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Developing Alternative Wood Harvesting Strategies with Linear Programming in Preparing Forest Management Plans

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Abstract: In this paper, the process of developing alternative wood harvesting strategies in forest management planning is presented. Alternative wood harvesting strategies based on linear programming (LP) include a planning horizon of 100 years, an objective of the maximization of net present value (NPV) and various constraints such as classical volume control (even flow) and wood assortments. Model outputs are presented and discussed along with NPVs and amounts of wood assortments by alternative wood harvesting strategies consisting of various discount rates and wood assortments.

Key Words: Forest management, Wood harvesting strategy, Linear Programming, Net Present Value.

Orman Amenajman Planlarının Hazırlanmasında Doğrusal Programlama ile Odun Üretimi Stratejilerinin Geliştirilmesi

Özet: Bu çalışmada, orman amenajman planlarının hazırlanmasında odun hammaddesi üretimine yönelik farklı alternatif odun üretim stratejilerinin geliştirilmesi süreci işlenmiştir. Bu amaçla, Doğrusal Programlama tekniğine dayalı ve 100 yıllık bir planlama görüngesini kapsayan bir model kurulmuştur. Geliştirilen bu planlama modeline göre, farklı odun çeşitlerinden elde edilen Net Bugünkü Değerin (NBD) farklı iskonto oranlarına göre en iyilendiği ve değişik kısıtlayıcı koşulların modele dahil edildiği farklı odun üretim stratejileri geliştirilmiştir. Kısıtlayıcılar, klasik alan ve hacim kontrolü ile üretimin farklı odun çeşitlerine göre kontrolünden oluşmaktadır. Modelin çözülmesi sonucunda elde edilen çıktılar, NBD ve miktar olarak; alternatif odun üretim stratejileri, farklı ıskonto oranları ve odun çeşitleri itibariyle periyotlara göre sunulmuş ve bulgular orman dinamiği açısından tartışılmıştır.

Anahtar Sözcükler: Orman amenajmanı, Odun üretim stratejisi, Doğrusal Programlama, Net Bugünkü Değer.

Introduction

Forests encompass various commodities and benefits that could be extracted and presented to the public through planned management actions. These include the production of clean and good quality water, supplies of energy and minerals, soil protection, sustainable supply of wood, wilderness and scenic beauty, clean environments for recreation, and fish and wildlife habitats. Over the past decades, several factors have altered the practice of forest management. As population and resource development increase, many forest-based products and services exceed sustainable levels of use. There is an increasing demand on various wood assortments such as logs, mining poles, and industrial wood. Nevertheless, society is aware of the need to protect and save the forest ecosystems to sustain the forest health and long-term productivity.

Consequently, social concerns and values with regard to the products, services, and factors involved in the harvesting processes from forestlands have been translated into new acts, laws and regulations as well as techniques. Within this new context, mathematical programming techniques have replaced the simple formulas used in the early years for wood supply analysis and management planning (Parades and Brodie, 1988). As is known, the traditional mathematical formulas simply convert old growth forests into younger ones, where the distribution of age class structure is assumed to be even. Although this classical area regulation approach is no longer the focus of forest management

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planning, it has still been used in various countries, including Turkey.

As this approach does not provide an optimal management schedule even for a single wood production objective, various techniques have been used. Mathematical optimization techniques such as linear programming (LP), integer programming (IP) and goal programming (GP) seek to find the maximum level of economic value for timber harvesting and ecological and social value from the forest's composition subject to some management and policy constraints.

LP is the first optimization technique widely used in forest management planning. Some LP applications include the scheduling of timber harvests (Field et al., 1980; Leuschner, 1990; Görücü, 1995, 2004; Davis et al., 2001), product optimization (Hof and Pickens, 1991), forest regulation (Hof et al., 1986; Leuschner, 1990; Gül, 1995; Davis et al., 2001), determining the rotation time of various commercial trees (Soykan, 1979; Hoganson and McDill, 1993; Gül, 1999), optimization of stumpage value (Geray, 1978) and multiple use forest management planning (Hof and Baltic, 1990; Haight et al., 1992; Rowse and Center, 1998; Gül, 1998; Hof and Bevers, 2000; Mısır, 2001; Keleş, 2003; Karahalil, 2003; Yolasığmaz, 2004).

While the application of LP in forest management is quite common in developed countries, very few studies have been carried out in Turkish forestry. Furthermore, the limited number of studies has meant that this subject remains a closed book and almost none of the foresters, in charge of or responsible for forest management planning in Turkey, have yet appreciated the advantage of LP. As a result, a simple yet comprehensive enough LP-based harvest scheduling model needs to be developed and presented to foresters.

In this research, alternative wood harvesting strategies including the scheduling of timber harvests, optimization of wood assortments, and regulation of forest structure are developed and solved by LP. Model outputs or forest performance are presented with the NPVs of harvest volume varied according to 3 discount rates and 4 wood assortments.

