Forest Systems
24(1), e005, 10 pages (2015)
eISSN: 2171-9845
http://dx.doi.org/10.5424/fs/2015241-05607
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Evaluation of Forest Dynamics Focusing on Various Minimum Harvesting Ages in Multi-Purpose Forest Management Planning

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Abstract

Aim of study: Exploring the potential effects of various forest management strategies on the ability of forest ecosystems to sequester carbon and produce water has become of great concern among forest researchers. The main purpose of this study is to evaluate the effects of management strategies with different minimum harvesting ages on the amount and monetary worth of carbon, water and timber values.

Area of study: The study was performed in the Yalnızçam planning unit located on the northeastern part of Turkey.

Material and Methods: A forest management model with linear programming (LP) was developed to determine the effects of various minimum harvesting ages. Twenty-four different management strategies were developed to maximize the economic Net Present Value (NPV) of timber, water and carbon values in addition to their absolute quantities over time. Amount and NPV of forest values and ending inventory with different minimum harvesting ages were used as performance indicators to assess and thus understand forest dynamics.

Main results: Amount and NPV of timber and carbon generally decreased with extended minimum harvesting ages. However, similar trends were not observed for water production values. The results pointed out that the performance of a management strategy depends highly on the development of a management strategy and the initial forest structure aside from the growth rate.

Research highlights: Minimum harvesting ages affect forest outputs under the same objectives and constraints. Performance of a management strategy highly depends on initial age class structure in addition to the contents of a management strategy.

Keywords: linear programming; forest management planning; carbon sequestration; water production; forest dynamics.

Citation: Mumcu Kucuker, D., Baskent, E.Z. (2015). Evaluation of Forest Dynamics Focusing on Various Minimum Harvesting Ages in Multi-Purpose Forest Management Planning. Forest Systems, Volume 24, Issue 1, e-005, 10 pages. http://dx.doi.org/10.5424/fs/2015241-05607.

Received: 16 Jan 2014. **Accepted:** 10 Dec 2014

http://dx.doi.org/10.5424/fs/2015241-05607

Funding: TUBITAK (The Scientific and Technological Research Council of Turkey) through a fellowship of a master student. Another financial support was also provided by KTU (Karadeniz Technical University) under project No: 2006.113.001.3.

Competing interests: The authors have declared that no competing interests exist.

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Introduction

Forests provide various outcomes and utilities such as carbon storage, water production, soil protection, hunting, amenities and recreational facilities for the society besides conventional wood and non-wood forest products. Due to a variety of expectations by the society from the forest resources over the last decades, multiple-use forest management has become the fundamental component of national forest policy. Additionally, managing forest ecosystems that provide multiple goods and services on a sustainable basis is of great challenge and can be achieved through holistic management of ecological, economical and socio-cultural values of forest ecosystems (Christensen *et al*., 1996; Davis *et al*., 2001; Baskent *et al*., 2008a) In this way, the integration of water production and carbon sequestration into forest management planning becomes a significant challenge of contemporary research endeavors.

Forest ecosystems cover wide range of areas on earth and as such they are one of the most important natural assets affecting the management of water resources. Therefore, forest ecosystems have significant function in the management of water resources. However, water resources in terms of quantity and quality are affected by anthropogenic activities as well as natural disturbances. Currently, the perceivable effects of climate change have raised great attention to disclose the water-forest relationship in forest ecosystems under multiple-use forest management concept (Birot *et al.*, 2011). Some studies figured out that change in forest ecosystems such as reforestation, afforestation and deforestation can affect water quantity and quality. For example, researchers such as Dijk & Keenan (2007) found out that increasing plantation age affects the amount of water negatively in afforested watersheds, raising attention to evaluate effects of various rotation ages for multiple-use in forestry. By using linear regression analysis, Sahin & Hall (1996) showed that a 10% reduction in cover caused 20-25 mm and 17-19 mm increase in water yield from conifer and deciduous forest, respectively. Thus, minimum harvesting age particularly in managed forest has become an effective indicator for the sustainable management of forest ecosystems for multiple values.

