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Dendrometric and Wood Anatomical Properties of *Pinus sylvestris* and *Quercus petraea* in Managed and Unmanaged Forests

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: Climate change is a serious problem in forest ecosystems and it is required to manage forest stability, resilience, and vitality truly sustainable in future climatic conditions. Particularly trees are one of the crucial components in the forest ecosystem since they are exposed to climate change-induced range shifts during their growth and development. The present study, therefore, investigated how dendrometric, tree ring widths and anatomical variables of Scots pine and Sessile oak trees showed variations between managed and unmanaged forests.

Results: Both Scots pine and Sessile oak trees indicated great variance in their dendrometric, tree ring width, and anatomical properties between managed and unmanaged forests. In this study, Scots pine showed taller trees in unmanaged forests, while Sessile oak forests did not show the difference in stem heights between managed and unmanaged forests. Stand characteristics revealed different patterns between managed and unmanaged forests; unmanaged forests revealed greater stand stability than managed forests for both Scots pine and Sessile oak trees. Managed forests of both Scots pine and Sessile oak trees indicated greater stem diameters than unmanaged forests. Dendrometric results also showed differences in managed and unmanaged forests since tree ring widths of Scots pine and Sessile oak trees had more than 1.5 times wider tree rings in managed forests than in unmanaged forests.

Conclusion: In this study, managed forests of Scots pine and Sessile oak showed greater stand characteristics and dendrometric traits than unmanaged forests. It may be suggested that managed forests can ensure better growth and development environment for particularly Scots pine and Sessile oak trees.

Keywords: Wood anatomy; Tree stability; Managed forests; Unmanaged forests; Tree Ring Width.

HIGHLIGHTS

This study brings first detailed investigation of the effect of forest management on dendrometric and anatomical traits of Scots pine and Sessile oak.
Managed forests of Scots pine and Sessile oak showed greater stem diameters than unmanaged forests.
Scots pine and Sessile oak trees indicated wider tree rings in managed forests than in unmanaged forests.
Tracheid anatomical variables of Scots pine showed higher values in managed forests than in unmanaged forests.

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INTRODUCTION

Forests play a significant role in the processes of climate mitigation goals. Climate change has been a key factor in increasing the risk of warmer and drying conditions (drought), wildfires (fire intensity, frequency, duration, and burned area), windstorms, and increase of non-indigenous invasive insect species and migratory pests (Gehring et al., 1997; Ayres and Lombardero, 2000; Dale et al., 2001; Özden Keleş et al., 2021). Each disturbance can result in forest ecosystem changes by altering the forest regeneration, stand productivity and plant biomass, plant extinction or biodiversity loss, plant growth and structure, tree mortality and survival, species range shifts, and species composition (Walther, 2003; Gauthier et al., 2014; Pretzsch et al., 2014; Clark et al., 2016; Huber et al., 2021).

Trees particularly are one of the crucial components in a forest ecosystem since they are exposed to climate change-induced range shifts during their growth and development. Precipitation and temperature are two fundamental climatic components that could cause a greater risk of extreme weather events (i.e. harsh storms, extreme heat waves and droughts, heavy rain, and floods), leading to marked effects on tree growth and development (Schweingruber, 1996). Due to, climate change-induced range shifts, it is required to promote more resilient, stable, healthy, and adaptive forests for trees that are adaptable to the changes in climate. At this point, silvicultural techniques and treatments have a key function in the climate sensitivity or breakdown and biodiversity of trees. There are many silvicultural management practices: selective logging, clear-cutting and coppicing with standards, conduction of regeneration, thinning, and enrichment planting to produce desired forest stand conditions and modifications. The main goal of all those practices is to manage forest stability, resilience, and vitality truly sustainable for future climatic conditions.

