

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

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ABSTRACT: Determining priority areas for conservation activities in the forests of the Congo Basin is increasingly important in the face of advancing human pressures and deforestation. Since 2004, the African Wildlife Foundation (AWF) has led conservation and land-use planning activities in the Maringa-Lopori-Wamba (MLW) Landscape located in northern Democratic Republic of the Congo (DRC). We identified four distinct spatial patterns of primary forest conversion in the landscape and compared rates of primary forest loss between 2000-2005 and 2005-2010. Although overall primary forest loss during 2000-2010 was relatively low, nearly two-thirds occurred during the second half of the decade and took place within one kilometer from existing human settlements. We developed a threat-based multi-criteria model addressing relative threats from hunting and habitat degradation using the bonobo (*Pan paniscus*) as a surrogate species in order to delineate a set of relatively undisturbed forest blocks for potential habitat conservation. Next, we used Corridor Designer to model the connectivity zones between them. Lastly, we compared the amount of primary forest loss taking place in the forest blocks and corridors to target areas for further prioritization. This work contributes to a deeper understanding of recent land use dynamics and conservation priorities to aid conservation planning in the Maringa-Lopori-Wamba area of the Congo Basin.

Keywords: spatial modeling, multi-criteria modeling, land-use planning, Democratic Republic of the Congo, threats to biodiversity, land use and land cover change

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. Systematic conservation planning (Margules and Pressey 2000, Groves *et al.* 2002, Pressey and Bottrill 2008) has been widely applied to conservation priority-setting, combining measures of 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 and LLP 2006, Wilson *et al.* 2007, Trombulak and Baldwin 2010). 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 targets areas of high conservation priority and includes accounting for measures of vulnerability and anthropogenic threat (Wilson *et al.* 2005, Brooks *et al.* 2006, Pressey and 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 and 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 and 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 and 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 and 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 and 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 the areas that contribute directly to maintaining biological connectivity and function within a landscape.

The Congo Basin spans approximately 2 million km² (772,204 mi²) in Central Africa and is the second largest tropical rainforest in the world after the Amazon (CBFP 2005). 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). The largest country in the Congo Basin, Democratic Republic of the Congo (DRC), has a human population of 71 million inhabitants (CIA 2010) and the highest population growth rate within Central Africa (CBFP 2009). Approximately 66% of DRC's population is rural (FAO 2010) and relies heavily on its forests for the provision of natural resources and livelihood subsistence (Klaver 2009). In recent decades, DRC's formal economy has collapsed from two damaging civil wars, and the country has suffered from social unrest, government mismanagement, and lack of

socio-economic capacity. These factors will likely pose challenges for biodiversity conservation and stewardship of forest resources for future generations.

Together, the Central African Forests Commission (COMIFAC), the Congo Basin Forest Partnership (CBFP), and the United States Agency for International Development's Central African Program for the Environment (USAID-CARPE) provide an institutional means to promote regional cooperation in forest conservation, rural development, and planning within Congo Basin countries (CBFP 2006). In 2002, the CBFP selected 12 priority landscapes across the Congo Basin for establishment of land-use management plans for conservation (CBFP 2005). Since 2004, the African Wildlife Foundation (AWF) along with several partner institutions has been working with the Government of DRC toward the development of a participatory landscape-wide land use plan for one of the CBFP priority landscapes, the Maringa-Lopori-Wamba (MLW) Landscape, located in northern DRC (CBFP 2005). The MLW Landscape was selected for its large expanses of intact forests with high levels of biodiversity and endemism, most prominently the bonobo (*Pan paniscus*) and Congo peafowl (*Afropavo congensis*). In 2009, the Government of DRC acknowledged the need to develop a national land-use plan for the conservation and sustainable use of its forests and formed a national Steering Committee for its oversight. Subsequently, the AWF-led land-use planning activities in the MLW Landscape were formally recognized by the DRC Government as a pilot model for the development of national-level planning strategies.

This paper 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 and 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 paper 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 in this paper 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.

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 and 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 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. Furthermore, the bonobo's requirement of large tracts of less-disturbed forest also lend it suitability as an umbrella species for other forest-dwelling taxa in the landscape. Of course, this particular criterion can be changed to accommodate different species according to conservation objectives, if such data become available.

