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PROF. DR. GÖKHAN AYDIN

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Chapter 1

ANALYSIS OF VARIABLES AFFECTING THE NUMBER OF PARTICIPANTS IN STUMPAGE-BASED AUCTION SALES*

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INTRODUCTION

To ensure the sustainable management of forests, long-term planning is essential. Forest management plans are developed for this purpose, outlining the quantity and method of timber production from forests. However, these plans often do not fully account for the ongoing needs of industrial consumers of timber, as they are typically prepared without market analysis and are not continuously adapted. Therefore, it is necessary to evaluate the economic aspects of the activities carried out by state forest enterprises and decision-makers, who play a significant role in the production and marketing of forest products, and to conduct a scientific analysis of these processes.

Globally, stumpage sales are evaluated in two ways. The first involves the sale of forest sections or areas that have been designated for cutting, while the second refers to the sale of the individual trees that have been selected for felling (İlter and Ok, 2007). In Turkey, the timber production and sales process, which begins with the stamping procedure, ends in two ways: The first method involves selling the stamped forest sections to forest village development cooperatives, local workers, or villagers working in nearby forest operations, with tasks such as cutting, skidding, loading, and transportation carried out. The timber is then transported to forest depots and primarily sold to buyers via an auction method, known as “subsequent sales.”

The second method of sale involves the sale of stamped trees based on Article 30 of the Forest Law No. 6831, as amended by Law No. 2896, and decree No. 6877, in a process known as “stumpage sales.” In this case, the buyer assumes the costs of cutting, skidding, loading, and transporting the timber. After the stamping process, the remaining steps are completed by the buyer, allowing the General Directorate of Forestry (OGM) to save on these operational costs. Since 2004, the OGM has shifted its focus to stumpage sales, which they argue offer greater profitability compared to the traditional production method. Both allocated stumpage sales and auction-based stumpage sales are commonly practiced in Turkey.

In Turkey, 99% of forests are under state ownership, with their management and operation carried out by the OGM and its affiliated regional offices. The management and operation of state forests by the government have been mandated by the Forest Law No. 6831, as well as the 1961 and 1982 Constitutions (Daşdemir, 2011).

The stumpage-based auction sales practice was introduced with the implementation of Regulation No. 5038 in 1996. However, this method has not become widespread due to various factors, including concerns of forest administration regarding protection and oversight, the risk of socioeconomic conflicts among villagers, uncertainties in determining sales prices and yield percentages, ambiguity about whether production tasks will be assigned to villagers, and the exclusion of cooperatives from the application process (Kaplan, 2005).

In its current strategic plan, the OGM aims to increase the share of stumpage-based auction sales. As an alternative to traditional production and sales methods, OGM implemented stumpage-based auction sales in all regional and forest management offices in 2007 through Circular No. 6521. This practice seeks to make production and marketing activities more economical and rational, ensure standardization, and address issues caused by measurement errors. The method was expanded to mitigate the drawbacks of the traditional system, such as the prolonged processes of production, transportation, and storage, as well as the loss of quality and increased costs due to repetitive loading and unloading operations.

The supply of wood raw materials by forest enterprises is determined based on the allowable cut value, which prioritizes the sustainability of forest resources. However, natural disasters such as storms and fires can negatively affect the quality of supply. On the other hand, economic fluctuations in sectors like construction, furniture, and paper have a direct impact on demand. In this context, it is crucial for forest product producers to adapt to market conditions, develop alternative resources, and market their products efficiently (İlter and Ok, 2004).

Sağkaya (2005) argued that the three-month period between the cutting phase of wood raw materials obtained from forests and their presentation for sale leads to a depreciation of resources, causing an annual loss of up to $250 million. Additionally, he emphasized that expenditures for operations such as cutting, skidding, transportation, stacking, and sorting reach significant levels. He further stated that if there is no market demand, holding the allowable cut unharvested would not be economically viable. In this context, he suggested that stumpage-based auction sales could provide an effective solution to overcome these issues.

In auction-based stumpage sales, the price formation is influenced not only by administrative decisions but also by market conditions. To determine the sale price, the authority first establishes an estimated price (reserve price). Several factors are considered in setting this reserve price, such as the quality of the standing timber, production challenges, the distance from consumption centers, ease or difficulty in transporting the products to these centers, market conditions, and historical stumpage sale averages. The timber cost is then calculated based on these factors, which include distribution expenses, tariff fees, sales costs, actual costs, and unforeseen expenses. If necessary, adjustments to the price can be made by the forestry manager or regional director. If the reserve price is set too low, it may result in a lack of competition in the auction, leading to the sale of public property at a lower price, which constitutes a national loss. Conversely, if the reserve price is set too high, fewer buyers may participate in the auction, leading to low competition and unsold products. As a result, managers often rely on past sale averages to set a price that aligns closely with market conditions. However, price formation in the market is influenced by various factors, and there is no study in Turkey that comprehensively identifies these factors.

One of the key challenges in efficiently addressing and applying the price formation process in Turkey is the lack of scientific decision-making methods. This issue is often raised in forestry-related conferences, seminars, and discussions. The scientific data derived from this study can provide valuable guidance to decision-makers by being presented at these events and published in articles.

Forest resource managers have the power to directly influence or intervene in the price of timber, one of the primary factors affecting stumpage sales, through administrative decisions and legal regulations. In light of this, forest resource managers will be able to guide the demand for stumpage sales at a national level using different policies and regulations, based on the sensitivity values related to participants in stumpage sales, which is one of the main results of this study. Therefore, the findings of this research are significant in terms of understanding the potential economic benefits that the OGM can generate from these types of sales.

The study analyzes participants in auction-based stumpage sales of *Pinus brutia* (red pine), which are held in nearly all of the 100 Forest Management Units under 10 Forest Management Directorates within the boundaries of the İzmir Forest Regional Directorate, responsible for the management of approximately 1 million hectares of forest land in the provinces of İzmir and Manisa. All 810 sales of red pine stumpage held between 2020 and 2024 were analyzed in the study. The hypothesis that eight independent variables, namely Tree Yield Percentage (X_1), Diameter Density in Stumpage Sales (X_2), Season-Month of Stumpage Sale (X_3), Forest Class (X_4), Slope (X_5), Reserve Price (X_6), Forest Age Class (X_7), and Timber Volume to be Harvested (m^3) (X_8), significantly affect the number of participants in red pine auction-based stumpage sales, was tested using multiple regression analysis.

MATERIALS AND METHODS

The independent variables included in the model are as follows: Trial Tree Yield Percentage, which is critical for planning and evaluating forest products in stumpage-based sales, is used to estimate the yield percentage of products anticipated for each tree species in the compartments or sub-compartments subject to sale. Diameter Density in Stumpage Sales represents the volume of timber based on diameter classes for marked standing trees. The stumpage measurement records contain four diameter classes: Class I includes individuals with diameters of 8–18 cm, Class II includes those with diameters of 20–34 cm, Class III includes those with diameters of 36–50 cm, and Class IV includes individuals with diameters exceeding 52 cm. Season-Month of Stumpage Sale refers to the timing of the auctioned timber sales and is categorized into Spring, Summer, Autumn, and Winter for analysis. Management Class represents the forest type and includes categories such as Class A (young stands), Class B (middle-aged stands), Class C (mature stands), Class D (coppice forests), Class E (protection forests), Class F (forests with ecological and social functions), Class G (degraded stands), Class H (open areas), Class I (conservation forests), Class J (forests for scientific and educational purposes), Class K (energy forests), and Class L (forests with controlled use and protection). Slope indicates the gradient of the compartment or sub-compartment where the stumpage sale is conducted. Appraised Value refers to the starting bid price for the stumpage sale. Stand Age Class defines the developmental stage of the stand, ranging from Age Class A (saplings and dense young stands) to Age Class E (thick timber stands). Lastly, Harvest Volume (m^3) represents the total volume of timber subject to the stumpage sale.

In this study, multiple regression analysis was employed to assess the impact of the specified independent variables on the dependent variable. Multiple regression is a statistical technique used to explore the relationship between one dependent variable and several independent variables. This method allows for the identification and quantification of the effects of multiple factors on the dependent variable. By examining multiple factors simultaneously, it helps to clarify the underlying patterns in complex data. Specifically, it is used to assess how various influences shape a particular event or behavior (Field, 2013).

In the context of multiple linear regression, the dependent variable is represented as Y, while the independent variables are denoted as X_1, X_2, ..., X_k. The strength of the relationship between the variables is measured by the correlation coefficient (R), with values closer to 1 indicating a stronger relationship. Once the dependent and independent variables are identified, the coefficient of determination (R^2) is utilized to evaluate the proportion of variance in the dependent variable that can be explained by the independent variables. The overall significance of the regression model is tested using the F-test (Koutsoyannis, 1989).

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \varepsilon_i$$

Here, Y represents the dependent (explained) variable, and X represents the independent (explanatory) variables. The number of variables is denoted as k, and the parameter values are represented as β (j = 1, 2, ..., k).

RESULTS

As shown in Table 1, the regression model is overall significant, with $F(8, 801) = 57.088$, $p < 0.05$. The independent variables have a significant effect on explaining the number of auction participants. When comparing the explained variance (Regression SS) to the unexplained error variance (Residual SS), it can be concluded that the model has strong explanatory power.

Table 1. *ANOVA Table: Factors Affecting the Number of Participants (Slope, Season, Trial Tree Yield Percentage, Diameter Density, Stand Age Class, Timber Volume, Management Class, and Appraised Value in TRY)*

Model	Sum of Squares	df	Mean Square	F	p
Regression	4756,939	8	594,617	57.088	.000*
Residual	8343,096	801	10,416		
Total	13100,036	809			

*p<0.05

The results in Table 1, when considered alongside the regression coefficients table in Table 3, support the reliability of the model (Tabachnick & Fidell, 2013).

In Table 2, the explanatory power of the model for the dependent variable (Number of Auction Participants) is 36.3%. Furthermore, the independent variables in the model explain approximately 35.7% of the variance in the dependent variable. An adjusted R^2 value of 0.357 can be considered a reasonable level of explanatory power in the economics literature (Wooldridge, 2015; Gujarati & Porter, 2009; Stock & Watson, 2019).

Model	R	R^2	Adjusted R^2	Estimated Standard Error	Durbin-Watson
	.603	.363	.357	3.227	1.828

Table 2. *Model Summary Table: Relationship Between the Number of Participants and Slope, Season, Trial Tree Yield Percentage, Diameter Density, Stand Age Class, Timber Volume, Management Class, and Appraised Value*

As seen in Table 2, there is a moderate positive relationship between the independent variables and the dependent variable (R = 0.603). Although there is unexplained variance in the model, overall, the model has a statistically satisfactory fit. The Durbin-Watson test, with a value of 1.828, indicates that there is no autocorrelation among the error terms, which also suggests that the regression model is reliable and valid (Durbin, 1950).

As shown in Table 3 below, the constant of the model is 1.826. The t-values of all independent variables are greater than 2, and since their p-values are less than 0.05, all the variables in the model are statistically significant and have a significant effect on the dependent variable. Some independent variables affect the dependent variable positively, while others have a negative effect, indicating that the model takes various factors into account (Tabachnick & Fidell, 2013).

Table 3. *Coefficients Table: Variables Affecting the Number of Participants in the Multiple Regression Model*

Model	B	*Std. Error*	95% CI		*t*	*p*	Tolerance	VIF
			Lower Bound	*Upper Bound*				
Sabit (Constant)	1.826	1.409	-.940	4.592	1.296	.195		
Deneme Ağacı Verim Yüzdesi	.036	.012	.013	.059	3.083	.002*	.733	1.364
Dikili Satışta Çap Yoğunluğu	1.342	.199	.952	1.733	6.749	.000*	.655	1.526
Dikili Satışı Yapılan Mevsim- Ay	-.716	.043	-.800	-.633	-16.823	.000*	.952	1.050
İşletme Sınıfı	-.169	.069	-.305	-.034	-2.449	.015*	.902	1.108
Eğim	-.277	.058	-.390	-.163	-4.790	.000*	.847	1.180
Muhammen Bedel (TL)	-.015	.003	-.020	-.010	-5.866	.000*	.627	1.594
Meşçere Çağ Sınıfı	-.618	.236	-1.081	-.154	-2.616	.009*	.752	1.330
Kesilecek Emval (m^3)	2.789	.329	2.143	3.434	8.484	.000*	.921	1.086

*p<0.05

1% increase in the Trial Tree Yield Percentage, Diameter Density of Standing Trees, and Timber Volume (m^3) results in an increase in the number of participants by 0.036, 1.342, and 2.789 units, respectively. A shift in the Season-Month of Standing Timber Sales towards the winter months, a shift in the Management Class variable away from young and middle-aged stands, a shift in the Stand Age Class variable from B and C ages to D and E ages, an increase in the Slope of the land, and a 1% increase in the Appraised Value (TL) would result in a decrease in the number of participants by -0.716, -0.169, -0.618, -0.277, and -0.15 units, respectively. Tablo 3'te ayırıcı değişkenlerin tolerans değerleri 0,1'in üzerindedir. Bu durum bağımsız değişkenler arasında multikollineerlik sorunu olmadığını gösterir. Bu durumda, modeldeki bağımsız değişkenler birbirlerinden bağımsız olarak çalışmaktadır. (Tabachnick & Fidell, 2013)

Since all VIF values are below 5, there is no issue of multicollinearity in the model. The highest VIF value, 1.594, belongs to the Appraised Value variable (O'Brien, 2007). Therefore, it can be concluded that there is no significant multicollinearity problem among the independent variables. The independent variables can be reliably used in the regression model. Furthermore, there is no need to exclude any variable from the model.

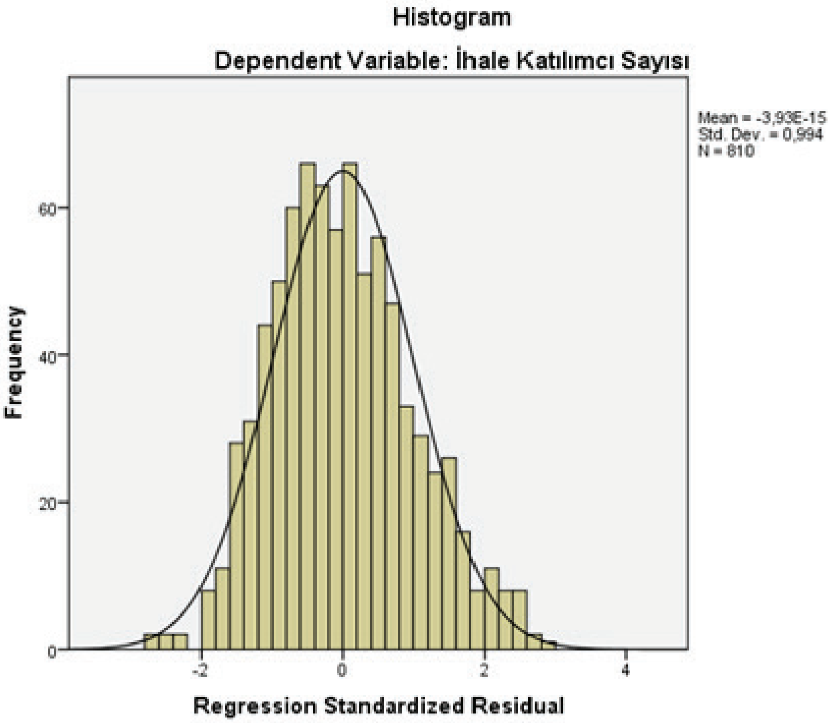
In Table 3, the coefficients (B) of the independent variables and the corresponding variables are substituted into the formula below to produce the regression formula of the model. In the formula, the coefficient (B) of each variable shows its effect on the number of Auction Participants. A positive coefficient indicates an effect in the direction of an increase, while a negative coefficient indicates an effect in the direction of a decrease.

The regression formula of the model is as follows:

Number of Auction Participants = 1.826 + 0.036 × (Tree Trial Yield Percentage) + 1.342 × (Stand Density in Stumpage Sale) - 0.716 × (Season-Month of Stumpage Sale) - 0.169 × (Management Class) - 0.277 × (Slope) + 2.789 × (Volume of Trees to be Cut) - 0.015 × (Appraised Value in TRY) - 0.618 × (Stand Age Class) + ε.

As shown in Figure 1 below, the histogram of the model reflects the increasing and decreasing data frequencies, indicating that the data distribution closely approximates a normal distribution. The curve is overlaid with a bell-shaped curve (normal distribution).

Figure 1. *Histogram: Distribution of Participant Count According to Independent Variables*



In the histogram, the mean value (Mean = -3.93E-15) is approximately zero, and the standard deviation is approximately 1 (Std. Dev. = 0.994).

CONCLUSION AND RECOMMENDATIONS

The analysis of the tree diameter density in the standing timber sales has shown that thicker trees in the auction increase the number of participants. The number of participants is also influenced by the auction dates. Specifically, winter sales tend to decrease the number of participants. Looking at the distribution of the stand age class, it is observed that participant density is concentrated in the most frequently auctioned C age class. In terms of the forest management class, it was found that the number of participants tends to be higher in the medium-aged forest stands. A higher starting price, represented by the estimated value determined by OGM, decreases the number of participants. The sloping terrain where the standing timber is located reduces the number of participants. The slope significantly impacts costs related to cutting, skidding, and transportation. An increase in the trial tree yield percentage leads to an increase in the number of participants. As the cubic meter volume of the timber increases, the number of participants also increases. All the independent variables used in the study significantly affect the number of participants, and the model constructed is statistically significant.

The findings from this study can provide strategic recommendations for decision-makers. First, it can be suggested that more mature and valuable trees should be offered for sale to attract more participants. Since winter sales negatively impact the number of participants, scheduling auctions during warmer months could increase participant density. Regarding stand age classes, it has been observed that forests in the C age class are preferred, so focusing sales on trees from this age group could be beneficial. In terms of forest management class, demand for medium-aged forest stands is higher, indicating the need for a more balanced and diverse sales strategy. Additionally, since high starting prices reduce the number of participants, setting more reasonable starting prices can help attract a broader participant base. The steepness of the terrain has been found to reduce the number of participants; thus, for sloped terrains, creating a skid and transport road network, particularly where the slope facilitates downward movement, could increase participation. Considering that an increase in the trial tree yield percentage increases the number of participants, timely and careful forest management practices and silvicultural interventions can enhance these percentages and, in turn, increase participation. Finally, since a higher cubic meter volume of timber increases the number of participants, increasing the amount of timber available for sale could lead to more bids. These recommendations aim to improve participation in timber auctions, thereby contributing to higher forest management revenues through appropriate regulations.

The results of the study are expected to significantly contribute to the R&D activities of the General Directorate of Forestry (OGM) and forestry research departments, particularly by increasing the number of participants in stumpage sales auctions in Turkey. Furthermore, it can be anticipated that the findings will be presented at various forums, seminars, meetings, conferences, and symposiums addressing issues in the forestry sector, and will be discussed in various publications, thereby informing a wide range of interest groups. It is expected that the number of participants in the auctions will have an impact on the economic revenue that the General Directorate of Forestry generates from stumpage sales.

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REFERENCES

Daşdemir, İ. (2011). Dikili ağaç satışlarının uygulaması üzerine değerlendirmeler. *Bartın Orman Fakültesi Dergisi, 13*, 71-79.

Durbin, J. (1950). Test for serial correlation in least squares regression analysis. *Biometrika, 37*(3/4), 179-188. https://doi.org/10.1093/biomet/37.3-4.179

Field, A. (2013). *Discovering statistics using SPSS* (4th ed., p. 190). SAGE Publications.

Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed., pp. 220-223). McGraw-Hill Education.

İlter, E., & Ok, K. (2004). *Ormancılık ve orman endüstrisinde pazarlama ilkeleri ve yönetimi (örnek olaylarla)*. İstanbul.

İlter, E., & Ok, K. (2007). Forestry and Forest Industry Marketing Principles and Management ISBN: 978-975-96967-4-0, 2007.

Kaplan, E. (2005). Orman ürünlerinin değerlendirilmesinde dikili ağaç satışı. 1. *Çevre ve Ormancılık Şurası*, Cilt 3, Antalya.

Koutsoyannis, A. (1989). *Ekonometri kuramı: Ekonometri yöntemlerinin tanıtımına giriş ve teori*. Ankara.

O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity, 41*(5), 673-690. https://doi.org/10.1007/s11135-006-9018-6

Sağkaya, A. (2005). *Koltuk savaşları: Bürokrat – iş adamı – siyasetçi üçgeni* (pp. 131-133). Art Ofset.

