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Natural Durability of Some Wood Species in Ground Contact at Four Sites in Turkey. Part 1: Physical Properties

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In this study, heartwood, sapwood, and copper-chromium-boron (CCB) impregnated sapwood samples of various tree species, including Scots pine (Pinus sylvestris L.), Caucasian spruce (Picea orientalis (L.) Peterm), European beech (Fagus orientalis L.) and common alder (Alnus glutinosa subsp. barbata), with dimensions of 20x20x300 mm, were investigated. These samples were subjected to soil contact, specifically under conditions of hazard class 4 according to EN 252, for a period of 3 years. The study was conducted in four different provinces of Turkey, namely Trabzon, Muğla, Çanakkale and Elazığ, which are characterized by different climatic conditions. The climatic index and soil structures of the sites were studied. The visual decay, weight loss and density values of the samples collected from the test sites were evaluated. Samples from Elazığ had the lowest visual decay rate, the lowest weight loss and the highest density. More negative values were observed in Çanakkale, Muğla and Trabzon. In terms of climate type, it was found that the Scots pine and Caucasian spruce wood samples have higher resistance than the European beech and common alder samples. In particular, the heartwood of conifers was found to be more durable than the sapwood. In addition, no deformation was observed in any of the impregnated wood samples. All impregnated wood samples exhibited very good durability.

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Introduction

Wood is a unique building material that is healthy, environmentally friendly, capable of storing carbon, renewable, low in energy requirements, and easier to recycle than other building materials such as concrete, steel, plastics, and composites. On the other hand, wood has some disadvantages, such as being degraded by avariety of decomposers (Ramage et al., 2017; Zhong and Ma, 2022). The long-term performance of wood exposed to the external environment varies depending on its chemical treatment, the quality of the material, its resistance to decay and the climate in its natural environment. Therefore, wood materials should be evaluated according to the climatic characteristics of the location (Winandy and McDonald, 1993; Highley, 1999). The natural durability of wood decreases with increasing exposure time, and different climatic conditions weaken wood's resistance to decay. In other words, changing climatic conditions gradually reduce the wood's resistance to decay and its service life (Highley, 1995). To ensure that wood lasts for a long time in its intended application, it must be either impregnated or made from species

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that have a high natural durability (Oh et al., 2023). Knowledge of soil composition and climate is particularly important for wood components that will come into contact with the ground in an outdoor environment. Many scientists have studied the potential changes that wood can undergo when exposed to the outside environment (Opoku, 2007). Unfortunately, the effect of weathering on wood in contact with the ground has not been the subject of sufficient research. The natural durability of wood is determined by the European standard EN 252 for wood in contact with soil. In the soil contact test method, wood piles are buried up to half of their length in the soil and exposed to microorganisms. EN 252 specifies how to evaluate ground-contact wood preservatives. A preservative-treated wood sample is provided for comparison. Test preservative efficacy is measured by comparing a defined treatment to a eference wood preservative (Baines, 1984; EN 252, 2014). Copper- and chromium-containing strong preservatives are predominant in research and in practical applications. As a prohibited substance, arsenic has been excluded from research. The strongest preservative possible allowed by law and ecological requirements has been applied to determine the natural and maximum durability of wood (Reinprecht, 2016).

Turkey's climate and soil composition vary from region to region. There are four different climate types in the country. It is expected that wood strength may deteriorate at different rates depending on soil structure and climate. In other words, it is necessary to evaluate and compare wood strength in different geographical areas. In research on wood durability, a group of timbers should be impregnated in order to determine the optimum lifetime, thus indicating the difference in durability between impregnated and unimpregnated wood.

In this study, sapwood/heartwood samples and CCB-impregnated sapwood samples from Scots pine, Caucasian spruce, European beech, and common alder were exposed to a three-year field test in accordance with the European standard EN 252 in the provinces of Trabzon, Muğla, Çanakkale and Elazığ to determine the natural durability of wood types. The visual decay rate, weight loss, density, climate index values and soil structure were determined.

Material and Methods

1. Material

Samples were provided from 30 logs, and all trees were felled in the winter season of 2015. All trees were 40 years old. Slope exposure was north. Caucasian spruce, European beech and common alder trees were cut from 1400 m altitude mixed type forest stands in Bakımlı village in Maçka (40.73703, 39.58366), while Scots pine trees were cut from 2100 m altitude pure stands in Güvemli village in Torul (40.48324, 39.24491), located within the borders of Trabzon Regional Directorate of Forestry. The development stage was mature forest; crown closure was medium coverage. The impregnation chemical used in the study, CCB (copper-chromium-boron), was purchased from Emsan Korusan Chemical Company in Istanbul, Turkey. CCB impregnation is in accordance with TS EN 599-1+A1 (2014) for wood of hazard classes 1, 2, 3 and 4. The measurements and analyses were carried out in the application laboratory of the Forest Engineering Department of the Forestry Faculty of Karadeniz Technical University.

2. Impregnation method

Impregnation was carried out using the full cell method. Scots pine, European beech and common alder were impregnated at a concentration of 3%, while Caucasian spruce, which is a difficult species to penetrate, was impregnated at a concentration of 5%. The samples were subjected to a pre-vacuum of 680 mmHg for 30 minutes and a pressure of 8 bar for 30 minutes. According to TS EN 599-1+A1 (2014), the fourth hazard class retention level for vacuum pressure impregnation processes using CCB is 18 kg/m^3. The samples for the study, which gave values close to this retention level, were selected with great care.