Over the last decade, the role of forest ecosystems in carbon sequestration has been well recognized because of their critical importance in controlling the global carbon cycle. Fossil-fuel burning and loss of terrestrial vegetation, for instance, have caused the atmospheric carbon dioxide to increase (Huston & Marland, 2003). The carbon dynamics in forests are largely influenced by periodic disturbances of wildfire, insects, disease, degradation, harvesting and over-harvesting (Kurz *et al.*, 2008; Brown, 2002). Besides, increasing gas concentration created greenhouse effects in the atmosphere that has become one of the factors on global climate change. In this respect, Kyoto protocol prepared by the UN Framework Convention on Climate Change (UNFCCC) is a critical instrument, highlighting the importance of forest ecosystems for meeting the limits for carbon emissions (Brown *et al.*, 1999). This protocol aims to minimize net greenhouse gas emissions through maximizing afforestation-reforestation activities and minimizing deforestation of forest ecosystems (Huston & Marland, 2003). Several management practices such as intensive silviculture interventions and various rotation ages can be effective on the amount of stored carbon in forest ecosystem (Backéus *et al.*, 2005; Swanson, 2009). Moreover, sustainable land use and forest ecosystem planning are two key factors on decreasing the level of greenhouse gases in the atmosphere (Hu & Wang, 2008).

In recent years, forest management planning has progressed from classical planning approach to ecosystem or landscape management approach that harmonizes various potential conflicts between goods and services. The new approach accommodates the sustainable management of multiple forest values. However, when various forest values were integrated into forest management plans, it is quite difficult to estimate what minimum harvesting ages would be optimal for the holistic management of the resources. Determining optimal minimum harvesting ages for sustainable utilization of multiple values from forests is a great challenge in forest management planning.

Minimum harvesting age is an important parameter of forest management planning in deciding amount and variety of forest products can be harvested from forests. As known, the timing of interventions (i.e., minimum harvesting ages) to attain the best mix of forest products and services greatly affects the production of goods and services. For instance, Cooper (1983) showed the effects of rotation ages on carbon sequestered in trees and soil. Calish *et al*. (1978) examined the changes of optimal economic rotation ages when some forest resources such as water quantity and mass soil movement are integrated into forest management planning. While deer management shortens the rotation age of Douglas fir, for example, mass soil movement lengthens it. Recently, Diaz-Balteiro & Romero (2003), Backéus *et al*. (2005) and Baskent & Mumcu-Kucuker (2010) incorporated carbon sequestration and water production into forest management planning to understand the trade-offs among forest values. Financial worth of carbon would influence the optimal rotation ages too. Some studies explained that when carbon prices increased, the minimum harvesting age would increase, but when timber prices increased, the minimum harvesting age would decrease (Van Kooten *et al.*, 1995). In addition, Olschewskia & Benitez (2010) demonstrated that cost of carbon have important effect on minimum harvesting ages that may cause a doubling of minimum harvesting age in contrary to optimum 15 years when considering just wood harvest. However, very few studies are involved in evaluating both the interactions between timber harvest and carbon storage and the effects of different minimum harvesting ages on dynamics of forest ecosystems under management (Swanson, 2009; Mumcu, 2007). Therefore, it has become necessary to explore the influence of forest ecosystems onto the carbon storage and water production by evaluating the effects of various harvesting ages on forest dynamics.

This study mainly presents a multiple-use forest management planning methodology accommodating carbon storage, water and timber production combined to form forest management strategies. In this context, carbon storage, water and timber production values were quantified based on forest biomass and twenty-four management strategies were established to maximize NPV of timber, water, carbon or all of them. The effects of three minimum harvesting ages on the level of management objectives were also examined. Management strategies include one forest value in objective function subject to desired level for other forest values as constraints and forest policies such as desired level of products, even flow timber products, and no restriction option. Forest management models developed under various planning strategies were solved by using modified linear programming (LP) approach over a planning horizon. Forest performance indicators such as NPV and amount of all forest values were used to understand forest dynamics created by the various management strategies.

Materials and Methods

Case study area

Yalnızçam Forest Planning Unit, located on the Northeastern part of Turkey, comprises wide area of approximately 44.679 hectares. 37.926 ha of the area consists of forest openings, agriculture, grassland, residential areas and water courses, and 6.752 ha contains pure Scots pine (*Pinus sylvestris L.)* stands. The planning unit has 1275 stands managed based on evenage management practices. In the planning unit mean annual precipitation is about 544,5 mm and mean annual temperature is 3,7 °C. The elevation changes from 1800 m to 2806 m above sea level with an average slope of 33%. The planning unit has an average 158,7 m^3 yield per ha with the initial growing stock mostly distributed on the older age classes. Historical pattern of forest management interventions such as lack of management incentives, insufficient field foresters and existence of social conflicts in the case study area has generated the irregular age class structure (Figure 1). As part of the ecosystems based multiple use forest management concept, the planning unit was divided mainly into two sub management units as timber production dominated planning areas (47%) and multipurpose or conservation dominated planning areas. In latter conservation dominated areas light silvicultural interventions are proposed (Mumcu, 2007). In overall, out of the 9.428 ha forest openings, only 9.046 ha of which is suitable for harvest scheduling.