Materials and Methods

The study area, Artvin Forest Planning Unit, covers 5175.68 ha. In the context of this study, only 274 ha are subjected to harvest scheduling. The forest contains coniferous and broadleaf trees along with open areas, and non-productive sites. The main tree species are spruce (*Picea orientalis*), fir (*Abies nordmanniana*), pine (*Pinus silvestris*) and beech (*Fagus orientalis*). The planning area consists of 116 sub-compartments (or stands) that are subject to certain management interventions.

The volume of merchantable timber is calculated by a timber growth and yield function for each species developed by Ercanlı (2003) for spruce, by Asan (1984) for fir, by Carus (1999) for beech, and by Alemdağ (1967) for pine. However, wood assortment rates of 4 timber assortments such as logs, mining poles, industrial wood, and firewood were determined by stand age and mean stand diameter for the relevant species prepared by Sun et al. (1977).

In calculating net present values (NPVs), the incomes from the case forest area are determined by means of various wood assortment volumes and the per unit value of the corresponding wood assortment. These values include effective market sale prices taken from the corresponding state forest enterprise. Similarly, the expenses are determined by harvesting costs including cutting, logging and hauling or transporting expenses. Finally, net revenues are determined by means of sale prices and harvesting costs. Some other costs such as general administration, building and maintenance costs of forest roads are not included in the calculation of net revenue. Financial valuations were carried out using various discount rates of 3%, 4%, and 5%.

In developing alternative harvesting strategies connected to wood production, LP was used. For this reason, all alternative models are developed according to Model I approach (Leuschner, 1990; Davis et al., 2001). In this study, before alternative wood harvesting strategies were developed, some assumptions dependent on scientific, ecological, economic, and enterprise conditions and requirements in addition to pre-defined decisions were accepted. These are briefly given below.

The goal of the alternative wood harvesting strategies developed here is to maximize the NPVs of harvested wood assortments. Minimum harvesting ages for spruce and fir are 90 years for good sites and 100 years for other sites. Minimum harvesting ages for beech are 100 years for the best sites and 120 years for others. Finally, minimum harvesting ages for pine are 80 years for best sites and 100 years for others. Open areas may be afforested in any period. All sub-compartments must be cut once when they have reached the minimum harvesting age or after. The planning horizon is 100 years and the planning period is 10 years. Timber products and their NPVs are calculated at the sub-compartment level. Stands whose crown closure is 11-40% cannot be thinned but can be regenerated when they have reached the minimum harvesting age. It is assumed that the development of forests after regeneration and forestation is optimal. Growth and yield projection of existing stands is estimated by increment percentages simulation (Eraslan, 1981). All stand parameters such as volume and values are calculated at the middle age of each period.

Depending on these assumptions, 4 alternative wood harvesting strategies are developed in the context of this study. Various strategies may also be developed according to the demands of forest managers or owners via the smart LP-based timber harvest model established here. The timber wood harvesting strategies developed are given below.

HARVEST1- Maximize NPVs of total production of wood assortments over the planning horizon with the constraint of 5% flow of optimal periodic area among periods.

HARVEST2- Maximize NPVs of total production of wood assortments over the planning horizon with the constraint of 5% flow of volume of total wood assortments among periods.

HARVEST3- Maximize NPVs of total production of wood assortments over the planning horizon with no constraints.

HARVEST4- Maximize NPVs of total production of wood assortments over the planning horizon with the constraint for even flow of log volumes and even flow of mining pole volumes among periods.

The problem is stated in an LP structure.

$$Z_{max} = \sum_{j=1}^{n} (LOG_j + MIN_j + IND_j + FIRE_j) \quad 1$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} log_{ij}\, a_{ij}\, x_{ij} - LOG_j = 0 \quad 2$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} min_{ij}\, b_{ij}\, x_{ij} - MIN_j = 0 \quad 3$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} ind_{ij}\, c_{ij}\, x_{ij} - IND_j = 0 \quad 4$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} fire_{ij}\, d_{ij}\, x_{ij} - FIRE_j = 0 \quad 5$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}\, x_{ij} - LOGMIK_j = 0 \quad 6$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} b_{ij}\, x_{ij} - MINMIK_j = 0 \quad 7$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, x_{ij} - INDMIK_j = 0 \quad 8$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}\, x_{ij} - FIREMIK_j = 0 \quad 9$$

