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Optimal rotation age for carbon sequestration and biodiversity conservation in Vietnam

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ABSTRACT

Biodiversity loss is a major problem in terms of loss of genetic and ecosystem services and more specifically via impacts on the livelihoods, food security and health of the poor. This study modeled forest management strategies that balance economic gains and biodiversity conservation benefits in planted tropical forests. A forest-level model was developed that maximized the net present value (NPV) from selling timber and carbon sequestration while maintaining a given level of biodiversity (as per the population density of birds). The model was applied to *Eucalyptus urophylla* planted forests in Yen Bai Province, Vietnam. It was found that the inclusion of biodiversity conservation in the model induces a longer optimal rotation age compared to the period that maximizes the joint value from timber and carbon sequestration (from 8 to 10.9 years). The average NPV when considering timber values plus carbon sequestration was 13 million Vietnamese Dong (VND) ha^{-1} (765 USD ha^{-1}), and timber, carbon sequestration and biodiversity values were 11 million VND (676 USD) ha^{-1}. Given this differential, governments in such tropical countries may need to consider additional incentives to forest owners if they are to encourage maximizing biodiversity and its associated benefits. The results also have some implications for implementing the climate control measure of "Reducing Emissions from Deforestation and Forest Degradation-plus (REDD+)" in developing countries, i.e., payment for carbon sequestration and biodiversity benefits in planted forests.

1. Introduction

According to the Copenhagen Accord, climate change is one of the greatest challenges of our time and a deep cut in global greenhouse gas emissions is required to deal with this problem (UNFCCC, 2009b). The Copenhagen Accord also recognizes the crucial role of reducing emissions from deforestation and the need to enhance the carbon uptake of forests. Furthermore, it commits to provide funding for implementing such actions in developing countries. Meanwhile, climate change may contribute to biodiversity loss, which poses a particularly real threat to the livelihoods, food security and health of the poor.

Forests (natural but also human-made or modified) are home to more than half of the known terrestrial plant and animal species (Hassan et al., 2005). Beside supplying wood production, plantation forests provide additional ecosystem services such as recreation and ecotourism (Evans, 2009), erosion control from land-slides (Dymond et al., 2006) and wind (Evans, 2009), flood protection and benefits to water quality, and climate regulation through carbon sequestration (Carnus et al., 2003; Rudel et al., 2005). Moreover, there is abundant evidence that plantation forests can provide habitat for a wide range of native forest plants, animals and fungi (some of which are used by people for food or traditional medicines). Since the annual global rate of natural forest loss is 0.3% (FAO, 2007), and is difficult to reverse (Brockerhoff et al., 2008), planted forests may be a "lesser evil" (compared to having agricultural land) as a means to protect indigenous vegetation remnants (Brockerhoff et al., 2008).

Lindenmayer and Franklin (2002) stated that "the use of long rotations can have direct and significant consequences for biodiversity conservation at both landscape and stand levels". Longer rotations reduce the rate of timber harvest over a given planning horizon, and hence help to decrease some of the negative impacts of short rotations while still continuing to allow forest products to be obtained (Curtis, 1997; Moning and Muller, 2008). In addition, longer rotations result in fewer clear-cut areas per decade (Carey et al., 1999), and thus contribute to the succession of species which is sensitive to the proportion of recently disturbed landscapes (Økland, 1996). Furthermore, increasing the rotation age allows more time for organisms to become re-established after clear-cutting and provides a habitat for species that depend on old-growth forests, such as large-diameter trees, large-snags and logs (Brockerhoff et al., 2005; Curtis, 1997).

In contrast to achieving biodiversity conservation, long rotations are not always positively related to carbon sequestration. Trees sequester carbon as they grow, so the rate of tree growth is critical for carbon sequestration (van Kooten et al., 1995). For fast-growing trees,

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which grow faster in the first several years of their life, carbon is sequestered more in these early years. For slow-growing trees, carbon sequestration may reach a peak after many years, depending on growth rate patterns.

Forests and changes in forest management practices can help to conserve biodiversity while contributing to carbon sequestration. "Reduce Emissions from Deforestation and Forest Degradation" (REDD) is a mechanism to encourage carbon sequestration after the period of 2008–2012 via payment for forest owners in developing countries to keep their forests growing (UNFCCC, 2011). Going beyond deforestation and forest degradation, "REDD+" considers the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The REDD+ mechanism has been suggested both to be an effective tool for climate change mitigation (via carbon sequestration) and to offer the important co-benefit of biodiversity conservation (Busch et al., 2011). The biodiversity co-benefit (i.e., reducing deforestation and forest degradation is better for both climate change control and biodiversity conservation) exists for natural forests, but might not be true for planted forests in some cases. Biodiversity conservation in planted forests might be achieved with some trade-offs in productivity gains (and hence carbon sequestration) (Bullock et al., 2011; Cannell, 1999; Lindenmayer and Hobbs, 2004), and therefore there may need to be a policy option for foresters to be compensated for that to ensure the optimal society-level outcomes.

