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Long-term socio-economic and spatial pattern drivers of land cover change in a Caribbean tropical moist forest, the Cockpit Country, Jamaica

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ABSTRACT

Very little research has considered the underlying drivers of land cover change in Caribbean islands, particularly in those islands that are still experiencing a net loss of forest cover. We investigated the underlying driving forces (socio-economic drivers) and spatial pattern drivers (biophysical features) of both deforestation and reforestation in the Cockpit Country, Jamaica. This area is one of the most globally important sites for plant diversity, but is threatened by clearance for small-scale agriculture. Drivers of change were assessed for both the individual time steps within the study period (1942–2010) and for the entire 68 years using multivariate, spatially explicit, statistical models. The primary drivers of deforestation over the study period were accessibility (gentler slopes, closer to forest edges, more fragmented forests) and greater relative wealth/socio-economic status (increased access to piped water). Reforestation generally increased closer to forest edges and in areas with lower market access (greater distances to roads and towns) and lower wealth/status (increased reliance on pit latrines). We found considerable temporal variation among the most important drivers for each time step, including climate, employment status, population density, population age structure and relative wealth. Forest reserve status was not a key determinant of deforestation but did increase the probability of reforestation between 1961 and 1980. During the final time step (2001–2010) access was less important as a deterrent to deforestation, which increased within the most contiguous forest blocks. If the deforestation drivers of the last decade do not change, deforestation is predicted to occur within the forest reserves, and in the largest, least fragmented forest blocks. Thus, conservation and management strategies for our study site must seek to address issues related to both enforcement and the socio-economic factors that influence deforestation and habitat fragmentation.

1. Introduction

Human-induced changes to natural landscapes constitute the main driving forces of land cover change at local, regional and global scales (Walker et al., 2004; Etter et al., 2006b; Wyman and Stein, 2010). They have been shown to contribute to climate change, biodiversity loss, and alteration of biogeochemical and hydrological cycles (Chowdhury, 2006a,b; Bradshaw et al., 2009). The importance of these processes, particularly in species-rich tropical developing countries, has prompted international efforts to identify the drivers of land cover change so as to mitigate the negative effects and promote desired outcomes (Mertens and Lambin, 1997; Irwin and Geoghegan, 2001; Munroe et al., 2004; Walker et al., 2004; Müller et al., 2011). These drivers are generally classified as either proximate causes (human physical actions that directly alter the landscape) or underlying driving forces (the socio-political, economic and cultural forces that underpin the proximate causes) (Geist and Lambin, 2001). A third group of factors termed "spatial pattern drivers" (Echeverría et al., 2006; Mitsuda and Ito, 2011) are the biophysical characteristics of the landscape, which are neither the root causes nor the direct human actions that result in land change, but instead are the determinants of *where* changes will occur. Importantly, these direct and indirect causal factors have several interlinking and feedback relationships, and operate at a number of different spatial scales or levels of aggregation (Geist and Lambin, 2001; Lambin et al., 2003; Lambin and Meyfroidt, 2010).

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At a global scale, tropical forests are cleared primarily for agricultural expansion, but also for wood extraction and infrastructure extension (Geist and Lambin, 2001). Five categories of underlying driving forces have been recognized, which influence decisions to clear or convert these forests (Geist and Lambin, 2001). The most important of these are economic factors, including market growth and commercialization, urbanization, industrialization, and relative wealth/poverty. The relative importance of the remaining factors has varied from region to region. These other categories include institutional or policy-related, technological, cultural and demographic factors. Within Latin American forests, where the bulk of the research on land cover change drivers has occurred (Kaimowitz and Angelsen, 1998; Geist and Lambin, 2001), environmental, demographic and socio-economic variables have been key explanatory factors of land cover change, including suitability of soils for agriculture, rural-urban migration, relative wealth and living standards, levels of unemployment and global demand for food (Geist and Lambin, 2001; Aide et al., 2013). Regional-scale studies have found that during the last decade, areas at lower elevations and at earlier stages of economic development were more susceptible to deforestation, while reforestation was more likely in more developed countries, and in areas where there was less rainfall, higher temperatures and steeper slopes (Aide et al., 2013; Redo et al., 2012).

Despite the concentration of land cover change studies from the Latin American region, drivers of change in Caribbean islands have been largely understudied. Caribbean island forests are vitally important due to their high plant endemism, function as watersheds and contribution to the tourism product and other economic activities in several developing states (FAO, 2010). The most recent general trend for the Caribbean has been increases in forest cover (Helmer et al., 2008; FAO, 2010; Aide et al., 2013); and most published studies of drivers of land use change have focussed on Puerto Rico, which has been experiencing net reforestation for the past six decades (e.g., Helmer, 2004; Crk et al., 2009; Yackulic et al., 2011). Much of this change has been attributed to abandonment of agricultural plots at the proximate level, and at the underlying level, to economic development and establishment of protected areas (Lugo et al., 1981; Helmer et al., 2008; Aide et al., 2013). In contrast, very little research has been conducted on the underlying drivers of land use change in the islands that continue to experience net forest loss.