3. Research method

The heartwood and sapwood of Scots pine and Caucasian spruce have similar colors. Therefore, benzidine staining was used as a marking method (Koch and Kreig, 1938; Holz, 1959; Rust, 1999). Common alder and European beech sapwood and heartwood differ little in color and moisture. The heartwood of these woods is called false heartwood. Heartwood was collected from the log's center core during the study. Any sections of heartwood or sapwood with differences in moisture were analyzed (Panshin and De Zeeuw, 1980). The samples of non-impregnated sapwood, CCB-impregnated sapwood and heartwood of Scots pine, Caucasian spruce, European beech and common alder measured 20 x 20 x 300 mm. The samples were half buried in the ground according to EN 252 (2014). Four different pilot provinces with four different climatic types were selected for the study (pictured in Fig. 1): Trabzon in the Black Sea region, Muğla in the Mediterranean region, Elazığ in the terrestrial climate region, and Çanakkale in the mixed climate zone.

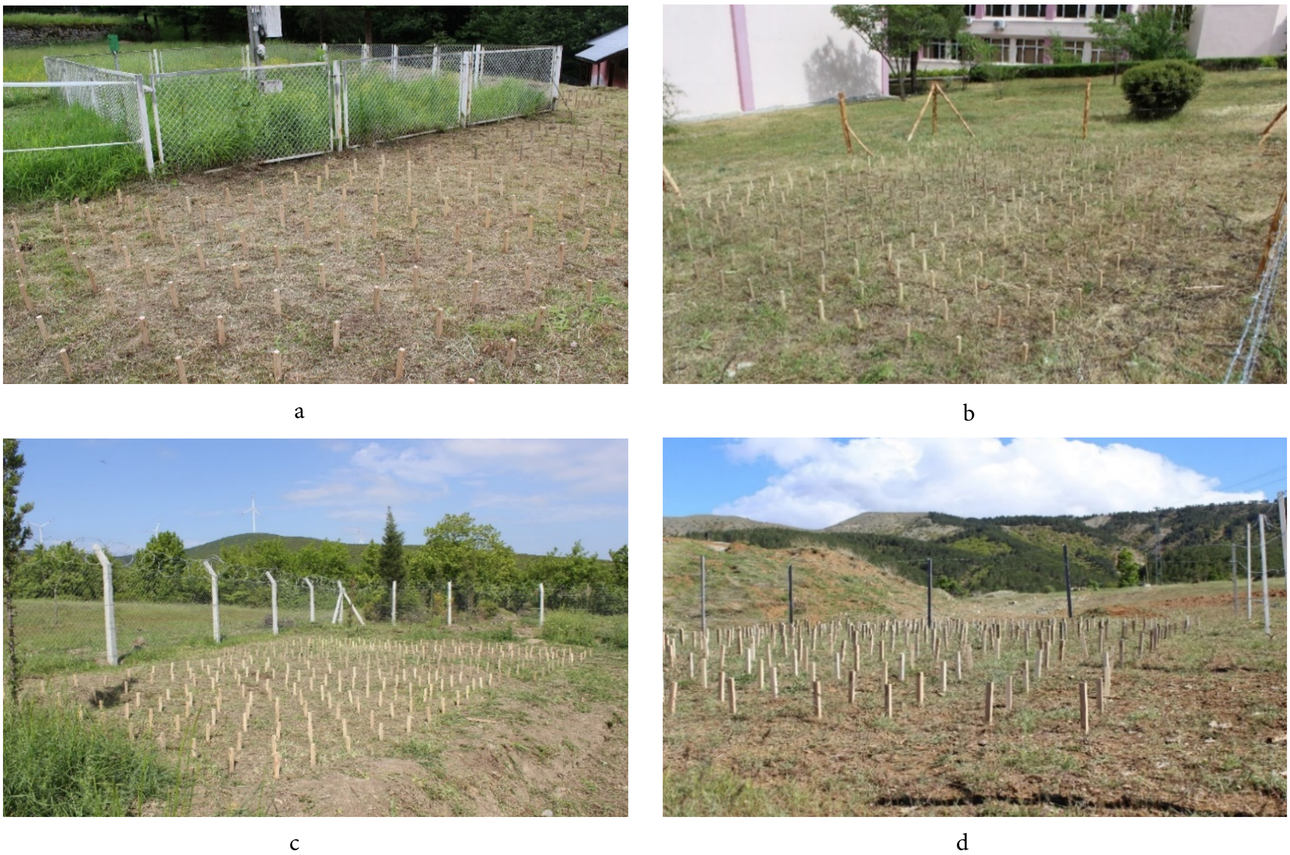

Fig. 1. Trial areas by province/region: a) Trabzon province, b) Muğla province, c) Çanakkale province, d) Elazığ province (Kılıç et al., 2023)

The experimental plots were selected based on their proximity to meteorological stations. In May 2016, samples were placed in experimental regions that were flat, free of weeds, homogeneous, well drained, secure, and protected from damage. The samples were buried in the soil to a depth of half their length (15 cm), spaced 30 cm apart and placed with their tangential sides facing south (Fig. 1). A total of 1500 samples were examined for this study: 600 sapwood, 600 impregnated sapwood and 300 heartwood. The numbers of test and control samples, together with the species and part of the wood from which they were taken, are listed in Table 1.

4. Soil analysis

Soil samples were taken randomly from 0–20 cm depth in each experimental area, in 8 replicates. Soil texture, soil pH, electrical conductivity (EC), amount of organic matter, field capacity, wilting point, available water capacity, soil water holding capacity, $CaCO_3$, and nutrients were determined in the samples. Texture was determined using the Bouyoucos hydrometer method (Gulcur, 1974) and pH was determined by measuring a solution consisting of a 1:2.5 mixture of soil and pure water with a digital pH meter (Gulcur, 1974; Karaoz, 1989). Electrical conductivity (EC) was measured with an EC meter from a solution consisting of a 1:2.5 mixture of soil and pure water (Akıllıoğlu and Direnç, 2002). The amount of organic matter was determined according to the Walkley–Black wet digestion method (Kacar, 1995). Field capacity was calculated as a percentage (%) using the Soil Moisture Pressure Plate tool, as the moisture lost and the moisture retained in the moisture equivalent of the absolute dry soil (Gulcur, 1974). The wilting point was measured under 15 atmospheres of pressure with a ceramic plate pressure device from Soil Moisture Equipment Co. (Gulcur, 1974). Available water capacity was calculated by subtracting the moisture content at the wilting point from the moisture equivalent values of the soil samples. The lime content of the soil was calculated according to the Scheibler calcimetry method (Gulcur, 1974). Soil water holding capacity (SWHC) was calculated using equation 1 (Olorunfemi et al., 2016).