Stock, J. H., & Watson, M. W. (2019). *Introduction to econometrics* (4th ed., pp. 204-206). Pearson Education.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed., pp. 50-55). Pearson Education.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed., pp. 101-105). Pearson Education.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed., pp. 295-300). Pearson Education.

Wooldridge, J. M. (2015). *Introductory econometrics: A modern approach* (5th ed., pp. 123-125). Cengage Learning.

Chapter 2

EFFECTS OF AFFORESTATION ACTIVITIES IN FORESTRY ON CARBON ECONOMY

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1. Introduction

Global climate change is one of the most significant problems that can deteriorate the ecological balance of natural ecosystems and cause excessive atmospheric carbon dioxide accumulation. This situation has brought about the need to focus on strategies to increase the carbon sequestration capacity of terrestrial ecosystems and develop solutions. The excess carbon accumulated in the atmosphere can be reduced by restricting human activities that cause excess carbon emissions, or by carrying out activities to store excess carbon.

Approximately 53% of the world's carbon is stored in soil and terrestrial ecosystems, whereas the remainder is stored in oceans (Abdalmoula, 2017). Friedlingstein et al. (2021) emphasized that carbon pools in terrestrial ecosystems can compensate for approximately 30% of anthropogenic carbon dioxide emissions in the atmosphere. Consequently, enhancing carbon pools in terrestrial ecosystems is a principal strategy by which nature can facilitate the removal of excess atmospheric carbon. (Huang et al., 2022). The terrestrial ecosystem with the highest potential in the carbon economy is forested because it can store a large amount of carbon dioxide in its vegetative mass and soil (Zhang et al., 2019) and because it consumes a large amount of carbon dioxide by photosynthesis. Forests account for ⅔ of organic carbon in terrestrial ecosystems. The most effective method for enhancing carbon storage in forests is to expand forest area through afforestation.

1.1. Carbon Storage in Forests

Approximately 31% of the total land area in the world is forest area covering 4.06 billion ha (FAO, 2020). Forests are severely damaged by abiotic factors, such as unplanned land use, improper interventions, insect or disease damage, fire, storms, or avalanches (FAO, 2018). These interventions in forest areas have consequences, such as habitat degradation, erosion, reduction of clean water, and carbon sequestration.

Trees play a significant role in the carbon economy as they can store carbon dioxide from the atmosphere through photosynthesis. This occurred in both the trees and forest soil. Forests have the potential to sequester approximately 80% of aboveground biomass carbon and approximately 40% of belowground carbon (He et al., 2017; Cai et al., 2022). Therefore, it can be reasonably deduced that the expansion of forested areas, coupled with the implementation of appropriate forestry interventions, will mitigate climate change and contribute to a carbon economy. The main carbon sink areas in forests are categorized into six groups (Karataş et al., 2017) (Figure 1).

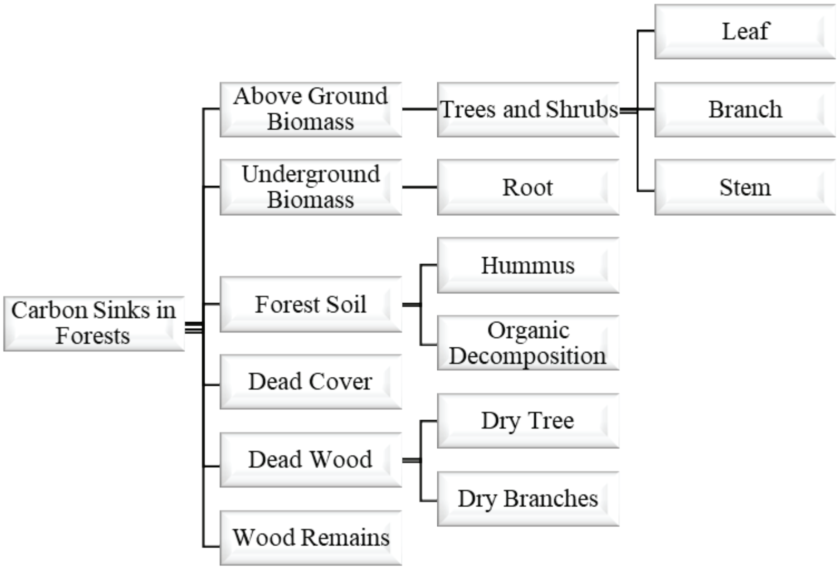

Figure 1. Main carbon sinks/stores in forests

Above Ground Biomass

Trees convert carbon dioxide from the atmosphere through the stomata on their leaves into glucose, a form of carbon, using the water and sunlight taken from their roots. The utilization of glucose in the growth and development of plants and the storage of atmospheric carbon in the plant body has been observed. Putney et al. (2023) stated that about half of the dry mass of wood consists of pure carbon. However, there is still no complete standardization of the number of carbon trees captured on a species-specific basis. First, it suggests that fast-growing trees sequester more carbon than other trees. Conversely, slow-growing trees are thought to live much longer than fast-growing species, and larger trunks enable them to sequester carbon longer (URL-1, 2024). These two perspectives lead to a contradiction regarding which species should be used for afforestation.

Underground Biomass

The root mass of a tree is related to the characteristics of the plant (e.g., species and age) and soil (e.g., depth, moisture, nutrients, and texture) (Cairns et al., 1997). In addition, the amount of carbon stored according to tree species differs depending on the root system. Tolunay and Çömez (2008) emphasized that trees with shallow root systems sequester less carbon than those with deep root systems. In yellow pine forests in Artvin and Ardahan, carbon storage in the roots was realized in fine and capillary roots in the 2nd age class, and coarse roots in the 5th age class (Tüfekçioğlu and Küçük, 2010).

Forest Soil

In forests, the organic carbon storage in the subsoil is approximately three times higher than that above the soil (Sarıyıldız et al., 2020). Carbon accumulation in the soil usually occurs when fallen leaves and fine roots decompose and mix (Kocabıyık et al., 2023). The amount of carbon stored in forest soils varies according to stand age (Deng et al., 2016; Mao et al., 2010), closure and density, tree species and mixture ratio, bedrock, and soil properties (Tolunay and Çömez, 2008).

Land afforestation can affect soil, either positively or negatively. Soil organic matter can be increased by afforestation in areas with no vegetation cover. Nevertheless, the practice of shaving and reforestation of forest ecosystems may result in a reduction of soil organic matter (Tolunay and Çömez, 2008). The amount of organic carbon stored in the soil differs according to land use. Many studies have shown that the amount of carbon stored in the soils of forest and pasture areas is higher than that in agricultural and bare land (Sarıyıldız et al., 2017; Korkanç et al., 2018). In addition, the amount of carbon sequestered in the soil varies depending on the changes in land use. It has been determined that the conversion of a natural ecosystem into agricultural land causes a decrease of approximately 50-60% in the organic carbon content of the soil (Tolunay and Çömez, 2007).

Numerous studies have been conducted on carbon storage in natural forests with similar ecological conditions and plantation forests obtained through afforestation. Işık and Göl (2021) found that soil organic carbon storage capacity in natural and plantation Anatolian larch forests was similar. This situation has shown that successful afforestation activities can contribute as much to soil carbon storage as natural forests. In addition, Kocabıyık et al. (2023) conducted a study on larch and coastal pine afforestation sites in areas with similar local and ecological conditions and found that soil carbon storage in larch afforestation sites was better than that of red pine.

Dead Cover and Dead Wood

Deadwood residues left in the forest after harvesting (Putney et al., 2023), standing dry trees, and dry branches in the forest can continue to store carbon for a long time. This contributes to a significant increase in the ability of forests to store carbon.

1.2. Relationship between Afforestation Activities and Carbon Storage

Afforestation is the process of growing trees on vacant land or in previously forested areas that have become treeless for various reasons such as fires, storms, or forestry strategies. With afforestation activities implemented worldwide for 30 years, there has been an increase of approximately 1.05 × 108 hectares in the cultivated forest area globally (Hong, 2020). In Turkey, forest area has increased by x% over the last 10 years with afforestation.

Afforestation and forestation provide many ecological and economic benefits. Carefully planned and implemented afforestation activities have ecological benefits, such as preventing soil erosion and landslides, stopping land degradation, regulating microclimate structures, providing biodiversity, and contributing to the water balance (Conant et al., 2017; Mohawesh et al., 2015). The main economic benefits are renewable resources, which contribute to the national economy with sustainable wood production and provide employment opportunities for workers in these areas. In addition, afforestation activities have a strong capacity to sequester carbon dioxide in the atmosphere and are effective methods for mitigating climate change (Zhao et al., 2016; Bastin et al., 2017; Cai et al., 2023). This situation has made afforestation activities for the forestation of vacant areas or the rejuvenation of forests a priority for climate change mitigation and carbon economy planning.

An increase in the carbon sequestration rate of afforestation activities can only be realized if carbon sequestration is synchronized among the vegetation, soil, and ecosystems. With increasing biomass in afforested forest areas, there is an increase in both the amount of stored carbon and the terrestrial carbon pool (Yao et al., 2018). In addition, the prevention of erosion and landslides by afforestation contributes to carbon sequestration in the soil by protecting the forest soil, where most carbon sequestration is realized. Wen and He (2016) found that forest carbon storage differs between vegetation and soil and is affected differently by climatic parameters such as precipitation and temperature. In addition, it has been stated that the removal of the main elements of organic matter such as roots, branches, and dead cover in the site preparation activities applied during afforestation activities conducted by planting fast-growing species leads to a decrease in carbon stocks (Li et al., 2015). Therefore, the soil characteristics of the area to be afforested should be planned by considering the type of tree used, climate, and ecosystem characteristics. Soils used for agricultural purposes retain less organic carbon than their capacity, whereas the carbon stock in the soil increases significantly when these areas are afforested (Lal, 2005).

Optimizing afforestation activities in forestry by considering tree species, land structure, and climatic characteristics and creating new carbon sink areas contributes directly and indirectly to combating climate change and reducing carbon emissions by maximizing the carbon sequestration potential of the forest in the future. In this chapter, the main stages of afforestation activities applied in forestry are discussed, the contributions of afforestation activities to the carbon economy are evaluated, and their long-term effects are emphasized.

2. Afforestation Activities in Forestry

Afforestation activities are conducted in five stages to ensure the long-term success of the afforestation process (Figure 2).

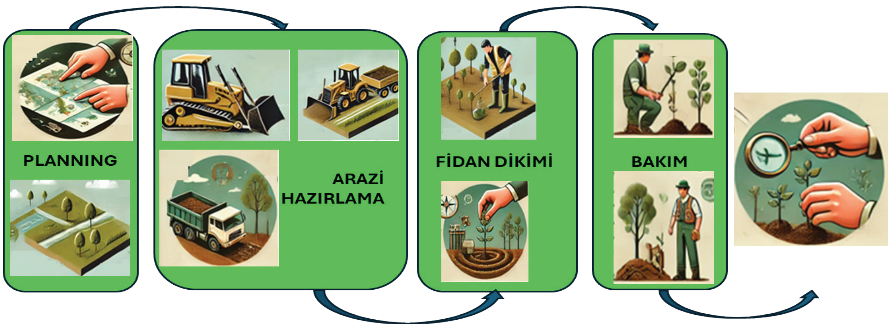

Figure 2. Stages of afforestation activities

As shown in Figure 2, afforestation activities begin with planning, which involves the selection of the most appropriate tree species and methods to be used, depending on climate, soil conditions, and potential carbon sequestration rates. This is followed by site preparation, which involves clearing the vegetation on the land and preparing the soil for planting. The next stage involves planting seedlings on prepared land. This is followed by maintenance to maintain seedling health, ensure optimum growth, and maximize carbon storage potential. The final stage includes monitoring and evaluation activities to determine the extent to which the objective of afforestation has been achieved because of all interventions.

2.1. Planning

The planning stage for afforestation (carbon storage, erosion control, etc.) includes assessing the suitability of the area for afforestation, determining the appropriate tree species for the local climate and soil conditions, making the implementation plan, and establishing the budget (Figure 3). In addition, to ensure the success of afforestation and minimize negative ecological impacts, local ecosystem impacts, and the long-term sustainability of the afforested area should also be considered.

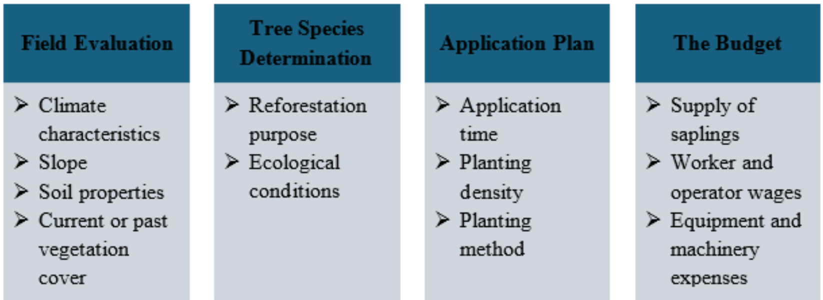

Figure 3. Planning stages of afforestation activities

Reducing human-induced greenhouse gas emissions and implementing strategies and policies for the protection and development of systems that will effectively maintain the carbon dioxide-oxygen cycle in land and marine ecosystems, especially forest ecosystems, are seen as the most important elements in combating climate change (Hoeberg et al. 2016; Şevik et al. 2018; Duyar, 2018). Most hollow closed forest areas have the potential to sustain carbon accumulation and biodiversity, like productive forests (Wheeler et al., 2016). As of 2023, there will be approximately 9,6 million ha of closed forest areas in Türkiye. These potential areas have become productive forest areas through afforestation activities. Therefore, strategies should be determined and implemented to create closed forested areas with gaps in the carbon economy. In Turkey, afforestation studies and projects were conducted on 928,503 ha, and afforestation on 152,520 ha between 2018-2022. Special afforestation was established on 22,826 ha during the same period (URL-3, 2024). In the context of a carbon economy, careful planning is essential to ensure that the carbon sequestration potential of the area to be afforested is at its highest level. This stage involves calculating the amount of carbon dioxide that afforested land is expected to sequester over time using models based on tree species, planting density, and land characteristics.

2.2. Land Preparation

Land preparation aims to create the necessary resources to reduce soil degradation and support healthy thriving forests in afforested areas. This stage generally involves activities, such as the removal of invasive species, soil cultivation, and terracing on slopes (Figure 4). However, soil improvement might also be required to create the conditions required by the selected tree species.

Figure 4. Land preparation activities in afforestation

Soil cultivation includes interventions with human or machine power to loosen and aerate the soil. In the land preparation phase, interventions such as terracing can be conducted to reduce the erosion risk when the slope is high.

Failure to prepare land may weaken young trees and make them difficult to grow, thus reducing their carbon sequestration potential. Soil plowing can generally increase soil organic carbon stocks by favoring faster growth of planted seedlings and the development of both above- and below-ground vegetative mass. However, plowing soils rich in organic matter may cause more decomposition and transport of organic matter by increasing soil air capacity and leachate (Tolunay and Çömez, 2008).

2.3. Sapling Planting

Planting is the main stage at which afforestation occurs. This involves planting selected tree species according to predetermined application patterns to maximize their growth potential. One of the important aspects here is to be carried out at the most appropriate time for the characteristics of the seedlings. It is also important to ensure that seedlings are planted at intervals determined by considering that the seedlings have sufficient space and nutrient supply. Seedling planting consists of the sub-stages of opening the pits (Figure 5a), planting the seedlings, and providing life water (Figure 5b). Therefore, it is important to plant seedlings correctly without damaging their roots and at an appropriate depth.

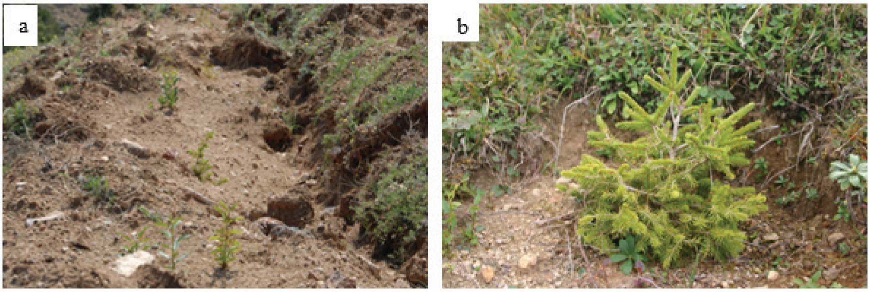

Figure 5. Sapling planting activities

2.4. Maintenance Activities

This includes regular activities to ensure the survival and healthy growth of the seedlings after planting. Maintenance activities include weeding, watering, thinning, pruning, pest control, and pest protection. Thinning involves the removal of weak seedlings after a certain period of growth to reduce competition for nutrients, water, and light (Figure 6a). Weeding involves the removal of weeds that grow between or under seedlings, making it difficult for seedlings to access nutrient sources (Figure 6b). Irrigation systems should be installed during the planning phase of afforestation activities, especially in arid regions, to ensure the development of saplings and the growth of healthy individuals. During sapling growth, irrigation should be carried out using appropriate techniques according to terrain and regional conditions (Figure 6c). In addition, precautions to be taken to prevent saplings from being exposed to pests, such as insects, fungi, and wild animals, and interventions in case of exposure, are also included in the group of maintenance activities.

Figure 6. Maintenance activities in afforestation areas

Ensuring a balanced development of the forest ecosystem through the healthy growth of saplings contributes not only to carbon sequestration but also to the maintenance of biodiversity and the health of surrounding ecosystems.

2.5. Monitoring and Evaluation

Regular monitoring and evaluation are necessary to ensure the long-term success of afforestation projects. Monitoring and evaluation are continuous processes from the beginning to the end of an afforestation activity. Monitoring and evaluation activities generally include growth monitoring, impact assessments, and taking measures. Growth monitoring includes the observation of growth rates, health status, and adaptation processes of saplings. Impact Assessment is the determination of the success of afforestation according to the purpose of afforestation and the analysis of its environmental, economic, and social impacts. According to the results of these evaluations, maintenance and protection strategies are updated in the case of deviations from the desired target or situations that adversely affect the process. The necessary measures are determined and implemented according to the new strategies, and the goal is achieved.

This involves monitoring the growth of trees, assessing their health, measuring carbon storage, and making interventions where necessary. Carbon credits are often generated based on verified increases in carbon stocks over time, making monitoring essential for participation in the carbon markets.

3. The Impact of Afforestation on The Carbon Economy

Carbon certificates can be obtained through afforestation and reforestation activities, which are among the most important means of combating global warming and soil erosion, as well as renewable energy and energy-saving projects. Carbon certificates are those given to projects that reduce carbon emissions or sequester carbon from the atmosphere within the scope of the carbon trade developed to combat climate change. The 'carbon certificate' obtained with each ton of carbon dioxide equivalent sequestered in afforestation sites is sold in international Voluntary Carbon Markets at the current market value.

To obtain carbon credits through afforestation projects, projects must be carried out in accordance with both the requirements of international standards organizations and the forest legislation applicable to Turkey. In this context, it may be possible to evaluate some of the conditions that will be valid for Türkiye under the following headings.

3.1. Carbon Credits and Market Participation

Afforestation projects should include efforts to reduce greenhouse gas emissions and increase carbon sequestration. These activities should include only those that will be implemented in the afforestation projects. In other words, if the activities within the scope of the project are not realized, such a practice cannot be implemented; the fact that the practices in the project include practices that will provide additional benefits to carbon sequestration should be in question. An afforestation program that can be conducted without a project will not be considered a project-mitigation activity.

For afforestation to be conducted in an area and a product obtained from it, land that has not been forested for the past 50 years must be subject to afforestation (UNFCCC CDM Methodology Guide, 2016). Otherwise, this project cannot qualify for carbon credits from afforestation (Pamukçu Albers et al., 2018). However, if it can be proven that the products obtained from the plantation areas and the natural forests are reduced, or if it can be proved that the carbon loss in the cutting of the plantation forest to obtain the same amount of product is less than in the natural forest, it may be entitled to carbon credits. In this case, there may be an opportunity not under afforestation carbon but under carbon conditions from Deforestation or Improved Forest Management. As a result of cadastral surveys, open areas that remain within forest boundaries and are labeled (OT) are not eligible for carbon credits. This is because forest soil areas are affected by their characteristics. Therefore, private afforestation in forestland areas is not eligible for carbon credit (Ülgen and Güneş 2016).

