, this scenario accounts for proximity to roads, navigable rivers and human settlements, factors which enable human activities. This scenario also assigns preference for agricultural expansion in existing agricultural areas that likely harbor higher population densities.

3. Conservation priority (human preference with conservation constraints) scenario: In this scenario, future agricultural and human expansion is

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driven by a combination of human preferences (as above) and conservation priority

areas. The conservation priority areas consist of formal protected areas and areas

located in remote forests with the lowest human influence (defined by hunting

accessibility and habitat degradation as described in Chapter 2), and the wildlife

corridors connecting them (parameterized for the bonobo, also detailed in Chapter 2).

3.2.3   Defining model targets and assumptions

We used a combination of human population data (ORNL, 2005) and primary forest

loss data (OSFAC, 2010; Potapov, 2012) to calculate the amount of agricultural land

needed to sustain growing human populations in the MLW Landscape for 2050.

Using 2005 human population derived from ORNL (2005) and applying 2000-2010

yearly growth rates (Barrientos & Soria, 2011), we estimated 605,529 people in the

landscape in 2000 and 824,285 by 2010. We used total 2000-2010 primary forest loss

(298 km^2) to project agricultural expansion rates. Because approximately 99% of

primary forest loss in the landscape during this time period was attributed to

agriculture (described in Chapter 2), we used primary forest loss rates as a surrogate

for agricultural expansion rates. We subtracted the 2000 human population from the

2010 human population to derive a per capita rate of agricultural expansion for 2000-

2010 (0.0013 km^2/person). Using a population growth rate of 3% per annum, the

average population growth rate for 2000-2010, we calculated decadal projections of

per capita agricultural expansion to 2050 and cumulatively added each decadal

expansion to the total surface area of agricultural land in MLW from the previous

decade. There were 5,991 km^2 of agricultural land in 2010 and we estimated that

8,538 km^2 of agricultural land would be needed by 2050 (a 43% increase from 2010),

assuming that 2000-2010 forest conversion rates remain constant.

In addition, we used a more liberal scenario of agricultural expansion for the

landscape to calculate a larger agricultural target for 2050. The rate of primary forest

loss in the landscape was not constant between 2000-2005 and 2005-2010. Because

of the war in DRC that ended in 2003, nearly two-thirds of MLW's 2000-2010

primary forest loss occurred during the second half of the decade, possibly due to

human migration patterns and the revitalization of agriculture following the war

(described in Chapter 2). To accommodate potentially accelerated rates of

agricultural expansion, we doubled the higher 2005-2010 amount of primary forest

loss (193 km^2 over a five-year period), which amounted to a projected need for 9,283

km^2 of agricultural land by 2050 (a 55% increase from 2010).

We defined a set of assumptions for optimizing the RDZ:

- Human populations will continue to live and farm in existing agricultural areas.
- Human populations will continue to grow at an average rate of 3% per annum.
- Whether a land unit is currently being farmed or not is already known.
- Human populations prefer to live and farm near existing settlements, roads, and navigable rivers.
- Human populations will not live or farm in swamps, wetlands, or water bodies.
- Once existing agricultural land becomes less productive, or human populations expand such that new agricultural land is needed, human populations will move into the dense forest, avoiding swamps and water bodies.

3.2.4   Preparing the planning unit inputs

Our model inputs were defined by a grid of 76,371 equally-sized 1 x 1 km planning

units. For each planning unit, a relative cost was assigned. Planning units with lower

relative cost were more likely to be selected for inclusion in the RDZ; likewise,

planning units with higher relative cost were more likely avoided. We used eight data

layers to generate three separate cost surfaces that determined agricultural favorability

for each scenario (Table 3.1, Figure 3.1). In Scenario 1, higher costs were assigned to

areas with low agricultural suitability as defined by land cover type. For Scenario 2,

higher costs were assigned to areas farther from roads, navigable rivers and human

settlements. In Scenario 3, higher costs were assigned to areas inaccessible to

hunting and habitat degradation. Each cost surface was normalized from 1 to 100 and

summarized by calculating the average cost score by planning unit. They are

summarized in Figure 3.1.

Marxan provides an option to assign each planning unit a 'status' value that

regulates how it will behave during optimization (Table 3.2). A status value of 3

"locks out" the planning unit from the final solutions (i.e., the planning unit is not

considered) whereas Status 2 "locks in" the planning unit (i.e., the planning unit is

forced into the final solution). Status 1 allows the planning unit to act as a "seed" that

will be included in the initial selection of planning units but may or may not be

chosen for the final solution. In summary, this value is essential for controlling which

planning units will be forced to end up in the final solutions, which will be avoided,

and which will be considered. For Scenario 1, we assigned all planning units

comprised of $\geq$ 75% swamp forests and rivers Status 3, as well as all planning units

comprised of $\geq$ 50% protected areas. We assigned all planning units comprised of $\geq$

25% agricultural land use Status 1. For Scenario 2, we assigned all planning units

comprised of $\geq$ 75% swamp forests and rivers Status 3 (protected areas were not

considered). We also subdivided planning units based on different proportions of

agricultural land; those comprised of 25% - 75% were assigned Status 1, while those

comprised of > 75% were assigned Status 2, so that heavily farmed areas were forced

into the final solution set. Scenario 3's rules were a combination of the first two, with

the inclusion of wildlife corridors (Status 3) included.

3.2.5   Calibrating the models

We calibrated the boundary length modifier (BLM) to control clustering and

compactness of modeled planning unit solutions (McDonnell *et al.,* 2002; Ardron *et*

al., 2010). We scaled our initial calibration range for the BLM to the same magnitude

as our 1-km planning unit boundary lengths and cost surface inputs (Ardron *et al.,*

2010: p. 86). We then ran Marxan several times for each scenario and altered the

BLM within our calibration range to identify the most appropriate BLM value that

minimized total cost and maximized compactness of the RDZ.

Table 3.1 A list of spatial data used to derive cost surfaces for each scenario.

Scenario	Data Type	Data Source
Scenario 1	Land cover and land use	University of Maryland (UMD) and South Dakota State University (SDSU). 2009. Land cover categories for the Maringa-Lopori-Wamba (MLW) Landscape at 30-meter resolution.
Scenarios 2 and 3	Roads: Transport only	World Resources Institute (WRI) and the Ministry of the Environment, Conservation of Nature and Tourism of the Democratic Republic of Congo (MECNT). 2010. Atlas forestier interactif de la République Démocratique du Congo - version 1.0. Washington, D.C.: World Resources Institute. Downloadable at: http://www.wri.org/publication/interactive-forest-atlas-democratic-republic-of-congo
Scenarios 2 and 3	Navigable rivers	CARPE database, University of Maryland. Downloadable at: ftp://congo.iluci.org/CARPE_data_explorer/Products/drc_rivr.zip
Scenarios 2 and 3	Human settlements	United Nations Organization Mission in the Democratic Republic of Congo (MONUC) and the NGA GEOnet Names Server (GNS). 1999. United Nations Office for the Coordination of Human Affairs (http://ochaonline.un.org/) Downloadable from: https://gistdata.itos.uga.edu/
Scenario 3	Roads: Logging	World Resources Institute (WRI) and the Ministry of the Environment, Conservation of Nature and Tourism of the Democratic Republic of Congo (MECNT). 2010. Atlas forestier interactif de la République Démocratique du Congo - version 1.0. Washington, D.C.: World Resources Institute. Downloadable at: http://www.wri.org/publication/interactive-forest-atlas-democratic-republic-of-congo
Scenario 3	Agricultural areas	University of Maryland (UMD) and South Dakota State University (SDSU). 2009. Landcover categories for the Maringa-Lopori-Wamba (MLW) Landscape.
Scenario 3	Urban areas and Plantations	Food and Agriculture Organization of the United Nations (FAO). 2000. Africover Multipurpose Land Cover Databases for Democratic Republic of Congo. Rome: FAO. Downloadable at: http://www.africover.org/system/africover_data.php
Scenario 3	Agricultural clearings 2000 - 2010	Observatoire Satellital des forêts d'Afrique central (OSFAC). 2010. Forêts d'Afrique Centrale Évaluées par Télédétection (FACET): Forest cover and forest cover loss in the Democratic Republic of Congo from 2000 to 2010. Brookings, South Dakota, USA: South Dakota State University. Downloadable at: http://osfac.umd.edu/facet.html

Scenario 1: Land cover/land use Data used: Land cover/ land use for MLW (Fig 1.1) On a cost scale ranging 1 - 100, agricultural areas and young secondary forests were assigned lowest cost. Primary and old secondary forests were assigned medium cost, and swamp forests and rivers were assigned highest cost.	Cost Low (1) High (100)
Scenario 2: Human preferences Data used: Distances to human settlements, roads, and navigable rivers. All data were normalized 1 -100, then added together using a weighted overlay: (0.4 * distance to settlements) + (0.35 * distance to roads) + (0.25 * distance to navigable rivers)	Cost Low (1) High (100)
Scenario 3: Conservation emphasis Data used: Transport and logging roads, navigable rivers, locations of human settlements, urban centers and palm plantations, and locations of 2000 - 2010 primary forest loss. The cost surface is comprised of a human intensity index detailed in Chapter 2. The index, which ranges from 1 - 100, measures relative threats to terrestrial biodiversity from hunting accessibility and habitat degradation.	Cost Low (1) High (100) All data sources are listed in Table 1. 0 35 70 140 Kilometers

Figure 3.1 Cost surfaces are detailed for each Marxan scenario.

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Table 3.2 Assignment of 'status' variables to the planning units by scenario.

SCENARIO 1	
Planning units comprised of:	**"Status" value**
≥ 25% agricultural land use	1
≥ 75% swamp forests	3
≥ 75% rivers	3
≥ 50% protected areas	3
SCENARIO 2	
Planning units comprised of:	**"Status" value**
25% - 75% agricultural land use	1
≥ 75% agricultural land use	2
≥ 75% swamp forests	3
≥ 75% rivers	3
SCENARIO 2	
Planning units comprised of:	**"Status" value**
25% - 75% agricultural land use	1
≥ 75% agricultural land use	2
≥ 75% swamp forests	3
≥ 75% rivers	3
≥ 50% protected areas	3
≥ 50% wildlife corridors (defined in Chapter 2 and parameterized for the bonobo)	3

3.3   Results

3.3.1   *Comparison of scenarios*

We used the simulated annealing and iterative improvement features of Marxan to

generate a portfolio of the most efficient solutions for each scenario for both the

smaller target (hereafter called the 143% target) and the larger (hereafter called the

155% target) for 2050. We generated 300 possible solutions (100 solutions for each of the three scenarios) for each target. For each scenario, we produced visual maps of the most efficient (lowest cost) solution (Figure 3.2).