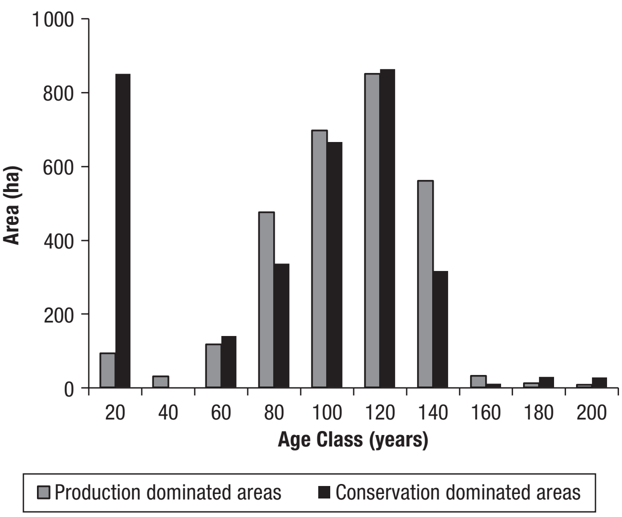

Figure 1. Initial age class structure of the study area.

Quantifying Timber, Water and Carbon Values

Since growth and yield models are not currently available for the study area, the development of the current stands was forecasted through a ratio between the actual and optimal basal areas from the yield table. However, the regenerated stands were presumed to grow according to the empirical yield table developed by Alemdag (1967) for Scots pine. While monetary revenues from various timber assortments were determined for the round wood volume of the relevant timber products and their sale values, the costs were calculated as the sum of general regeneration, administration, maintenance, harvesting, and reforestation costs of the related forest enterprise. To estimate NPV of wood harvests and other values over time 3% guiding rate was determined to be used as discount rate (Turker, 2000).

Interception, evapotranspiration and infiltration are the important parameters determining quantity and quality of water flow (Ferguson, 1996). Reduction of forest cover may cause some hydrological changes such as decreasing interception of rainfall, evapotranspiration and increasing runoff (Stednick, 1996). Bosch & Hewlett (1982), reviewing numerous studies showed that reducing forest cover increases amount of surface water. Therefore, a regression model [1], developed based on a basal area by using SPSS v.11.5 software as part of a master thesis by Mumcu (2007), was used to calculate the amount of runoff surface water in the case study area.

$$WP = 1797{,}97 * e^{-0{,}0196*\mathrm{BA}} \quad R^2 = 51\% \qquad (1)$$

Where; *WP* is the amount of surface water (m^3) and *BA* is the basal area (m^2) of a stand.

The monetary value of water was determined based on incomes and expenses from the Regional Directorate of State Hydraulic Works. The average value of one m^3 water was calculated as average net revenue based on the average utilization rates of 75%, 15% and 10% breakdowns in Turkey for irrigation, drinking-use and industrial water, respectively. Net revenue for one m^3

of different water uses was assumed as half of the sale price, decided by state development agency of Turkey (Anonymous, 2001). Consequently, the weighted average value of one m^3 water was found as \$0.408 (Mumcu, 2007).

Calculating the value of carbon is quite difficult as carbon sequestration is predicted separately for each component of forest ecosystem such as forest floor, understory vegetation, dead wood and soil (Woodbury *et al*., 2007). Carbon cycle in forest ecosystems contains components such as storage in forest soil and products, and emissions from decomposition and burning of forest products, logging and timber transport. In recent years, a number of models have been built to estimate carbon stocks and fluxes in forest soil (Rolff & Agren, 1999). There are some appealing studies analyzing carbon fluxes and integrating them into management planning by different modeling approaches, different scales and different components (Liski *et al*., 2001; Pussinen *et al*., 2002).