METHODS

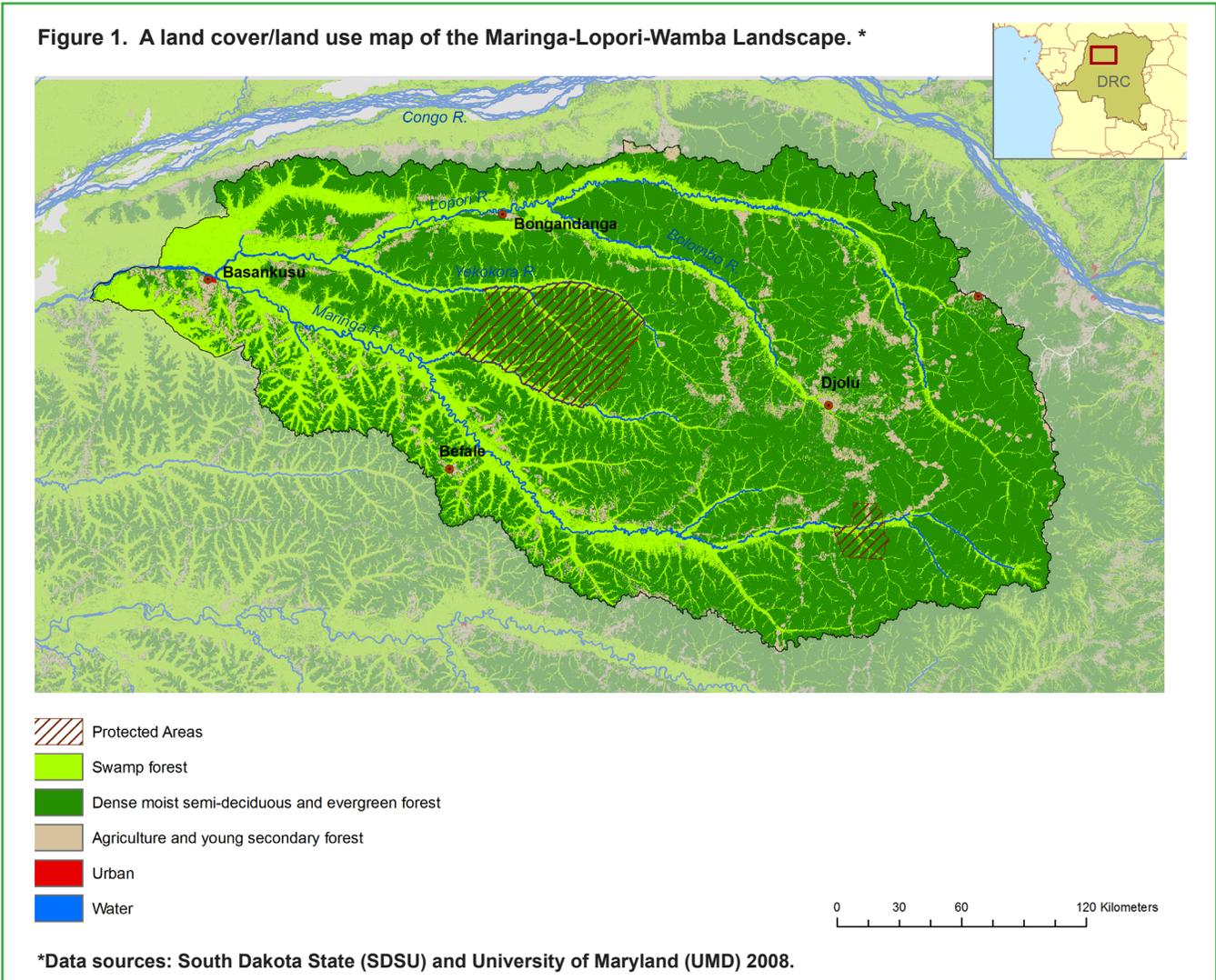
Study Area

The Maringa-Lopori-Wamba (MLW) Landscape covers a 72,000 km² (27,799 mi²) swath of land in remote Equateur Province in northern DRC. The landscape comprises a number of land use and land cover types, including 68% moist dense equatorial evergreen forest, 25% swamp forest, and 5% agriculture (Figure 1). It harbors an array of threatened terrestrial species, including the bonobo —

listed as Endangered since 2007 (Fruth *et al.* 2008), the Congo peafowl—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). The landscape contains one abandoned logging concession, vacant since 1999.