$$LOGMIK_j + MINMIK_j + INDMIK_j + FIREMIK_j - TOTCUT_j = 0 \quad 10$$

$$\sum_{i=1}^{m} x_{ij} = T_i \quad 11$$

$$\sum_{j=1}^{n} x_{ij} - A_j = 0 \quad 12$$

$$\sum_{j=1}^{n} (-(1-y)\, TOTCUT_j + TOTCUT_{j+1} \geq 0 \quad 13$$

$$\sum_{j=1}^{n} (-(1+y)\, TOTCUT_j + TOTCUT_{j+1} \leq 0 \quad 14$$

$$\sum_{j=1}^{n} LOGMIK_j + LOGMIK_{j+1} = 0 \quad 15$$

$$\sum_{j=1}^{n} MINMIK_j + MINMIK_{j+1} = 0 \quad 16$$

Equation 1 represents the objective function, which is to maximize the NPVs of total production of wood assortments over the planning horizon. Equations 2, 3, 4 and 5 represent the NPVs of log, mining pole, industrial wood and firewood products from the planning area in period j, and are expressed as LOG_j, MIN_j, IND_j, and $FIRE_j$, respectively. Equations 6, 7, 8, and 9 represent the volumes of log, mining pole, industrial wood and firewood products from the planning area in period j, and are expressed as $LOGMIK_j$, $MINMIK_j$, $INDMIK_j$, and $FIREMIK_j$, respectively. Furthermore, $TOTCUT_j$ in equation 10 represents the volume of total timber production harvested in period j. Equation 11 is the area constraint, which defines land availability in each sub-compartment. Equation 12 is the even age distribution constraint. In the alternative wood harvesting strategy HARVEST1 used in this study, however, the optimal periodic area for each period may fluctuate 5% between sequential periods. Equations 13 and 14 are volume control constraints. In HARVEST2, harvest may fluctuate 5% (y) between successive periods. In addition, HARVEST4 uses a volume control policy. In this model 2 constraints, even flow of log and mining pole production as volume, are used. These are represented in equations 15 and 16. Other notations in the model express the following statements. m: number of sub-compartments; n: number of periods; X_{ij}: number of hectares of sub-compartment i assigned to cut in period j; a_{ij}: log production from sub-compartment i in period j (m^3); b_{ij}: mining pole production from sub-compartment i in period j (m^3); c_{ij}: industrial wood production from sub-compartment i in period j (m^3); d_{ij}: firewood production from sub-compartment i in period j (m^3); log_{ij}: NPV log product from sub-compartment i in period j ($); min_{ij}: NPV mining pole product from sub-compartment i in period j ($); ind_{ij}: NPV industrial product from sub-compartment i in period j ($); $fire_{ij}$: NPV firewood product from sub-compartment i in period j ($); T_i: forest areas available for harvest in period j; and A_j: optimal periodic area in period j.

Results and Discussion

Table 1 shows total NPV and production of wood assortments for each alternative over the planning horizon. Results for each alternative wood harvesting strategy are also given in Tables 2 through 5, respectively. They show amounts (m^3) and NPVs of various wood assortments by periods and various discount rates for each wood harvesting strategy. Figures 1 (a, b, c) and 2 (a, b, c) also show total NPV and production of wood assortments for each period with various discount rates, respectively. Figure 3 shows the distribution of age class structure of wood harvesting strategies at the end of the planning horizon.

HARVEST1 has the lowest total NPVs for each discount rate at the end of the planning horizon (Tables 1 and 2). As the discount rate increases, total NPV of the wood harvesting strategy decreases (Görücü 1995, 2004; Gül, 1999; Türker, 2000). The NPV reductions for discount rates of 4% and 5% compared to 3% are 24.7% and 41.7%, respectively, although the total amounts of wood assortments harvested at the end of the planning horizon are identical (Figure 1a, b, c). Görücü stated that NPV reductions for discount rates of 5% and 6% compared to 4% are 32.2% and 44.2%, respectively. Furthermore, log, mining pole, industrial wood and firewood volumes obtained from the planning unit at the end of the planning horizon are almost equal at each discount rate. Figure 2a, b, c shows the flow of periodic wood volume associated with each management strategy generated with various discount rates. The differences among the periods are notable, as seen in a fluctuated or unregulated structure. The age class

Table 1. Total production of wood assortments and total net present value of wood harvesting strategies for various discount rates at the end of the planning horizon.

Wood Harvesting Strategies	Total Production of Wood Assortments (m^3)			Total Net Present Value ($)		
	Discount Rates			Discount rates		
	3	4	5	3	4	5
HARVEST1	143,862	143,454	143,454	886,375	667,422	516,894
HARVEST2	145,681	145,690	145,709	1,018,241	826,343	692,887
HARVEST3	133,569	133,569	133,601	1,362,824	1,207,238	1,077,733
HARVEST4	148,013	147,952	147,946	925,761	730,626	599,917

Table 2. Results of HARVEST1 strategy according to various discount rates.

