A computer-based optimization model for multiple use forest management planning: a case study from Turkey

Modelo de otimização baseado em computador para o planejamento do manejo florestal para usos múltiplos: um estudo de caso da Turquia

Sedat Keleş[1] e Emin Zeki Başkent[2]

Abstract

Multiple-use forest management planning focuses on developing alternative management strategies to achieve a desired flow of products and benefits from the forest ecosystem over time. A forest management planning model is indispensable to generate planning alternatives and determine an optimal management schedule. This research has developed an optimization model for multiple use forest management planning. A number of applications and analyses are performed by using the model. The main objective of these applications is to assess the effects of different minimum cutting ages and some forest management policy constraints on timber production, carbon sequestration, oxygen production, soil erosion and water production in a forest management unit in Turkey. Based on a reference case, results showed that increasing the minimum cutting ages by 10 and 20 years decreased the net present value (NPV) of timber by 19.25% and 42.16%, respectively. With a reduction of 20 years, however, total timber production, carbon sequestration and oxygen production increased by 37.74%, 12.1% and 12.1%, respectively. On the other hand, the amounts of soil erosion and water production decreased by 3.18% and 1.2%, respectively. Results showed that volume control policies decreased the amounts of the NPV of timber production (between 24.19% and 45.3%), carbon sequestration and oxygen production (between 9.01% and 20.25%). It was also estimated that a model including a regulated timber volume constraint resulted in an increase in the amounts of water production and soil erosion (between 1.71% and 5.09%) compared to an unconstrained model.

Keywords: Forest management, Optimization, Forest ecosystem values,

Resumo

O planejamento do manejo florestal de uso múltiplo se concentra no desenvolvimento de estratégias alternativas de manejo para atingir um fluxo desejado de produtos e benefícios do ecossistema florestal. A utilização de um modelo de planejamento de gestão florestal é imprescindível para gerar alternativas de planejamento e determinar um cronograma de gestão otimizada visando justificar o uso sustentável das florestas. O presente trabalho desenvolveu um modelo de otimização para planejamento de manejo florestal de uso múltiplo. Várias aplicações e análises foram realizadas usando o modelo em questão. O principal objetivo desses aplicativos é avaliar os efeitos de diferentes idades mínimas de corte e algumas políticas de restrição em relação à produção de madeira, seqüestro de carbono, produção de oxigênio, erosão do solo e produção de água em uma unidade no manejo florestal na Turquia. Com base no caso de referência, os resultados mostraram que o aumento da idade mínima de corte de 10 e 20 anos diminuiu o valor presente líquido (VPL) de madeira de 19.25% e 42.16%, respectivamente. No entanto, com uma redução de 20 anos, a produção total de madeira, seqüestro de carbono e produção de oxigênio no final do horizonte de planejamento aumentou 37.74, 12.1 e 12.1%, respectivamente. Por outro lado, com uma redução de 20 anos na idade mínima de corte, os valores de erosão do solo e produção de água diminuiu em 3.18% e 1.2%, respectivamente. Os resultados também mostraram que as políticas de controle de volume diminuiram os valores do VAL da produção de madeira (entre 24.19 e 45.3%), seqüestro de carbono e produção de oxigênio (entre 9.01 e 20.25%). Foi também estimado que um modelo com uma restrição de volume de madeira regulamentada resultou em um aumento nos valores de produção de água e erosão do solo (entre 1.71 e 5.09%), em comparação com um modelo irrestrito.

Palavras-Chave: Manejo florestal, Otimização, Valores ecossistema floresta,

[1]Çankırı Karatekin University, Faculty of Forestry, Çankırı-Turkey. Department of Forest Engineering, 18200 Çankırı – Turkey - E-mail: skeles79@gmail.com; skeles@ktu.edu.tr

[2]Karadeniz Technical University, Faculty of Forestry, Trabzon-Turkey.

INTRODUCTION

Forest ecosystems provide a number of values, such as timber production, forest recreation, aesthetics, biodiversity, habitat for some wildlife species, water production, soil protection, carbon sequestration and oxygen production. Forest management practices affect forest ecosystem dynamics and all the forest ecosystem values are influenced by forest ecosystem characteristics such as tree species, forest age distribution, stand basal area, growing stock, and development stages of forest stands.

Recently, emphasis in forest management planning is placed not only on timber production but also on the other forest ecosystem values. Thus, the meaning of sustainable forest management has broadened from sustainable timber management to ecosystem-based multipurpose forest management (Başkent; Keleş, 2009). While multipurpose forest management is accepted as a leading forest management policy, there is still a need to develop forest simulation and optimization models that incorporate multiple uses of forests as management objectives. On the other hand, in order to address complex forest management problems, decision makers need appropriate information, good impact forecasting models, mechanisms to promote standards, and decision tools that aid in the development of forest management plans (Church *et al.*, 2000).

