



Research article

Using spatial metrics and surveys for the assessment of trans-boundary deforestation in protected areas of the Maya Mountain Massif: Belize–Guatemala border

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ABSTRACT

Understanding the trans-boundary deforestation history and patterns in protected areas along the Belize–Guatemala border is of regional and global importance. To assess deforestation history and patterns in our study area along a section of the Belize–Guatemala border, we incorporated multi-temporal deforestation rate analysis and spatial metrics with survey results. This multi-faceted approach provides spatial analysis with relevant insights from local stakeholders to better understand historic deforestation dynamics, spatial characteristics and human perspectives regarding the underlying causes thereof. During the study period 1991–2014, forest cover declined in Belize's protected areas: Vaca Forest Reserve 97.88%–87.62%, Chiquibul National Park 99.36%–92.12%, Caracol Archeological Reserve 99.47%–78.10% and Colombia River Forest Reserve 89.22%–78.38% respectively. A comparison of deforestation rates and spatial metrics indices indicated that between time periods 1991–1995 and 2012–2014 deforestation and fragmentation increased in protected areas. The major underlying causes, drivers, impacts, and barriers to bi-national collaboration and solutions of deforestation along the Belize–Guatemala border were identified by community leaders and stakeholders. The Mann-Whitney *U* test identified significant differences between leaders and stakeholders regarding the ranking of challenges faced by management organizations in the Maya Mountain Massif, except for the lack of assessment and quantification of deforestation (LD, SH: 18.67, 23.25, $U = 148$, $p > 0.05$). The survey results indicated that failure to integrate buffer communities, coordinate among managing organizations and establish strong bi-national collaboration has resulted in continued ecological and environmental degradation. The information provided by this research should aid managing organizations in their continued aim to implement effective deforestation mitigation strategies.

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1. Introduction

Literature attributes significant merits to trans-boundary protected areas, such as socio-economic development, the promotion of cooperation and peace and conservation (Trillo-Santamaría and Paül, 2016). However, in much of the developing world, forests outside and within trans-boundary areas are threatened by complex, interconnected drivers such as agricultural expansion and

forest degradation (Tejada et al., 2016). These drivers may be hard to control; especially in trans-boundary areas. Deforestation drivers might originate in and adjacent country where environmental laws, enforcement capabilities and socio-economic pressures differ (McCallum et al., 2015). It is therefore urgent to balance trade-offs between human needs and ecosystems integrity in tropical forests of developing countries (Brandt et al., 2016).

The Belizean–Guatemalan trans-boundary protected area system presents unique management challenges for both nations. Deforestation along the Belize–Guatemala border has been a persistent issue for the past 30 years, and continues today (The Belize Times, 2015; Rath, 2016). In each country, deforestation is caused by complex, interconnected socio-economic problems that

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manifest and interact in the border-adjacent protected areas. In Guatemala, population growth, economic development and agricultural expansion have depleted most of the forest in the Montañas Mayas Biosphere Reserve (MMBR) (Coca et al., 2012; Carr, 2000). Local organizations have teamed with government through CONAP to provide protected areas management in the Guatemalan border area. However, their efforts have not been able to stop illegally entering Belize and forest degradation on both sides of the border. In Belize, a lack of population along the border, the relative remoteness of the area and insufficient resource allocation to management has left Belize's protected areas vulnerable to trans-boundary incursions (Bridgewater et al., 2006; Salas and Meerman, 2008). These incursions from Guatemala into Belize have resulted in deforestation, environmental degradation, illegal natural resource extraction and illegal semi-permanent agricultural settlements. Because the border area of Belize is largely unpopulated and remote, natural resource protection enforcement is challenging. Therefore natural resources in Belize have been left largely unguarded despite their financial, ecological and aesthetic values. In order to understand the dynamics of the deforestation process, stakeholders' perspectives and generate historical deforestation rates along the Belize-Guatemala border it is necessary to undertake a multidisciplinary approach and incorporate multi-temporal deforestation rates, surveys and spatial metrics.

Spatial metrics are algorithms that measure spatial characteristics of class patches, landscape patches, or entire landscape mosaics (Zaragozı et al., 2012). Spatial metrics have been used to plan strategically for environmental management, to quantify ecological processes, to measure and monitor landscape change, to study the effects of society on landscape, and to examine habitat fragmentation (Bailey et al., 2007; Zhou and Li, 2015). Information derived from spatial metrics can describe the structure and pattern of a landscape, lending information about socio-economic circumstances (Tang et al., 2008). And also spatial metrics ability to quantify changes in class patch characteristics as a result of land use changes and human behavior can be useful in assessing a landscape process; such as deforestation (Jiao et al., 2012).