Dis. Rate	Period	Log (m^3)	Log ($)	Mining Pole (m^3)	Mining Pole ($)	Industrial Wood (m^3)	Industrial Wood ($)	Fire Wood (m^3)	Fire Wood ($)
3	1	2617	60,966	1305	29,890	1233	17,945	804	1702
	2	1982	27,126	981	16,728	924	10,002	571	900
	3	20,761	258,823	9176	116,362	7858	63,323	6140	7203
	4	1344	8782	924	8723	891	5342	622	542
	5	14,227	69,092	6212	43,616	6073	27,094	3549	2304
	6	1006	3700	653	3410	630	2092	1260	608
	7	11,678	33,426	4842	18,825	4952	12,233	5004	1799
	8	1068	2224	980	2836	910	1672	1325	354
	9	7094	11,045	2846	6126	2797	3825	3225	642
	10	1462	1764	1213	1943	1130	1150	1595	236
	Total	63,239	476,948	29,133	248,459	27,397	144,678	24,095	16,290
4	1	2617	58,096	1305	28,483	1233	17,100	804	1622
	2	1982	23,455	981	14,464	924	8648	571	778
	3	20,761	203,219	9176	91,364	7858	49,719	6140	5655
	4	1344	6252	924	6210	891	3803	622	386
	5	14,395	44,986	6225	28,265	6067	17,505	3404	1429
	6	978	2124	644	1983	622	1217	1257	358
	7	12,173	18,177	4958	10,267	5034	6625	4688	898
	8	936	957	943	1327	873	781	1339	174
	9	6145	4515	2694	2575	2687	1632	3746	331
	10	1462	702	1224	780	1140	461	1688	99
	Total	62,793	362,483	29,075	185,718	27,329	107,491	24,259	11,730
5	1	2617	54,777	1305	27,132	1233	16,289	804	1545
	2	1982	20,328	981	12,536	924	7495	571	674
	3	20,761	159,866	9176	71,873	7858	39,112	6140	4449
	4	1344	4472	924	4442	891	2720	622	276
	5	14,395	29,201	6225	18,347	6067	11,363	3404	928
	6	978	1245	644	1162	622	713	1257	209
	7	12,173	9787	4958	5528	5034	3567	4688	483
	8	936	469	943	651	873	383	1339	85
	9	6145	2006	2694	1144	2687	725	3746	147
	10	1462	263	1224	292	1140	173	1688	37
	Total	62,793	282,414	29,075	143,107	27,329	82,540	24,259	8833