Internationally, there is a wide range of variation in forest management planning models, with respect to both methodology and complexity. In general, the most comprehensive models are found in the Nordic countries and in the USA. The most important optimization-based forest management planning models developed in the USA are TimberRAM (NAVON, 1971), MUSYC (JOHNSON; JONES, 1980), FORPLAN (JOHNSON *et al.*, 1986), TEAMS (COVINGTON *et al.*, 1988), Spectrum and RELMdss (GREER; MENEGHIN, 2000; CHURCH *et al.*, 2000). In Sweden and Finland, forest management models corresponding to the development of long-term timber production analyses are HUGIN (LUNDSTRÖM; SÖDERBERG, 1996), Forest Management Planning Package (FMPP) (JONSSON *et al.*, 1993), and JLP-J-MELA (LAPPI, 1992; REDSVEN *et al.*, 2005). Furthermore, review articles describing some important forest management planning models from different perspectives are provided by Kent *et al.* (1991), Nabuurs and Paivinen (1996), Weintraub and Bare (1996), Mowrer *et al.* (1997), Martell *et al.* (1998), Eid and Hobbelstad (2000), Church *et al.* (2000), and Turner *et al.* (2002).

To date, not many forest planning models have been developed in Turkey as the country has recently embraced the concept of modeling in forest management planning process. While the forest management department in Turkish Forest Service developed a sequential computer-based programme to prepare forest management plans in Turkey, the model is just a computer program that queries forest inventory database to document tables specified by the management guidelines. It is not exactly a forest management planning model as it does not project the future forest condition under a number of forest management regimes. Thus, a new forest planning model of ETÇAPOptimizasyon has been developed based on ecosystem based multiple use forest management planning philosophy (BASKENT *et al.*, 2008b). The ETÇAPOptimizasyon accommodates linear programming and information technologies, and provides various opportunities in preparing forest management plans while enabling the process to be faster, sound and timely while using relatively less amount of time and labor.

This study presents an optimization-based multiple-use forest management planning model (ETÇAPOptimizasyon) to assist in the formulation of forest management plans. The primary objective of the research was to introduce the general framework of the model in brief. The second objective is to use the forest management planning model by analyzing the long-term effects of different minimum cutting ages and a number of forest management policy constraints on forest ecosystem structure and some forest ecosystem functions such as timber production, carbon sequestration, oxygen production, water production and soil erosion.

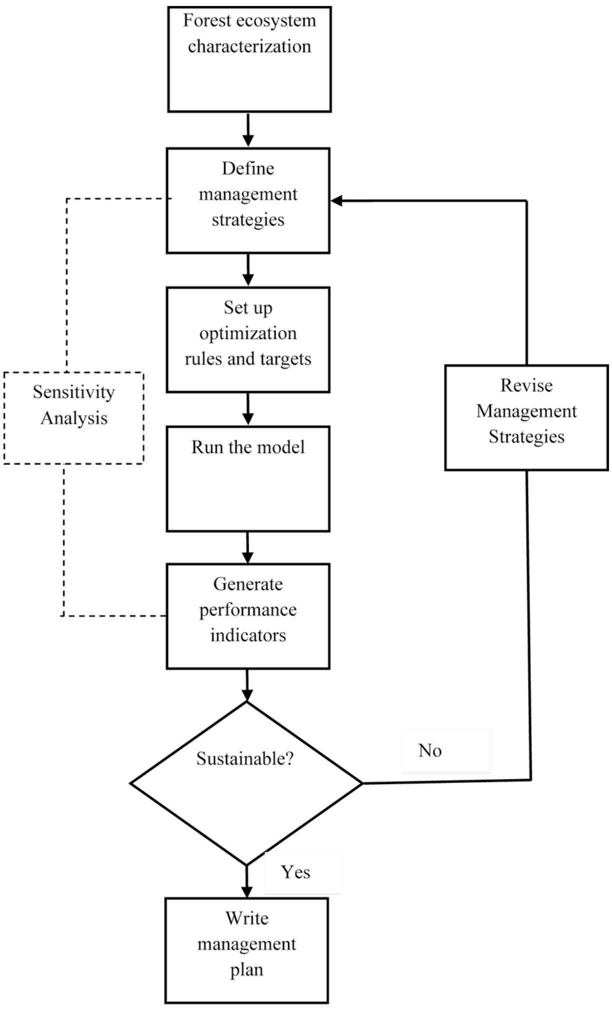
MATERIAL AND METHODS

ETÇAPOptimizasyon Model Description

ETÇAPOptimizasyon is a Linear Programming (LP)-based forest management planning system that consists of a matrix generator and report writer, both of which interface with a commercial mathematical programming solution package. The current implementation of ETÇAPOptimizasyon is also a collection of modules and components which can be re-used when constructing new applications and models. The development of the model is based on both user requirements and operational specifications. In ETÇAPOptimizasyon, conventionally large-scale ecosystem management optimization problems have been modeled using linear programming. ETÇAPOptimizasyon model is written in DELPHİ, an object-oriented programming language. The system was developed to operate on a personal computer under Windows. It sets up the problem in standard mathematical programming system (MPS) format for solving by a commercial LP package such as LINGO (and LINDO) as used here (KELEŞ, 2008).

