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Optimal forest rotation for carbon sequestration and biodiversity conservation by farm income levels

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ABSTRACT

This study aimed to estimate the optimal forest rotation age for tropical plantations of a native tree species, *Canarium album* (Lour.) under the management of high, medium, and low income groups of farm households of Vietnam. The results suggest that: (i) the optimal rotation age for the low income group is longer than that for the high income group; (ii) low income farmers are more sensitive in terms of the land expectation value to changes in discount rate; (iii) low income farmers gain less if the carbon price increases; and (iv) the carbon payment scheme at the start of a rotation is more financially attractive to forest farmers, but the carbon payment scheme at the end of a rotation is more advantageous in terms of forest biodiversity. These findings lead to potential policy implications for forest management for the provision of multiple ecosystem services in the context of a developing country, demonstrating a tradeoff between forest income and biodiversity conservation. While an increase in carbon prices would benefit forest farmers, we also suggest that these farmers could be compensated for their income losses or rewarded to maintain or increase forest biodiversity. However, relatively greater attention could be paid to compensating low income farmers as they potentially lose more with an increase in discount rate and gain less with an increase in carbon price.

1. Introduction

Forests are the source of many ecosystem services which are important to human well-being (MA, 2005; Deal et al., 2012; Amacher et al., 2014). This is particularly relevant in tropical regions where forests are a means of livelihoods of many human communities (Nagendra, 2007; Babulo et al., 2009; Abebaw et al., 2012; Zenteno et al., 2013; Porro et al., 2015). Despite signs of forest recovery in a few countries (Meyfroidt and Lambin, 2011), rates of tropical deforestation remain alarmingly high (Mahapatr and Kant, 2005; FAO, 2010; Köthke et al., 2013; Barua et al., 2014; Lawrence and Vandecar, 2015). Thus, reforestation is important to support livelihoods and to reduce the pressure of additional deforestation (Takasaki, 2007; Mombo et al., 2014). Large reforestation programs have been implemented in a number of countries, for example, China and Vietnam, to deal with the challenges of global climate change (Nguyen and Tenhunen, 2013; Mbatu, 2015) and biodiversity loss (Sadath et al., 2013; Uggla et al., 2016), and to provide a solution to the current problem of forest loss (Angelsen, 2010; Bele et al., 2015). However, little attention has been paid to the crucial problem of sustaining the economic activity of the people who participate in reforestation programs (Chazdon, 2008; Rico and González, 2015), given the fact that tropical reforestation activities in developing countries are mainly undertaken by individual farm households characterized by various levels of income (Lamb et al., 2005; Coulibaly-Lingani et al., 2011; Nguyen et al., 2016a).

Vietnam has experienced critical changes in forest resources and management over the last few decades along with a transformation from state-owned to multi-stakeholder forest management schemes (Sikor, 2001; Nguyen, 2008; Nguyen et al., 2010). Such a transformation has allowed the allocation of forest land to individual farm households for reforestation. In 2010, farm households were the second largest forest land user group with a share of 25% of all forest land (Lambini and Nguyen, 2014). This share will increase in the upcoming years, since the allocation has not yet been completed. In Vietnam, "forest land" is defined as "land designated for reforestation" and might not necessarily be covered by forest. In addition, current regulation states that forest land allocated to farmers can only be used for the purpose of reforestation (Nguyen et al., 2013; Nghiem, 2014). Moreover, allocated forest land is generally degraded, thus early plantation development in Vietnam focused on the monoculture of fast-growing exotic tree species of *Acacia*,

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Eucalyptus, and *Pinus* (McNamara et al., 2006). Recently, native tree species have been gradually preferred (Nguyen et al., 2014), partly due to their ecological benefits (Knoke et al., 2008).

One of the main issues in forestry is to determine optimal forest rotation ages (Chang, 1998; Díaz-Balteiro et al., 2009; Olschewski and Benítez, 2010; Asante and Armstrong, 2012). In the past, timber production was the main objective of plantation management (Chang and Gadow, 2010; Faustmann, 1849; Hartman, 1976). During the last couple of decades, the increasing realization of the importance of various ecosystem services provided by forests has led to the consideration of other aspects in determining optimal forest rotations (van Kooten et al., 1995; Gan et al., 2001; Tahvonen, 2004; Termansen, 2007; Hyytiäinen and Penttinen, 2008; Guthrie and Kumareswaran, 2009; Thompson et al., 2009; Touza et al., 2010; Juutinen et al., 2014; Tahvonen, 2016). The first additional aspect to be considered is the conservation of biodiversity (Sadath et al., 2013; Juutinen et al., 2014). Forests are home to more than half of the known terrestrial plant and animal species (MA, 2005; Cardinale et al., 2012) and prolonged forest rotations allow the re-establishment of organisms and habitats for species depending on old-growth forests (Juutinen et al., 2012).

The second additional important aspect is carbon sequestration (Gutrich and Hawarth, 2007; Couture and Reynaud, 2011; Parajuli and Chang, 2012; Millner and Dietz, 2015). Forests are considered as potential carbon sinks (Olschewski and Benítez, 2005; Asante et al., 2011; Ekholm, 2016). This aspect is very important as climate change is occurring (Rose and Sohngen, 2011; Chang, 2013) and will very likely have harmful effects on economies and human well-being (Stern, 2007; IPCC, 2012). The determination of optimal forest rotations for the provision of multiple ecosystem services has become a challenging task in forest management (Nguyen, 2015).