Traditionally, planted forests are usually managed by determining rotation lengths to optimize timber values only. Optimal forest rotation has been scientifically investigated for over 150 years and the optimal management strategy for a single stand forest was developed by Faustmann (1849). The optimal rotation length is positively related to changes in planting costs and inversely related to the changes in timber prices and discount rates. Going beyond timber values, other benefits from forests have been taken into account in optimizing forest rotation length. Hartman (1976) extended the Faustmann model to include the amenity value of forests. He found that the optimal rotation is longer or shorter than the Faustmann rotation if environmental values increase or decrease with the stand age. Subsequently, Englin and Callaway (1993) considered the value of carbon and reported that the optimal rotation age differed from the standard Faustmann model. The effect of carbon taxes and subsidies on the optimal forest rotation age was then studied by van Kooten et al. (1995) who concluded that the "carbon optimal rotation age" was slightly longer than the Faustmann rotation age.

While the above analyses (Englin and Callaway, 1993; Faustmann, 1849; Hartman, 1976; van Kooten et al., 1995) dealt with a single forest stand, forests usually consist of many stands. A forest stand is defined as "a contiguous group of trees sufficiently uniform in species composition, arrangement of age classes, site quality, and condition to be a distinguishable unit" (Smith et al., 1997) and this definition can vary by country. The optimal management strategy for a multiple stand forest (i.e., management at the forest-level) was introduced by Mitra and Wan (1985, 1986). They applied a dynamic programming approach and found that: (i) if the utility function is linear, the Faustmann periodic solution is optimal, and (ii) if the utility function is increasing and strictly concave, an optimal solution converges to the maximum sustained yield solution (that is maximizing the mean annual increment (Hyytiainen and Tahvonen, 2003)). Tahvonen (2004) included old-growth values into his forest level model and found that the optimal rotation age was longer than the Faustmann rotation. However, there is no study at a forest level that collectively includes timber values, carbon sequestration benefits, and biodiversity conservation to determine the optimal rotation length. Therefore the study presented here aimed to determine the optimal management strategy at a forest level for multi-stand planted forests while considering all these three issues (timber values, carbon sequestration and biodiversity conservation). Furthermore, it conducted this in a tropical developing country context which is relevant since tropical planted forests contribute to 28% of the total world forest area (FAO & JRC, 2012), and carbon sequestration via forests and biodiversity conservation need to be enhanced in this area (Convention on Biological Diversity, 2002; UNFCCC, 2009b).

The setting for this study was Vietnam which belongs to the Indo-Burma hotspot, one of 25 global biodiversity hotspots (Myers et al., 2000). The total forest area in Vietnam is 31% (13 million ha) of the total land area in 2010 (FAO, 2010). Vietnam has implemented a Clean Development Mechanism (CDM) project so there is scope for revenue generation for foresters from carbon sequestration via this Mechanism (DOF/MARD, 2008; UNFCCC, 2009a). Furthermore, Vietnam is a pilot country to develop the REDD+ mechanism (Government of Vietnam, 2008, 2010; UN-REDD Programme, 2013).

In Vietnam, all forest land is under state ownership and forest land allocated to individual households does not exceed 30 ha in size and is limited to a 50 year-land-use right (Government of Vietnam, 1999). These features of household ownerships make this type of forest ownership different from other types of ownerships in other nations which have been studied previously (Englin and Callaway, 1993; Tahvonen, 1999; van Kooten et al., 1995) (e.g., individual private owners, which are more focused on a commercial purpose; non-industrial forest owners, which are more focused on obtaining forest services such as biodiversity conservation and recreation; and private-owned enterprises). The 50 year-land-use right is also different to the infinitive investment period for forestry in the optimal rotation literature. This relatively short investment period could limit Vietnamese foresters in applying long rotations, and hence has impacts on carbon sequestration services and biodiversity conservation.

In Vietnam, most of the fast-growing tree species such as *Eucalyptus urophylla* in plantation forests are cut at the average age of five years (Nguyen et al., 2006). Moreover, the majority of forest farmers apply a clear-cut practice (Bui and Hong, 2006) that destroys habitat and causes serious loss of biodiversity (Pawson et al., 2006). Short rotation periods and clear-cutting are common forestry practices in plantation forests nation-wide in Vietnam. Another aspect of Vietnam is the tropical nature of the forests. Most of the studies on optimal forest rotation lengths focus on slow-growing trees in developed countries and temperate forests, which account for 10% of the total world forest area (FAO & JRC, 2012). However, optimal rotation lengths for the same tree species may still be different by both country and climate zone because of the differences in input parameters such as timber growth rates, planting costs, annual management costs and harvesting costs (Diaz-Balteiro and Rodriguez, 2006).

2. Method

2.1. The selection of taxa for a biodiversity indicator

The biodiversity of even a small area is far too complicated to be comprehensively measured (Duelli and Obrist, 2003). Measuring biodiversity requires not only identification of the explanatorily salient dimensions of diversity (i.e., to define variety or differentiation among systems in order to determine which system is more diverse) but also a measurement of biological systems (i.e., the biodiversity level) and given the constraints on time, resources, and information available (Maclaurin and Sterelny, 2008), this task is neither practical or feasible. Thus, suitable indicators have to be found to measure biodiversity instead (Duelli and Obrist, 2003).

Among biodiversity indicators, species diversity (species richness and species abundance) is the most commonly accepted indicator in terms of measurement and valuation (Pearce et al., 2002) and is widely applied to measure biodiversity by economists (Eppink and van den Bergh, 2007; Juutinen and Mönkkönen, 2004; Smith et al., 2008). This indicator is relatively simple (Begon et al., 1996; Magurran, 1988), has a good discriminant ability (Magurran, 1988), and is the most available