Trees are however long-term living plants due to their extraordinary adaptation performances to provide critical functions for their survival (Thomas, 2000; Ennos, 2001; Tu; Rappel, 2018). Trees can adjust their growth, development, and metabolism to cope with environmental stresses and maintain them to grow successfully in various environmental circumstances. Morphologically, they could change their architecture and allometry based on the different environmental gradients such that trees that grow under light limitation tend to show smaller diameters in their stem; trees also can produce shorter stems and internodes under low soil fertility and high levels of light (Poorter, 2001; Fisher and Honda, 1979; Chapin et al., 1998). Trees can adjust their anatomical traits in response to different environments. Wood anatomy can provide snapshots of regional climatic information and natural environmental changes. The wood is made up of highly specialized wood cells (i.e. tracheids, fibres, vessels, rays, and parenchyma cells) which are responsible for performing various functions and tasks (mechanical support, conduction, and storage) depending on the environmental demands of tree growth and development (Carlquist, 1988; Wheeler et al., 2007). Ecological conditions and environmental changes have a crucial impact on the size of wood cells because the size of the cells indicates how trees resist or adapt to the seasonal periodicity of different ecological settings (Sperry et al., 2006). Trees may adjust their hydraulic architecture by regulating cambial activity and reactivation (Tyree and Zimmermann, 2002; Schreiber et al., 2015). The shape, arrangement and size of wood cells can be highly plastic to cope with adverse environmental conditions (Borchert, 1996; Gibson, 2012; Begum et al., 2013; Rossi et al., 2013). Previous studies have shown that the number, shape, and size of vessel and tracheid elements are so vulnerable to climate variability (Sperry et al., 2006; Castagneri et al., 2017). Tracheid and vessel dimensions particularly may adjust and adapt the water use strategy of trees to cope with diverse environments. Trees have wider vessels in moister areas, while vessel distribution and diameter decrease with decreasing temperature and precipitation to prevent drought-induced cavitation (Levitt, 1980; Hacke and Sperry, 2001; Pittermann and Sperry, 2003, 2006; Yaman, 2007; Akkemik and Yaman, 2012; Fajardo et al., 2020). However, tracheid lengths are shorter and tracheids have narrower diameters to provide greater conductive efficiency in water stress conditions (Carlquist, 1977). Vessels and tracheids thus record the effect of weather conditions on their formation process. The variations in the number, shape, and size of vessels and tracheids have adaptive significance concerning environmental changes. The tree ring width is also one of the significant anatomical indicators to show the response of a tree to changes in environmental conditions. Tree rings are wider during favorable temperatures and rainfall, but narrower under dry and cold conditions (Schweingruber, 1996; Novak et al., 2013).

To date, there are limited studies in the literature to determine how anatomical traits, growth, and development of different tree species vary between managed and unmanaged forests (Klein et al., 2013; Kara, 2021, 2022; Parhizkar et al., 2022). The present study thus aimed to investigate how the stand characteristics, dendrometric and anatomical properties of *Pinus sylvestris* (Scots pine) and *Quercus petraea* (Sessile oak) vary between managed and unmanaged forests. Understanding the dendrometric and anatomical adaptation of different tree species between managed and unmanaged forests plays a significant role in determining the adaptation and survival potential of trees under a changing climate.

MATERIAL AND METHODS

Study site

In this study, managed and unmanaged stands of Scots pine and Sessile oak trees were chosen to understand how dendrometric and anatomical properties of Gymnosperm and Angiosperm tree species show differences in managed and unmanaged forests. Scots pine and Sessile oak trees are widely distributed and are one of the most common trees in Türkiye (Figure 1). Those species are also ecologically and economically valuable tree species in Türkiye.

