Yield Models of Pure Fir (*Abies nordmanniana* S. subsp. *bornmülleriana* (Mattf.)) Stands (Western Black Sea Region)

***Nuray MISIR, Mehmet MISIR, Cemile ÜLKER**
Karadeniz Tehnical University, Faculty of Forestry, 61080-Trabzon TURKEY
*Corresponding author: nuray@ktu.edu.tr

Abstract

Yield models are important tools in forest management planning because they can simulate stand development and production under various management alternatives. Yield of forest stands is determined using tables containing values of height, diameter, number of trees, volume, etc., for different site and age classes. These tables have been created by using basically mathematical equations with statistical analyses.

Some species are of low economic importance, but all of them are of high ecological importance for the ecosystems. *Abies nordmanniana* subsp. *bornmülleriana* Mattf. is one of the both-way important tree species in Turkey. Hence, site index curves and yield tables for natural fir stands in the Western Black Sea region were developed. Data were collected from a total of 20 sample plots and 15 sample trees. Site index curves were used to classify into site classes of I, II and III, in order of decreasing productivity. The yield models can be calibrated on Turkish Forest Management Planning Department field plot data and tested against independent long-term growth and yield records.

Key Words: *Abies n.* subsp. *bornmülleriana,* site index, yield

Introduction

Growth models assist forest researches and managers in many ways. Some important uses include the ability to predict future yields and to explore silvicultural options. Models provide an efficient way to prepare resource forecasts, but a more important role may be their ability to explore management options and silvicultural alternatives.

There is an extensive literature on growth modeling of pure even-aged forest stands, especially of plantations. However, these ecosystems are in many respects rather simplistic, and many of these modeling approaches do not apply in forest stands with trees of many ages or many species (Vanclay, 1994).

It is useful to classify growth models on the level of detail they provide. A model may be considered a whole stand model, a size class model, or a single-tree model, depending on the detail required, provided and utilized by model (Davis and Johnson, 1987; Vanclay, 1994; Laar and Akça, 1997; Porté and Bartelink, 2002).

Whole stand models are often simple and robust, but may involve complexities not possible in other approaches. Population parameters such as stocking, stand basal area and standing volume are used to predict the growth or yield of forest. No details of the individual trees in the stand are determined.

Size class models provide some information regarding the structure of the stand. Several techniques are available to model stand structure, but one of the most widely used is the method of stand table projection which essentially produces a histogram of stem diameters. This approach is a compromise between the whole stand models and single-tree models.

The most detailed approach is that of single-tree models which use the individual tree as the basic unit of modeling. The minimum input required is a list specifying the size of every tree in the stand. Some models also require the spatial position of the tree, or tree height and crown class.

The first growth and yield model was constructed by Alemdağ (1962) for the ideal, fully stocked or normal Brutian pine (*Pinus brutia* Ten.) forest stands in Turkey. Since then, many normal yield tables have been constructed, for example for cedar (Evcimen, 1963), Anatolian black pine (Kalıpsız, 1963), Scots pine (Alemdağ, 1967), spruce (Akalp 1978), the Kazdağı fir (Asan 1984), alder (Batu and Kapucu, 1995), and beech (Carus, 1998).

Until now, variable density yield tables for natural Brutian pine stands (Yeşil, 1992), spruce stands (Köse et al., 2001), chestnut stands (Kapucu et al., 2002) and Scots pine (Yavuz et al., 2010), growth and yield tables for the I-214 poplar plantations (Birler, 1983) and Asian pyramidal black poplar plantations (Birler et al., 1992) were constructed in Turkey.

In this study, an empirical growth model for *Abies nordmanniana* subsp. *bornmülleriana* Mattf. in Bostan Forest District was developed and compared with the results of other natural tree species growth model.

Material

The data used in this study were collected from natural fir stands in Bostan Forest District of Kastamonu Forest Enterprise. Total area of the study area is 8,297.5 ha and forested area is 5,764 ha. Mean altitude and slope of this area are 1,750 m and 60%, respectively. These fir forests show an even-aged stand structure.

From the various age and site classes, 20 temporary sample plots and 15 sample trees were measured in 2012. Plot size is 600 sq.m. In each sample plot, diameter at breast height, stump diameter and bark thickness of all trees, and the height of at least 30 trees with different sizes were measured. In addition, 15 sample trees 65 to 186 years old were used to determine the site index and perform stem analysis. The age, diameter at breast height and total height of these trees are shown in Table 1.