$$\mathrm{SWHC}(\%) = 36.0 - [0.215x\mathrm{Sand}\ (\%)] + [0.113x\mathrm{Clay}\ (\%)] + [10.36xOrganic\ Carbon]\ (\%) \quad (1)$$

Table 1. Total numbers of samples in the study (Kılıç et al., 2023)

Wood type	Climate type/Region	Sapwood	Impregnated sapwood	Heartwood	Total
Scots pine	Black Sea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Caucasian spruce	Black Sea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
European beech	Black Sea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Common alder	Black Sea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Control samples (samples in laboratory)		120 (30x4)	120 (30x4)	60 (15x4)	300
Total samples		600	600	300	1500

Note: Heartwood was studied with 5 repetitions, sapwood and impregnated sapwood with 10 repetitions.

5. Visual decay rating

Samples exposed to soil in May 2016 were collected in May 2019. Decay was graded according to EN 252 (2014) as "0" no attack, "1" slight attack, "2" moderate attack, "3" severe attack, "4" failure. The samples were evaluated according to their appearance, general condition, texture and condition of the sections, color change, and decay structure.

6. Weight loss and density

Before exposure, the samples were weighed and measured after drying until they reached a fixed weight. After exposure, samples were dried again and weighed and measured. Weight loss and density were calculated using the formulas below.

$$WL = \frac{(M1 - M2)}{M1} x\, 100 \tag{2}$$

$$\delta_O = \frac{M_O}{V_O} \tag{3}$$

WL: weight loss, *M1*: pre-exp. mass, *M2*: post-exp. mass, δ_o: density, M_o: dried mass, V_o: dried volume

7. Statistical analysis

The data in this study were analyzed using the SPSS 22.0 statistical package and based on a 95% confidence level. Statistical differences between the data were calculated by simple analysis of variance. The Duncan homogeneity test was applied to determine which variations and which wood type the obtained differences concerned.

When comparing the data as a result of soil contact tests, it was evaluated whether there was a difference between the variations.

Results and discussion

1. Retention

The study covered values that were 10% below (~16.98 kg/m³) and 10% above (~19.77 kg/m³) the 18 kg/m³ threshold (EN 252, 2014). The retention rates observed indicate that the required range of retention values was provided. The ordering of the impregnated test samples in the study according to retention was common alder > European beech > Scots pine > Caucasian spruce. Yalınkılıç et al. (1996) reported the order according to retention after impregnation with Tanalith-CBC (copper-borate-chromate) as alder > beech > Scots pine > spruce.

According to the climate index formula proposed by Scheffer (1971), given in equation (4), the highest climate index was found in Trabzon and the lowest in Muğla (Figure 3). The highest index was found in the third year. This is the case for all types of climates. Year 3 was generally rainy throughout Turkey. The fact that the samples experienced severe deterioration in the third year may be explained by the high index as well as the length of time for which they were exposed to the soil. The strength and decay resistance of wood decrease with increasing soil contact time, although this varies from species to species. Climatic variations have an effect on the durability of wood, depending on regional conditions (Highley, 1999; Gündüz, 2007).

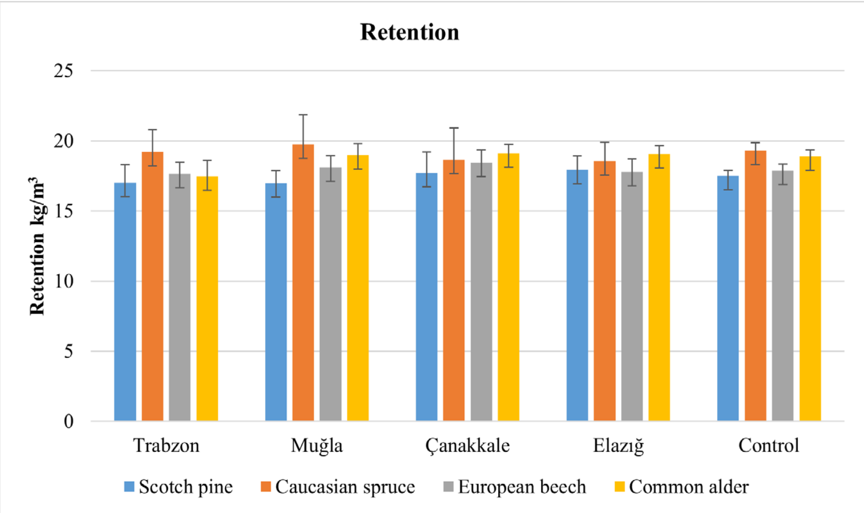

Fig. 2. Retention values of test and control samples as a result of impregnation with CCB

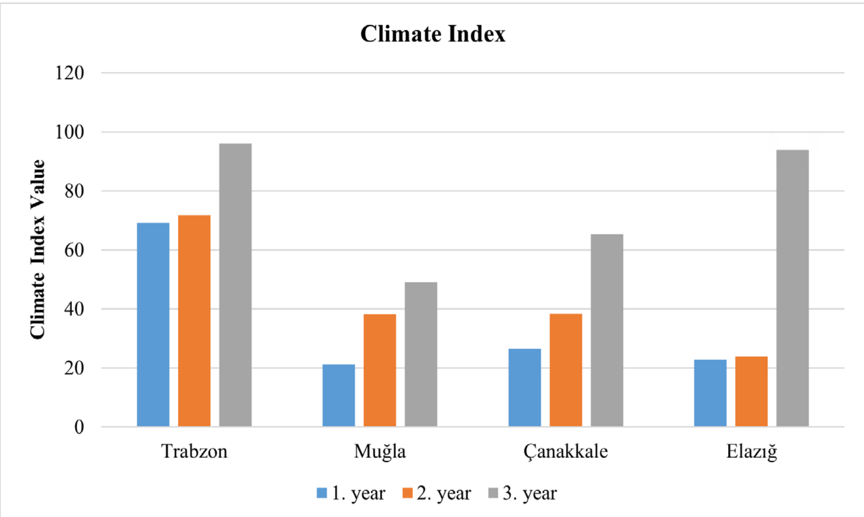

Fig. 3. Climate index in year 1 (May 2016–April 2017), year 2 (May 2017–April 2018), year 3 (May 2018–April 2019)