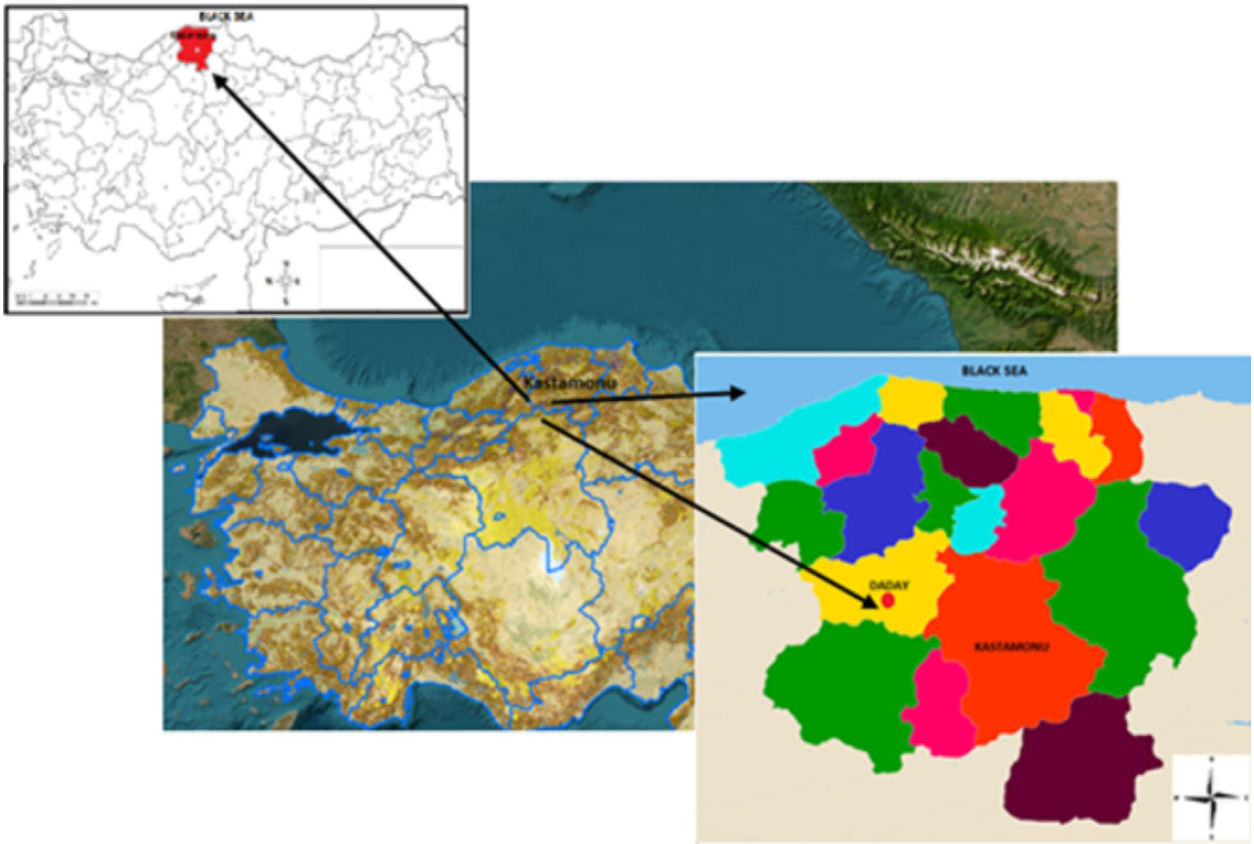

Figure 1: The location of study forests. Managed forest and unmanaged forest area in Daday, Türkiye.

The study site was located in Daday Forest Sub-District, 29 km west of Kastamonu, in western Blacksea, Turkiye (33° 30′ 20″ E and 33° 27′ 50″ E and 41° 23′ 54″ N and 41° 26′ 30″ N) (Figure 1). This study site was particularly selected because there were both managed and unmanaged forests of Scots pine and Sessile oak. The average time since the last harvesting was almost 60 years for unmanaged stands. Apart from Scots pine and Sessile oak trees, black pine, and hornbeam trees are the other tree species within the study site. In the study site, Scots pine, Sessile oak, and other two species combine in mixed forests. The unmanaged forests had natural stand dynamics and no silviculture practices were used to control the composition, quality, and growth of the forests for the last 60 years. However, specific thinning, intermediate treatments, and selected silvicultural regeneration methods were used in managed forests to achieve sustainable forest management and maximize the production of timber crops.

The study site is characteristic of a continental climate with cold and snowy winters and hot and arid summers. In the study site, climate data showed that mean annual precipitation was 490 mm and the annual temperature was almost 9 °C for the period 1991-2022. In the study site, the soil is brown containing rich organic matter and litter (i.e. large amounts of carbon, dead plant material and minerals).

