POPULATION VARIABILITY OF SCOTS PINE (PINUS SYLVESTRIS L.) IN TURKEY ACCORDING TO THE NEEDLE MORPHOLOGY

SUMMARY

In the present study, needle variation of Scots pine (Pinus sylvestris L., Pinaceae) populations in Turkey was investigated. From selected eight populations, a total of 1314 needles belonging to 206 trees were examined. Four morphological needle traits were measured and analyzed to describe the population diversity and differentiation. Analyzed morphological traits showed significant variability. The trees within populations differ significantly in all analyzed needle characteristics, while the differences between populations were significant for the three of four studied characteristics. Present findings revealed that needle length, needle width and the ratio of needle length to needle width showed clinal variation in response to altitudinal gradients. Populations from higher altitudes were characterized with the smaller and wider needles as compared to the populations from lower altitudes. The results of this study could be valuable baseline data for the development of more efficient management plans for this forest tree species.

KEY WORDS: Scots pine, population variability, needle characteristics, morphometric analysis, clinal variation

INTRODUCTION

Scots pine (Pinus sylvestris L., family Pinaceae) is one of the most important timber and forest tree species globally (Koprowski et al. 2012). It has a very wide distribution in Europe and Asia due to its high degree of ecological tolerance (Alemdağ 1967; Pehlivan 2010). The tree is tolerant to poor soils, drought, and frost. It is a pioneer species, able to colonize nutrient-poor soils in disturbed areas (Mátys et al. 2004; Houston Durrant et al. 2016). Scots pine frequently grows in large single species stands in altitudes ranging from sea level up to 2600 MASL. However, across its huge range it may also be found in mixed stands with most of the boreal tree species of Europe and Asia.

Scots pine is the third-most dominant conifer tree species in Turkey (Kandemir and Mataracı 2018). Its distribution in Turkey extends from Pınarbaşı to Ayancık in the longitudinal, and Orhaneli to Kağızman in the latitudinal directions (Saatçioğlu 1944; Kayacık 1954; Pamay 1962). The geographical limits of the southeastern distribution of Scots pine have been reported in the Pınarbaşı district of the Kayseri province of Turkey (Demirci 2006; Pehlivan 2010).
sylvestris grows from sea level (along the Black Sea) to 3125 MASL in the Allahuekber Mountains of Eastern Anatolia (Eliçin 1971).

Wide geographical distribution resulted with considerable morphological and genetic diversity within P. sylvestris (Wright and Bull 1963; Pravdin 1969; Ruby 1967; Mirov 1967; Szmidt 1984; Wang et al. 1991; Androsiuk et al. 2011; Jasińska et al. 2014; Dering et al. 2017). Variation observed in its needle and cone characteristics resulted in the description of several subspecies and varieties (Gaussen 1960; Mirov 1967; Farjon 2008; Jasińska et al. 2014). Farjon (2008) reported the existence of three varieties of P. sylvestris: var. sylvestris, var. mongolica Litv., and var. hamata Steven. According to Farjon (2008), the distribution range of the var. sylvestris and var. hamata extend through Turkey. In addition, Kandemir and Mataracı (2018) described a new variety, var. elicinii Kandemir and Mataracı, from Turkey mainly based on needle length and color.

Jasińska et al. (2014) detected morphological differences between the East and West Anatolian populations of P. sylvestris. Similar results were also reported by Bilgen and Kaya (2007). The isolation of the eastern from western Anatolian populations was explained by the mountain ranges known as the “Anatolian diagonal”. In addition, Jasińska et al. (2014) stated that morphological pattern of diversity in Anatolian populations of the Scots pine may also be a result of: (1) another origin source - the western populations from the Balkans and the eastern ones from the Caucasus; and (2) different rates of evolution in the two regions. Furthermore, Dering et al. (2017) revealed strong spatial genetic structure within the Scots pine range, involving four distinct groups well related to the LPG refugial areas previously defined for this species (Naydenov et al. 2007; Pyhäjärvi et al. 2008; Sinclair et al. 1998, 1999). Authors revealed that two most spatially restricted groups of populations correspond to Scots pine refugia located on the Iberian and Asia Minor Peninsulas. Those populations represent the valuable relict genetic resources that are of high conservation priority (Naydenov et al. 2007; Pyhäjärvi et al. 2008; Dering et al. 2017).

The aim of the present study is to assess needle size variation among Scots pine populations of Turkey and identify relationships with respect to altitude.

