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Effect of environmental factors on the productivity of crimean pine (*Pinus nigra* ssp. *pallasiana*) in Sutculer, Turkey

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Abstract: *This study was conducted on Pinus nigra sub sp. pallasiana commonly known as crimean pine. The purpose of this study was to determine the important site factors affecting the development of these forests in Sutculer district. This district experiences a transitional climate between Mediterranean and Continental regions. There is a strong water deficit in summer. The data was collected from 37 sample plots. It was analyzed statistically by using upper stand height as a dependent variable and some site characteristics as independent variables. The results revealed that there was only one important negative linear relationship between upper stand height and Ah organic matter. This result was uncommon. The reasons for this depend indirectly other site factors (aspect, slope position, altitude, slope degree and humus forms). This result was explained at 69.53% of total variance using these site factors by means of factor analysis (FA). After FA, these site factors were transferred to stepwise disciriminant analysis (SDA) to determine eigenvalue ratios of the bonitet models. As a result of SDA, three bonitets and five variables (3B5V) were found as the best model with 71.5 % of variance and 0.007 % significance level.*

Key words: *Crimean pine, Environmental factors, Height growth, Productivity, Simple regression analysis*
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Introduction

European black pine (*Pinus nigra* Arnold) has a very discontinuous distribution in its range. It is mainly a southern European species, extending from Spain to Turkey. Its natural distribution extends from about 5° West longitude in Spain and Morocco to some 40° East in Anatolia, Turkey and from 35° north latitude in Morocco and Cyprus to 48° north-eastern Austria and up to 45° in Crimea. Because of the pattern of its natural distribution, it is considered to be a very variable species in morphological, anatomical and physiological characteristics (Scaltsoyiannes *et al*., 1994; Unaldi and Toroglu, 2009). European black pine may be regarded as a species subdivided into several subspecies and varieties. Schwarz (1938) divided the black pine into six subspecies: ssp. *pallasiana*, ssp. *fenzlii*, ssp. *dalmatica*, ssp. *nigra*, ssp. *laricio*, and ssp. *salzmannii*.

The Turkish species of European black pine, *Pinus nigra* ssp. *pallasiana* (Lamb.) Holmboe (crimean pine or anatolian black pine), is widely distributed in quite different regions of Anatolia and on various soil types in the Taurus, western Anatolia and northern Anatolian mountains. This subspecies, because of its good adaptability is preferred for forestation in Turkey. It has become one of Turkey's most valuable commercial trees lately. Nowadays, it is one of the main timber species of the Mediterranean mountain forests in Turkey (Boydak, 2004). It has a major economic role providing pulp, resin, nuts, and some other products besides of timber. In Turkey it covers an area of 2.2 million hectares out of 20.2 million hectares of the total forest area. However, most of the total area covered by crimean pine is highly degraded and therefore ecologically unstable and economically unproductive. Recently efforts have been made to restore degraded forest areas, and the need for species-specific site selection criteria has been recognized (Fontaine *et al*., 2007).

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Several studies have been conducted on the geographical variations, productivity in the natural sites, tree mortality, relationship between diameter and volume increment, seed, wood, silvicultural characteristics of crimean pine in Turkey (Kalipsiz, 1963; Saatcioglu, 1979; Alptekin, 1986; Carus, 2005; Misir *et al.,* 2007). Knowledge of site productivity in these studies is of major importance for forest resource management, especially for the restoration of the degraded forest areas. Site index is the most common site productivity measurement for pure and even-aged stands. For such stands, site index is defined by the dominant height at a given reference age and the analysis of this kind of study consists of modeling the site index as a function of various ecological, topographical, and soil variables (Chen *et al*., 2002; Szwaluk and Strong, 2003).

Relationships between environmental characteristics and height growth of crimean pine have been studied extensively by Sevim (1954) in Alacam Forest in Dursunbey district, Eruz (1984) in Balikesir district and Yucel (2000) in Central Anatolian region of Turkey. In this study an attempt was made to increase our knowledge and enlighten the relationships between the height growth as productivity and some site characteristics of *P. nigra* ssp. *pallasiana* from Sutculer district, Turkey.