Road infrastructure in the MLW Landscape is very poor; 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. Settlements and villages occur along rivers and road axes, and agricultural 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. Active and inactive palm and rubber plantations exist in the landscape, although specific numbers are not known. These plantations were active before DRC's war; the majority of them are now inactive with some exceptions. We know definitively that three or four large-scale commercially-owned active palm



plantations (ranging between 25 km² and 53 km² (9.65 mi² and 20.46 mi², respectively)) 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 several bonobo populations. Hunting is the largest contributor to the bonobo's endangered status (IUCN 2010). Poaching of bonobos has been observed and documented in the Luo Scientific Reserve, located in the southeast region of the MLW Landscape, since the mid-1980's. Researchers stationed there observed dramatic increases in bonobo hunting since the start of DRC's war (Tashiro *et al.* 2007, Hashimoto *et al.* 2008). An increasing human population will escalate demand for bushmeat and agricultural land within the landscape, and subsequent hunting pressure and habitat fragmentation will continue to be principle threats to areas of high conservation value.

Assessing Recent Patterns of Land Use and Land Cover Change in the MLW Landscape

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 features 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.

Development of a Multi-criteria Threat-based Model to Identify Areas of Highest Conservation Potential in the MLW Landscape

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 Geographic Information System (GIS) using a simple additive weighting (SAW) process within a spatially-explicit multi-criteria decision analysis (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. The model considered 1.) Hunting pressure (including human accessibility and relative population demand for bushmeat), as well as 2.) Habitat degradation (including the influence of agricultural and urban areas as well as large-scale plantations). The inputs to the model were spatially-explicit raster grids mapped at 90 meter (969 ft) resolution, detailed in Table 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 and LLP 2006) and altered for this analysis. First, using a gridded surface of land use and land cover for the MLW Landscape (see Table 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 (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. 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.