$$Scheffer\ Climate\ Index = \sum_{April}^{May} \frac{(t-2)(g-3)}{16.7} \quad (4)$$

t: monthly average temperature (°C),

g: average number of days with precipitation of 0.25 mm or more during the month, 16.7: this number replaces the denominator used in the Fahrenheit index to enable the use of values in Celsius,

Σ: sum of the temperature and precipitation for all months between May and April. Since there will be no fungal activity at negative temperatures in the study, a restriction was placed on the formula: when $t < 0$, (t-2) was taken as 0, and when precipitation < 0, (g-3) was taken as 0 (Gündüz and Vurdu, 1995)

2. Soil analysis

In the study, the province with the highest amount of sand in the soil was Muğla, while the province with the lowest was Çanakkale. The province with the highest clay ratio was Elazığ, while the province with the lowest clay ratio was Muğla. The soil of Muğla province, which has a mostly sandy and slightly clayey structure, was found to have the lowest soil water holding capacity (SWHC) (Table 2). High SWHC plays a role in increasing the rotting of wood in contact with the soil (Jebrane et al., 2014; Meyer-Veltrup et al., 2017; Brischke and Meyer-Veltrup, 2017). The highest SWHC values were found in Çanakkale (45.95%) and Trabzon (44.01%). In the studies conducted, in order to increase the wood decomposition potential of the soil, peat and various mulch mixtures are added to the soil in the test area to reach 95% water retention capacity, and then soil contact tests are performed (Klinka et al., 1995; Ali et al., 2011; Brischke et al., 2014). Another important factor is the presence of organic matter in the soil. The most organic matter was found in the soils of Trabzon and Çanakkale. The least organic matter was measured in Elazığ. Klinka et al. (1995) report that soil thickness, amount of organic matter in the soil, and soil acidity affect the decay of wood in contact with the soil.

3. Visual decay

No decay was observed in any of the impregnated samples in any of the climates. Each impregnated sample received a decay score of 0 (no attack). Therefore, evaluations were made on non-impregnated sapwood and heartwood. In Trabzon, the best resistance was calculated for Scots pine heartwood and sapwood, with a visual decay score of 1.4, while the worst resistance was obtained for common alder heartwood, with a visual decay score of 3.4. In Muğla, the best resistance was calculated for Caucasian spruce heartwood, with a visual decay score of 1.4, and the worst for European beech sapwood (4.0). In Çanakkale, the best resistance was calculated for Caucasian spruce heartwood (1.0), and the worst for common alder sapwood and heartwood of common alder and European beech (4.0). There is no statistical difference between the sapwood of Scots pine with a visual decay grade of 3.7, the sapwood of European beech with a grade of 3.9, and the species with a grade of 4.0. In Elazığ, the best resistance was calculated for the sapwood of common alder and Caucasian spruce and the heartwood of Caucasian spruce and Scots pine, with a visual decay grade of 1.0, while the worst was obtained for European beech heartwood, with a visual decay grade of 2.0. Elazığ had the best index out of all climate types.

It can be stated that the average annual precipitation and the average annual relative humidity of the terrestrial climate are lower than for other climate types (MGM, 2019). In addition, the average temperature calculated for 3 years in Elazığ is lower than in other climates. This is below the temperature required for fungal decay to occur. It is assumed that fungal activity does not occur because the humidity level required for fungal activity is not reached, although high temperatures do occur from time to time (Gündüz, 2007; MGM, 2019).

Degradation was more severe in the warmer and wetter climates of Çanakkale, Muğla and Trabzon. These three climates also have maritime characteristics. The high temperature and humidity create a unique environment for fungal decay. Decay has been extensively

Table 2. Soil analysis

	Sand	Dust	Clay	Fc	Fp	Awc	Ph	Ec	Organic	Lime	$CaCO_3$	Swhc
Trabzon	62.41[b]	21.14[b]	17.75[b]	20.39[b]	14.15[b]	6.23[a]	6.61[a]	0.09[b]	3.75[c]	0[a]	0[a]	44.01[c]
Muğla	67.79[c]	20.22[b]	11.99[a]	12.35[a]	4.91[a]	7.44[a]	7.53[b]	0.16[c]	1.19[a]	28.03[b]	70.27[c]	23.78[a]
Çanakkale	43.99[a]	27.76[c]	29.49[c]	24.46[d]	15.97[c]	8.49[a]	6.46[a]	0.07[ab]	3.10[b]	0[a]	0[a]	45.95[c]
Elazığ	47.18[a]	16.66[a]	36.06[d]	22.58[c]	15.92[c]	6.44[a]	7.38[b]	0.04[a]	0.66[a]	1.84[a]	4.05[b]	33.32[b]

Fc: field capacity, Fp: fading point, Awc: available water capacity, Swhc: soil water holding capacity. Different letters in the same row indicate statistical difference ($p < 0.05$)

