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Examining spatially varying relationships between coca crops and associated factors in Colombia, using geographically weight regression

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ABSTRACT

This article addresses the expansion of illicit crops (coca) and the associated socio-institutional and geographical drivers in Colombia between 2001 and 2008. The analysis is based on a Geographically Weighted Regression (GWR) models and shows that the relationships between the analyzed variables and the coca crops are not constant over space. Similarly, it is demonstrated that the factors commonly associated with the expansion of coca crops are not constant with respect to time, as changes can be seen between the years of the study (2001 and 2008). The article finds that the models that include the local reality offer the best way of understanding the factors associated with the expansion of illicit coca crops in Colombia, a fundamental step in the formulation of effective policies in the reduction of crops for illicit use (coca).

Introduction

The economic benefits generated by the illegal trafficking of natural resources create an incentive for illegal armed groups to take advantage of the adverse social, economic and institutional conditions that exist in some countries such as the Republic of Congo (coltan), Sierra Leone (diamonds) and Colombia (coca to produce cocaine). Most instances involving natural resources and violent conflicts are found in developing countries and particularly in areas with vulnerable populations, typically with a combination of illegal armed groups and weak government presence (Le Billon, 2001).

Coca is a traditional crop in many Andean countries (Matteucci & Morello, 2003; Timothy, 1981). However, since the 1970s, the production of coca has been increasingly focused on the manufacture of cocaine because of increased demand, principally from the United States and Europe (Guridi, 2002). In the last few decades, Colombia, Peru and Bolivia have been responsible for the bulk of coca leaf production. Peru was the principal producer of the coca leaf until 1997, when Colombia became the world's number one producer (UNODC, 2008).

In the literature, various factors have been identified as being linked to illicit crops, including the forced displacement of populations and violence (Díaz & Sánchez, 2004; Garcés, 2005; Vargas, 2005), poverty (Dion & Russler, 2008), corruption (Molano, 2004), land tenure (Fajardo, 2002, 2004), an abundance of land and inaccessible forests (Álvarez, 2003; Dávalos, Bejarano, & Correa, 2009; Dávalos et al., 2011), an absence of the state (Kalmanovitz & López, 2005; Molano, 2004; UNDP, 2003) and the institutional weaknesses of Colombian society (Thoumi, 2005a, 2005b, 2005c). Illegal armed groups take advantage of the absence of the state, creating their own rules (Rangel, 2000). Although it has been argued that violence and armed conflict in Colombia are factors that aid in the conservation of forests (Dávalos, 2001) and that isolation from traditional markets, low road density and therefore low accessibility have facilitated environmental protection (Ali, Benjaminsen, Hammad, & Dick, 2005; Chomitz & Gray, 1996; Rincon, Romero, Bernal, Rodriguez, & Rodriguez, 2006), these assumptions have changed with the expansion of drug trafficking. Inaccessibility and violence are no longer obstacles, but rather combine to facilitate the degradation of forests due to the illegal use of coca crops for cocaine production (Díaz & Sánchez, 2004; Jaramillo, Mora, & Cubides, 1989; Posada, 2009; Sánchez, 2007; Sánchez, Díaz, & Formisano, 2003).

This study examined the relationships between the expansion of illicit crops and several of the factors mentioned as drivers of this behavior in the literature. The study emphasizes the importance of local heterogeneity—a topic that has been largely overlooked in the

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literature on illicit crops. Specifically, answers are sought to the following questions:

Can models that incorporate local realities enable an improved understanding of the factors associated with the expansion of coca crops in Colombia?
Is it possible to make generalizations regarding the factors associated with the expansion of coca crops that are applicable to the entire country?
Are the types of relationships between illicit crops and the associated factors the same on the global and local levels? Are the relationships constant with respect to space (i.e., stationary)?
Are the factors commonly associated with the expansion of illicit crops constant over time?

The aim of the examination of the issues above is to achieve an improved understanding of the factors associated with the expansion of illicit crops in Colombia between 2001 and 2008 by taking the local reality into account. The paper aims to show that the factors associated with the expansion of illicit coca crops have changed geographically during the last decade and therefore demand new policies that integrate local realities rather than more general ones.