Methods

In this study, polymorphic method was used to determine site index of fir stands. Different approximations have been used in polymorphic method (Johnson and Worthington 1963; Curtis 1964; Heper 1968; Lenbert 1972; Graney 1973; Monserud 1984; Alemdağ 1985). But, these approximations are similar to each other. In this study, the “indirect method” with three independent variables and developed by Alemdağ (1985) was used. The standard age was 100 years and three site classes (good, medium, and poor) were formed.

In order to build the growth model, at first step mean diameter ($\bar{d}_q$), mean height ($\bar{h}_q$), dominant height (h_{100}), age (t), number of trees (N), basal area (BA), and volume (V) per hectare of each stand were calculated by using the data obtained from the sample plots.

Table 1. Summary Statistics of Sample Trees

Number of Trees	Age (Years)	*Dbh* (cm)	Total Height (m)
1	100	10.0	6.2
2	146	57.5	36.9
3	159	47.5	31.4
4	140	57.3	39.5
5	106	32.6	22.7
6	160	37.5	29.3
7	103	11.4	10.1
8	69	19.2	17.6
9	79	32.2	26.3
10	85	16.8	14.8
11	67	14.0	10.6
12	65	12.9	12.1
13	121	51.9	28.8
14	105	28.7	22.2
15	186	32.4	26.3

We constructed the single-entry volume table to predict tree volume. At second step, as a function of stand age and dominant height, site index of each stand was calculated. At third step, mean diameter, mean height, number of trees, basal area and volume per hectare of main stands were predicted as a function of stand age and site index. Lastly, volume of removed stand (in this study, the total volume of the trees cut in the last cutting periods was taken as volume of removed stand). The diameter at breast height, total height, and volume of cut trees was calculated from the diameter at breast height-stump diameter, total height-diameter at breast height, and volume-diameter at breast height-total height relationships, respectively. After calculating the mean volume of cut trees for each growth period, these values were predicted as a function of stand age and site index, and for each site classes and age classes (ten year-intervals), the elements of main stand and removed stand were tabulated.

Results

According to standard age 100, the site index equations according to site classes are as follows.

$$be_{I} = -5.143 + 0.494 \times t - 0.001 \times t^{2}$$

R^2=0.92 $S_{y.x}E$=3.3m P<0.001

$$be_{II} = -2.768 + 0.306 \times t - 0.001 \times t^{2}$$

R^2=0.94, $S_{y.x}$=2.05 P<0.001

$$be_{III} = 0.014 \times t^{1.495}$$

R^2=0.84, $S_{y.x}$=0.45 (log), P<0.001

By using these equations, 10-year interval from age 30 to 110, and 2 m intervals from site index 6.5 to 34.5, the site index table was shown in Table 2.

Table 2. Site Index Table For Fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf.) Stands

Age	Site Indices (m)														
	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35
	Poor (Class III)					Medium (Class II)					Good (Class I)				
30	1.2	1.5	1.8	2.1	2.5	5.3	5.9	6.5	7.1	7.7	6.9	7.4	7.9	8.4	8.9
40	1.8	2.3	2.8	3.3	3.8	7.5	8.4	9.3	10.2	11.0	10.2	11.0	11.7	12.5	13.3
50	2.4	3.2	3.9	4.6	5.3	9.6	10.7	11.8	12.9	14.1	13.4	14.4	15.4	16.4	17.4
60	3.3	4.2	5.1	6.1	7.0	11.4	12.8	14.1	15.5	16.8	16.4	17.6	18.9	20.1	21.3
70	4.1	5.3	6.5	7.6	8.8	13.1	14.7	16.2	17.7	19.3	19.3	20.7	22.1	23.6	25.0
80	5.0	6.5	7.9	9.3	10.7	14.6	16.3	18.0	19.7	21.5	22.0	23.6	25.2	26.9	28.5
90	6.0	7.7	9.4	11.1	12.8	15.9	17.8	19.6	21.5	23.4	24.5	26.3	28.2	30.0	31.8
100	7.0	9.0	11.0	13.0	15.0	17.0	19.0	21.0	23.0	25.0	26.9	28.9	30.9	32.9	34.9
110	8.1	10.4	12.7	15.0	17.3	17.9	20.0	22.1	24.2	26.3	29.2	31.3	33.5	35.6	37.8

The mean diameter, mean height, dominant height, stand age, site index at standard age 100, number of trees per hectare, basal area per hectare, and volume per hectare were calculated from sample plots data. Some summary data of sample plots are shown in Table 3.