Sampling and stand measurements

The study plots were selected in similar environmental conditions (almost the same altitude, slope, topography, and substrate) and climatic conditions. The age of Scots pine and Sessile oak trees ranged from 50 to 60 years old for both managed and unmanaged forests. The total stem heights (m), and diameters at breast height (DBH) (cm) were measured for all trees between managed and unmanaged forests. The total stem heights of trees were measured using a laser distance meter (KL, KLLZM60). The diameter at breast height (DBH) was determined using a diameter tape. A total of 400 trees were measured in this study. The Height-to-diameter at breast height (DBH) ratio (HDR, m cm^{-1}) was also calculated for each tree using the DBH measurements.

Dendrometric and wood anatomical measurements

To measure tree ring widths of trees, the cross-sectioned discs (1-2 cm thick stems) were cut transversely at the DBH level of each tree. For each managed and unmanaged forest, 20 cross-sectioned discs (one disc per tree) were taken. The cross-sectioned discs were dried and then sanded progressively using sandpapers to obtain a fine surface with distinct tree rings. Tree ring widths were thus measured on sanded cores from bark to pith radius.

To measure the anatomical characteristics of each tree, a total of 40 cross-sectioned discs (i.e. 10 for managed pine, 10 for unmanaged pine, 10 for managed oak, and 10 for unmanaged oak) for managed and unmanaged forests of Scots pine and Sessile oak were selected with trees have similar cambial age. The barks of sampled discs were then removed and sampled discs were prepared. Each sampled core was then cut into small wood pieces from the mature wood part of each disc. To prepare anatomical slides, the small pieces were heated with a glass of water for 10-12 hours. The softened samples were then prepared from the earlywood zone of each tree growth ring for managed and unmanaged types of each tree and cut into transverse, tangential, and radial sections (10-20 µm) using a sledge microtome. The sections were then stained with safranin and dehydrated to make permanent slides (Bond et al., 2008). For the wood cell anatomical measurements of Scots pine samples, tracheid length and width (TL and TW), tracheid lumen width (TLW), tracheid wall thickness (TWT), ray height and width (RH and RW) were determined. For the wood cell anatomical measurements of Sessile oak samples, fibre length and width (FL and FW), fibre lumen width (FLW), fibre wall thickness (FWT), vessel diameter (VD), RH and RW were determined. For TL, TW, FL and FW cell characteristic measurements, wood blocks were split into small strips (1x10 mm in size) and were macerated using Franklin's (1945) method (equal parts (1:1 v:v of hydrogen peroxide and concentrated glacial acetic acid). The cell anatomical characteristics measured in cross sections were tracheid length/width, tracheid lumen width, tracheid wall thickness, fibre length/width, fibre lumen width, fibre wall thickness and vessel diameter. In the tangential section, ray height and ray width were analyzed. Leica DM750 light microscope (Leica Microsystems Ltd., Switzerland) with Leica Application Suite (LAS EZ) Image Analysis Software (Version 3.4.0. 2016) was used to capture and analyze the wood anatomical cell characteristics. The wood cell anatomical measurements were conducted based on the IAWA lists of microscopic features for softwoods and hardwoods identification (IAWA 1989, 2004).

Statistical analyses

Stand characteristics (total tree height, stem diameter, tree stability), tree ring widths and anatomical properties (tracheid length, tracheid width, tracheid lumen width, tracheid wall thickness, fibre length, fibre width, fibre lumen width, fibre wall thickness, vessel diameter, ray height and ray width) were analyzed in managed and unmanaged stands of Scots pine and Sessile oak trees using the analysis of variance (ANOVA) (α-level = 0.05). The Tukey post-hoc test was also used to test differences in stand characteristics, tree ring widths, and anatomical properties between managed and unmanaged stands for significance.

RESULTS

Stand characteristics

In this study, the unmanaged forests had no silviculture practices for the last 60 years depending on the management plans of forestry Sub-district Directorates within the study plots of Scots pine and sessile oak trees (Table 1). The stand characteristics differed between managed and unmanaged forests of Scots pine and Sessile oak trees (Table 1). In Scots pine forests, one-way ANOVA results showed that tree height significantly differed between managed and unmanaged forests ($p < 0.05$). The total tree height was 17.2% times greater in unmanaged forests than in managed forests of Scots pine trees. However, DBH was significantly higher in managed forests than in unmanaged forests ($p < 0.05$) (Table 1). The mean DBH varied from 9 to 29 cm in the managed stands and from 10 to 31.6 cm in the unmanaged stands.