Table 3. Visual decay of wood samples

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1	2	3	1	2	3	1	2	3	1	2	3
Scots pine	Sapwood	1.00^{bc}	1.10^{bc}	1.40^{bcd}	1.20^{bc}	1.20^{bc}	2.10^{e}	1.10^{cd}	1.30^{cd}	3.70^{g}	0.30^{abc}	0.90^{de}	1.10^{efg}
	Impregnated	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	Heartwood	1.00^{bc}	1.00^{bc}	1.40^{bcd}	1.00^{bc}	1.00^{bc}	1.60^{cde}	0.00^{a}	1.00^{bc}	1.20^{cd}	0.40^{bc}	1.00^{ef}	1.00^{ef}
Caucasian spruce	Sapwood	1.10^{bc}	1.60^{cd}	2.00^{de}	1.00^{bc}	1.90^{de}	2.20^{e}	1.30^{cd}	2.30^{e}	2.90^{ef}	1.00^{ef}	1.00^{ef}	1.00^{ef}
	Impregnated	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	Heartwood	1.60^{cd}	1.80^{de}	2.40^{efg}	1.00^{bc}	1.00^{bc}	1.40^{bcd}	1.00^{bc}	1.00^{bc}	1.00^{bc}	1.00^{ef}	1.00^{ef}	1.00^{ef}
European beech	Sapwood	1.10^{bc}	2.70^{fgh}	3.30^{hi}	1.90^{de}	3.20^{f}	4.00^{g}	1.20^{cd}	1.70^{d}	3.90^{g}	0.20^{ab}	1.30^{fgh}	1.50^{hi}
	Impregnated	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	Heartwood	1.00^{bc}	3.00^{ghi}	3.20^{hi}	1.20^{bc}	2.20^{e}	3.40^{fg}	1.00^{bc}	3.00^{f}	4.00^{g}	1.80^{ij}	1.80^{ij}	2.00^{j}
Common alder	Sapwood	1.00^{bc}	2.30^{ef}	3.30^{hi}	0.90^{b}	3.50^{fg}	3.70^{fg}	1.00^{bc}	2.40^{ef}	4.00^{g}	0.60^{cd}	1.00^{ef}	1.00^{ef}
	Impregnated	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
	Heartwood	1.60^{cd}	2.40^{efg}	3.40^{i}	1.00^{bc}	3.40^{fg}	3.80^{fg}	1.60^{cd}	3.80^{g}	4.00^{g}	0.40^{bc}	1.00^{ef}	1.40^{gh}

Different letters in the same row indicate statistical difference ($p < 0.05$)

reported in both the sapwood and heartwood of European beech and common alder. Beech is an extremely nondurable species in changing weather conditions and particularly in contact with soil (Findlay, 1985). Like beech, alder wood is one of the most susceptible to fungal decay among deciduous species (Scheffer and Morrell, 1998). In a study, the natural strength of seven wood species in contact with the soil, which were driven into fields with different climate types, different biodiversity and different soil structure in three different regions in Mexico for 12 months, was examined. Beech wood was used as a control sample. The region where decay was most prevalent was in the temperate city of Veracruz, located on the coast of the Gulf of Mexico. The highest visual decay grade (3.4) was observed in the beech control sample. This grade shows that beech wood decomposes almost completely in one year (Colin-Urieta et al., 2018). In a study, many wood species were left in contact with soil for 5 years in Hannover (Germany) and Boras (Sweden) and their decay rates were determined according to the EN 252 test standard. The highest decay rate was observed in beech in Hannover and Boras (Meyer-Veltrup et al., 2017). Ali et al. (2011) reported that much more decay was observed in Scots pine and beech wood soil contact samples in a Mozambique field trial than in the Swedish field trial, due to high humidity and temperature, and that beech in particular had completely decayed (visual decay grade 4.0).

In the current study, it was found that coniferous tree species exhibited lower visual decay grades than deciduous tree species. This means that coniferous trees are more durable in contact with the soil. Scots pine and Caucasian spruce showed better durability in all climate types. Scots pine had a lower decay grade than Caucasian spruce. This can be explained by the fact that Scots pine wood has richer components than spruce wood (Vainio-Kaila et al., 2015). The heartwood of both wood species was found to be more durable than the sapwood. Storage substances in the parenchymal cells of sapwood make it more susceptible to decay than the heartwood; the sapwood has poorer protective properties due to the presence of soluble extractive chemicals (Taylor et al., 2002). The tannins, phenolic contents, essential oils, and low moisture content in the heartwood make it more resistant to pests (Koch, 1972; Panshin and De Zeeuw, 1980). These elements have the ability to stop or postpone wood deterioration. However, heartwood exposed to the soil loses its water-soluble preservatives and can decay (Sivrikaya, 2003; Şen and Yalçın, 2010). In a study of Scots pine, it was determined that the resistance of sapwood was lower than that of the heartwood and that the tomographic rays were more permeable in sapwood. In the same study, it was determined that heartwood has higher extractive and lower moisture content than sapwood (Bieker and Rust, 2010). In another study, the distribution of sugar compounds such as glucose, fructose, and sucrose in Scots pine wood was examined in outer sapwood, inner sapwood, the transition zone, and heartwood. According to the results, most sugar compounds are found in sapwood. There is a proportional decrease from the outside to the inside. These sugar components were found in trace amounts in the inner core of the heartwood (Saranpää and Höll, 1989). The difference in visual index and strength between heartwood and sapwood in the current study can be expressed by the amount of nutrients they contain and the ratio of extractive components. In another study, the resistance of sapwood and heartwood samples of Scots pine and Caucasian spruce to fungal decay according to EN 113-2 (2020) was investigated. In both Scots pine and spruce samples, the heartwood exhibited more strength and lower weight loss than the sapwood (Çetin et al., 2010). However, termite attack was detected on Scots pine and spruce sapwood in Çanakkale in the third year. Termites have never been found in the region before and there is no definitive information about their source. A decay grade of 3.7 was observed in Scots pine sapwood, and a grade of 2.9 in Caucasian spruce sapwood. One study reported that Scots pine and spruce were the species most affected by termite attack (Cornelius and Osbrink, 2015). It was also found in the current study that the attack only affected sapwood; heartwood and impregnated wood were left unaffected. Another interesting result in the study was that Caucasian spruce in Elazığ had the same visual decay grade for sapwood and heartwood. This may be explained by the fact that the low humidity seen in the terrestrial climate in general did not provide the humidity values required for fungal decay. In addition, the low organic matter content and low water retention capacity in the soil taken from Elazığ may have been a factor in the minimum decay observed in Caucasian spruce wood in contact with the soil for 3 years.