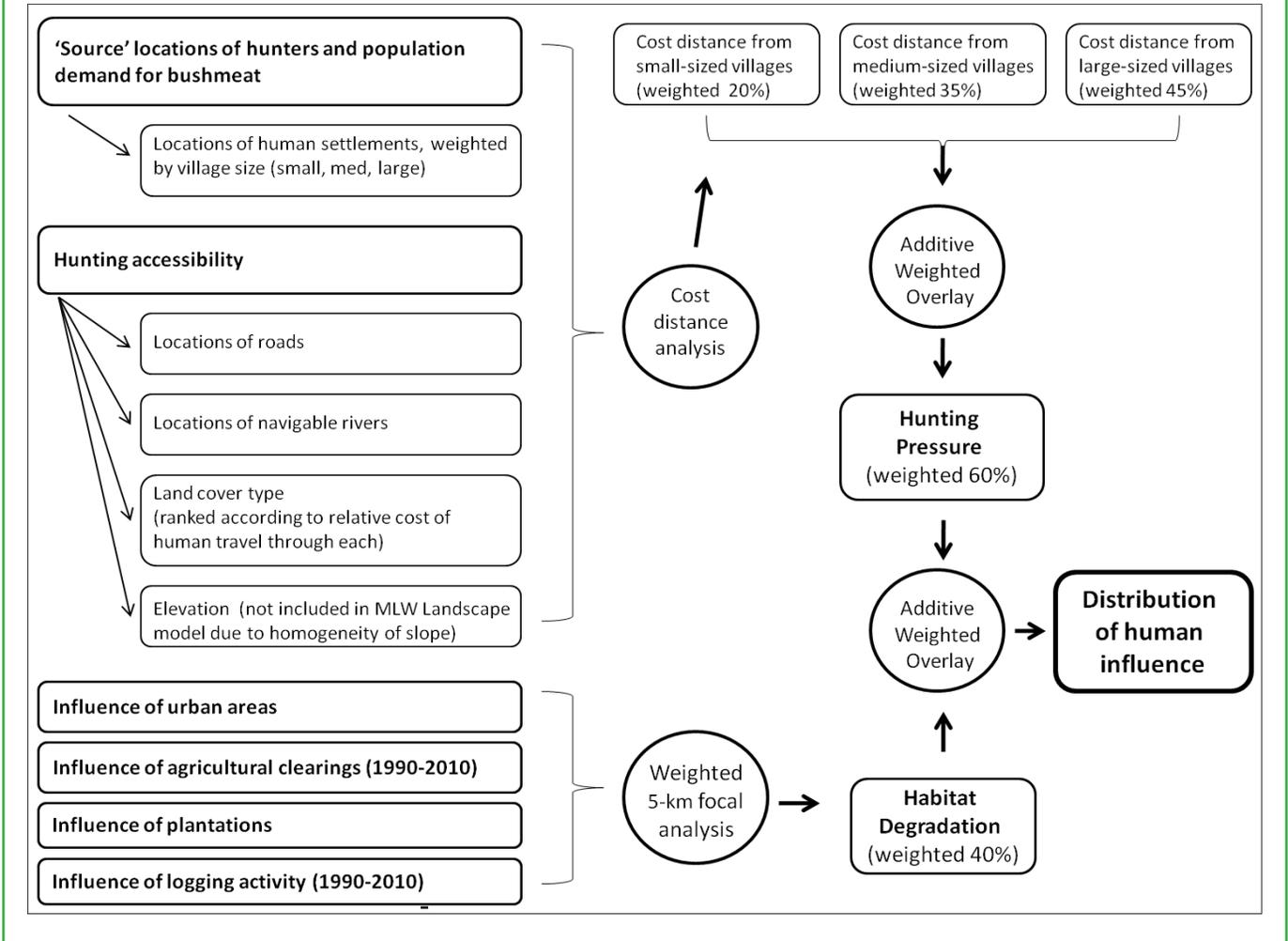


Table 1. A list of spatial data and sources used in the multi-criteria model.

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. 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 rank in three categories to reflect the potential number of hunters in each village and the approximate 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 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 (3.12 mi) 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 (Figure 2).

Identification of Wildland Blocks and Corridors

We followed the methods outlined in Sanderson *et al.* (2002) and McPherson *et al.* (2008) to systematically identify 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 km² (0.39 mi²) 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 km² (7.72 mi²) (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 home range area of 20 km² (7.72 mi²) and a breeding patch size of 10,000 km² (3861 mi²). 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 we applied them in the corridor suitability model as a constraint to bonobo connectivity.

RESULTS

Assessing Decadal Patterns of Primary Forest Loss in the MLW Landscape

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 (35.3 % of all primary forest loss in MLW took place in 2000–2005, and 64.6% occurred in 2005-2010, see Figure 3). 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-owned palm plantation significantly expanded into the primary forest (approximately 2 km² (0.77 mi²)).

We identified four common spatial patterns of primary forest conversion occurring in the MLW Landscape (Figure 4): 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 and Van Krunkelsven (2002), the authors attribute the conversion patterns detected and shown in map subset #4 to the particular human 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 5, 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.

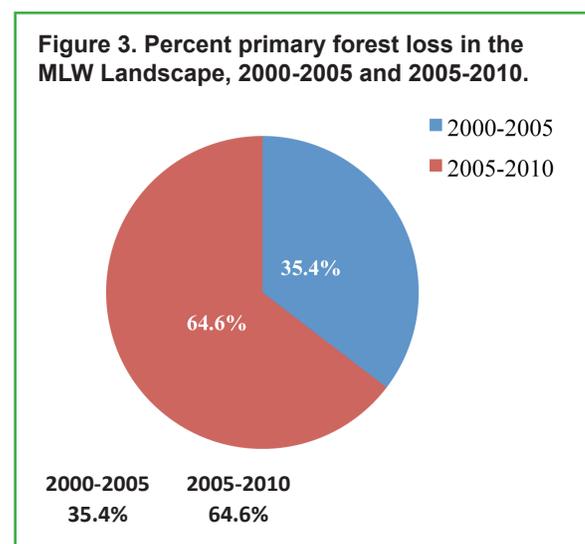
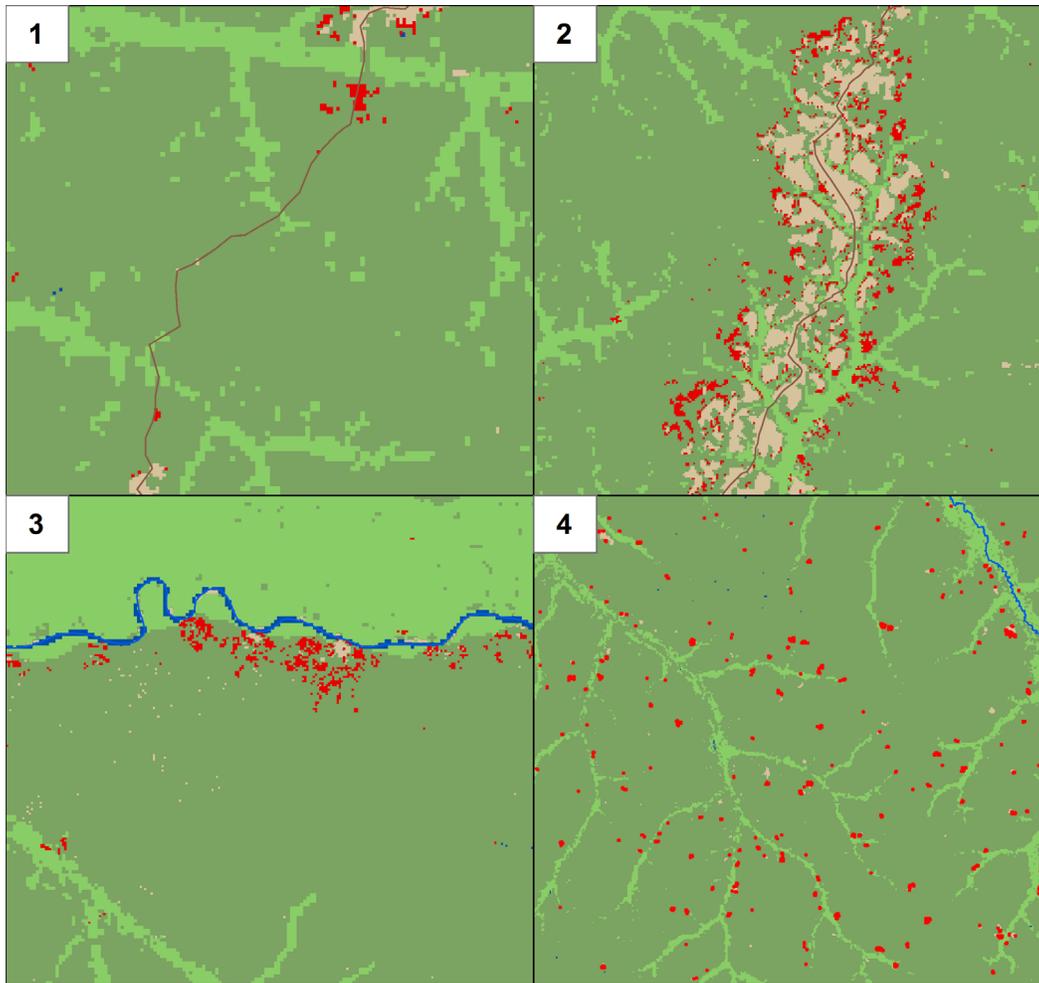