Solutions were fairly consistent among scenarios. Planning units selected by the most efficient solutions were clustered around the roads and existing 2010 agricultural complexes, and largely avoided protected areas and remote forest blocks. The 2010 agricultural complexes featured fairly uniform expansion patterns across all three scenarios and for each agricultural target. However, the results of the conservation scenario, Scenario 3, show increased expansion in the east-central portion of the landscape. This area is highlighted by a box drawn on Figure 3.2

For the 143% target, 70% of the planning units were selected by all three scenarios; 85% of the planning units were selected by at least two scenarios (Figure 3.3a). Of the planning units selected by all three scenarios, 70% were located inside existing 2010 agricultural complexes and the remaining 30% were located outside or on the periphery. Agreement was slightly lower for the 155% target; 65% of the planning units were selected by all three scenarios, while 80% were selected by at least two scenarios (Figure 3.3b). This is likely due to the fact that the 155% target exhibited more scattering (less clumping) of planning unit solutions, thereby increasing the chances of non-overlap among scenarios.
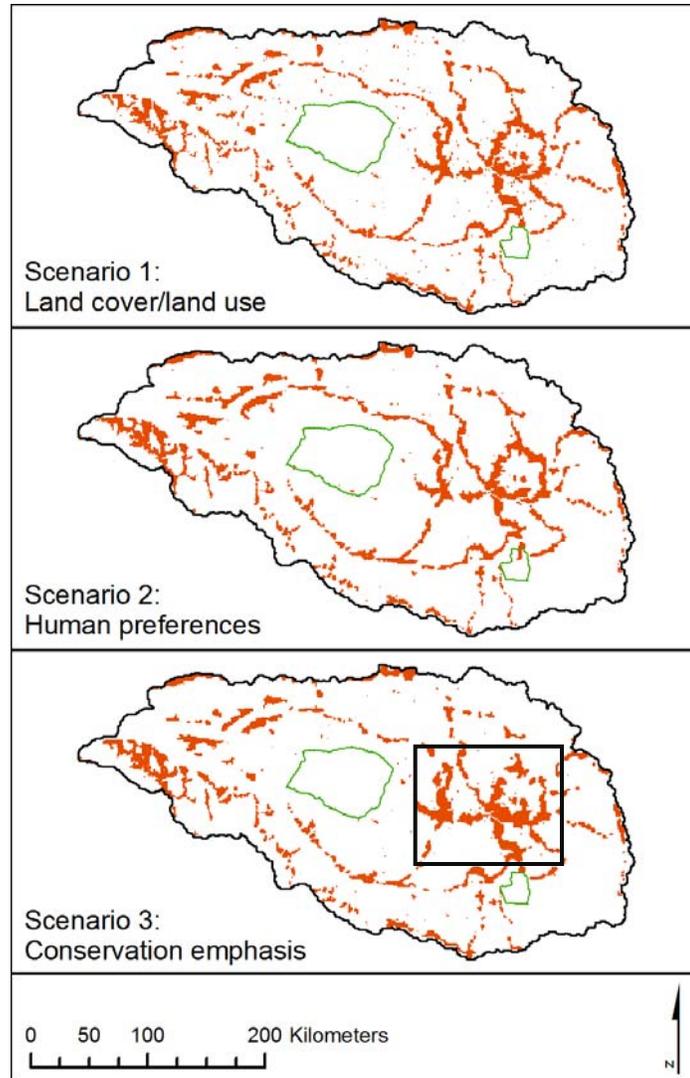
Figure 3.2 The most efficient (least cost) planning unit solutions for the 143% agricultural target for the three Marxan scenarios. MLW's two protected areas are shown outlined in green. The box shown on the map for Scenario 3 shows more intensive agricultural expansion in the central and eastern part of the landscape when considering conservation areas.
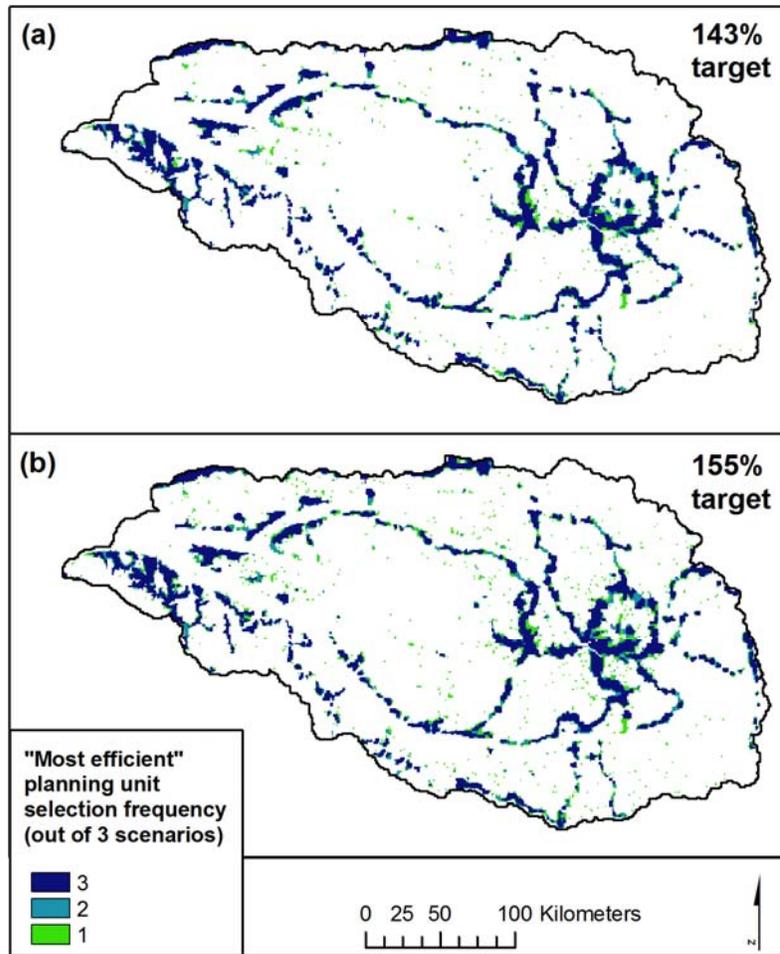
Figures 3.3 (a) and (b). Selection frequency of the most efficient (least cost) planning unit solutions across all three Marxan scenarios. Figure 3.3a shows selection frequency for the 143% agricultural target. Figure 3.3b shows selection frequency for the 155% target.

3.3.2   Model calibration

The BLM values that were selected from our calibration varied among scenarios and 2050 targets and ranged from 0.005 to 0.02. Selecting the optimal BLM that provided the most agricultural "clumping" while still meeting targets at minimal cost was important. Without BLM calibration, outputs demonstrated a high level of rural scattering (Figure 3.4). For Scenario 1 (143% target), we estimated that calibrating

the BLM to 0.01 improved the configuration of 8 - 10% of planning unit solutions

that were formerly scattered when using the default BLM value of zero. For

Scenarios 2 and 3, calibrating the BLM to 0.005 and 0.02 respectively improved only

3 - 5% of planning unit solutions. This is likely because the modeled outputs of these

particular scenarios were generated using cost surfaces that already promoted some

clumping around roads and existing agricultural complexes. Solutions generated for

the 143% agricultural target scenarios exhibited more overall clumping than for the

155% agricultural target scenarios with the same calibration methods.
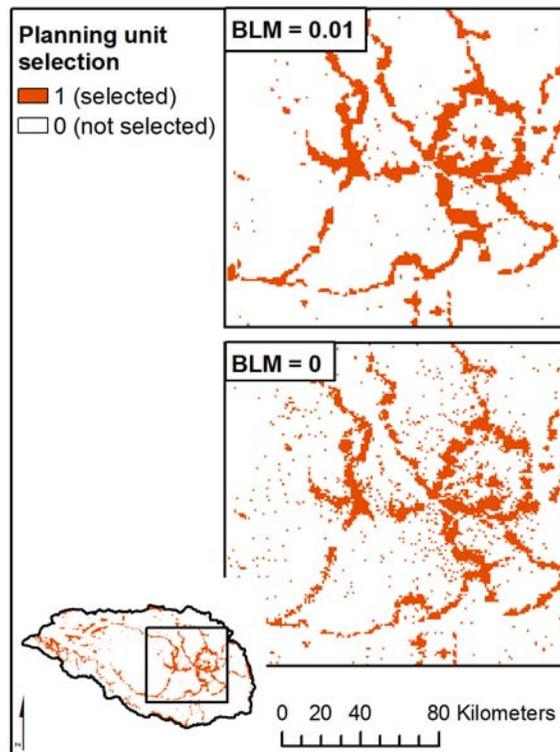
Figure 3.4 Calibration of the BLM proved to be critical to promote agricultural compactness. For Scenario 1 (143% target), calibrating the BLM to 0.01 (top map) eliminated most of the agricultural scattering that occurred when the BLM was set to the default value of zero (bottom map).

3.3.3   Conservation priority areas

We examined how conservation priority areas fared in the two non-conservation

scenarios (Scenarios 1 and 2) and how this varied between agricultural target sizes.

For both the 143% and 155% agricultural targets, planning units located within the

bonobo corridors were more often selected for agricultural expansion than planning

units located within protected areas. Scenario 2, which took human preferences into

account, produced outputs that exerted the most pressure on the bonobo corridors. Of

the total planning units located within the corridors, 17.4% were selected (432 km^2)

for the most efficient solution for Scenario 2 (143% agricultural target). For Scenario

1, this was just 0.10% lower (428 km^2). Bonobo corridors were even more threatened

for the 155% agricultural target, as 19.7% of planning units located within the

corridors were selected (489 km^2) for the most efficient solution for Scenario 2. This

was about 1% lower for Scenario 1 (461 km^2). Protected areas were locked out of the

solution for Scenario 1; for Scenario 2, just 1.2% (47 km^2) and 1.4% (57 km^2) of all

planning units located in protected areas were selected for the 143% and 155%

agricultural targets, respectively.

A frequency map was generated to show how many times the planning units

located within protected areas and corridors were selected across all model runs for

Scenarios 1 and 2 (the total number of runs after BLM calibration for each scenario

was 100, therefore, the map shows the frequency of agricultural selection across 200

total runs) (Figure 3.5). Because protected areas were locked out of Scenario 1, the

planning units shown inside the two protected areas (displayed on the map using a

thicker boundary width) reflect selection frequency for 100 model runs only. The

Luo Scientific Reserve, located in the southeastern part of the landscape, showed the

highest selection frequency of both protected areas.
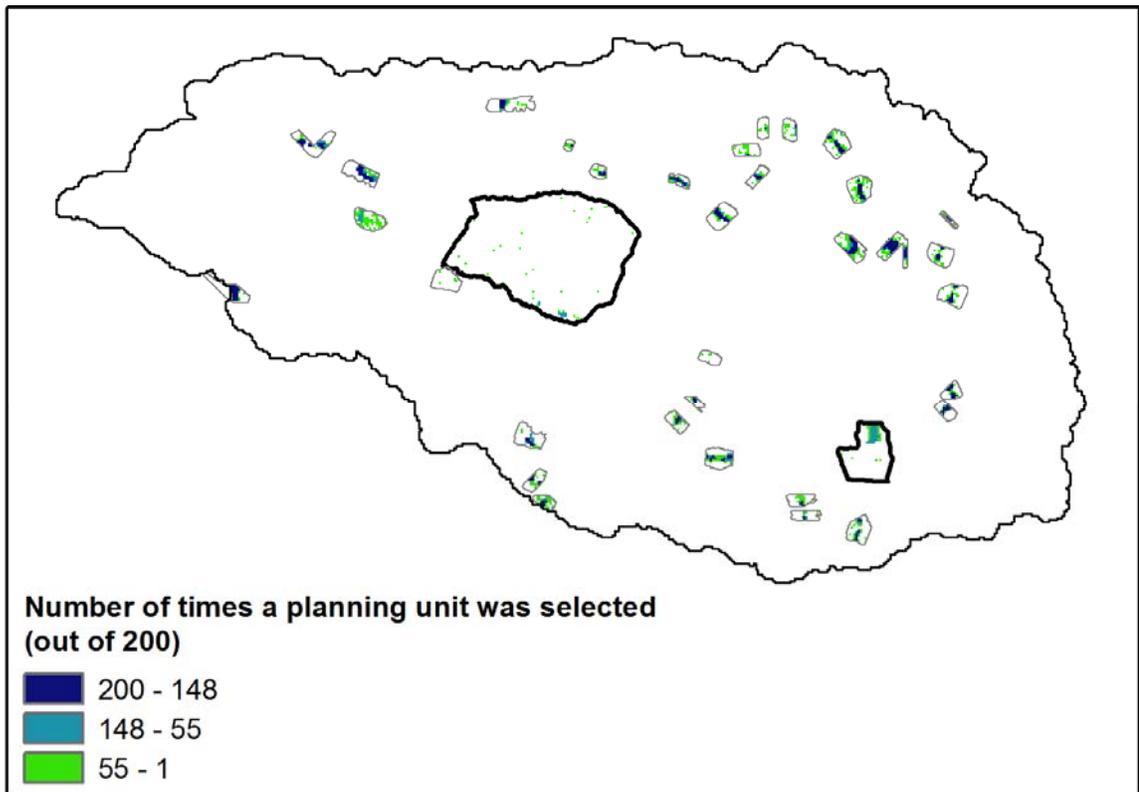
Figure 3.5 Selection frequency within protected areas and wildlife corridors for the most efficient solutions for the two non-conservation scenarios (Scenarios 2 and 3) for the 143% agricultural target. Protected areas are differentiated from the corridors in the map by a thick black outline.

3.3.4   Sensitivity analysis

We ran sensitivity analyses to understand the contribution of the 'status' variable and

how seeding (status = 1) and "locking in" (status = 3) agricultural planning units

affected the modeled outcome. Particularly, we were interested in knowing the

overall influence of locking in the planning units that were comprised of $\geq 75\%$

agricultural area in 2010. We re-ran the models for the 143% agricultural target for

Scenarios 2 and 3. Instead of locking in these particular planning units, we assigned

them a status value of 1 so that they would instead act as a seed. For both scenarios,

<1% of the planning units in the most efficient solutions were affected by this

adjustment. We tested how the models would run without any seeding (Status 0).

Again, we found that for both scenarios <1% of the planning units in the most

efficient solutions were affected.