ETÇAPOptimizasyon is a deterministic optimization model consisting of a number of primary components: data input, actions, and an output (Figure 1). Data input includes all the procedures required to enter the spatial data about initial forest structure, yield tables, economic revenues and costs, silvicultural regimes, and management guidelines. The actions refer to the prescriptions identified for each stand type and management policies for the whole forest. Prescription is a series of silvicultural treatments or management interventions to be applied to a stand type over a planning horizon. Model output component is the forest performance indicators to show the temporal change of forest ecosystems.

Figure 1. A typical process of forest management optimization model.
Figura 1. Processo típico de modelo de otimização de manejo florestal.



ETÇAPOptimizasyon is specifically designed to schedule the management strategies of a forested area over time. It typically involves the allocation of forest area to management regimes for treatment and product outputs, which is developed through the incorporation of concerns for multiple use and protection of environmental and ecological values. It also offers the capability to simulate management strategies across forest landscapes through time. On the other hand, defining management strategies is necessary before forecasting forest development over time. A management strategy consists of an objective and a set of constraints. The problem can be formulated with an objective function of timber production, water production, soil erosion, carbon sequestration, oxygen production, and their net present values. Furthermore, total net present values of some forest values can be selected for an objective function such as the net present value of timber plus the net present value of water. There is also a wide variety of optional constraints that users incorporate in their models. Examples include constraints required to ensure that policy constraints and minimum management standards are met, constraints on output production targets, constraints on budget revenue, and constraints on water, soil, carbon, and oxygen. Some of these constraints can be applied to the entire forest, while others can be applied to subsets of the forest. In addition, each constraint can be imposed for one or more time periods during the planning horizon. A management strategy also accommodates the option of planning horizon length, planning period length and harvesting method.

In ETÇAPOptimizasyon model, the landscape is stratified into analysis areas. Each analysis area consists of forest stands which is the smallest management unit. An analysis area would also be identified as each stand. The model provides means for alternative silvicultural regimes for each analysis areas selected manually by the user. One or more silvicultural regimes can be prescribed to the analysis area. Silvicultural regimes for each analysis area are designed based on inventory data, forest-level and stand-level defined forest treatment assumptions. Management regimes are represented in the ETÇAPOptimizasyon model by one or more decision variables.

The functionality provided by ETÇAPOptimizasyon may be interpreted as the generation and real-time visual display of different management strategies and alternatives over time. The results can be displayed in the formats of tables, graphics and forest maps. In order to increase the visual representation of the forest landscape, ETÇAPOptimizasyon provides the capability for viewing graphics, tables and maps associated with actual or simulated forest areas in relation to potential management regimes.

Growth and Yield Projection

A stand simulation model within the ETÇAPOptimizasyon model was developed to project the growth of each existing stand. This model is a time based, non-stochastic empirical model for simulating in detail the growth of an even aged stand. This model assumes that the growth of a particular stand will follow some definable and predictable pattern in relation to the trend established by a yield table. ETÇAPOptimizasyon model utilizes user-supplied empirical yield tables. Thus, the model provides all the information such as basal area, growing stock, increment, and number of tree associated with forest stands. This model is not limited in the number of yield tables that can be included.

Financial Analysis

The financial information associated with timber assortments is used to calculate all the costs and revenues derived from the harvest, thinning, regeneration, and reforestation activities. Timber harvest financial data includes the timber values, harvesting costs and wood assortments revenues. The model assumes that values and costs can change throughout the simulation length, and uses the Net Present Value economic approach. This allows for the calculation of actual net revenues for each year of the simulation. The discount rate is being used to compute revenue and cost present values and present net revenues. As a consequence it is mandatory that the user enter these values. Furthermore, economic values for the other forest ecosystem values can be inserted into the model as a unit value (e.g., $20/ton carbon) in a window of list box.

Carbon Sequestration

In ETÇAPOptimizasyon model, carbon sequestration in successive periods is determined by accumulating the amount of timber biomass of the forests and subtracting the biomass removed from the ecosystem by various reasons such as harvesting. Forest timber biomass and carbon storage for each stand is estimated using species-specific biomass expansion or conversion factors (KELEŞ; BAŞKENT, 2007; BAŞKENT *et al.*, 2008a; KELEŞ, 2008; BAŞKENT; KELEŞ, 2009). The carbon emissions from various forest timber assortments are also taken into consideration and estimated in this study based on the lifetime of each wood product for each stand (KELEŞ; BAŞKENT, 2007; BAŞKENT *et al.*, 2008a; KELEŞ, 2008; BAŞKENT; KELEŞ, 2009).