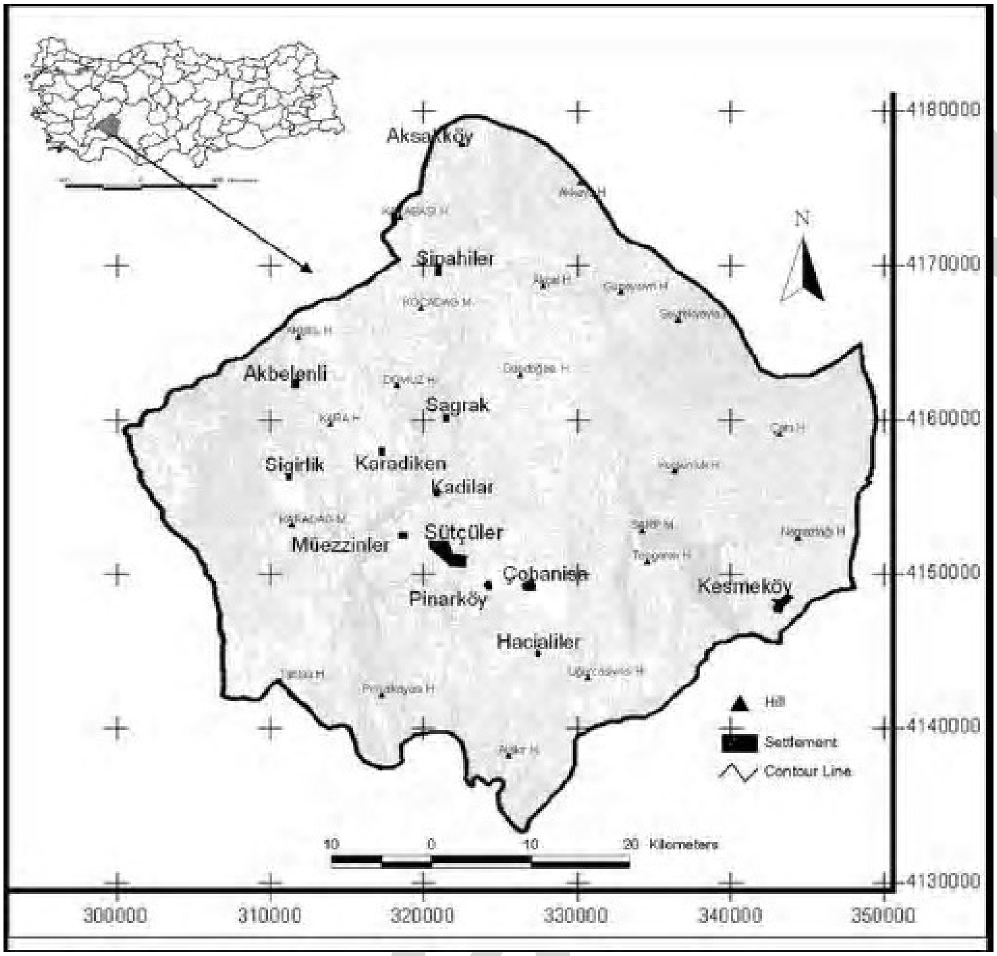

Fig. 1: Location of Sutculer district of southern Anatolia, Turkey

Materials and Methods

Study area: Data used in this study were obtained from Sutculer district (1288 km^2) located at a distance of 70 km from Isparta and 120 km from Antalya in the Mediterranean region of Turkey (Fig. 1). It lies between 37°29' 17" N latitude and 30° 59' 46" E longitude, 250-2500 m sea level according to UTM coordinate system. It is bounded on the north by Egirdir lake, Kovada lake and Koca mountain (1742 m) in the northeast by Beysehir lake, Kuyucak (2337 m) and Dedegol (2980 m) mountain and Tota tableland, in the west by Sarp mountain (2548 m), in the south by Ak mountain and Sanli tableland, in the southwest by Karacaoren lake, in the west and northwest parts by Kara mountain and Burdur lake.