3.4   Discussion

Modeled outputs were somewhat consistent and demonstrated a great deal of overlap

among scenarios. Excluding those planning units that were already included in the

2010 agricultural complexes, many of the planning units that were selected for the

most efficient solutions for all three scenarios were comprised of areas lying outside

or located on the periphery of the existing agricultural complexes. Areas that

recurred in the solution set for the range of scenarios represent a good starting point

for RDZ design discussions. Outputs were less consistent between the two

agricultural targets. The most efficient solutions for the smaller 143% agricultural

target exhibited more agricultural clumping than for the 155% target, especially for

Scenarios 1 and 3, even though BLM calibration was used consistently. We believe

this may be due to a combination of the configuration of our cost surfaces and an

inherent challenge of the optimization method to find the lowest-cost solution while meeting targets; as agricultural targets increased, it became more difficult for Marxan to find both the lowest cost and most compact solution using the cost surfaces as a basis. Therefore, it may no longer be practical to apply our method to targets higher than 155%.

Calibrating the models to find the appropriate BLM value that allowed the models to meet targets most efficiently while promoting the maximum amount of RDZ compactness was critical. The BLM required different values for each scenario and agricultural target. Modeled outputs showed a high level of agricultural scattering without proper BLM calibration and affected up to 8 - 10% of the planning units in the most efficient planning unit solutions.

Taking conservation needs into account, the results of Scenario 3 show that future agricultural demands in MLW can be met without seriously impacting conservation priority areas. We could expect more intensive expansion around existing agricultural complexes located to the north, south and east of Lingomo, as well as east of Djolu. For non-conservation scenarios 1 and 2, however, the protected areas, which are remote and far from human and agricultural activity in the landscape, fared better than the potential bonobo corridors which thread through agricultural areas. Some corridors are more prone to more intensive future agricultural expansion than others (Figure 2.5). Furthermore, the corridors will be more severely impacted if considerably aggressive agricultural expansion patterns (reflected by the 155% agricultural target) are to occur. The areas surrounding these corridors could benefit from targeted discussions with local stakeholders during the zoning process. The Luo

Scientific Reserve exhibited higher agricultural selection frequency than Lomako Reserve for both 2050 agricultural targets because the northern part of Luo already contains significant human settlement and agricultural complexes. Because the Luo Reserve does not permit new agricultural fields >1 km from the road, our decision to lock out future agricultural selection from this reserve in the conservation scenario was justified.

Marxan good practices recommend conducting sensitivity analyses that vary cost surfaces and targets (Ardron *et al.,* 2010). Because our three scenarios were based on different cost surfaces and agricultural targets, these sensitivity tests were already inherent in our analysis. However, we tested the sensitivity of the models to adjustments in the 'status' values that regulate which planning units are used for seeding, and which are locked out or locked in to the final solution portfolio. We were surprised to find that altering which agricultural planning units were locked in, and which were designated for seeding (even eliminating all agricultural planning units from seeding), affected approximately only 1% of planning units for the most efficient solutions. Overall, we concluded that the underlying cost surfaces were the greatest drivers of our solution outcomes for each 2050 agricultural target. Fischer and Church (2003) also found that making even small changes in planning unit costs greatly influenced model results. In addition, the models were highly sensitive to the BLM, critical for achieving the most compact agricultural zones.

The models presented are derived from purely a land cover and land use perspective and are highly limited from a socio-economic standpoint. A more robust estimate of the amount of land required to sustain agricultural livelihoods in MLW

would benefit from data describing agricultural productivity, including the ratio of products consumed versus products sold, agricultural inputs used, and other data describing farmers' decisions and behavior. Factors influencing these conditions, including market activity and market access, likely vary considerably across the MLW Landscape, and accounting for their spatial heterogeneity is important. However, in this remote region where such socio-economic data have not been collected, the use of spatially-explicit primary forest loss data in combination with human population data and projected growth rates provided a basis for the creation of two distinct assumptions about future agricultural expansion across the landscape. Once these data are collected, future work could explore an additional scenario involving implementation of agricultural intensification strategies that could meet future agricultural needs with a smaller agricultural footprint.

Our assumptions are based purely on business-as-usual scenarios of human and agricultural expansion according to 2000-2010 data. We do not account for factors that may significantly inhibit or promote future agricultural expansion such as the re-construction of roads for market access or the establishment of new markets, logging concessions, and large-scale palm plantations. Furthermore, our assumptions presume that agricultural expansion rates are uniformly distributed across the MLW Landscape, which is undoubtedly false. The model assumptions also do not consider the influence of administrative boundaries at the *Groupement* level that tend to influence where people in the landscape live. Rather than relocate to a different Groupement, human populations tend to continue living within the Groupement where they were born (Sifa-Nduire, 2008). The Groupement boundary data for the

MLW landscape, however, are outdated and substantially inaccurate. Once these data become available, we could re-run our models using the boundaries to stratify agricultural and human expansion within each Groupement. This is recommended for future work.

The use of planning tools such as Marxan complement, but do not replace, stakeholder-driven land use planning procedures (Klein *et al.,* 2008). We merely present a portfolio of options that can be reviewed and collaboratively refined by stakeholders during the MLW macro-zoning process. Furthermore, macro-zoning broadly guides and informs the subsequent micro-zoning process defined by communities at local levels. Because different stakeholders have different priorities, having a range of alternative options rather than one "optimal" solution, is prudent (Brill, 1979; Stewart *et al.,* 2004). As a result of our analysis, our stakeholders will have an understanding of the factors driving the models' most efficient solutions and some of the trade-offs inherent in balancing the landscape's future livelihood and conservation needs in light of divergent stakeholder preferences. While agricultural expansion patterns across all three scenarios and for each agricultural target were similar, juxtaposing scenarios at the regional to local scale underscore key scenario differences (e.g., wildlife corridor protection). Overall, stakeholders can use the improved understanding and confidence inspired by consideration of multiple scenarios and the sensitivity analyses as a foundation for conceiving and exploring other scenarios that may benefit RDZ design.

In order to promote a transparent process with stakeholders, careful attention should be given to the construction of the underlying cost surfaces (Ardron *et al.,*

2010). Our cost surfaces for Scenarios 2 and 3 are the result of combining multiple

surfaces with assigned weights, which can be quite subjective and appear overly

complex from the perspective of a stakeholder. One solution is to break down the

cost surfaces into smaller parts and re-run step-wise models in Marxan (Ardron *et al.,*

2010) to explain how each component of the cost surfaces contributes to the modeled

outcome, and to illustrate the strengths and weaknesses inherent in using certain data

layers. This would also allow stakeholders to become more involved in using Marxan

in a collaborative environment, stimulate discussion, and allow for their own

formulation of new cost surfaces and scenarios.

3.5   Conclusion

As land use planning in the DRC moves to the national level, maps that communicate

an array of plausible scenarios of future land use change will be essential. Although

Marxan is traditionally used for the optimization and design of marine reserves and

protected areas, we found that it was just as useful for exploring scenarios of

optimization for African rural livelihoods. Marxan provided a critical tool for

creating a set of alternatives for agricultural zoning for 2050 at the landscape level.

The options illustrate how competing needs might be balanced in planning for both

livelihood expansion and terrestrial biological conservation in the MLW Landscape

and are meant to guide stakeholders and assist decision-makers for future macro-level

planning activities. The models and outputs will likely be further refined in a more

collaborative process with stakeholders in the future.

Chapter 4: Coupling participatory mapping and GIS to inform village-level agricultural land use planning in the Democratic Republic of the Congo[1]

4.1   Introduction

Consideration of people and their livelihoods is key to building sustainable development strategies (Hulme & Murphree, 1999; Blaikie and Jeanrenaud, 1997). In the world's tropical forests, where competing demands for land and resources are high, sustainable and equitable management of land and natural resources will be increasingly important to conserve forests and promote human well-being for the local populations who depend on them for their livelihoods. Increasingly, national governments are becoming aware of the need to formalize and secure land rights for forest stakeholders (Molnar *et al.,* 2004; Sunderlin *et al.,* 2008). Local knowledge is critical to land use planning, and participatory approaches have become widely accepted for contributing to the development of strategies for collaborative forest management within forest-dependent indigenous communities (Craig *et al.,* 1990; Robiglio *et al.,* 2003; Johnson *et al.,* 2004; McCall & Minang, 2005; Chambers, 2006). Accordingly, studies have shown that direct participation of local stakeholders

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in planning processes is essential to establishing lasting conservation strategies (Fisher *et al.,* 2005; Zimmerer, 2006; Velazquez *et al.,* 2009).

Over the past half century, participatory mapping methods have emerged to capture unique indigenous spatial knowledge about land resources and their use (Chambers, 2006; McCall & Dunn, 2012). As technological capacities have improved, especially with advances in GIS coupled with an increased availability of satellite imagery, mapping capabilities have become progressively more rich and participatory methods more diverse, encompassing a variety of methods and facilitation approaches. Participatory mapping methods have been used as a tool for landscape land-use planning (Wang *et al.,* 2008; Hessel *et al.,* 2009; Valencia-Sandoval *et al.,* 2010; Bourgoin *et al.,* 2012), management of natural resources (Patrick, 2002; Kalibo & Medley, 2007; Cronkleton *et al.,* 2010), and addressing tenure rights and mediating land conflict (Peluso, 1995; Forbes, 1999).

This chapter is part of a larger project that is working toward participatory land-use planning at the micro-level, coupled with livelihood improvement strategies (including agricultural intensification and agro-forestry intervention) for sustainable forest management and conservation in eastern MLW Landscape. We developed a method combining participatory mapping, satellite image interpretation and GPS data collection for the delineation of the agricultural frontier for 16 villages in the study site. As this area is dominated by shifting cultivation practices (alternating periods of cropping with relatively long fallow periods, which last between 6 years in the eastern central part of the landscape and over 10 years in the western part of the landscape), we defined the agricultural frontier as consisting of all active and fallow fields farmed

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by members within each village community. Second, we analyzed the results of the

mapping data alongside corresponding population information in order to quantify

village-level agricultural land use to inform resource planning strategies.

Specifically, we compared the total amount of agricultural land used across all

villages and investigated the statistical relationship between the villages' agricultural

land area and the corresponding size of their human populations. Finally, we noted

several observations and key points learned from our mapping experiences and offer

recommendations for the participatory mapping methods developed. We demonstrate

how the participatory delineation of the villages' agricultural zone boundaries has

served as an essential first step for informing local communities how they are using

their agricultural space, targeting the villages that might be most in need of

agricultural extension, and strengthening local capacity for land-use planning and

zoning in a country with no existing land tenure.

4.2   Methods

4.2.1   Study area

The study takes place in a 2,000 km^2 area located just west of the town of Djolu in the

eastern-central part of the MLW Landscape (Figure 4.1). It comprises a number of

land use and land cover types, including 24% moist dense equatorial evergreen forest,

56% swamp forest, and 20% agriculture and young secondary forest. The study area

contains an array of terrestrial species, including the red-tailed monkey

(*Cercopithecus ascanius*), Angolan colobus (*Colobus angolensis*), black and black-
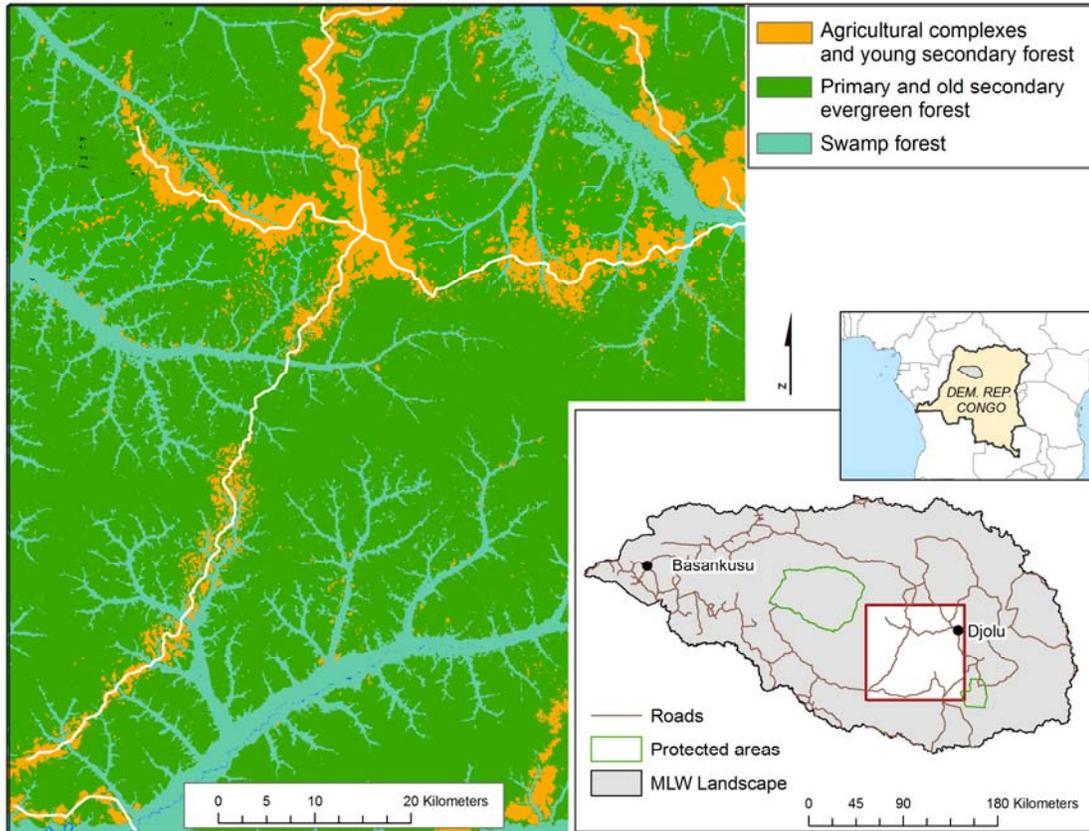
Figure 4.1 A land cover and land use map of the study site. The study site is located in the eastern-central part of MLW Landscape, just west of Djolu. Data source: South Dakota State (SDSU) and University of Maryland (UMD) 2008.

crested mangabey (*C. aterrimus* and *Lophocebus aterrimus*), wolf's monkey (*C. wolfi*), and the bonobo.