Private afforestation conducted with the allocation of treasury lands that do not have to be afforested by legislation may be eligible for carbon credit. However, forest management plans are prepared for afforestation in areas larger than 3 ha, and planted trees can be harvested when the management period expires (Albers et al., 2018). The fact that harvested trees will not release the atmospheric carbon they sequester into the atmosphere for 30 or 60 years is an important point for standard organizations. The production of firewood means that trees release carbon, which they sequester back into the atmosphere during growth. Therefore, the carbon credits obtained thus far have been invalid (Ülgen and Güneş, 2016). For afforestation, the use of natural species growing in a region or species suitable for the environmental conditions should be supported. The certification process, defined as the project period, is a maximum of 50 years after the implementation of this protocol. In addition, if the developer of the project is not the owner of the land, she should have the right to use it at least for the duration of the project (Pamukçu Albers et al., 2018).

The carbon market is a mechanism that provides financial support for projects that would not otherwise be realized but are undertaken for the sole purpose of sequestering carbon from the atmosphere. Except in exceptional cases, carbon credits cannot be claimed for previously planted afforested areas. To receive carbon credits, organizations with afforestation as one of their founding objectives must prove that afforestation cannot be carried out without carbon finance. Otherwise, support is not given to organizations obliged to carry out afforestation by regulation, considering that they do not make an additional effort to sequester extra carbon from the atmosphere. In addition, in cases where an organization increases its afforestation rates from one thousand hectares to one thousand five hundred hectares per year because of the return provided by carbon financing, it may be entitled to apply for carbon credits for an area equal to the difference. Thus, areas that are not afforested under normal conditions are affected by the carbon market and financing. If land that is foreseen to be afforested as per legislation cannot be afforested for social or cultural reasons and if these barriers can be overcome using carbon finance, that area may be eligible to apply for carbon certification. However, it must be proven that the area cannot be afforested in any other way (Ülgen and Güneş, 2016).

3.2. Local Economic Benefits

Afforestation refers not only to afforestation in terms of carbon credit. Afforestation can be carried out with forest tree species and multiple beneficial afforestation, including agricultural tree species. This afforestation activity can be carried out on private properties or agricultural land allocated by the Ministry of Food, Agriculture, and Livestock. Thus, by sequestering carbon in multi-benefit afforestation, both economic inputs are provided to the local people who work in these areas and profits are obtained from the sale of fruits. The number of buyers preferring credit from multi-benefit projects in the carbon market is increasing. Carbon credits from such projects are traded at higher prices in the market (Ülgen and Güneş, 2016).

References

Abdalmoula, M.M. 2017. Carbon accumulation in the forest floor and soil under maritime pine (*Pinus pinaster* Ait.) and stone pine (*Pinus pinea* L.) plantations at the Istanbul-Durusu Dune. PhD Thesis, Istanbul University Institute of Graduate Studies in Science and Engineering, 148p., Istanbul.

Bastin, J.F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C.M., Crowther, T.W. 2019. The global tree restoration potential. Science 365(6448): 76-79. Doi: 10.1126/science.aax0848

Cai, W., He, N., Li, M., Xu, L., Wang, L., Zhu, J., et al. 2022. Carbon sequestration of Chinese forests from 2010 to 2060: spatiotemporal dynamics and regulatory strategies. Sci. Bull. 67: 836–843. Doi: 10.1016/j.scib.2021.12.012.

Cai, W., He, N., Xu, L., Li, M., Wen, D., Liu, S., Sun, O.J. 2023. Spatial-temporal variation of the carbon sequestration rate of afforestation in China: Implications for carbon trade and planning. Science of The Total Environment 884: 163792.

Cairns, M., Brown, S., Hemler, E., Baumgardner, G. 1997. Root biomass allocation in the world's upland forests. Oecologia 111: 1-11.

Conant, R.T., Cerri, C.E.P., Osborne, B.B., Paustian, K. 2017. Grassland management impacts on soil carbon stocks: a new synthesis. Ecol. Appl. 27: 662–668. doi: 10.1002/eap.1473

Deng, L., Zhu, G., Tang, Z., Shangguan, Z. 2016. Global patterns of the effects of land-use changes on soil carbon stocks. Global Ecol. Conserv. 5: 127–138. doi: 10.1016/j.gecco.2015.12.004

Duyar, A. 2018. A projection about the contribution of rehabilitation studies on forest assets and carbon sequestration in the forest of Turkey. Journal of Bartin Faculty of Forestry 20(2): 373-381. Doi: 10.24011/barofd.426501.

Friedlingstein, P., Jones, M.W., O'Sullivan, M., Andrew, R.M., Bakker, D.C.E., Hauck, J., et al. 2021. Global carbon budget 2021. Earth Syst. Sci. Data: 1-191. Doi: 10.5194/ essd-2021-386.

He, N., Wen, D., Zhu, J., Tang, X., Xu, L., Zhang, L., et al. 2017. Vegetation carbon sequestration in Chinese forests from 2010 to 2050. Glob. Chang. Biol. 23: 1575–1584. Doi: 10.1111/gcb.13479.

Hoberg, G., St-Laurent, G.P., Schittecatte, G., Dymond, C.C. 2016. Forest carbon mitigation policy: A policy gap analysis for British Columbia. Forest Policy and Economics 69: 73-82.

Hong, S., Yin, G., Piao, S., Dybzinski, R., Cong, N., Li, X., Wang, K., Penuelas, J., Zeng, H., Chen, A. 2020. Divergent responses of soil organic carbon to afforestation. Nat Sustain 3: 694-700. Doi: 10.1038/s41893-020-0557-

Huang, Y., Sun, W., Qin, Z., Zhang, W., Yu, Y., Li, T., et al. 2022. The role of China's terrestrial carbon sequestration 2010–2060 in offsetting energy-related CO2 emissions. Natl. Sci. Rev. 9, nwac057. Doi: 10.1093/nsr/nwac057

Işık, E., Göl, C. 2021. Assessment of some soil properties and organic carbon and total nitrogen storage capacities of natural and plantation black pine forests in semi-arid regions. Turkish Journal of Forestry 22(3):202210.

Karataş, R., Çömez, A., Güner, Ş.T. 2017. Determination of carbon stocks in cedar (Cedrus libani A. Rich.) afforestation areas. Journal of Forestry Research 4(2): 107-120. Doi: 10.17568/ogmoad.338029

Kocabıyık, O., Güner, Ş.T., Çömez, A. 2023. Comparison of carbon sequestration and soil/litter characteristics in black pine and maritime pine afforestation areas in the Western Black Sea Region. Turkish Journal of Forestry 24(3): 299-308.

Korkanç, S.Y., Şahin, H., Özden, A.O., Özkurt, B. 2018. The effects of land use conversion on soil organic carbon and selected properties of soils: A case of Nigde province. Turkish Journal of Forestry 19(4): 362-367. Doi: 10.18182/tjf.436132

Lal, R. 2005. Forest soils and carbon sequestration. Forest Ecology and Management, 220: 242-258. Doi: 10.1016/ j.foreco.2005.08.015

Li, X., Ye, D., Liang, H., Zhu, H., Qin, L., Zhu, Y., Wen, Y. 2015. Effects of successive rotation regimes on carbon stocks in eucalyptus plantations in subtropical China measured over a full rotation. Plos-One 10(7).

Mao, R., Zeng, D., Hu, Y., Li, L., Yang, D. 2010. Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in northeast China. Plant Soil 332: 277–287. Doi: 10.1007/s11104-010-0292-7

Mohawesh, Y., Taimeh, A., Ziadat, F. 2015. Effects of land use changes and soil conservation intervention on soil properties as indicators for land degradation under a mediterranean climate. Solid Earth 6: 857–868. Doi: 10.5194/se-6-857-2015

Pamukçu Albers, P., Lise, Y., Özdemir, E. 2018. Forest carbon standard implementation project in combating climate change: national afforestation carbon standard proposal. Nature Conservation Centre and General Directorate of Forestry, Ankara.

Putney, J.D., Kline, N., Fitzgerald, S., Grand, L., Schnpf, C., Latta, G., Shult, P., Rizza, J. 2023. Introduction to Forest Carbon, Offsets and Markets. Pacific Northwest Extension (PNW) Publishing 775: 1-17.

Sarıyıldız, T., Savacı, G., Maral, Z. 2017. Effect of different land uses (mature and young fir stands- pasture and agriculture sites) on soil organic carbon and total nitrogen stock capacity in Kastamonu Region. Kastamonu University Journal of Forestry Faculty, 17(1): 132-142. Doi: 10.17475/kastorman.296912

Sarıyıldız, T., Parlak, S., Tanı, M. 2020. Investigation of the conversion of Bursa Karacabey flood plain forests to poplar and stone pine plantations on soil organic carbon and nitrogen stocks. Tree and Forest 1(1): 28 35.

Şevik, H., Çetin, M., Güney, K., Belkayalı, N. 2018. The Effect of some ındoor ornamental plants on the CO2 level during the Day. Pol. J. Environ. Stud. 27(2): 839-844. Doi: 10.15244/pjoes/76243

Tolunay, D., Çömez, A. 2008. Carbon storage in forest soils and the situation in Turkey. Proceeding of Forests in the Solution of Global Climate Change and Water Problems, 13-14 December, Istanbul, 97-108.

Tüfekçioğlu, A., Küçük, M. 2010. Variation of root mass, root production and root carbon storage in pure Scots pine stands according to age classes. Proceeding of III. National Black Sea Forestry Congress, 20-22 May, Volume: III: 1030-1037

URL-1, 2024. Living in a carbon world. https://serc.carleton.edu/eslabs/carbon/1a.html. 12/12/2024.

URL-2, 2024. https://www.carboncommunity.org/carbon-community-updates/trees-and-carbon. 17/11/2024.

URL-3, 2024. https://www.ogm.gov.tr/tr/e-kutuphane-sitesi/FaaliyetRaporu/Orman%20Genel%20M%C3%BCd%C3%BCrl%C3%BC%C4%9F%C3%BC%202022%20Y%C4%B1l%C4%B1%20Faaliyet%20Raporu.pdf. 10/10/2024.

Ülgen, H., Güneş, Y. 2016. Afforestation Carbon. Nature Conservation Centre, 73p., Ankara.

Wen, D., He, N.P. 2016. Forest carbon storage along the north-south transect of eastern China: spatial patterns, allocation, and influencing factors. Ecol. Indic. 61, 960–967. Doi: 10.1016/j.ecolind.2015.10.054.

Wheeler, C. E., Omeja, P. A., Chapman, C. A., Glipin, M., Tumwesigye, C., Lewis, S. L. 2016. Carbon sequestration and biodiversity following 18 years of active tropical forest restoration. Forest Ecology and Management, 373: 44-55.

Yao, Y., Piao, S., Wang, T. 2018. Future biomass carbon sequestration capacity of Chinese forests. Sci. Bull. 63: 1108–1117.

Zhang, X., Han, H., Shi, Z., Yang, X. 2019. Biomass accumulation and carbon sequestration in an age-sequence of Mongolian pine plantations in Horqin sandy land, China. Forests 10(2): 197. Doi: 10.3390/f10020197.

Zhang, D., Zuo, X., Zang, C. 2021. Assessment of future potential carbon sequestration and water consumption in the construction area of the Three-North Shelterbelt Programme in China. Agric. For. Meteorol. 303, 108377. Doi: 10.1016/j.agrformet. 2021.108377.

Zhao, W., Hu, Z., Yang, H., Zhang, L., Guo, Q., Wu, Z., et al. 2016. Carbon density characteristics of sparse *Ulmus pumila* forest and *Populus simonii* plantation in onqin daga sandy land and their relationships with stand age. Chin. J. Plant Ecol. 40: 318–326.

Chapter 3

CHEMICAL COMPOSITION AND FIBER PROPERTIES OF EUROPEAN BLACK PINE: A LITERATURE REVIEW

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INTRODUCTION

Pinus nigra (Arnold), commonly known as European black pine, is a fast growing conifer. It is among the oldest European pine species, originating from a group that dates back to the Cretaceous period, approximately 100 million years ago (Enescu et al. 2016). European black pine covers about 4 million hectares, stretching from western North Africa through southern Europe to Asia Minor (Isajev et al. 2004). It is also found on the islands of Cyprus, Sicily, and Corsica and has been planted for pulpwood production in Australia and New Zealand (Ilvessalo-Pfäffli et al. 1995). Outside of Europe, it has also been introduced to the United States, where it is commonly known as Austrian pine (Enescu et al. 2016). Its widest global distribution is in Türkiye (altitudes of 400-2100 m), where it covers approximately 2.8 million hectares (OGM, 2022). This percentage reflects approximately 12% of the country's forested lands.

European black pine is an evergreen conifer that typically grows up to 30 meters tall, though it can occasionally reach 40–50 meters. It usually has a straight trunk, and its bark, which ranges from light gray to dark gray-brown or black, becomes deeply furrowed with age. The crown is broadly conical in young trees but develops a distinctive umbrella shape in older trees, particularly in shallow, rocky soils (Isajev et al. 2004; Enescu et al. 2016).

European black pine thrives primarily in mountainous areas and exhibits high adaptability to diverse soils, climates, and environmental conditions, including resistance to drought, wind, and pollution (EUFORGEN, 2024). It is also present on the islands of Corsica and Sicily. Due to its extensive, though fragmented, range and significant genetic and phenotypic variability, it is considered a collective species (Rubio-Moraga et al. 2012). European black pine consists of six subspecies: *Pinus nigra* ssp. *pallasiana* from Türkiye and Crimea, *Pinus nigra* ssp. *dalmatica* from the Balkans, *Pinus nigra* ssp. salzmannii from France and Spain, *Pinus nigra* ssp. *laricio* from Corsica, Sicily, and Calabria, *Pinus nigra* ssp. *nigra* from the Alps, and *Pinus nigra* ssp. *mauretanica* from North Africa (Afzal-Rafii and Dodd, 2007).

European black pine is an economically important native conifer in southern and central Europe. The species is highly adaptable to various ecological conditions. These traits have made it a key species for reforestation programs in Europe since the 19th century (Isajev et al. 2004). Despite its relatively limited native range, the widespread European distribution of black pine spans several regions prone to high erosion rates, such as the European mountain systems (Enescu et al. 2016).

European black pine is a commercially significant species in Europe. Its timber is durable, resin-rich, and easy to process, making it ideal for interior flooring, general construction, and furniture manufacturing. In addition, it has historically been widely used in naval construction (Enescu et al. 2016). The species is highly adaptable, making it appropriate for planting in a variety of situations (Isajev et al., 2004). Due to its resilience to pollution and soil erosion, it is widely used as an ornamental tree in parks, large gardens, and urban or industrial areas. It is also utilized as a windbreak and for preventing soil erosion and landslides in reforestation programs (EUFORGEN, 2024).

Figure 1. The distribution area of European black pine (EUFORGEN, 2024).

European black pine is one of the most economically and ecologically important tree species in southern and central Europe. Its wood is widely used in construction (such as timber framing, roof trusses, flooring, and plywood), as well as in pulp and paper production and furniture manufacturing. To fully harness its potential across various applications, a thorough understanding of its chemical composition and fiber properties is crucial. This paper provides a comprehensive review of European black pine wood, focusing on the composition of cellulose, hemicellulose, lignin, extractives, and ash. Additionally, it examines the morphological properties of its fibers and their impact on the wood's suitability for a range of industrial processes.

CHEMICAL COMPOSITION OF EUROPEAN BLACK PINE WOOD

The chemical composition of European black pine wood is characteristic of softwoods, although it can vary slightly based on factors such as growth conditions, age, and tree location. Understanding its chemical structure is essential for optimizing its use in applications like pulp and paper production, bioenergy, and other industrial processes. European black pine wood is mainly composed of cellulose, hemicellulose, lignin, extractives, and ash. Each of these components influences the wood's properties and its response to different processing conditions. The chemical composition of European black pine is detailed in Table 1.

Table 1. Chemical composition of European pine wood from various regions.

Geographical Region	**H (%)**	**α-C (%)**	**L (%)**	**HWS (%)**	**CWS (%)**	**1% NaOH (%)**	**E (%)**	**A (%)**	**Reference**
New Zealand (Site No. 12, HW)	-	-	-	-	-	-	16.10[4]	-	Cown (1974)
New Zealand (Site No. 12, SW)	-	-	-	-	-	-	4.60[4]	-	Cown (1974)
-	-	49.49	27.23					0.17	Fengel and Wegener (1989)
Türkiye	72.15	57.91*	28.94	4.71	-	12.16	6.07[2]	-	Usta (1993)
Kütahya/Türkiye	85.09	-	24.67	-	-	-	4.47[3]	-	Uçar and Fengel (1995)
Kütahya/Türkiye	84.66	-	23.08	-	-	-	4.73[3]	-	Uçar and Fengel (1995)
Türkiye	69.25	-	38.85	6.52	-	18.28	16.16[2]	0.59	Erten and İlter (1995)
Türkiye	-	-	-	4.18	-	15.78	-	-	Balaban and Uçar (2001)
Isparta/Türkiye	-	-	27.01	-	-	-	5.95[2]	-	Tanrıverdi (2004)
Black Sea/ Türkiye	72.34	43.55	26.40	3.17	2.02	13.00	3.45[2]	0.18	Ateş (2004)
Bartın/Türkiye	65.70	45.60*	25.70	2.90	4.60	15.10	-	-	Alkan (2004)
Türkiye (SW)	-	47.60	28.20	3.20	2.00	10.80	4.90[2]	0.30	Hafızoğlu and Usta (2005)
Türkiye (HW)	-	46.80	27.90	4.70	3.00	12.20	6.10[2]	0.40	Hafızoğlu and Usta (2005)
Bartın/Türkiye (NW)	71.53	50.41	26.74	4.18	2.11	12.76	3.16[1]	0.19	Sarıusta (2007)
Bartın/Türkiye (CW)	69.84	46.45	31.80	4.48	2.40	13.05	3.52[1]	0.22	Sarıusta (2007)
Kütahya/Türkiye (HW)	-	-	-	3.43	2.97	12.96	8.65[1]	-	Hafızoğlu and Özalp (2007)
Kütahya/Türkiye (SW)	-	-	-	3.10	2.72	12.56	5.47[1]	-	Hafızoğlu and Özalp (2007)
Düzce/Türkiye (JW)	64.70	35.50	33.00	2.25	3.88	19.00	2.51[2]	0.90	Guler et al. (2007)
Isparta/Türkiye	65.50	-	23.80	-	-	-	10.70[2]	-	Sahin (2008)

Kütahya/Türkiye (HW)	78.98	69.07*	26.01	-	-	-	8.86[2]	-	Özalp and Hafızoğlu (2008)
Kütahya/Türkiye (SW)	79.89	67.07*	22.01	-	-	-	5.83[2]	-	Özalp and Hafızoğlu (2008)
Isparta/Türkiye	-	-	24.00	-	-	-	11.84[2]	-	Uner et al. (2009)
Isparta/Türkiye	-	-	22.00	-	-	-	11.03[2]	-	Uner et al. (2009)
Türkiye	64.70	35.50	33.00	2.25	3.88	19.00	2.50[2]	0.90	Akgül et al. (2010)
Bartın/Türkiye	69.01	50.99	27.84	1.53	0.98	12.35	4.52[2]	-	Gulsoy and Eroglu (2011)
Bartın/Türkiye (HW)	65.42	41.84	26.57	4.29	2.40	22.30	16.64[1]	-	Ataç and Eroğlu (2013)
Bartın/Türkiye (SW)	67.46	44.60	25.60	1.69	1.29	9.43	4.28[1]	-	Ataç and Eroğlu (2013)
Karabük/ Türkiye (RW)	72.93	45.32 α	28.04	3.14	2.33	12.26	2.24[1]	-	Şahin (2014)
Karabük/ Türkiye (BW)	78.83	54.55 α	24.52	3.08	2.11	11.63	1.96[1]	-	Şahin (2014)
Karabük/ Türkiye (HW)	74.78	52.03 α	28.43	3.83	1.04	13.20	4.17[1]	-	Şahin (2014)
Karabük/ Türkiye (SW)	77.32	54.08 α	25.24	4.12	1.67	11.78	1.48[1]	-	Şahin (2014)
Bartın/Türkiye	69.66	47.87	26.35	2.43	1.28	11.17	4.40[1]	-	Gulsoy and Ozturk (2015)
Kastamonu/ Türkiye (average of 10 clones, BW)	-	-	32.89	6.63	6.33	24.96	-	-	Yigit et al. (2016)
West Black Sea/ Türkiye	76.27	56.87	26.79	3.34	2.29	-	5.59[1]	-	Sivrikaya et al. (2016)
Türkiye	70.53	48.61	29.67	-	-	-	3.06	0.20	Özbay et al. (2016)
Bolu/Türkiye (bottom of stem)	73.09	52.07	24.77	3.30	2.50	-	5.67[1]	-	Kılıç Pekgözlü et al. (2017)
Bolu/Türkiye (middle of stem)	73.58	50.27	25.48	3.14	3.00	-	6.54[1]	-	Kılıç Pekgözlü et al. (2017)
Bolu/Türkiye (top of stem)	73.48	49.70	25.74	4.32	4.02	-	7.96[1]	-	Kılıç Pekgözlü et al. (2017)
Kütahya/Türkiye	64.67	40.10	34.32	8.68	7.42	19.75	8.71[5]	0.60	Akyurek et al. (2021)
Muğla/Türkiye (Balıkesir origin, JW)	61.80	37.30	35.30	18.40	3.53	1.41	3.28[2]	0.62	Arslan et al. (2021)
Muğla/Türkiye (Bursa origin, JW)	62.50	35.00	34.30	20.50	4.85	3.22	4.00[2]	0.62	Arslan et al. (2021)
Muğla/Türkiye (Denizli origin, JW)	60.50	65.10	33.80	22.80	5.09	2.29	4.89[2]	0.71	Arslan et al. (2021)

Muğla/Türkiye (Kütahya origin, JW)	59.00	36.60	35.20	18.80	4.44	2.21	3.53[2]	0.55	Arslan et al. (2021)
Muğla/Türkiye (Muğla origin, JW)	64.20	34.90	26.00	15.60	3.20	1.55	2.68[2]	0.42	Arslan et al. (2021)
Isparta/Türkiye	-	-	26.26	-	-	-	-	-	Beram and Yasar (2022)
Kastamonu/ Türkiye (OW)	80.33	39.10	27.07	12.40	3.16	2.62	3.24[1]	0.33	Kaz (2022)
Kastamonu/ Türkiye (CW)	77.33	33.00	36.49	15.73	3.69	3.02	3.67[1]	0.38	Kaz (2022)
Bolu/Türkiye	72.70	50.80	27.50	12.60	4.21	2.05	3.41[1]	-	Koksal et al. (2024)

H: Holocellulose, **α-C:** α-cellulose, **L:** Lignin, **HWS:** Hot water solubility, **CWS:** Cold water solubility, **1% NaOH:** 1% NaOH solubility, **E:** Extractives, **A:** Ash, SW: Sapwood, HW: Heartwood, JW: Juvenile wood, RW: Root wood, BW: Branch wood *Kürschner-Hoffer, [1]Ethanol, [2]Alcohol/benzene, [3]Acetone, [4]Methanol, [5]Toluene/acetone/ethanol.