The climate data of the area was obtained from the Meteorology Station in Sutculer based on the data for the past 30 years (DMI, 2006). It is a typical Mediterranean type characterized by dry-hot summers and rainy winters. Mean annual precipitation in the region is 950.1 mm $year^{-1}$, most arid and hottest months being July and August, with a mean annual temperature of 13.1°C, and 54% average relative humidity. Above 1400 m sea level a mountainous Mediterranean climate with a higher precipitation prevails (Fontaine *et al.*, 2007). Minimum relative humidity is recorded during August (43%) and maximum during December (66%). Heavy rains occur in November, December, January and February, while the dry period extends from the beginning of June until the end of October.

Flora of the study area is composed of 63 family, 225 genus and 478 species. More than fifty five percent (55%) of plant species belong to Fabaceae, Asteraceae, Carypohyllaceae, Lamiacea, Brassicaceae, Boraginaceae, Rosaceae, Apiaceae, Scrophulariaceae and Ranunculaceae families (Ozcelik and Korkmaz, 2002). The study area is covered about 50% by Mediterranean mountain forests mainly composed of *Pinus brutia* Ten. (Brutian pine), *Pinus nigra* Arn. ssp. *pallasiana* (Lamb.) Holmboe (Crimean pine), *Ouercus* spp., *Juniperus* spp. and some relic stand of *C. libani* (Lebanon cedar).

Field sampling methods: A total of 37 sample plots were surveyed. The different environmental factors (topography, soil and vegetation) were recorded as qualitative and quantity values to predict the impacts on crimean pine for each sample plot.

To calculate upper stand height 3 dominant trees for each sample plot were selected and age was measured on same

Table - 1: Main site variables and abbreviations

Variables	Units	Abbreviations
Topographic variables		
Aspect	-	ASPECT
Slope position	-	SLPPOS
Altitude	m	ALTITU
Slope	%	SLPE
Soil variables		
Total soil depth	cm	SDEPT
Stoniness	%	STONI
A horizon skeleton	%	AHSKLTN
A horizon pH	%	AHPH
A horizon total calcium carbonate	%	AHCACR
A horizon organic matter	%	AHORGMAD
A horizon clay	%	AHCLY
A horizon silt	%	AHSLT
A horizon sand	%	AHSND
Total litter height	cm	TLITER
Leaf layer	cm	LEAFLYR
A little decomposed layer	cm	LTLCMPLYR
Decomposed layer	cm	DECMPLYR
Site index		
Bonitet index value at the reference age of 100 years	m	SINDX

Table - 2: Eigen values and % of variance values of factor analysis (FA)

Factors	Eigen values	% of variance	% cumulative
1	2.186	19.875	19.875
2	1.530	13.910	33.785
3	1.454	13.216	47.001
4	1.292	11.746	58.747
5	1.186	10.779	69.526
6	0.962	8.7460	78.272
7	0.751	6.8260	85.098
8	0.666	6.0550	91.153
9	0.376	3.4210	94.574
10	0.355	3.2310	97.805
11	0.241	2.1950	100.00

Table - 3: Results of original factor analysis

Variables	Factors				
	1	2	3	4	5
SINDX	-0.655	-0.226	0.074	0.441	-0.040
ASPCT	0.437	0.211	0.379	0.164	0.541
SLPPOS	-0.359	0.459	-0.264	0.447	0.268
ALTITU	0.649	0.106	-0.016	0.244	-0.043
SLPE	-0.638	0.526	0.099	-0.283	-0.023
SDEPT	0.110	-0.312	0.633	-0.201	0.350
STONI	-0.175	0.487	-0.262	-0.500	0.250
AHPH	0.150	-0.012	-0.462	0.104	0.685
AHORGMAD	0.556	0.027	-0.401	-0.454	-0.180
AHSND	0.130	0.621	0.611	-0.066	-0.117
TLITER	0.466	0.465	-0.090	0.469	-0.345

dominant trees using an increment borer 30 cm above the ground. The number of rings was counted directly on the plot. Dominant age was calculated by the average of the three measured ages. Site index was calculated for each plot at the reference age of 100 years using a dominant height growth model (Kalipsiz, 1963).

