Forest Policy and Economics 55 (2015) 28–36

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Using mixed integer multi-objective goal programming for stand tending block designation: A case study from Turkey

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ARTICLE INFO

Article history:
Received 5 June 2014
Received in revised form 12 March 2015
Accepted 23 March 2015
Available online 3 April 2015

Keywords:
Sustainable forest management
Forest management plan
Thinning
Linear goal programming
Nonlinear goal programming
Mixed integer programming

ABSTRACT

Sustainable forest management is a key to maintaining the economic, social, environmental and cultural benefits and services of forests for the long term. In Turkey, all forestry activities, such as regeneration and stand tending, are carried out according to forest management plans, which are used as a tool for achieving sustainable forest management goals. An intermediate yield harvest plan, which is a part of management plan, is used for stand tending. Every year, the compartments (stands) within the same stand tending block are thinned. Decision support systems have not been used so far in order to designate the size and location of these stand tending blocks. In this study, we used multi-objective goal programming to designate stand tending blocks for an entire decade. We developed two models: a linear goal programming model and a nonlinear goal programming model. To design these models, we only considered wood flow and distance between the centroids of compartments as the objectives. Then, we used a working circle of the Golcuk forest sub-district, which is a planning unit in Turkey, as a case study. The linear model worked very well, and for reference scenarios, the deviation in volume scheduled for the entire decade was only 16.8 m^3 and the deviation in total distance between compartments was 172 km. Scenario 3, with weights of 0.2 for distance and 0.8 for volume, produced the best results. The nonlinear model, which in theory would better represent the problem, was not as useful due to a combination of the time required to produce a solution and the quality of the solutions. The linear model can be developed by including other factors and used by forest planners.

1. Introduction

Forests are nature's most bountiful and versatile renewable resource, providing simultaneously a wide range of economic, social, environmental and cultural benefits and services (Maini, 1992). Sustainable forest management is a key to maintaining these benefits and services of forests for the long term. Forest management plans are important tools for achieving sustainable forest management goals. More than 1.6 billion ha of forests, which is 40% of the 4 billion ha of total world forests, is managed under management plans (Food and Agriculture Organization of the United Nations, 2010). All of the forests in Turkey are covered by management plans, which are designed for the sub-district management unit level. Turkey's forests are state-owned (private forests are only 18,000 ha or 0.1% of the total forest area), cover 27.6% of land area, and have significant economic, environmental and cultural functions (Koc et al., 2012).

The General Directorate of Forestry is the responsible institution for managing the forests of Turkey according to the principle of sustainability. Forest inventory and forest management planning are the responsibilities of the Forest Management and Planning Department under the General Directorate of Forestry. The department undertakes forest surveys and compiles forest inventory data as the plans are renewed at 10–20 year intervals. Every year around 130 forest management plans, which cover the 1/10th of total forest area, are renewed by the department. Final yield and intermediate yield harvest (thinning/stand tending) plans are included in these management plans. The annual allowable cut for an intermediate yield harvest is determined by dividing the total intermediate yield allowable cut by the re-entry period length, which is generally 5 to 10 years. To implement an intermediate yield plan, consideration is given to the advantages of working in the same terrain and the same general area, and thus compartments are often clumped together to create thinning blocks (stand tending blocks). Without considering working circles (sub-sets of planning units), 10 stand tending blocks are created for every single planning unit. These stand tending blocks can be created either by forest planners during the planning process or by plan implementers during the plan implementation (General Directorate of Forestry, 2010). Furthermore, annual stand tending compartments can be deployed to the planning

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http://dx.doi.org/10.1016/j.forpol.2015.03.007
1389-9341/

unit, in parallel with the distribution of the labor force and the request of plan implementers.

In this research, wood flow and distance of compartments' centroids have been considered to create stand tending blocks for intermediate yield plans. Other factors such as road availability, silvicultural priority, labor force, fair job opportunities for forest villagers, production policies of the forest service, and local timber needs were not considered. Goal programming is applicable to solve forestry problems such as this, where there is more than one type of objective. Since the entire compartments are expected to be scheduled for harvest, mixed integer multi-objective goal programming was selected for this purpose. In order to compare the results of two different approaches, a problem formulation was designed for both linear goal programming and non-linear goal programming.

Goal programming is a mature problem-solving technique. The basic elements of the method were introduced by Charnes et al. (1955) as simply an alternative use of linear programming. The term “goal programming” was coined by Charnes and Cooper (1961) in their textbook *Management Models and Industrial Applications of Linear Programming*. Using a goal programming approach, Charnes et al. (1968a, 1969, 1971a, 1971b) developed a model for manpower planning for the Office of Civilian Manpower Management of the U.S. Navy. Ijiri's (1965) text *Management Goals and Accounting for Control* and Lee's (1972) text *Goal Programming for Decision Analysis*, which includes a copy of his goal programming computer routine, were some of the main references on goal programming at the end of 1960s and early 1970s. In 1968, Charnes et al. (1968b, 1968c) published an illustrative example which is developed from an actual application of goal programming to media planning over a period of time. Lee (1971) presented a simple, hypothetical application of goal programming to the ubiquitous television-assembly problem. Lee et al. (1971) applied the goal programming to the allocation of limited budgets to the personnel needs of academic institutions. Lee and Clayton (1972) applied the technique to the selection of efficient portfolios for commercial banks. Courtney et al. (1972) applied goal programming to the problem of population location in a metropolitan area.

