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Effects of road network on diversiform forest cover changes in the highest coverage region in China: An analysis of sampling strategies

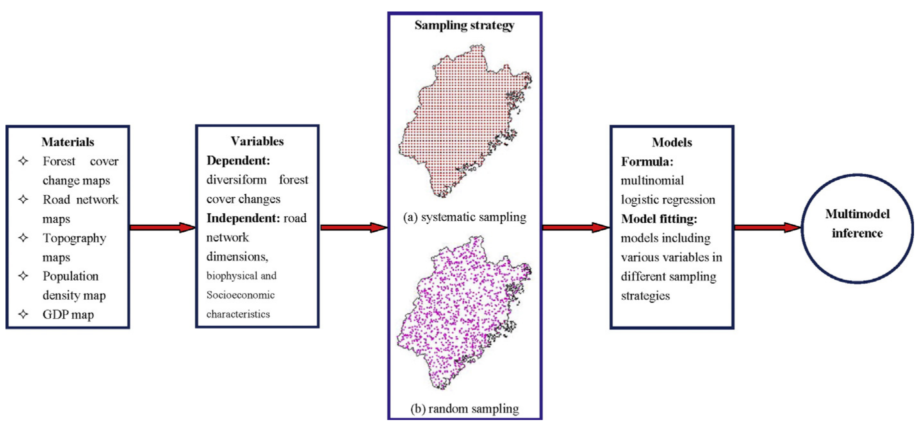
Xisheng Hu [a], Zhilong Wu [a], Chengzhen Wu [b,c], Limin Ye [a], Chaofeng Lan [a], Kun Tang [a], Lu Xu [a], Rongzu Qiu [a,*]

[a] College of Transportation and Civil Engineering, Fujian Agriculture and Forestry University, Fuzhou 350002, China
[b] College of Forestry, Fujian Agriculture and Forestry University, Fuzhou 350002, China
[c] Department of Ecology and Resource Engineering, Wuyi University, Nanping 354300, China

HIGHLIGHTS

- More than two forest-cover change categories are recommended.
- Two sampling designs were compared.
- Limited differences between the two sampling designs
- The sample size had great impact on the regression outcomes.
- Different predictors of the different change categories were observed.

GRAPHICAL ABSTRACT



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ABSTRACT

Forest cover changes are of global concern due to their roles in global warming and biodiversity. However, many previous studies have ignored the fact that forest loss and forest gain are different processes that may respond to distinct factors by stressing forest loss more than gain or viewing forest cover change as a whole. It behooves us to carefully examine the patterns and drivers of the change by subdividing it into several categories. Our study includes areas of forest loss (4.8% of the study area), forest gain (1.3% of the study area) and forest loss and gain (2.0% of the study area) from 2000 to 2012 in Fujian Province, China. In the study area, approximately 65% and 90% of these changes occurred within 2000 m of the nearest road and under road densities of 0.6 km/km^2, respectively. We compared two sampling techniques (systematic sampling and random sampling) and four intensities for each technique to investigate the driving patterns underlying the changes using multinomial logistic regression. The results indicated the lack of pronounced differences in the regressions between the two sampling designs, although the sample size had a great impact on the regression outcome. The application of multi-model inference indicated that the low level road density had a negative significant association with forest loss and forest loss and gain, the expressway density had a positive significant impact on forest loss, and the road network was insignificantly related to forest gain. The model including socioeconomic and biophysical variables

* Corresponding author.
E-mail address: fjxsh@126.com (R. Qiu).

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illuminated potentially different predictors of the different forest change categories. Moreover, the multiple comparisons tested by Fisher's least significant difference (LSD) were a good compensation for the multinomial logistic model to enrich the interpretation of the regression results.

1. Introduction

The pace, magnitude and spatial reach of human alterations of the earth's land surface are unprecedented. Changes in forest cover are among the most important (Goldewijk and Battjes, 1997; Lambin et al., 2001). Forest cover changes are so pervasive that when aggregated globally they significantly affect key aspects of earth ecosystem functioning, including biodiversity conservation, climate warming, carbon storage, and water supplies (Chase et al., 1999; Foley et al., 2005; Hansen et al., 2013). By altering ecosystem services, these changes affect the ability of ecosystems to support humans (Vitousek et al., 1997). The forest cover altered by humans has lasted for centuries, but recent rates of change are higher than ever (Goldewijk, 2001; Foley et al., 2005; Hansen et al., 2010) with a global net loss of 521,080 km^2 between 2000 and 2010 (Redo et al., 2012). Hence, forest loss (FL; deforestation and degradation) has been deemed to be among the world's most pressing land cover change problems and has triggered a mass of studies in many regions and on many different scales (local to regional to global) with different map resolutions (Wimberly and Ohmann, 2004; Hamre et al., 2007; Lira et al., 2012). More recently, the finding that nations and regions may undergo a "forest transition" from a pattern of deforestation in the early stages of economic development to net forest gain (FG) as agriculture and other extensive pressures decline has incited a great deal of research interest (Rudel et al., 2005; Drummond and Loveland, 2010; Redo et al., 2012). The common aggregation of deforestation and reforestation into net forest change makes it unclear whether the factors that favour deforestation will simultaneously hinder reforestation or vice versa. By separately examining the deforestation and reforestation patterns, we can illuminate the potentially different predictors of these two processes. Many studies on forest cover changes have shown that deforestation and reforestation are different processes that may respond to distinct factors on different temporal and spatial scales (ranging from multi-national to national to municipality scales) (Millington et al., 2007; Meyfroidt and Lambin, 2009; Yackulic et al., 2011). The effects of factors on the changes vary at different spatial resolutions of socioeconomic and biophysical data (Hamre et al., 2007; Millington et al., 2007; Zhou et al., 2011). However, most studies on forest cover dynamics and its drivers classify forest cover change into only two categories: forest change (forest to non-forest) versus no change (forest remains unchanged) (Millington et al., 2007; Nandy and Kushwaha, 2014). Because these two opposing forces (FL and FG) are present in many regions or countries (Redo et al., 2012) and forest transitions have a significant effect on the creation of more sustainable societies (Rudel et al., 2005), it behooves us to carefully examine the patterns and drivers of these forest cover changes by subdividing them into several categories, such as FL, FG and forest loss and gain (FLG, indicating intensive plantation practices and natural reforestation), to achieve land-use sustainability in the face of rapid global environmental changes.