Physical soil properties were evaluated through a soil pit. Since the soil profiles were distinguished as two (Ah/Cv) and three (Ah/Bv/Cv) soil horizons, the soil samples were collected from Ah horizon which is common in both profile types. This means we considered the depth between 0-10 cm ateach site.

All of the soil samples used in laboratory were acquired from a total of 37 Ah horizons; the texture was determined by hydrometer method (Bouyoucos, 1962), pH with glass electrode (1/2.5 soil-solution ratio) (Peech, 1965), total calcium carbonate ($CaCO_3$) with Scheibler calcimeter (Allison and Moodie, 1965), and organic matter by Wakley-Black method (Walkey and Black, 1934).

The original data regarding altitude, slope position, slope degree, soil depth, stoniness, total calcium carbonate, pH, soil texture, organic matter, soil skeleton and sand-silt-clay contents, total litter height, leaf layer, a little decomposed layer and decomposed layer were entered. Aspect variable as 1 (north), 2 (northeast and northwest), 3 (east and west), 4 (southeast and southwest) and 5 (south) and slope position variable as 1 (ridge), 2 (upper slope), 3

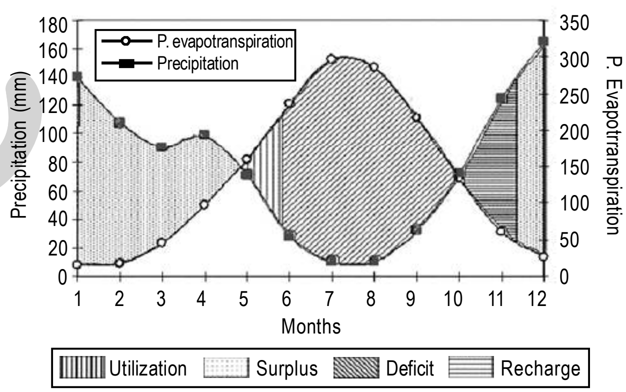

Fig. 2: Water balance diagram of Sutculer district

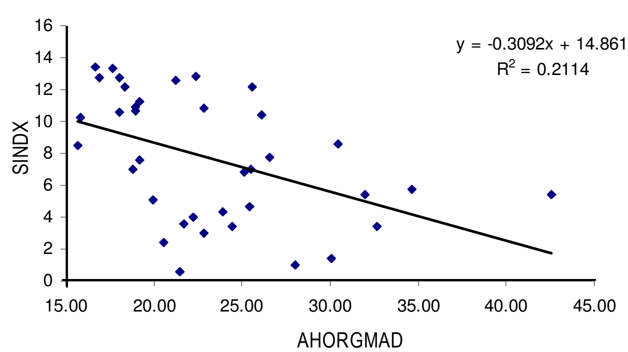

Fig. 3: Graphs of regression analysis on significant relation between Sindx and Ahorgmad

Table - 4: Eigen values of stepwise discriminant analysis (SDA) in function 1

Models	Eigen value	% of variance	% cumulative	Canonical correlation
5B6V	0.793	66.9	66.9	0.665
5B5V	0.771	68.1	68.10	0.660
3B6V	0.726	72.0	72.00	0.649
3B5V	0.685	71.5	71.50	0.638

Table - 5: Wilks' lambda values of stepwise discriminant analysis (SDA) in function 1

Models	Wilks' lambda	Chi-square	df	Significant level
5B6V	0.395	28.802	18	0.051
5B5V	0.410	28.080	15	0.021
3B6V	0.452	25.010	12	0.015
3B5V	0.466	24.415	10	0.007

Table - 6: Standardized stepwise discriminant analysis (SDA) coefficients of based on 3B5V

Variables	Function 1
ASPCT	0.114
ALTITU	0.001
SLPE	-0.036
AHORGMAD	0.236
TLITER	-0.179
CONSTANT VALUE	-1.454

(middle slope), 4 (lower slope) and 5 (flat) were rotated (Hahs *et al.,* 1999). A total of 17 independent and 1 dependent variables were listed using their abbreviations in the statistical analysis (Table 1).