In this study, stored net carbon was predicted by taking into consideration of growth, production, loss in forest biomass based on various types of timber [2] (Diaz-Balteiro & Romero, 2003). In addition, decay rates of various timber assortments were determined periodically by equation [3] (Masera *et al*., 2003).

$$CB_t = [\gamma(V^t - V^{t-1} + H_t) - CE_t] \tag{2}$$

$$Cp_{mt+1} = Cp_{mt} * (1 - a_m) \tag{3}$$

Where; CB_t is carbon balance at tth period, CE_t is carbon emissions, H_t is the timber amount harvested, V^t is the timber volume, γ is the conversion factor to carbon, Cp_{mt} is carbon stored in each timber assortment type m and a_m is the portion of the product decaying each period.

Because carbon amount in soil was not involved in the model owing to ambiguous and unreliable data, carbon balance was restricted as below and above ground carbon sequestration. Merchantable volume was employed to calculate the biomass of trees using some equations (Asan *et al*., 2002; Baskent *et al*., 2008b). The carbon emissions were calculated based on the lifetime of timber assortments as suggested in the literature; 50, 40, 15 and 10 years for sawlogs, mining pole, boards, and woody debris such as fuel wood, bark and harvest waste respectively (Krcmar *et al*., 2005). In determining the NPV of sequestered carbon, net carbon income was assumed to be \$20/ton according to UN-ECE/FAO (2000).

Model development

A multiple use forest management model was built with Model I approach (Davis *et al*., 2001) and solved by Lindo 6.1. The model allows achieving various levels of objectives and outputs. The NPV of carbon, timber, water or sum of them were incorporated separately into the model as an objective function. In addition some forest values are kept at desirable levels as a constraint. Twenty-four management strategies were formulated based on the combination of various management objectives with various levels of constraints such as no restriction, no reforestation, and certain levels of desired water and carbon amounts over time (Table 1). Minimum harvesting ages were grouped into short (80) labeled as S*, medium (100) labeled as M* and long (120) years labeled as L* and used as lower harvesting. While maximum harvesting age is fixed as 200 years for all timber production areas, 180 and 300 years were used as lower and upper harvesting ages for the conservation dominated areas. In fact, some minimum harvesting ages were tested before selecting 80, 100 and 120 years of lengths, as others outside this range have limited effects based on the problem formulation in the case study area.

Table 1. Alternative forest management planning strategies.

	Minimum harvesting ages (years)			**Objectives**	**Constraints**
	80-180	**100-180**	**120-180**		
Strategies	ST1	MT1	LT1	Max NPV^{timber}	–
	ST2	MT2	LT2		$W \geq 25x10^7 m^3$
	ST3	MT3	LT3		Even timber flow
	SW1	MW1	LW1	Max NPV^{water}	–
	SW2	MW2	LW2		$C \geq 4x10^6$ton
	SC1	MC1	LC1	Max NPV^{carbon}	–
	SC2	MC2	LC2		No reforestation
	STWC	MTWC	LTWC	Max $NPV^{timber,water,carbon}$	–

Not: Unless indicated such as ST3, MT3 and LT3, all other strategies used relaxed harvest flow constraint.

Some assumptions were established to better understand the complex relationships of forest ecosystem in focus. The planning horizon of 100 years and ten-year periods were decided. All calculations for each stand were assumed to be at the midpoint of each period. The specified planning actions were thinning, clear-fell or no intervention. However, thinning was not allowed for low coverage stands (11%-40%). The study area was separated primarily into two parts as production and conservation dominated areas that included recreation areas, social conflicts areas, rehabilitation areas, high mountain forest ecosystem areas and sensitive areas for biodiversity conservation. In the conservation areas, light silvicultural interventions were proposed (Mumcu, 2007; Baskent & Mumcu-Kucuker, 2010):

– Objective function

$$Z_{max} = NPV^x \quad (4)$$

– Constraints and accounting variables

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}^{x} x_{ij} - NPV^{x} = 0 \quad (5)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} b_{ij}^{x} x_{ij} - V^{x} = 0 \quad (6)$$

$$H_{t+1} - H_t = 0 \quad (7)$$

$$\sum_{t=1}^{T} C_t >= C \quad (8)$$

$$\sum_{t=1}^{T} W_t >= W \quad (9)$$

Here; equation 4 is objective function maximizing NPV of various forest values over the planning horizon. NPV^x represents four different objective functions; NPV of timber production, NPV of water production, NPV of carbon sequestration and NPV of sum of three forest values (timber, carbon and water). While equation 5 shows the NPV of timber, water or carbon, equation 6 carries the quantity of these forest values (timber, water or carbon). Equation 7 expresses the even flow constraint of timber volume. Equations 8 and 9 indicate the required levels of carbon and water as constraints over the planning horizon, respectively. m and n are the number of stands and periods respectively, x_{ij} is the area of stand i treated at period j, a_{ij} is the financial values of products from stand i in period j, b_{ij} is production values of stand i at period j, T is the number of periods, C and W are the required level of ending inventory for carbon and water, respectively.

