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Impacts of civil conflict on primary forest habitat in northern Democratic Republic of the Congo, 1990–2010

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ABSTRACT

War and civil conflict have been shown to contribute directly to increased wildlife poaching and environmental degradation, especially in developing countries. The Democratic Republic of Congo (DRC) suffered heightened political instability that intensified during its first (1996–1997) and second (1998–2003) civil wars. Ground-based observations reported severe impacts on wildlife from increased human reliance on bushmeat as well as evidence of human populations moving deeper into interior forests to escape conflict. Both were observed in the study area comprised of forests in and around Luo Scientific Reserve located in northern DRC, where studies on wild bonobos (*Pan paniscus*) have been conducted since 1973. Using Landsat TM and ETM + satellite imagery, we employed an automated classification tree algorithm developed specifically for Central Africa to monitor wartime patterns of human migration and resource use in the study area. We analyzed and compared primary forest loss and degradation rates across two decades (1990–2010). Annual rates of primary forest loss occurring during the 1990–2000 decade were over double the rates of the mainly post-war 2000–2010 decade, indicating higher human pressure on the forests during wartime. Maps and analyses of peripheral forests occurring around the edges of forest clearings illustrated an increased prevalence of small, scattered clearings during the war. We also found evidence showing there was likely less human pressure on interior forests after the wars ended. We demonstrate the utility of satellite-based remote sensing techniques for monitoring human access in interior forests and examining wartime links to observed declines in wildlife.

1. Introduction

Between 1996 and 2003, the Democratic Republic of Congo (DRC) experienced two devastating wars that collapsed its formal economy and caused 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). The largest country in Central Africa, the DRC comprises about half the area of the Congo Basin rainforest (Wolfire et al., 1998). It serves as critical habitat for a wealth of faunal species including large mammals of conservation concern like the forest elephant (*Loxodonta africana*) and three types of great apes: the endangered (IUCN, 2013) eastern chimpanzee (*Pan troglodytes schweinfurthii*), the endemic and endangered (IUCN, 2013) Grauer's gorilla (*Gorilla beringei grauer*), and the endemic and endangered (IUCN, 2013) bonobo (*P. pansiscus*). War and civil conflict have been shown to contribute directly to increased wildlife poaching and environmental degradation (Westing, 1992; Blom et al., 2000; Dudley et al., 2002; Yamagiwa, 2003). In developing countries such as DRC, much of this is caused by displacement of human populations who seek refuge in nearby forested areas and are forced to rely more heavily on their natural surroundings for food and shelter (Dudley et al., 2002; Hanson et al., 2009). Increased access to formerly remote forested areas and local proliferation of arms during wartime often contribute to a rise in wildlife poaching, especially when lawlessness and poverty are prevalent and there is a disruption in normal village trade (Dudley et al., 2002; Draulans and Van Krunkelsven, 2002; McNeely, 2003).

1.1. Environmental impacts of civil conflict in DRC

Wildlife poaching was especially severe during the DRC wars. De Merode and Cowlishaw (2006) found that the sale of protected species as bushmeat in urban markets located near their field site in Garamba National Park in northeastern DRC increased by 23%

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during the war, with observed increases in sales of larger species such as elephant, hippo, and buffalo. Another study found that forest elephant densities in the Okapi Faunal Reserve (located in eastern DRC) decreased by half during the wars, from 0.47/km^2 to 0.24/km^2 due to increased poaching (Beyers et al., 2011). Yamagiwa (2003) found that half of the gorilla population in the Kahuzi-Biega National Park, also located in eastern DRC, was killed for bushmeat during the war. Bonobos were also greatly affected during the DRC wars. About one-third of the wars' main frontline, where most of the fighting occurred, cut through the center of the bonobo range (Draulans and Van Krunkelsven, 2002). Increased incidences of bonobo poaching were reported in Vogel (2000), Reinartz and Inogwabini (2001), and Furuichi et al. (2012), among others. Draulans and Van Krunkelsven (2002) 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.

Internal displacement of human populations in DRC as a result of the conflicts that began in the 1990s continues to be an issue of concern today (Zeender and Rothing, 2010). Internally displaced people peaked at 3.4 million toward the end of the second war in 2003 (Faubert, 2006). Although many are now returning to their natal villages, around 2.7 million are still displaced, though the majority of this is due to continued conflict in eastern DRC (OCHA, 2012). During the wars, Draulans and Van Krunkelsven (2002) observed human populations taking refuge in interior forests to escape conflict with soldiers. This particular type of human displacement can put substantial pressure on surrounding natural environments, not only because of increased instances of hunting and poaching as explained above, but also due to forest degradation resulting from the creation of small-scale agricultural clearings and temporary camps. The effects of clearings on species composition and forest structure, and their contribution to altered habitat around forest edges, known as edge influence, have been widely studied (Chen et al., 1995; Laurance et al., 2002; Harper et al., 2005; Laurance et al., 2007). Edge influences can cause micro-climatic differences that lead to drier forests (Chen et al., 1992), reduced soil moisture (Denslow, 1987) and contribute to overall degradation of interior forests (Wickham et al., 2007). Resource extraction by humans increase forest edges and make previously undisturbed forests more vulnerable to hunting (Laurance et al., 2000; Peres 2001).

