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Determining Optimum Cutting Ages Including Timber Production and Carbon Sequestration Benefits in Turkish Pine Plantations

(Menentukan Umur Tebangan Optimum Termasuk Pengeluaran Kayu Balak dan Manfaat Pensekuesteran Karbon di Ladang Pine Turki)

SEDAT KELEŞ*

ABSTRACT

*This study presents the optimum cutting ages in Turkish pine (*Pinus brutia *Ten.) plantations including timber production and carbon sequestration values in Turkey. Four different growing spaces are considered. The study also evaluates the effects of different discount rates and carbon prices on the optimum cutting ages using net present value approach. The growth and yield curves, biomass equations and carbon conversion factors as well as forest plantation costs and timber assortments revenues for Turkish pine plantations are used to determine the optimum cutting ages. The results of the case study showed that the integration of carbon sequestration benefits into timber production increased the optimum cutting ages of Turkish pine plantations for each growing spaces in order to sequester more carbon. The optimum cutting ages decreased depending on the increase in discount rates. When carbon prices increased the optimum cutting ages also increased.*

Keywords: Climate change; cutting age; forest management; forest values; net present value

ABSTRAK

*Kajian ini membentangkan umur tebangan yang optimum di ladang pain Turki (*Pinus brutia *Ten.) termasuk nilai pengeluaran kayu dan pensekuesteran karbon di Turki. Empat ruang pertumbuhan berbeza diambil kira. Kajian ini juga menilai kesan perbezaan kadar diskaun dan harga karbon pada umur memotong optimum menggunakan pendekatan nilai bersih terkini. Faktor lengkung pertumbuhan dan hasil, persamaan biojisim dan penukaran karbon serta kos ladang hutan dan pelbagai hasil kayu untuk ladang pain Turki digunakan untuk menentukan umur tebangan yang optimum. Keputusan daripada kajian kes menunjukkan bahawa manfaat integrasi pensekuesteran karbon ke dalam pengeluaran kayu meningkatkan umur tebangan optimum ladang pain Turki bagi setiap ruang pertumbuhan untuk sekuester karbon yang lebih banyak. Umur tebangan optimum menurun bergantung kepada peningkatan dalam kadar diskaun. Apabila harga karbon meningkat, umur optimum juga meningkat.*

Kata kunci: Pengurusan hutan hutan nilai; perubahan iklim; nilai kini bersih; umur memotong

INTRODUCTION

Turkish pine (*Pinus brutia* Ten.) is the leading softwood species in Turkey, covering 27% (5.8 million ha) of its mainland forested area, 1.5 million ha of which are afforestation. It is mostly distributed in the Mediterranean and Aegean regions of the country. Since a very long time, Turkish pine forests have been damaged because mainly of inappropriate silvicultural and management interventions, illegal cuttings, overgrazing, forest fires and land use and forest cover changes. According to the latest forest inventory, almost half of the Turkish pine forest area (2.6 million ha) is consisting of unproductive (damaged) forest stands with low growth and yield potential (GDF 2012). In this context, reforestation and afforestation activities with fast-growing tree species have a vital importance in the improvement of degraded areas. They will provide not only high and quality timber production but also many non-timber forest values such as soil protection, water production and carbon sequestration.

A series of significant changes have been occurred in forest management planning system of Turkey especially after 2000s. Timber-oriented forest planning approach was abandoned and ecosystem-based multiple-use forest management including other forest ecosystem functions has been adopted as main planning approach in recent years. This new approach focuses on an initial determination of forest ecosystem functions using a number of criteria and indicators and zoning the forest areas accordingly. However, there are many needs to be solved for the effective implementation of ecosystem-based forest management planning approach (Başkent et al. 2005). Determining rotation ages (or optimum cutting ages) according to multiple ecosystem values is one of them. Rotation ages are generally determined based on management objectives along with biological characteristics of forest trees and site productivity in Turkey. Age where mean annual increment is maximum, has been accepted as rotation age in the areas of timber production function. But there are no ecological and economic considerations or models in determining optimum cutting ages in the presence of multiple ecosystem functions.