Prior to this study, population information specific to the study area was largely unknown (the most recent census for the DRC was undertaken in 1984). Human settlements occur along the two road axes in the study area, and agricultural areas extend outward from the roads into the forest. Agricultural activities undertaken are relatively consistent among the villages. Slash-and-burn techniques

are used to open land to cultivate crops such as cassava, maize, and peanuts, which are grown primarily for subsistence.

Since 2010, the MLW program has been engaging in participative micro-zoning and livelihood improvement through a voluntary process with local communities living in the study area. The objective of the micro-zoning process is to limit unplanned expansion of agriculture into the surrounding primary forest. The program chose this particular area as a priority site for implementing these activities because it encompasses important wildlife corridors connecting the landscape's only two protected areas (Figure 4.1). In addition, it is a historically well-established agricultural area. Recent maps of land use and land cover change prepared for the DRC (shown in OSFAC (2010)) show instances of rapid primary forest loss occurring around the outermost edges of the agricultural complexes located within the study area.

In partnership with the DRC Ministry of the Environment, the MLW program is developing a formal strategy to distinguish between 'non-permanent' forests (intended for the sustainable expansion of agricultural activities under a management plan) and 'permanent' forests (protected for community-based natural resource management or CBNRM) located within the "*forêt protégée*" class established by the 2002 DRC Forest Code and designated for community use (i.e., not protected areas or logging concessions). Forests located within the 'non-permanent' forest zone will comprise the agricultural frontier of each village; boundaries will be somewhat flexible in order to accommodate future population growth. Representatives from 16 villages (this number is still expanding), belonging to five administrative

'*Groupements*' (Grpmts) (Figure 4.2), have voluntarily signed a Memorandum of Understanding (MOU) with the program to define collaboratively the boundaries of their non-permanent forest zone (hereafter referred to as "agricultural zone") in exchange for provision of support to increase agricultural productivity within the defined zone. As part of the MOU, the communities agree to farm only within the defined agricultural boundaries and engage in collaborative monitoring to ensure adherence to the boundaries. After the boundaries are defined, the MLW program works directly with the villages and the DRC Ministry of Environment to develop zone-specific management plans and obtain their formal government recognition.

4.2.2   *Delineation of the agricultural zone*

A method was developed combining the use of participatory mapping, satellite image interpretation and GPS data collection for the delineation of historical village-level agricultural boundaries for the 16 villages that signed the MOU agreement.

Step 1. *Development of a GIS database and village-level satellite maps:* First, we developed a GIS database, integrating the most recent cloud-free Landsat Thematic Mapper (TM) and ETM+ satellite imagery with various sources of digital spatial information mapped at the regional level, including locations of roads and rivers. Human settlements and villages occur nearly continuously along both road axes in the study area with the exception of two areas interrupted by forested corridors occurring along the north-south road axis. While one can see the locations of human settlement along the road, it is not possible to identify where one village's limits begin and another's ends using satellite imagery interpretation alone.
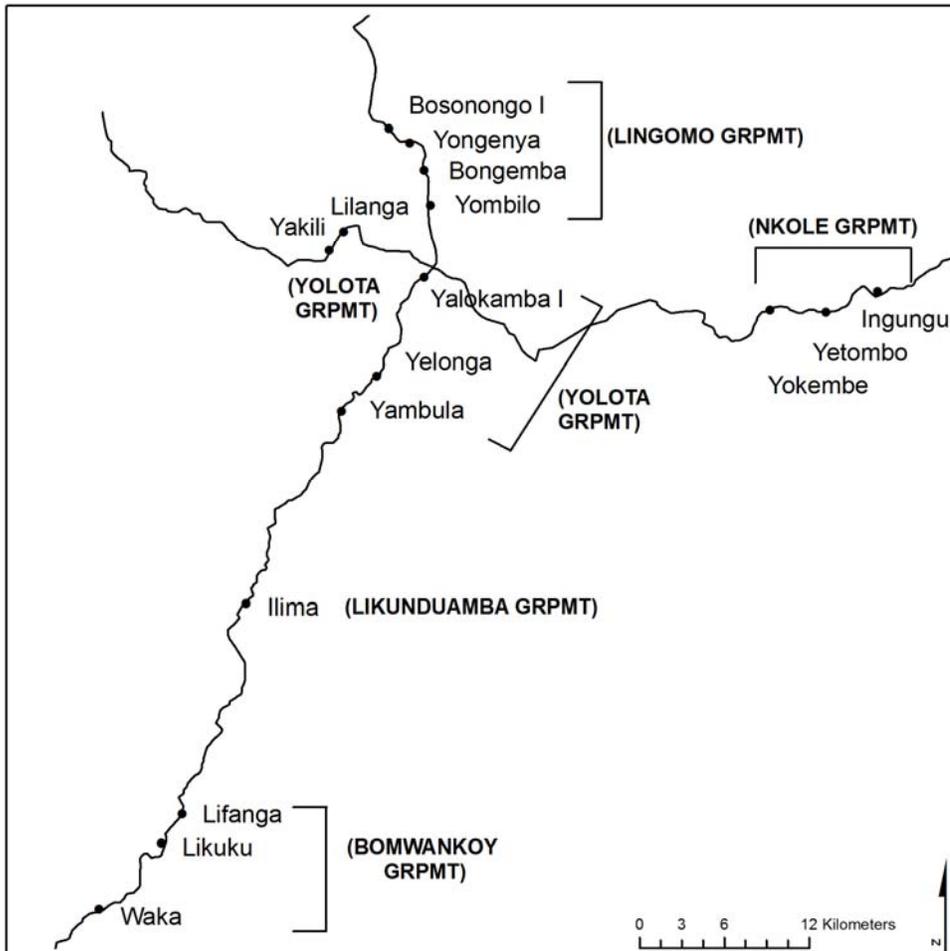
Figure 4.2 The location of the sixteen villages that voluntarily signed the MOU agreement to delineate the boundaries of their agricultural zones.

Therefore, we collected, with a representative of the village present, GPS data indicating the farthest-most limits along the road (in each direction) for each village that signed the MOU agreement. We then prepared a satellite image map for each village, featuring locations of roads and rivers from our GIS database and the GPS data marking the village limits overlaid on top of the most recent cloud-free Landsat image available. In order to mimic true color as much as possible, we created layer

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stacks with the satellite bands so that forested areas on the image were green. We scaled each satellite map to accommodate our best guess of each village's general agricultural area using the satellite image and ancillary land cover data as a guide.

 Step 2. Meeting: We conducted a meeting with village leaders to receive permission to map their agricultural boundaries. The meeting was a follow-up from earlier meetings that introduced the villagers to the project objectives. During this meeting, we reviewed the goals of the Memorandum of Understanding (MOU) agreement with the leaders and discussed what we hoped to accomplish with their participation and assistance. We also asked the chief and village representatives to estimate the human population of their village. The meeting was conducted in Lingala, the local language of the region.

 Step 3. Participatory mapping: Next, we engaged in a participatory mapping process to gain an indicative understanding of the spatial distribution of the village's current and historical agricultural boundaries. To minimize disagreements or conflict, we established a committee composed of chiefs from neighboring villages that had signed the MOU as well as the chief of the administrative sector to which the village belongs to be present during the mapping process. First, we asked the committee to identify a person from the village to lead the drawing of the participatory map. Usually, this individual was an agronomic specialist or someone who possessed a long history of geographic knowledge about the village's land use. On occasion, the mapping procedure was led by more than one individual, depending on village preference. We offered a large blank sheet of paper (approximately 60 cm x 86 cm), along with pencils and colored pens for participants to draw a map of the village and

its agricultural boundaries. If desired by participants, the mapping procedure began

by drawing with sticks in the sand on the ground. As the village leaders drew the

map in the presence of the village and the village committee, we asked for the

following information to guide the process and ensure consistent comparison between

multiple villages' maps:

a. The location of the village limits along the road, and their geographic
   orientation (i.e., the geographic direction of each limit, or the name of
   the next village);
b. The location of the Chief's house;
c. The location and names of all significant rivers, and the approximate
   distance of each river from the road;
d. The location of the outermost limit of the active agricultural boundary
   and its approximate distance from the road;
e. The location of identifiable features or landmarks describing the limits
   of the agricultural boundary between villages, including rivers,
   abandoned fields, or primary forest.

Step 4. *Transposition to a digital satellite map:* We showed the village leaders

a hard-copy print of the satellite map and explained the basic interpretation of the

features and colors shown. This included the location of the main road, locations of

the outermost village limits, agricultural fields and young secondary forest, primary

and old secondary forest, rivers and swamp forest. As a group, we transcribed the

features that helped define the relevant agricultural boundaries from the hand-drawn

participatory map to the satellite map. Such features included visible features such

as edges of primary forest, locations of particular rivers or swamp forest, or locations

of particular fallow or active agricultural fields. Together, we ensured these features

were identified and clearly labeled on the satellite map.

Step 5. *Drawing the agricultural boundaries:* We then asked the leaders to

draw, in pencil, the agricultural boundaries onto the satellite map using a combination of the participatory map and the transcribed features from the previous step as a guide. This was usually done in sections, as some parts of the boundary were more easily distinguishable than others. Where the geographic placement of any particular boundary section was evidently understood and there was no cause for dispute amongst the village leaders about its placement, the section was re-traced with a pen. Any sections of the boundary that were not easily transposed, or which inspired conflict or dispute, remained drawn in pencil or were left blank. In general, it was important at this stage to assess the extent of conflict the mapping exercise might or might not have created between villages, and act in our best manner to avoid it, which would have included stopping the work altogether.

Step 6. *Critical analysis and GPS data collection:* We next initiated a discussion with the village to capture more information about the locations where the extent of the agricultural boundaries was not clearly defined. If, as a team, we confirmed that the forest boundaries of those particular areas could not be drawn on the satellite map, we asked to be taken by local guides to those areas for GPS data collection. To be most efficient, we generally split into multiple groups consisting of one or two local guides and at least one GPS technician from the program team who was trained in the GPS protocol.

Step 7. *Creating a draft map:* Next, we digitized into the GIS database the features identified from the satellite map as well as the agreed sections of the agricultural boundaries as determined from our meeting. We imported the GPS points into the GIS and used them to complete the remaining sections of the

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agricultural boundaries. We then created digital polygons delimiting the full extent of the agricultural boundaries. Finally, we created an informative map in draft form to be presented to the village committee and representative leaders for final approval. The map contained the satellite image in the background with all important features (including the locations of important rivers and their names, the location of the Chief's house and any important physical landmarks identified during the previous steps) overlaid on top, as well as marked locations of the agricultural boundaries.

Step 8. *Approval of final map:* Once complete, the draft maps were presented back to each village for final approval by the village committee and representative leaders. If a village did not at first agree with its draft map, then we collected more data to refine the boundaries until they were accepted. Once approved, we considered the map final, and it was formally presented back to the village community for their keeping.

