Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
http://dx.doi.org/10.5424/fs/2013222-03516

Forest Systems 2013 22(2), 232-240
ISSN: 2171-5068
eISSN: 2171-9845

Forecasting forest development through modeling based on the legacy of forest structure over the past 43 years

E. Z. Baskent[1] and D. A. Çelik[2]*

[1] *Professor. Faculty of Forestry. Karadeniz Technical University. 61080 Trabzon, Turkey*
[2] *Research assistant. Faculty of Forestry. Karadeniz Technical University. 61080 Trabzon, Turkey*

Abstract

Aim of study: Sustainable management of forest ecosystems requires comprehensive coverage of data to reflect both the historical legacy and the future development of forests. This study focuses on analyzing the spatio-temporal dynamics of forests over the past 43 years to help better forecast the future development of forest under various management strategies.

Area of study: The area is situated in Karaisalı district of Adana city in the southeastern corner of Turkey.

Material and methods: The historical pattern from 1969 to 2012 was assessed with digital forest cover type maps, produced with high resolution aerial photo interpretation using Geographic Information Systems (GIS). The forest development over the next 120 years was forecasted using ecosystem-based multiple use forest management model (ETÇAP) to understand the cause-effect relationships under various management strategies.

Main results: The result showed that over the past 43 years while total forest areas decreased about 1,194 ha (4%), the productive forest areas increased about 5,397 ha (18%) with a decrease of degraded forest (5,824 ha, 20%) and increase of maquis areas (2,212 ha, 7%).The forecast of forest development under traditional management strategy resulted in an unsustainable forest due to broken initial age class structure, yet generated more total harvest (11%) due to 88% relaxing of even timber flow constraint. While more volume could be harvested under traditional management conditions, the sustainability of future forest is significantly jeopardized.

Research highlights: This result trongly implies that it is essential adopting modeling techniques to understand forest dynamics and forecast the future development comprehensively.

Key words: forest management; simulation; optimization; forest dynamics; land use change.

Introduction

Forest management plans are prepared based on geographic and attribute data available over the past and the future. In one hand, the historical legacy of the forest structure under interventions or natural disturbances is important in developing appropriate management interventions and understanding the real effects of interventions on current forest. On the other hand, the projected forest development into the future under various management strategies is needed to understand forest dynamics and justify current implementation of management actions towards sustainability. In both cases, the forest cover type maps and their associated attribute data in the past and present are vital to prepare a comprehensive forest management plans (Ribeiro *et al.,* 2004; Başkent and Kadiogulları, 2007; Başkent and Mumcu-Kucuker, 2010).

Forestry in a broadest sense involves the art, science and business of managing the forest landscape as a whole for human benefit. As the demand for wood fibre outgrew the growing stock obtainable by exploiting the forest resources, new approaches were developed. The earliest form of forestry is characterized as custodial, focusing on protecting the forest from overexploitation and fire usually followed by sustained yield timber production. More recently, however, explicit efforts were made to manage forest for a broad array of resources such as multiple-use forestry. Same forests continue to be managed extensively, with little investment other than protection. "Many believe we have entered an era of ecological forestry, in which maintenance of ecological integrity will be paramount" (Seymour and Hunter, 1999). As such, forestry has come to point of ecosystem management for integrating ecological,

---

* Corresponding author: dacelik@ktu.edu.tr
Received: 11-09-12. Accepted: 26-05-13.

economic and socio-cultural values of forests ecosystems with various decision making tools (Borges and Hoganson, 1999; Davis *et al*., 2005; Başkent *et al*., 2008a).

Forest management planning in various jurisdictions such as in Turkey has gone through such evolution process. Management interventions since 1960s have mainly focused on timber production that created various forest compositions and configurations. In addition to the natural disturbances, sporadic illicit cutting and social pressure due to poor welfare of the rural areas caused the forest covers to deteriorate (Başkent and Kadıoğulları, 2007). The changes in land use/land cover have important consequences for forest resources through their impacts on soil and water quality, biodiversity and climate systems (Houghton, 1994; Turner *et al*., 1995). Changes in landscape in the form of habitat fragmentation and forest loss, as an indication of biodiversity, have been recognized as a major threat to ecosystems worldwide (Armenteras *et al*., 2003; Laurance, 1999; Noss, 2001) and a challenge in ecosystem based forest management planning. The ecological consequences of fragmentation in landscape structure may differ depending on the spatial configuration imposed on a landscape over time (Ite and Adams, 1998; Armenteras *et al*., 2003; Karahalil *et al*., 2009b). Therefore, understanding the spatiotemporal dynamics between landscape structure and the ecological processes is required by forest managers to provide a basis for making effective land use decisions in preparing management plans (Turner *et al*., 2001).