The determination of optimum cutting ages when considering timber production and carbon sequestration benefits together is among the hot topics in forest management in recent years. Furthermore, there is a limited research on the determination of optimal cutting ages including both two important forest ecosystem values in the world (Asante & Armstrong 2012; Diaz-Balterio & Rodriguez 2006; Diaz-Balteiro et al. 2014; Kula & Gunalay 2012; Romero et al. 1998; Sohngen and Mendelson 2003; Torres et al. 2010; van Kooten et al. 1995).

The main objective of this study was to determine optimum cutting ages including timber production and carbon sequestration benefits in Turkish pine plantations cultivated in various growing spaces. This study also analyses the effects of various discount rates and carbon prices on optimum cutting ages of Turkish pine plantations. For this aim, net present value (NPV) approach is used and results are presented and discussed along with relevant figures and tables.

Materials and Methods

Forest Ecosystem Functions

This study considers two important forest functions, timber production and carbon sequestration. For the case study, growth and yield curves of Turkish pine plantations per hectare was considered. Figure 1 shows the growth cycle of this species planted with various growing spaces (2 m^2, 3 m^2, 4.5 m^2 and 6 m^2) in the good sites (Usta 1991). Turkish pine plantations produce sawlog, mining pole, industrial wood and fire-wood in Turkey. Volumes of these timber assortments as a result of clear-cutting at any age were determined by product rates of mean stand diameter of the relevant species (Sun et al. 1977). The financial data associated with timber production includes harvesting costs and timber assortments revenues. The net values of timber assortments used in this study are 40, 30, 30 and 10 US$/$m^3$ for sawlog, mining pole, industrial wood and fire-wood, respectively.

Above-ground biomass of Turkish pine plantations in this study is estimated using species-specific allometric regression equation relating diameter at breast height in the tree level. The equation is below (Ünsal 2007).

$$\ln (AGB) = -1.92352 + 2.243357 * \ln (d) \quad (1)$$

where AGB is the above-ground biomass of a tree including stem, branch and canopy (kg); and d is the diameter at breast height (cm).

The below-ground/root biomass is predicted as a proportion of the above-ground biomass using given root-to-shoot ratio of 0.40 if above-ground biomass is smaller than 50 ton/ha, 0.29 if above-ground biomass is between 50 and 150 ton/ha and 0.20 if above ground biomass is higher than

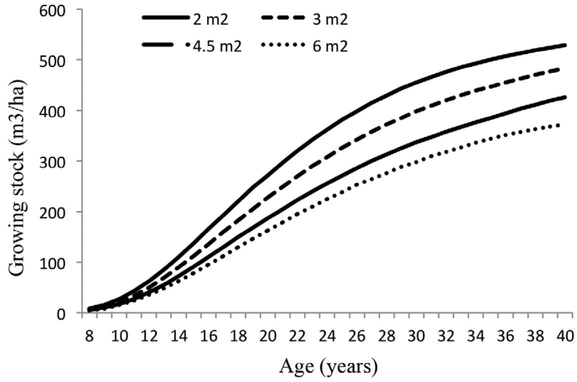

FIGURE 1. Growing stock development of Turkish pine plantations for different growing spaces cultivated in good sites

150 ton/ha. All these conversion factors for the relevant tree species were obtained from the literature (Tolunay 2011). Total tree biomass is then estimated by summation of above-ground and below-ground tree biomass values. Finally, tree-level biomass was converted to per hectare by multiplying tree numbers in the stand. Figure 2 shows the carbon capture amounts of Turkish pine plantations depending on its growth and yield curves for four different growing spaces cultivated in good sites. A slight recession in carbon captures is observed between the ages of 18 and 20 because of the decreasing in root-to-shoot ratios used in the study (from 0.40 to 0.29).