Height-to-DBH ratio (HDR) varied also significantly between managed and unmanaged forests of Scots pine trees ($p < 0.05$). Unmanaged forests of Scots pine trees showed almost 1.3 times greater HDR values than managed forests; the average HDR was 1.03 m cm^{-1} in unmanaged forests and 0.81 m cm^{-1}in managed forests (Table 1). In Sessile oak forests, one-way ANOVA results revealed that total tree height did not indicate significant differences between managed and unmanaged forests ($p > 0.05$). The total tree height was 8.8 m in managed forests and 8.3 m in unmanaged forests. The DBH indicated significant variances between managed and unmanaged forests ($p < 0.001$). The managed forests showed 1.3 times thicker stems than unmanaged forests (Table 1). The mean DBH varied from 8 to 23 cm in the managed stands and from 7 to 20 cm in the unmanaged stands. The stand stability did not differ significantly between managed and unmanaged forests of Sessile oak trees ($p > 0.05$). The mean HDR was 0.85 m cm^{-1} in unmanaged forests and 0.74 m cm^{-1} in managed forests (Table 1).

Table 1: Management history and stand characteristics of Scots pine and Sessile oak trees between managed and unmanaged forests.

	Scots pine		Sessile oak	
Stand Characteristics	**Managed**	**Unmanaged**	**Managed**	**Unmanaged**
Management history	-	>60 years	-	>60 years
Total tree height (m)	15.1^b	17.7^a	8.8^a	8.3^a
DBH (cm)	18.8^a	17^b	12.8^a	10.2^b
Height-to-DBH ratio (HDR, m cm^{-1})	0.81^b	1.03^a	0.74^b	0.85^a

Different letter superscripts show a significant difference in stand characteristics ($p < 0.05$).

Dendrometric and anatomical traits also showed different patterns between managed and unmanaged forests of Scots pine and Sessile oak trees (Table 2). In Scots pine forests, TRWs varied significantly between managed and unmanaged forests ($p < 0.001$); managed forests showed 1.4 times wider tree rings than unmanaged forests (Table 2). Anatomical wood cell characteristics showed quite different results (Figure 2) such that mean TL and TLW were significantly higher in managed forests than in unmanaged forests, while the mean TWT and RH were significantly greater in unmanaged forests than in managed forests. The mean TL and TLW were 1430.3 μm and 9.3 μm respectively in managed forests; mean TL and TLW were 1246.3 μm and 7.4 μm respectively in unmanaged forests (Figure 2, Table 2).

In Sessile oak forests, TRWs showed significant differences between managed and unmanaged forests. The tree rings were almost 1.6 times wider in managed forests than in unmanaged forests (Table 2). Anatomical wood cell characteristics also indicated different patterns between managed and unmanaged forests of Sessile oak trees (Table 2, Figure 3). The mean FL and FLW values differed significantly between managed and unmanaged forests ($p < 0.05$). Managed stands showed higher mean FL and FLW values than unmanaged stands (Table 2). However, the mean values of FW, FWT, VD, RH, and RW did not show significant differences between managed and unmanaged forests of sessile oak trees ($p > 0.05$).

DISCUSSION

In this study, Scots pine and Sessile oak trees showed clear differences in their stand characteristics, dendrometric and anatomical traits in managed and unmanaged stands. Scots pine and Sessile oak trees revealed quite different results in their total stem heights in managed and unmanaged stands. Although Scots pine trees had greater total stem heights in unmanaged stands than in managed stands, Sessile oak trees showed almost equal total stem heights in managed and unmanaged stands. The present study partly confirms previous findings. Parhizkar et al. (2022) studied the quantitative and qualitative characteristics of *Fagus orientalis* saplings in managed vs. unmanaged forests. In their study, beech saplings showed on average 12.2% higher stem heights in unmanaged forests than in managed forests. The characteristics related to tree heights performed much better in unmanaged forests of Scots pine could be probably due to the specific habitat conditions of unmanaged forests within the study area. In unmanaged forests, Scots pine trees could compete with each other for the sunlight much more available in habitat than in managed forests thus trees could perform at higher stem heights. However, more research is required in mature trees to compare how stem heights of different tree species differ between managed and unmanaged stands.