Step 9. *Archiving the data:* A comprehensive digital archive, organized by village, was developed to organize and store all maps and GPS data pertaining to the delineation of the agricultural boundaries. Each participatory map was transposed onto A4 paper and scanned, with its corresponding satellite map from the individual village meetings, into high-resolution digital format for sharing among project partners. The GPS points were archived in organized folders with descriptive data about the data points. The final GIS maps delineating the agricultural boundaries were exported at high resolution and saved in a folder marked by village name.

4.2.3   Data analysis

We calculated the surface area of each of the village-level agricultural zones and added their villages' corresponding human population to our GIS database. For each village, we calculated the amount of agricultural land used per person and compared results by village as well as aggregated by administrative Grpmt. We selected the Grpmt unit for analysis because we wanted to understand whether any spatial clustering was inherent in the villages' agricultural land use patterns. We also calculated the maximum distance that each village's agricultural zone extended from the nearest road. Finally, we used linear models to test the relationship between village-level human population and agricultural surface area, as well as village-level human population and the corresponding maximum distance of agricultural extension from the road.

4.3   Results

4.3.1   Quantifying village-level agricultural land use

Figure 4.3 shows an example of a final map depicting the agricultural zone boundaries for the village of Yongenya. Yongenya's agricultural boundaries are continuous and extend both north and south away from the road; we found that the other 15 villages' agricultural boundaries were also continuous (with the exception of the village of Ingungu, whose agricultural zone is interrupted by a swath of swamp forest) and extended in opposite directions away from the roads accordingly (Figure 4.4).

The average surface area of the villages' defined current and historical agricultural limits was $1,016 \pm 589$ ha and ranged from 241 ha (Lifanga) to 2,616 ha (Ingungu) (Table 4.1). The average human population per village was $1,505 \pm 1,626$ and ranged from 184 (Bongemba) to 4,800 (Yetombo) (Table 4.1). We found that 43% of the variance in village agricultural land area was explained by village population size (*coef*=0.24, DF=14, *p*=0.005) (Figure 4.5). The average area of agricultural land used per person among the villages studied was 1.4 ± 1.2 ha/person and ranged from 0.17 ha/person (Yetombo) to 4.25 ha/person (Yombilo). The villages of Yetombo, Lifanga, Yokembe and Ingungu had the lowest number of agricultural hectares per person, ranging from just 0.17 to 0.58 ha/person. These villages, with the exception of Lifanga, were all located within Nkole Grpmt and had human populations over double the amount of all other villages in the study area (the relationship between human population and agricultural area per capita, however, was significant only at the 0.05 level, $r^2 = 0.35$, DF= 14).
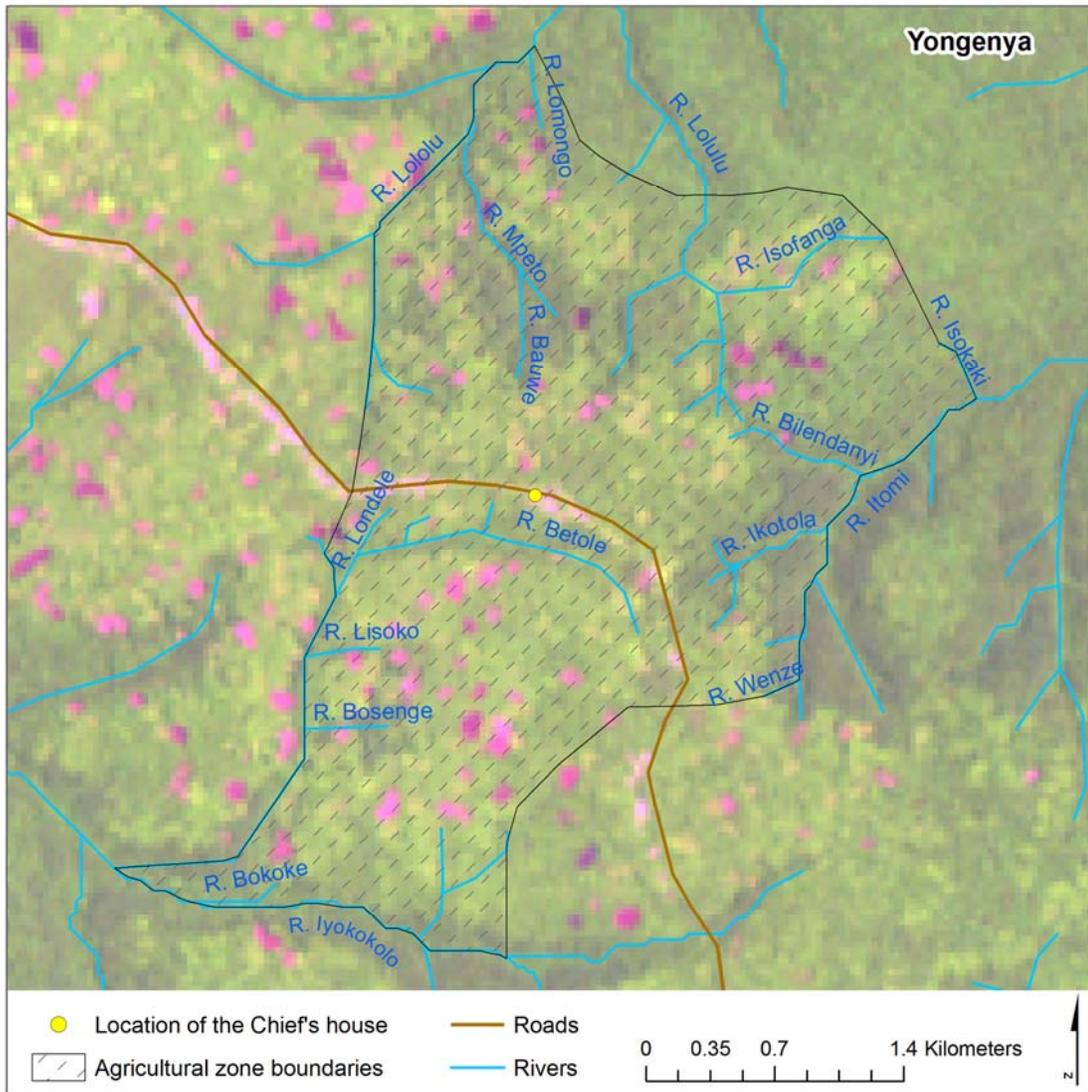
Figure 4.3 A final map showing the agricultural zone boundaries for the village of Yongenya. Agricultural fields and young secondary forests are displayed in colors of pink, yellow and light green. Primary and old secondary forests are displayed in darker green (as shown in the upper right-hand corner of the map), while rivers and swamp forests are displayed in the darkest shades of green surrounding river features.
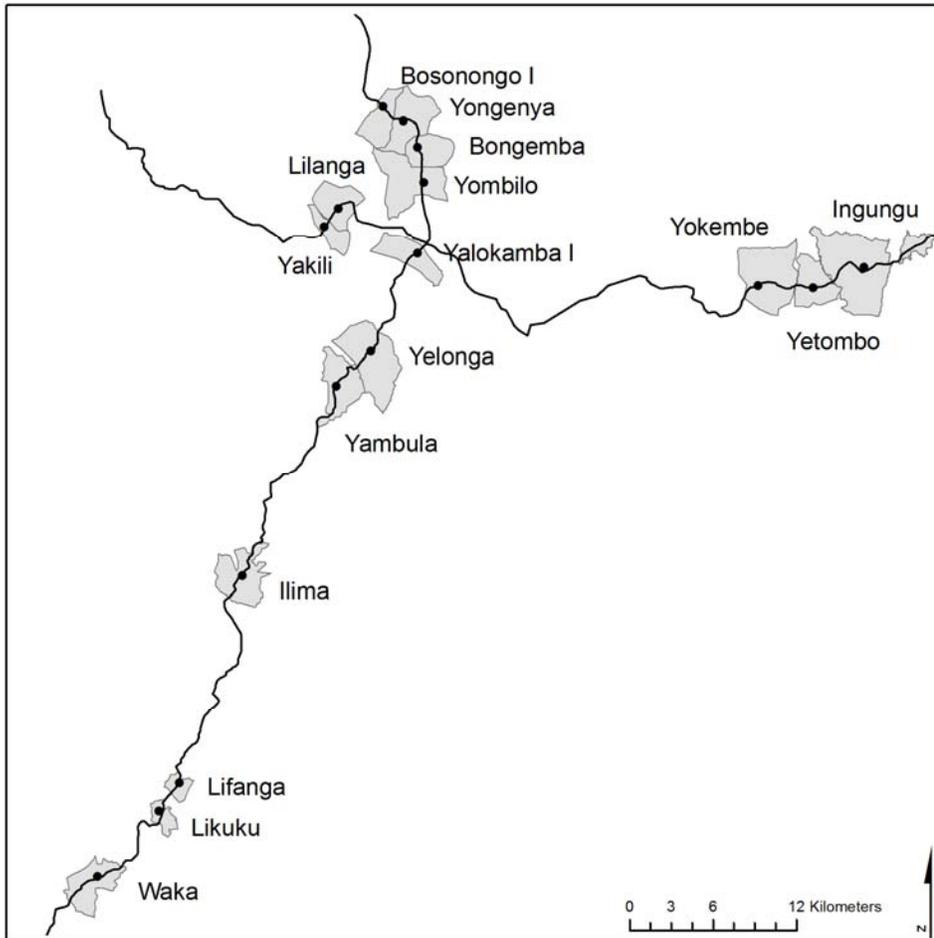
Figure 4.4 Agricultural zone data, collected using a combination of participatory mapping and GPS data collection, are displayed for the sixteen villages that signed the MOU agreement.

Table 4.1 Summary data for 16 villages in the study area, sorted by agricultural land used per person (smallest to largest).

Village name	Administrative Grpmt	Agricultural Zone: Surface area (ha)	Agricultural zone: Maximum distance from road (km)	Human population	Agricultural land per person (ha/person)
Yetombo	Nkole	831	2.25	4800	0.17
Lifanga	Bomwankoy	241	1.00	653	0.37
Yokembe	Nkole	1655	3.27	4220	0.39
Ingungu	Nkole	2616	3.59	4500	0.58
Yelonga	Yolota	1581	3.59	2700	0.59
Waka	Bomwankoy	942	2.07	1375	0.69
Ilima	Likunduamba	1098	2.14	1557	0.71
Likuku	Bomwankoy	282	1.42	386	0.73
Yambula	Yolota	988	2.18	1200	0.82
Yalokamba I	Yolota	775	2.25	530	1.46
Lilanga	Yolota	807	2.10	450	1.79
Yakili	Yolota	411	2.20	223	1.84
Yongenya	Lingomo	1021	2.40	550	1.86
Bosonongo I	Lingomo	920	2.64	420	2.19
Bongemba	Lingomo	685	2.42	184	3.72
Yombilo	Lingomo	1397	3.13	329	4.25
Mean		**1016**	**2.42**	**1505**	**1.39**
S.D.		**589**	**0.71**	**1626**	**1.19**
Median		**931**	**2.25**	**602**	**0.78**
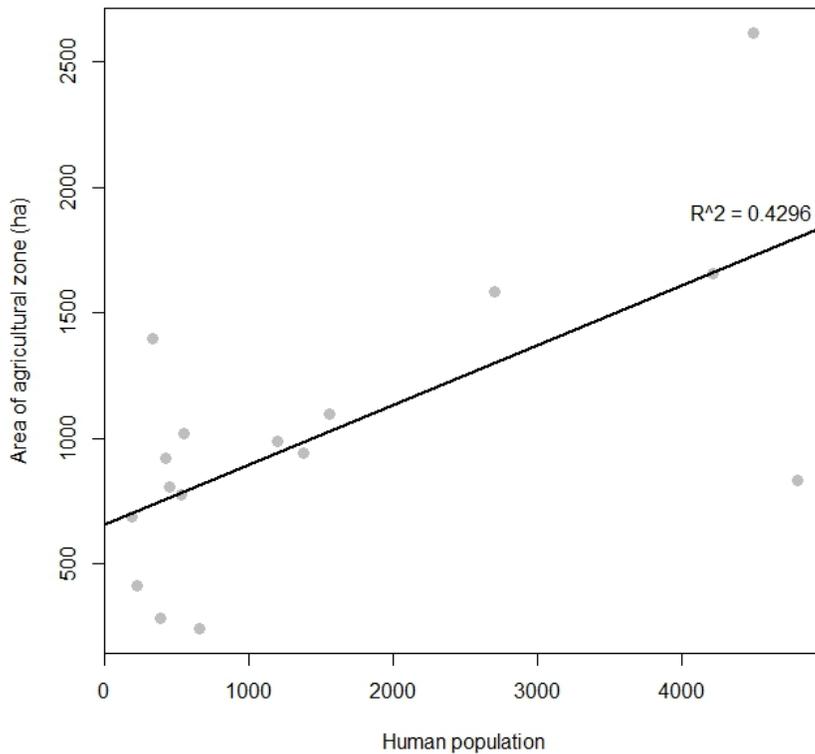
Figure 4.5 A scatterplot showing the relationship between the surface area of the villages' agricultural zones (ha) and their human populations.