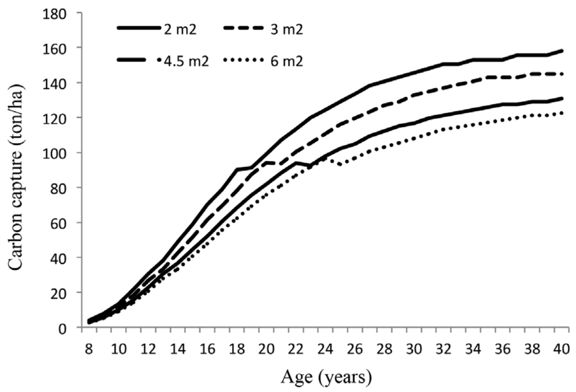

FIGURE 2. The development of carbon captures of Turkish pine plantations for different growing spaces cultivated in good sites

Optimum cutting age model A methodology proposed by Cacho et al. (2003) was used to determine the optimal cutting age including timber production and carbon sequestration benefits for Turkish pine plantations. According to the methods, the value of a stand of forest in the presence of carbon-sequestration payments and with redemption upon harvest is as follow.

$$NPV(T) = v(T)xp_v(age(T))x(1 + r)^{-T} + \sum_{t=0}^{T}[\Delta b(t)xp_c x[1 + r]^{-t}] - C_E - b(T)xp_c x[1 + r]^{-T}, \quad (2)$$

where *NPV(T)* is the net present value of a forest harvested in year T after planting. The first term on the right-hand side corresponds to the value of the timber harvest. The second term corresponds to the sum of the annual net benefits from carbon captured in the interval (0-T). c_E is the plantation establishment cost; p_v is the net value of timber assortments that depend on the mean diameter of trees at harvest; p_c is the price of carbon sequestration in tree biomass in tonnes per hectare; v(T) and b(T) are the timber volume in cubic meters per hectare and the carbon stock in tree biomass in tonnes per hectare, respectively. The last term in the equation corresponds to the assumption that credits obtained during forest growth have to be fully redeemed upon harvest. The annual rate of carbon sequestration is estimated as $\Delta b_t = b_{(t)} - b_{(t-1)}$.

Table 1 shows the estimated costs of an afforestation project with Turkish pine plantations in Turkey. All these values were obtained from the related units of General Directorate of Forestry in Turkey and the relevant literature (Birler 1998).

Some assumptions were also taken into consideration in this study. It was supposed that clear-cutting was only one silvicultural regime. Thinning and pre-commercial thinning are not considered here because there is no growth and yield model for alternative silvicultural treatments of the species. Rental value of the land was not included to estimations of net present values for timber production and carbon sequestration benefits. Because of the uncertainty as well as insufficient information, carbon storage in the litter, soil and the other above-ground vegetation was not included in the model. A discount rate of 3% was used in the reference case and a sensitivity analysis was also carried out. A reference price of 20 US$/ tonne for carbon sequestration was used in the analysis, and followed by a sensitivity analysis.

RESULTS AND DISCUSSION

When carbon sequestration benefits are not included, optimum cutting ages for Turkish pine plantations are 29, 30, 32 and 31 years for the four growing spaces considered (2 m^2, 3 m^2, 4.5 m^2 and 6 m^2), respectively. Obtained net present values are also 1901, 1861, 1701 and 1580 US$ respectively (Figure 3). Figure 4 shows the results of optimum cutting ages including timber production and carbon sequestration benefits for Turkish pine plantations cultivated in four growing spaces in good sites. When compared to above alternatives not including carbon sequestration benefits, NPVs increased for the four growing spaces of 2, 3, 4.5 and 6 m^2 by 30, 31, 34 and 35%, respectively. Optimum cutting ages also increased from 29 to 33 years in growing spaces with 2 m^2, from 30 to 34 years in growing spaces with 3 m^2, from 32 to 39 years in growing spaces with 4.5 m^2 and from 31 to 38 years in growing spaces with 6 m^2, respectively. In all this calculations, carbon price per tonne is considered as 20 US$ and discount rate is taken 3%.

This study also analyzed the effects of various carbon prices and discount rates on optimum cutting ages including timber production and carbon sequestration benefits in Turkish pine plantations. For this, the results of growing space with 2 m^2 were used. Figure 5 and Table 2 presents the changes in the number of optimum cutting ages for the Turkish pine plantations with growing space of 2 m^2 when the discount rate varies from 1% to 5%. The