Oxygen Production

Forests produce oxygen in response to the consumption of CO_2 as part of photosynthesis. In ETÇAPOptimizasyon model, we adopted a method similar to Guo *et al.* (2001), Asan *et al.* (2002), and Başkent *et al.* (2008a) based on the formula of photosynthesis and respiration. The formula of photosynthesis and respiration is as follows:

$$CO_2\ (264\ g) + H_2O\ (108\ g) \rightarrow C_6H_{12}O_6\ (180\ g) + O_2\ (193\ g) \qquad (1)$$

According to Equation 1, forest absorbs 264 g CO_2 for the production of 162 g dry material. In other words, it needs 1.63 g CO_2 and releases 1.2 g oxygen to form 1 g dry material. Carbon is converted to CO_2 equivalent by multiplying by 44/12 (3.6667). Oxygen balance is calculated like carbon balance because oxygen is consumed when cutting residues, deadwood and forest products decomposed.

Soil Erosion

The amount of soil protected by forest ecosystems is estimated according to three different soil erosion models in the current version of ETÇAPOptimizasyon model. Based on the modularity of ETÇAPOptimizasyon model, however, a new soil erosion model can be incorporated into the model easily. In this paper, we selected the soil erosion model developed for conifer forests including Pinus sylvestris stands in the northeastern forest ecosystems (YOLASIĞMAZ, 2004). In determining soil losses of forest stands, Yolasığmaz (2004) used the Universal Soil Loss Equation which includes some important parameters such as rainfall erosivity factor, soil erodibility factor, slope length factor, slope factor and cover management factor. The equation is as follows;

$$SL=30.437*e^{(-0.0488*BA)}$$
$$(R^2:0.55,\ SE:\ 69\%) \qquad (2)$$

Where, *SL*: the amount of soil loss (ton/ha/year), *BA*: residual stand basal area (m^2/ha), and *e*:2.71828.

Water Production

In the current version of ETÇAPOptimizasyon model, the amount of water production of forest ecosystems was estimated according to a few water production functions. Again, based on the modularity of ETÇAPOptimizasyon model, however, new water production models can easily be incorporated into the model. In this paper, the water production function developed by Mumcu (2007) for *Pinus sylvestris* stands in the case study area was used. The model equation for the water that runs off is as follows;

$$WP=1797.97*e^{-0.0196*BA}$$
$$(R^2:0.50,\ SE:\ 19\%) \qquad (3)$$

Where: *WP*: annual water production (ton/ha), *BA*: residual stand basal area (m^2/ha), and *e*: 2.71828.

CASE STUDY AREA

The study area of Yalnızçam Forest Planning Unit is situated in Ardahan province in the northeastern corner of Turkey. The area consists of primarily high mountain forests and scattered settlements such as villages and upland shelter lands. The altitude varies between 1800 m and 2920 m with an average slope of 23%. Naturally, the region is covered by *Pinus sylvestris* L., the most widely distributed species in the world and the species is in its most southern site of the world distribution. The study area covers an area of 44,680 ha of which 6,753 ha is forestland. The total number of stands in forested areas is 944 with an average size of 2.5 ha. Forest stand types in the study area are grouped according to the tree species, development stage and crown closure.

FOREST PLANNING MODEL DESCRIPTION

The forest planning model in the reference case maximizes the net present value of timber production. A reference case was defined as minimum cutting ages 100 years in good sites and 120 years in poor sites. Maximum cutting age, however, was set to 200 years. In reference case, all financial calculations were discounted to today's value (NPV) with a 3% interest rate, as generally applied to the financial evaluation of forestry projects in Turkey. Commercial thinning action was designed for the stands whose ages range from 30 years to 100 years. These age limits define the operability window of the stands and are reference cases as adopted from the Turkish Forest Management Guidelines in timber-oriented forest management planning approach. All forest stands are subject to harvesting, and also the model includes "do nothing" intervention. The planning horizon is 100 years and the planning period is 10 years. All forest ecosystem values and forest stand characteristics are calculated at stand (sub-compartment) level. Regeneration is assumed to follow immediately after harvesting and regenerated areas are assumed to develop according to empirical yield tables. Growth and yield projection of actual stands is forecast according to typical simulation of growth potential of stands. All forest stand parameters and forest values are estimated at the midpoint of each period. The model also analyses the effects of different minimum cutting ages and forest management policy constraints on pre-defined forest ecosystem values. The policy constraint includes regulating the harvested timber volume over time.