While Nkole Grpmt (n=3) had the lowest overall agricultural land area per person, Lingomo Grpmt (n=4) had the highest (sampling sizes were not consistent across all Grpmts; refer to Table 4.1) (Figure 4.6). The average maximum distance of the villages' agricultural zones from the nearest road was 2.41 ± 0.71 km and ranged from 1 km (Lifanga) to 3.6 km (Ingungu and Yelonga). There was a positive relationship (though significant only at the 0.05 level and with a weak r^2), between the sizes of the villages' human populations and the maximum distance that their agricultural limits extended from the road ($r^2 = 0.26$, DF= 14) (Figure 4.8). The

agricultural zones for the villages of Yokembe, Ingungu and Yelonga extended

farthest from the road, ranging between 3.25 - 3.6 km. The three villages with the

lowest maximum distance from the road all belonged to Bomwankoy Grpmt, located

in the southern portion of the study area (Figure 4.7). The average amount of

agricultural land per capita for these villages was 0.59 ha/person, roughly 43% of the

study area average. The agricultural zones of the villages located in Nkole Grpmt

extended the farthest from the road; these villages used an even lower average

amount of agricultural land per capita (0.38 ha/person).
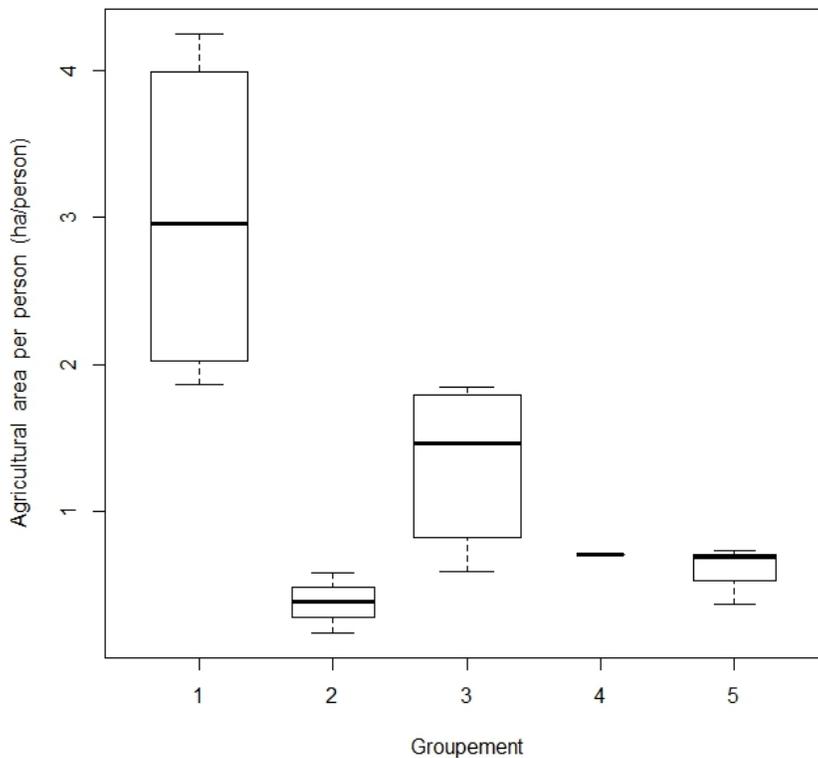
Figure 4.6 Agricultural area per person (ha/person), aggregated by administrative
Groupement (Grpmt): 1= Lingomo Grpmt, 2= Nkole Grpmt, 3= Yolota Grpmt, 4=
Likunduamba Grpmt, 5= Bomwankoy Grpmt.
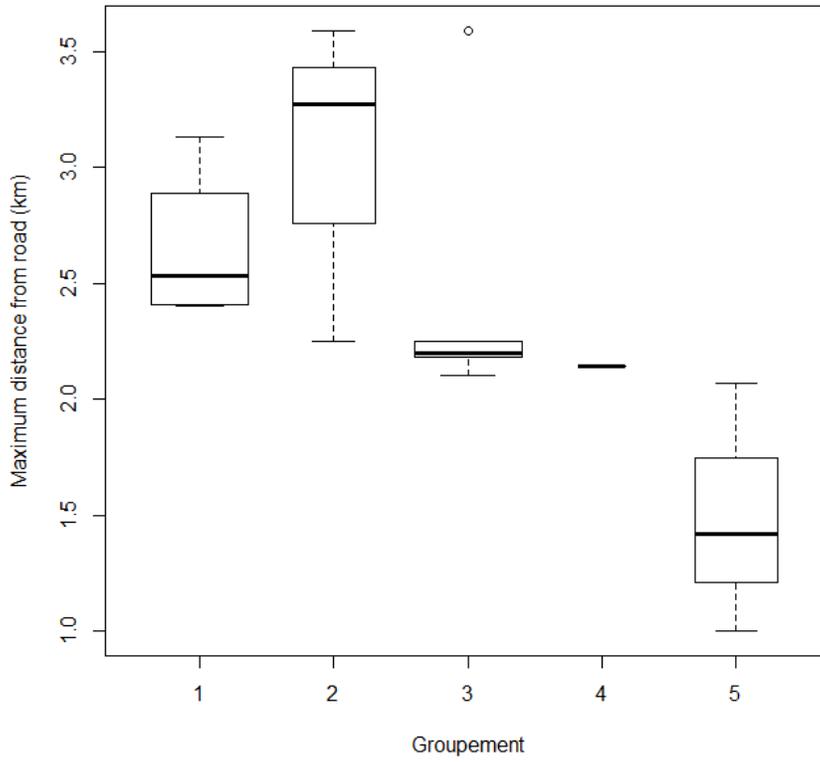
Figure 4.7 The maximum distance that each village's agricultural zone extends from the road (km), aggregated by administrative Groupement (Grpmt): 1= Lingomo Grpmt, 2= Nkole Grpmt, 3= Yolota Grpmt, 4= Likunduamba Grpmt, 5= Bomwankoy Grpmt.
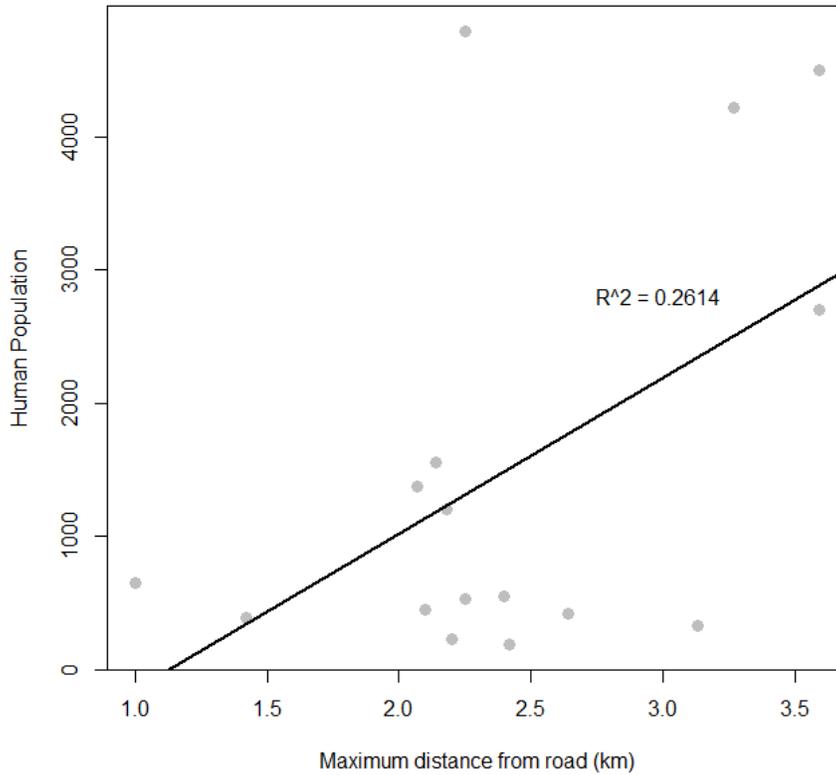
Figure 4.8 A scatterplot showing the relationship between the maximum distance that the villages' agricultural zones extend from the road (km) and the villages' human populations (p= 0.043).

4.3.2   Methodological experiences

We highlight several key experiences from the mapping process:

Stakeholder participation, transparency and ownership: We felt that providing an open, transparent process for community engagement was of utmost importance to our work. This is a common belief that is also emphasized in IFAD (2009) and McCall & Dunn (2012). To ensure interactive participation, where members take control over decisions that are made during the process and consider

multiple perspectives (Pretty, 1995), we invited all members (including women and children) from each village community to join our meetings and take part in the participatory mapping procedure (while women were present, they did not directly contribute, however). It was important to include representatives from the neighboring villages located immediately adjacent to the village being mapped as well as representatives from the larger administrative Grpmt in order to promote transparency, gain diverse perspectives, and provide legitimacy. At the same time, including representatives from neighboring villages and inviting them to provide input to the mapping process minimized possible conflict that could arise when discussing potentially sensitive boundary issues. The adjacent villages of Bosonongo I and Yongenya, for example, share a 230 ha parcel of land containing individual farms owned by families belonging to both villages. With representatives of both villages present, we collaboratively mapped the boundaries of this particular parcel. Finally, it was important to instill in the villages a sense of ownership during the mapping process. We emphasized during our meetings that both the participatory map and the resulting map of the agricultural zone belong to the village community, not to the MLW program. The final map, used as a means to facilitate communication about the MOU agreements during the zoning process, also provides a tool to enable the village to make its own land-use planning decisions in the future.

Use of satellite imagery: The use of satellite imagery in the mapping methodology provided a means of reference to connect certain features from the hand-drawn participatory map to real features on the ground. Because agricultural areas are already visible on the imagery, the imagery offered a real-world reference to

locations of the agricultural areas and allowed for easier determination of the portions

of the agricultural boundaries that needed verification via ground data. As such, GPS

data were only collected where ground data were most needed. Landsat imagery was

chosen for our mapping procedure because it was freely available and provided a

useful resolution (30 m) to meet our objectives. We did obtain higher-resolution (1-

meter) imagery for a few of the villages in the study area, but while these data were

helpful for desktop analysis, their resolution was too fine for hard-copy logistical

reasons to use in the field (the MLW program has an A4 color printer at their field

site for printing imagery; the fine scale at which we would need to zoom into the

high-resolution imagery would necessitate over ten printouts strategically taped

together and this was not practical given our limited resources). Landsat 7 imagery

post-2003 exhibits horizontal lines due to failure of the satellite's scan line corrector

(Markham *et al.,* 2004); however, we were able to complement these areas with

imagery from Landsat 5, acquired by the Malindi Ground Station.

Assessment of ancillary data: We overlaid road and river data on top of the

satellite maps that had been prepared in advance in order to provide an increased level

of reference detail when relating the hand-drawn participatory map to the satellite

map. We learned that it is important to check all ancillary data carefully in advance

for errors and spatial mis-registration. We relied heavily on river course data that we

derived from a 30-meter SRTM digital elevation model. Because the rivers were

derived from a model, they did not contain names, and while they were representative

of hydrologic systems, they were not always represented correctly. In addition, the

river data often included very small streams that were only seasonal. These factors

sometimes added confusion to the data transposition process. It was therefore imperative to compare carefully the river data against the satellite imagery in order to make an objective assessment of which rivers to include and exclude; we found it best to err on the conservative side and include only the higher-level (main and permanent) rivers on the satellite map in order to minimize confusion.

Data organization and archiving: We maintained a structured database, organized by village, for all spatial data and descriptive metadata collected during the mapping procedure. We organized the village data by a numeric identification code and saved our data in three sub-folders containing each village's boundary files, GPS files, and map files (including digital scanned copies of the participatory maps). Creating a digital archive of all data collected was crucial in order to maintain a record of the participatory process. In a multi-partner project such as ours, it was also extremely important to be able to share the maps and data with our partners. Transposing the hand-drawn participatory map to A4 paper for scanning was done carefully in order to minimize human error.