It seems like the paper by Field (1973) is the first example of the application of goal programming to forestry problems. Field (1973) presented the technical details of the goal programming model, a review of its published use, and an illustration of a possible application to a forest management problem. Other pioneer forestry applications of goal programming included selecting forest residue treatment alternatives (Bare and Anholt, 1976), analyzing potential gains from tree improvement programs (Porterfield, 1974), and evaluating land-use planning options for United States national forests (Bell, 1975; Schuler et al., 1977).

2. Materials and methods

Within some planning units in Turkey, foresters want to harvest the same amount of wood every year and to observe the benefits of working in the same general area during the course of a year. The planner (during the planning process) or the plan implementer decides which compartments will be cut to achieve the annual allowable cut. These compartments are designated for each year of the re-entry period, and collectively are called a *stand tending block*. For a 20-year overall management plan there are two 10-year re-entry periods; during the second decade of the plan, the same compartments will be revisited in the same order as the first decade. In order to address these needs, the planner would need to minimize both the deviations from a harvest volume target and the distance (total or average) between compartments. Therefore, these ideas form the objective function of the planning problem. The foresters also want to cut each compartment as a whole when they are entered, therefore the decision for a compartment is discrete (harvest or do not harvest). The nature of the management situation suggests then that mixed integer multi-objective goal programming is applicable to solve this problem.

2.1. Study area

The study area, located in the western part of Turkey, contains of 5321.8 ha of state forest. Since this study concerns the stand tending block designation for an intermediate yield plan, only 2615.8 ha of this forest, which is suitable for stand tending, is examined. Regeneration areas and pre-commercial thinning areas are also not considered. The dominant tree species in the study area are Anatolian Black Pine [*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe var. *pallasiana*] and oaks (*Quercus* spp.). The main management objective of this forest is pine wood production. Since even-aged management is applied, every year the same amount of forest area is being regenerated and same amount of wood flow is desired from regeneration cuts and from thinnings. The stand tending area has been divided into 106 compartments in the management plan, which was renewed in 2008 for a 20 year time horizon. The total growing stock of the examined compartments is about 455,116 m^3. Fig. 1 presents the growing stock distribution by compartments. The total allowable cut of the compartments for the re-entry period (10 years for black pine tree species) is 29,462 m^3. Fig. 2 presents the allowable cut distribution by compartments. Forest area, growing stock, increment and allowable cut distribution by seral stages and age classes are given in Table 1.

In forest management planning in Turkey, seral stages are separated into five groups. Seral stages are grouped based on the average stand diameter including bark at 1.30 m above ground level. The seral stages and their symbols are provided in Table 2. If trees within a stand are essentially the size suggested for *Stage e* but do not compose the stand as a whole, the stand is usually assessed as *Stage d*.

2.2. Study area data

For stand tending blocking, one needs inventory data for each compartment, one needs to determine the potential allowable harvest level from each compartment for each year, and one needs to calculate the annual allowable cut. In order to calculate the annual allowable cut, the total allowable cut, which is determined for the re-entry period by the forest planner after the area and growing stock inventory have

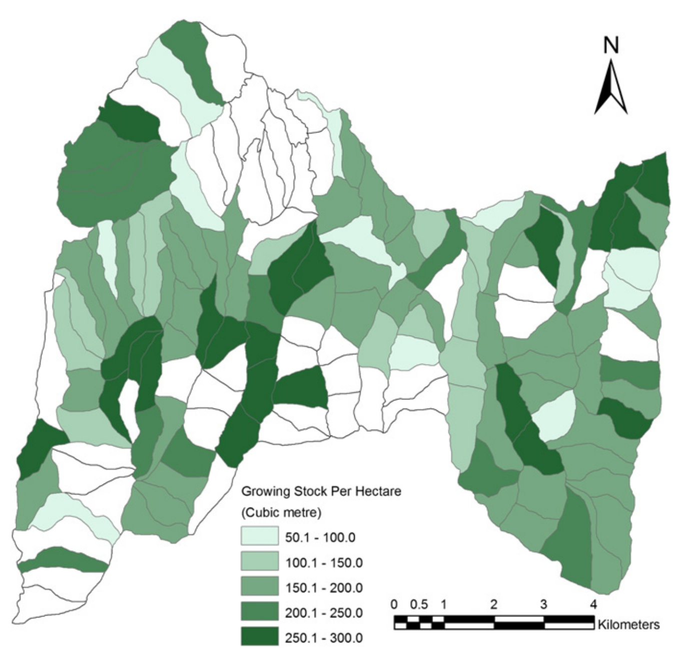

Fig. 1. The growing stock distribution by compartments.