Both Scots pine and Sessile oak trees showed on average 1.2 times thicker stems (DBH) in managed stands than in unmanaged stands in this study. The previous studies also found similar results to the findings of this study (Mausolf et al., 2018; Parhizkar et al., 2022). Mausolf et al. (2018) studied the radial growth of European beech in managed and unmanaged forests. They found that beech trees had higher DBH in managed stands than in unmanaged stands. However, there were opposite findings in previous studies. Baran et al. (2020) determined the effect of forest management (managed vs. unmanaged forests) on stand structure in ravine forests. The study showed that unmanaged stands had almost 40% thicker stems than managed stands. Kara (2021) also investigated the diameter distributions of Kazdağı fir trees in managed and unmanaged stands in Turkiye. He found that the mean DBH was 1.4 times greater in unmanaged forests of fir trees than in managed forests. The opposite findings could be due to the different types of tree species, and also different environmental conditions.

Table 2: Variation in tree ring widths and wood anatomical characteristics of Scots pine and Sessile oak trees in managed and unmanaged forests.

	Scots pine			Sessile oak	
Anatomical Variables	**Managed**	**Unmanaged**	**Anatomical Variables**	**Managed**	**Unmanaged**
TRW	2.18 ± 0.087^a	1.59 ± 0.085^b	TRW	2.27 ± 0.090^a	1.42 ± 0.068^b
TL	1430.3 ± 97.6^a	1246.3 ± 64.8^b	FL	966.1 ± 39.2^a	836.2 ± 70.1^b
TW	38.9 ± 3.51^a	39.1 ± 2.95^a	FW	23.5 ± 1.16^a	24.5 ± 1.28^a
TLW	9.36 ± 0.64^a	7.44 ± 0.43^b	FLW	2.87 ± 0.18^a	1.73 ± 0.14^b
TWT	2.80 ± 0.080^b	4.1 ± 0.21^a	FWT	2.71 ± 0.10^a	2.51 ± 0.09^a
	-	-	VD	92.8 ± 9.04^a	101.7 ± 4.74^a
RH	195 ± 11.2^b	246.6 ± 23.1^a	RH	347.9 ± 29.4^a	303.5 ± 22.1^a
RW	26.7 ± 1.09^a	28.3 ± 1.56^a	RW	33.4 ± 7.8^a	28.7 ± 7.13^a

Values indicate the mean ± standard error (SE); n = 30 for each study site for the parameters.
Different letter superscripts show significant differences in tree ring widths and anatomical characteristics ($p < 0.05$).
TRW – tree ring width, TL – tracheid length, TW – tracheid width, TLW- tracheid lumen width, TWT - tracheid wall thickness, FL – fibre length, FW – fibre width, FLW- fibre lumen width, FWT - fibre wall thickness, RH - ray height, and RW - ray width.