**MATERIAL AND METHODS**

**MATERIJAL I METODE**

Samples for morphometric analysis were collected from eight natural Scots pine populations in Turkey (Table 1). Needles were sampled from 14 to 31 trees per population, and each individual tree was represented by 5 to 10 needles from well-grown shoots. In total 1314 needles belonging to 206 individuals were analyzed. The following traits were included in the analysis: needle length, needle width, needle length/needle width ratio, and sheath length.

Minimal and maximal values of characteristics were determined, and arithmetical means, standard deviation and variation coefficients were calculated and analyzed for each population. Analysis of variance (ANOVA) was performed to determine the statistically significant differences between populations and between trees within populations.

The relationship between average values of morphological needle traits and altitude (e.g. Krauze-Michalska and Boratynska 2013; Poljak et al. 2015, 2018) were tested using Spearman’s coefficient (Sokal and Rohlf 2012).

Multivariate statistical methods were used to identify the population differentiation (McGarigal et al. 2000; Zebec et al. 2010; Poljak et al. 2012, 2018): cluster analysis and discriminant analysis. The conducted cluster analysis resulted in a hierarchical tree, where the unweighted pair-group method with arithmetic mean (UPGMA) was used to join

| Table 1. Sampled populations. |
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| Tablica 1. Uzorovane populacije. |
| Populations (Populacija) | Total number of trees (Ukupan broj stabala) | Nadmorska visina (m) | Geographical region of Turkey (Kantarcı 2005) | Geografska regija Turske (Kantarcı 2005) | Habitat zones (Kantarcı 2005) | Stanjište zone (Kantarcı 2005) |
| Ardahan-Yalnuçam (AY) | 30 | 1850-2300 | Eastern Anatolia | Habitat zone of the Kars |
| Artvin-Arhani, Hopa (AH) | 14 | 0-600 | Black Sea | Habitat zone of the Rize - Kaçkar Mountains, Rize-Hopa Sub-Region |
| Trabzon-Sümmene (TS) | 15 | 0-450 | Black Sea | Habitat zone of the Trabzon Mountains |
| Giresun-Espiye (GE) | 30 | 1600-2200 | Black Sea | Habitat zone of the Canik - Giresun Mountains |
| Kastamonu-Taşköprü (KT) | 30 | 1200-1800 | Black Sea | Habitat zone of the Mountainous area |
| Bolu – Aladağ (BA) | 31 | 1200-1800 | Black Sea | Habitat zone of the Mountainous area |
| Ankara-Çamlıdere (AC) | 26 | 1400-2000 | Central Anatolia | Habitat zone of behind the Western Black Sea Region |
| Eskişehir-Çatacık (EC) | 30 | 1200-1800 | Central Anatolia | Habitat zone of the West Central Anatolia |
the clusters, and the Euclidean distance to define the distance between the studied populations. For the discriminant analysis, standardized data were used. The plot was constructed by two discriminant functions showing analyzed individuals and populations.

The above statistical analyses were conducted using the SPSS Statistics 23.0 (Nie et al. 1975; IBM Corp 2015), SYNTAX 2000 (Podani 2001), and Past 3x (Hammer et al. 2001) statistical programs.

RESULTS
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Average values of needle characteristics of the 206 trees belonging to eight natural Scots pine populations from Turkey are given in Table 2. The highest mean values for needle length were observed in the two eastern populations TS and AH. In contrast, the shortest needles were observed in the AČ, GE and BA populations, respectively. Furthermore, the longest sheaths were observed in AH and GE populations, and the widest needles in AY and GE populations. In addition, the highest values for the ratio of needle length to needle width were observed in the populations AH and TS, and the lowest for the population GE.

As expected, strong correlations between needle morphological traits were observed. Almost all measured needle traits correlated with each other at a statistically significant level. Using Spearman’s correlation coefficient, a highly positive correlation was found between altitude and needle width. On the other hand, needle length and the ratio of needle length to needle width were highly negatively correlated with the altitude.

The ANOVA revealed significant differences with respect to needle properties among the eight populations examined, with the exception of sheath length, which did not significantly differ among tested populations. The trees within populations differ significantly for all studied variables.