Decision making tools have been developed to analyze the effects of various management strategies on the future forest structure and the potential production of forest values as they are integrated into forest management plans (Başkent *et al*., 2008b; Keleş *et al*., 2009a). The performance of a model in producing a forest management plan is measured by a number of indicators such as age class distribution, basal area, growing stock and amount of forest values over time (Köchli and Brang, 2005; Keleş *et al*., 2007; Başkent and Keleş, 2009). The quality of model output is influenced by forest ecosystem characteristics, initial forest conditions, modeling tools used and the planning parameters; various combinations of them make up a management strategy. Here, the forecast of forest development over time and space based on a specific management strategy has been a great challenge for the sustainable management of forest ecosystems.

Some studies have developed forest management models to incorporate some forest values such as amenity, recreation, soil protection, carbon sequestration and biodiversity into forest management plans (Kangas and Kuusipalo, 1993; Pukkala *et al*., 1995; Hof and Bevers, 2000; Bertomeu and Romero, 2001; Krcmar *et al*., 2001; Díaz-Balteiro and Romero, 2003; Keleş *et al*., 2007; Başkent *et al*., 2008a; Karahalil *et al*., 2009a). However, these studies have used current forest inventory data and generally focused on the broad level characterization of forest ecosystems such as age class structure or stand types to predict the interactions among forest ecosystem values. Most of the previous initiatives either focused on the evaluation of historical pattern of landscape structure or the projection of future forest developments. None or very limited number of research initiatives have used both simulation and optimization models to present the effects of forest management strategies on forest ecosystem structure and functions such as carbon sequestration and water production based on historical and current spatial data.

This study, first of all, examines the historical pattern of forest ecosystems with ArcGIS Geographic Information System (GIS). The future forest development is forecasted using both simulation and optimization approaches based on the forest inventory and the historical data. ETÇAP forest management models of *ETÇAPSimülasyon* and *ETÇAPOptimization* developed by (Başkent *et al*., 2008b; Keleş, 2008; Keleş *et al*., 2009b) are used to assist the preparation of forest management plans under various planning strategies. Thus, the research focuses on characterizing the historical pattern of forest resources and examining the effects of three forest management strategies on future forest development. The secondary objective of the research is to predict the long-term effects of these policies on some forest ecosystem values such as timber production, carbon sequestration, and water production as forest performance indicators.

Material and methods

Case study area

The study area of Akarca Forest Planning Unit, a typical Eastern Mediterranean area, is located within the latitude of 37° 13’ 00”, 37° 29’ 00” N and longitude of 35° 12’ 00”, 35° 20’ 00” E in Turkey. The area is situated in Karaisalı district of Adana city in the southeas-

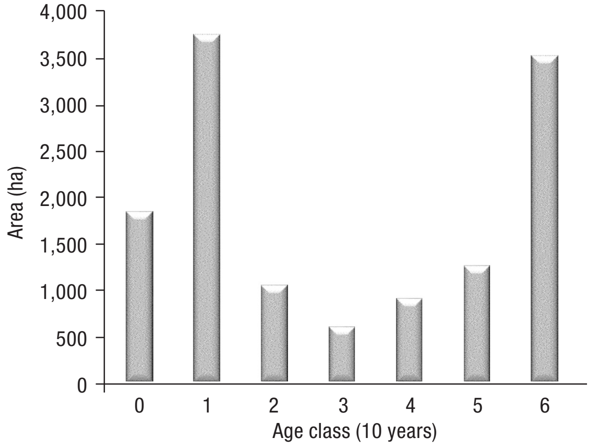

Figure 1. The initial age class structure.

tern 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 400 m and 2,000 m with an average slope of 40%. Naturally, the region is covered by a mix of, *Pinus brutia* Ten. (Red pine), *Pinus nigra* L. (Black pine), *Pinus pinea* L. (Stone pine), *Abies cilicica* Carr. (Cilician fir), *Cedrus libani* A. Rich (Toros cedar), *Quercus* spp. (*Oak*), *Juniperous* spp. (Juniper) and thickets. The study area covers an area of 28,560 ha, of which 20,333 ha is of forest ecosystems. The total number of stands in forested areas is 3,156 with an average size of 6.44 ha. Forest stand types in the study area are grouped according to the mixture of tree species, development stage, crown closure and age class (Fig. 1).