Statistical analysis: The statistical analyses were conducted using SPSS 13.0 Software for Windows (SPSS Inc., Chicago, IL). General linear model regression was used to predict site index as a function of the various environmental variables. The model construction followed three main stages: (i) by correlation analysis (CA) we analyzed the correlations between each environmental variable and site index to establish a first model that included the main factors that influence crimean pine growth (at a level of significance of 1‰); (ii) we studied the form of the relationship between each previously identified factor and site index (*e.g.*, aspect, soil depth, organic matter) to establish a second model with factor analysis (FA); and (iii) to obtain the final model, we tested whether the interactions among the selected factors should be introduced into the equation with stepwise discriminate analysis (SDA) (Poole, 1974; Ozdamar, 1997,1999).

Results and Discussion

In this study, 17 independent variables and SINDX were transposed to statistical analyses for the purpose of determining the affecting factors on height growth of crimean pine in Sutculer district. Bedrock wasn't used as a variable because almost all of the sample plots had limestone and the distribution of the other bedrocks in the study area is inadequate in a ratio in terms of limestone. As a result of regression analysis (RA) from the 17 variables, the only relationship obtained from the AHORGMAD variable with site index at a level of 5% (Fig. 3). This is a predictable result. Because, Sutculer district is karstic area and especially lower and middle parts of the area include deep valleys. This situation causes a lot of local climates in the general climate. Hence, we predict that important relation between SINDX and AHORGMAD is derived from the AHORGMAD variable's relation with the other variables. Similar results were found by Ozkan (2000) in Bekir Sitki Evcimen Cedar Protection Forest.

Because between other 16 environmental variables and height growth of crimean pine wasn't found any significant relation in RA, it was benefited from multiple statistical analysis (FA and SDA) to determine the groups of variable of most effective on height growth of crimean pine.

Before multiple analyses, it was applied CA in order to solve multiple relation problems among independent variables. It was found relations between STONI and AHSKLTN, AHCACR and AHPH, AHSND and AHSLT, AHCLY also TLITER and LEAFLYR, LTLCMPLYR, DECMPLYR by means of CA. Because of this, AHSKLTN, AHCACR, AHSLT, AHCLY, LEAFLYR, LTLCMPLYR and DECMPLYR variables weren't used in the multiply statistical analysis.

After CA, a total of 11 variables together with SINDX were transmitted to FA. As a result of FA, we obtained 5 factors that have a variance value greater than "1" and have % of variance value greater than "10" (Table 2). Results of original factor analysis of these five factors showed that SINDX variable has a high correlation with Factor 1 and Factor 5 (Table 3).

Factor 1 has an important relation with ASPCT, SLPPOS, ALTITU, SLPE, AHORGMAD and TLITER variables despite of SINDX. SINDX has negative sign in Factor 1. Hence, SINDX variable has a positive relation with SLPPOS and SLPE variables because both have same signs in Factor 1. But, it has negative relation with ASPCT, ALTITU, AHORGMAD and TLITER variables which have positive sign in Factor 1. In other words, height growth is better as the slope degree increases and as site changes from ridge to lower slope. But the height growth decreases as the aspect changes from shadowy to sunny, altitude increases, gaining of organic matter in Ah horizon and leaf layer thickness.

At Factor 4 SINDX's sign is positive. This factor is in correlation with SLPPOS, STONI, AHORGMAD and TLITER. But, the direction of relation between SINDX and TLITER at Factor 4 differed from Factor 1. Also, the Original Factor Analysis was altered to Varimax, Quartimax and Equmax methods and the numerical results that were obtained from these methods were parallel to the Original Factor Analysis.

Results of the Factor Analysis showed that the most affected factors on the height growth of crimean pine in Factor 1. These factors were altitude, slope, leaf layer thickness, aspect and organic matter in Ah horizon. We hypothesized that the affluence of organic matter in Ah horizon and leaf layer thickness essentially related with increasing of the altitude. Altitude has a big role on the effects of climatic variables on soil organic matter (Garten *et al.,* 1999; Lemenih and Itanna, 2004). Especially, the climatic changes along altitudinal gradients influence the productivity of vegetation (Quideau *et al.,* 2001). Thus, when Factor 1 is considered as the altitude increases, the numerical values of these variables also increase. Because of ALTITU variable, AHORGMAD and TLITER variables have to be related with SINDX.