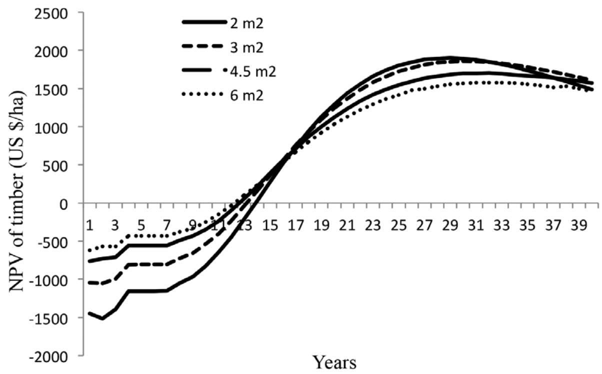

FIGURE 3. Net present values of timber benefits of Turkish pine plantations for the four growing spaces

TABLE 1. Standard operations and their costs (US$/ha) in Turkish pine plantations planted in different growing spaces

Operations	Cost Details	Operation Years	Growing Spaces 2 m^2 (5000 trees/ ha)	3 m^2 (3333 trees/ ha)	4.5 m^2 (2222 trees/ ha)	6 m^2 (1667 trees/ha)
Establishment	Ploughing and Planting	0	1128	780	531	407
	Hoeing (weed control)	1, 2, 3	179	125	88	70
Maintenance	Beating up	2	202	135	90	68
	Fertilization	3	68	68	68	68
	Wire fence construction	1	120	120	120	120
	Chemical intervention against pests	3	10	10	10	10
General Administration	Management, fire control and road maintenance	Each year	30	30	30	30

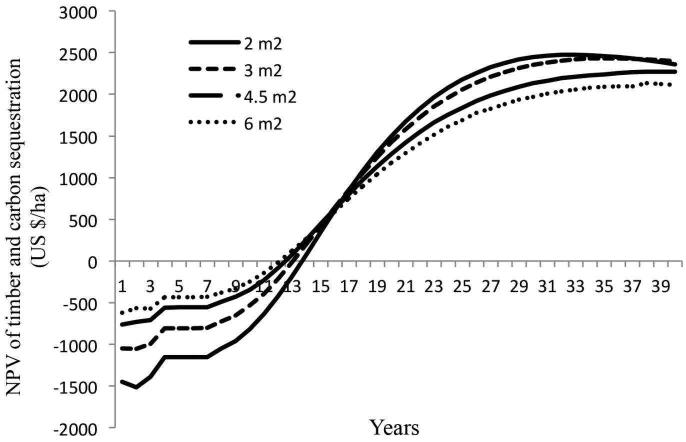

FIGURE 4. Net present values of timber production and carbon sequestration benefits of Turkish pine plantations for the four growing spaces

results showed that optimum cutting ages for the discount rates of 1, 2, 4 and 5% are higher than 40, 36, 31 and 29 years, respectively. It means that increase in the discount rate resulted in a decrease of optimum cutting age and decrease in the discount rate resulted in an increase of optimum cutting age. When the carbon price increased, optimum cutting ages including timber production and carbon sequestration benefits in Turkish pine plantations also increased (Figure 6 and Table 2). Total net present values obtained from timber production and carbon sequestration benefits increased between 14 and 70% depending on the increase in carbon prices (from 0 to 40 US$ per ton carbon). For example, when the unit carbon price is increased from 0 to 10 US$, total net present value increase from 1901 to 2170 US$/ha. While the optimum cutting age is increasing from 29 to 31 years, a profit of 135 US$/ha/year is provided.

Regulating the optimum cutting ages of forest stands is an effective way to manage the multiple ecosystem functions/values of forest ecosystems in a sustainable manner (Liski et al. 2001). It is also one of the most important forest management policies affecting the forest ecosystem structure and composition and quality and quantity of functions provided by forest ecosystems (Creedy & Wurzbacher 2001). Several studies have showed that increasing minimum cutting ages will lead to increases in carbon benefits of forest trees. It means that the integration of carbon sequestration benefits into multiple-use forest management has increased the optimum cutting ages of forest stands (Kaipainen et al. 2004; Liski et al. 2001; Seely et al. 2002). Optimum cutting ages are also very sensitive to unit carbon prices. When the unit carbon price increased, the NPV of carbon sequestration benefits and optimum cutting ages including carbon and timber benefits increased (Backeus et al. 2005; Başkent & Keleş 2009; Diaz-Balteiro & Rodrigez 2006; Kula & Gunalay 2012; Sohngen & Brown 2008; Yousefpour & Hanewinkel 2009). On the other hand, various discount rates have affected the optimum cutting ages of forest stands in the presence of multiple ecosystem values. When the discount rate has increased, the optimum cutting ages have usually decreased (Diaz-Balteiro & Rodriguez 2006; Kula & Gunalay 2012).