The ETÇAP model description

A general purpose forest management planning model ETÇAP (Başkent *et al.*, 2008b) with different sub models (*ETÇAPSimulation* and *ETÇAPOptimization*) has been developed to prepare forest management plans. *ETÇAPSimülasyon* is a forest-level decision support tool with traditional simulation technique based on stand based information for assessing the effects of forest management practices on forest dynamics and functions. *ETÇAPOptimization* is a linear programming (LP) based optimization model to solve complex problems involving various management objectives and constraints. The model is developed according to Model I approach (Johnson and Scheurman, 1977) where decision variables are in hectares in a management unit and the identity of each stand is maintained through the planning horizon. The mathematical representation of the model is as follows;

Objective:

$$\text{Max} \sum_{i=1}^{ns}\sum_{j=1}^{np} a_{ij}x_{ij} = ETA \qquad [1]$$

Constraints:

$$(1, pH_{t+1} - H_t) \geq 0 \text{ and } (0, pH_{t+1} - H_t) \leq 0 \qquad [2]$$

$$\sum_{t=1}^{T} H_t \geq H^* \qquad [3]$$

$$\sum_{t=1}^{T} CB_t \geq CB^* \qquad [4]$$

$$\sum_{t=1}^{T} WF_t \geq WF^* \qquad [5]$$

Accounting Variables:

$$CB_t = [\gamma(V^t - V^{t-1} + H_t) - CE_t] \qquad [6]$$

$$WF_t = W_t - W_{t-1} \qquad [7]$$

where, *objective* function ETA is the total production of timber (*ns*, number of stands, *np*, number of periods, *xij* area of stand *i* cut at period *j*, *aij* yield of stand *i* cut at period *j*) over the planning horizon in equation [1]. Equation [2] from *constraints* imposes an even flow of timber volume with *p*% variation between successive periods (t, t + 1). Equations [3], [4] and [5] indicate harvest volume (H^*), carbon sequestration (CB^*) and water flow (WF^*) targets over the planning horizon, respectively. Equations [6] and [7] are accounting variables used to chase the amount and dynamics of carbon and water stocks. Equation [6] measures the sequestration of net carbon in the generic t^{th} period, expressing the difference of timber volume between consecutive periods (the growth of the timber biomass) plus the harvest minus the carbon emissions (CE_t) for each period. Equation [7] refers to water flow (WF_t, the differences in water production-W_t between consecutive periods) in period *t*.

Developing a sound management strategy is necessary before forecasting forest development over time. A management strategy accommodates management objectives, specific constraints and planning parameters as part of management policy (Baskent and Jordan, 2002). Each model forecasts forest development over time in response to a management strategy. In *ETÇAPSimulation* model, for example, a management strategy consists of a set of rules for queuing stands for harvest, various limits to constraint actions, and a set of levels at which these activities will be carried out in a typical simulation. Forest response to management actions, as controlled by queuing rules, is forecast on an iteration-by-iteration basis. When harvesting is completed in a period, the forest is simulated by aging all the stands one period ahead. Future stands are assigned to the first age class and follow the development pattern of empirical yield tables. Unharvested stands are assumed to follow their predecessor yield curve after breakup and reassigned to the first age class. The harvesting process is repeated until the requested time horizon is reached or the available periodic wood supply is completed. In *ETÇAPOptimization* model, a management strategy is composed of objectives and constraints and the model structure and process follow typical LP procedure with Model I approach.

Developing and assigning prescriptions to each forest unit is challenging and paramount in a model. The basic spatial unit represented in both models is a user defined analysis area. Each analysis area is identified by each stand or a combination of stands, defined based on forest conditions such as sites, species compositions, crown closure and development stages. One or more silvicultural regimes can be prescribed to an analysis area. Silvicultural regimes for each analysis area are designed by a user based on historical pattern of forest, current inventory data, stand-level defined forest treatment assumptions.

Projection of growth and yield, carbon sequestration and water production

A built-in stand simulation model was developed to project the growth of each existing stand as there was no growth and yield model for the species of the case study area. The growth model is a time based, non-stochastic empirical model for simulating the growth of an even aged stand over time. The stand simulation model assumes that the growth of a particular stand will follow the similar definable and predictable development pattern of the empirical yield table. The current growth of each stand was compiled based on timber cruising data. The future growth of each stand is projected by relating the current growth rate of each stand with the growth rate of the same stand in the yield table. The regenerated stands follow the trends in the empirical yield table. Therefore, the models provide all stand level information related to each stand, such as basal area, growing stock, increment, and number of tree associated parameters of a stand.

Carbon sequestration in successive periods was determined by accumulating the amount of timber biomass of the forests and subtracting the biomass removed from the ecosystem by treatments such as final felling and thinning, and other actions. The following equation measuring the net carbon sequestration (Equation [8]) in the t^{th} period was used in this study (Díaz-Balteiro and Romero, 2003).

$$CS_t = [\gamma(V^t - V^{t-1} + H_t) - CE_t] \qquad [6]$$

where γ is the proportion of carbon contained in timber biomass, CS_t is the amount of carbon sequestration in period t, CE_t is the amount of carbon emission in period t, H_t is the volume harvested in period *t* and V^t is the volume of forest inventory at the end of *tth* period.