Figure 4. Four distinct spatial patterns of forest conversion in the MLW Landscape are illustrated: 1.) conversion in areas around roads where there previously were no clearings, 2.) conversion along the outermost edges of existing agricultural areas fanning out from the roads, 3.) conversion alongside 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 for visual clarity).



Legend

- Primary forest loss 2000-2010
- Agriculture and young secondary forest
- Swamp forest
- Primary forest
- Major rivers
- Roads

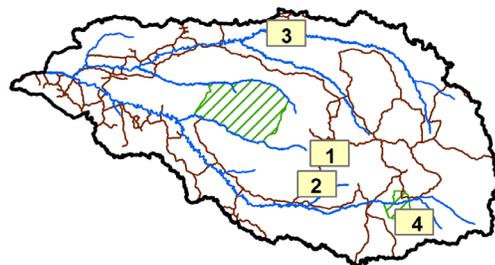
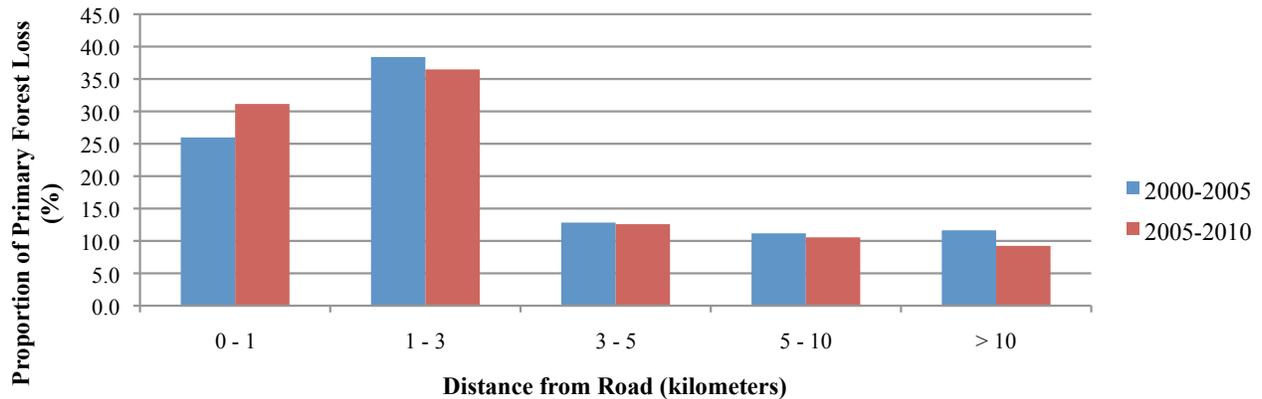


Figure 5. The proportion of forest loss in the MLW Landscape in relation to distance from roads is shown for 2000-2005 and 2005-2010.