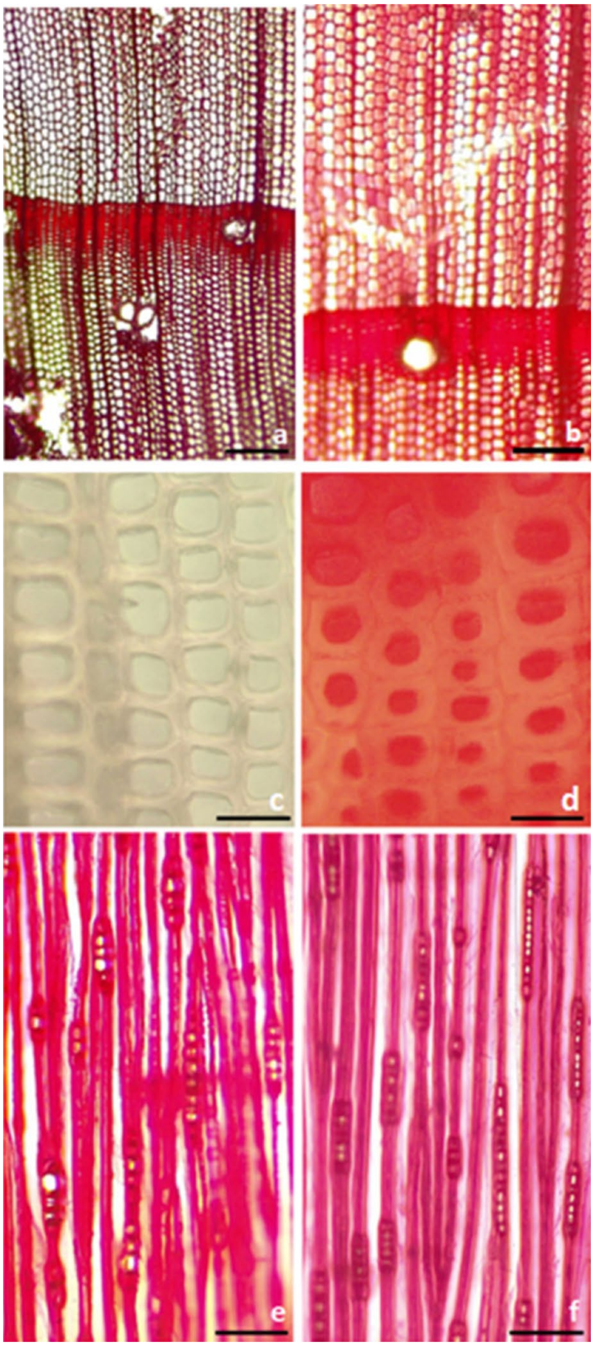

Figure 2: Light microscopy images showing the general cross-section of the stem of the Scots pine tree between managed and unmanaged forests; (a) cross-section of the Scots pine in managed forests (500 µm - 4×), (b) cross-section of the Scots pine in unmanaged forests (500 µm - 4×), (c) tracheid lumen width and tracheid wall thickness in the cross-section of the Scots pine in managed forests (10×), (d) tracheid lumen width and tracheid wall thickness in the cross-section of the Scots pine in unmanaged forests (90 µm - 100×), (e) ray height and width in the radial section of the Scots pine in managed forests (250 µm - 10×), (f) ray height and width in the radial section of the Scots pine in unmanaged forests (250 µm - 10×).

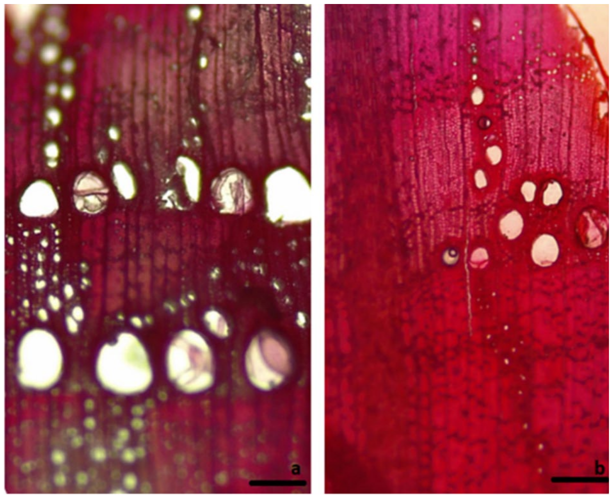

Figure 3: Light microscopy images showing the general cross-section of the stem of the Sessile oak tree between managed and unmanaged forests; (a) cross-section of the Sessile oak in managed forests (500 µm - 10×), (b) cross-section of the Sessile oak in unmanaged forests (500 µm - 10×).

We also found that unmanaged stands of Scots pine and Sessile oak trees exhibited a higher Height-to-DBH ratio (HDR) than in managed forests. The HDR is generally used tree-level index of slenderness which show the stability and vulnerability of trees to natural disasters (i.e. windstorm, icing) (Wonn et al., 2001; Vospernik et al., 2010; Sharma et al., 2019). Trees with large values of HDR indicate that trees could grow in crowded or extremely open stands therefore trees face an increased risk of mortality or vulnerability to changing climate and natural disasters. Trees with smaller values of HDR however show well-developed root systems, more stable balance in trees (the lower the centre of gravity), and thus higher stand stability (Sharma et al., 2019). In this study, we can assume that trees grown in unmanaged forests can be more susceptible to windstorms, icing, and snow damage than in managed forests. Ecologically, managed forests ensure sustainable productivity and health of the forest ecosystem and also increase the biodiversity of trees (Keenan, 2015; Campetella et al., 2016; Picchio et al., 2018; Latterini et al., 2023). Managed forests are generally better designed for the influence of natural disasters and climate change adaptation thus forests with good silvicultural treatments exhibit high long-term stability and vulnerability to environmental stressors.