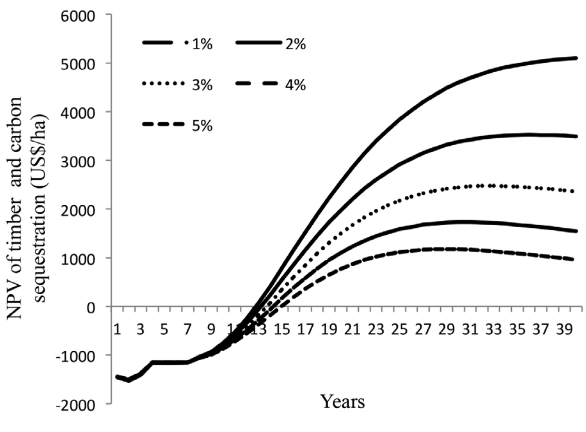

FIGURE 5. Net present values of timber production and carbon sequestration benefits of Turkish pine plantations according to various discount rates

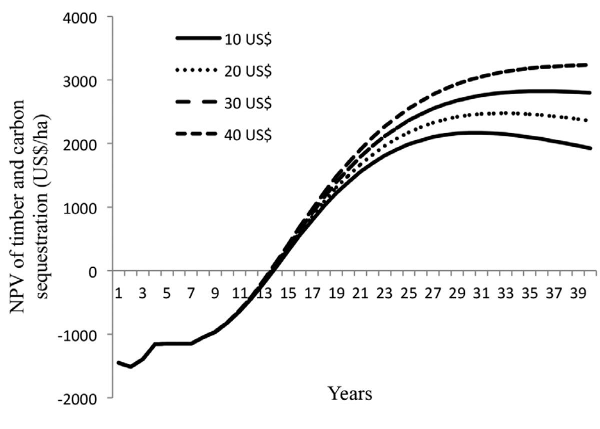

FIGURE 6. Net present values of timber production and carbon sequestration benefits of Turkish pine plantations according to various carbon prices

TABLE 2. Optimum cutting ages for various discount rates and carbon prices

r (%)	NPV of timber	NPV of timber and carbon	Definition
1	38	>40	Carbon price (20 US$/ton)
2	32	36	
3	29	33	
4	27	31	
5	25	29	
Carbon Price (US$)	NPV of timber	NPV of timber and carbon	
10	29	31	Discount rate (3%)
20	29	33	
30	29	36	
40	29	>40	

A sustainable flow of carbon sequestration and timber production benefits are influenced by forest ecosystem characteristics such as tree species, species composition, growing stock and increment. Carbon sequestration amount of forest ecosystems is highly correlated to timber and biomass growth rates of forest ecosystems. In this context, fast-growing forests accumulate a large amount of carbon more rapidly on productive areas. Long-term protection of forest ecosystems managed for timber production has also positive effects on the net carbon sequestration (Huston & Marland 2003). Namely, carbon sequestration and timber production values of forest ecosystems are generally contradictory (i.e. negatively affecting each other). However, when carbon benefits are incorporated into timber production-based models, total net benefit obtained from forest ecosystems increases with increased carbon benefit over time.

CONCLUSION

In this paper, we have determined the optimum cutting ages when carbon sequestration benefits are integrated into timber production benefits in Turkish pine plantations. The results of the case study showed that the integration of carbon sequestration benefits into timber production increased the optimum cutting ages of Turkish pine plantations for different growing spaces. As expected, optimum cutting ages were sensitive to changes in discount rates and carbon prices.

Forest tree plantations may play an important role in solving some ecological and environmental problems in the world. In addition to timber production, forest tree plantations provide many other forest ecosystem functions such as carbon sequestration, soil protection, clean water production and biodiversity conservation. It is also expected that the importance of forest tree plantations will increase in the future. However, forest tree plantations must be managed according to the sustainability principles in order to maximum benefit from them. In this context, determining optimum cutting ages are one of the most important management decisions in ecosystem-based multiple-use forest management.

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