FIBER PROPERTIES OF EUROPEAN BLACK PINE WOOD

The fiber properties of European black pine wood are crucial in determining its suitability for industrial applications, especially in pulp and paper production. These fibers affect the strength, flexibility, and overall quality of the final products. The fiber properties of European black pine are detailed in Table 2.

Table 2. Fiber properties of European black pine wood from various regions.

Geographical Region	FL (mm)	FW (µm)	LW (µm)	CWT (µm)	SR	FR	RR	Reference
Türkiye	4.20	48.00	-	9.00	-	-	-	Göker (1969)
Türkiye (bottom of stem)	3.34	41.80	28.50	6.70	-	-	-	Bozkurt (1971)
Türkiye (middle of stem)	3.59	42.30	30.20	6.00	-	-	-	Bozkurt (1971)
Türkiye (top of stem)	3.60	42.90	31.10	5.90	-	-	-	Bozkurt (1971)
New Zealand (Site No. 12, breast height, ring 2)	1.20	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, breast height, ring 10)	2.80	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, breast height, ring 15)	3.80	-	-	-	-	-	-	Cown (1974)

New Zealand (Site No. 12, 15th internodes, ring 2)	1.40	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, 15th internodes, ring 10)	2.00	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, 15th internodes, ring 15)	4.10	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, 25th internodes, ring 2)	1.50	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, 25th internodes, ring 10)	2.90	-	-	-	-	-	-	Cown (1974)
New Zealand (Site No. 12, 25th internodes, ring 15)	3.70	-	-	-	-	-	-	Cown (1974)
Corsica (10 years old)	0.94	-	-	-	-	-	-	Lee (1979)
Spain (10 years old)	0.93	-	-	-	-	-	-	Lee (1979)
France (10 years old)	0.95	-	-	-	-	-	-	Lee (1979)
Austria (10 years old)	0.94	-	-	-	-	-	-	Lee (1979)
Yugoslavia (10 years old)	0.96	-	-	-	-	-	-	Lee (1979)
Greece (10 years old)	0.97	-	-	-	-	-	-	Lee (1979)
Türkiye (10 years old)	0.99	-	-	-	-	-	-	Lee (1979)
Crimea (10 years old)	0.99	-	-	-	-	-	-	Lee (1979)
North Greece	3.09	-	-	-	-	-	-	Tsoumis and Panagiotidis (1980)
South Greece	2.92	-	-	-	-	-	-	Tsoumis and Panagiotidis (1980)
Türkiye	4.09	48.40	41.50	3.45	84.50	85.70	0.17	Erten and İlter (1995)
Pinus nigra Arn.	3.20	39.00	-	-	-	-	-	Ilvessalo-Pfäffli (1995)

Kütahya/Türkiye (EW)	-	35.00	27.00	4.00	-	-	-	Doğu and Yılgör (2001)
Kütahya/Türkiye (EW)		30.00	15.00	8.00	-	-	-	Doğu and Yılgör (2001)
Anglesey/UK (suppressed trees)	2.47	-	-	-	-	-	-	Amarasekara and Denne (2002)
Anglesey/UK (co-dominant trees)	2.37	-	-	-	-	-	-	Amarasekara and Denne (2002)
Anglesey/UK (dominant trees)	2.49	-	-	-	-	-	-	Amarasekara and Denne (2002)
France (seedling)	1.02	-	10.40	-	-	-	-	Froux et al. (2002)
Black Sea/ Türkiye	2.77	40.6	27.32	6.64	-	-	-	Ateş (2004)
Bartın/Türkiye	2.92	43.80	29.10	7.30				Alkan (2004)
Bartın/Türkiye (NW)	3.47	43.45	27.75	7.10	-	-	-	Sarıusta (2007)
Bartın/Türkiye (CW)	3.04	48.05	31.20	8.45	-	-	-	Sarıusta (2007)
Karabük/Türkiye (ring 1)	1.05	18.30	11.70	3.30	57.60	63.93	0.56	İstek et al. (2008)
Karabük/Türkiye (ring 15)	2.75	36.50	27.20	4.65	75.45	74.52	0.34	İstek et al. (2008)
Karabük/Türkiye (ring 30)	3.58	42.70	29.20	6.75	83.93	68.38	0.46	İstek et al. (2008)
Karabük/Türkiye (ring 45)	3.88	46.90	31.60	7.65	82.75	67.38	0.48	İstek et al. (2008)
Karabük/Türkiye (ring 60)	4.25	51.60	35.90	7.85	82.27	69.57	0.44	İstek et al. (2008)
Karabük/Türkiye (ring 75)	4.70	53.20	38.60	7.30	88.44	72.56	0.38	İstek et al. (2008)
Karabük/Türkiye (ring 90)	4.67	52.60	37.90	7.35	88.76	72.05	0.39	İstek et al. (2008)
Karabük/Türkiye (ring 109)	4.73	52.40	38.00	7.20	90.32	72.52	0.38	İstek et al. (2008)
Karabük/Türkiye (ring 130)	4.13	52.10	38.30	6.90	79.23	73.51	0.36	İstek et al. (2008)
Karabük/Türkiye (ring 146)	4.47	51.90	39.30	6.30	86.11	75.72	0.32	İstek et al. (2008)
Zonguldak/ Türkiye. (bottom of stem, HW)	1.44	38.50	26.00	6.25	-	-	-	İstek et al. (2010)
Zonguldak/ Türkiye. (middle of stem, HW)	1.58	36.50	25.00	5.75	-	-	-	İstek et al. (2010)

Zonguldak/ Türkiye. (top of stem, HW)	1.60	37.10	26.50	5.30	-	-	-	İstek et al. (2010)
Zonguldak/ Türkiye. (bottom of stem, SW)	2.65	44.00	30.20	6.90	-	-	-	İstek et al. (2010)
Zonguldak/ Türkiye. (middle of stem, SW)	2.40	42.00	30.40	5.80	-	-	-	İstek et al. (2010)
Zonguldak/ Türkiye. (top of stem, SW)	3.15	47.10	33.90	6.60	-	-	-	İstek et al. (2010)
Türkiye	1.21	36.12	26.23	4.95	-	-	-	Akgül et al. (2010)
Spain (Region 7A)	2.83	46.50	34.50	3.60	-	-	-	Esteban et al. (2012)
Spain (Region 7B)	3.30	50.60	36.00	3.50	-	-	-	Esteban et al. (2012)
Spain (Region 7C)	2.80	33.20	31.00	4.00	-	-	-	Esteban et al. (2012)
Spain (Region 8A)	2.60	43.80	34.50	3.20	-	-	-	Esteban et al. (2012)
Spain (Region 8B)	2.40	43.00	33.60	3.90	-	-	-	Esteban et al. (2012)
Spain (Region 8D)	2.50	44.00	39.10	4.00	-	-	-	Esteban et al. (2012)
Spain (Region 8E)	2.70	39.60	33.50	3.40	-	-	-	Esteban et al. (2012)
Spain (Region 10)	3.10	49.20	35.10	3.60	-	-	-	Esteban et al. (2012)
Spain	-	30.36	25.82	-	-	-	-	Martin-Benito et al. (2013)
Spain (EW)	-	38.22	34.45	-	-	-	-	Martin-Benito et al. (2013)
Spain (LW)	-	13.95	8.02	-	-	-	-	Martin-Benito et al. (2013)
Bartın/Türkiye	3.00	46.30	23.40	11.45	-	-	-	Gulsoy et al. (2013)
Bartın/Türkiye (HW)	1.52	36.50	25.00	2.40	-	-	-	Ataç and Eroğlu (2013)
Bartın/Türkiye (SW)	2.40	42.00	30.40	5.80	-	-	-	Ataç and Eroğlu (2013)
Iran	-	-	-	-	66.56	72.65	0.39	Farsi and Kiaei (2014)
Karabük/Türkiye	2.56	-	-	-	-	-	-	Şahin (2014)
Bartın/Türkiye	3.01	46.40	23.40	11.50	64.87	50.43	0.98	Gulsoy and Ozturk (2015)
Soria/Spain	3.08	51.98	-	-	-	-	-	Esteban et al. (2017)

Bolu/Türkiye (bottom of stem)	1.89	31.90	19.50	6.20	59.20	61.10	0.64	Kılıç Pekgözlü et al. (2017)
Bolu/Türkiye (middle of stem)	1.92	39.40	22.00	8.70	48.60	55.8	0.79	Kılıç Pekgözlü et al. (2017)
Bolu/Türkiye (top of stem)	1.54	34.20	19.20	7.50	45.00	56.10	0.78	Kılıç Pekgözlü et al. (2017)
Kastamonu/ Türkiye (OW)	2.81	46.56	26.87	9.84	-	-	-	Kaz (2022)
Kastamonu/ Türkiye (CW)	2.47	44.15	20.27	11.94	-	-	-	Kaz (2022)

FL: Fiber length, **FW:** Fiber width, **LW:** Lumen Width, **CWT:** Cell wall thickness, **SR:** Slenderness ratio (FL/FW), **FR:** Flexibility ratio [(LW/FW)*100], **RR:** Runkel ratio [(2xCWT)/LW], EW: Earlywood, LW: Latewood, SW: Sapwood, HW: Heartwood, NW: Normal wood, OW: Opposite wood, CW: Compression wood.

CONCLUSIONS

European black pine wood's adaptability and commercial value are reflected in its chemical composition. European black pine is a great raw material for pulp production, bioenergy, and construction because of its high cellulose content, moderate levels of lignin and hemicellulose, and noteworthy resin extractives. Chemical analysis is essential for optimal industrial use since its extractives improve durability but can also affect wood processing techniques.

The fibers of European black pine are distinguished by their length, thick cell walls, and moderate lumen size, making the wood ideal for applications requiring strength and durability. These characteristics make it ideal for making kraft paper, cardboard, fiberboard, and bio-based products. However, its larger fibers may limit its use in fine or high-smoothness paper grades. Understanding its fiber properties enables industry to maximize its utilization in a variety of applications.

REFERENCES

Afzal-Rafii, Z., Dodd, R. S. (2007). Chloroplast DNA supports a hypothesis of glacial refugia over postglacial recolonization in disjunct populations of black pine (*Pinus nigra*) in Western Europe. Molecular Ecology, 16(4): 723-736.

Akgül, M., Güler, C., Çöpür, Y. (2010). Certain physical and mechanical properties of medium density fiberboards manufactured from blends of corn (*Zea mays indurata* Sturt.) stalks and pine (*Pinus nigra*) wood. Turkish Journal of Agriculture and Forestry, 34: 197-206.

Akyurek, S., Akman, M., Ozalp, M. (2021). Effects of heat treatment on some chemical compound and mechanical properties of black pine wood. Wood Research, 66: 621-629.

Alkan, Ç. (2004). Türkiye'nin önemli yapraklı ve iğne yapraklı ağaç odunlarının migrografik yönden incelenmesi. Yüksek Lisans Tezi, Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Zonguldak.

Amarasekara, H., Denne, M. P. (2002). Effects of crown size on wood characteristics of Corsican pine in relation to definitions of juvenile wood, crown formed wood and core wood. Forestry, 75(1): 51-61.

Arslan, M. B., Avcı, E., Tozluoğlu, A., Birtürk, T., Saraçbaşı, A., Örtel, E. (2021). Comparison of some wood properties of juvenile black pines of different origin planted in the same habitat. Maderas. Ciencia y tecnología, 23: 66.

Ataç, Y., Eroğlu, H. (2013). The effects of heartwood and sapwood on kraft pulp properties of *Pinus nigra* JF Arnold and *Abies bornmuelleriana* Mattf. Turkish Journal of Agriculture and Forestry, 37(2): 243-248.

Ateş, S. (2004). Kraft yöntemi ile karaçam (*Pinus nigra* subsp. *pallasiana*) yongalarının pişirilmesinde kullanılan farklı deneme desenleri yardımıyla elde edilen regresyon modellerinin karşılaştırılması. Doktora Tezi, Karadeniz Teknik Üniversitesi, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Trabzon.

Balaban, M., Uçar, G. (2001). The correlation of wood acidity to its solubility by hot water and alkali. Holz als Roh- und Werkstoff, 59: 67-70.

Beram, A. Yasar, S. (2022). Comparison of different methods used in wood lignin determination. A. Beram M. D. Ulusan (Eds.), Forest and Agricultural Studies from Different Perspectives (p. 43-58). Lithuania: SRA Academic Publishing.

Bozkurt, Y. (1971). Doğu ladini (*Picea orientalis* Link. Et Carr.) ile Toros karaçamı (*Pinus nigra* var. *caramanica* [Loud.] Rehd.)'dan birer ağaçta lif morfolojisi üzerine denemeler. İ.Ü. Orman Fakültesi Dergisi, Seri A, 21(1): 70-93.

Cown, D. J. (1974). Physical properties of Corsican pine grown in New Zealand. New Zealand Journal of Forest Science, 4(1): 76-93.

Doğu, A.D., Yılgör, N. (2001). Kütahya bölgesi karaçam (*Pinus nigra* L.) varyetelerinde (*P. nigra* var. *pallasiana* - *P. nigra* var. *pyramidata*) anatomik yapıların karşılaştırmalı incelenmesi. İstanbul Üniversitesi Orman Fakültesi Dergisi, A51(2): 51-64.

Erten, A.P., İlter, E., (1995). Karaçam Odununun Kimyasal Bileşenlerinin Belirlenmesi, Ormancılık Araştırma Enstitüsü Yayınları, Teknik Bülten No: 250.

Esteban, L. G., Martín, J. A., de Palacios, P., Fernández, F. G. (2012). Influence of region of provenance and climate factors on wood anatomical traits of *Pinus nigra* Arn. subsp. *salzmannii*. European Journal of Forest Research, 131(3): 633–645.

Esteban, L. G., de Palacios, P., Conde, M., Fernández, F. G., García-Iruela, A., González-Alonso, M. (2017). Application of artificial neural networks as a predictive method to differentiate the wood of *Pinus sylvestris* L. and *Pinus nigra* Arn subsp. *salzmannii* (Dunal) Franco. Wood Science and Technology, 51: 1249-1258.

EUFORGEN, (2024). European forest genetic resources programme https://www.euforgen.org/species/pinus-nigra/

Farsi, M., Kiaei, M., (2014). Wood physical properties and tracheid dimensions of non-native softwoods in Iran. Cellulose Chemistry and Technology, 48 (5-6): 445-454.

Fengel, D., Wegener, G. (1989). Wood Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin.

Froux, F., Huc, R., Ducrey, M., Dreyer, E. (2002). Xylem hydraulic efficiency versus vulnerability in seedlings of four contrasting Mediterranean tree species (*Cedrus atlantica*, *Cupressus sempervirens*, *Pinus halepensis* and *Pinus nigra*). Annals of Forest Science, 59(4): 409-418.

Giovannelli, G., Roig, A., Spanu, I., Vendramin, G.G., Fady, B. (2017). A new set of nuclear microsatellites for an ecologically and economically important conifer: the European black pine (*Pinus nigra* Arn.). Plant Molecular Biology Reporter, 35: 379–388.

Göker, Y. (1969). Dursunbey ve Elekdağ karaçamları (*Pinus nigra* var. *pallasiana*)'nın fiziksel, mekanik özellikleri ve kullanış yerleri hakkında araştırmalar. İstanbul Üniversitesi Orman Fakültesi Dergisi, 19(2): 91-135.

Guler, C., Copur, Y., Akgul, M., Buyuksarı, U. (2007). Some chemical, physical and mechanical properties of juvenile wood from black pine (*Pinus nigra* Arnold) plantations. Journal of Applied Science, 7(5): 755-758.

Gulsoy, S. K., Eroglu, H. (2011). Influence of sodium borohydride on kraft pulping of European black pine as a digester additive. Industrial & Engineering Chemistry Research, 50(4): 2441-2444.

Gulsoy, S.K., Ozturk, F. (2015). Kraft pulping properties of European black pine cone. Maderas. Ciencia y tecnología 17(4): 875 – 882.

Gulsoy, S.K., Kustas, S., Erenturk, S. (2013). The effect of old corrugated container (OCC) pulp addition on the properties of paper made with virgin softwood kraft pulps. Bioresources, 8(4): 5842-5849.

Hafızoğlu, H., Özalp, M. (2007). Su soğutma kulelerinde kullanılan emprenyesiz bazı çam türlerinin çözünürlük değerlerinde meydana gelen değişimin incelenmesi. Z.K.Ü. Bartın Orman Fakültesi Dergisi, 9(12): 20-25.

Hafızoğlu, H., Usta, M. (2005). Chemical composition of coniferous wood species occurring in Turkey. Holz als Roh- und Werkstoff, 63: 83-85.

Ilvessalo-Pfäffli, M.S. (1995). Fiber Atlas. Identification of Papermaking Fibers, Springer-Verlag, Berlin, Germany.

Isajev, V.,Fady, B., Semerci, H., and Andonovski, V. (2004). EUFORGEN Technical Guidelines for genetic conservation and use for European black pine (*Pinus nigra*). Rome, International Plant Genetic Resources Institute. 6 pages.

İstek, A., Eroğlu, H., Gülsoy, S.K. (2008). Karaçamın yaşına bağlı olarak lif ve kağıt özelliklerinin değişimi. Kastamonu Üniversitesi, Orman Fakültesi Dergisi, 8(1): 61-66.

İstek, A., Gülsoy, S.K., Eroğlu, H. (2010). Karaçam öz odunu ve diri odunu lifsel özelliklerinin karşılaştırılması. II. Karadeniz Ormancılık Kongresi Bildiriler Kitabı, Cilt V, 1916-1924.