Determining Locations of High Conservation Potential in the MLW Landscape

Figure 6 presents the mapped result of the threat-based model of human influence at 90 m (969 ft) 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.

The maps in Figure 7 show the result of aggregating the average human influence scores to a grid of 1 km² (0.39 mi²) planning units to determine locations of high-priority wildland blocks. 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. 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 km² (7.72 mi²), the home range of the bonobo. The largest identified wildland block extends almost 13,000 km² (5,019 mi²). While the wildland blocks smaller than 20 km² (7.72 mi²) may be insufficient to support a bonobo population’s home range, they may still offer value for dispersal and connectivity.

Figure 6. 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.

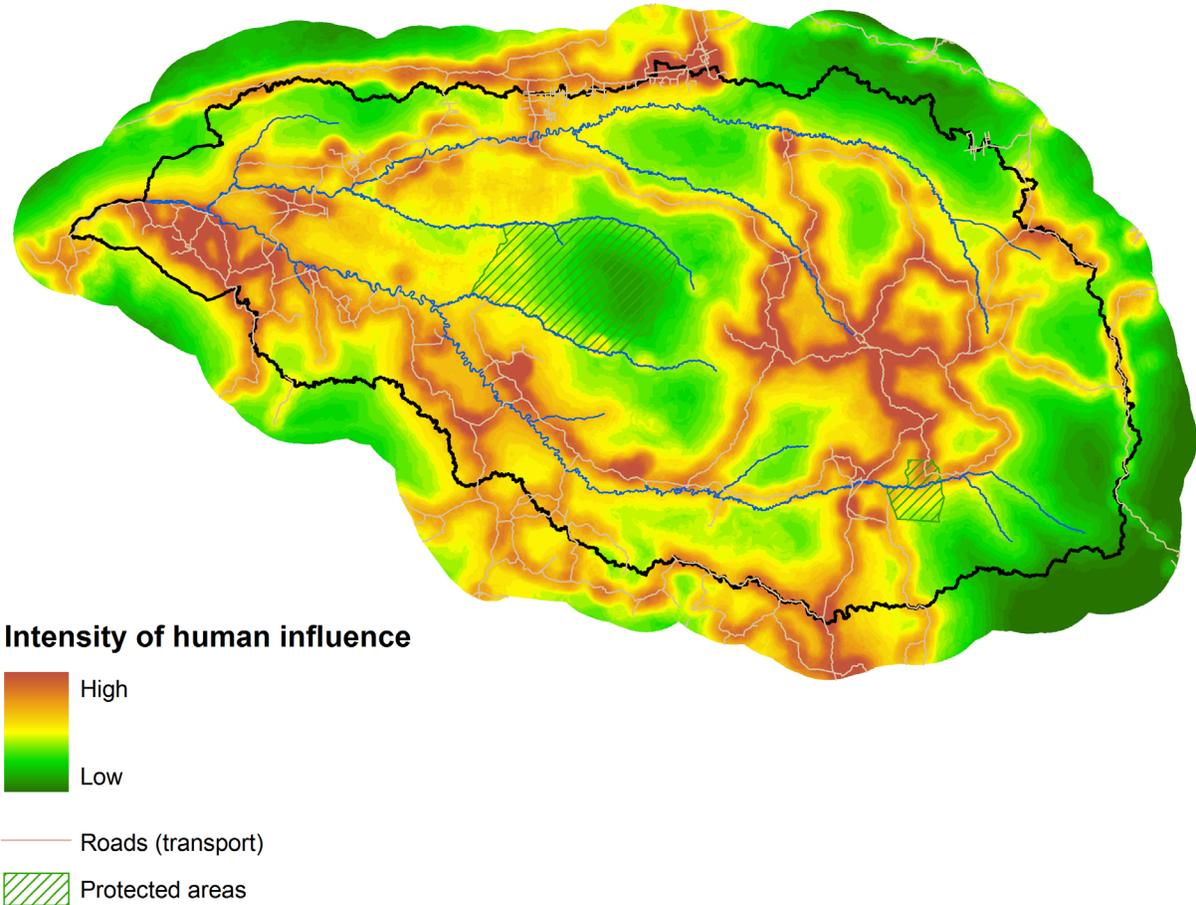
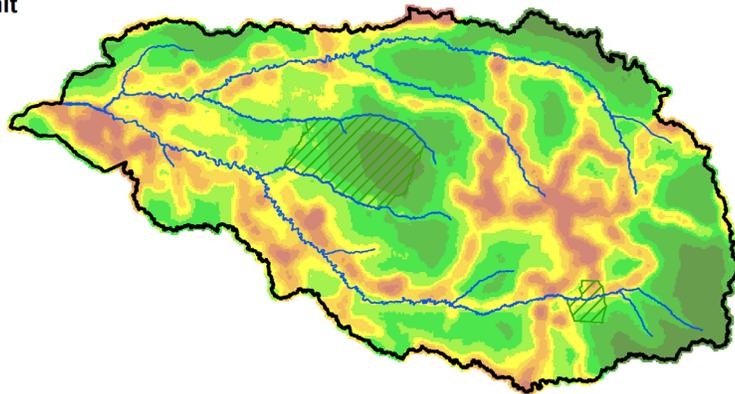