Negative correlation between altitude and the height growth of crimean pine is an unexpected result. Negative effect altitude together with other variables on the height growth may be related to decrease of the temperature because of elevation. Reasons of this situation can be explained as follows; (i) mountainous structure which has steep walls fractioned in deep valleys dominates Sutculer region. This situation forms many different local climate areas in general climate characteristics; (ii) humid climate has important affect on the height growth (Lebourgeois *et al.,* 2005). Since the areas in low and medium altitudes are fractioned into deep valleys, the slope of those areas is more than the high mountain areas. Since, the limited exposure against the sun in those areas causes humid climate conditions, this positively affects the growth of crimean pine; (iii) the height of the mountainous structure of the sample plots on the hillside is effective on the rainfall of those areas. For instance, in the northern hillside of Sarp mountain, bonitet is found to be high in sample areas which are taken from low altitudes, because, the air mass leaning to this mountain may cause rain as it gets cooler. Thus, the height growth of black pine located at the hillside of the mountain is positively affected. In good bonitet, the height of the mountain belonging to the hillside located on black pine forests rather than the altitude of the place on which they are located causes more humid weather to get cold while rising and to get more rainfall than the places deprived of these characteristics at the same altitude. Ozkan and Kantarci (2008) emphasized a similar explanation in the respect of differences in spreading of the species *Juniperus excelsa* and *Pinus nigra* in Gencek region; (iv) the height of the mountainous hills on the opposite side of the sample areas also affect the climate prevailing in the area on a local basis. The higher the hill opposing the place of positioning is and the closer the hill and the slope parts of the mountain are to the place taken as a sample in horizontal; the more the the effect of shadowing and blocking to the direct winds towards the sample place the mountain has. In such places, the vertical growth of black pine is expected to be better; (v) the fact that the area has major limestone resources also affects this situation significantly. The reason for this is the cracked structure of the limestone and the growing of plant’s roots in these cracks. In other words, in order for the plants to survive and grow, what matters is not the absolute depth of the soil in the areas where limestone resource exists; it is the physical depth of the soil in the resource area.

The maximum coefficient of SINDX was in Factor 1 (SINDX:-0.655). Because of this, it was decided to study the variables which have important relations with SINDX at Factor 1. In other words, ASPCT, SLPPOS, ALTITU, SLPE, AHORGMAD and TLITER were chosen for consideration in SDA as independent variables from the Factor 1 (Table 3).

These 6 independent variables were transferred to SDA. As a classification variable 3 and 5 bonitet classes were used. Also, four different classifications were obtained to determine eigenvalue ratio as following; three bonitets and six variables (3B6V), five bonitets and six variables (5B6V), three bonitets and five variables (3B5V) and five bonitets and five variables (5B5V). As a result of SDA, three bonitets and five variables (3B5V) were found as a best model among all these classification models with 71.5% of variance in Table 4 and with 0.007% significance level in Table 5. The equation of these variables was found from the standardized coefficients of SDA as SINDX: [(-1.454) + (ASPCTx0.114) + (ALTITUx0.001) + (SLPEx(-0.036)) + (AHORGMADx0.236) + (TLITERx(-0.179)] (Table 6).

As a result, amongst the discriminant analysis made between the three bonitet and five bonitet class of crimean pine, the discriminant analysis based on three bonitet has given better results. Also, Dasdemir (1992) has reached the same conclusion in his study on *Picea orientalis*. This shows that it is more meaningful to discriminate crimean pine based on three bonitet rather than five bonitet. The equations achieved in this study related to crimean pine can be used to identify the current bonitet class of vacant areas within the potential dissemination areas of crimean pine that will be afforested. This information is important in terms of initializing the foresting work starting from the areas with more significance value to productivity of crimean pine and thus ensuring the highest return by the end of the term by means of compounded interest (Dasdemir, 1992; Ozkan *et al.,* 1998).

In conclusion, crimean pine appears particularly sensitive to humid climate dealing with an environmental factors group. Especially, changes of these environmental factors may influence the height growth of crimean pine.

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