Patience and adaptability: The delineation of the zones has comprised a multi-year process that has required extensive involvement and follow-up with local communities. Although the detailed methods presented here generally took less than one week to perform per village (the execution of step 1 through the beginning of the critical analysis for GPS data collection could take up to a full day, while the collection of GPS points usually took anywhere between two to three days, with a few more days added for adjustments and final approval by the village), they represent a culmination of several lengthy introductory meetings and a constant

multi-year field presence that built confidence in the working relationship (the importance of these qualities is highlighted in IFAD (2009)). Adaptability was important; re-collection of GPS data was necessary for certain villages where insufficient data were collected. Also, being perceptive and adaptable to potential conflicts that might arise and intervening when appropriate (even stopping the mapping procedure altogether), was an important component of our methodology. In addition, it was important to maintain flexibility in the zoning process in order to accommodate the chance that boundaries might change in the future. Our MOU agreements were structured as such, allowing for further community agricultural expansion if necessary; we believed that this quality of the MOU agreements also made the communities more amenable to them.

4.4   Discussion

Land use planning and management strategies require assessments of natural resources used by local communities (Ahamed *et al.,* 2008). This is the first such study undertaken in the MLW Landscape; used together, the results of our mapping and data assessment of village-level agricultural land use can add value to the land use planning process. The results of our data assessment are useful for informing local communities how they are using their agricultural space and for targeting the villages that might be most in need of agricultural extension (including crop diversification, provision of agricultural trainings, and enhanced market access) and flexibility during planning processes. The results enhance our understanding of

which villages might be supporting greater numbers of people with a smaller amount of agricultural space, or which villages' farmers are walking the farthest to access new fields (assuming that new fields are created at the outermost margin of the agricultural frontier), for example. Understanding the maximum distance that the agricultural zones extended from the road might indicate how far a farmer may be willing to walk to access new fields and could in turn inform landscape-wide models of agricultural expansion as presented in Chapter 3. In terms of their ability to have enough agricultural land to support their high human populations, our results showed that the villages located in Nkole Grpmt are potentially under the most pressure in the study area. If the human populations of these villages are to grow significantly in the near future, they may have a greater need to expand more readily their agricultural areas into the primary forest. Two of the villages in this Grpmt, Ingungu and Yokembe, have agricultural boundaries that extend farther from the road than all other villages in the study area, indicating that their farmers are already walking the farthest to access new fields and might benefit from agricultural intensification strategies. Villages like Lifanga (Bomwankoy Grpmt), that have both very low agricultural land per capita and extend only a minimal distance from the road, might benefit from the demarcation of extra land during the planning process for possible future agricultural expansion.

These analyses would benefit from the complementary use of socio-economic data, as demonstrated by Vedeld *et al.,* (2004 and 2007), who analyzed the economic drivers of forest dependence. Although certain models of deforestation use human population data as a major input — discussed in Rudel & Roper (1997) and Angelsen

& Kaimowitz (1999) — other factors, such as roads (market access), alternative employment and off-farm income opportunities, agricultural prices, and even traditional remedies for reducing deforestation, such as agricultural intensification and land titling, are shown to be potentially more important (Angelsen, 1999; Angelsen & Kaimowitz, 1999). We found a high variability in per capita agricultural land use, ranging from 0.17 ha/person to 4.25 ha/person. The villages located in Lingomo Grpmt had the highest agricultural land area per capita; from our conversations with these villages we hypothesize that this may be due to the fact that they have greater access to markets and employ an external agricultural labor force. Because we do not know what proportion each village's human population contributes to the labor force, interpretation of these figures should be only loosely considered. Analyzing socio-economic data collected from household surveys would be most useful for explaining the high variability in per capita agricultural land use and developing appropriate agricultural intensification and planning strategies for the future. Finally, knowing whether the results from this particular study area are consistent throughout the MLW Landscape will be important for scaling up models of agricultural expansion to the regional level; this is recommended for future work.

There is great utility for complementing participatory mapping with spatial mapping technologies for resource planning (McCall & Minang, 2005; Hessel *et al.,* 2009; Robiglio *et al.,* 2009). We learned several lessons from the mapping process. Most importantly, we recognized the value of promoting as transparent a process as possible by inviting and including leaders of neighboring villages, as well as leaders of the larger administrative Grpmt, in order to encourage an exchange of diverse

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perspectives. While women were present during the mapping process, they did not

directly contribute. We realize this shortcoming and are investigating ways to

enhance their participation, such as allowing the communities to choose a female

representative to contribute to the map drawing in future micro-zoning activities, as

described in Kalibo & Medley (2007) and Bourgoin *et al*. (2012). Promoting

ownership among stakeholders was important; it was key that all participants

recognized the value of their participation in the mapping process and their ownership

of any and all subsequent outcomes. The use of satellite imagery enhanced the

mapping experience as it provided real-world reference to locations of features on the

ground; it also saved time, as it provided a more efficient assessment of where ground

data were needed. In tropical countries in particular, where issues of cloud cover are

often problematic, we recommend considering issues of cost, resolution vs. project

scale, and image availability when choosing appropriate satellite imagery for

complementing participatory mapping methods. We also emphasize the importance

of maintaining a structured database, organized by village, of all data used (including

imagery and ancillary data) and collected (including GPS points and zone

boundaries), as well as creating a digital archive of the outputs of each step of the

mapping process, including hard-copy scans of each hand-drawn participatory map

and satellite map. This maintains an historical record of each step of the mapping

process, and makes sharing of data possible among village and project partners.

One of our main challenges has been building sufficient capacity in the region

to carry out this work. Our project resources and technological capacity have been

limited. Collection of satellite imagery and reliable ancillary data require sufficient

bandwidth and hard drive space; consequently, we have relied on the non-governmental organization, Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC), based in Kinshasa, to assist. Collecting GPS data in the field, as well as importing it into the GIS and creating the digital maps required thorough training of local staff and the development of detailed protocols. Other community mapping studies feature community use of digital information and 3-dimensional participatory modeling in planning processes (Rambaldi & Callosa-Tarr, 2002; Jankowski, 2009). Because of the mentioned challenges in boosting technological capacity and delivering appropriate resources to our field site where electricity is limited, we have not been able to integrate these latter innovative methods into our own work.

There is an expanding role for resource planning in tropical countries, especially as carbon accounting programs and conservation incentive mechanisms such as REDD+ (UNFCC, 2010) are established. Fortunately, more and more attention has been focused on the need to include local communities actively in these processes as they are the biggest stakeholders essential to the development of equitable land use policies and their implementation (Thibault & Blaney 2001; Ahamed *et al.,* 2008; Sunderlin *et al.,* 2008). As such, community mapping will be key to strengthening local capacity for land-use planning and zoning and securing indigenous land rights. In the DRC, this will be especially important as no system of land tenure currently exists. The participatory mapping activities undertaken in our study culminated in the first maps documenting village-level agricultural land use in this study area. The resulting maps, used as a means to facilitate communication among the community, the project partners and the government about forest resource

planning and micro-zoning, can also serve as a tool to enable the village communities

to make their own land-use planning decisions in the future, and potentially secure

their land rights as land use planning mechanisms in the DRC progress formally to

the national level.

Chapter 5: Summary of Findings, significance, applications and future research directions

This research explored the development of geospatial methods and tools for determining conservation priorities and assisting land use planning efforts in the MLW Landscape. The spatio-temporal patterns of recent primary forest loss were analyzed and complemented by the development of spatial models to highlight the locations where conservation actions will be most important to promote the future viability of landscape-wide terrestrial biodiversity. To complement this analysis, the research explored three scenarios of potential agricultural expansion by 2050 and provided spatially-explicit information to show how trade-offs between biological conservation and human agricultural livelihoods might be balanced in land use planning processes. The research also described a methodological approach for integrating spatial tools into participatory mapping processes with local communities and demonstrated how the resulting maps and spatial data can be used to inform village-level agricultural land use for resource planning and management. This approach at the local scale will contribute to the implementation of the landscape-level planning process informed by the landscape-scale models and analyses presented in Chapters 2 and 3.

5.1   Conservation implications for terrestrial biodiversity in the MLW Landscape

Habitat loss and degradation, resource extraction and changes in Earth's climate (refer to Sala *et al*. (2000) and Pimm (2009) for information on the third), all caused by increased human impact, have led to enormous global losses of biodiversity. The MLW Landscape has experienced relatively low human impact and subsequent deforestation, habitat loss, and degradation, thanks to an absence of large-scale commercial logging and its remote location in northern DRC. It therefore maintains relatively large tracts of intact forests that are critical to sustaining a variety of terrestrial species, including the bonobo. The bonobo's Endangered status on the IUCN Red List make it a priority species for conservation in the landscape. MLW comprises approximately 17% of the bonobo range, and survey data collected during the past five years have confirmed the presence of multiple populations throughout the landscape (Dupain *et al.,* 2001; Furuichi *et al.,* 2012; Hickey *et al.,* 2012). Consequently, Chapters 2 and 3 of this research center around the bonobo as a focal species associated with high quality habitat and low human disturbance as a focus for conservation prioritization in the landscape. Although the use of surrogate species for conservation has been debated in the literature, Warman *et al.* (2004), Freemark *et al.* (2006), and Drummond *et al.* (2010) have found that prioritizing conservation of particular species at risk can yield benefits for other species as well. This research identified 42 least-disturbed wildland blocks covering 60% of the MLW Landscape that exceed the minimum home range size required for sustaining bonobo populations

and 32 potential bonobo corridors, which thread through the agricultural areas and provide connectivity between the forest blocks. The locations of these forests blocks and corridors provide a strong basis for conservation targeting and prioritization to benefit bonobos and other forest-dwelling taxa in the landscape.

Human impact in the MLW Landscape is generally confined to the agricultural complexes that extend anywhere between 1 - 3 km from existing roads and parts of the navigable rivers. Indeed, like other parts of Central Africa, roads (in all cases unpaved) and navigable rivers are main drivers of human access and settlement in the landscape (Zhang *et al.,* 2006), and therefore can be linked to increased primary forest loss. However, the research conducted in Chapter 2 also showed instances of isolated pockets of primary forest loss occurring in remote forests of MLW. These disturbances were anthropogenically-induced and were likely caused by human migration patterns during DRC's war. Draulens & Van Krunkelsven (2002) explained that many human populations fled their natal villages during the war to escape conflict and seek shelter in remote forests, far away from roads and navigable rivers that were used by soldiers. These instances, being spatially distinct from the more common patterns of deforestation described above, are of greater concern from a conservation standpoint, as they contribute to perforation and fragmentation of interior forests. Forest disturbances in fragmented landscapes have been shown to affect vertebrate populations' abundance (Johnstone *et al.,* 2010), behavior (Norris & Stutchbury, 2001; Gardner, 2004), and physiology (Martínez-Mota *et al.,* 2007). Forest edges around the perimeter of these disturbances have been shown to impact interior forests negatively, contributing to drier micro-

climatic conditions (Chen *et al.,* 1992), reduced soil moisture (Denslow, 1987), and to the overall degradation of ecological and ecosystem processes within (Laurance *et al.,* 2002; Wickham *et al.,* 2007). In addition, forest edges provide greater access for humans to pursue activities such as hunting and resource extraction in previously undisturbed forests. Monitoring the spatial patterns of human impact and subsequent patterns of deforestation will be key to understanding the prevalence of further forest fragmentation and assist in targeting conservation actions that minimize the human footprint in intact forests.

Despite its remote location and relatively low rates of deforestation, the MLW Landscape is faced with its own conservation challenges, as both the least-disturbed forest blocks and potential bonobo corridors are vulnerable to forest conversion. Primary forest loss in the landscape is attributed primarily to small-scale subsistence agricultural activities, and deforestation resulting from these activities increased substantially during the second half of the 2000-2010 decade. However, the majority of this deforestation occurred within 1 kilometer of existing settlements and agricultural complexes, which, as described earlier, is more preferable from a conservation standpoint. As explained in Chapter 2, the conclusion of the DRC war in 2003 was likely a causative factor for the observed rapid increase in primary forest loss around the agricultural complexes during the second half of the 2000-2010 decade, demonstrating the potential impact of human populations who migrated back to their natal villages to revitalize and expand their farms. Because the potential bonobo corridors are located in and around these agricultural complexes, they are most vulnerable to current and future forest loss as surrounding human populations

grow and expand their agricultural livelihoods. These areas should be monitored carefully and prioritized for targeting, planning and implementing on-the-ground conservation with local communities.