Figure 7. The map at the top of the figure reveals the 1 km² (0.39 mi²) planning units falling above (shown in orange) and below (shown in green) the threshold of "medium" mean human influence across the MLW Landscape. The map at the bottom of the figure shows the planning units with a human influence score falling below the threshold and comprising the least disturbed wildland blocks.

**Mean human influence score
summarized by 1 km² planning unit**



**Mean human influence score
summarized by 1 km² planning unit**

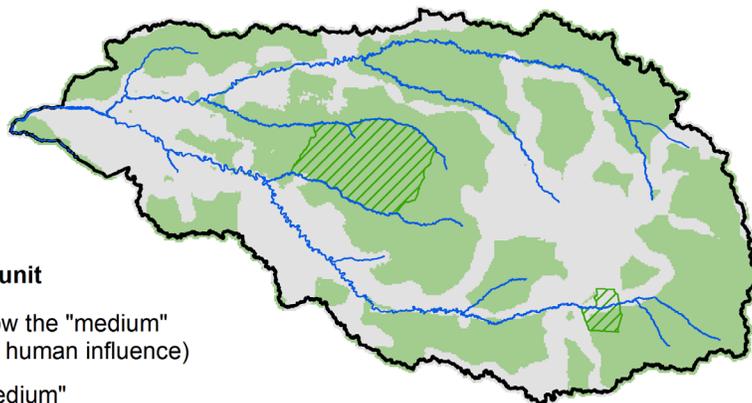
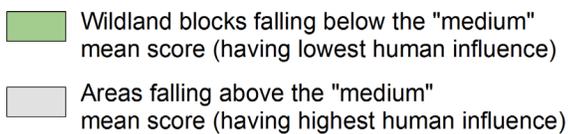
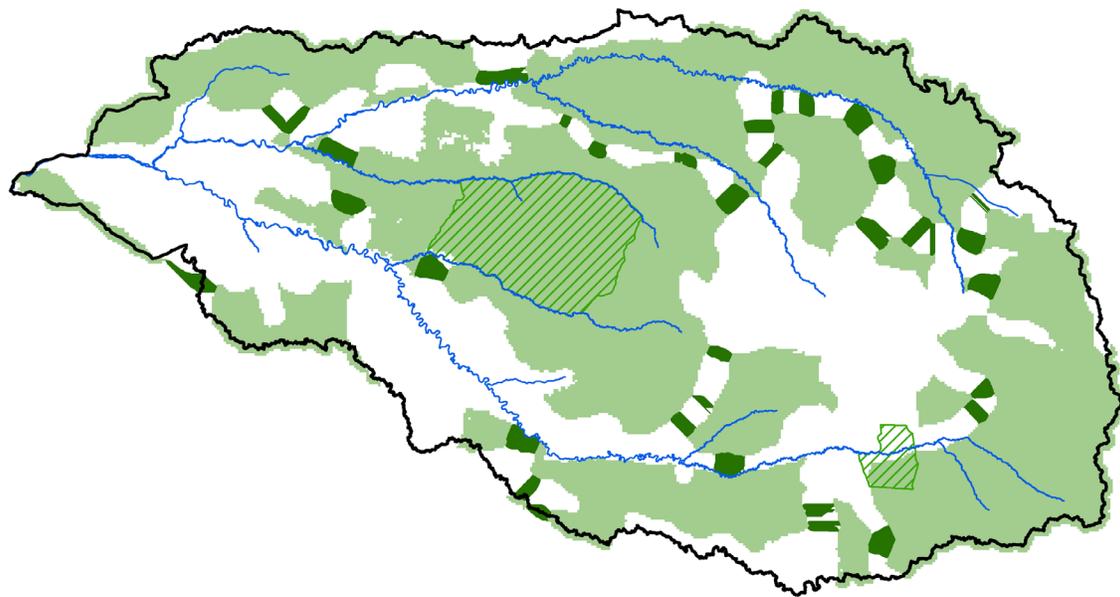