Tree ring width and anatomical properties are useful environmental indicators in trees to determine climate-growth-forest management practices-forest stand structure relationships. Tree ring width is one of the most important parameters enhancing radial growth. Understanding the effect of forest management on tree ring width can provide better knowledge related to how managed and unmanaged forests respond to climate change. In this study, the tree ring width was almost 1.5 times higher in managed stands than in unmanaged stands. The previous studies also well agreed with the current findings of this study (Mausolf et al., 2018; Kara, 2021). In this study, it can be suggested that forest management had a positive influence on the radial growth of Scots pine and Sessile oak trees in managed forests and also we can assume that managed forests could exhibit more adaptive trees to environmental stressors than in unmanaged forests.

In this study, wood anatomical characteristics also differed in managed and unmanaged stands of Scots pine and Sessile oak trees. Scots pine trees showed wider tree rings in managed forests and also had greater TL and TLW anatomical properties in managed stands than in unmanaged stands. Longer tracheids and wider tracheid lumens can show better conducting efficiency in managed forests. In this study, it can be suggested that Scots pine trees had better hydraulic architecture in managed forests since the size of the xylem conduits was bigger (Panshin and de Zeeuw, 1970; Sperry et al., 2006). Similarly, managed stands of Sessile oak trees showed higher FL and FLW anatomical properties than unmanaged stands. Particularly, longer fibres could provide mechanical support in trees. The previous studies suggested that increased fibre dimensions provide increased cavitation resistance and stem mechanical strength (Jacobsen et al., 2005; Sperry et al., 2006). In this study, managed forests show better hydraulic and mechanical architecture in both Scots pine and Sessile oak trees. However, future studies should be carried out on different tree species to show how xylem conduits and mechanical resistance change between managed and unmanaged forests. Wood anatomical characteristics determine how xylem anatomical properties differ in tree species to analyze the relationships between the growth and development of trees and the environment and show how those relationships vary depending on forest management (Fonti et al., 2010). The xylem anatomical features (the size of tracheids and fibres) can be affected during plant functioning by external factors such as forest management practices. Tracheids particularly record the effect of environmental conditions on their formation process. Fibres however maintain mechanical support to trees. In this study, longer tracheids could show that trees are more efficient in conducting and storing water(Sperry et al., 2006) in managed stands than unmanaged stands; longer fibres however can indicate that trees are more stable and stronger in managed stands than unmanaged stands.

CONCLUSION

The findings indicated that forest management (managed vs. unmanaged) significantly influenced the stand characteristics, tree ring widths, and anatomical properties of Scots pine and Sessile oak trees. Scots pine trees exhibited different patterns in their stand characteristics between managed and unmanaged stands. Although trees had thicker stems in managed stands, unmanaged stands indicated taller trees and greater HDR values. Similarly, Sessile oak trees also showed greater stem diameters in managed forests and higher HDR values in unmanaged forests. In this study, unmanaged stands of Scots pine and Sessile oak trees were more likely prone to environmental damage than trees grown in managed forests. Tree ring widths of trees were also found to be greater in managed stands than in unmanaged stands for both two tree species. This study addressed for the first time how anatomical properties of Scots pine and Sessile oak tree species were influenced by forest management. Scots pine trees showed greater tracheid length and tracheid lumen width in the managed stand than in the unmanaged stand. Sessile oak trees also had higher fibre length and fibre lumen width in the managed stand. This study thus showed how trees grown in different forest management practices regulated their stand characteristics, tree ring width, and anatomical features. It can be suggested that managed forests ensure that better growth and development environment for Scots pine and Sessile oak trees.

AUTHORSHIP CONTRIBUTION

Project Idea: SÖK

Funding: SÖK

Database: SÖK

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Analysis: SÖK

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Review: SÖK

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