This issue of illegal trans-boundary incursions is exacerbated by surging demand for resources in Guatemala. Incursions continue given the insufficient enforcement on both sides of the border and lack of bi-national collaboration. Research and advocacy has again largely been left to NGOs on both sides of the border, which to their credit, work very hard and effectively with few resources. Organizations are under pressure to quantify deforestation along the border, and to make the case to their respective governments and the world for more resource allocation. Through this research we seek to improve the historic knowledge-base regarding deforestation in Belize's protected areas along the Belize-Guatemala border utilizing multi-temporal deforestation rates and spatial metrics. Also, this analysis is supplemented with data generated by surveys of key stakeholders within the protected areas management community in Belize to better understand their perspective regarding deforestation along the border. The information provided by this research should aid managing organizations in their continued efforts to improve deforestation mitigation strategies along the border.

2. Study site

The study site includes an 81 km long by 6 km wide section of the Belize-Guatemalan "Western Border". The study site includes several protected areas within the Maya Mountain Massif (MMM); Vaca Forest Reserve (VFR), Chiquibul National Park (CNP), Caracol Archeological Reserve (CAR) and Columbia River Forest Reserve (CRFR) (Fig. 1). The MMM has no permanent Belizean settlements

and shares a border with Petén, Guatemala. In Guatemala there are numerous settlements along the border allowing easy access to protected areas in Guatemala and Belize. The ecosystem types found in the study area are mostly variants of tropical broadleaved forests, and aquatic ecosystems. Geologically, the study area was formed by geological uplifting and consists of sandstone, granite, limestone, and volcanic rock (Salas and Meerman, 2008). The MMM contains steep slopes with a maximum elevation of 1124 m above sea level. Historically, the study area's remote locale provided a buffer against over-exploitation; but since the mid-nineties settlements along the border and incursions from Guatemalans have significantly degraded biological and cultural resources (UNEP, 2011). Guatemalan communities buffering the Belize-Guatemala border have created a complex trail system to conduct subsistence agriculture and access resources inside the protected areas within the MMM (Salas and Meerman, 2008).

Conversely, access into the MMM from Belize is limited due to absence of roads and trails. Population growth, climate change, poverty and land degradation processes continue to cause environmental quality decline within the study area.

2.1. Background

Over the previous decades, many tropical countries have established protected areas to safeguard their natural resources (Chiaravalloti et al., 2015; Morales-Hidalgo et al., 2015), Belize and Guatemala are no different. In Belize, protected areas account for 36% of national territory (Meerman and Cherrington, 2005), the highest percentage in the region. Guatemala's protected areas account for 27% of Guatemala's national territory (The Nature Conservancy, 2016). As Belize's and Guatemala's economies and populations grow at annual rates of 2.7% and 2% (World Bank, 2016), demand for land and natural resources continues to increase. This pressure, coupled with simultaneous threats from climate change, poverty, and environmental decline strains Belize's protected areas (Young and Horwich, 2007). Protected areas managers have long engaged local communities adjacent to protected areas in order to achieve conservation objectives (Buta et al., 2014; Pietrzyk-Kaszyńska et al., 2012). However, adjacent communities' attitudes towards protected areas depend on a number of complex factors pertaining to access and resources rights which may govern losses and gains in their livelihood (Kelboro and Stellmacher, 2015). These factors coupled with socio-economic, policy, institutional frameworks and political differences between Belize and Guatemala make bi-national cooperation and co-management challenging.

Over the past 20 years, a host of studies attributed the increase of deforestation in Petén, Guatemala to internal Guatemalan migration, local population growth, landlessness, poverty, depletion of forest resources and unsustainable agricultural practices (Shriar, 2014). There is a clear timeline correlation between internal Guatemalan migration, population growth in Petén, and deforestation in Belize-Guatemala border area. According to Shriar (2014) in 1970, 70–80% of Petén was densely forested. By the late 1990s, half of it had been cleared. This study's results support the deforestation timelines proposed by Carr (2009) and Brooks et al. (2002), which indicate escalating deforestation in the late nineties and aughts. Much of this timing can be explained by socio-economic circumstances and political events in Guatemala that have encouraged internal migration and agricultural expansion (Shriar, 2014).

The increasing deforestation during the 1990s, particularly in Petén, was caused by a wave of internal migration, from more populated regions of Guatemala to Petén (Gómez and Mendez, 2005). There were several causes for this human migration. First,

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