The bonobo corridors are also vulnerable to potential future agricultural expansion. Business-as-usual scenarios of human and agricultural expansion for 2050 showed that the corridors are highly threatened, ranging between approximately 17% to 19% of their individual corridor area. Accommodating the future agricultural needs of growing human populations can be achieved to complement conservation priorities in MLW, however. By considering the corridors and protected areas as constraints to future growth in a proposed conservation scenario of future agricultural expansion, forest loss in the corridors can be minimized at the expense of increased agricultural development around historically active agricultural complexes surrounding the villages of Djolu and Lingomo in the eastern part of the landscape. Utilizing tools that help visualize these potential trade-offs between conservation and development objectives, and engaging with local stakeholders to find ways to achieve balance between these objectives, will be essential to future planning processes.

5.2   The utility of spatial data and tools for conservation planning in the Congo Basin

There is growing awareness about the field of systematic conservation planning and its broad applicability to a range of planning solutions (see Moilanen *et al.* (2009) for a comprehensive review). Spatial conservation prioritization provides conservation planners and decision makers with location-specific information that helps identify

areas where conservation efforts are most needed. Necessarily, spatial data and tools

play a critical role. Due to accelerating losses of global biodiversity, allocating

resources to conservation problems effectively and efficiently is of utmost

importance, especially in areas as rich in biological resources as the Congo Basin.

Consequently, as planning efforts move forward in the DRC and in other CBFP

landscapes across the Basin, conservation practitioners will need access to spatial

tools and methods that will help them to suitably allocate their resources. The

wildland forest blocks identified in Chapter 2 and the potential corridors connecting

them are critical foci for conservation planning and targeting in MLW at the

landscape scale. As demonstrated in Chapter 3, these areas can also serve as input to

more sophisticated spatial models that coarsely explore the frontier between

conservation and livelihood development.

Congo Basin countries harbor a range of stakeholders comprised of

government representatives, members of international, national and local NGOs,

members of local communities, and resource extraction interests such as palm

production and logging companies. As stakeholders have different priorities,

presenting a set of maps depicting a range of planning alternatives rather than just

one, is important (Brill, 1979; Stewart *et al.,* 2004). Doing so promotes greater

transparency and can lead to increased stakeholder involvement (Ardron *et al.,* 2010)

as well as increased insight into potential outcomes of various planning actions. As

such, land use planning processes will benefit from spatial tools that allow

stakeholders to visualize a set of planning and management scenarios. Maps provide

necessary visualizations to communicate to a wide variety of stakeholders and

therefore can serve as a useful tool for negotiations and discussion. The optimization models developed in Chapter 3 provide an example of the use of spatial data and tools for generating alternative scenarios of anthropogenic land use change for planning purposes. The resulting maps provide a starting basis for alternative scenario exploration; here, they illustrate locations where trade-offs between conservation and development objectives may be necessary in the face of future population growth and agricultural expansion.

Monitoring land use and land cover change using spatial data and tools will also be crucial for land use planning in the Congo Basin. Analyses of past and present changes in land use and land cover can elucidate the relative vulnerability of areas of high conservation priority to anthropogenic pressure and habitat fragmentation. Datasets like FACET, which map locations of primary forest loss occurring in 5-year intervals (featured in Chapter 2), therefore, have real value for identifying 'hotspots' of deforestation and providing targeted intervention action for planning processes with multiple stakeholders. In addition, these types of datasets can be critical inputs to models that rely on historic patterns of land cover and land use change for projecting likely future scenarios of land cover and land use change, such as optimization (Chapter 3), or cellular automata models.

Participatory mapping, which utilizes spatial thinking and tools in collaboration with engagement of local stakeholders, will be essential for any zoning implementation of the local scale. It has been shown to add a valuable component to land use planning processes in both the developed and developing world (see Vajjhala (2005), Wang *et al.* (2008), Hessel *et al.* (2009), Valencia-Sandoval *et al.* (2010) and

Bourgoin *et al.* (2012) for some examples). Recognizing and including local

communities (which in the DRC are often marginalized) in planning procedures

promotes local empowerment and transparency, essential ingredients in any planning

process (McCall & Minang, 2005; Chambers, 2006). Because the DRC has no

existing land tenure, strengthening local capacity for securing land rights in zoning

processes will be increasingly important. Furthermore, complementing participatory

mapping with spatial mapping technologies can capture valuable information about

local resource use and provide new geographic perspectives to local communities.

The research conducted in Chapter 4, which focused on the participatory delineation

of village-level agricultural zone boundaries, demonstrated how the resulting spatial

data captured from participatory processes can provide value for targeting villages

that might be most in need of agricultural extension or development assistance.

Results showed a high variability in per capita agricultural land use across the study

area in eastern MLW Landscape. Further analysis indicated which villages are

supporting greater numbers of people with a smaller amount of agricultural space, or

which villages' farmers are walking the farthest to access new fields.

5.3 Policy implications for land use planning in the DRC

The results of this research have certain implications for national-level land use

planning in the DRC. The research provides substantial evidence that spatial data and

tools should play a prominent role in land use planning processes; this will require

centralized facilities of strong GIS capacity to build technological faculty,

information development, and streamlined data management. One such facility, located in Kinshasa, DRC, is the Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC). It was initiated in 2000 and is a focal point of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) network for Central Africa. OSFAC currently distributes Congo Basin satellite imagery and provides training and capacity building for spatial data management and analysis to public- and private-sector institutions throughout Congo Basin countries. Accordingly, OSFAC's capacities, which provide valuable resources to a country such as DRC that has limited technological capabilities, should be leveraged by the DRC Government as the country proceeds toward initiating national-level planning processes.

There is growing recognition that Congo Basin countries will play a significant role in global efforts to reduce greenhouse gas emissions by reducing emissions from deforestation and forest degradation through programs such as REDD (refer to UNFCC (2010) for more information). As carbon accounting programs and conservation incentive mechanisms such as REDD+ (a related program designed to increase forest cover through conservation and sustainable management of forests; also described in UNFCC (2010)) are initiated, deforestation monitoring in Congo Basin countries, particularly in the DRC, will be critical. REDD feasibility assessments require known information about historical patterns of land use and land cover change dating back to at least ten years prior (VCS, 2012). The DRC Government should therefore develop partnerships between government Ministries and local and regional facilities and organizations (such as OSFAC mentioned above) to enhance its capabilities to participate and direct in-country forest monitoring

efforts.

Consistent monitoring and detection of primary forest conversion patterns will be increasingly important in order to develop land use planning strategies in areas most vulnerable to habitat loss and fragmentation. Efforts to move forward with national-level strategies for conservation land-use planning in DRC, however, will likely be challenged by limited collection of data for target wildlife species due to issues of inaccessibility and high costs of implementing data collection procedures. Planning strategies that consider the identification of core areas that achieve representation of native species and ecosystems and their inter-connectivity, therefore, will help streamline conservation prioritization efforts in Congo Basin forests.

Finally, involving local stakeholders in planning processes in the DRC will be essential. DRC law now requires extensive public participation in forest zoning processes (MECNT, 2011; Sidle *et al.,* 2012). Despite this advance and other recent advances to promote sound forest governance, however, there is still much criticism of past and present forest governance in the DRC (see Hoare (2007) and Kiyulu (2010) for examples). The DRC's lack of land tenure combined with its history of favoring large-scale timber and mining companies over the rights of local communities will undoubtedly be important challenges to overcome. Fortunately, increased global attention has focused on the need to include local communities actively in planning processes, as they are the biggest stakeholders essential to the development of equitable policies and their implementation (Ahamed *et al.,* 2008; Sunderlin *et al.,* 2008). There is an expanding role for resource and land use planning

in tropical countries such as the DRC, especially as carbon accounting programs and conservation incentive mechanisms such as REDD+ are established. As such, involving local stakeholders via the development of participatory mapping strategies will be key to strengthening local capacity and securing indigenous land rights in the DRC.

5.4 Future research directions

The research presented here highlights several opportunities for future development. The models focusing on conservation prioritization and alternative scenarios of agricultural expansion for the MLW Landscape offer a useful starting basis for initiating discussions about landscape-wide land use planning. The methods developed here have wide applicability for conservation prioritization and land use planning in other areas of the Congo Basin (such as in other CBFP landscapes), especially those areas that may be hampered by a lack of biological habitat data. Threat-based models, such as the model of human influence developed in Chapter 2, require coarse-scale assessments of threats to biological diversity which can be subjective. Because there are no precise rules for selecting threats and assigning potential corresponding weights of influence, involving the knowledge of local or regional experts is encouraged, if not essential (Mcpherson *et al.,* 2008), and the use of participatory threats analyses as demonstrated in Beazley *et al.* (2010) would be a useful complement. The models can always be improved as new data are developed; outputs should be kept up-to-date for maximum effectiveness in planning procedures.

Locations of the conservation priority areas developed in this work rely on the

assumption that the locations of the potential bonobo corridors, developed in Chapter 2, are truly used as connectivity zones for bonobos and other similar forest-dwelling taxa. Verifying and understanding the relative importance of the identified corridors should be undertaken in the future. This would be accomplished by field validation and wildlife surveys conducted by local biological experts and guided by AWF and/or other knowledgeable regional entities.

Given the Earth's steadily expanding human population, especially in Sub-Saharan African countries, demand for land and resources will likely accelerate. There is much speculation about the future of Congo Basin forests and the future of their terrestrial and freshwater biodiversity as human activities such as bushmeat hunting, commercial logging, large-scale intensive agriculture, mining, and oil palm expansion increase. With this in mind, future work should focus on the continued development of spatial models that map alternative future scenarios of land cover and land use change and their effects on surrounding biological resources. Spatial modeling work conducted by Zhang *et al.* (2006) found that Congo Basin forests will gradually shrink toward their interior by potentially 10-20 km per decade. Models such as this should be further developed and refined to include a range of development scenarios (as demonstrated in Chapter 3) that can better inform stakeholders during planning processes.

The alternative-scenario optimization models developed in Chapter 3, while useful for coarse-scale planning purposes, should be further refined to accommodate more accurate assumptions about agricultural expansion. First, the model assumptions do not consider the influence of administrative boundaries at the

Groupement level that tend to influence where people live in the landscape. Rather than relocate to a different Groupement, human populations (with the exception of females) tend to continue living within the Groupement where they were born; once spatial data describing these boundaries become available, new models could be built that stratify agricultural and human expansion within each Groupement. Second, because the model assumptions are based purely on business-as-usual scenarios of human and agricultural expansion according to the FACET data, they do not account for factors that may significantly inhibit or promote future agricultural expansion, such as the improvement or addition of roads or the establishment of new markets, logging concessions, or large-scale oil palm plantations. Like the threat-based conservation prioritization models developed, these optimization models could be further improved with the incorporation of such data. Third, since the model assumptions are derived from purely a land cover and land use perspective, they are highly limited from a socio-economic standpoint. They falsely presume that both agricultural expansion and human population growth rates are uniformly distributed across the MLW Landscape. A more robust estimate of future agricultural expansion in MLW would benefit from data describing agricultural productivity, including the ratio of products consumed versus products sold, agricultural inputs used, and other data describing farmers' decisions and behavior. Factors influencing these conditions, including market activity and market access, likely vary considerably across the landscape, and accounting for their spatial heterogeneity would be important. Collection of landscape-wide socio-economic data would be an enormous undertaking, but strategically targeting the collection of such data across the

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landscape would better inform agricultural land use and subsequent rates of current and possibly future agricultural expansion.

The participatory mapping methodology developed in this work is being continued in the study region in eastern MLW Landscape for the fine-scale delineation of community forest zones in partnership with the sixteen villages featured in Chapter 4. Lessons learned from this work are assisting those efforts. The MLW Landscape is currently the only CBFP landscape engaging in fine-scale micro-zoning; nevertheless, these methods should be explored and refined by other CBFP landscapes as they begin to initiate their own micro-zoning procedures with local communities. The delineated agricultural zone data collected in Chapter 4 were analyzed in order to develop a better understanding of agricultural resource use in the landscape. These data should be complemented by village- and household-level socio-economic data in order to enhance this understanding and better inform the agricultural expansion scenarios developed in Chapter 3. In addition, it would be useful to employ more detailed analysis of the agricultural zones to parse out the proportion of active to inactive (temporarily fallow) fields in each agricultural zone, as well as the proportion of the villages' human populations able to contribute to the agricultural labor force. Doing so would greatly contribute to our understanding of current and possibly future agricultural land needed to support crop rotation processes that are a necessary part of agricultural livelihoods in the region.

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