Biological Conservation 164 (2013) 140–149

Contents lists available at SciVerse ScienceDirect

Biological Conservation

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

A comparison of scenarios for rural development planning and conservation in the Democratic Republic of the Congo

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ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form 7 April 2013
Accepted 12 April 2013
Available online 7 June 2013

Keywords:
Democratic Republic of the Congo
Congo basin
Land use planning
Marxan
Agriculture
Conservation planning

ABSTRACT

Including a diverse set of stakeholders in collaborative land use planning processes is facilitated by data and maps that communicate and inform an array of possible planning options and potential scenarios of future land use change. In northern Democratic Republic of the Congo (DRC), the African Wildlife Foundation (AWF) has engaged stakeholders and the DRC Government to lead a participatory zoning process in the Maringa–Lopori–Wamba (MLW) Landscape. To assist landscape scale macro-zoning efforts, we employed a spatial allocation decision support tool called Marxan to develop a set of three scenarios of potential human and agricultural expansion for 2050. The results offer guidance to stakeholders and assist decision-makers in determining the most suitable land for inclusion in a proposed Rural Development Zone (RDZ), designed to accommodate the expansion of agricultural activities and subsequent deforestation while considering conservation priority areas. We used data describing current patterns of human activity, including historical primary forest loss, land cover suitability for agricultural activity, and presence of important wildlife connectivity zones and protected areas to identify locations where future agricultural expansion might be encouraged. We found that future agricultural demands can be met by expansion around historically intensive agricultural areas in the eastern portion of MLW without significantly compromising conservation priority areas. Wildlife connectivity zones are most vulnerable to future agricultural expansion because of their proximity to current agricultural activity. Our results demonstrate the need to prioritize conservation action in these areas and illustrate how competing needs might be balanced in planning for both agricultural expansion and terrestrial biological conservation in this landscape.

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1. Introduction

Deforestation and forest degradation driven largely by agricultural expansion are key drivers of biodiversity loss in the tropics (Achard et al., 2002; Laurance, 1999). Africa's Congo Basin contains approximately 20% of the world's remaining tropical forests (Mayaux et al., 2004) and serves as important habitat for over half of Africa's flora and fauna. About 60% of Congo Basin forests lie in the Democratic Republic of Congo (DRC). DRC's mostly rural population is heavily reliant on forests for natural resources and livelihood subsistence (Klaver, 2009). Accordingly, slash-and-burn methods for subsistence agriculture and fuelwood collection constitute the majority of both deforestation and forest degradation in the DRC (Hansen et al., 2008; Potapov et al., 2012). Recent forest cover monitoring efforts undertaken in the DRC show a near doubling in primary forest loss between 2000–2005 and 2005–2010 (Ernst et al., 2012). The DRC is recovering from two recent civil wars that collapsed its formal economy and caused widespread poverty. There is concern that forests in post-conflict DRC will experience increasing pressure due to the country's high population growth and poverty rates, weak governance, and limited capacity to modernize food production, posing challenges for biodiversity and human welfare (USAID, 2010).

Sustainable and equitable management of land and natural resources will be important to slow deforestation in the Congo Basin and promote the well-being of local populations dependent upon forests for their livelihoods (UNEP, 2007). Land use planning and zoning provide an approach to resolve competing needs for land, determine appropriate trade-offs (Halpern et al., 2008), and plan sustainable use of physical, biological and cultural resources (Ahern, 1999). A spatial dimension incorporating biological conservation priorities and their geographic relationship to human livelihoods and natural resource use is crucial for landscape planning (Forman, 1995). Decision support systems (DSSs) that consist of both a computer-based knowledge system and a problem-solving system (Holsapple, 2003) can be used to inform decision-makers in planning processes given a set of criteria and stakeholder preferences. Used in conjunction with a Geographic Information System (GIS),

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0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.04.011

DSS can produce spatially-explicit maps of land use planning options and their implications (Crossland et al., 1995; Jankowski et al., 2001).

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

The DRC Government is currently laying the foundation for a national land-use plan for conservation and sustainable use of its forests (USAID, 2010). Since 2004, the African Wildlife Foundation (AWF) along with several partner institutions has worked with the DRC Government to develop a participatory landscape-wide land use plan for the Maringa–Lopori–Wamba (MLW) Landscape located in northern DRC (CBFP, 2005). The MLW Landscape was defined in 2002 by the Congo Basin Forest Partnership (CBFP), a consortium of national governments and international and national non-governmental organizations as one of twelve priority Congo Basin landscapes targeted for the establishment of land-use management plans (CBFP, 2005). A highly collaborative process among stakeholders has already produced a preliminary land use plan covering 70% of the MLW Landscape (Dupain et al., 2009). The types of macro-zones being defined in the landscape consist of community-based natural resource management areas (CBNRMA), protected areas, logging concessions, and a Rural Development Zone (RDZ). Land use planning activities in MLW have been recognized by the DRC Government as a pilot model for the creation of a national-level planning strategy (USAID, 2010).

