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Biophysical and socioeconomic determinants of tea expansion: Apportioning their relative importance for sustainable land use policy

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ABSTRACT

Tea expansion, a typical process of regional land use and cover change (LUCC), has raised great concerns on regional sustainability. In this regard, exploring the determinants of tea expansion should provide critical implications for land use policy. It has been widely recognized that LUCC interacts nonlinearly with a set of determinants and their feedbacks should be rather complex. Policy makers are now facing the challenge to identify, apportion, and compare the determinants of regional tea expansion for designing more targeted political intervenes. Our paper utilizes a robust tool, the random forest (RF) regression in particular, to explore the determinants of tea expansion across two periods (1985–2007 and 2007–2016) in Anji County, a typical region of tea production in subtropical China. More specifically, tea is extracted from Landsat imageries and total tea cultivated area acts as the dependent variable. Exploratory variables include 38 potential determinants and these determinants are divided into two categories (biophysical and socioeconomic) at two levels (pixel and village). We obtain some similar findings, though the relative importance of determinants varies with the two periods. In general, biophysical determinants (e.g., topography, soil type, land use in the neighborhood) present greater relative importance than the socioeconomic determinants in both periods. In period 1985–2007, biophysical determinants at pixel level are more essential in governing tea expansion. In period 2007–2016, the relative importance of pixel level biophysical determinants is comparable with that of the village level determinants. Comparisons of the two periods indicate that relative importance of soil type and socioeconomic proximity becomes greater in period 2007–2016, while that of the total employees and non-agricultural population proportion becomes lower. Partial dependency plots are further drawn to visualize the marginal effect of each determinant. We finally propose three options for land use policy towards sustainability. Our study demonstrates that the RF regression is efficient for policy makers to understand the determinants of tea expansion with a nonlinear and complex nature.

1. Introduction

Tea plantations are rapidly expanding in subtropical regions due to the increasing market demand in recent decades (Su et al., 2014). Global total tea production reaches 6.34 million tons in 2015, and the entire cultivation area is estimated to cover an area of three million hectares (FAO, 2015). However, many observations have highlighted that dramatic rates of forest and farmland clearing were occurring in Southeastern Asia due to tea expansion (Akhlas et al., 2003; Hung, 2013; Mortimer et al., 2015; Prokop and Ploskonka, 2014; Su et al., 2014; Wickramagamage, 1998; Xiao et al., 2015). Tea expansion, in most cases, causes disturbances to ecosystems (Chen and Lin, 2016; Zhu et al., 2014), accelerates soil erosion (El Kateb et al., 2013; Su et al., 2017a), fragments traditional landscapes (Su et al., 2014a), threats biodiversity maintenance (Chaudhary and Kastner, 2016; Mortimer et al., 2015), and increases carbon dioxide emissions (Li et al., 2011). Growing recognition has been raised that the rapid tea expansion should be a great threat to regional sustainability. Policy makers are eager for identifying the areas that are of high ecological value but vulnerable to further tea expansion. In this regard, exploring the determinants of tea expansion should provide critical implications for sustainable land use policy.

Tea expansion, as a typical process of land use and cover change (LUCC), occurs at a diversity of geographical scales and is involved in

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complicated natural and social environments. LUCC presents locality-varying characteristics and the internal mechanism can be manifested as a multidimensional profile of principle determinants (e.g., biophysical, social, economic, and political) (Zhang and Su, 2016). Owing to their robust and understandable characteristics, the empirical-statistical approaches have been frequently adopted to explore the determinants of LUCC. However, these approaches have received criticism for their high dependence on prior knowledge (Su et al., 2017b). Few studies have examined the determinants of tea expansion and we cannot refer to well-established theory for guiding the development of empirical-statistical models. The empirical-statistical approaches are found to have two other major limitations. For one thing, they are incapable of addressing qualitative and quantitative data of high dimensions (Müller et al., 2013; Redo et al., 2012). For another, they are unable to uncover the nonlinear and complex associations (Wang et al., 2016; Müller et al., 2013; Parker et al., 2008; Redo et al., 2012; Turner et al., 2007). Therefore, we should search for alternative robust tools for identifying the determinants of regional tea expansion.

Recent literature has demonstrated the advantages of data mining techniques over the traditional empirical-statistical approaches in LUCC modeling. Superiorities of the data mining techniques are generalized into four aspects in Su et al. (2017b): (1) capability to handle with high dimensional or multimodal data; (2) ability to address the nonlinear relationships; (3) capacity to deal with overfitting problem; and (4) no requirement for a priori assumption. Among the various data mining techniques, random forest (RF) regression is particularly suitable for examining the determinants of tea expansion. Except for the advantages summarized above, the RF regression can generate estimations that are easier to interpret and understand, compared with support vector machine and neural networks. For example, the exploratory variables can be sorted according to the ranking in the relative importance. Also, the individual marginal effect can be visualized for each determine after controlling the interactive effects among exploratory variables. With respect to the relative importance of determinants of tea expansion, however, no studies have been conducted to systematically compare the differences and similarities across periods by using RF regression.