RESULTS AND DISCUSSION

Based on the reference case, 100-years-of planning horizon is defined as minimum cutting age on good sites and 120 years on poor sites. In the reference case, the NPV of timber was $33,925,398. When the minimum cutting ages were extended to 20 or 40 years, the NPV of timber decreased reasonably. These reductions were 19.25% and 42.16%, respectively (Table 1). With a reduction of 20 years, the NPV of timber increased by 11.68% (from $33,925,398 in the reference case to $37,887,571). In addition, with a reduction of 20 years, total timber production at the end of the planning horizon increased by 37.74% (from 2,994,859 m^3 in the reference case to 4,125,223 m^3). According to the results, the minimum cutting ages should be reduced by 20 years to allow maximizing the NPV of timber and timber production.

Table 1. Relative changes in the forest ecosystem values with various minimum cutting ages.
Tabela 1. Mudanças relativas nos valores do ecossistema florestal com diversas idades mínimas de corte.

Minimum Cutting Age (years)	NPV of Timber ($)	Timber Production (m^3)	Carbon Sequestration (ton)	Soil Erosion (ton)	Water Production (ton)	Oxygen Production (ton)
Reference case	33 925 398	2 994 859	1 213 562	18 900 880	1 398 519 900	3 236 166
- 20	+ 11.68	+ 37.74	+ 12.1	- 3.18	- 1.2	+ 12.1
+ 20	- 19.25	- 24.86	- 12.69	+ 5.36	+ 3.19	- 12. 69
+ 40	- 42.16	- 27.06	- 28.67	+ 11.72	+ 7.37	- 28.67

Results showed that the extension of the minimum cutting ages decreased carbon sequestration and oxygen production. When the minimum cutting ages were extended by 20 and 40 years, total carbon sequestration and oxygen production of forest ecosystem decreased by 12.69% and 28.67%, respectively. However, with a reduction of 20 years in minimum cutting age these forest values increased by 12.1% (Table 1). Harvested and standing timber volumes over time are important forest performance indicators in analyzing the effects of forest management practices on forest ecosystem structure and its values. As mentioned previously, carbon sequestration and oxygen production of forest ecosystems are related to timber and biomass growth rates of forest ecosystems (BAŞKENT *et al*. 2008a; BAŞKENT; KELEŞ 2009). The performance of growing stock according to various minimum cutting ages over the planning horizon is shown in Figure 2. With a reduction of 20 years in minimum cutting age, model produced the highest timber growth rates depending upon the harvested and standing timber volumes. Thus, it was found that the amounts of carbon sequestration and oxygen production in forest ecosystem were greater than those in other minimum cutting ages. On the other hand, with a reduction of 20 years in the minimum cutting age, the amounts of soil erosion and water production decreased by 3.18% and 1.2%, respectively. When the minimum cutting ages were extended by 20 and 40 years, total soil erosion and water production at the end of the planning horizon increased reasonably (Table 1). As mentioned previously, soil erosion and water production values are directly related to basal area development of forest ecosystem. The development of basal area of forest according to various minimum cutting ages is shown in Figure 3. With an extension of minimum cutting age, basal area development of forest follows a lower course than reference case, and model produces more soil erosion and more water production.

On the other hand, volume control policies decreased the NPV of timber and timber production. In other words, the timber volume constraints were binding. As already known, in most cases, the integration of regulatory constraints into forest management plans causes losses in both financial profits and timber volume (Field *et al*., 1980; HOF *et al*., 1986; HAIGHT *et al*., 1992; HOGANSON; MCDILL, 1993; BAŞKENT; KELEŞ, 2009). Compared to reference case model, the reductions in the total NPV of timber varied between 24.19% and 45.3% (Table 2). However, the timber volume

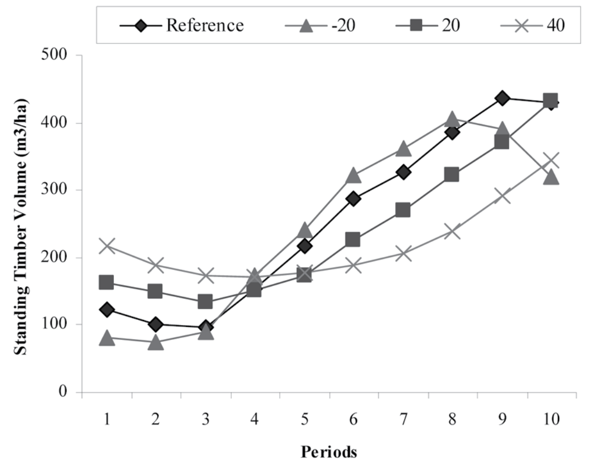


Figure 2. Standing timber volume change over time for various cutting ages
Figura 2. Variação do volume de madeira em pé (remanescente) ao longo do tempo para várias idades de corte.