Figure 8 presents the result of the corridor suitability analysis parameterized to facilitate bonobo movement between wildland blocks. The 32 corridor sections identified occupy 3% of the landscape. Corridor Designer produced a nested set of increasingly wide “slices” comprised of the pixels

with lowest cost distance between wildland blocks; here, we show the smallest 1% slices. Figures 6-8 demonstrate the pivotal role of spatial data and analysis in determining the spatial distribution of conservation priority areas in the MLW Landscape.

Figure 8. A map of the resulting corridor suitability analysis parameterized to facilitate bonobo movement between wildland blocks.

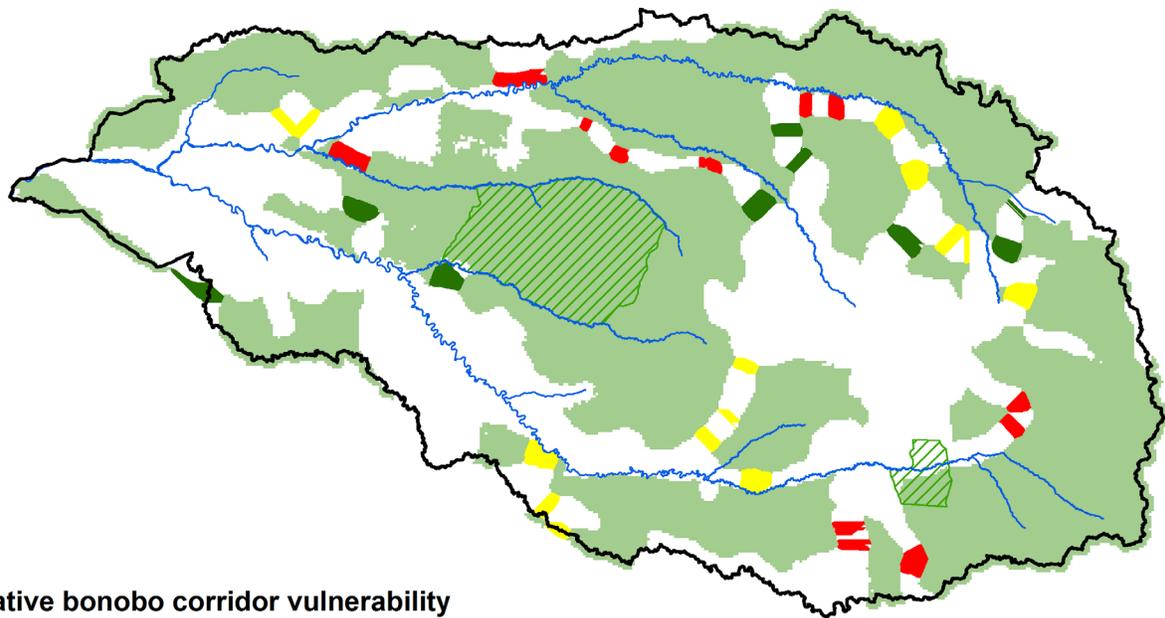


-  Potential bonobo corridors (constrained by major rivers shown)
-  Wildland forest blocks for potential bonobo habitat (minimum 20 km² area and sub-divided by major rivers shown)
-  Protected areas

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 9 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 9. 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.



Relative bonobo corridor vulnerability to primary forest loss, 2000-2010

- High
- Medium
- Low
- Bonobo wildland blocks
- Protected areas

DISCUSSION

Patterns of Land Use Change and Primary Forest Loss in MLW

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 and 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 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.

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 9 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 their 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 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 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 weights based on expert- and field- based knowledge; this is not always ideal, as explained in Beazley *et al.* (2010). In addition, much 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.

CONCLUSION

As carbon accounting programs and conservation incentive mechanisms such as REDD+ 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.

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