Table 3. Some Statistics of Sample Plots

	n	Mean	Min	Max	Standard Deviation
Stand age	20	102	33	186	29.4
Mean diameter	20	28.8	18.8	41.5	5.6
Mean height	20	20.2	8.2	36.9	4.8
Dominant height	20	30.8	13.5	37.9	3.2
Site index	20	25.2	9.6	42.0	4.8
Number of trees	20	873	475	1400	300
Basal area	20	55.6	13	113	24.6
Volume	20	1061	275	2134	483

The regression equations predicting some growth elements of main and removed stands, as a function of plantation age and site index are shown below.

$$\hat{d} = -5.473 + 0.010 \times be \times t$$

R^2= 0.56 SE=3.75 p<0.001

$$\hat{h} = -144.329 + 520.2140.401 \times \ell n(be \times t)$$

R^2= 0.25 SE=4.18 p<0.001

$$\hat{N} = 41854.698 - 4.060 \times t + 1.816 \times be \times t - 5744.241 \times \ell n(bet)$$

R^2= 0.36 SE=0.19621 p<0.001

$$\hat{G} = -92.448 + 0.043 \times be \times t$$

R^2= 0.55 SE=16.42 p<0.001

$$\ell n(\hat{V}) = 4.115 + 0.001 \times be \times t$$

R^2= 0.66 SE=0.247 p<0.001

The results obtained from these equations for 10-year interval from 30 to 110, and for poor, medium, and good site classes are shown in Tables 4-6.

Conclusions

In this study, an empirical growth model was constructed for fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf) natural stands which included three site classes (good, medium and poor).

Several basic functions were derived for the construction of empirical yield tables. Independent or predictor variables in these functions are stand age and site index. All of the regression equations were found at 0.001 significance level. The volume, mean height, mean diameter, and basal area regression equations gave the highest coefficient of determination (R^2) and the lowest standard error of estimation (SE).

The results indicate that fir is a fast growing tree species. The mean annual increment at standard age 100 for good, medium, and poor sites are 16.2, 8.5 and 6.1 m^3, respectively.

In Turkey, comparing the growth and yield relationships of fir to different hardwoods, fir has greater values than them.

SITE CLASS: I (Good Sites)

Table 4. An Empirical Yield Table for Fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf) stands

Stand	Main Stand						Removed Stand			Current Annual Increment		Total Yield		Mean Annual Increment	
Age	Dominant Height	Mean Height	Mean Diameter	Number of Trees	Basal Area	Volume	Number of Trees	Volume	Total Volume			Volume	Intermediate Yield %	Main Stand	Total Growth
	m	m	cm		m^2	m^3		m^3	m^3	m^3	%	m^3	%	m^3	m^3
30	7.7	6.2	10	4293	28	151						151	0.0	5.0	5.0
40	11.4	10.7	14	3144	36	203	1148	92	92	14.5	6.5	295	31.1	5.1	7.4
50	14.9	14.3	19	2367	44	275	778	78	170	14.9	5.4	444	38.2	5.5	8.9
60	18.2	17.7	23	1824	54	371	543	65	235	16.1	4.5	605	38.8	6.2	10.1
70	21.4	20.6	35	1442	65	500	381	53	288	18.3	4.0	788	36.6	7.1	11.3
80	24.4	23.6	39	1180	75	675	263	45	333	22.0	3.6	1008	33.0	8.4	12.6
90	27.3	27.0	43	1007	88	911	172	34	367	27.1	3.3	1279	28.7	10.1	14.2
100	30.0	29.3	50	906	93	1230	101	23	391	34.2	3.2	1621	24.1	12.3	16.2
110	32.4	31.0	60	863	102	1161	43	11	402	44.1	3.0	2062	19.5	15.1	18.7

SITE CLASS: II (Medium Sites)

Table 5. An Empirical Yield Table for Fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf) stands