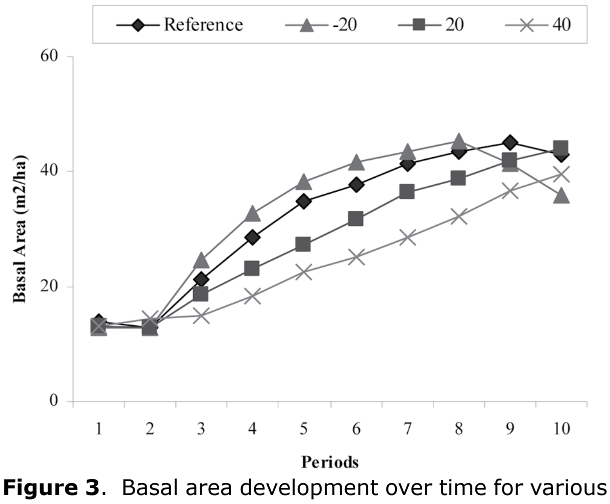


Figure 3. Basal area development over time for various cutting ages.
Figura 3. Desenvolvimento da área basal ao longo do tempo para várias idades de corte.

variation within given fractional decrease and increase was allowed among periods in these scenarios, or namely volume control policies were carried out. Compared to the scenarios including volume control policies, reference model provided non-regulated timber volume among periods, and it focused on cutting more stands in the first periods to increase timber production.

Results also showed that volume control policies decreased the amounts of carbon sequestration and oxygen production moderately. These reductions changed between 9.01% and 20.25%. Depending on the decreasing harvested and standing timber volumes, volume control policies caused a reduction in timber growth rates of forest ecosystem (Figure 4). Thus, it was found that the amounts of carbon sequestration and oxygen production were lower than reference case. It was also estimated that a model including a regulated timber volume constraint resulted in an increase in the amounts of water production and soil erosion compared to an unconstrained model. As expected, decreasing basal area caused less soil protection and more water production (Figure 5).

SUMMARY AND CONCLUSION

This study developed and used a stand based forest-level optimization model –ETÇAPOptimizasyon. The model simulates the development of a forest ecosystem and the long-term effects of various management activities on the forest ecosystem structure and its functions over time. In this study, a number of forest ecosystem values (timber production, soil erosion, water production, carbon sequestration and oxygen production) were successfully incorporated into the forest management planning process with timber oriented forest management.

On the other hand, the specific scope and characteristics for the ETÇAPOptimizasyon model in this research can be summarized as follows:

- It is a general purpose long-term management model that simulates the dynamic behavior of forest ecosystems with ecological and financial understandings of forest management activities.
- ETÇAPOptimizasyon will enable the preparation of forest management plans, easy to be updated as it was developed in-house with object-oriented approach to accommodate various management needs as they arise. The model ac-

Table 2. Relative changes in the forest ecosystem values at different levels of harvesting timber volume constraints.
Tabela 2. Mudanças relativas nos valores do ecossistema florestal em diferentes níveis de restrições de volume de colheita de madeira.

Forest Management Policy Constraint	NPV of Timber ($)	Timber Production (m³)	Carbon Sequestration (ton)	Soil Erosion (ton)	Water Production (ton)	Oxygen Production (ton)
Reference case	**33 925 398**	**2 994 859**	**1 213 562**	**18 900 880**	**1 398 519 900**	**3 236 166**
Even flow	- 45.3	- 19.52	- 20.25	+ 5.09	+ 3.87	- 20.25
10% fluctuation	- 34.76	- 20.56	- 13.99	+ 3.45	+ 2.58	- 13.99
20% fluctuation	- 24.19	- 21.17	- 9.01	+ 2.52	+ 1.71	- 9.01

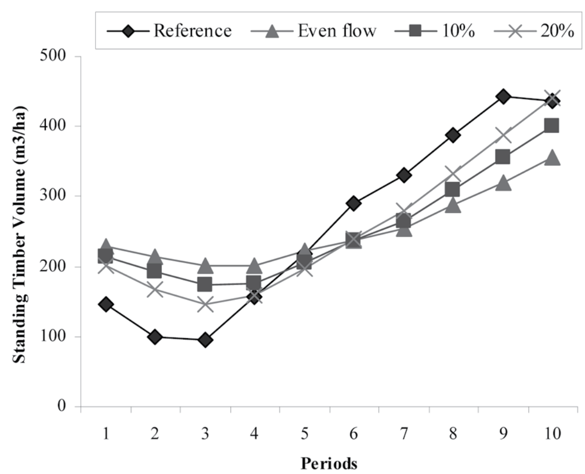


Figure 4. Standing timber volume change over time for different management policy constraints.
Figura 4. Variação do volume de madeira em pé (remanescente) ao longo do tempo para diferentes restrições políticas de manejo.