Results

The effects of minimum harvesting ages on timber production

The results indicate that the highest timber harvest and its NPV over the planning horizon were produced by the strategies with short rotation ages (S*[1]) except strategy ST3 (Figures 2 and 3). The shorter harvesting ages generated more regenerated areas causing the amount of harvested timber and NPV of timber to increase. Furthermore, the stands in timber production areas had chances to be harvested twice over the planning horizon, causing high harvest level and NPV too. When all strategies with the same objective and constraints are compared, shortening harvesting ages from 100 to 80 increases NPV of timber about 14%, from 120 to 80 increases it about 24%. However, the similar trend in strategy *T3[2] was not observed as model afforested all forest opening areas in the first period due to the even flow constraint.

Unexpectedly, among all strategies, the SC1 strategy with max NPV of carbon obtained more timber volumes than did other strategies (Figure 2). Because afforestation of some opening areas contributes more to sequester carbon, model afforested all forest opening areas (9.046 ha) in the first period in *C1 strategies to meet management objectives (Table 2). Compared to SC1, strategy SC2 produced less timber harvest volume because of no reforestation of forest opening areas. Thus, C1 strategies contributed more to timber harvest by regenerating older and unproductive stands in the planning area (Table 2).

The main reason of lesser amount of timber harvest in *T strategies is the objective function that caused to reforest less amount of forest openings (Table 2). As

1. (*) is used as a wild card in the labels of management strategies for a condensed and clearer paper. S* means any management strategy that has letter S at the beginning of it. For example, S* refers the strategies of ST1, ST2, ST3, SW1, SW2, SC1, SC2 and STWC.
2. *T means any management strategy that has letter T in it. For example, *T refers the strategies of ST1, ST2, ST3, MT1, MT2, MT3, LT1, LT2 and LT3. *T1 refers to ST1, MT1 and LT1 strategies and so on.

Table 2. Reforested and regenerated areas over planning horizon by the strategies.

Minimum harvesting age	Type of areas (ha)	Strategies							
		T1	T2	T3	C1	C2	W1	W2	TWC
S 80-180	Reforested	8093	672	1891	9046	0	660	6753	9046
	Regenerated	8542	7865	4674	8780	8812	6982	8761	8780
M 100-180	Reforested	7922	10	6529	9046	0	650	8151	9046
	Regenerated	5640	4772	3966	5949	5949	4614	5819	5949
L 120-180	Reforested	7922	0	1992	9046	0	665	8215	9046
	Regenerated	5648	4872	4373	5958	5958	4627	5891	5958

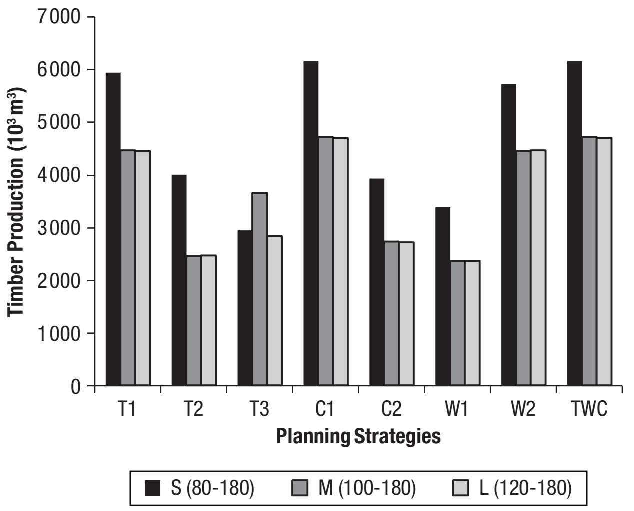

Figure 2. Timber harvest volumes produced by each planning strategy at the end of planning horizon.