1.2. Forest monitoring and objective

Satellite image interpretation has been used as a timely, objective, cost effective, and verifiable means to monitor humanitarian violations (Bjørn, 2000; Prins, 2008; Bromley, 2010), presence of refugee camps (Lang et al., 2010; Hagenlocher et al., 2012) and environmental degradation (Lodhi et al., 1998; Suthakar and Bui, 2008; Witmer, 2008; Stevens et al., 2011; Gorsevski et al., 2012) in remote locations during wartime. Witmer (2008) and Gorsevski et al. (2012) discussed the use of satellite imagery to capture both the *direct* (i.e., physical landscape) impacts of civil conflict as well as the *indirect* impacts that may result in changes in land use caused by displaced human populations and their associated environmental consequences, two components covered by this research.

We used the Luo Scientific Reserve and adjacent Iyondji Community Bonobo Reserve (both located in Equateur Province in northern DRC) as a case study to investigate both the direct impacts of DRC's wars on land cover and land use, and indirect impacts of the wars on primary forest habitats for species such as the bonobo, a flagship species for this particular geographic area and that depends on large tracts of undisturbed forest. To do this, we employed a twenty-year spatio-temporal analysis (1990–2010) of land use and land cover change using satellite image interpretation. We quantified and mapped both the rate of primary forest loss and the increase in peripheral (edge) forests that occurred both during war and non-war periods in order to investigate the degree that civil conflict affected human migration and resource use patterns. We hypothesized that the wars increased deforestation and promoted greater human access to remote forested areas in this region, patterns that were likely consistent for other forested regions of DRC. The research will contribute to an increased understanding of the effects of DRC's wars on deforestation and degradation of core primary forest habitats as detected and monitored by satellite.

2. Methods

2.1. Study area

The study took place in Luo Scientific Reserve (referred hereafter as "Luo SR") and the Iyondji Community Bonobo Reserve (referred hereafter as "ICBR") located in Equateur Province in northern DRC (centered at 0°02′N, 22°35′E) (Fig. 1). Approximately 81% of the study area consists of both primary and old secondary lowland rainforest, while 17% is comprised of swamp forest. The total area of the study site is 1510 km^2 (Luo SR extends approximately 480 km^2 to the northwest, while ICBR extends approximately 1030 km^2 to the southeast). The northern part of Luo SR contains a roughly 21 km^2 stretch of agricultural complexes and young secondary forest (almost 2% of the study area) surrounding a road, shown in Fig. 1. This area contains about six homesteads and supports a local population of approximately 6500 people. Small hunting camps are scattered in the southern part of the reserve.

Luo SR was officially recognized in 1992 by the DRC Ministry of the Environment. A management plan allows local communities to live within its boundary and abide by certain land use policies. The members of these communities are allowed to hunt animals other than primates using traditional means, but they are not allowed to hunt primates or hunt or trap other animals using guns, poison arrows, or metallic snares (Kano et al., 1996; Idani et al., 2008; Furuichi et al., 2012). The management plan also disallows the creation of new agricultural fields for commercial products in the primary forest area, although the re-use of fields and the creation of new fields for cassava or other subsistence products is allowed within 1 km from the road in the north. Since the formal creation of the reserve and its management plan, the bonobo research team and Centre de Recherche en Ecologie et Forestrie (CREF) of the DRC Ministry of Scientific Research have been supporting local community development, including provision of support for local schools and medical services, in order to compensate for the limitations regarding forest use. ICBR was recognized as a Community Reserve by the DRC Government in April 2012 (Sakamaki et al., 2012; Dupain et al., 2013). It was therefore not under any sort of protection or management plan during the course of the dates studied in this research. Because it has been so recently established, a community-based natural resources management plan, which will regulate usage of the ICBR forests, is still being formalized.

2.2. Period of civil conflict in Luo SR and ICBR

A distinctive quality of Luo SR is that it can be considered to contain several of the longest and most consistently studied bonobo populations in the world (bonobo populations living there have been studied and monitored since 1973). The study area has therefore produced a wealth of historical data on bonobos, including research on the impacts of DRC's war on the populations living