The study revealed no significant variation in durability between the sapwood and heartwood of European beech and common alder. Non-durable wood types such as beech have insignificant differences between their heartwood and sapwood, and they are all susceptible to decay. Additionally, beech heartwood has shorter fibers than sapwood (Ataç and Eroğlu, 2013). Short-fibered beech heartwood is more degradable than longer-fibered beech sapwood. According to a study by Rao (1976), the heartwood of deciduous trees is generally less durable than the sapwood. Nelson and Heather (1972) stated that the heartwood of trees that are poor in extractives may have equally poor resistance.

4. Weight loss

In Trabzon, the highest weight loss was observed in European beech sapwood (52.62%), and the lowest in Scots pine heartwood (6.34%). Common alder sapwood, with a weight loss of 51.03%, is in the same homogeneity group as European beech sapwood. In Muğla, the highest weight loss was observed in European beech sapwood (56.26%), and the lowest in Caucasian spruce heartwood (5.41%). In Çanakkale, the highest weight loss was observed in European beech heartwood (53.52%), and the lowest in Caucasian spruce heartwood (6.09%). Common alder sapwood, with aweight loss of 51.60%, is in the same homogeneity group as European beech heartwood. In Elazığ, the highest weight loss was observed in European beech sapwood (22.33%), and the lowest in Caucasian spruce sapwood (2.21%). In the study, weight loss in both sapwood and heartwood increased from year to year. The amount of lignin and holocellulose shed from the wood increases with the length of time wood samples are left in the field (Gençay, 2010). As a result, throughout the trial, the components of the wood separate, and its weight decreases due to the action of soil microbes and the climate. This reveals the durability of the wood in the relevant hazard class. In a study, it was stated that weight loss is the most important indicator among parameters such as mechanical resistance tests, color change, visual rot, weight loss and density in determining wood strength (Delucis et al., 2016). In the relevant standards ENV 807 (1993) and EN 350 (2016) and in a prior study (Van Acker et al., 2003), it is emphasized that weight loss must be investigated in soil contact tests relating to hazard class 4. It was thought that the weight losses observed in impregnated samples were due to the impregnation material being leached away from the wood. This leaching occurred in all impregnated samples in the first year, and no leaching occurred in the following years. Since no decay or even minimal change was observed in the impregnated wood for 3 years, it can be said that the leached substance is the impregnation chemical located in the lumen. Leaching occurs at the initial stage and there is no leaching process in the later stages; the leaching process is attributed to the structure of the wood, its size, amount, type of surface area, and the degree of fixation of the impregnation chemical components. Although boron in CCB has the ability to be leached, the fixed part serves as an important fungicide (Bozkurt et al., 1993). Homan and Militz (1993) reported that although boron is leached away from the wood, it provides sufficient protection in applications.

The study showed that a wood species could exhibit different weight losses in different climates. To gain

Table 4. Weight loss of wood samples

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1	2	3	1	2	3	1	2	3	1	2	3
Scots pine	Sapwood	6.76 abcdef	9.72 bcdefgh	10.42 cdefghi	4.87 abc	6.21 abcde	8.00 bcdef	4.56 a	7.64 abcd	31.00 kl	3.64 abcde	5.02 defghi	6.21 ghijk
	Impregnated	16.04 ijk	16.74 jk	14.40 hij	16.62 l	15.06 kl	15.05 kl	17.21 fgh	18.36 gh	14.29 efg	17.90 pr	17.99 pr	22.64 s
	Heartwood	3.57 a	5.21 abcd	6.34 abcde	3.97 ab	4.85 abc	6.97 abcde	3.41 a	4.17 a	6.58 abcd	3.24 abcd	3.99 abcde	4.23 bcdef
Caucasian spruce	Sapwood	4.99 abc	10.93 defghi	12.16 efghij	3.21 a	6.18 abcde	7.66 abcdef	4.34 a	12.86 ef	27.58 jk	2.86 abc	2.64 ab	2.21 a
	Impregnated	6.68 abcdef	11.60 efghij	14.23 hij	14.18 ijkl	13.60 hijkl	12.71 ghijkl	14.20 efg	13.80 efg	11.67 de	12.89 no	12.60 no	11.79 mn
	Heartwood	4.04 ab	6.53 abcdef	12.33 fghij	3.27 a	4.13 ab	5.41 abcd	3.23 a	4.14 a	6.09 abc	2.78 abc	2.60 ab	2.91 abc
European beech	Sapwood	10.01 cdefgh	36.05 no	52.62 p	22.44 m	37.37 o	56.26 p	10.11 bcde	20.18 hi	46.92 n	6.22 ghijk	11.67 mn	22.33 s
	Impregnated	7.08 abcdef	6.66 abcdef	7.03 abcdef	6.96 abcde	6.92 abcde	6.27 abcde	6.73 abcd	6.51 abc	6.30 abc	6.51 hijk	6.13 fghijk	5.47 efghi
	Heartwood	20.88 k	29.30 lm	32.01 mn	11.80 fghijk	26.16 m	32.15 n	10.83 cde	32.30 lm	53.52 o	11.33 lmn	16.41 p	18.92 r
Common alder	Sapwood	13.58 ghij	34.30 mno	51.03 p	9.64 defgh	37.37 o	39.62 o	14.85 efg	30.91 kl	51.60 o	5.32 efghi	6.79 ijk	8.05 k
	Impregnated	11.10 efghij	11.03 efghi	10.97 defghi	10.60 efghij	10.36 efghi	10.21 efghi	10.9 6cde	11.16 cde	10.21 bcde	10.71 lm	10.42 lm	9.80 l
	Heartwood	1.60 cd	26.58 l	37.84 o	8.82 cdefg	31.14 n	39.66 o	18.65 gh	43.78 n	24.39 ij	5.61 efghij	7.50 jk	14.31 o

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line.

knowledge about the natural strength of a wood, it is necessary to know its strength properties in different climates. It is thought that wood samples will show similar performance in the same climate. In a study, the differences in decay resistance and mechanical properties of four different wood species (*Eucalyptus botryoides, Corymbia citriodora, Eucalyptus paniculata* and *Eucalyptus tereticornis*) were investigated in a soil contact test carried out in three different trial areas in the same city. It was determined that there was no difference between the trial areas. It was reported that in all wood types, as exposure time increased, weight loss increased and resistance properties decreased (Delucis and Gatto, 2017). Mattos et al. (2014) stated that all mechanical properties decline with increased weight loss.