Timber biomass of the forest and carbon storage for each stand was estimated using species-specific biomass conversion factors from the literature (Keleş and Başkent, 2007; Başkent *et al.,* 2008b; Başkent and Keleş, 2009). The carbon emissions from various forest timber assortments were also taken into consideration and estimated in this study based on the lifetime of each wood product for each stand (Keleş and Başkent, 2007; Başkent *et al*., 2008b; Başkent and Keleş, 2009). Decomposition rates were estimated by applying the methodology proposed by Masera *et al*. (2003).

$$Cp_{mt+1} = Cp_{mt} x(1 - a_m) \qquad [9]$$

where, Cp_m is the carbon stored in (Equation [9]) a wood product *m* at time *t*, a_m is the share of the product that decomposes each year.

Both the quality and quantity of water in forest ecosystems have been affected by the characteristics of forest stands such as tree species, crown closure, basal area, mean diameter, number of stems, standing timber volume and leaf area index of trees. The amount of water production of forest ecosystems was estimated according to a few water production functions. The model equation for the water that runs off is adopted from Yolasıgmaz (2004) as followings;

$$WP = 471.181 * \exp(-0.0273 * BA) * 10 \qquad [10]$$

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

Forest management strategies

Three major forest management strategies were developed to examine forest dynamics over time. These include traditional planning strategy (TPS), maximum wood production strategy (MWPS) and area control strategy (ACS). The traditional planning strategy attempts to extend contemporary management decisions implemented in the first planning period, over 120 years into the future. The strategy attempted to harvest 491,960 m^3, decided by traditional management team, in each period over 120 years. Failing so, the strategy varies harvest level up to 88% between successive periods. The maximum wood production strategy tries to sustain as much even harvest flow as possible over 120 years as a long term sustained yield policy. The area control strategy, however, focused on the sustainability of regenerated areas over time (Davis *et al*., 2005). Specifically, the strategy regenerates equal area of forest in each period to create an even age class distribution at the end of a rotation period. The expectation from these strategies is to understand long term forest dynamics under various conditions and thus help prepare a sound sustainable forest management plans.

In all strategies, the future forest is forecasted over 120 years of planning horizon with 10 years of period length. The simulation model used the "oldest first" rule in both harvesting and thinning operation, whereas optimization model aimed to maximize wood production as an overall objective function. Both models applied commercial thinning to stands starting from 20, 30 and 40 years with a rate varying from 3% to 9% level of basal area. All forest stands are subject to harvesting unless they are stratified in a conservation area. Minimum rotation/cutting ages for Calabrian pine is 60 years and for fir-cedar-juniperus and oak stands 140 years in timber management areas. However, the minimum cutting age for Calabrian pine in conservation areas is set to 120 years. Maximum cutting age, however, was set to 120 years in managed Calabrian pine, 140 years in conservation Calabrian pine stands and 160 years in, fir-cedar-juniperus and oak stands. These age limits define the operability window of the stands and are reference cases as adopted from the Turkish Forest Management Guidelines.

Results

Changes in forest resources were analyzed using the area statistics derived from forest cover type maps of 1969 and 2012. According to these maps, the total forested area decreases from 20,660.55 ha to 19,465.9 ha during a 43 year period, a net decrease of 1,190 ha (4%) forest areas. In fact, when degraded maguis areas are classified as degraded forest then total forest areas do not seem to decrease. However, the productive forest areas continually increased from 10,462 ha to 15,859 ha over the last 43 years with a net increase of 5,397 ha (50%). Very little changes (less than 0,5%) in all open areas such as agriculture and settlement were observed from 1969 to 2012. There was a net decline of 370 ha in forest opening areas and net decrease of 1,250 ha in agricultural areas. An apparent increase of 4,423 ha was detected on the area of Calabrian pine and a slight increase in Juniperous forest areas.

Under the simulation model, the traditional planning strategy generated total volume of 7,144,534 m^3, maximum wood production strategy 5,162,373 m^3 and area control strategy 4,730,642 m^3 (Fig. 2). Under the optimization model, TPS generated total volume of 8,055,640 m^3, MWPS 5,637,212 m^3 and ACS 5,022,101 m^3 (Fig. 2). In both models, TPS produced the highest amount of total timber volume among others due mainly to 88% flexibility of even flow constraint and the broken initial age class structure. The MWPS maintained 430,000 m^3 harvest level for each period in simulation and 469,767 m^3 in optimization model. ACS maintained 360,000 m^3 to 450,000 m^3 periodic harvest levels in simulation and 288,502 m^3 to 448,469 m^3 in optimization, while both strategies regenerated 1,300 ha in each period to create even age class distribution.