Kaz, S. (2022). Bazı ağaç türlerine ait reaksiyon odunlarının anatomik, kimyasal, optik ve lif morfolojileri açısından karşılaştırılması. Yüksek Lisans Tezi, Kastamonu Üniversitesi, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Kastamonu.

Kılıç Pekgözlü, A., Gülsoy, S.K., Ayçiçek, Y. (2017). Karaçam (*Pinus nigra* Arnold.) odununun lif morfolojisi ve kimyasal yapısı üzerine ağaç gövde yüksekliğinin etkisi. Bartın Orman Fakültesi Dergisi, 19(2): 74-81

Koksal, S. E., Kelleci, O., Tekingunduz, G., Aydemir, D. (2024). The influence of road traffic and industrial plant-induced air pollution on the physical, mechanical, chemical and morphological properties of the black pine wood. Maderas: Ciencia y tecnología, 26(1), 1.

Lee, C. H. (1979). Absence of growth-wood property correlation in twenty-seven black pine seed sources. Wood and Fiber Science, 11(1): 22-28.

Martin-Benito, D., Beeckman, H., Canellas, I. (2013). Influence of drought on tree rings and tracheid features of *Pinus nigra* and *Pinus sylvestris* in a mesic Mediterranean forest. European Journal of Forest Research, 132(1): 33-45.

OGM (2022). Tarım ve Orman Bakanlığı, Orman Genel Müdürlüğü,"Orman İstatistikleri 2022".

Özbay, G., Özçifçi, A., Kökten, S. (2016). The pyrolysis characteristics of wood waste containing different types of varnishes. Turkish Journal of Agriculture and Forestry, 40: 705-714.

Rubio-Moraga, A., Candel-Perez, D., Lucas-Borja, M.E., Tiscar, P.A., Viñegla, B., Linares, J.C., Gómez-Gómez, L., and Ahrazem, O. (2012). Genetic diversity of *Pinus nigra* Arn. populations in southern Spain and northern Morocco revealed by inter-simple sequence repeat profiles. International Journal of Molecular Sciences, 13(5): 5645–5658.

Şahin, E. (2014). Camiyani karaçami (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) odunu, ibresi ve kozalağinin anatomik, fiziksel ve fitokimyal özellikleri. Yüksek Lisans Tezi, Bartın Üniversitesi, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Bartın.

Sahin, H.T. (2008). Application of various solvent-type alkyd resins to pine and cedar woods for achieving water repellence. Pigment & Resin Technology, 37(6): 395-401.

Sarıusta, S.E. (2007). Sarıçam (*Pinus sylvestris* L.), karaçam (*Pinus nigra* Arnold.) ve kızılçam (*Pinus brutia* Ten.) reaksiyon odununun anatomik yapısı ve kimyasal bileşimi üzerine araştırmalar. Yüksek Lisans Tezi, Zonguldak Karaelmas Üniversitesi, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Zonguldak.

Sivrikaya, H., Çetin, H., Tümen, İ., Temiz, C., Borges, L.M.S. (2016). Performance of copper azole treated softwoods exposed to marine borers. Maderas. Ciencia y tecnología, 18(2): 349-360.

Tanrıverdi, H. (2004). Karaçam (*Pinus nigra* Arnold.) ve kızılçam (*Pinus brutia* Ten.) odunundaki polisakkarit karakterizasyonu ve miktarı ile lignin miktarı üzerine kromatografik ve spektrofotometrik araştırmalar. Yüksek Lisans Tezi, SDÜ, Fen Bilimleri Enstitüsü, Orman Endüstri Mühendisliği Anabilim Dalı, Isparta.

Tsoumis, G., Panagiotidis, N. (1980). Effect of growth conditions on wood quality characteristics of black pine (*Pinus nigra* Arn.). Wood Science and Technology, 14(4): 301–310.

Uçar, G., Fengel, D. (1995). Variation in composition of extractives from wood of *Pinus nigra* varieties. Phytochemistry, 38(4): 877-880.

Uner, B., Oyar, O., Var, A. A., & Altnta, O. L. (2009). Effect of thinning on density of *Pinus nigra* tree using X-ray computed tomography. Journal Environmental. Biology, 30(3): 359-362.

Usta, M. (1993). Yerli çam türlerimizin kabuk ve odun bileşenlerinin karşılaştırılması, "ORENKO'93" II. Ulusal Orman Ürünleri Kongresi Bildiri Metinleri, 6-9 Ekim 1993, Trabzon.

Yigit, N., Sevik, H., Cetin, M., Gul, L. (2016). Clonal variation in chemical wood characteristics in Hanönü (Kastamonu) Günlüburun black pine (*Pinus nigra* Arnold. subsp. *pallasiana* (Lamb.) Holmboe) seed orchard. Journal of Sustainable Forestry, 35(7): 515-526.

Chapter 4

THE EFFECTS OF NATURAL DISASTERS ON THE SOCIOECONOMIC FUNCTIONS OF FORESTS

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1. Introduction

Disaster is defined as destructive events of natural, technological, or human origin causing physical, economic, and social losses that disrupt normal life and human activities (Gökçe & Tetik, 2012). Often considered from an anthropocentric perspective, natural disasters occur when processes within Earth's natural environments interact and affect human settlements and the built environment. Actions like earthquakes, floods, hurricanes, storms, forest fires, volcanic eruptions, and landslides have sculpted the topography for thousands of years, and though they are natural, they remained concerns for humans: their impact has earned them the term "disasters." Such activities are generally not termed as disasters when they take place in regions that are uninfluenced by human beings, but when they destroy residential zones or agricultural, economic, and social zones, they are termed "natural disasters" since they are destructive (Alexander, 2018; Chaudhary & Piracha, 2021).

In an anthropocentric perspective, disasters are divided into three main categories in terms of human needs and human-nature relationships: resource, benign, and hazard. If a natural element can be productively utilized by humanity, it is considered a "resource." For example, the use of wind for energy generation or the extraction of minerals for industrial use fall under the resource category. A benign relationship represents situations in which a natural element provides neither benefit nor harm to humanity. For instance, a desert in a remote area or an underwater volcano in the depths of the ocean that does not affect human life is considered benign. A hazardous relationship is one in which the natural element is threatening human life or the built environment, therefore becoming potentially a "natural disaster." Examples are a river overflowing and causing a flood, or buildings falling down because of an earthquake, should fall under the hazard category (Pelling, 2001).

Natural events and conditions may have quite different meanings for a society or individual; hence, they fall into either the "resource" or "hazard" category. A forest fire may present an immediate economic threat to a farmer but might be seen by an ecologist as a "resource," as it develops biodiversity within the forest ecosystem. All these different interpretations attributed to these events according to varied knowledge and value systems give a picture of how natural disasters leave an impression upon social structures (Pelling, 2001; Quarantelli, 1985).

Natural disasters can be broadly classified as either "catastrophic" or "chronic" disasters. Catastrophic disasters include sudden and widespread destructive events such as hurricanes, earthquakes, floods, and extreme temperature fluctuations. Chronic disasters are less observable yet develop over the long term and impact basic needs such as public health, sanitation, and clean water, thus threatening the long-term health of a society incrementally and unremittingly. While chronic disasters have wider impacts, loss of life, and difficulties than catastrophes, the consequences are long-term and adverse, with involvement in every kind of sector in society (Alexander, 1997; Pelling, 2001).

Natural hazards that trigger natural disasters may be further divided into geophysical, hydrological, meteorological, climatological, biological, and extraterrestrial hazards (Figure 1). The geophysical hazards include earthquakes and volcanic activities. Hydrological hazards include water-related events such as floods and wave surges. Meteorological hazards involve short-term atmospheric events such as storms and sudden changes in temperature. Climatological hazards take in long-term climate events such as droughts and forest fires. Biological hazards result from life forms, such as pandemics. Finally, there are the extraterrestrial hazards including asteroid and meteor impacts, which sometimes cause disastrous results. Each type of hazard generates different environmental and socioeconomic effects on humans and requires various management approaches (Chaudhary & Piracha, 2021; Mata-Lima et al., 2013).

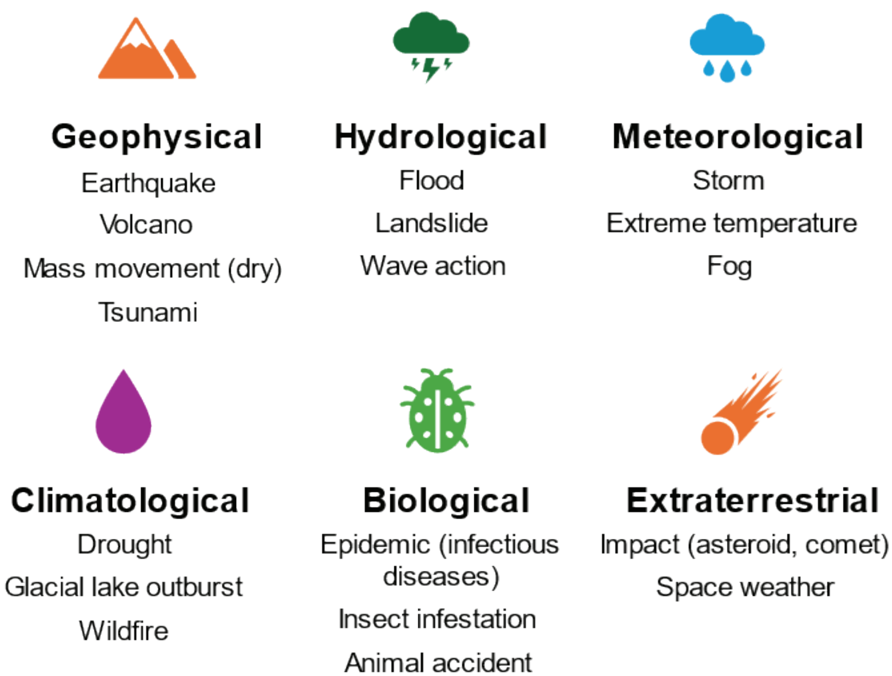

Figure 1. Natural hazards subgroups and types in the IRDR peril classification and hazard glossary ((CRED), 2023)

Natural events that occur away from human settlements or environments are generally not referred to as "disasters" because such happenings were considered to have no consequence on human life or the economy. However, natural events independent of human settlements or interventions also impose natural environment and ecological effects. In particular, natural forest ecosystems may not directly contribute to causing harm to human life, but their long-lasting effects are normally felt throughout socioeconomic life. For example, even in cases where forest fires take place in remote forested regions, the services which the ecosystem might have been providing in that area, such as regulation of the water cycle, carbon storage, and biodiversity, are weakened, thereby directly affecting human life and economic systems. Although such natural events might not constitute "natural disasters" if they take place far from human abodes, such factors' degradation of forest ecosystem functionality may seriously affect socioeconomic functions related to societies. Therefore, indirect consequences for the functionality of forest ecosystems should not be undermined.

Though natural disasters have a negative impact on forest ecosystems, as well as on all ecosystems, and thus on all the functions of these ecosystems, the scope of this study is limited to the socioeconomic functions of forests. Therefore, in the following headings, the impacts of various natural disasters on the socioeconomic functions of forests are discussed.

2. Functions of Forest Ecosystems

More than thirty percent of the earth's surface is covered by forests and forests contribute a variety of values to human society. Food, clean water, climate management, carbon sequestration and productive soils are just a few of the many services that healthy forest ecosystems offer. Forests also support many of society's fundamental requirements, economic activities, and cultural or spiritual values (Waage et al., 2008; Jenkins and Schaap, 2018). All these services are called forest ecosystem services. These services can be categorized as below (MEA, 2003; MEA, 2005):

Provisioning services: Including products or goods that are consumed by humans or used in the production of other goods such as food, fresh water, fuelwood, genetic resources, biochemicals and fiber.

Regulating services: The benefits obtained from forest ecosystem's control of natural processes such as climate regulation, disease regulation, erosion, water quality and flows, and pollination.

Cultural services: The non-material benefits people obtain from forest ecosystems such as spiritual and religious, recreation and ecotourism, aesthetic, educational.

Supporting services: The natural processes such as soil formation, primary production, nutrient cycling.

With many products, services and benefits that forests provide, they also have some externalities. For this reason, in parallel with the increasing importance of forest resources nowadays, determining the externalities of forests and forestry activities is also gaining importance. An externality can be defined as an event in which a person or organization's production or consumption activity benefits or adversely affects the activities of another person or organization without any demand or payment. The main reason for the existence of externalities in the context of both benefits and costs is that all economic activities interact with the environment (Demirci, 2017).

These externalities occur as positive and negative externalities. Examples of benefits or positive externalities provided by forests include soil conservation, avalanche and flood prevention, landscape enhancement, carbon storage, climate regulation, water quality enhancement and purification, income generation and biodiversity conservation (Merlo and Briales, 2000; Merlo and Croitoru, 2005).

One of the positive externalities of forest ecosystems is natural disaster risk reduction, which is also the focus of this study. Since forests serve as a natural buffer to stop or lessen natural disasters that endanger life and property, they can be extremely important in reducing the risk of natural disasters. On the other hand, as a result of interventions in forests, negative externalities also occur in forests. The following examples can be given for these negative externalities (Merlo and Briales, 2000; Merlo and Croitoru, 2005):

- Erosion, floods and avalanches due to poor or no forest management
- Loss of landscape values to excessive expansion of forest land use
- Pollen and other allergic factors
- Risk of damage by forest fires
- Loss of bio-diversity, landscape values, etc due to plantation forestry
- Loss of recreation opportunities due to intensive plantation forestry and poor management

These negative externalities are related with natural disasters. Across the world, natural disasters seriously threaten the above-mentioned economic, ecological and sociocultural functions of forest ecosystems. Nowadays, based on the generally accepted classification in line with international forestry processes, these three forest functions are accepted as main forest function categories and under economic, ecological and sociocultural functions, ten general forest functions have been determined (OGM, 2014). While forest products production sub-function is considered as economic function, nature conservation, erosion prevention and climate protection sub-functions are listed as ecological functions. On the other hand, ecotourism and recreation, community health, aesthetics, hydrological, national defense and scientific sub-functions are the sociocultural function of forest ecosystems.

Economic, ecological and sociocultural functions constitute the three dimensions of Sustainable Forest Management (SFM). SFM has become an integral component of international agreements and forest policy negotiations over the last two decades, and is expressed as the main objective of international organizations and processes, particularly the United Nations. Various criteria and indicators have also been set for monitoring and evaluating SFM at national, regional or global level.

According to Forest Europe, criteria define and characterize the key elements, conditions or processes by which sustainable forest management can be assessed, while according to the UN Food and Agriculture Organization (FAO), criteria define the key elements by which sustainability can be assessed, taking due account of the productive, protective and social roles of forests and forest ecosystems. Meanwhile, according to Forest Europe, indicators provide information on the criteria to which they belong and show change and development over time. Whereas according to FAO, indicators are measurable parameters that correspond to a specific criterion and help to monitor the status and change of forest values in order to reflect quantitative, qualitative and descriptive aspects (OGM, 2020).

Countries establish a set of criteria and indicators for SFM by taking into consideration the characteristics of forest resources and forestry sector in their own country and other national conditions. Based on these criteria and indicators, they can determine their level of achievement of sustainable forest resources management. For instance, as a result of the efforts to prepare sustainable forest management criteria and indicators at the country scale initiated in 2017 in Türkiye, a unique national set of 6 criteria and 40 quantitative indicators in line with the Forest Europe process, including the priorities of our country, as well as the legal, institutional and policy framework applicable to each criterion and 5 qualitative indicators were put forward (OGM, 2020).

- Forest Resources & Global Carbon Cycles
- Forest Ecosystem Health and Vitality
- Productive Functions of Forests

- Forests Biological Diversity
- Protective Functions
- Socioeconomic Functions

One of these criteria, socioeconomic functions, is the focus of this study. Forest resources, on the one hand, directly meet the needs of people, both tangible and intangible, and contribute positively to socioeconomic life, while on the other hand, as an "invisible hand", they ensure the protection and/or development of the balance of all natural systems. The contribution of forest resources to the national economy, employment and rural development, their importance in the supply-demand balance, institutional, financial, legal and R&D capacity constitute the basic components of the socioeconomic functions of the sector. The indicator values of these components provide information to the sector on whether the forestry of the country is moving towards sustainable management or not.

Table 1 shows the indicators for the socioeconomic function, which is the 6th criterion, according to Forest Europe and Türkiye. Unlike Forest Europe, some indicators have been developed uniquely for Turkish conditions (GDF, 2019; Forest Europe, 2020). While 10 indicators are determined by Forest Europe, in Türkiye 11 indicators are identified under this criterion.

Table 1. Indicators of socioeconomic function

Ind. No	**Türkiye**	**Forest Europe**
6.1	Contribution of forestry sector to GDP	Forest holdings
6.2	Forest products supply demand equilibrium	Contribution of forest sector to GDP
6.3	The size and quality of employment in forestry sector	Net revenue
6.4	Financial balance of forestry	Investments in forests and forestry
6.5	The share of the state's budget allocated for forestry	Forest sector workforce
6.6	Size of the population dependent on forest	Occupational safety and health
6.7	Beneficiaries of recreation services	Wood consumption
6.8	Transfer of income from forestry sector to forest villagers	Trade in wood
6.9	Research improvement extension and training works	Wood energy
6A/6.10	Activities of NGOs on forestry	Recreation in forests
6B	Forest - society conflicts	

3. Effects of Natural Disasters on Socioeconomic Function of Forest Ecosystems

3.1. Geophysical Hazards

3.1.1. Earthquake

Earthquakes are sudden movements of the ground that can be intense enough to severely damage forest ecosystems. They commonly trigger geophysical hazards like landslides, rock avalanches, or soil liquefaction, resulting in soil displacement, unstable slopes, and structural tree damage. For instance, studies of Nothofagus forests in the Matiri Valley of New Zealand showed that large canopy gaps created by landslides following a 1929 earthquake (M = 7.7) allowed particular species, such as Nothofagus fusca, to establish, whereas smaller gaps promoted mixed-species regeneration. This indicates that the changes in canopy gaps due to earthquakes change the pattern of species establishment and forest structure as a function of landform vulnerability to soil and rock movement (Vittoz et al., 2001).

Landslides and debris flows during the 2008 Wenchuan earthquake in Sichuan, China, wholly buried complete sections of forests, leading to heavy losses of vegetation in affected forest areas and reducing canopy cover. The resulting bare slopes then promoted increased erosion rates and sediment transport, disturbing downstream hydrology and further reducing the natural ability of the forested landscape to regulate water flow and prevent erosion. It increased the risk of geo-hazards in river valleys and impeded the long-term ecological recovery after the event (Cui et al., 2012; Wang et al., 2012).

These impacts create gaps in the canopy that open up the forest floor to additional sunlight, which aids the reestablishment of some species but also increases erosion hazards. Soil liquefaction further disrupts soil conditions, lowering soils' stability and oxygen supply in root zones, limiting the roots' access to nutritional resources and possibly compromising tree survival. The combined impact of these effects causes landscape fragmentation, degradation of soils, and loss of habitat, which essentially alters the composition of species and functioning over time (Morgenroth & Armstrong, 2012; Wang et al., 2012).

Earthquakes have many direct and indirect impacts on the socioeconomic functions of forests. Forests not only maintain ecological balance, but also create jobs in local economies, provide raw materials for food and medicine, improve water quality, store carbon and have cultural significance for many communities. Earthquakes can negatively affect many of these functions and cause serious socioeconomic damage. The effects of earthquakes on the socioeconomic functions of forests can be indicated under the following headings:

- ***Effects on forest products and income losses:*** Earthquakes can reduce wood production by causing direct damage, such as trees falling over. This leads to loss of income for forest villagers. Also non-wood forest products such as resin, cork, plant extracts, etc. may also decrease or disappear after an earthquake, negatively affecting the income and livelihoods of local people. Moreover, enterprises forest products industry may also have difficulties in raw material supply.
- ***Effects on tourism and recreation activities:*** Earthquakes can have devastating effects on forests and destroy structures such as tourist facilities, parks and walkways within the forest. This disrupts forest tourism and leads to loss of income for local businesses.
- ***Effects on water resources management and agriculture***: Forests play an important role in protecting water resources and ensuring water quality. However, earthquakes can disrupt the forest ecosystem, increasing the risk of erosion and reducing water retention capacity. This makes sustainable management of water resources difficult. Decreased water quality and water scarcity after an earthquake may lead to a decrease in agricultural production and damage to the local economy.
- ***Social and cultural effects:*** Forests have cultural and spiritual significance for many communities. When earthquakes damage forests, the cultural ties and rituals of these communities can also be damaged.
- ***Post-earthquake forest rehabilitation and costs:*** Post-earthquake rehabilitation of damaged forest areas entails significant costs. These costs can be a major burden on the budgets of governments and local communities.