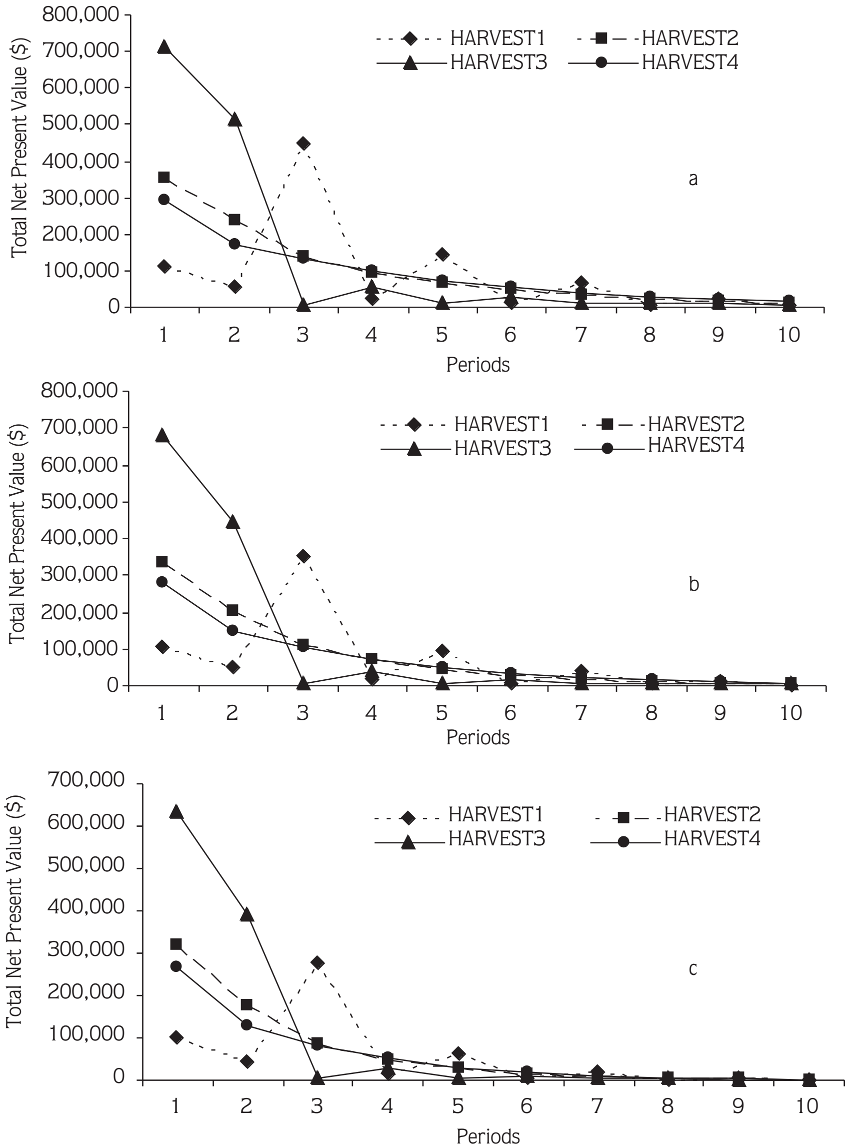


Figure 1. The total net present values of wood harvesting strategies according to various discount rates for a) 3%, b) 4% and c) 5%.

structure of the forest at the end of the planning horizon is within the interval of 5% change of the optimal periodic area (regulated forest) in periods (Figure 3).

HARVEST2 just follows HARVEST3 from the point of view of both total production of wood assortments and total NPV obtained at the end of the planning horizon for the same discount rates, but is different from HARVEST1 (Tables 1 and 3). The NPV reductions in increasing discount rates are identical to those in HARVEST1. For example, the NPV reductions with discount rates of 4% and 5% compared to 3% are 18.8% and 31.9%, respectively. A 5% fluctuation in volume of total wood assortments is allowed among periods, or namely a volume control policy is carried out (Figure 2a, b, c). Figure 3 shows the age class structure of the forest at the end of the planning horizon associated with HARVEST2. The differences among the areas of age classes are scattered; especially the area of the fifth age class is

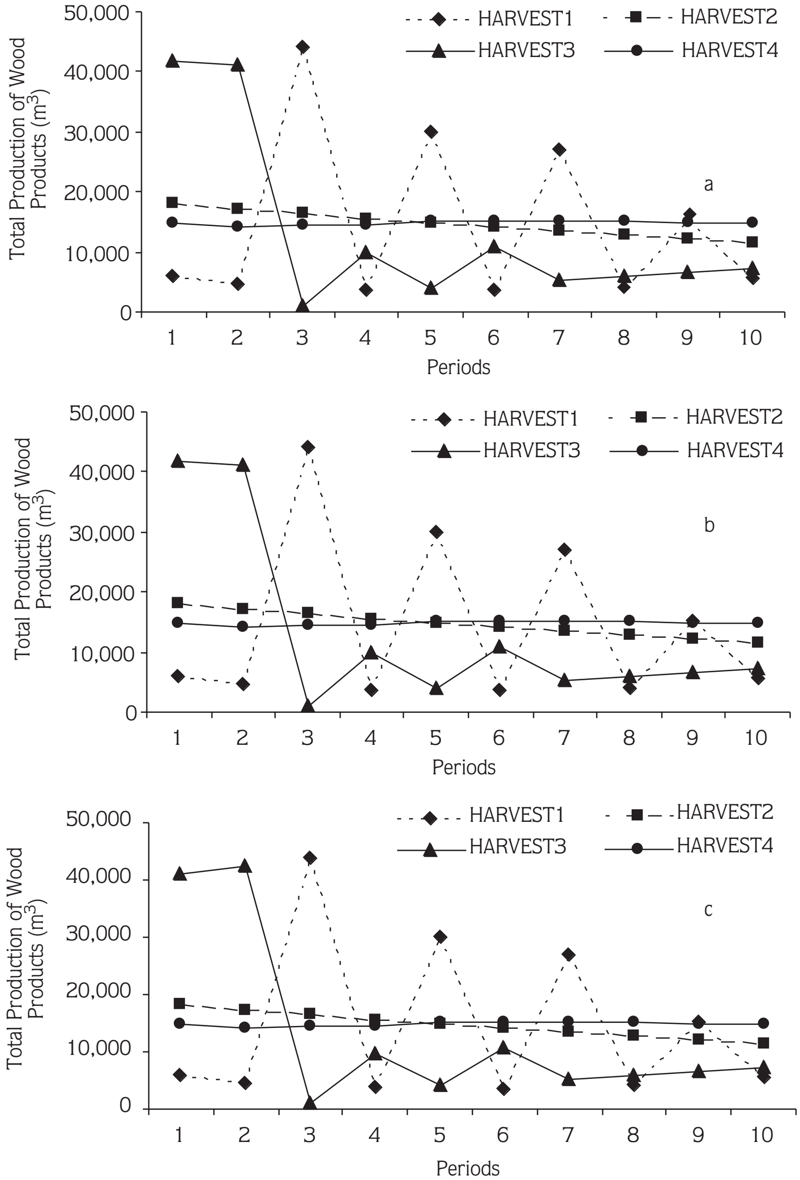
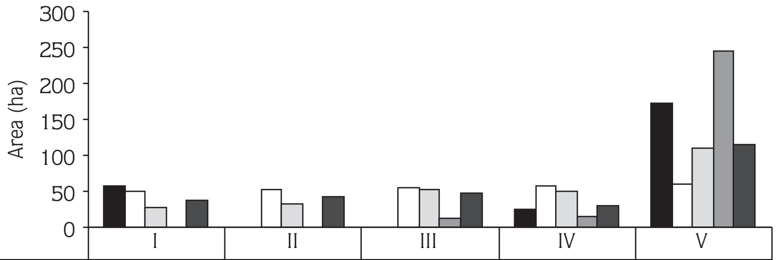