With regard to the water production, TPS strategy produced slightly more amount of water than other two strategies did (Fig. 3) in both models as the latter two strategies regenerated or planted open areas over time. Total water productions of TPS, ACS and MWPS at the end of the planning horizon were 8,393 million tons, 8,258 million tons, and 8,179 million tons, respectively, in simulation model. In optimization model,

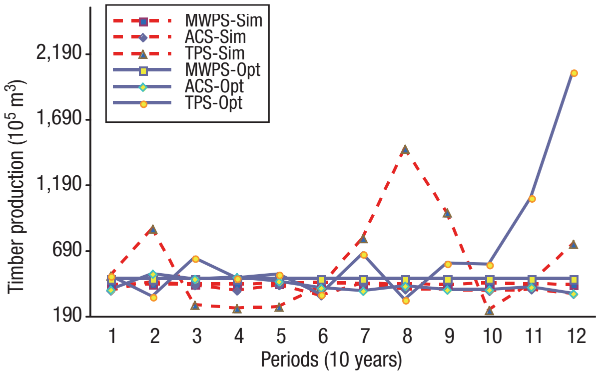

Figure 2. The change of timber production over 120 years based on simulation and optimization models under three management strategies. -Sim: simulation, -Opt: optimization.

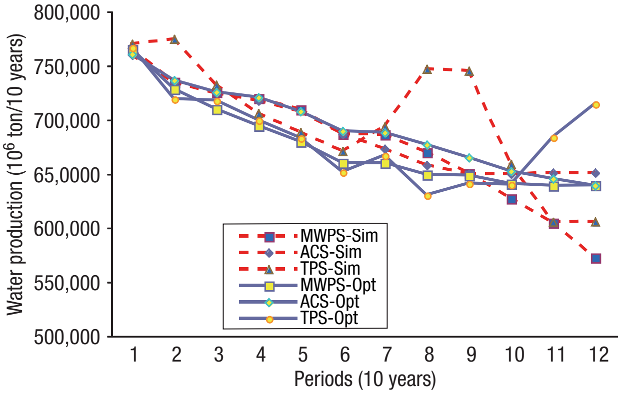

Figure 3. The change of water production over 120 years based on simulation and optimization models under three management strategies. -Sim: simulation. -Opt: optimization.

total water productions of ACS, TPS and MWPS at the end of the planning horizon were 8,301 million tons, 8,209 million tons, and 8,108 million tons, respectively. Three strategies under both models produced a slightly decreasing amount of water over the planning horizon. As expected, increasing basal area (Fig. 4) caused less water production during the forecasting of forest resources over time.

The periodical flow of carbon sequestration in all strategies was illustrated in Fig. 5. At the end of the 120 years of planning horizon, MWPS strategy sequestered slightly more carbon (752,552 ton) than ACS strategy (675,654 ton) and TPS strategy (524,401 ton) did in simulation model. In optimization model, MWPS strategy sequestered slightly more carbon (1,227,043 ton) than ACS strategy (971,913 ton) and TPS strategy (790,247 ton) did. In general, the amount of carbon sequestration under three management strategies in both models gradually decreased over time (Fig. 5). There was a sharp dip in TPS which is possibly caused by the highest periodical harvest level in the associated period of both models. Three strategies under both models produced an apparent decreasing amount of carbon over the planning horizon. This result could be explained with the dynamics of growing stock (Fig. 6) and basal area (steady increase over time) (Fig. 4), an inversely proportional relationship was then observed.

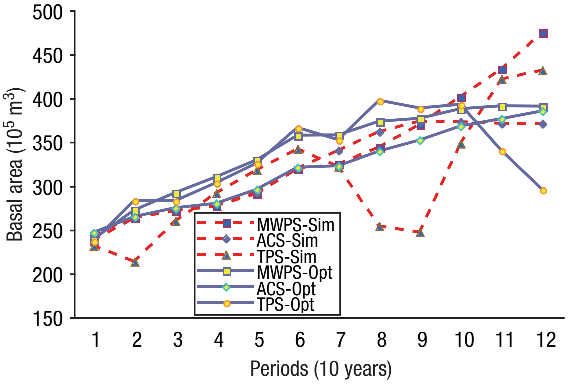

Figure 4. The change of basal area over 120 years based on simulation and optimization models under three management strategies. -Sim: simulation. -Opt: optimization.