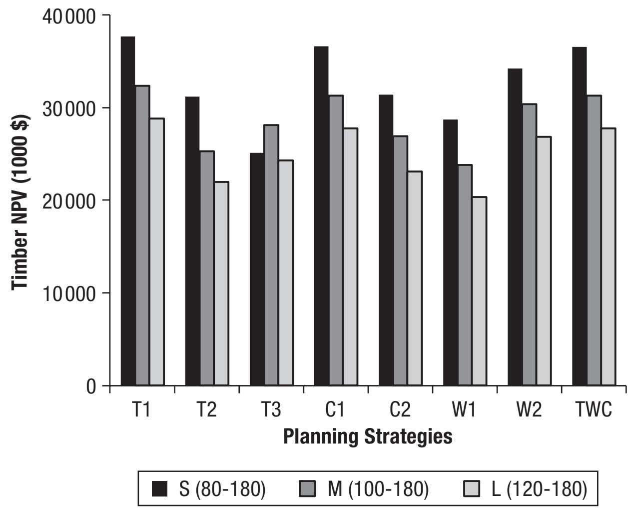

Figure 3. Timber NPV for each planning strategy at the end of planning horizon.

reforestation of forest openings negatively affected NPV of timber, *T strategies produced less amount of timber yield over planning horizon. The results indicated that when the amount of target water ($25x10^7$ tons) was incorporated in strategy *T2, both of volume and NPV of timber decreased. When *T2 strategies were compared to unrestricted strategies of *T1; timber volume reductions were observed as 33%, 45%, 45%, and timber NPV reductions as 18%, 22% and 24% in minimum ages 80, 100 and 120, respectively. Similarly, when the even timber flow constraint (*T3) was included in the model timber volume decreased by 50%, 18% and 36%, and the NPV of timber by 33%, 13% and 16% in minimum harvesting ages 80, 100 and 120, respectively. In addition, as model aimed to maximize water, timber and carbon revenues together, NPV of timber decreased too.

As expected, among all, *T1 and *C1 strategies produced the highest timber NPV ($37.689.256, $36.627.585) over the planning horizon (Figure 3). Even though the objective of *T strategies is the same, *T3 strategies produced lower monetary income than T1 and T2 strategies did due mainly to even-timber flow constraint.

The effects of minimum harvesting ages on carbon sequestration

The strategies with various minimum harvesting ages clearly showed that shorter ages generated more amount and NPV of carbon over the planning horizon, except with even timber flow constraint. When all strategies with the same objective and constraints are compared, for example in strategy *C1, extending minimum ages from 80 to 100 and 120 years decreased carbon values about 6% and 7%, respectively (Figure 4). Similarly, changing minimum harvesting ages from 80 to 100 and 120 years caused to decrease carbon NPV about 4% and 7%, respectively (Figure 5).

Strategies *C1 with maximization of carbon NPV produced the highest carbon and carbon NPV values among all strategies and minimum harvesting ages (Figure 4 and 5). Since the strategies aimed to maximize NPV of carbon sequestration over the planning horizon, most of the stands that reached minimum harvesting age were immediately regenerated particularly in the early periods. As known, slower growth rate of older stands sequester less carbon. As regenerated stands developing in a regulated forest have

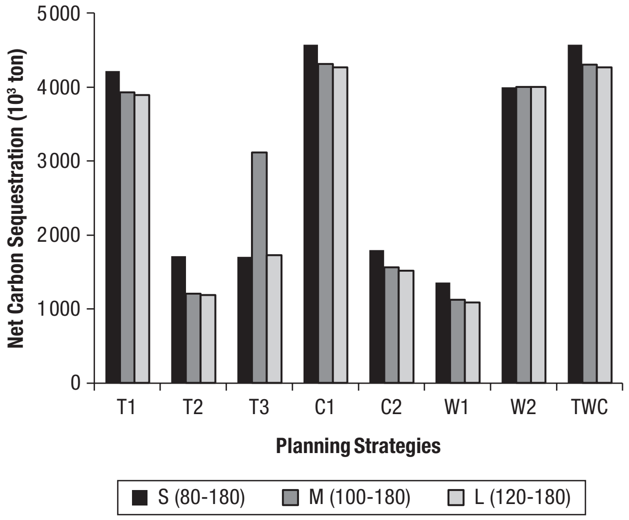

Figure 4. Carbon flux of forest management strategies at the end of planning horizon.