Stand	Main Stand						Removed Stand			Current Annual Increment		Total Yield		Mean Annual Increment	
Age	Dominant Height	Mean height	Mean Diameter	Number of Trees	Basal Area	Volume	Number of Trees	Volume	Total Volume			Volume	Intermediate Yield %	Main Stand	Total Growth
	m	m	cm		m^2	m^3		m^3	m^3	m^3	%	m^3	%	m^3	m^3
30	5.2	6.2	8.8	6077	25	112						112		3.7	3.7
40	9.7	8.8	12	4747	30	136	1330	66	66	9.1	5.8	203	32.8	3.4	5.1
50	11.3	11.3	15	3788	38	167	959	58	124	8.8	4.9	291	42.7	3.3	5.8
60	15.7	13.4	20	3063	42	203	725	58	182	9.5	4.4	385	47.2	3.4	6.4
70	20.4	15.4	22	2500	46	248	563	62	244	10.7	4.2	492	49.5	3.5	7.0
80	21.5	17.2	25	2056	51	303	444	58	302	11.3	3.7	605	49.9	3.8	7.6
90	25.0	18.7	29	1702	64	371	354	50	351	11.7	3.2	722	48.7	4.1	8.0
100	27.3	20.0	30	1419	68	453	283	45	396	12.7	2.9	849	46.7	4.5	8.5
110	29.8	21.1	35	1194	74	553	225	40	437	14.1	2.7	900	44.1	5.0	9.0

SITE CLASS: III (Poor Sites)

Table 6. An Empirical Yield Table for Fir (*Abies nordmanniana* subsp. *bornmülleriana* Mattf.) stands

Stand	Main Stand						Removed Stand			Current Annual Increment		Total Yield		Mean Annual Increment	
Age	Dominant Height	Mean Height	Mean Diameter	Number of Trees	Basal Area	Volume	Number of Trees	Volume	Total Volume			Volume	Intermediate Yield %	Main Stand	Total Growth
	m	m	cm		m^2	m^3		m^3	m^3	m^3	%	m^3	%	m^3	m^3
30	2.8	1.2	4	9021	8	85						85		2.8	2.8
40	3.8	2.8	8	7527	17	95	1493	60	60	7.0	5.8	155	38.6	2.4	3.9
50	4.9	3.3	10	6405	24	106	1123	56	116	6.7	5.2	222	52.2	2.1	4.4
60	6.1	5.4	14	5517	26	119	888	62	178	7.5	5.2	297	60.0	2.0	4.9
70	7.5	6.4	16	4790	30	132	726	65	243	7.9	5.0	376	64.8	1.9	5.4
80	8.9	7.2	19	4182	33	148	608	61	304	7.6	4.5	452	67.3	1.8	5.6
90	10.4	9.7	21	3665	38	165	517	62	366	7.9	4.2	531	69	1.8	5.9
100	12.0	11.0	23	3219	42	184	446	58	424	7.7	3.8	608	69.7	1.8	6.1
110	13.7	12.1	26	2831	43	205	388	58	483	8.0	3.6	688	70.1	1.9	6.3

Acknowledgements

We thank the field assistant crew for their endeavor throughout this study. We extend our thanks to Sena Karapınar, Ramazan Şekerci, Ecrin Kapucu, Mehmet Aksu and Bahar Özdemir who helped on field and laboratory studies.

References

Alemdağ, Ş., 1962: Türkiye'deki Kızılçam Ormanlarının Gelişimi, Hasılatı ve Amenajman Esasları, Ormancılık Araştırma Enstitüsü Teknik Bülten No: 11, Ankara, 160 sayfa.

Alemdağ, Ş., 1967: Türkiye'deki Sarıçam Ormanlarının Kuruluşu, Verim Gücü ve Bu Ormanların İşletilmesinde Takip Edilecek Esaslar, Ormancılık Araştırma Enstitüsü Teknik Bülten No: 20, Ankara, 160 sayfa.

Alemdağ, Ş. 1985: Bonitet Endeksi Denklemlerinin Kuruluşunda Gövde Analizine Dayanan Bir Metod, İ.Ü. Orman Fakültesi Dergisi, Seri A, 35 (1), 132-141 s.

Akalp, T., 1978: Türkiye'deki Doğu Ladini (*Picea orientalis* Lk. Carr) Ormanlarında Hasılat Araştırmaları, İ.Ü. Orman Fakültesi Yayın No: 2483/261, İstanbul, 145 sayfa.

Asan, Ü., 1984: Kazdağı Göknarı (*Abies equi-trojani* Aschers. Et Sinten) Ormanlarının Hasılat ve Amenajman Esasları Üzerine Araştırmalar, İ.Ü. Orman Fakültesi, Yayın No: 3205/365, İstanbul, 207 sayfa.