The Anji County, located in Zhejiang Province of eastern coastal China (Fig. 1), provides a typical example to explore the determinants of tea expansion. Covering an area of approximately 1900 km^2, Anji County has a subtropical monsoonal climate, characterized by warm, humid and rainy summers with sufficient sunshine and abundant rainfall. The average annual temperature ranges 16–19 °C, and annual mean rainfall is 1100–1900 mm. The red soil with loamy texture, thick soil layer, and slightly acidic pH values is the most dominant soil type in Anji County. The biophysical conditions are very beneficial for tea cultivation. More specifically, the 'White Tea' originates from this region, and Anji County enjoys a high reputation of 'Tea Capital'. Motivated by the profitability, more and more smallholder farmers have participated in tea cultivation in the past decades. Particularly, tea cultivation was stimulated intensely since the local county government has published a series of policies that encouraged and developed tea industry since 2006 (Su et al., 2017a). Statistics show that total tea cultivated area first increased gradually in the 1985–2007 period and then grew rapidly in the 2007–2016 period (Fig. 2). This paper attempts to quantify the determinants of tea expansion from 1985 to 2016 in Anji County using the RF regression. The key objective is to reveal the similarities and differences in determinants of tea expansion as well as their relative importance for the two periods (1985–2007 and 2007–2016). Temporal comparisons allows for the identification of the principle determinants that govern tea cultivation over time. To generate comparative insights for policy implications, the same conceptual framework (potential determinant selection) and analytical approach (RFs regression) are rigorously applied to both periods. Our study, to a broader degree, engages the current debate over the relative importance of biophysical and socioeconomic determinants of regional LUCC.

2. Literature review and conceptual framework

2.1. Literature review

2.1.1. LUCC determinants: categories and scale effects

Determinants represent the independent variables that are supposed to govern LUCC in the mathematical models (Hersperger et al., 2010). Prior studies have reported a diversity of determinants of LUCC (da Silva et al., 2016; Dempsey et al., 2017; Gutzler et al., 2015; Mancino et al., 2016; Marcos-Martinez et al., 2017; Nandy et al., 2014; Smaliychuk et al., 2016; Su and Xiao, 2013; Xiao et al., 2015; Xu et al., 2014. For example, Müller et al. (2013) analyzed the topography, physical accessibility, rainfall and primary socioeconomic determinants of cropland abandonment. Li et al. (2013) reviewed the literature and summarized that LUCC determinants could be divided into four categories, including the physical factors, neighborhood factors, socioeconomic factors, as well as land use policy and urban planning. Nandy et al. (2014) considered distance variables as anthropogenic pressure and topography as natural explanatory variable of forest cover change. Munteanu et al. (2014) categorized LUCC determinants into economic, demographic, cultural, institutional and climatic groups. da Silva et al. (2016) used aspect, elevation, slope, proximity and socioeconomic variables as LUCC determinants. Zhang and Su (2016) examined the determinants of urban expansion from four dimensions, namely natural, economic, social, and demographic.

Although no formally accepted framework is available to guide the category of LUCC determinants, literature based on *meta*-analysis summarizes that LUCC occurs as a consequence of complex interactions among a range of structural and behavior factors and the LUCC determinants can be divided into biophysical and socioeconomic categories (Plieninger et al., 2016; Su and Xiao, 2013; van Vliet et al., 2015; Zhang and Su, 2016). In particular, biophysical determinants refer to the climatic, locational, and topographic features, while socioeconomic determinants represent the demographic, economic, and social factors (Plieninger et al., 2016). Some ecological researches used similar conceptualizations named human use (socioeconomic) determinants and environmental (biophysical) determinants of LUCC (Dempsey et al., 2017). Nelson et al. (2006) categorized the determinants as indirect (biophysical) and direct (socioeconomic) determinants. Other scholars pointed that the two principle categories can be further divided into certain subcategories (Su and Xiao, 2013; Xiao et al., 2015; Su et al., 2016). For example, Su and Xiao (2013) reviewed the literature and proposed a four-category classification framework for selecting the LUCC determinants, including physical, accessibility, neighborhood, and socioeconomic determinants. Xiao et al. (2015) followed this framework to establish the LUCC model for quantifying the determinants of cash crop expansion.

The biophysical and socioeconomic processes are nested across different levels and the LUCC should be subjected to the interactions among determinants of different levels. It is suggested that multilevel biophysical and socioeconomic factors should be considered during the examination of LUCC determinants (Overmars and Verburg, 2006). A LUCC study in Philippines took into account the determinants at field, household and village level (Overmars and Verburg, 2006). Another LUCC study in Bolivian Amazon showed that deforestation was subjected to the multilevel land governance (Bottazzi and Dao, 2013). Müller et al. (2013) quantified the determinants of cropland abandonment in Albania and Romania at pixel and village levels. Ma et al. (2016) adopted demography, economy, and transportation determinants at three administrative levels, i.e., provinces, prefectures, and counties. Su et al. (2016) investigated the biophysical and socioeconomic determinants of cash crop expansion at three levels (household, parcel, and village). Temporal effect is another critical factor, since observations have highlighted that LUCC determinants should vary with periods (Basse et al., 2016; Stürck et al., 2015; Tepe et al., 2017). Related studies typically quantified the LUCC determinants