3.1.2. **Mass movement (dry)**

Dry mass movements such as landslides and rockfalls have a very intense impact on forest ecosystems because they result in slope instability, soil structure destruction, and vegetation cover removal. These kinds of movements, occurring on sloping topography without the direct influence of water, displace nutrient-rich topsoil and expose the subsoil. Organic matter and other necessary nutrients crucial to soil fertility and the realization of varied plant species continue to be lost as surface soil is taken away. Over time, the continued removal and disturbance of the soil through mass movements weaken the stability of vegetation and impede the ecosystem's processes of regeneration and growth due to increased vulnerability to further erosion and climatic stressors (Ren, 2012; Rotaru, 2007).

In addition to the alteration of properties in soils, landslides also produce complex microtopographical features like ridges, hummocks, and depressions that effectively create site diversity by altering localized climates, soil moisture, and light exposure. The heterogeneity then enhances the establishment of distinct plant communities throughout the lands that have been affected. Both landslides and rockfalls contribute to soil diversity by the exposition of parent material variations, the initiation of new development processes in the soil, and the creation of different mixtures in soil textures and various densities. While coarse debris left by rockfalls supports well-drained soils, finer sediment accumulations provide moisture retention, thereby producing a variety of conditions that can favor different successional stages of plants. This kind of natural diversity in conditions and habitat within areas affected by such deposits is able to support a wide range of flora and fauna and, therefore, maintain biodiversity in frequently disturbed regions (Geertsema & Pojar, 2007).

Besides the immediate physical destruction of the vegetation, these dry mass movements impact habitat structures by way of fragmenting forested landscapes and exposing mineral soils, commonly first taken over by early-successional species. These will eventually be replaced by forest vegetation and multilayered habitats, on which proportion of wildlife resources depends. Meadows and open areas formed due to landslides and rockfalls would turn into important foraging sites for herbivores like deer and moose. Standing dead trees and also the exposed ground provide nesting sites for birds. On the other hand, the disturbances make ecosystems more susceptible to the invasion of opportunistic species that will further modify the native plant composition and possibly exclude specialized species depending on a certain persistence of conditions. While mass movements challenge the forest ecosystems in areas like loss of soil fertility and fragmentation within habitats, on the other hand, they enhance biophysical diversity. This complex and multifaceted role of natural disturbances in forest ecosystems is thereby underlined (Geertsema & Pojar, 2007; Ren, 2012; Rotaru, 2007).

Like other natural disasters, mass movements (landslides and rockfalls) cause significant negative impacts and damages both directly and indirectly on the socioeconomic functions provided by forests. These damages can be expressed as follows:

- ***Loss of income as a result of destruction of natural resources:*** As a result of landslides and rock falls, wood and timber production and non-wood forest products (medicinal and aromatic plants) production are damaged. This leads to loss of income for local people who depend on these products for their livelihood. In addition, the fact that agricultural areas are affected by landslides makes it difficult for local people to balance their livelihoods between agriculture and forestry.

- ***Effects on soil and erosion control:*** Landslides limit the soil protection function provided by forests. This leads to increased erosion in the long term and adversely affects the quality of forest soils. Decreased soil quality limits the healthy growth of trees, reduces the yield of forest products and endangers the sustainability of vegetation and the water cycle.
- ***Effects on infrastructure and transport:*** Landslides and rockfalls threaten roads and infrastructure passing through forested areas. This makes transport difficult for local people and makes it difficult to access emergency services, affecting the quality of life and safety of local people.
- ***Effects on tourism and recreation activities:*** Landslides and rock falls may damage hiking trails, campsites and other touristic infrastructures that are important for nature tourism and ecotourism. Local people, whose livelihoods are based on nature tourism, experience loss of income with the decrease in the flow of tourists.

3.1.3. **Volcanic activity**

Depending on their intensity, volcanic eruptions tend to have a range of destructive impacts on the ecosystem in general and on forest ecosystems particularly through mechanisms that include ash fall, lahar flows, lava flows, and pyroclastic flows. Ash fall can bury extensive areas, wherein a thick layer of fallen ashes with alterable pH can actually smother vegetation and impede photosynthesis, which usually results in high mortality of trees and understorey plants. Thinner layers of ash can partially kill vegetation and thus allow eventual secondary succession, whereas thicker deposits typically cause the complete loss of all plants, initiating primary succession, which requires soil structure and texture to be rebuilt by pioneer species. Ash layers can also alter soil properties, including available nutrients and the infiltration of water, each slowing landscape recovery processes (Arnalds, 2013; Grishin, 1996; Korup & Mohr, 2019).

Lahar flows intensify destruction by: vegetation and soil cover on the slopes stripped sediments deposited are nutrient-poor, preventing rapid regrowth critical changes in the landscapes coarse material are left behind that is unsuitable for immediate plant re-establishment However, the fine sediments in these flows have moisture retained in them that will, over time, support the growth of hardy, moisture-tolerant pioneer species. These pioneers, over time-actually, hundreds of years-create an environment that is ripe for more complex plant succession: first from herbaceous pioneers to shrubs and finally to forest species as organic material builds up and stabilizes the ecosystem (Arnalds, 2013; Korup & Mohr, 2019).

The most serious volcanic impacts, those involving lava and pyroclastic flows, destroy all vegetation and organic layers, leaving behind treeless expanses that pose serious challenges for ecosystem recovery over long spans. The lava flows blanket and sterilize a piece of land from processes of ecological succession until hardy moss, lichen, and specialized pioneer plants can eventually stabilize the substrate. The extreme temperature and rapid ascent of pyroclastic flow cause extensive incineration and soil sterilization, rendering these areas particularly inhospitable to an initial recovery. Primary succession in pyroclastic and lava flow zones takes centuries, usually starting with heat-resistant species that build organic matter little by little until complex forest vegetation is able to return. Over time, Andisols, or ash-derived soils, form and have characteristic fertility that eventually will enhance the resilience of forests in such case. Initial impacts to biodiversity, soil health, and ecosystem structure are, however, extreme and long-lasting (Arnalds, 2013; Grishin, 1996; Korup & Mohr, 2019).

Volcanic activities are less common than other natural disasters and are effective in limited areas. Nevertheless, forest ecosystems are severely damaged in areas where volcanic activities occur. Volcanic activities can have far-reaching negative consequences on societies and economic activities by threatening the functions of forests. The effects of volcanoes on the socioeconomic functions of forests can be analysed under the following headings:

- ***Timber and non-wood forest products:*** Volcanic events can damage timber resources, leading to a shortage of wood for construction, fuel, and other uses. This can impact the local economy by increasing the costs of timber-related products and services. Moreover, non-wood forest products, including medicinal plants, can also be affected as habitats are destroyed or altered. These resources often serve as a livelihood for local communities and are significant in traditional and herbal medicine.

- ***Effects on soil and water resources:*** Volcanic ash covers the soil surface and prevents the nutrient and water intake of plants. In this case, soil fertility in the forest decreases and plant growth is adversely affected. In some cases, ash temporarily enriches the soil in terms of minerals, but the dense ash layer negatively affects vegetation and agriculture in the long term. On the other hand, ash and lava flows can alter watershed patterns, impacting water quality and availability. This can affect drinking water, agriculture, and industry, often leading to increased costs for water treatment and management.

- ***Effects on livelihoods and local economy:*** Volcanic eruptions directly affect forestry and agriculture areas, leading to labor losses and reduced income. In particular, people who make a living from forest products experience economic difficulties due to losses caused by volcanic activities. Also local people engaged in agricultural production around the forest may become unable to use their fields due to ash and lava flows. This situation seriously affects local production and local economy and may lead to a decrease in food production.

- ***Effects on tourism and recreation activities:*** Like other natural disasters, volcanic activities have a negative impact on tourism activities. Volcanic eruptions and their ash deposits can damage hiking trails, campsites and natural attractions. This could lead to a decrease in the number of tourists visiting the forest and damage to the local economy dependent on tourism.

- ***Social and cultural effects on local people:*** Volcanic activities often lead to displacement because of ash fall, toxic gases, and destruction of infrastructure, impacting the health and safety of people living near forests. Ash can also pose a health burden by causing respiratory problems and skin irritations. Furthermore, for people that are culturally linked to forests, volcanic eruptions can destroy sacred sites or areas of cultural value in the forest, which means a spiritual loss for the local population.

3.2. Hydrological Hazards

3.2.1. Flood

Floods significantly reshape forest ecosystems, altering soil structure, vegetation, and the overall water balance within these habitats. Forest soils typically have a high capacity to absorb water due to their complex root networks and organic matter content, making forests natural buffers that can mitigate flood impacts. During intense rainfall events, however, this absorption capacity may be exceeded, leading to surface runoff that erodes nutrient-rich topsoil, displaces essential sediments, and removes plant cover, especially among shallow-rooted species. These soil layers are important for maintaining vegetation health, and their loss disrupts the growth of forest flora and contributes to habitat degradation both locally and downstream, affecting species that rely on stable soil and water conditions (Gallay et al., 2021; Nel et al., 2014).

As floodwaters sweep through forested regions, they often uproot vegetation, destabilize soil, and leave behind sediment deposits that alter the forest floor. This process not only impacts plant growth by compacting and layering the soil but also reshapes forest biodiversity. The accumulation of sediments brought by floods often alters soil chemistry, changing nutrient dynamics in ways that can inhibit the regrowth of native species. This can lead to an increased risk of invasive species establishing themselves in the disturbed soil, potentially outcompeting local flora and reducing biodiversity. Forests fragmented by flooding face additional risks to their species composition, as plant and animal habitats are disturbed and sometimes permanently altered (Blöschl, 2022; Gallay et al., 2021).

Forests are important in flood control through their natural operations of regulating water flow and reducing flood peaks. Intact and healthy forests in this regard act like a "natural sponge"—they absorb the excess water and release it slowly, hence lessening the intensity of flooding in lower regions and facilitating faster ecological recovery post-flood events. Such human-induced changes, in the form of deforestation coupled with expansion into urban zones, disrupt this natural order by weakening the capability of the forest to retain water. Loss of vegetation cover and land use changes weaken the natural flood-buffering functions of the landscape, again focusing on the importance of forest conservation and sustainable management. The retained ecosystems will afford protection for the surrounding diverse landscapes and communities against the growing vulnerability to flooding and preserve an important hydrological role of forests towards long-term resilience (Blöschl, 2022; Gallay et al., 2021; Nel et al., 2014).

On the other hand, the effects of floods on the socioeconomic functions of forests are far-reaching and manifest themselves in both direct and indirect ways. Floods seriously threaten the functions of forests and cause economic, social and environmental damage to society. Floods have a major effect on the social and economic life of those who are exposed to flood disaster. They affect infrastructure and services such as public and private buildings, road networks, electricity supply facilities, agricultural land and livestock. We can express these damages as follows:

- ***Infrastructure damage:*** Floods can damage residential areas, buildings, bridges and roads. Due to floods, settlements and houses are severely damaged and become unusable. In addition, floods also seriously affect transportation and many roads and bridges are destroyed. Again, other infrastructure services are also damaged and social and economic conditions of the people are deteriorating. Compensation for these damages to infrastructures is very costly, and billions of dollars of economic losses occur worldwide every year due to flood damages.

- ***Loss of natural resources and ecosystem services:*** As with other natural disasters, flooding damages trees and non-wood forest products, thus disrupting the income loss of local people who make their living from wood and non-wood forest products. Beside, due to flood water quality and quantity is negatively affected. Flooding can disrupt hydrological patterns, affecting water supply to for local people. The sediments and pollutants carried by floods can deteriorate water quality, which not only affects ecosystems, as well as the water resources used by humans.
- ***Erosion and deterioration of soil quality:*** Flood events reduce the soil retention capacity of forests by accelerating soil erosion. Erosion also increases the amount of sediment transported to agricultural areas, leading to loss of productivity in agricultural lands. This affects both communities that depend on forests and those that utilize the surrounding agricultural land.
- ***Effects on livelihoods and local economy:*** For local people, especially forest villagers, forest resources are main source of income. Flood damage to the forest ecosystem also affects forestry activities and related activities such as agriculture and tourism sector. People working in these sectors may suffer temporary or permanent job losses. These are all negative effects of flood on the local economy.

3.2.2. **Mass movement (wet)**

Mass movement events triggered by hydrological factors, such as landslides, mudflows, and wet rockfalls, pose significant threats to forest ecosystems by impacting soil stability and vegetation. Wet landslides typically occur on steep slopes where saturated soil loses stability, leading to large volumes of earth and plant life sliding downslope. This process strips the area of essential vegetation cover, exposing bare soil highly prone to erosion. Over time, these disturbances hinder native plants from reestablishing, as destabilized soil layers and altered site conditions favor invasive species, disrupting biodiversity and changing forest composition (Cui et al., 2012; Geertsema et al., 2009; Schuster & Highland, 2003).

Mudflows, a type of debris flow with high water content, further exacerbate these impacts by carrying sediment and organic debris over long distances, depositing compacted, nutrient-poor material. These thick layers bury root systems, impede water infiltration, and restrict the establishment of new vegetation, leading to prolonged recovery periods and reduced habitat availability for forest-dependent species. Mudflows often affect areas with weakened soil or previous deforestation, underscoring the importance of forest integrity in reducing these destructive events. The compacted sediment deposited by mudflows limits root penetration, slowing down regrowth and making it challenging for native species to return, while creating conditions that invasive plants may exploit (Cui et al., 2012; Geertsema et al., 2009; Schuster & Highland, 2003).

Wet rockfalls, though less frequent, also contribute to forest disruption by dislodging large rocks that crush vegetation on impact and alter soil structure. These events create openings in the forest floor that encourage opportunistic species, further disturbing the ecosystem. Rockfalls can also reshape the physical landscape, impacting drainage patterns and nutrient flow, which affects overall forest health and stability. Together, these hydrologically driven mass movements fragment forest habitats, reduce biodiversity, and introduce barriers to natural regeneration, leaving affected areas in prolonged states of ecological change that may require significant intervention to restore soil quality and support reforestation efforts (Cui et al., 2012; Geertsema et al., 2009; Schuster & Highland, 2003; Walker & Shiels, 2010)

The effects of mass movements on the socioeconomic functions of forests are given under the "3.1.2." subheading. In order to avoid repetition, no evaluation has been made under this heading.

3.3. Meteorological Hazards

3.3.1. Extreme temperature

Wide and extreme temperature fluctuations have had a great impact on the forest ecosystem because they disrupt essential physiological and ecological processes. High temperatures are usually associated with long droughts, thus increasing rates of evapotranspiration that reduce the soil moisture; as a result, they also stress the trees by making them weak. This condition predisposes them to pests, such as bark beetles, which usually attack trees weakened by droughts, thereby leading to outbreaks that can decimate entire forest populations (Jentsch & Beierkuhnlein, 2008; Lindner et al., 2010). High temperatures alter the rate of photosynthesis and respiration, impacting growth and reducing forest productivity, aside from their probable alterations in carbon and nitrogen cycling. This has, for example, happened during the European heat wave 2003, when decreased primary productivity temporarily switched forests from a carbon sink to a carbon source. (Handmer, 2012).

In contrast, extreme cold events, including frost, can severely impact tree physiology, particularly during vulnerable growth phases such as early spring and late autumn. Frost events can damage or kill sensitive plant tissues, particularly in species not adapted to sudden cold temperatures, reducing their growth potential and reproductive success for the season. Cold waves also restrict the distribution range of species by creating inhospitable conditions, thus impacting biodiversity and possibly shifting species composition within forest ecosystems (Jentsch & Beierkuhnlein, 2008; Lindner et al., 2010). For example, frost damage to young buds and shoots can limit growth and impair photosynthetic capacity, ultimately affecting the forest's structural dynamics and productivity.

These temperature extremes, through their cumulative effects, disrupt biodiversity, species composition, and ecosystem function. Forests may see a shift in species composition as drought-tolerant species gain a competitive advantage under prolonged heat stress. This shift alters forest structure and ecosystem services, including carbon sequestration and water regulation. Additionally, extreme temperatures contribute to a weakened resistance to invasive species, which further threatens biodiversity and ecosystem resilience, potentially transforming forests from stable ecosystems into vulnerable ones with limited adaptive capacity (Handmer, 2012; Lindner et al., 2010).

Extreme hot and cold weather conditions have also significant impacts on the socioeconomic functions of forest ecosystems, both directly and indirectly. Here are the some of these impacts:

- ***Effects on ecosystem services:*** Ecosystem services such as carbon storage capacity, soil quality, nutrient cycling, water cycle and water supply are negatively affected because of extreme temperatures. For instance, extremely hot weather reduces the carbon storage capacity of vegetation in forests. Drying or dying trees can cause the release of stored carbon into the atmosphere. Cold waves also reduce the carbon storage capacity of forests, especially affecting young trees. Beside extreme temperatures can reduce soil organic matter and moisture, degrading soil structure and slowing nutrient cycling. Furthermore extremely hot weather can increase evaporation, making water supply difficult and increasing the risk of drought. Cold weather can limit soil and surface water through freezing, slowing the water cycle and reducing the water supply function of forests. All these changes in ecosystems reduce the socioeconomic value of forests.
- ***Effects on livelihoods and local economy:*** Extreme weather can have a negative economic impact on local communities that

depend on forestry, agriculture, or non-wood forest products by decreasing yields and productivity. Food security, rural economic stability, and local income are all affected directly by less access to these resources. Declines in timber production, tourism, and on-wood forest products production negatively affect employment and economic activity in forest areas. For instance extremely hot weather can reduce timber yields by reducing the growth rate of trees. Drought can weaken trees and make them more vulnerable to disease. Cold waves can cause frost damage, reducing timber quality and causing economic losses. Loss of employment weakens the local economy and increases the costs for governments to provide support.

- ***Health problems:*** Extreme heat waves can pose health risks for communities living around forests. Individuals living in these areas may face health problems such as heat stroke or dehydration. Cold weather increases the risk of hypothermia and frostbite. This situation leads to additional healthcare burdens for governments.
- ***Effects on tourism and recreation:*** Extremely hot weather can increase the risk of forest fires, causing damage to tourism and recreation areas. On the other hand, extreme cold weather can cause temporary closure of some recreational areas. Difficulty in accessing the touristic area due to extreme cold weather in winter can limit touristic activities and slow down economic activities in the region, as it prevents the continuation of tourism activities throughout the year. The sustainability of tourism is at risk as the frequency and severity of such events increase.

3.3.2. **Storm**

Storms affect the structure of forests through strong winds, heavy rain, hail, and sometimes lightning. Strong winds cause breaking and snapping of branches, creating gaps in the canopy where trees may be snapped or uprooted, again changing light availability and forming microsites that are optimum for invasive species. Such structural changes drive changes in species composition as opportunistic species begin to colonize disturbed areas and often reduce native biodiversity (Jentsch & Beierkuhnlein, 2008; Lindner et al., 2010). Besides that, hailstorms and serious winter storms contribute to the physical insults on trees, as heavy snow and ice accumulation can lead to broken branches or even tree falls, further disrupting the forest canopy and exposing the understory to a harsher environment (Handmer, 2012).

Intense rainfall from storms greatly accelerates soil erosion and landslides, particularly on steep, forested slopes. Heavy rains displace soil, weakening root systems and making trees more vulnerable to being uprooted by wind, which over time further destabilizes the soil. This disruption of soil layers impacts forest hydrology by changing infiltration rates and stream flows, potentially altering nutrient cycling and decreasing forest productivity. Additionally, severe storms carrying dust and sand particles can abrade leaves, reducing photosynthetic efficiency, which undermines forest health and resilience (Handmer, 2012; Lindner et al., 2010).

Beyond immediate physical damage, storms introduce long-term ecological impacts by altering species composition and reducing ecosystem resilience. Lightning strikes in thunderstorms, for example, often ignite wildfires that can dramatically reshape forest landscapes by removing vegetation and altering soil properties. The gaps created by storm events and subsequent fires reduce forest resilience, facilitating the establishment of invasive species and pests. This, in turn, compromises biodiversity and ecosystem services such as carbon storage, soil protection, and water regulation. Over time, such disturbances may push forest ecosystems toward alternative states, affecting their capacity to function as stable carbon sinks and sources of biodiversity (Jentsch & Beierkuhnlein, 2008; Peterson, 2000).