Figure 2. The total wood production of wood harvesting strategies according to various discount rates for a) 3%, b) 4% and c) 5%.

higher than other age classes. The reason for this difference among the periods is that a sufficiently large area of sub-compartments is being cut in the preceding periods to increase the total NPV of wood assortments.

Among all the wood harvesting strategies, HARVEST3 resulted in the highest NPVs from wood assortments over the planning horizon for each discount rate (Tables 1 and 4). The reason for these large amounts of NPV can be explained by more harvesting of wood assortments, especially log production, in the first 2 periods. Most importantly, no constraints including area or volume control policies are imposed in this wood harvesting strategy. The integration of regulated constraints into wood-based forest management planning causes both economic profit and wood volume losses (Field et al., 1980; Hof et al., 1986; Haight et al., 1992; Hoganson



	I	II	III	IV	V
ACTUAL	57.3	0.0	0.0	25.6	172.7
HARVEST1	49.4	51.9	54.5	57.2	60.1
HARVEST2	27.6	31.9	52.7	49.7	111.1
HARVEST3	0.0	0.0	13.6	14.0	245.6
HARVEST4	37.6	42.8	46.5	31.1	115.2

Age Classes

Figure 3. Distribution of the age classes of alternative wood harvesting strategies at the end of the planning horizon.

and McDill, 1993). For example, Haight et al. (1992) found that a model including a volume regulated constraint resulted in a NPV reduction of 5% compared to an unconstrained model. The values of NPV for discount rates of 3%, 4% and 5% in this strategy are $1,362,824, $1,207,238 and $1,077,733, respectively. As seen, as the discount rate increases, the total NPV of the profits of wood assortments over the planning horizon decreases (Görücü, 1995, 2004; Gül, 1999; Türker, 2000). These NPV reductions compared to a discount rate of 3% are 11.4% for a discount rate of 4% and 20.9% for a discount rate of 5%. The periodic volume of wood assortments and age structure of the forest in HARVEST3 are extremely scattered (Figures 2a, b, c and 3). For example, periodic volumes in the first 2 periods are significantly larger than those in periods 3 and 10, because most sub-compartments are cut in very early periods, and then the area of the last age class is large. Figure 3 shows that no area in the first 2 periods exists, but one of 245.6 ha is present in the last age class.

HARVEST4 provides more total NPV of the profits of wood assortments than does HARVEST1 except for other strategies, but it has also the largest total production of wood assortments at the end of the planning horizon (Table 1). The total NPV reductions for increasing discount rates in HARVEST4 are identical to those of the other strategies. The reductions compared to a discount rate of 3% are 21.1% for a discount rate of 4% and 35.2% for a discount rate of 5%. However, this strategy enables even flow of log and mining pole volumes among periods; thus, total periodic volumes associated with each management plan generated for various discount rates are similar (Table 5). However, a regulated forest (uniform distribution of age classes) does not guarantee even flow of volume. Because this strategy includes only volume control constraints within the model, age class distribution is not guaranteed. As a result, the area of the last age class, 115.2 ha, is fairly far from the optimal periodic area (the regulated forest).

Conclusions

Operations research techniques have long been inevitable tools of decision makers in the development of sustainable forest management plans. From ecological and economic viewpoints, a regulated forest with relatively even wood and cash flow over time is preferable to irregular ones as it facilitates forward-looking sustainable planning of forests. This study examined the impacts of volume and area constraints (indicators for sustainable forest management) on total production of wood and its NPV. In addition, since the discount rate is considered in an essential tool for management decisions and the resulting economic return, wood harvesting strategies are developed to examine the effects of 3 levels of discount rates (3%, 4% and 5%) on maximum wood production and NPVs. The LP-based forest management model for optimization of wood production developed here enables us to reach the following conclusions:

Table 3. Results of HARVEST2 strategy according to various discount rates.