The structure of the eight Scots pine populations was inferred by the cluster analysis. The results are presented with the hierarchical tree (Figure 1), where the unweighted pair-group method with arithmetic mean (UPGMA) was used to join the clusters. The results clearly indicated that studied populations can be divided into three distinct sub-clusters. The first sub-cluster consisted only of GE population. The second sub-cluster consisted of AH and TS populations. Finally, the third sub-cluster consisted of the

| Trait Značajka | Statistical parameters Descriptive pokazatelji | Populations Populacije |
|----------------|---------------------------------------------|------------------------|
|                |                                             | AY         | AH         | TS         | GE         | KT         | BA         | AČ         | EC         |
| NL             | mean                                        | 5.41       | 7.09       | 7.59       | 4.49       | 4.74       | 4.25       | 4.34       | 5.13       |
|                | max                                         | 7.70       | 9.50       | 13.20      | 7.45       | 11.10      | 6.40       | 6.40       | 7.10       |
|                | min                                         | 3.50       | 5.50       | 4.10       | 2.10       | 2.55       | 2.40       | 1.85       | 3.40       |
|                | SD                                          | 2.97       | 2.82       | 6.43       | 3.78       | 6.05       | 2.82       | 3.22       | 2.62       |
|                | CV (%)                                      | 54.90      | 39.77      | 84.72      | 84.19      | 127.64     | 66.35      | 74.19      | 51.07      |
| NW             | mean                                        | 1.56       | 1.42       | 1.37       | 1.64       | 1.32       | 1.43       | 1.38       | 1.30       |
|                | max                                         | 2.04       | 1.94       | 1.73       | 2.26       | 1.82       | 1.83       | 2.07       | 1.84       |
|                | min                                         | 1.27       | 1.24       | 1.18       | 1.13       | 1.06       | 1.14       | 1.07       | 0.93       |
|                | SD                                          | .54        | .49        | .39        | .80        | .54        | .49        | .71        | .64        |
|                | CV (%)                                      | 34.62      | 34.51      | 28.47      | 48.78      | 40.91      | 34.27      | 51.45      | 49.23      |
| NL/NW          | mean                                        | 3.45       | 5.00       | 5.57       | 2.71       | 3.55       | 2.97       | 3.14       | 3.95       |
|                | max                                         | 4.83       | 6.44       | 6.93       | 3.91       | 6.97       | 4.36       | 4.52       | 6.23       |
|                | min                                         | 2.38       | 3.35       | 2.83       | 1.47       | 2.24       | 1.65       | 1.54       | 2.73       |
|                | SD                                          | 1.73       | 2.18       | 2.90       | 1.73       | 3.34       | 1.92       | 2.11       | 2.47       |
|                | CV (%)                                      | 50.14      | 43.60      | 52.06      | 63.84      | 94.08      | 64.65      | 67.20      | 62.53      |
| SL             | mean                                        | 4.83       | 5.22       | 4.95       | 5.32       | 4.91       | 4.79       | 4.61       | 4.96       |
|                | max                                         | 15.42      | 9.45       | 8.36       | 12.81      | 9.24       | 11.03      | 11.62      | 10.58      |
|                | min                                         | 1.82       | 2.85       | 2.03       | 2.14       | 2.12       | 1.25       | 1.52       | 2.17       |
|                | SD                                          | 9.62       | 4.67       | 4.48       | 7.54       | 5.03       | 6.92       | 7.14       | 5.95       |
|                | CV (%)                                      | 199.17     | 89.46      | 90.51      | 141.73     | 102.44     | 144.47     | 154.88     | 119.96     |
remaining five populations: AC, AY, KT, EC, BA. As seen in Figure 1, the most similar populations were KT and EC, and the most distinct population was GE.

The results of the discriminant analysis are presented in two-dimensional plot in the Figure 2. The first discriminant function explained 65.2% of the total variation, and
the second discriminant function explained 29.0%. The discriminant analysis showed that the trees from eight natural populations of Scots pine in Turkey cannot be clearly separated.

**DISCUSSION AND CONCLUSIONS**

The conducted research established significant variability of the morphological characteristics of Scots pine populations in Turkey. Statistically significant differences between the trees within and between populations were confirmed for all studied characteristics, except for the sheath length. In general, the morphological traits of needles appeared to be a useful tool for estimating pine species variability (Irvine et al. 1998; Niinemets et al. 2001; Pensa et al. 2004; Pravdin 1969; Želawski and Niwiński 1966; Paule 1971; Urbaniak et al. 2003; Androstuk et al. 2011; Jasińska et al. 2014; Poljak et al. 2020).

