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Assessing deforestation and fragmentation in a tropical moist forest over 68 years; the impact of roads and legal protection in the Cockpit Country, Jamaica

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ABSTRACT

Historical data on landuse changes are important for interpreting the current status of natural systems such as forests. Analyses of road network dynamics can be particularly useful as network expansion is often a precursor to and an indicator of increased human activity. Legal protection is often seen as the most viable option available for protecting natural forests; but over the past decade, its effectiveness has been questioned. We assessed the impact of roads and the designation of a forest reserve on deforestation and forest fragmentation in a tropical moist forest, Cockpit Country, Jamaica, from 1942 to 2010. Specifically, we classified multi-temporal images (black and white aerial photographs, IKONOS and GeoEye images) using an object based image analysis and we included a vector of digitized roads for each year of assessment during the classification process. We then conducted a fragmentation analysis of the classified images and assessed the relationship between road density and several fragmentation metrics over time, and the spatial influence of the reserves (presence/absence) and roads (Euclidean distance from roads) on deforestation and several fragmentation metrics using generalized linear models.

Between 1942 and 2010, road density nearly doubled (from 0.67 km/km^2 to 1.22 km/km^2), with significant increases occurring within forest reserves, and was significantly related to the area-weighted mean shape index of the forest (forest patches became more regularly shaped and linear). Initially, relatively high deforestation rates and high levels of fragmentation between 1942 and 1961 were likely related to the large increase in road density. Deforestation and forest fragmentation were more likely to occur closer to roads over all time periods, and the magnitude/significance of this relationship peaked in subsequent time periods after road density doubled; but in the final time period, its influence declined. Legal protection afforded to the forest in the 1950s and 1960s coincided with an increase in total and core forest area and a reduction in deforestation rate, and deforestation and forest fragmentation were significantly lower inside the reserve. Therefore, the Forest Reserves were initially effective; however, their effectiveness waned after 1980. Increased deforestation and fragmentation in the 1980s and the 2000s indicate a more complex pattern of human encroachment, as these changes do not appear to have been influenced by changes to the road network, or by the presence of the Forest Reserves. Further research into the factors influencing human use of these forested areas is needed for effective management of the area.

1. Introduction

Roads have several deleterious effects on forest systems, including direct mortality of forest species from road construction and vehicle collisions (Goosem, 2007), modification of normal animal behaviour (e.g. road avoidance), (Laurance et al., 2004), facilitated introduction of invasive exotics and pathogens (Forman and Deblinger, 2000; Goosem, 2007), and habitat degradation due to chemical pollution, increased soil erosion and stream sedimentation (Forman and Deblinger, 2000). The construction of new roads also results in division of large areas of forest into smaller patches with altered shapes, creation of high-contrast edge habitats, and reduction in landscape connectivity for specialist species (Reed et al., 1996; Hawbaker et al., 2006; Goosem, 2007).

Fragmentation of the landscape may have severe consequences for forest biota, including loss of viable habitat for area-sensitive animal species and shade-tolerant plant species (Mendoza et al., 2005), increased competition from generalist species (Laurance et al., 2009), and genetic isolation of sub-populations (Goosem,

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2007), all of which may ultimately result in local extinctions of native, forest-dependent species (Laurance et al., 2009). However, while much recent research attention has focussed on the effects of roads on natural forest systems, relatively few studies have considered the dynamics of road networks and the impacts of changes in these networks on forest landscape structure (exceptions include Hawbaker et al., 2006, and Ahmed et al., 2013).

Road network expansion is often unavoidable. Roads connect people to resources and markets and are therefore essential for economic development (Wilkie et al., 2000; Hawbaker et al., 2006). On an international scale, road density is strongly correlated with higher gross national product (Wilkie et al., 2000). Resource managers, particularly those in developing countries, have a difficult task balancing the necessities of infrastructure development and natural resource conservation. Thus, roadless forest areas have become increasingly rare, leading to growing concerns over the conservation of remaining areas (Hawbaker et al., 2006; Laurance et al., 2009). Road construction in forest systems is seen to have a "Pandora's box effect" (Laurance et al., 2009), in which access to adjacent areas are inadvertently provided, facilitating human colonization and land use changes. This in turn leads to increased infrastructure demand and increased human access to forested areas. (Hawbaker et al., 2006; Laurance et al., 2009).