Termite degradation in Çanakkale caused a significant reduction in weight in coniferous species. In Trabzon, weight loss was slightly higher. It was evident that the protective qualities of the wood are impaired by excessive rains in Trabzon, which has the highest climate index. At the end of the third year, the weight loss of the impregnated samples steadily decreased in Muğla, Çanakkale and Elazığ, but increased in Trabzon. Although it is reported that washing occurs in the initial stages and gradually decreases in the following periods, it is thought that weight loss increases due to heavy rainfall and the high climate index in Trabzon. It is also important to consider other elements, including the variety of microorganisms and the soil qualities unique to the Trabzon microclimate. As a result of the acidic soil in Trabzon (Ateşalp, 1977), wood deteriorates quickly, leading to significant losses of arsenic, copper, and chromium (Blankenhorn et al., 1999). The soil in Trabzon province on which the current study was conducted is richer in organic

Table 5. Density of wood samples

Wood	Part	Trabzon			Muğla			Çanakkale			Elazığ		
		1	2	3	1	2	3	1	2	3	1	2	3
Scots pine	Sapwood	0.48 fghijk	0.47 efghij	0.49 ghijk	0.48 defghijk	0.51 fghijkl	0.44 cdefg	0.49 hijkl	0.48 ghijk	0.36 cd	0.50 efghijk	0.44 abcd	0.41 a
	Impregnated	0.53 ijkl	0.54 jklm	0.52 ijkl	0.51 ghijkl	0.56 lmno	0.53 jklmn	0.54 klmno	0.54 klmno	0.55 mnop	0.53 ghijkl	0.51 fghijk	0.49 cdefghij
	Heartwood	0.45 defgh	0.46 efghi	0.43 cdefgh	0.45 defgh	0.44 cdefg	0.45 defgh	0.46 fghi	0.45 efgh	0.49 ghijk	0.45 abcdef	0.44 abcde	0.50 defghijk
Caucasian spruce	Sapwood	0.41 cdef	0.40 cde	0.40 cde	0.44 cdefg	0.43 cde	0.41 cd	0.42 ef	0.35 cd	0.34 cd	0.42 ab	0.44 abcdef	0.42 ab
	Impregnated	0.54 jklm	0.49 ghijk	0.48 fghijk	0.45 defg	0.47 defghij	0.47 defghij	0.45 efgh	0.47 fghij	0.47 fghij	0.45 abcdef	0.46 abcdefg	0.50 defghijk
	Heartwood	0.42 cdefg	0.42 cdefg	0.40 cdef	0.46 defghij	0.43 cde	0.44 cdefg	0.43 efg	0.47 fghij	0.46 fghi	0.42 abc	0.47 bcdefgh	0.46 abcdefg
European beech	Sapwood	0.53 ijkl	0.40 cde	0.33 ab	0.47 defghij	0.37 bc	0.27 a	0.54 klmno	0.48 ghijk	0.32 bc	0.55 kl	0.54 jkl	0.50 defghijk
	Impregnated	0.60 m	0.58 lm	0.59 lm	0.59 no	0.58 mno	0.60 no	0.58 nop	0.61 p	0.60 op	0.58 lm	0.58 lm	0.62 m
	Heartwood	0.50 hijk	0.41 cdef	0.42 cdefg	0.54 klmno	0.47 defghijk	0.44 cdef	0.55 lmnop	0.42 ef	0.28 ab	0.53 ghijkl	0.50 defghijk	0.54 jkl
Common alder	Sapwood	0.40 cde	0.33 ab	0.29 a	0.47 defghij	0.27 a	0.34 b	0.42 ef	0.33 c	0.23 a	0.48 bcdefghij	0.50 fghijk	0.54 jkl
	Impregnated	0.53 ijklm	0.53 ijkl	0.55 klm	0.53 ijklmn	0.52 hijklm	0.59 no	0.55 lmno	0.53 jklmn	0.55 lmno	0.53 hijkl	0.53 ijkl	0.58 lm
	Heartwood	0.38 bcd	0.36 bc	0.28 a	0.43 cde	0.27 a	0.27 a	0.35 cd	0.26 a	0.35 cd	0.49 cdefghij	0.47 bcdefghi	0.49 defghijk

Different letters in the same row indicate statistical difference ($p < 0.05$). Due to the very small size of the mean and Duncan homogeneity groups, the letters are placed on a separate line.

terms than the soil from other regions. Cooper (1991) reports that complex organic acids such as fulvic and humic acids, which are commonly found in organic soils, accelerate leaching.

It was observed that impregnated European beech and common alder samples undergo less leaching than Scots pine and Caucasian spruce. Considering that all impregnated samples were treated at close retention, it can be assumed that European beech and common alder woods are resistant to leaching. Gezer (2004) reported in their study that beech and alder woods with higher densities showed more resistance to leaching. Beech and alder are high-permeable species, and high permeability provides good impregnation performance, ensures that the impregnation material adheres to the inner parts of the wood, and prevents superficial leaching (Örs et al., 2005).