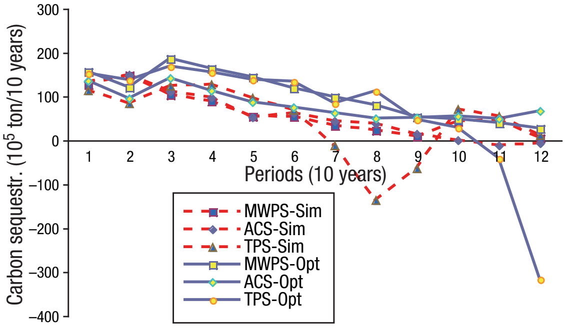

Figure 5. The change of net carbon sequestration over 120 years based on simulation and optimization models under three management strategies. -Sim: simulation. -Opt: optimization).

Discussions

Detecting the changes of forest areas over the history is important to understand cause and affect relationships in forest regulation. The slight increase of forest area over the last 43 years is consequential in forest management. These positive changes are generally due to the establishment of sustainable forest management initiatives, increase of forest stewardship and increase of natural and environmental awareness over the last couple of decades. There may be the

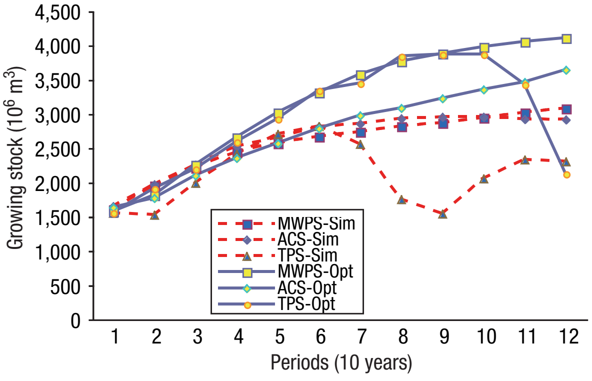

Figure 6. The change of growing stock over 120 years based on simulation and optimization models under three management strategies. -Sim: simulation. -Opt: optimization.

effects of the immigration of local people from the rural areas to urban and sub-urban areas leaving the countryside for natural forestation. Similar studies have found the positive change of forest areas in Turkey using both GIS and remote sensing (Başkent and Kadıogulları, 2007; Günlü *et al*., 2009) reflecting the comparable reasons for the change of forest in the past. It is, therefore, quite essential to monitor the change of forest cover before any crisis such as in tropical forest cases arises (Turner *et al*., 2001; Laurance, 1999).

Forecasting future condition of forests based on various forest management activities is a great challenge as well. The forest forecasted by ETÇAP model based on traditional management strategy is unsustainable over 120 years of projection. Specifically, the sustainability of both forest resources and the wood production is jeopardized under the contemporary forest management philosophy in both simulation and optimization techniques. This is due to the fact that the periodical flow of annual allowable cut (AAC) and the first period's AAC were not maintained over the planning horizon. The traditional management decision is certainly made without forward looking thinking about the forest ecosystems.

When both simulation and optimization model results were compared, optimization through linear programming technique outperformed as expected (Johnson and Scheurman, 1977). However, optimization models provide divisibility results and not easy to spatially locate the harvest scheduling results. Although integer or mixed integer programming techniques as exact models create integer solutions to forest management problems (Nelson and Brodie, 1990; Constantino *et al*., 2008), it takes much longer time to simulate large scale problem settings let aside the spatial control of the management actions (Hof and Bevers, 2000; Başkent and Jordan, 2002). Thus various metheuristic or combinatorial optimization techniques such as simulated annealing, taboo search and genetic algorithms are employed in forest management planning (Yashimoto *et al*., 1994; Başkent and Jordan, 2002; Bettinger *et al*., 2007) as they do not guarantee optimal solutions.

Integration of both water production and carbon sequestration into the forest management plans is not straightforward (Hoen and Solberg, 1994; Díaz-Balteiro and Romero, 2003). The functional relationships between the value of water and carbon and the forest structure has to be quantified to prepare a multiple use forest management plans (Krcmar *et al*., 2001). This study employed empirical models, representing the relations with the basal area, to measure the performance of a management strategy. However, the models do not exactly represent actual production of water and balance of carbon in a real forest ecosystem, as basal area is not the only predictor of those forest values. Further work is definitely needed to develop better growth and yield models for various forest values to understand their interactions with various forest management strategies (Başkent and Keleş, 2009).