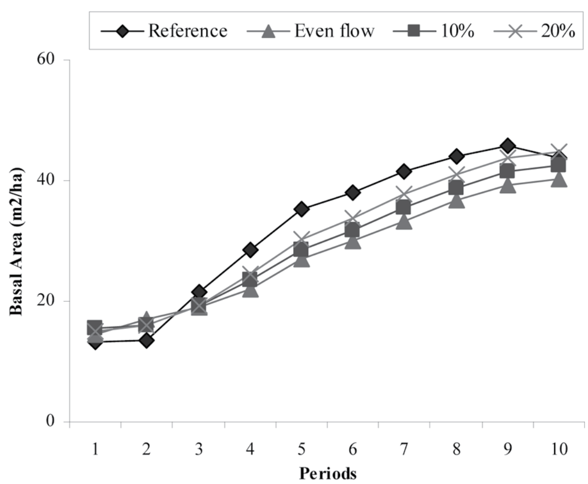


Figure 5. Basal area development over time for different management policy constraints.
Figura 5. Desenvolvimento da área basal ao longo do tempo para diferentes restrições políticas de manejo.

commodates decision support techniques and information technologies and provides various opportunities in preparing forest management plans while enabling the process to be faster, sound and timely using relatively less amount of time and labor. This model will also be used in the implementation of contemporary forest management planning process, scientific studies and forestry education.

- The smallest and basic management area for this model is a stand. There is no limit in the number of stands to be included in the optimization.
- ETÇAPOptimizasyon is a deterministic model for even-aged stands, as it stands.
- The dynamics of growth is driven by yield tables and forest inventory data provided by the user.
- The user can select any forest value or its net present value as an objective function in the model. It means that not only timber production but also the other forest ecosystem values can be selected as objective function. Further, the combinations of two or more forest ecosystem values with financial term can also be selected as an objective function (i.e. NPV of timber + NPV of carbon). Thus, alternative forest management strategies can easily be developed.
- The model provides area and volume control management policies and the user predefines the target volume or area to be harvested or treated. In addition, the targets on the other forest ecosystem values can be given in the model. As such, the model enables decision makers to assess the trade-offs among forest values by both NPV and the absolute amounts. Complex applications of ETÇAPOptimizasyon to forest planning problems and detailed trade-off analysis among forest values and forest structure will be done in the next studies.
- There is no limit in the number of forest management strategies and silvicultural regimes to be prescribed.
- The model simulates long-term effects of management prescriptions on some forest ecosystem values provided by the user. The model accommodates not only the wood production objective but also water production, soil protection, carbon balance and oxygen production.
- The user can create, edit, save, and retrieve the different input files needed to accomplish a simulation run. The user is able to design customized reports. The results can be obtained in the formats of tables, text, figures and maps.

One problem associated with ETÇAPOptimizasyon model is that maintaining spatial constraints for the various planning levels is difficult. This has led to the development of a spatial decision support system to assist analysts and decision makers in forest management plan generation. For that reason, ETÇAPOptimizasyon model is continuing to be extended and refined in order to better address spatial forest planning problems. It is expected that similar extensions and additions will be integrated and developed as the needs of contemporary forest management approach evolve.

ACKNOWLEDGEMENTS

This study was partly funded by The Scientific and Technological Research Council of Turkey (TÜBİTAK) and BAP of Karadeniz Technical University.

REFERENCES

ASAN, Ü.; DESTAN, S.; & ÖZKAN, U.Y. **Istanbul korularının karbon depolama, oksijen üretimi ve toz tutma kapasitesinin kestirilmesi, Orman Amenajmanında Kavramsal Açılımlar ve Yeni Hedefler Sempozyumu**. Bildiriler Kitabı: Istanbul, 2002.

BAŞKENT, E.Z.; KELEŞ S.; YOLASIŞMAZ, H.A. Comparing multi-purpose forest management with timber management in incorporating timber, carbon and oxygen values: A case study. **Scandinavian Journal of Forest Research**, Oslo, v.23, n.2, p.105-120, 2008a.

BAŞKENT, E.Z.; TERZIOŞLU, S.; BAŞKAYA, ŞDeveloping and implementing multiple-use forest management planning in Turkey. **Environmental Management**, Heidelberg, v.42, n.1, p.37-48, 2008b.

BAŞKENT, E.Z.; KELEŞ S. Developing alternative forest management planning strategies incorporating timber, water and carbon values: An examination of their interactions. **Environmental Modeling and Assessment**, v.14, n.4, p.467-480, 2009.

CHURCH, R.L.; MURRAY, A.T.; FIGUEROA, M.; BARBER, K.H. Support system development for forest ecosystem management. **European Journal of Operational Research**, Amsterdan, v.121, n.2, p.247-258, 2000.

