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Research article

# A planning tool for tree species selection and planting schedule in forestation projects considering environmental and socio-economic benefits

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ABSTRACT

Species selection is a crucial step in the planning phase of forestation programs given its impact on the results and on stakeholder interactions. This study develops a planning tool for forestation programs that incorporates the selection of tree species and the scheduling of planting and harvesting, while balancing the maximization of the carbon sequestered and income realized, into the forestation decision-making and planning process. The validation of the goal programming model formulated demonstrates that the characteristics of natural tree species along with the behavior of growth and timing of yield are significant factors in achieving the environmental and socio-economic aspirations. The proposed model is therefore useful in gauging species behavior and performance over time. Sensitivity analysis was also conducted where the behavior of the income generated and carbon sequestered with respect to the external factors such as carbon market prices, percentage area allocated for protection and discount factor was assessed.



## 1. Introduction

Forestation is referred to as the activity of planting trees in empty areas to rehabilitate, rebuild, or create forests (International Panel on Climate Change, 2000) and forestation programs are conducted for different reasons.

Environmentally, the concept of forestation was formed as a response to mitigating the effects of climate change, environmental imbalance, biodiversity loss, and other harmful events on the environment. On a global scale, deforestation results to 35% of the carbon emission of developed countries while it is worse in least developed countries, where it accounts for 65% of the carbon emissions (United Nations Department of Economic and Social Affairs, 2009). The Food and Agriculture Organization of the United Nation (2015) estimates that while in 1990, forests amount to 31.6% of the world's land areas, or about 4128 million hectares, it has decreased to 30.6%, or about 3999 million hectares in 2015.

From a socioeconomic standpoint, forestation programs are conducted to sustain the demand for forest products, which are materials extracted from forestry for direct usage or commercial use. The growth in population has increased the demand for production thereby increasing the need for raw materials and products, such as lumber, paper, and charcoal (Segura et al., 2013). Plantation forests are therefore created to satisfy this economic need and become an income-generating and resource-mining activity.

Rose and Haase (2006) discussed that several decisions are made in forestation planning, which is the first step in forestation programs. It includes planning complexity, species selection, planting schedule, harvest rotation, harvesting methods, and success metrics. The implementation of forestation programs relies greatly on its planning, especially species selection, which has impacts on the results of the program and on stakeholder interactions. As such, this study proposes an alternative for existing species selection methodologies to address their limitations.

Forests provide a multitude of products and services, also known as ecosystem services, which are inherently anthropogenic; therefore, the values assigned to these depend on the value placed upon it by the community that gains these benefits (Potter and Woodall, 2012). The ecosystem services framework combines ecology, economics and sociology into one unified idea and its central goal is to benefit human society (Costanza et al., 2014), especially for non-commodity provisioning and cultural services

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where quantification in terms of monetary amount or others are difficult. Regulating and supporting services are entirely environmental in nature; these concern ecosystem processes that are very hard to quantify and forecast given the multitude of factors and factor interactions that affect them.

Income from forest products and carbon sequestration are the two performance measures used to account for the socio-economic and environmental considerations of tree species selection, respectively. These measures are found to be heavily dependent on the tree species chosen. Income for timber is computed based on volume, which is dependent on the rate tree species grow. Similarly, income for non-timber forest products (NTFPs) depend both on growth and yield rates of species (Rahman, 2012). For carbon sequestration, oven-dry biomass, which is also a function of the species growth rate (Zheng et al., 2013), proves to be a good estimator of amount sequestered. Higher biomass is proportional to a greater capacity to sequester carbon (Ecosystems Research and Development Bureau, 2010).

United States (2004) stated that sustainable forestry is based on the maintenance of ecosystem cycles as well as timing tree harvest based on growth rate. Tree growth, which varies per species, follows a general sigmoidal curve, which means that the growth rate increases initially and then quickly reaches the maximum. Once the tree reaches its maximum growth rate, this rate begins to decline as it ages (Avery and Burkhart, 2015). Carbon accumulation, which can be observed as a function of tree growth, is slow and increases during a short period before plateauing (Susaeta et al., 2014); carbon sequestering capabilities and yield values are dependent on the same sigmoidal curve for tree growth (Gorte, 2009) (see Fig. 1).

Decisions with certain objectives must then look to species selection and harvest rotation as two of the most crucial factors in planning due its direct cause-effect relationship with income and carbon sequestration benefits derived, how much will be realized, and when they are availed from the forest (Le et al., 2012).