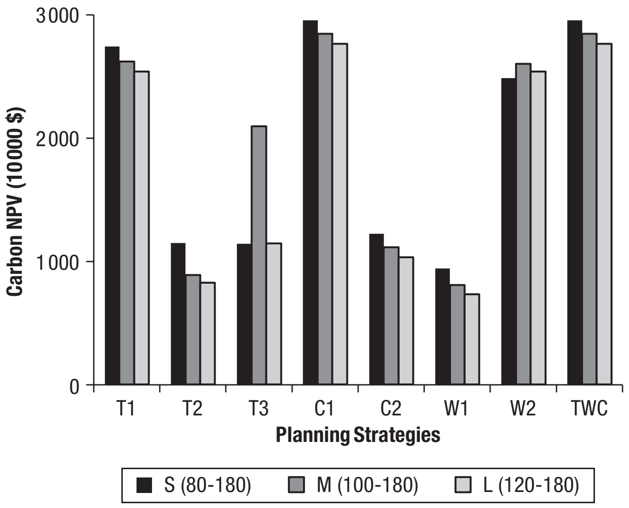

Figure 5. Carbon NPV of forest management strategies at the end of planning horizon.

faster growth rates, strategies with maximization of carbon or monetary value regenerated most of the current stands especially in the former periods. The sequestered carbon is then reduced along with the declining growth rate, probably causing over mature stands to lose carbon (Jarvis *et al*., 2005). More areas were regenerated in the first period in *C1 strategies due to initial broken age class distribution of the planning unit. Since the study area is composed of mainly mature stands, model naturally tended to harvest stands that exceeded the minimum harvesting age particularly in the first period as expected.

Although strategies *C2 have the same objective function, they generated lower value and NPV of carbon. When the afforestation constraint was released from the model, both value and NPV of carbon decreased. Compared to strategies *C1, sequestrated carbon decreased about 61%, 64% and 64% in strategies *C2, NPV of sequestrated carbon also decreased almost 59%, 61% and 63% in minimum harvesting ages 80, 100 and 120, respectively. While all forest opening areas (9.046 ha) were afforested in strategies *C1 especially in the first period, in strategies *C2 no areas were afforested because of the constraint (Table 2). In addition, TWC strategies obtained almost the same amount of carbon and NPV over the planning horizon as the strategies afforested all forest opening areas.

Effects of minimum harvesting ages on water production

The results showed that total water production and NPV in different minimum ages did not follow a sys-

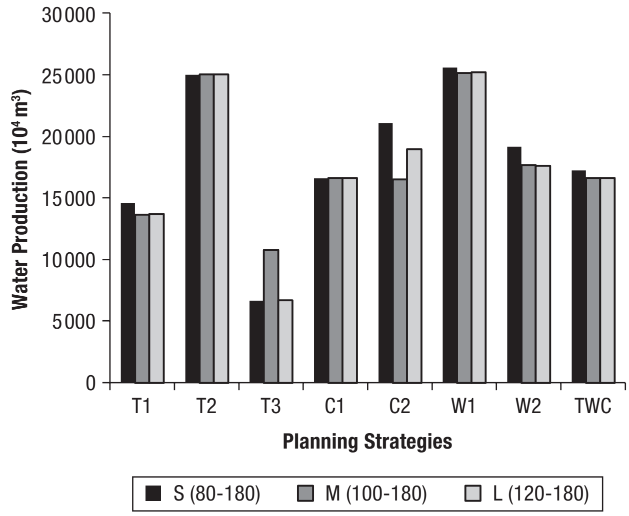

Figure 6. Water production of forest management strategies at the end of planning horizon.

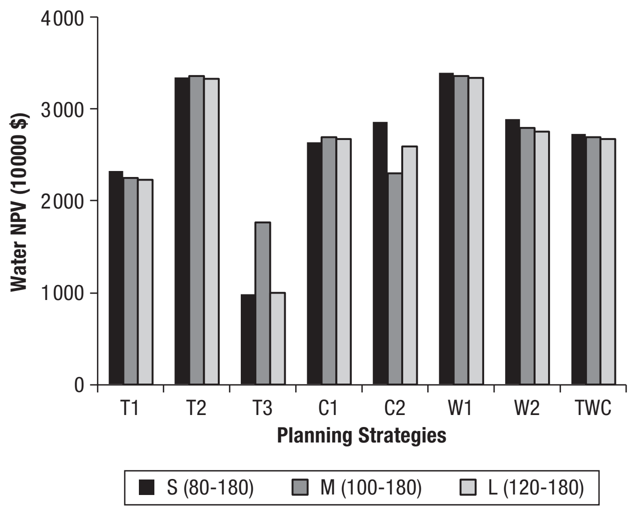

Figure 7. Water NPV of forest management strategies at the end of planning horizon.