The third additional point that needs to be considered for developing countries is that individual farm households managing plantations have different levels of income and economic constraints (Nakhumwa and Hassan, 2012; Nguyen et al., 2015). Due to imperfect capital markets (Samuelson, 1976; Tahvonen et al., 2001) high income households might invest more capital in forest management than low income households, which could shorten forest rotations. In other words, forest management investments are not homogenous and the assumption of investment homogeneity might lead to a biased estimate of optimal forest rotations. Different levels of forest investment obviously lead to different outcomes of forest management, for example, carbon sequestration, forest income, and forest biodiversity. The identification of different forest management outcomes provides useful information for forest management for the provision of multiple ecosystem services, for example, the Clean Development Mechanism (Millock, 2002), payments and rewards for forest ecosystem services (PES) (Robert and Stenger, 2013) or reducing emissions from deforestation and forest degradation (REDD) programs (Pukkala, 2011; Pistorius et al., 2012; Hofstad and Araya, 2015).

This study aims to determine optimal forest rotation ages for three different income groups of forest farm households in Vietnam with the inclusion of the monetary values of timber, non-timber forest products (NTFP), and carbon sequestration while maintaining a certain level of forest biodiversity. To our knowledge, this study is the first to estimate optimal forest rotations of farm households of different income levels in a developing country. The underlying motivation is to identify to what extent the differences in farm household income affect forest management outcomes. This understanding is useful to develop efforts that aim to achieve both environment and development objectives. The modeling exercise is applied to private plantations of *Canarium album* (*C. album*), a native species of the study area.

Our paper is structured as follows. Section 2 describes the study design, including a farm survey, the structure and data inputs of the optimization model. Section 3 presents and discusses the results. The conclusions and policy implications are summarized in Section 4.

2. Study design

2.1. Study site and data collection

This study was conducted in the Northern Uplands of Vietnam, where the majority (82%) of the region's territory (102,000 km^2) consists of hills and mountains with a minimum elevation of 500 m above sea level (Nguyen, 2012). It is the region with the largest degraded forest land area of the country (FAO, 2010). Thus, various reforestation efforts have been undertaken in this region which is home to 31 of the 54 officially recognized ethnic groups of Vietnam (Khong, 1995).[1] Due to its unfavorable ecological conditions, food insecurity is still a major concern in the Northern Uplands (Nguyen et al., 2016b), and three fourth of the rural population of this region partly depend on forests for their livelihoods. Three districts, namely Cho Moi, Na Ri, and Mai Son, in the two provinces of Son La and Bac Kan (Fig. 1) were chosen as the study sites, as they have a large area of degraded forest land (Nguyen et al., 2014) and the allocation of forest land to individual households has not been completed yet (Nguyen et al., 2013). Moreover, *C. album* is one of the major native tree species used in reforestation programs in these two provinces. Local farmers have been familiar with this species for years. In addition to timber, it also provides fruits as a sort of intermediate NTFP. Given food insecurity problem in the region, this NTFP is a valuable source of plant proteins and vitamins for local residents. Plantations of *C. album* are monocultures (Nguyen et al., 2014). Timber is harvested by clear-cutting and farmers sell standing trees due to its ease of silvicultural procedure (Nghiem, 2015).

The data were collected from 2006 to 2010. The whole data collection procedure can be briefly described as follows. First, from the District People's Committees, a list of all farmers who had been granted forest land for reforestation was obtained. Two hundred farm households were randomly selected from the list for the investigation of their reforestation efforts. Seventy-three percent of these households ($n = 146$) possessed *C. album* plantations, which varied in age. Second, a survey was conducted in the winter of 2006 to collect data on farm household characteristics, income and assets, employment status, area of allocated forest land, and forest land property rights (forest land title). Each household was provided with a Farm Forest Management Book containing tables to record the costs and benefits (including expected costs and benefits) of reforestation activities. Annual household income from 2006 to 2010 was also recorded. In addition, permanent sample plots were established on the forest land of each household. Each sample plot had an area of 500 m^2 (20 m $\times$ 25 m). The total area of the plots for each household equaled to 10% of the degraded forest land area of that household. The measurements of tree diameter and height were made annually from 2006 to 2010 to provide data for timber growth estimates, which were validated by secondary data sources (see the next sub-sections). All Farm Forest Management Books were collected in 2010, providing the following data: (1) farm household characteristics, including annual income, asset and employment status[2]; (2) costs and benefits of forest management; and (3) diameters and heights of trees of different ages.

2.2. Optimization model structure

The optimal forest rotation model at a forest-level by Nghiem (2014, 2015) was extended to include the NTFP (Gong et al., 2005) of the tree species (*C. album*) and for three income levels. The model assumes that the plantation of a household consists of n stands ($n > 1$). Interactions among forest stands are captured by economies of planting scale (Termansen, 2007). The objective of the model is to maximize the land expectation value (LEV) (Chang, 1984; Parajuli and Chang, 2012)

[1] Kinh is the majority ethnic group of Vietnam with about 85% share of the population.
[2] Some collected data are beyond the scope of the current study.