Modeling the related factors to coca crops

Previous studies (Dávalos et al., 2011; Dion & Russler, 2008) aimed to define the relationship between coca crops and social, institutional and biophysical factors using global regression analysis. In this study, a "global" analysis refers to an analysis on a national scale without accounting for regional characteristics. Previous studies presented the results as average values, assuming that the relationship does not change over space or time. However, this assumption is not necessarily true. Models testing the influences of related factors on coca crops reveal relationships on a global scale between coca crops and factors such as violence, poverty, accessibility (distance to rivers and roads), aerial fumigation and deforestation (Dávalos et al., 2011; Díaz & Sánchez, 2004; Dion & Russler, 2008; Moreno-Sanchez, Kraybill, & Thompson, 2003). Dávalos et al. (2011) applied logistic regression models to determine how coca crops increase the risk of deforestation and how so-called protected areas minimize this risk. However, as that study was detailed in its scope, socioeconomic and institutional information, which are typically used at a more aggregated scale, were not included. Moreover, those authors do not consider the spatial or temporal variation in the variables.

A study on Columbia was conducted by (Dion & Russler, 2008) to explain the persistence of coca crops in Colombia over the last decade, but their analysis focused on global models and assumed that there would be no changes in the global parameters (Díaz & Sánchez, 2004) better determined the spatial relationship and enhanced understanding of the different processes at both local and municipal scales, although their primary focus was the relationship between coca crops and armed conflict.

Interestingly, thus far, no modeling or correlation analysis of coca crops has considered the possible non-stationarity of the analyzed variables, nor has such an analysis included indicators that compare the significance of accessibility, violence and institutional factors (a weak or absent state) over more than a single time period. The Geographically Weighted Regression – GWR (Fotheringham, Brunsdon, & Charlton, 2002) was recently developed to explore spatially varying relationships and has been employed in different areas such as studies of reforestation (Clement, Orange, Williams, Mulley, & Epprecht, 2009), environmental justice (Gilbert & Chakraborty, 2011), freshwater acidification (Harris, Fotheringham, & Juggins, 2010), land use and water quality (Tu & Xia, 2008), wealth and land cover (Ogneva-Himmelberger, Pearsall, & Rakshit, 2009) and deforestation (Pineda Jaimes, Bosque Sendra, Gómez Delgado, & Franco Plata, 2010).

In this study, we applied GWR methods to examine and compare the spatially varying relationships between coca area percentages on a municipal scale and socio-institutional factors and geographical characteristics, such as road density and forest area. GWR is a widely used method for this type of study, in which the local aspects of an area are considered with the aim of improving the understanding of the actual situation, beyond the global and general models (Clement et al., 2009; Gao & Li, 2011). Additionally, this study is the first to apply GWR in examining the impact of socio-institutional and physical variables on the presence of illicit crops over two time periods.

Study area

Colombia covers an area of 2,070,408 km^2, of which 1,141,748 km^2 correspond to terrestrial territory and the remaining 928,660 km^2 to maritime territory. Colombia is located in the northwestern corner of South America and consists of five continental natural regions (Map 1): the Andean (AN) region, Caribbean (CA) region, Pacific (PA) region, Orinoquia (OR) region and Amazon (AM) region. The country is divided into 32 departments and 1101 municipalities, of which 23 departments (72%) and 274 municipalities (25%) reported the presence of coca crops for at least one year during the period 2001–2008. Colombia is responsible for over 50% of the global production of coca for cocaine production (UNODC, 2006a). The region with the highest average area and production of coca at the beginning of the study period (2001) is the Amazon region, principally in the departments of Putumayo, Meta and Guaviare. However, in the following years, coca cultivation spread to the Pacific region and the north of Colombia (UNODC, 2006, 2009).

Methodology

The Geographically Weighted Regression (GWR) model is an extension of the Ordinary Least Squares (OLS) regression model that allows spatial (local rather than global) parameters to be estimated (Fotheringham et al., 2002; Fotheringham, Charlton, & Brunsdon, 2001). OLS models lead to generalized relationships that are not applicable to the entire territory, while they do not allow for the consideration of the local characteristics of certain areas. This issue becomes an obstacle for the analysis of issues such as the expansion of illicit crops, which is a topic that requires a better understanding of local realities. GWR follows a local statistics approach, introducing a set of local parameter estimates that demonstrate how a relationship varies across space. Subsequently, the spatial patterns of the local variables are assessed to provide an improved understanding of hidden possible causes of the patterns observed (Brunsdon, Fotheringham, & Charlton, 2002). A global regression (OLS) is expressed as follows:

$$Y_i = \beta_0 + \sum_k \beta_k \chi_{ik} + \varepsilon_i \quad (1)$$

where Y_i is the dependent variable at location i, β_0 is the intercept, χ_{ik} is the value for the kth independent variable at location i, β_k is the parameter estimate for the independent variable k and ε_i is the error term at location i.

GWR generates a separate regression equation for each observation and provides a method to assess the degree of spatial non-