It is well known that phenotypic differences among populations are often a result of the environmental distances between populations (Dewoody et al. 2015; Poljak et al. 2012, 2014, 2018; Zebec et al. 2014). This is because the distribution of plant species depends highly on their competitive abilities to respond to environmental factors (Schoettle and Rochelle 2000). In some cases, morphological variability can be related to the altitude (Friend and Woodward 1990; Schoettle and Rochelle 2000; Poljak et al. 2015, 2018, 2020; Zebec et al. 2015). Specific gradient i.e. changes in morphological variability related to the change in altitude have been reported for Scots pine populations in Turkey (Turna and Güney 2009) and Croatia (Poljak et al. 2020). The mentioned authors stated that populations from lower altitudes had smaller cones as compared to the populations from higher altitudes. The present study revealed that needle length, needle width and the ratio of needle length to needle width significantly vary depending on altitude. In general, we revealed that populations from lower elevations were characterized with larger needles than the populations from higher altitudes. This may be related to the capacity of trees to adapt to environmental variation, which causes morphological changes in plant species and also facilitates the successful survival of plants subjected to new environmental conditions (Abrams 1990; Ellsworth and Reich 1992; Kubiske and Abrams 1992; Lei and Lechowicz 1997; Teklehaiamanot et al. 1998; Aranda et al. 2001). Similarly, needle length of *P. roxburghii* Sarg. from the northwestern Indian Himalayas significantly correlated with altitude (Tiwari et al. 2013). Furthermore, differences in the morphological and anatomical properties of cones, needles and seeds along altitudinal and longitudinal gradients were reported in four populations of *P. brutia* Ten. by Dangasuk and Panetsos (2004). In addition, Xu et al. (2016) noted that needle length and the ratio of needle length to fascicle sheath length showed clinal variation in response to latitudinal and altitudinal gradients in *P. yunnanensis* Franch.

The results of the cluster and discriminant analysis did not confirm divergence between the populations from different habitat zones from Turkey. Moreover, microclimatic effects that depended on existing geological structures, even when very short distances are considered, can result with significant interpopulation variability of Scots pine populations in Turkey (Ergül Bozkurt 2017). According to Kantarci (2005), vicinities in which Bolu, Kastamonu, Ankara and Eskişehir are found share similar ecological conditions. However, samples collected from these localities were not distinctly separated from the rest of the samples examined via multivariate statistical analysis.

According to reports within the Flora of Turkey and the East Aegean Islands (Davis et al. 1984), only *P. sylvestris* var. *hamata* is naturally distributed in Turkey. However, Farjon (2008) noted that *P. sylvestris* var. *sylvestris* and *P. sylvestris* var. *hamata* are naturally distributed in Turkey. In addition, Kandemir and Mataracı (2018), described a new variety of *P. sylvestris*, var. *elicini* Kandemir and Mataracı, based on needle length from a Sürmene-Camburnu population (TS). However, average, minimum, and maximum values of needle length of the TS population are closely related to Artvin-Arhai (AH) and Kastamonu-Taşköprü (KT) populations. Additionally, present findings inferred from multivariate statistical analysis did not support the separation of TS population. In general, our result does not support the validity of different subspecies and varieties of Scots pine in Turkey. In addition, Jasińska et al. (2014) reported that the morphological needle and cone characteristics of *P. sylvestris* varied among the populations of Iberia, Anatolia, the Balkans, and Crimea. Nevertheless, their results did not confirm the existence of *P. sylvestris* subsp. *sylvestris* and *P. sylvestris* subsp. *hamata*.

We observed significant phenotypic differentiation of studied populations of *P. sylvestris* in Turkey. Those populations represent the valuable relict genetic resources that are of high conservation priority. To confirm the conclusions reached on the variability of the Scots pine populations obtained by morphometric methods, the research also needs to be extended to molecular methods.

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SAŽETAK

U radu je istražena varijabilnost prirodnih populacija običnoga bora (*Pinus sylvestris* L., Pinaceae) u Turskoj s obzirom na morfologiju iglica. U istraživanje je ukupno uključeno osam populacija, 206 stabala i 1314 iglica. Kako bi se utvrdila raznolikost i struktuiranost populacija izmjerene su i analizirane četiri značajke iglica. Istraživanjem je utvrđena značajna varijabilnost te da se istraživane populacije, kao i stabla unutar populacija, statistički značajno razlikuju. Izuzetak čini značajka dužina rukavca za koju nisu potvrđene razlike na međupopulacijskoj razini. Dobiveni rezultati također upućuju na to da značajke dužina i širina iglice te odnos dužine i širine iglice pokazuju klinalnu varijabilnost s obzirom na nadmorsku visinu. Populacije s viših nadmorskih visina odlikovale su se kraćim i debljim iglicama u odnosu na populacije s nižih nadmorskih visina. Općenito, rezultati ovog istraživanja mogu poslužiti kao vrijedna osnova za određivanje i razvijanje smjernica za učinkovitije planove gospodarenja ovom važnom šumskom vrstom drveća.

KLJUČNE RIJEČI: obični bor, populacijska varijabilnost, svojstva iglica, morfometrijska analiza, klinalna varijabilnost