Many studies have focused on elucidating the factors that lead to forest cover changes and have concluded that these changes are combined results driven by a number of biophysical and socioeconomic factors (Yackulic et al., 2011; Hu et al., 2014). Biophysical features, such as land form, soil type and slope, may lead to the concentration of agriculture on flatter and more suitable areas, thereby allowing the deforestation or reforestation of marginal agricultural lands (Rudel et al., 2000; Crk et al., 2009). Socioeconomic factors, such as urbanization or the connectivity of the land to urban centres, may reduce the probability of reforestation by increasing the relative land value (MacDonald and Rudel, 2005; Crk et al., 2009). Forest cover changes may also be mediated by other external factors, such as technological progress, market forces, government policies and institutional factors (Barbier et al., 2010; Lambin and Meyfroidt, 2010). Of all of the types of disturbances that humans have introduced into the changes, the road network may be the most ubiquitous and significant long-term legacy of our activities (Reed et al., 1996; Forman et al., 2002). The road network opens land for resource extraction and other human activities while increasing accessibility and mobility, thereby 'scaling up' the level of human disturbance on many ecological processes (Jaeger et al., 2007; Selva et al., 2011). However, most studies on the effects of roads on land use/land cover change have been performed using a separate indicator (i.e., either road density or distance from road) (e.g., Rutherford et al., 2007; Cai et al., 2013; Nandy and Kushwaha, 2014) with little effort to compare the impacts of these two measurements. Therefore, our understanding of the effects of the road network is far from comprehensive due to the lack of related knowledge. China's road network has grown rapidly over the past three decades in accordance with the government's reform policy. Forest cover changes and the subsequent effects of roads have been widely studied in many countries, but similar studies have only recently been initiated in China (Forman et al., 2002; Li et al., 2010; Liu et al., 2014). Thus, a more direct investigation on the impacts of roads on forest landscape dynamics is needed.

Many empirical models (e.g., regression approaches) can be used to improve the explanation of the mechanisms and the processes of the change by examining the statistical significance of the influence of the predictor variable upon the dependent variable (Rutherford et al., 2007). Binary and multinomial logistic regressions are among the most common methods (Aspinall, 2004; Hu et al., 2014). Both methods are examples of discrete outcome models that allow outcomes with the same initial forest cover type to be modelled as a group (Agresti, 1996). Additionally, these methods can be used to model non-normally distributed dependent variables and thus overcome some of the problems with the assumptions of other linear regression models (Venables and Ripley, 2002; Millington et al., 2007). This ability is useful for forest cover change modelling where the dependent variable is typically a categorical variable. Furthermore, these types of logistic models may incorporate both continuous and categorical predictor variables (Müller et al., 2012). In these cases, multinomial logistic regression provides an appropriate statistical framework for our research. The regression assumes that the different outcome classes (forest cover change types) are nominal and mutually exclusive (Agresti, 1996). These techniques are being increasingly used in studies of land cover changes (Müller and Zeller, 2002; Millington et al., 2007; Rutherford et al., 2007) and forest dynamics (Augustin et al., 2001; Htun et al., 2013). Thus, our first goal was to ① compare the effects of different road network dimensions and biophysical and socioeconomic factors on different forest cover change categories (i.e., FL, FG and FLG) using multinomial logistic regression.

The choice of an appropriate statistical model is important because it can affect the outcome and thus the interpretation of the results. The sampling design is often of similar importance because the performance result is affected by the nature and design of the sampling strategies, such as systematic (regularly spaced), random and bootstrap resampling of the entire study area (Guisan and Zimmermann, 2000; Guisan et al., 2006). Using all available data, bootstrap resampling techniques may introduce spatial autocorrelation into the models, resulting in biased estimates of the variables (Wagner and Fortin, 2005, Nandy and Kushwaha, 2014). To eliminate spatial autocorrelation, the minimum distance between sampling points has been recommended