Where roads do exist in forested landscapes, it is therefore useful to monitor changes to the network over time and to assess the impacts of any changes on the natural system. Some assessments of forest extent and spatial configuration have incorporated roads (e.g. Miller et al., 1996; Reed et al., 1996; Tinker et al., 1998) but few have considered changes over time (Hawbaker et al., 2006). Hawbaker et al. (2006) highlighted the need for historical analyses of landscape changes including changes to road networks using, for example, aerial photographs. The use of such historical data is important for the development of conservation strategies and effective land management policies (Swetnan et al., 1999). Outside of their application to assessments of road effects, studies of historical land use patterns have demonstrated the long-term effects of past anthropogenic impacts (e.g. Thompson et al., 2002), the resilience of some tropical forests to disturbance (e.g. Foster et al., 1999), the conservation importance of secondary or re-growth forests (e.g. Pascarella et al., 2000), and the fallacy of a priori assumptions of increasing degradation in natural landscapes (e.g. Lunt and Spooner, 2005). Historical data have been used to correct false forest histories/land use narratives and explain failed policies and management strategies (Fairhead and Leach, 1995). Yet historical arguments are often ignored in favour of static or short-term models of changes in landscape pattern (Foster et al., 1999; Lunt and Spooner, 2005; Hawbaker et al., 2006).

In this study we use historical data (1942–2010) to assess landscape changes in the Cockpit Country, Jamaica – the largest and most intact wet limestone forest area on the island, and a biodiversity hotspot of international importance (Eyre, 1989, 1995; Davis et al., 1997). There has been much disagreement on the levels of deforestation and human encroachment, particularly within areas of interior forest that have been afforded legal protection by being designated as Forest Reserves since the 1950s and 1960s. Additionally, the effectiveness of protected areas has been called into question over the past several years (Chai et al., 2009; Porter-Bolland et al., 2012). Roads have been identified as major contributors to forest conversion and degradation, even within forest reserves (Proctor, 1986; Eyre, 1995, 1996), and have been targeted in proposed conservation strategies for the area. To date however, the direct impacts of roads on the forest system have not been investigated, and in general, the area is largely understudied.

Consequently, we investigated long term changes in the Cockpit Country forest using remotely sensed images (aerial photographs and satellite images) and map/GIS data. Specifically, we sought to (1) assess changes in road density over time within the interior forest/forest reserve areas, (2) assess changes in forest spatial extent and configuration of the study area and the reserves, and (3) determine how much of the changes in forest extent and landscape structure can be explained by changes in the road network and by the establishment of the forest reserve. We hope this research will assist in guiding future conservation of this vulnerable area and add to the growing body of knowledge on the impacts of roads on forest fragmentation and the effectiveness of legal protection – particularly in tropical forested landscapes.

2. Materials and methods

2.1. Study site

The Cockpit Country, located in west central Jamaica, West Indies, is the global type locality for "cockpit karst" limestone, developed through the erosion of a highly permeable white limestone plateau. The resulting topography consists of steep sided conical hills (with 30–40° slopes in some areas) and bowl-shaped depressions ca. 150 m deep and 1 km in diameter (Barker and Miller, 1995; Miller, 1998). Elevation ranges from approximately 200 m in the north to a maximum of 600 m in the south (Eyre, 1989). Annual rainfall for a ten year period (1994–2004) ranged from 1100 mm to 2400 mm (The Meteorological Service of Jamaica), though Proctor (1986) reported mean rainfall to be 1900–3800 mm. The Cockpit Country aquifer and rivers contribute 40% and 25% respectively of the island's exploitable groundwater and surface water. There are no true geo-political boundaries for the area. Our study area (Fig. 1) is a proposed conservation area with a largely uninhabited forest area bounded by several communities and their associated road network along its periphery. The 68,024.40 ha area is mostly enclosed by the so-called "Ring road" constructed by British colonialists in the 18th century (Eyre, 1989). Other roads in the area are also centuries old, including the Burnt Hill-Barbeque Bottom Road that transects the forest. Road construction in the forests has been mostly constrained by the very rugged terrain. However in the 1980s conservationists noted with alarm extensions of roads leading to the forest interior near its southern edge (Proctor, 1989; Eyre, 1995, 1996). Conservationists have viewed this expensive construction through tower karst as unnecessary and likely politically motivated (Eyre, 1996).

Approximately 30,070.35 ha of the study area were designated Forest Reserves in the 1950s, and a further 1,207.27 ha were included as Forest Reserves in the 1960s. There are presently 17 individual reserve areas. These reserves, managed by the Forestry Department, are the main means of legal protection for the Cockpit Country's forest. The wet limestone forest, considered to be one of the most globally important sites for plant diversity (Davis et al., 1997), is known to contain at least 400 Jamaican endemic plant species and at least 101 Cockpit Country endemics (Proctor, 1986). The forest provides habitat to several forest-dependent, rare and endangered faunal species. Forest clearance is typically for agriculture and commercial logging which has occurred mostly in the cockpit depressions, but has also been observed on hilltops and steep slopes (Eyre, 1989; Barker and Miller, 1995; Miller, 1998). Agricultural production primarily involves cultivation of yams (*Dioscorea* sp.), and this is the major economic activity of the area's inhabitants. Cleared areas are sometimes later abandoned and allowed to revert to bush fallow, or may be used as cattle pasture (Barker and Miller, 1995). The forests have also been degraded by selective removal of trees by loggers and of saplings for use in yam cultivation (Eyre, 1989; Barker and Miller, 1995; Barker, 1998; Miller, 1998).