Conclusions

This study characterized the historical structure of forest ecosystems over the last 43 years with ArcGIS GIS and forecasted the forest development over 120 years into future using ETÇAP forest management planning model. The historical pattern from 1969 to 2012 was assessed in a typical Eastern Mediterranean forest ecosystem in Turkey. Both simulation and optimization techniques are used to forecast forest development for understanding the cause-effect relationships under three distinct management strategies. In this study, a number of performance indicators such as the total amount of timber production, water production and carbon sequestration as part of forest management model were used to assess the performance of each management strategy.

The study indicated that over the past 43 years while total forest areas decreased about 1,194 ha (4%), the productive forest areas increased about 5,397 ha (18%) with a decrease of degraded forest (5,824 ha, 20%) and increase of maquis areas (2,212 ha, 7%). The forecast of forest development under current management strategy resulted in an unsustainable future forest due to broken initial age class structure, yet generated more total harvest (11%) over 120 years due to 88% relaxing of even timber flow constraint. While more total volume could be harvested under current management decisions, the sustainability of future forest is significantly jeopardized. The study clearly revealed and concluded that current management decisions are not appropriate in creating sustainable future forest conditions. The current structure of forest ecosystem and the result from historical management regulations may have certain impacts on various timber and non-timber forest goods and services. The quality and quantity of all forest goods and services are influenced by forest characteristics such as stand structure, spatial distribution, tree species composition, and developmental stages as well as management policies. Thus, the result strongly implies that it is essential to adopt modeling techniques to comprehensively forecast the future development and understand forest dynamics under various management strategies including various policy constraints and targets before implementation of any management activities.

The economical evaluation of each management strategy is missing here, yet could be evaluated to analyze the combined effect of management strategies on various forest values and forest structure. As well, the spatial configuration or lay-out of future forest structure may also be forecasted using combinatorial modeling approach. Finally, a wider range of silvicultural prescriptions or possible actions could also be developed to comprehensively analysis the spatio-temporal dynamics of forest ecosystems over time.

Acknowledgements

Special Thanks go to Mr Miraç KILIÇ the following for help and support in the development of these Study GIS.This study was funded by the internal research fund (BAP) of Karadeniz Technical University, Trabzon.

References

Armenteras D, Gast F, Villareal H, 2003. Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes. Colombia Biological Conservation 113: 245-256.

Başkent EZ, Jordan GA, 2002. Forest landscape management modeling using simulated annealing. Forest Ecology and Management 165: 29-45.

Başkentt EZ, Başkaya Ş, Terzioğlu S, 2008a. Developing and implementing participatory and ecosystem based multiple use forest management planning approach (ETÇAP): Yalnızçam case study. Forest Ecology and Management 256: 798-807

Başkent EZ, Kadıoğulları AI, 2007. Spatial and temporal dynamics of land use pattern in Turkey: a case study in İnegöl. Landscape and Urban Planning 81(4): 316-327.

Başkent EZ, Keleş S, Yolasığmaz HA, 2008b. Comparing multi-purpose forest management with timber management in incorporating timber, carbon and oxygen values: a case study. Scandinavian Journal of Forest Research 23(2): 105-120.

Başkent EZ, Keleş S, 2009. Developing alternative forest management planning strategies incorporating timber, water and carbon values: an examination of their interactions. Environmental Modeling and Assessment 14 (4): 467-480.

Başkent EZ, Mumcu-Kucuker D, 2010. Incorporating water production and carbon sequestration into forest management planning: a case study in Yalnızcam planning unit. Forest Systems 19(1): 98-111.

Bertomeu M, Romero C, 2001. Managing forest biodiversity: a zero-one goal programming approach. Agricultural Systems 68: 197-213.

Bettinger P, Boston K, Kim YH, Zhu J, 2007. Landscape-level optimization using tabu search and stand density-related forest management prescriptions. European Journal of Operational Research 176(2): 1265-1282.

Borges JG, Hoganson HM, 1999. Assessing the impact of management unit design and adjacency constraints on forestwide spatial conditions and timber revenues. Canadian Journal of Forest Research 29(11): 1764-1774.

Constantino M, Martins I, Borges J, 2008. A new mixed-integer programming model for harvest scheduling subject to maximum area restrictions. Operations Research 56(3): 542-551.

Davis LS, Johnson KN, Bettinger P, Howard TE, 2005. Forest management: to sustain ecological, economic, and social values. Waveland Press, Dubuque, USA. 804 pp.

Díaz-Balteiro L, Romero C, 2003. Forest management optimisation models when carbon captured is considered: a goal programming approach. Forest Ecology and Management 174: 447-457.

Günlü A, Kadıoğulları A, Keleş S, Başkent EZ, 2009. Spatiotemporal changes of landscape pattern in response to deforestation in Northeastern Turkey: a case study in Rize. Environmental Monitoring and Assessment 148: 127-137.