## 2. Literature review

Van Kooten, Binkley and Delcourt (1995) proved that forest rotation is affected by taxes and subsidies, which are environmental in nature such that the longer one waits to get the subsidies, the more carbon is stored in the environment. Their findings became the basis of other harvest rotation studies, and raised the awareness that carbon can save proponents money or can even bring them income. However, they only used static figures such as averages. Following their research, there was a growing trend in the inclusion of carbon trading as a viable source of income in forestation. Asante et al. (2011) used dynamic programming to find the combination of biomass and stand age states to increase net present value based on carbon sequestration, but their study is entirely economic in nature; effects to the environment were not discussed.

A study developed by Tóth et al. (2013) modelled an auction tool ECOSEL, which gives the seller the decision of whether to sell the carbon credits at a particular forest stand age or to decline the offer. The study uses growth rates and introduces its time dependent nature unlike most studies which only refer to constants and averages.

Several studies made use of various approaches to select tree species. The study of Garcia et al. (2013) examined species to see which was most likely to survive by conducting simulations that modelled climate change scenarios. Arias et al. (2011) studied the productivity of native and introduced species in Costa Rica using a complete randomized block design. Conway and Vander Vecht (2015) explored tree species selection criteria used by practitioners involved in urban tree planting and supply through surveys and interviews with stakeholders. Species selection was also applied for the development and restorations of ecosystems. Villacís et al. (2016) evaluated the performance of the saplings of species to generate a list of recommended species based on environmental concerns, such as sapling survival and potential cause of death. Similarly, Todd et al. (2015) assessed the appropriate test species based on ecological impacts and hazards. To date, reforestation programs are highly one-dimensional in direction; thus, there is a need for species selection to incorporate both income and environmental gains.

Harvest rotation studies considering both environmental and economic dimensions of sustainability are abundant. Mönkkönen et al. (2014) used a multi-objective optimization tool to find the best rotation mix among 10 species that will provide the best habitat for biodiversity while maximizing the net present value. Triviño et al. (2015) used a bi-objective optimization to maximize harvest revenues and carbon sequestration and study the trade-offs between provisioning and regulating ecosystem services. Shanin et al. (2016) used EFIMOD to assess the effect of selection cuttings on ecosystem production, carbon sequestration, and volume increment in spruce stands. There is a research gap found on the production of the multiple ecosystem services with uneven-aged management in boreal forests and the economic analyses of the management alternatives. A recent study by Cerutti et al. (2017) quantitatively assessed the causal impact of forest management plans on harvesting levels using a standard difference-in-difference model, which uses a fixed effect estimation method, to a longitudinal data set with a reduced form econometric model. These results were used to deduce the impacts of carbon sequestered.

Despite the significance of considering multiple-specie forests in harvest rotation and methods, most studies refer only to single-species forests. Mönkkönen et al. (2014) incorporated multiple species but does not give insight as to what species should be planted. Harvest rotation provides great insight as to how mathematical modelling greatly helps decision-making for forestation activities, but the simplicity of the models developed may not be as realistic as they should be.

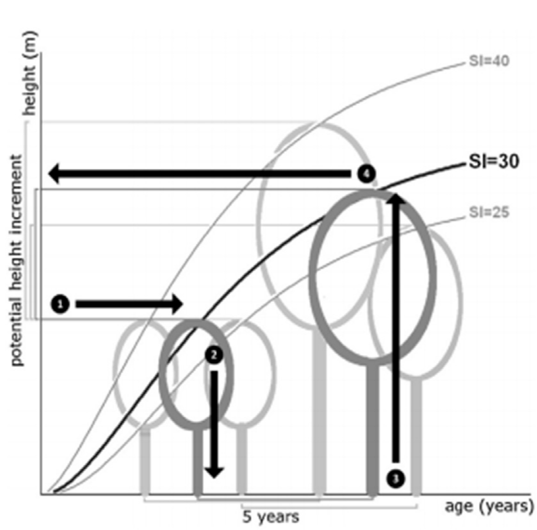


**Fig. 1.** Tree growth curve.
Source: Thurnher et al. (2017). MOSES – A tree growth simulator for modelling stand response in Central Europe. *Ecological Modelling*, *352*, 58–76.

## 3. Problem definition

### 3.1. Research gap

It was discovered that decisions on planting schedules and harvest rotations for forestation are based on stand level modelling