COVINGTON, W.W; WOOD, D.B.; YOUNG, D.L.; DYKESTRA, D.P.; GARRETT, L.D. TEAMS: A decision support system for multiresource management. **Journal of Forestry**, Bethesdam, v.86, n.8, p.25-33, 1988.

FIELD, R.C.; DRESS, P.E.; FORTSON, J.C. Complementary linear and goal programming procedures for timber harvest scheduling. **Forest Science**, Bethesda, v.26, n.1, p.121-133, 1980.

GREER, K.; MENEGHIN, B. (1991). SPECTRUM. **An analytical tool for building natural resource management models**. Disponível em: <http://nrs.fs.fed.us/pubs/gtr/other/gtr-nc205/pdffiles/p53.pdf> Acesso em 15 maio, 2010.

GUO, Z.; XIAO, X.; GAN, Y.; ZHENG, Y. Ecosystem functions, services and their values – a case study in Xingshan County of China. **Ecological Economics**, Amsterdam, v.38, n.1, p.141-154, 2001.

HAIGHT, R.; MONSERUI, R.A.; CHEW, J.D. Optimal harvesting with stand density targets: Managing Rocky Mountain conifer stands for multiple forest outputs. **Forest Science**, Bethesda, v.38, n.3, p.554-574, 1992.

HOF, J.G.; PICKENS, J.B.; BARLETT, E.T. A maxmin approach to non-declining yield timber harvest scheduling problems. **Forest Science**, Bethesda, v.32, n.3, p.653-666, 1986.

HOGANSON, H.M., & MCDILL, M.E. More on forest regulation: An LP perspective. **Forest Science**, Bethesda, v.39, n.2, p.321-347, 1993.

JOHNSON, K.; JONES, D.B., (1980). **A user's guide to multiple use-sustained yield resource scheduling (MUSYC)**. Colorado: USDA Forest Service, Fort Collins, 1980. 242p.

JOHNSON, K.; STUART, T.; CRIMM, S. (1986). **FORPLAN Version 2: An overview**. Washington: USDA Forest Service, 1986. 80p.

KELEŞ, S.; BAŞKENT, E.Z. (2007). Modeling and analyzing timber production and carbon sequestration values of forest ecosystems: A case study. **Polish Journal of Environmental Studies**, Olsztyn, v.16, n.3, p.473-479, 2007.

KELEŞ, S. **Designing and developing a decision support system for forest management planning, 2008**. Thesis (PhD Forestry), Karadeniz Technical University, Trabzon, Turkey, 2008.

KENT, B.; BARE, B.; FIELD, R.C.; BRADLEY, G.A. Natural resource land management planning using large-scale linear programs: the USDA forest service experience with FORPLAN. **Operations Research**, Cambridge, v.39, n.1, p.13-27, 1991.

LAPPI, J. **JLP: A linear programming package for management planning**, Suonenjoki: Finnish Forest Research Institute, 1992. 134p. Research Paper 414

MOWRER, T. (1997). **Decision support systems for ecosystem management: an evaluation of existing systems**. Washington: USDA Forest Service. General Technical Report. Disponível em: <http://www.ncsonline.org/NCSSF/DSS/Documents/docs/Mowrer1997.doc>. Acesso em 15 maio 2010.

MUMCU, D. **Ecosystem based planning of Yalnızçam forests and evaluation of forest dynamics depending upon rotation lengths**. 2007. Thesis (Msc Forestry) - Karadeniz Technical University, Trabzon, Turkey, 2007.

NAVON, D. (1971). **TimberRAM, - a long range planning method for commercial timber lands under multiple- use management**. Albany: US Department of Agriculture, 1971. 30p. Research Paper PSW-70

REDSVEN, V., ANOLA-PUKKILA, A., HAARA, A., HIRVELÄ, H., HÄRKÖNEN, K., KETTUNEN, L., KÄRKKÄINEN, L., LEMPINEN, R., MUINONEN, E., NUUTINEN, T., SALMINEN, O., & SIITONEN, M. **MELA2005 Reference Manual** Suonenjoki: Finnish Forest Research Institute, 2005. 621 p.

TURNER, B.J.; CHIKUMBO, O.; DAVEY, S.M. Optimisation modelling of sustainable forest management at the regional level: an Australian example. **Ecological Modelling**, Kidlington, v.153, n.1-2, p.157-179, 2002.

YOLASIĞMAZ, H.A. (2004). **The concept and implementation of forest ecosystem management: a case study of Artvin Planning Unit**., 2004. Thesis (PhD Forestry) - Karadeniz Technical University, Trabzon, Turkey, 2004.

Recebido em 24/11/2009
Aceito para publicação em 02/02/2011