Batu, F., Kapucu, F., 1995: Doğu Karadeniz Bölgesi Kızılağaç Meşcerelerinde Bonitet Endeksi ve Hasılat Tablosunun Düzenlenmesi, I. Ulusal Karadeniz Ormancılık Kongresi Bildirileri, 4. Cilt, s: 349-362.

Birler, A.S., 1983: I-.214 Melez Kavağı Plantasyonlarında Hasılat Araştırmaları, Ormancılık Araştırma Enstitüsü, Teknik Bülten Serisi No: 19, Ankara.

Birler, A.S., Diner, A. ve Koçer, S., 1992: Karakavak Ağaçlandırmalarında Hasılat Araştırmaları, Kavak ve Hızlı Gelişen Orman ağaçları araştırma Enstitüsü, İzmit.

Carus, S., 1998: Aynıyaşlı Doğu Kayını (*Fagus orientalis* Lipsky.) Ormanlarında Artım ve Büyüme, Yayınlanmamış Doktora Tezi, 359 sayfa.

Curtis, R.O., 1964: A Stem Analysis Approach to Site Index Curves. Forest Science, 10, p. 241-256.

Davis, L.S., Johnson, K.N., 1987: Forest Management, Third Edition, McGraw-Hill Book Company, USA, 790 p.

Evcimen, B.S., 1963: Türkiye Sedir Ormanlarının Ekonomik Önemi, Hasılatı ve Amenajman Esasları, O.G.M. Yayınlarından Sıra No: 355, Seri No:16, Ankara, 199 sayfa.

Graney, D.L., Burckhart, H.E., 1973: Polymorphic Site Index Curves For Shortleaf Pine in The Ouachita Mountains, USDA Forest Service, Res. Paper p: 50-85.

Heper, L., 1968: A Method of Constructing Site Index Curves From Stem Analysis, Forest Chronicle, 44 (49), pp: 11-15.

Johnson, F.A. and Worthington, N.P., 1963: Procedure For Developing A Site Index Estimating System From Stem Analysis Data, USDA Forest Service, Pac. Northwest For. Range Exp. Sta. Research Paper PNW-7, 10 p.

Kalıpsız, A., 1963: Türkiye'de Karaçam Meşcerelerinin Tabii Bünyesi ve Verim Kudreti

Üzerine Araştırmalar, O.G.M. Yayınlarından, İstanbul, 141 sayfa.

Kapucu, F., Yavuz, H., Gül, A.U. and Mısır, N., 2002: Kestane Meşcerelerinin Hasılat ve Amenajman Esasları, TÜBİTAK-TOGTAG TARP 2229 Nolu Proje.

Köse, S., Yavuz, H., Mısır, M., Mısır, N., 2001: KTÜ Orman Fakültesi Araştırma Ormanı Ladin Meşcerelerinin Hasılat Esasları Sonuç Raporu, KTÜ Araştırma Fon Başkanlığı, 74 sayfa.

Laar, A., Akça, A., 1997: Forest Mensuration, Cuvillier Verlag, Göttingen, 385 p.

Lenbert, J.D., 1972: An Alternative Procedure For Improving Height/Age Data From Stem Analysis, Forest Science, 18, p: 332-342.

Monserud, R.A., 1984: Height Growth and Site Index Curves for Inland Douglas Fir Based on Stem Analysis Data and Forest Habitat Type, Forest Science, 30, (4), p: 943-965.

Porte, A. and Bartelink, H.H., 2002: Modelling Mixed Forest Growth: A Review of models For Forest Management, Ecological Modelling, 150, pp (141-188).

Vanclay, J.K., 1994: Modelling Forest Growth and Yield, Applications to Mixed Tropical Forests, CAB International, Wallingford UK, 312 p.

Yavuz, H., Misir, N, Tüfekçioğlu, A., Misir, M, ALTUN, L, 2010. Karadeniz Bölgesi Saf ve Sarıçamın Hakim Olduğu Karışık Olduğu Karışık Meşcerelerin Mekanstik büyüme modelleri ile Biyokütle ve Karbon Depolama Kapasitesinin Belirlenmei, TÜBİTAK TOGTAG 107O274 sayılı araştırma Projesi Sonuç Raporu.

Yeşil, A., 1992: Değişik Sıklık ve Bonitetlerdeki Kızılçam Meşcerelerinin Yaşa Göre Gelişimi, (Yayınlanmamış Doktora Tezi), İ.Ü. Fen Bilimleri Enstitüsü, İstanbul, 179 sayfa.