Dis. Rate	Period	Log (m^3)	Log ($)	Mining Pole (m^3)	Mining Pole ($)	Industrial Wood (m^3)	Industrial Wood ($)	Fire Wood (m^3)	Fire Wood ($)
3	1	9031	213,065	3608	82,633	3483	50,688	2031	4304
	2	5099	106,400	4979	84,866	3655	39,582	3512	5537
	3	8861	78,882	2775	35,193	2708	21,821	2039	2392
	4	7152	46,457	3135	29,584	3055	18,316	2222	1940
	5	5388	28,741	2957	20,765	2973	13,265	3467	2252
	6	6405	23,297	2664	13,921	2615	8682	2362	1141
	7	4566	13,580	2765	10,748	2811	6944	3202	1152
	8	4791	9758	2813	8139	2684	4934	2388	639
	9	5618	8560	2268	4882	2188	2992	1969	392
	10	5450	6272	2022	3239	1952	1987	2017	299
	Total	62,361	535,012	29,987	293,970	28,123	169,211	25,210	20,048
4	1	9032	203,044	3608	78,748	3483	48,305	2031	4101
	2	5099	92,007	4980	73,387	3655	34,227	3512	4788
	3	8778	61,363	2807	27,954	2738	17,325	2060	1898
	4	7265	33,592	3089	20,752	3013	12,863	2198	1366
	5	5389	18,587	2958	13,429	2973	8578	3467	1456
	6	6414	13,752	2667	8215	2618	5124	2348	669
	7	4553	7215	2735	5664	2782	3662	3275	627
	8	4806	4761	2840	3996	2709	2422	2324	302
	9	5609	3795	2269	2169	2189	1329	1977	175
	10	5452	2497	2022	1289	1952	791	2015	119
	Total	62,395	440,613	29,974	235,603	28,113	134,626	25,208	15,501
5	1	9033	192,864	3608	75,020	3483	46,019	2032	3907
	2	5099	79,750	4981	63,617	3656	29,668	3513	4150
	3	8625	47,434	2871	22,489	2795	13,913	2095	1518
	4	7343	24,293	3057	14,692	2985	9116	2182	970
	5	5406	12,192	2905	8561	2938	5502	3540	965
	6	6511	8117	2672	4825	2613	2998	2254	376
	7	4543	3878	2726	3040	2774	1966	3303	341
	8	4811	2338	2841	1961	2710	1189	2317	148
	9	5604	1685	2262	961	2182	589	1998	79
	10	5442	935	2013	481	1944	295	2044	45
	Total	62,416	373,486	29,935	195,647	28,080	111,255	25,278	12,499

Table 4. Results of HARVEST3 strategy according to various discount rates.

Dis. Rate	Period	Log (m^3)	Log ($)	Mining Pole (m^3)	Mining Pole ($)	Industrial Wood (m^3)	Industrial Wood ($)	Fire Wood (m^3)	Fire Wood ($)
3	1	19,948	388,119	8462	193,821	8298	120,769	5215	11,049
	2	14,879	224,209	10,518	179,264	8988	97,334	6799	10,719
	3	108	970	178	2256	171	1380	691	811
	4	2452	16,340	2347	22,151	2248	13,479	2799	2443
	5	163	855	647	4541	612	2732	2602	1690
	6	2023	8801	2000	10,450	2074	6887	4602	2224
	7	816	2373	1504	5849	1396	3450	1476	531
	8	1273	2762	1576	4559	1471	2704	1614	432
	9	1840	2971	1682	3620	1577	2157	1406	280
	10	2517	3047	1808	2896	1708	1739	1079	160
	Total	46,019	650,447	30,723	429,407	28,544	252,631	28,283	30,339
4	1	19,948	369,847	8462	184,697	8298	115,084	5215	10,529
	2	14,879	193,868	10,518	155,004	8988	84,162	6799	9269
	3	108	762	178	1772	171	1083	691	637
	4	2452	11,633	2347	15,770	2248	9596	2799	1739
	5	163	553	647	2936	612	1766	2602	1093
	6	2023	5188	2000	6161	2074	4060	4602	1311
	7	816	1264	1504	3116	1396	1838	1476	283
	8	1273	1344	1576	2218	1471	1316	1614	210
	9	1840	1319	1682	1608	1577	958	1406	124
	10	2517	1212	1808	1152	1708	692	1079	64
	Total	46,019	586,990	30,723	374,434	28,544	220,555	28,283	25,259
5	1	19,421	342,179	8270	171,940	8111	107,149	5115	9837
	2	15,474	173,249	10,714	136,841	9181	74,511	6899	8151
	3	108	599	178	1394	171	852	691	501
	4	2452	8322	2347	11,282	2248	6865	2774	1233
	5	163	359	647	1906	612	1147	2586	705
	6	2023	3041	1989	3591	2063	2367	4634	774
	7	813	678	1504	1677	1396	989	1475	152
	8	1268	657	1576	1088	1471	645	1615	103
	9	1834	585	1682	714	1577	426	1408	55
	10	2514	454	1808	432	1708	259	1080	24
	Total	46,071	530,123	30,715	330,865	28,538	195,210	28,277	21,535

Table 5. Results of HARVEST4 strategy according to various discount rates.