Here are the socioeconomic effects of storms:

- ***Effects on forest products:*** Storms cause reductions in the production of timber and other forest products. Storms and cyclones cause trees to fall and branches to break, reducing timber quality. Destroyed trees are generally not usable as construction timber and are diverted to other products with lower economic value. This leads to a reduction in timber-based revenues. Valuable forest products such as fruits, seeds, medicinal plants and mushrooms can also be damaged by storms. The decrease in the amount of these products creates serious decreases in the incomes of local people that depend on forest products.
- ***Effects on livelihoods and local economy:*** As stated in the previous heading, the production of timber and non-wood forest products decreases due to storms and therefore storms threaten the livelihoods of people, especially those that rely on forest products for income. Reduction in forest resources endangers the economic security of rural communities that depend on timber and other products for their livelihoods. Post-storm damage causes a reduction in the production of forest products, leading to employment losses in the forestry sector. At the same time, the decline in tourism negatively affects job opportunities in the

service sector. Also rehabilitation and reforestation of damaged forest areas are costly. Such maintenance costs strain the forest management budget and limit resources for other forestry activities.

- ***Effects on tourism and recreation:*** Like other natural disasters, storms have a similarly negative impact on tourism and recreation functions, which are important socioeconomic functions of forests. The aesthetic value of forests decreases as natural landscapes are damaged. At the same time, various tourism infrastructure damages occur and touristic activities in the relevant forest area decrease. As a result, local companies including restaurants, hotels, and tour operators are impacted by this decline in tourism-related income, which also lowers tax revenues of governments.

- ***Effects on ecosystem services:*** Many important forest ecosystem services are also damaged due to storms and cyclones, and therefore socioeconomic functions are also affected. For example, due to storms and tornadoes, trees fall down and their trunk breaks occur and the carbon storage capacity of forests decreases. In addition, erosion increases with the fall of trees and water resources are damaged. All these negativities adversely affect the quality of life of the local people.

3.4. Climatological Hazards

3.4.1. Drought

Drought has an impact on forest ecosystems, putting significant stress on trees and slowing their growth, reducing seed production, and, in severe cases, causing dieback. Large trees, with their high water demands, are particularly at risk, which can change the structure of the forest and gradually favor species that are more tolerant to dry conditions (Peñuelas & Sardans, 2021). Long-lasting drought also disrupts nutrient cycles, degrades soil quality, and lowers fertility, as water becomes scarce. In extreme cases, forests can shift toward shrublands or grasslands as smaller, drought-resistant species start to dominate in place of trees (Peñuelas & Sardans, 2021).

Additionally, drought-induced moisture loss elevates the risk of wildfires within forests. Low soil moisture and high temperatures dry out vegetation, making forests more prone to fires. The shift in species composition to drought-resistant but more flammable vegetation types further heightens this risk (Atalay et al., 2024). In grazed forested areas, drought can alter the understory by reducing fine fuels through grazing; however, overgrazing can degrade soil and impede recovery, thus making forests more vulnerable to fires and subsequent droughts.

Drought also weakens trees, reducing their ability to produce defensive chemicals, which increases susceptibility to pests such as bark beetles (Furniss et al., 2020). This vulnerability is particularly acute in dense forested areas where competition for limited water resources is high. As a result, drought amplifies tree mortality, alters forest composition, and heightens ecosystem susceptibility to biotic and environmental disturbances, contributing to a more pronounced ecological imbalance (Şahan et al., 2023).

Drought leads to similar socioeconomic effects stemming from other natural disasters.

- ***Effects on forest products:*** Drought reduces the quality of timber production by causing trees to become dead. Dead trees are prone to cracking and deformity, which reduces the product quality and production capacity of the timber industry. Likewise, drought reduces the growth rate of non-wood forest plants and reduces productivity. Beside, drought increases the risk of forest fires and fires cause short-term and long-term destruction of forests and slow down the regeneration process. Also, drought-affected forests become vulnerable to invasive species that can change forest composition, reduce biodiversity and affect the availability of forest products.
- ***Effects on livelihoods and local economy:*** Drought has very serious negative impacts on forests, agriculture and livestock. Drought worsens water shortages by affecting the flow of water from forested areas to downstream farmland. People who depend on these sectors for their livelihoods suffer income losses due to drought. As a result, the local economy is directly affected and may lead to employment losses in rural communities. For all these reasons, local people experience income losses.
- ***Effects on tourism and recreation:*** Loss of vegetation in forests due to drought reduces the beauty of the landscape and reduces its touristic attractiveness. Drought can also increase the risk of fire, leading to the temporary closure of some forested areas for safety reasons. Such closures disrupt nature tourism and reduce revenues from the tourism sector. Trails, campsites, picnic places, and other infrastructure are frequently damaged by drought and the fires that proceed, necessitating costly replacements.
- ***Effects on ecosystem services:*** Drought directly affects the products and services provided by agricultural and forest ecosystems and

causes very serious problems, especially famine. Due to drought, the amount of organic matter and fertility of the soil decreases and the soil becomes prone to erosion. This leads to the loss of the fertile layer of the soil and thus to a decrease in the productivity of forest land and agricultural land. In addition, soil moisture decreases because of drought and forests lose their water retention capacity. As a consequence of this situation, agricultural activities of the local population suffer owing to water scarcity.

3.4.2. **Wildfire**

Wildfires, especially under prolonged drought conditions marked by high temperatures and low humidity, severely threaten forest ecosystems. They damage vegetation, deplete essential nutrients, and increase erosion—effects that are especially pronounced on sloped landscapes (Atalay et al., 2024). In regions prone to fires, such as Antalya, Türkiye, extreme fire risks become more prevalent during the hottest and driest months. When wildfires occur frequently, they can drive lasting changes in vegetation, pushing forests toward shrubland or grassland ecosystems, which reduces biodiversity and slows down ecosystem recovery. The cycle of drought feeding into wildfire intensity and frequency further challenges the resilience of forests, making it harder for these ecosystems to bounce back (Atalay et al., 2024).

Dry conditions accelerate soil degradation and alter nutrient cycles post-fire, making recovery slow and difficult. Fires often promote shrub regrowth over trees, especially in ecosystems subjected to repeated burning (Peñuelas & Sardans, 2021). Frequent fires deplete soil fertility and organic matter, favoring species that quickly resprout, such as shrubs. This trend promotes shrubland expansion over forest regrowth, jeopardizing soil health, ecosystem stability, and biodiversity, as both drought and fire cycles contribute to ongoing ecosystem degradation (Peñuelas & Sardans, 2021).

Climate-induced factors and human interventions influence wildfire frequency and intensity, affecting species composition and forest management strategies. Fire regimes, determined by frequency, intensity, and spread, are shaped by climate and human activities (Şahan et al., 2023). Livestock grazing can reduce fine fuels and mitigate fire risks, but in areas with intense fire suppression, fuel accumulation raises the risk of severe fires. Wildfires contribute to landscape heterogeneity by creating a patchwork of burned and unburned areas, which influences forest structure and supports resilience against future disturbances, such as drought and pest infestations (Furniss et al., 2020).

Compared to other natural disasters, forest fires have the most negative impact on forests. Since it destroys forested areas, it almost eliminates all the functions of forest ecosystems. Forest fires not only damage forest areas, but also affect the production of forest products and cause disasters such as erosion, deterioration of water resources, air pollution, desertification, flooding, landslides and avalanches. In addition, it damages areas used for recreational purposes such as picnic areas and tourism areas, settlements near and around forest areas and people's homes, and also damages the sociocultural structure.

- ***Effects on forest products:*** Fire weakens the forest products industry by directly affecting timber production. Burned trees become unusable and there is a reduction in wood supply after the fire. This situation means serious loss of income for forest enterprises. Non-wood herbal forest products such as resin, medicinal plants, mushrooms and fruits are also damaged by fire and the livelihoods of people who make a living with these products are affected.
- ***Effects on livelihoods and local economy:*** In areas where forest fires occur, livelihoods based on forest resources are also destroyed. People working in agriculture, animal husbandry, forestry and tourism lose their jobs and income, and the local economy is adversely affected, especially considering the livelihoods of people living in rural areas. Forest fires also damage agricultural lands and pastures, affecting food production. When water resources supplied from forests are also polluted, agricultural irrigation opportunities are reduced and thus agricultural productivity decreases. Hence, the socioeconomic situation of people living in rural areas deteriorates. Also it takes years for forests to regain their former productivity after fire. Reforestation works and the recovery process of the ecosystem are expensive and time-consuming, which imposes a long-term economic burden on the forestry sector.
- ***Effects on tourism and recreation:*** Burned areas lose their tourism potential and there is a decrease in ecotourism activities. This leads to a decrease in income from tourism. After the fire, some forest areas are closed to the public due to security measures. This situation restricts recreational activities such as nature sports and camping and causes economic damage to local tourism enterprises.
- ***Effects on ecosystem services:*** Although forests are the largest terrestrial carbon store, they are the world's third largest source of

emissions after coal and oil in case of combustion or destruction. According to Intergovernmental Panel on Climate Change (IPCC) reports, 17% of the world's total greenhouse gas emissions are caused by deforestation and forest degradation (OGM, 2010). The main reason of deforestation is forest fires. In other words, forest fires are one of the main causes of climate change. Therefore, they adversely affect not only the nearby geography where the fire occurs, but also the whole world and ecosystems. On the other hand, forest fires also reduce the quality of life of people by disrupting the water cycle, reducing soil quality and causing erosion.

- ***Long-term socioeconomic changes and effects on forest management:*** Strategic changes in forest management are needed to reduce fire risk. This includes measures such as the selection of fire-resistant tree species, regular forest clearing and the creation of fire lanes. As forest fires are becoming more frequent and severe due to the effects of climate change, more investment is needed to establish fire-resilient and climate change-adapted forest ecosystems. In addition, reforestation efforts are necessary to restore fire-affected forests. All these efforts are costly and require a significant share of the state budget.

3.5. Biological Hazards

3.5.1. Epidemic

The health of forest ecosystems has been greatly compromised as a result of disease outbreaks. This is mostly attributed to invasions by various pathogens which include fungi, bacteria, viruses and phytoplasmas. Such pandemics cause high levels of tree death, which negatively affects important ecosystem functions such as services. Chestnut blight and Dutch elm disease are examples of outbreaks that have changed the structure of forests and reduced biodiversity by decimating tree numbers (LeBoldus et al., 2024; Zulperi et al., 2022). The loss of these trees has an impact on many ecosystem services including timber harvesting, carbon sequestering, flood moderation and temperature regulation. There is also a decline in the structural complexity and resilience of forests which affect their capacity to enhance biodiversity, improve soil and water quality, and sustain connected aquatic systems downstream.

The spread of pathogens like Hymenoscyphus fraxineus, which leads to ash dieback, illustrates the wider ecological effects of tree epidemics, especially in uniform forest areas. The loss of dominant tree species impacts food, habitat, and shelter for various wildlife, including birds, mammals, and insects, causing broader declines in biodiversity (Freer-

Smith & Webber, 2015). For example, the loss of tanoak from sudden oak death reduces acorn availability, an essential food for wildlife, which can disrupt predator populations and even affect disease patterns that may have implications for human health (LeBoldus et al., 2024).

Beyond the loss of species, epidemics compromise ecosystem services by altering nutrient cycles and destabilizing soils. With the reduction of canopy trees, forests lose some of their capacity to sequester carbon, contributing to elevated atmospheric CO_2 levels. Moreover, the decline in forest cover weakens soil structure, increasing erosion risks and threatening water quality in nearby aquatic systems. Pathogen-driven forest degradation can also alter local climate conditions, adding stress to surviving plant and animal species, while impacting ecosystem functions like water filtration and habitat provision (Skrzecz et al., 2024).

Managing forest epidemics requires a combination of preventive and adaptive strategies. Enhancing species diversity and monitoring can help slow the spread of pathogens. Integrated pest management, which includes the use of biological control agents like entomopathogens, provides a sustainable alternative to chemical treatments, preserving ecological balance and supporting forest resilience (Skrzecz et al., 2024). Additionally, addressing climate change, which exacerbates disease spread and heightens tree vulnerability, is crucial for maintaining forests' roles in carbon storage, biodiversity conservation, and ecosystem stability (Balla et al., 2021).

3.5.2. Insect infestation

Insect infestations are major threats to forest ecosystems, particularly when involving non-native species. The emerald ash borer (Agrilus planipennis), introduced from Asia, has decimated ash trees across North America, altering forest composition and impacting species reliant on ash. The loss of trees disrupts ecosystem services like air purification, water regulation, and carbon storage, with ripple effects on habitat connectivity and forest biodiversity (LeBoldus et al., 2024). These infestations not only threaten individual tree species but also impact entire ecosystems, affecting food webs and numerous organisms.

Invasive insects inflict direct damage on trees as well as heightening their vulnerability to disease, lowering their survival rates. In particular, the mountain pine beetle (Dendroctonus ponderosae) and bark beetles interfere with the tree nutrient cycle and bring about pathogens which lead to tree mortality and deeper carbon sinks in the forests becoming rarer (Balla et al., 2021; Zulperi et al., 2022). Such ecological alteration diminishes the ability to hold water, enhances soil erosion, and makes the forests more susceptible to wildfires, further deteriorating the forests against added burdens like climate change. In their new niches however, invasive insects are often unable to find natural enemies which leads to population explosions that cause extensive destruction across whole forested areas.

The expansion of the range of the mountain pine beetle is an example of how climate change enhances insect pest infestations through the conditioning of these insects' survival and dispersal. Such infestations cause severe tree death with concomitant change to the structure of the ecosystems, loss of biodiversity, and loss of forest species that rely on it for shelter (Freer-Smith & Webber, 2015). The losses of trees through such infestations affect the services of the ecosystems increasing carbon emissions, soil destabilization, and threats of landslides and erosion. The diminishing forested landscapes and escarpments also bring down the cultural and aesthetic and recreational value impacting on tourism and local economies as the pleasant views are destroyed and the places become difficult to reach.

Bacillus thuringiensis is an example of a biological control agent that can be used to control insect infestations as part of an integrated pest management (IPM) strategy, which is more environmentally friendly than chemical pesticides (Skrzecz et al., 2024). The success of these agents works range from unpredictably low, such as in the case of being adapted to varying conditions across the forest types. The growing likelihood of invasions by exotic species of insects makes it necessary to develop adaptive management and breeding strategies of trees that will be pest resistant for the sake of maintaining the forests in good health as these biological threats increase (LeBoldus et al., 2024).

In this part, the impacts of epidemic and insect infestation disasters are evaluated together.

- ***Effects on biodiversity and habitat:*** Biological disasters have devastating effects on local flora and fauna, reducing biodiversity. Especially invasive species or pathogens threaten native plant and animal species. This reduces the ecosystem services provided by the forest and the economic benefits derived from biodiversity. Insect infestations lead to the destruction of important habitats for birds, mammals and other forest species. When the bio diverse structure of forests decreases, the ecotourism potential also decreases. This situation negatively affects the economy of local communities that generate income from biodiversity-based tourism.
- ***Effects on forest products:*** Insect infestations, especially pests such as bark beetles, cause serious damage to the trunk of trees

and reduce the quality of timber. This leads to economic losses in the timber industry. Since insect-damaged wood has low commercial value, it causes economic losses and negatively affects the livelihoods of local people. Losses also occur in non-wood forest products due to insect damage. Insect damage and biological disasters reduce the availability and diversity of these products.

- ***Effects on livelihoods and local economy:*** Rural economies based on forest products are greatly affected by such losses. For example, chestnut tree, which is a forest tree with high economic value, is frequently damaged by chestnut gall wasp and chestnut blight damage, and this situation negatively affects chestnut and chestnut honey production and causes loss of income for forest villagers who depend on chestnut for their livelihood. Also, as timber quality decreases, it affects livelihoods of local people and may increase economic stagnation in forest villages.
- ***Increase in forest management costs:*** To reduce the impacts of insect infestations, forest management should prioritize pest-resistant tree species, apply biological control methods and establish regular monitoring systems. Such measures increase forest management costs and require a review of forestry policies. Reforestation and ecosystem restoration are important for the regeneration of insect-damaged forests. However, this process is costly and can take years. Reforestation activities require labor and financial resources, which creates an additional burden for local governments.

4. Conclusions and Suggestions

Natural disasters seriously affect forest ecosystems as well as all ecosystems. Especially in recent years, forest resources all over the world are under threat due to global environmental problems and natural disasters, especially climate change. Since forests have many products, services and functions of vital importance for humans and all living things, their sustainable management becomes even more important. Therefore, one of the most critical sectors for sustainable development is the forestry sector. However, as stated in this study, various geophysical, hydrological, meteorological, climatological and biological disasters seriously damage the provisioning, regulating, cultural and supporting services provided by forests.

The scope of this study is limited to the socioeconomic functions of forests and the effects of natural disasters on these functions are discussed in detail. Within the scope of this study, the following conclusions and suggestions were tried to be put forward.

- In order to reduce the effects of natural disasters, necessary precautions should be taken by the authorized institutions, in other words, they should be proactive. Nevertheless, when some unavoidable disasters occur, the impact of the damage should be minimized by immediate actions. Combating disasters should be an important policy issue for countries and strategies for effective and efficient combating global environmental problems and natural disasters should be determined in all sector plans including development plans.
- All natural disasters directly or indirectly affect the socioeconomic functions of forests negatively. As a result of natural disasters, ecosystem services, forest products production, ecotourism and recreation activities, infrastructure and transport, soil fertility and water quality are damaged. Therefore, the livelihoods and incomes of local people are adversely affected and problems arise in the local economy. People living in rural areas and interacting with forest resources for their livelihoods usually constitute the poorest group of the population. Hence, natural disasters worsen the socioeconomic situation of local people. The task of governments or local authorities here is to try to prevent disasters, protect forest resources and at the same time financially support local people.
- Removing the damages caused by disasters and restoring the areas are very costly and create a burden on the budgets of state or local governments. In this case, endeavouring to provide alternative financial resources other than the budget may provide facilities to the administrators in meeting the costs.
- It is essential to protect forest resources, which offer a cost-effective solution to combat climate change and other global environmental problems. Especially as a result of forest fires, while the whole ecosystem is damaged on the one hand, on the other hand, greenhouse gas emissions increase significantly because of the trees burning. For this reason, it is necessary for all countries to increase measures to prevent forest fires and to carry out studies to shorten the extinguishing time after the fire occurs.

References

Alexander, D. (1997). The study of natural disasters, 1977-1997: some reflection on a changing field of knowledge. Disasters, 21(4), 284-304. https://doi.org/10.1111/1467-7717.00064

Alexander, D. (2018). Natural Disasters. Routledge. https://doi.org/10.4324/9781315859149

Arnalds, O. (2013). Chapter Six - The Influence of Volcanic Tephra (Ash) on Ecosystems. In D. L. Sparks (Ed.), Advances in Agronomy (Vol. 121, pp. 331-380). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-407685-3.00006-2

Atalay, H., Dervisoglu, A., & Sunar, A. F. (2024). Exploring Forest Fire Dynamics: Fire Danger Mapping in Antalya Region, Türkiye. ISPRS International Journal of Geo-Information, 13(3). https://doi.org/10.3390/ijgi13030074

Balla, A., Silini, A., Cherif-Silini, H., Chenari Bouket, A., Moser, W. K., Nowakowska, J. A., Oszako, T., Benia, F., & Belbahri, L. (2021). The Threat of Pests and Pathogens and the Potential for Biological Control in Forest Ecosystems. Forests, 12(11). https://doi.org/10.3390/f12111579

Blöschl, G. (2022). Three hypotheses on changing river flood hazards. Hydrology and Earth System Sciences, 26(19), 5015-5033. https://doi.org/10.5194/hess-26-5015-2022

Chaudhary, M. T., & Piracha, A. (2021). Natural Disasters—Origins, Impacts, Management. Encyclopedia, 1(4), 1101-1131. https://doi.org/10.3390/encyclopedia1040084

CRED, C. f. R. o. t. E. o. D. (2023). Natural Hazards Subgroups and Types in the IRDR Peril Classification and Hazard Glossary. Retrieved 11/11/2024 from https://doc.emdat.be/docs/data-structure-and-content/disaster-classification-system/#fnref:3

Cui, P., Lin, Y.-m., & Chen, C. (2012). Destruction of vegetation due to geo-hazards and its environmental impacts in the Wenchuan earthquake areas. Ecological Engineering, 44, 61-69. https://doi.org/10.1016/j.ecoleng.2012.03.012

Demirci, U. (2017). Orman Kaynaklarinin Toplam Ekonomik Değerinin Tahmini: Camili Biyosfer Rezerv Alani Örneği, Doktora Tezi, Artvin Çoruh Üniversitesi Fen Bilimleri Enstitüsü Orman Mühendisliği Anabilim Dali, Artvin

Forest Europe. (2020). State of Europe's Forests 2020. Ministerial Conference on the Protection of Forests in Europe - Forest Europe, Liaison Unit Bratislava

Freer-Smith, P. H., & Webber, J. F. (2015). Tree pests and diseases: the threat to biodiversity and the delivery of ecosystem services. Biodiversity and

Conservation, 26(13), 3167-3181. https://doi.org/10.1007/s10531-015-1019-0

Furniss, T. J., Larson, A. J., Kane, V. R., & Lutz, J. A. (2020). Wildfire and drought moderate the spatial elements of tree mortality. Ecosphere, 11(8). https://doi.org/10.1002/ecs2.3214

Gallay, I., Olah, B., Gallayová, Z., & Lepeška, T. (2021). Monetary Valuation of Flood Protection Ecosystem Service Based on Hydrological Modelling and Avoided Damage Costs. An Example from the Čierny Hron River Basin, Slovakia. Water, 13(2). https://doi.org/10.3390/w13020198

GDF. (2019). Criteria and Indicators of Sustainable Forest Management Implementation Guide, General Directorate of Forestry, Ankara

Geertsema, M., Highland, L., & Vaugeouis, L. (2009). Environmental Impact of Landslides. In (pp. 589-607). https://doi.org/10.1007/978-3-540-69970-5_31

Geertsema, M., & Pojar, J. J. (2007). Influence of landslides on biophysical diversity — A perspective from British Columbia. Geomorphology, 89(1-2), 55-69. https://doi.org/10.1016/j.geomorph.2006.07.019

Gökçe, O., & Tetik, Ç. (2012). Teoride ve Pratikte Afet Sonrası İyileştirme Çalışmaları. AFAD.