The highest weight loss was detected in European beech and common alder. These two types are classified as non-durable wood according to EN 350 (2016). Significant weight loss was observed in climatic types other than the terrestrial climate (Elazığ) in the study. After the second year, several European beech and common alder samples in Trabzon, Muğla, and Çanakkale had entirely decayed in the soil. In a study, many wood species were exposed to soil contact testing outdoors for 3 years. In half of that period, 80% of the Andean alder (*Alnus acuminata*) wood was completely degraded compared to the number of samples at the beginning of the test (Moya and Berrocal, 2015). In the current study, decay started at the top of the test sample and increased downward. In a study, Torres-Andrade et al. (2019) reported that the decay in the test samples increased as they descended from the upper part of the piles to the underground part.

5. Density

In Trabzon, the highest density was observed in Scots pine sapwood (0.49 g/cm^3), and the lowest density in common alder heartwood (0.28 g/cm^3). In the Black Sea climate, European beech wood exhibited the best performance among the impregnated wood samples. In unimpregnated samples, Scots pine sapwood is the species with the best density (0.49 g/cm^3). In Muğla, the highest density was observed in Scots pine heartwood (0.45 g/cm^3), and the lowest in common alder heartwood and European beech sapwood (0.27 g/cm^3). In the Mediterranean climate, European beech wood samples displayed the best performance among the impregnated wood samples. In Çanakkale, the highest density was observed in Scots pine heartwood (0.49 g/cm^3), and the lowest in common alder sapwood (0.23 g/cm^3). In the mixed climate, European beech wood exhibited the best performance among the impregnated wood samples. Both Scots pine and Caucasian spruce heartwood exhibited good density in unimpregnated samples. In Elazığ, the highest density was observed in European beech heartwood and common alder sapwood (0.54 g/cm^3), and the lowest in Scots pine sapwood (0.41 g/cm^3). In the terrestrial climate, all wood species showed good density performance compared to other climates.

Density is one of the key factors that determines the strength of wood. Numerous studies (Venäläinen et al., 2014; Mattos et al., 2014; Dadzie and Amoah, 2015; Delucis et al., 2016; Benfratello et al., 2017) have demonstrated a direct proportionality between wood density and wood strength, particularly resistance qualities. However, unexpected outcomes are occasionally observed in open field trials. Although in the current study density was predicted to decline annually, in some wood types and climate types, the density occasionally increased and occasionally stayed the same. This might be because the density, which is determined by the mass-to-volume ratio, did not follow the expected pattern (Bal and Bektaş, 2018). A species that has been in the study area for three years will lose volume as well as mass due to decay and decomposition. If the weight loss is less than the volume loss in some locations, this indicates a higher density than the previous year. Wood density cannot always be used as a criterion for decay resistance. This is because species with high densities and low levels of extractives may be less resistant to decay. High-strength species may have low density but contain sufficient extractives to prevent or delay decay. As a result, the relationship between density and natural durability may vary depending on the presence of extractives (Sivrikaya, 2008).

Moya and Berrocal (2015) exposed different types of wood to soil contact for 36 months and examined the elastic modulus properties after the test. The densities of *Alnus acuminata, Bombacopsis quinata* and *Vochysia guatemalensis* woods were 0.34, 0.32 and 0.32 g/cm^3, respectively. However, the visual decay ratings of these wood types after 36 months were 0, 6.2, 5.6, respectively, according to AWPA E7 (2000). In other words, the two species with lower density gave better results than Andean alder. In addition, the loss of elasticity modulus in the samples after 36 months was 100%, 56.3%, 81.7%, respectively. Even though its density is higher than the others, Andean alder wood had completely decayed.

Throughout the test period, a certain amount of density loss was noted in the Scots pine and Caucasian spruce unimpregnated test samples. The weight loss resulting from leaching is the cause of the density reduction in impregnated samples. No volumetric loss or decay was observed in the impregnated wood. It is possible that the natural durability and high extractive content of heartwood are the reasons why it loses density less quickly than sapwood. It has been observed that density loss is generally higher in temperate climates than in continental climates. Density loss was high in the unimpregnated European beech and common alder test specimens. It is thought that the low density loss in the impregnated samples is due to the fact that beech wood fixes the impregnation material well (Gezer, 2003). In a study, it is stated that the highest retention among alder, beech and Scots pine woods impregnated with various substances was achieved in alder wood (Yalınkılıç et al., 1996). Additionally, it was observed that heartwood and sapwood exhibited density loss at similar rates. The reason for this is that beech heartwood is not very rich in extractives. It was reported that adequate utilization of carbohydrates in fast-growing trees was associated with low polyphenols in the heartwood (Sivrikaya, 2008). Since alder is a fast-growing species, the low strength of its heartwood can be explained by these factors (Saraçoğlu, 1991). However, late heartwood formation, which is sometimes seen in alder wood, may also be an explanation for low heartwood strength (Bozkurt et al., 2000).

Conclusion

Samples from Çanakkale, Muğla, and Trabzon had the highest visual decay rating, the largest weight loss, and the lowest density when analysis was performed by wood type, while Elazığ typically produced the lowest visual decay rating, highest density, and lowest weight loss. It was concluded that coniferous trees' heartwood was more durable than their sapwood. In deciduous trees, the difference between heartwood and sapwood was negligible. Across all climatic types, Scots pine and Caucasian spruce test samples displayed higher density, lower visual decay ratings, and lower weight loss. Visual decay rating and weight loss of common alder and European beech samples were found to be high in all climate types, but their densities were lower. The visual decay rating was found to be "0" in all impregnated samples. It was concluded that the weight losses were due to the leaching of CCB. The density values of the impregnated samples were found to be higher than those of the other test samples. Based on the results of the study, it is concluded that all wood types can be used in contact with soil for some time in a terrestrial climate. However, in other climate types, the use of deciduous trees' wood without impregnation should be avoided, especially when in contact with the soil. Field trials are of great importance to determine the service life of wooden materials to be used outdoors. Visual decay grading serves a very important role in predicting other properties of wood. The results of the study showed that different climates and different soil structures have a significant effect on the strength of wood.

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