Jamaica has reported high rates of deforestation and net losses in forest cover since at least the 1980s (Eyre, 1987; Evelyn and Camirand, 2003). Between 2001 and 2010, the island experienced the greatest reduction in area of woody vegetation of the Caribbean region (Aide et al., 2013). Despite this, few studies have addressed drivers of deforestation in Jamaica – and even fewer have considered factors that could influence forest recovery. Indeed only two known studies, Tole (2001, 2002), employed quantitative empirical research to identify socio-economic drivers of island-wide deforestation. The author showed that for the period 1987–1992, deforestation in Jamaica was significantly related to age structure and dependency (i.e., the ratio of dependents to economically active adults) and indicators of deprivation, including fuelwood dependency and low education levels (Tole, 2001, 2002). However, such national scale studies of land use change, while useful, provide limited information about the driving forces operating at the local level – the scale at which land cover transformation is actually occurring (Etter et al., 2006a,b; Campos et al., 2012). Data aggregation at larger geographic scales can lead to false conclusions about the factors influencing the agents of change (Turner et al., 1994; Serneels and Lambin, 2001; Etter et al., 2006a). Local-level studies better inform conservation planning by providing more realistic and accurate estimates of the impacts of social, political and economic trends, as well as changes to the physical landscape, both of which influence the choices of local land users (Turner et al., 1994; Verburg et al., 1999; Kaimowitz et al., 2002; Etter et al., 2006b; Campos et al., 2012).

Consequently, we aim to conduct the first known quantitative empirical analysis of local-level determinants of land use change in a Jamaican forested area. Our focus will be on both deforestation and reforestation in the Cockpit Country, the largest wet limestone forest on the island and an important centre of endemism. The primary proximate cause of deforestation in the Cockpit Country has been suggested in previous research to be forest clearance for small-scale agriculture (Proctor, 1986; Eyre, 1989, 1996; Barker and Miller, 1995; Miller, 1998; Newman et al., in preparation), but spatial data on possible proximate causes are not available. Furthermore, the underlying driving forces and the spatial pattern drivers have not been studied. The objectives of this study are, therefore, to: (1) identify the underlying socio-economic and biophysical factors that best explain the spatial patterns of both deforestation and forest re-growth, and (2) identify areas that are most likely to undergo land cover change in the near future. Specifically, we will use spatially explicit models to evaluate the relationships between changes in land cover and potential drivers of land use/cover change for the period 1942–2010. The analysis will therefore include data at more disaggregated spatial scales and over longer time periods than the previous Jamaican studies.

2. Study site

The study site (Fig. 1), located in west central Jamaica, is a proposed conservation area for Cockpit Country biodiversity. However, there are no true geo-political boundaries for the Cockpit Country, and several boundaries have been used for various purposes. Our study area encompasses 68,024.40 ha of a largely uninhabited forested area bounded by a degraded zone of agriculture and human settlements and their associated road network. Approximately 30,070.35 ha of the study area were designated forest reserves in the 1950s, and a further 1207.27 ha were included as forest reserves in the 1960s. There are presently 17 individual reserve areas (Fig. 1). These reserves, managed by the local Forestry Department, are the main means of legal protection for the Cockpit Country's forests, though the larger forested area has been proposed as a national park since the 1970s (Eyre, 1989), and even as a World Heritage Site since the late 1980s (Eyre, 1989, 1995).

The Cockpit Country is the type locality for "cockpit karst" limestone (Sweeting, 1958), characterized by steep sided conical hills (with 30° to 40° slopes in some areas) with humus-poor clay soils; and concave depressions up to 150 m deep and 1 km in diameter filled with bauxitic soils and rubble (Sweeting, 1958; Barker and Miller, 1995). Elevation ranges from approximately 200 m in the north to a maximum of 600 m in the south (Eyre, 1989). In the central core, rainfall may average 3800 mm (Proctor, 1986). Most of the rainfall is channelled to the subsurface, moving by slow vertical percolation through the cockpits to the limestone aquifer which occupies approximately 83% of the total area (Barker and Miller, 1995). This aquifer contributes significantly to the island's exploitable freshwater resources. 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, including 15 endemic frogs; over 100 species of land snails; 27 endemic birds, including the island's most endangered bird species, the Jamaican blackbird (*Nesopsar nigerrimus*); and several endemic butterfly species, including the largest butterfly species in the western hemisphere (and the second largest in the world) – the endangered giant swallowtail butterfly (*Papilio homerus*).