We employed a spatial allocation decision support tool called Marxan (Ball and Possingham, 2000; Possingham et al., 2000) to generate options for delineating the most suitable land for inclusion in the proposed RDZ in the MLW Landscape. The RDZ is a macro-level zone designated for the controlled expansion of agricultural activities under a management plan (Sidle et al., 2012). It is intended to contain deforestation from slash-and-burn activities, reserving surrounding forests for the collection of non-timber forest products (e.g. bushmeat, fuelwood, fruits and medicinal plants) and for biodiversity conservation.

Given a set of assumptions about population growth and agricultural expansion derived from both population and land cover change data, we employed Marxan to develop a series of potential scenarios for human and agricultural expansion for 2050 to guide stakeholders and assist decision-makers for MLW macro-level planning activities. 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 biological conservation.

2. Methods

2.1. Study area

The MLW Landscape spans 72,000 km^2 in northern DRC and comprises several land use and land cover types, including 68% moist dense equatorial evergreen forest, 25% swamp forest, and 5% agriculture (Fig. 1). It has a relatively low human population density (approximately 3–5 inhabitants per square kilometer (CBFP, 2006)). Human populations are settled along roads and navigable rivers, and agricultural areas extend from the roads outward into the forest. Agricultural activities are predominately subsistence-based, and slash-and-burn practices are used to cultivate crops such as cassava, maize, and peanuts. Being remote and relatively inaccessible, MLW has historically experienced a relatively low deforestation rate. During 2000–2010, the deforestation rate was 0.45% in MLW and 1.03% in DRC (Nackoney and Williams, 2012). In the absence of commercial logging, deforestation is due mostly to small-scale agricultural activities. The landscape therefore still maintains large tracts of intact forests that are of high conservation value to a range of terrestrial species.

The bonobo (*Pan paniscus*), a great ape 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 approximately 500,000 km^2 range. Bonobos primarily use areas consisting of primary forest for sleeping and nesting, and swamp and secondary forests for foraging (Hashimoto et al., 1998). Habitat loss and hunting are their greatest threats, the latter being the primary contributor to their endangered status (IUCN, 2010). In the MLW Landscape, both of these activities threaten the bonobo; expansion of agricultural activities into the primary forest degrades bonobo habitat and increases hunting accessibility and is being monitored in areas where biological surveys have confirmed bonobo presence. Overall, the bonobo's endemism, requirement of large tracts of less-disturbed forest, vulnerability, and flagship species value argue for it being a focal species for conservation in the MLW Landscape.

2.2. 2050 Agricultural reserve design

Numerous studies have employed optimization models for rural land allocation such as Meyer-Aurich et al. (1998), Raja et al. (1997) and Roetter et al. (2005) using linear programming and employing various agricultural data (labor, fertilizer use, productivity, etc.). Due to the absence of such spatially explicit agricultural data for MLW, our methods were derived from a purely land cover and land use perspective based on human population growth and historical primary forest conversion rates.

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 and Klein, 2008). The freely available tool is known by conservation practitioners for its flexibility (it can be used within a variety of different front-end software packages, including ESRI ArcGIS), its accommodation of spatially explicit data, its use of a powerful simulated annealing algorithm that arrives at alternative solutions relatively quickly, and its training programs and free online support (Ball et al., 2009). Although our particular application of Marxan is somewhat unconventional (it is commonly used for the identification of marine reserves and protected areas), we chose it for this research for its direct relevance to our optimization problem.

To create the optimization models, we first defined our objective, or "target," as the projected amount of agricultural land needed to satisfy agricultural livelihoods in the landscape by 2050 (detailed in Section 2.4). Next, we assigned each planning unit a value describing its "cost," which is minimized by Marxan's objective function. *Cost* is a relative term that describes any number of measures, including socio-economic costs or land protection opportunity costs (Richardson et al., 2006; Wilson et al., 2005) and represents a range of values assigned to the planning units to control their relative suitability for selection. Our costs were based on the prevalence of factors determining relative suitability for future agricultural expansion, including the intensity of human activity

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