Dis. Rate	Period	Log (m^3)	Log ($)	Mining Pole (m^3)	Mining Pole ($)	Industrial Wood (m^3)	Industrial Wood ($)	Fire Wood (m^3)	Fire Wood ($)
3	1	6614	178,197	2993	68,565	2951	42,957	2220	4704
	2	6614	86,253	2993	51,019	2709	29,335	1738	2739
	3	6614	70,979	2993	37,963	2581	20,802	2381	2793
	4	6614	53,613	2993	28,248	2600	15,592	2223	1940
	5	6614	39,165	2993	21,019	2755	12,293	2882	1872
	6	6614	25,776	2993	15,640	2906	9650	2836	1371
	7	6614	18,442	2993	11,638	2992	7392	2631	946
	8	6614	13,692	2993	8660	2952	5426	2444	654
	9	6614	10,034	2993	6444	2892	3955	2090	416
	10	6614	7516	2993	4795	2878	2929	2274	337
	Total	66,142	503,667	29,935	253,991	28,217	150,331	23,719	17,772
4	1	6610	169,743	2994	65,343	2962	41,087	2292	4628
	2	6610	74,932	2994	44,118	2698	25,262	1745	2378
	3	6610	55,697	2994	29,810	2581	16,334	2380	2192
	4	6610	38,140	2994	20,112	2601	11,101	2206	1371
	5	6610	24,969	2994	13,593	2762	7969	2768	1163
	6	6610	15,238	2994	9221	2885	5647	2679	763
	7	6610	9828	2994	6200	2994	3941	2650	508
	8	6610	6687	2994	4213	2962	2649	2521	328
	9	6610	4453	2994	2862	2891	1756	2177	192
	10	6610	2989	2994	1908	2878	1166	2284	135
	Total	66,098	402,676	29,937	197,380	28,215	116,912	23,702	13,658
5	1	6596	161,006	2998	62,329	2966	39,191	2295	4413
	2	6596	65,162	2998	38,289	2691	21,836	1755	2073
	3	6596	43,805	2998	23,483	2583	12,856	2384	1728
	4	6596	27,280	2998	14,408	2602	7946	2208	982
	5	6596	15,984	2998	8836	2780	5207	2808	766
	6	6596	8902	2998	5413	2881	3305	2597	434
	7	6596	5276	2998	3343	2995	2123	2640	272
	8	6596	3289	2998	2070	2975	1305	2548	163
	9	6596	1975	2998	1274	2894	781	2229	88
	10	6596	1119	2998	716	2882	438	2291	51
	Total	65,963	333,798	29,979	160,161	28,249	94,988	23,755	10,970

- It is possible to control the optimal periodic area (the regulated forest) by changing rates of return, in sacrificing some total volume of wood production over time.
- It is possible to control total volumes of wood assortments (volume control) over sequential periods by various levels of changing rates.
- The model enables decision makers to assess the trade-offs between periods and various wood assortments.
- The model enables decision makers to assess the effect of different discount rates on total production of wood assortments and the total NPV over a planning horizon.
- The model provides various outputs such as volumes and NPVs of logs, mining poles, industrial wood, and firewood produced in each period, afforested areas in each period, and age class distribution of alternative wood harvesting strategies over the planning horizon.

The results of wood harvesting strategies indicated that the impact of the selected classical volume and area control policies varied considerably. While wood harvesting strategies with area control constraints provided a regular forest structure, those with volume control constraints provided a regulated wood flow, as expected. However, both constraints may not always be imposed in a model, because of a possible infeasible solution resulting from an over-unregulated initial age class structure in the short term.

Discount rates are an important means of controlling the economic aspects of plan outputs. As the discount rate increases, the total NPV of wood harvesting strategies at the end of a planning horizon decreases with certain proportions. High discount rates quickly liquidate the growing stock of a forest, when economy is the leading factor in management. However, when ecology dominates the decision, low discount rates should be considered.

It is possible to develop alternative forest management plans with LP as the preparation of management plans is convenient in solving forest management problems with area and volume control policies. The wood harvesting strategies can be modified according to the demands of decision makers and stakeholders. Thus, decision makers may make more accurate and consistent decisions when solving various forest management planning problems.

Developing forest planning models based on various simulation or mathematical optimization techniques, like the model developed here, is extremely important for Turkish forestry and the sustainability of its forest ecosystems. Since traditional forest management philosophy has already faded away, contemporary forest management philosophy flourishes, requiring the active use of decision making tools. The quantitative models encourage forest managers and decision makers to solve complex forest management problems including ecological, economic and social concerns such as biodiversity, water and soil protection, recreation, wildlife habitat and spatial considerations in the future.

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