Hoen HF, Solberg B, 1994. Potential and economic efficiency of carbon sequestration in forest biomass through silvicultural management. Forest Science 40: 429-451.

Hof JG, Bevers M, 2000. Optimal timber harvest scheduling with spatially defined sediment objectives. Canadian Journal of Forest Research 30(9): 1494-1500.

Houghton RA, 1994. The worldwide extent of land-use change. BioScience 44: 305-313.

Ite UE, Adams WM, 1998. Forest conversion, conservation and forestry in Cross River State, Nigeria. Applied Geography 18(4): 301-314.

Johnson KH, Scheurman HL, 1977. Techniques for prescribing optimal timber harvest and investment under different objectives – discussion and synthesis. For Sci Mono 18.

Kangas J, Kuusipalo J, 1993. Integrating biodiversity into forest management planning and decision-making. Forest Ecology and Management 61: 1-15.

Karahalil U, Keleş S, Başkent EZ, Köse S, 2009a. Integrating soil conservation, water production and timber production values in forest management planning using linear programming. African Journal of Agricultural Research 4(11): 1241-1250.

Karahalil U, Kadıoğulları Aİ, Başkent EZ, Köse S, 2009b. The spatiotemporal forest cover changes in Köprülü Canyon National Park (1965-2008) in Turkey. African Journal of Biotechnology 8(18): 4495-4507.

Keleş S, Başkent EZ, 2007. Modeling and analyzing timber production and carbon sequestration values of forest ecosystems: a case study. Polish Journal of Environmental Studies 16(3): 473-479.

Keleş S, Yolasığmaz HA, Başkent EZ, 2007. Long term modeling and analyzing of some important forest ecosystem values with linear programming. Fresenius Environmental Bulletin 16(8): 963-972.

Keleş S, 2008. Designing and developing a decision support system for forest management planning, Doctoral thesis. Karadeniz Technical University, Trabzon, Turkey.

Keleş S, Başkent EZ. Kadıoğulları Aİ, 2009a. simulation-based multiple use forest management planning: a Framework. Kastamonu Univ. Journal of Faculty of Forestry 9(2): 136-145.

Keleş S, Başkent EZ, Kadıoğulları Aİ, Bingöl Ö, 2009b. simulation-based forest management planning: ETÇAP-Optimizasyon. Kastamonu Univ. Journal of Faculty of Forestry 9(2): 124-135

Köchli DA, Brang P, 2005. Simulating effects of forest management on selected public forest goods and services: a case study. Forest Ecology and Management 209: 57-68.

Krcmar E, Stennes B, Van Kooten GC, Vertinsky I, 2001. Carbon sequestration and land management under uncertainty. European Journal of Operational Research 135: 616-629.

Laurance WF, 1999. Reflections on the tropical deforestation crisis. Biol Conserv 91: 109-117.

Masera OR, Garza-Caligaris JF, Kanninen M, Karjalainen T, Liski J, Nabuurs GJ, Puss-Inen A, De Jong BHJ, Mohren GMJ, 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecological Modelling 164: 177-199.

Nelson J, Brodie JD, 1990. Comparison of random search algorithm and mixed integer programming for solving area-based forest plans. Canadian Journal of Forest Research 20: 934-942.

Noss RF, 2001. Beyond Kyoto: forest management in a time of rapid climate change. Conservation Biology 15: 578-590.

Pukkala T, Nuutinen T, Kangas J, 1995. Integrating scenic and recreational amenities into numerical forest planning. Landscape and Urban Planning 32(3): 185-195.

Ribeiro RP, Borges JG, Oliveira V, 2004. A framework for data quality for Mediterranean sustainable ecosystem management. Annals of Forest Science 61(6): 557-568.

Seymour RS, Hunter ML Jr, 1999. Principles of ecological forestry. In: Managing biodiversity Ecosystems (Hunter ML Jr, ed). Cambridge University Press. pp: 22-61.

Turner DP, Koerper GJ, Harmon ME, Lee JJ, 1995. A carbon budget for forests of the conterminous United States. Ecol Appl 5: 421-436.

Turner BL, Cortina Villar S, Foster D, Geoghegan J, Keys E, Klepeis P *et al.*, 2001. Deforestation in the southern Yucatan peninsular region an integrative approach. Forest Ecology and Management 154: 353-37.

Yolasığmaz HA, 2004. The concept and implementation of forest ecosystem management (a case study of Artvin Planning Unit). Doctoral thesis. Karadeniz Technical University, Trabzon, Turkey.

Yoshimoto A, Brodie JD, Sessions J, 1994. A new heuristic to solve spatially constrained long-term harvest scheduling problems. Forest Science 40(3): 365-396.