tematic trend unlike timber and carbon values (Figures 6 and 7). *W1 strategies aiming maximal NPV of water produced the highest amount of water and their NPV. However, water production decreased about 25%, 29% and 30% when carbon target was incorporated into *W2 strategies with minimum harvesting ages 80, 100 and 120, respectively. It can be seen in Table 2 that in strategies *W2 more forest opening areas were reforested compared to *W1 strategies.

Discussions

In this study, timber, water and carbon values in association with their monetary values were incorporated successfully into a multi purposed forest management plan and the effects of different minimum harvesting ages on these values were explored. Twenty-four management alternatives with various objectives, minimum ages and constraints were developed and solved with LP for a real case study area.

In current study, 180-year minimum harvesting age was used in conservation areas and three different minimum ages such as 80, 100 and 120 years were tested in timber production areas. Shorter harvesting ages facilitated higher timber and its NPV over the planning horizon. A similar study demonstrated that shorter harvesting ages increased the amount of harvested timber (Liski *et al*., 2001). The same study showed that the mean net incomes of timber were the highest for Scots pine and Norway spruce was managed with 90-year and 60-year rotation age respectively. The study obviously showed that when the financial values of timber are integrated into the model, the model overlooks some expenses like reforestation. As expected, additional constraints into management planning cause loss of volume and NPV of timber products (Raymer *et al.,* 2005; Baskent *et al*., 2008b).

In addition, when carbon values from all strategies with the same objective and constraints were compared, 80-year harvesting age caused higher carbon storage to take place. The mature initial age class structure in the planning unit seemed to be the most important factor causing for this response. As known, older stands sequester less carbon because of slower growth rate while regenerated stands developing in a regulated forest sequester more carbon (Jarvis *et al*., 2005). Similarly, Backéus *et al*. (2005) demonstrated that total carbon storage increases at a slower rate when a forest matures over time, implying less amount of carbon flux in a forest. Perez- Garcia *et al*. (2005) figured out that when carbon emissions are taken into account, shorter rotations incline to increase total carbon storage. Liski *et al*. (2001), however, showed that while the cumulative amount of carbon sequestered in Scots pine forest increased with increasing harvesting age it reduced in Norway spruce forest. Similarly, some researchers indicated that some silviculturel interventions such as reforestation (Krcmar *et al*., 2001; Baskent *et al*., 2008b) or afforestation (Kaul *et al*., 2009) particularly in early periods, cause high biomass and provide positive effects on the sequestrated carbon despite the certain amount of expenses of reforestation.

However, the results indicated that total water production and NPV in different minimum harvesting ages did not follow a systematic trend observed in timber and carbon values. As the water production is related to the basal area, strategies *W2 regenerated further areas in the early periods and accordingly most of the forest openings were reforested in the first period. In following periods, the renewed or reforested subcompartments created further basal area, resulting in less quantity of water production. Similar correlations were detected by other researches (Brown *et al*., 2005; Benyon *et al*., 2007).

This study showed that the amount of forest products and services derived from forest ecosystem depend on minimum harvesting ages as well as forest management activities. Thus, the minimum harvesting age can then be considered a good tool and effective method to manage the forest products and services in developing forest management policies (Liski *et al.,* 2001). Additionally, the performance of a management strategy depends highly on the components of a strategy and the initial forest structure aside from the growth rate.

The model developed in this study may have some shortcomings for further improvements. The stand simulation model is related to a simple allometric relationship between the current and the optimal development pattern of the stands. Realistically, however, a dynamic growth and yield model should be developed based on permanent sample plots and site information. There are many forest management objectives such as controlling soil loss that may have to be integrated into the model as well. The spatial arrangement of the harvest schedule such as block size, adjacency and opening sizes needs to be controlled either by using mixed integer programming or meta-heuristic techniques. Decomposition rates of timber should be calculated according to time and species too. The amount of soil carbon should also be taken into account in calculating total sequestered carbon. Furthermore, stochastic incidents such as forest fires, wind, insect fungi and climatic change affecting forest products and monetary values should also be involved in multiuse forest management planning.

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