Grishin, S. Y. D. M., Roger. (1996). Dynamics of Forests After Catastrophic Eruptions of Kamchatka's Volcanoes. In L. M. D. Turner, C.H.; Lim, S.S.L.; Ng, P.K.L. (Ed.), Biodiversity and the Dynamics of Ecosystems (Vol. 1, pp. 133-146). DIWPA.

Handmer, J., Y. Honda, Z.W. Kundzewicz, N. Arnell, G. Benito, J. Hatfield, I.F. Mohamed, P. Peduzzi, S. Wu, B. Sherstyukov, K. Takahashi, and Z. Yan. (2012). Changes in impacts of climate extremes: human systems and ecosystems. In C. B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Ed.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (pp. 231-290). Cambridge University Press.

Jenkins, M., Schaap, B. (2018). Forest Ecosystem Services, Background study prepared for the thirteenth session of the United Nations Forum on Forests, United Nations.

Jentsch, A., & Beierkuhnlein, C. (2008). Research frontiers in climate change: Effects of extreme meteorological events on ecosystems. Comptes Rendus. Géoscience, 340(9-10), 621-628. https://doi.org/10.1016/j.crte.2008.07.002

Korup, O. S., Jan, & Mohr, C. H. (2019). Increased landslide activity on forested hillslopes following two recent volcanic eruptions in Chile. Nature Geoscience, 12(4), 284-289. https://doi.org/10.1038/s41561-019-0315-9

LeBoldus, J. M., Lynch, S. C., Newhouse, A. E., Sondreli, K. L., Newcombe, G., Bennett, P. I., Muchero, W., Chen, J. G., Busby, P. E., Gordon, M., & Liang, H. (2024). Biotechnology and Genomic Approaches to Mitigating Disease Impacts on Forest Health. Annu Rev Phytopathol, 62(1), 309-335. https://doi.org/10.1146/annurev-phyto-021622-114434

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M. J., & Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management, 259(4), 698-709. https://doi.org/10.1016/j.foreco.2009.09.023

Mata-Lima, H., Alvino-Borba, A., Pinheiro, A., Mata-Lima, A., & Almeida, J. A. (2013). Impacts of natural disasters on environmental and socio-economic systems: what makes the difference? Ambiente & Sociedade, 16(3), 45-64. https://doi.org/10.1590/s1414-753x2013000300004

MEA. (2003). Ecosystems and human well-being: a framework for assessment, Millennium Ecosystem Assessment, Island Press, Washington, DC, USA.

MEA. (2005). Ecosystems and human wellbeing. Biodiversity Synthesis. Millennium Ecosystem Assessment, Island Press. Washington DC, USA.

Merlo, M., Briales, E.R. (2000). Public Goods and externalities linked to Mediterranean forests: economic nature and policy, Land Use Policy, 17(3): 197-208.

Merlo, M., Croitoru, L. (2005). Concepts and methodology: a first attempt towards quantification, Valuing mediterranean forests: towards total economic value, 17-36.

Morgenroth, J., & Armstrong, T. (2012). The impact of significant earthquakes on Christchurch, New Zealand's urban forest. Urban Forestry & Urban Greening, 11(4), 383-389. https://doi.org/10.1016/j.ufug.2012.06.003

Nel, J. L., Le Maitre, D. C., Nel, D. C., Reyers, B., Archibald, S., van Wilgen, B. W., Forsyth, G. G., Theron, A. K., O'Farrell, P. J., Kahinda, J. M., Engelbrecht, F. A., Kapangaziwiri, E., van Niekerk, L., & Barwell, L. (2014). Natural hazards in a changing world: a case for ecosystem-based management. PLoS One, 9(5), e95942. https://doi.org/10.1371/journal.pone.0095942

OGM. (2010). İklim Değişikliği Kapsamında Ormanların Önemi, Kopenhag Müzakere Sonuçları, İklim Değişikliği ve Biyoenerji Çalışma Grubu, Orman Genel Müdürlüğü, Ankara.

OGM. (2014). Ekosistem tabanlı fonksiyonel orman amenajman planlarının düzenlenmesine ait usul ve esaslar, Tebliğ No: 299, Orman ve Su İşleri Bakanlığı Orman Genel Müdürlüğü Orman İdaresi ve Planlama Daire Başkanlığı, Ankara.

OGM. (2020). Sürdürülebilir Orman Yönetimi Kriter ve Göstergeleri Türkiye Raporu 2019, Tarım ve Orman Bakanlığı Orman Genel Müdürlüğü Strateji Geliştirme Dairesi Başkanlığı, Ankara.

Pelling, M. (2001). Natural Disasters? In N. Castree & B. Braun (Eds.), Social Nature: Theory, Practice, and Politics. Blackwell Publishers.

Peñuelas, J., & Sardans, J. (2021). Global Change and Forest Disturbances in the Mediterranean Basin: Breakthroughs, Knowledge Gaps, and Recommendations. Forests, 12(5). https://doi.org/10.3390/f12050603

Peterson, C. J. (2000). Catastrophic wind damage to North American forests and the potential impact of climate change. Sci Total Environ, 262(3), 287-311. https://doi.org/10.1016/s0048-9697(00)00529-5

Quarantelli, E. L. (1985). What Is Disaster? The Need For Clarification In Definition And Conceptualization In Research. In B. Sowder (Ed.), Disasters and Mental Health Selected Contemporary Perspectives (pp. 41-73).

Ren, D. L., Lance M.; Duan, Qingyun. (2012). Landslides Caused Deforestation. In P. Moutinho (Ed.), Deforestation Around the World (pp. 96-120). InTech.

Rotaru, A. O., Daniel; Răileanu, Paulică. (2007). Analysis of the Landslide Movements. International Journal of Geology, 1(3), 70-79.

Schuster, R. L., & Highland, L. M. (2003). Impact of Landslides and Innovative Landslide-Mitigation Measures on the Natural Environment. International Conference on Slope Engineering, Hong Kong, China.

Skrzecz, I., Sierpinska, A., & Tumialis, D. (2024). Entomopathogens in the integrated management of forest insects: from science to practice. Pest Manag Sci, 80(6), 2503-2514. https://doi.org/10.1002/ps.7871

Şahan, E. A., Gürçay, B., & Tuncay Güner, H. (2023). The history of fire, human and climate in black pine forests of western Anatolia: The Taurus mountains. Dendrochronologia, 82. https://doi.org/10.1016/j.dendro.2023.126149

Vittoz, P., Stewart, G. H., & Duncan, R. P. (2001). Earthquake impacts in old-growth Nothofagus forests in New Zealand. Journal of Vegetation Science, 12(3), 417-426. https://doi.org/10.2307/3236856

Waage S, Bracer C, Inbar M. (2008). Payments for ecosystem services: getting started, A primer. Forest Trends, the Katoomba Group, and UNEP.

Walker, L., & Shiels, A. (2010). Landslide Ecology. Landslide Ecology, 1-318. https://doi.org/10.1017/CBO9780511978685

Wang, Y. K., Fu, B., & Xu, P. (2012). Evaluation the impact of earthquake on ecosystem services. Procedia Environmental Sciences, 13, 954-966. https://doi.org/10.1016/j.proenv.2012.01.089

Zulperi, D., Ibrahim, R., Ujat, A. H., Md. Zali, A. Z., Ja'afar, Y., & Karam, D. (2022). Forest Pathology in Ecosystem Services. In Z. Samdin, N. Kamaruddin, & S. M. Razali (Eds.), Tropical Forest Ecosystem Services in Improving Livelihoods For Local Communities (pp. 15-28). Springer. https://doi.org/10.1007/978-981-19-3342-4_2

Chapter 5

OCCUPATIONAL SAFETY AND RISK MANAGEMENT IN WILDFIRE SUPPRESSION

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1. Introduction

Fire is a natural part of the forest ecosystem and has various effects on it (Dantas et al., 2016; Doerr and Santin, 2016; Alamgir et al., 2020; Pausas and Keeley, 2019). Wildland fires are an ecological factor that affects the structure, composition, and function of a wide range of ecosystems, influencing everything from nutrient cycling to vegetation distribution (Usta, 2023). The level and direction of this impact can vary depending on the characteristics of the ecosystem. While fires are essential for the sustainability of fire-dependent ecosystems, they are a threat to fire-sensitive ecosystems or those where the fire regime has been altered by humans (Yuan et al., 2015). Wildfire suppression is crucial in eliminating or minimizing the destructive effects of fires on the forest ecosystem.

There has been a significant increase in wildland fires globally, affecting areas from tropical regions to temperate Australia and subtropical regions to boreal Eurasia (Tyukavina et al., 2022). Furthermore, due to climate change, it is projected that by the end of this century, the fire season will extend, fire regimes will change, fires will become prevalent even in ecosystems where they are not currently a concern, and fire intensity and frequency will increase in ecosystems already affected by fire (Flannigan et al., 2013; Grant and Runkle, 2022). Considering fire-ecosystem interactions, it is not possible to eliminate fires from ecosystems (Pausas and Keeley, 2019; Pheko, 2021). Therefore, well-planned wildfire suppression strategies are essential for using fires for forestry aims and minimizing their negative effects. Such strategies also require developing policies prioritizing occupational health and safety (OHS).

The effects of wildland fires can be grouped into four main categories: ecological, economic, social, and occupational safety and health (OSH) (Figure 1) (Xanthopoulos, 2007; Martinez-de Dios et al., 2008; Bhosle and Gavhane, 2016; Xu et al., 2020). It is important to plan wildfire suppression efforts with possible risks in mind.

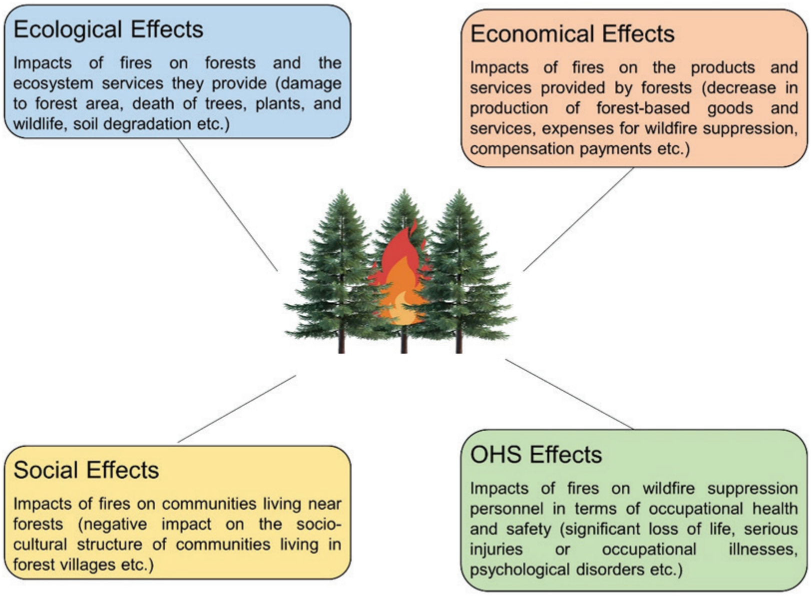

Figure 1. General effects of wildland fires

Studies have generally focused on fire behavior and the ecological, economic, and social effects of fires. However, the direct and indirect hazards exposed to wildland firefighters working in wildfire suppression and the precautions that should be taken have not yet been fully addressed. In this book chapter, the state of wildland fires in Türkiye and the conceptual framework of wildfire suppression organizations are discussed. The hazards and risks that wildland firefighters may encounter concerning OHS are evaluated and suggested solutions for preventive measures are developed.

2. Wildland Fires in Türkiye

About 65.0% of the forests, which cover 29.6% of Türkiye's territory, are in fire-prone areas. About 54.6% of these fire-prone areas are classified as first and second-degree fire-sensitive areas. The areas of first and second-degree sensitive forests are 8.8 million hectares and 6.23 million hectares, respectively (GDF, 2022a). According to the European Forest Fire Information System (EFFIS) data, the average burned area per fire in European countries in the Mediterranean climate zone over 10 years (2012-2022) is 28.44 thousand hectares in Greece, 65.6 thousand hectares in Italy, 102.2 thousand hectares in Spain, 134.7 thousand hectares in Portugal, 22.9 thousand hectares in Türkiye, and 19.5 thousand hectares in France (EFFIS, 2021).

Türkiye ranks seventh in terms of both the average annual burned area (7,332.1 hectares) and the number of fires (2,477.3) among wildland fires worldwide between 2010 and 2019 (Şahan and Kaya, 2022). According to records from the last ten years (2013-2022), an average of 22,919 hectares of forest area has been affected by an average of 2,783 wildland fires annually in Türkiye (GDF, 2022a). In the 2021 fires, considered the largest in Türkiye's history, 139,503 hectares of forest area were burned (Atmış et al., 2023). The number of wildland fires that occurred in Türkiye between 1937 and 2022, along with the distribution of the area burned by year, is given in Figure 2 (GDF, 2022b).

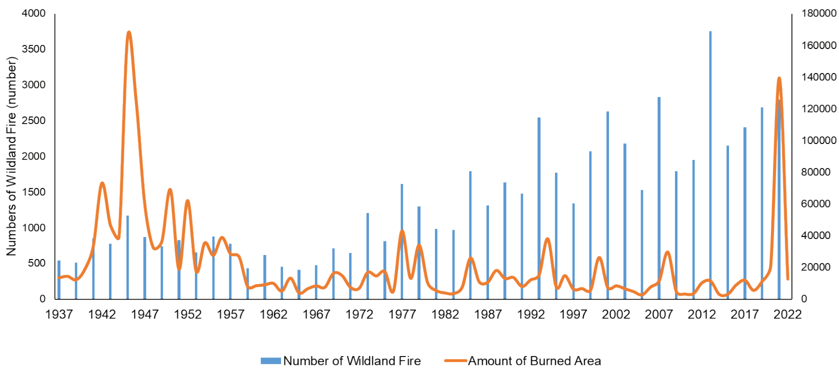

Figure 2. Numerical and spatial distribution of wildland fires in Türkiye 1937-2022

Flames primarily reach forest areas due to natural events such as lightning or human activities. Human-caused fires vary depending on factors such as the cultural level of society and activities in rural areas (GDF, 2022a). The main human activities that cause fires include stubble, garden cleaning, rubbish burning, picnics, and shepherd fires. The proportional distribution of the causes of wildland fires in Türkiye between 1997 and 2022 is shown in Figure 3 (GDF, 2022b).

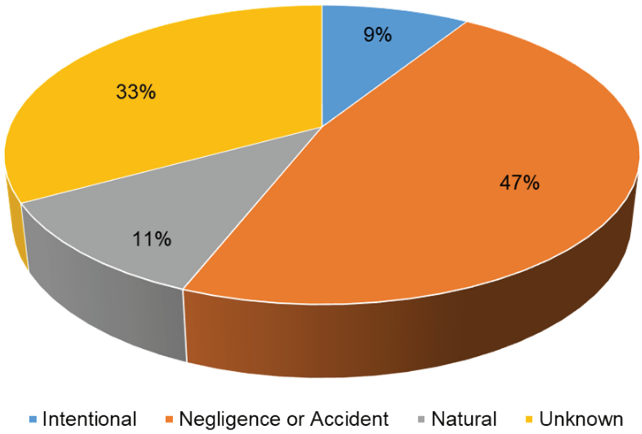

Figure 3. Distribution of main causes of wildland fires between 1997 and 2022

As seen in Figure 3, only 11% of the wildland fires in Türkiye between 1977 and 2022 were caused by natural events. While 56% were caused by factors such as intent, negligence, or accidents, the cause of 33% could not be determined.

3. Wildland Fire Suppression

Wildland firefighting includes all the activities carried out before, during, and after the fire. Wildfire suppression is the most dangerous, difficult, and risky of these activities, where firefighters are in direct contact with the fire.

3.1. Wildland Firefighters

Although there are different types of crews, wildfire suppression is fundamentally carried out by two teams: ground crews and air crews (Koopmans et al., 2022). The main element of wildfire suppression is the intervention by ground crews, with air crews supporting ground crews when necessary. Ground crews respond to fires directly or indirectly using various equipment. Crews may consist of trained firefighters or volunteers (Figure 4).

Figure 4. Crews and various equipment involved in fire suppression (URL-1, 2024)

Until recently, wildland firefighting was one of the jobs that was not in high demand due to its difficulty and high occupational risk, and the average age of the workers was quite high. Before the mega wildland fires that occurred in Türkiye in 2021, an average of 7,000 to 8,000 temporary wildland firefighters were employed annually for fire suppression, while today this number has increased to approximately 15,000 permanent firefighters (GDF, 2022a). While the core of wildfire suppression crews in Türkiye consists of firefighters from the General Directorate of Forestry, external stakeholders also participate in suppression efforts voluntarily from time to time.

3.2. Wildfire Suppression Techniques

Wildfire suppression includes the activities or procedures carried out from the time a fire is reported until the elimination of fire hazards. Wildfire suppression is conducted in three stages: intervention, control, and cooling (Heikkila, 2010). Intervention involves efforts to stop or limit the spread of fire. Control means that the fire is contained and prevented from further spreading. The final stage, cooling, ensures the fire is completely extinguished and removed from the forest (Figure 5).

Figure 5. Wildfire suppression stages: (a)intervention, (b)control, (c)cooling (Heikkila, 2010)

While these stages are applied in succession to suppress large wildland fires, all stages can be carried out simultaneously to suppress small fires. Although there are many variations, two basic techniques are used in wildfire suppression: direct attack and indirect attack.

<u>Direct attack:</u> In this method, the fire is directly suppressed from a close distance. This method is generally used at the head of low-intensity fires where fuels burn underground or on the surface until in the side or rear parts of high-intensity fires. Suppression is carried out by applying water, foam, or directly soil onto the burning material or flames. Hand tools are often used for intervention. The use of this method depends on creating conditions that allow firefighters to intervene safely. Otherwise, wildland firefighters may face risks such as exposure to intense heat or smoke, burns, or loss of consciousness (Figure 6a).

<u>Indirect attack:</u> This method is used when a direct attack is unsafe due to fire conditions (such as fire behavior, fuel, etc.). The time taken for suppression, the skills of the firefighters, and efficiency are as important as the behavior of the fire. The main indirect attack methods for wildland fires are the parallel and the backfire methods.

The parallel method involves creating a fire line at an appropriate distance from the fire by firefighter crews (Figure 6b). On the other hand, the backfire method involves reducing or eliminating the fuels in front of rapidly spreading fires to bring the fire under control. This method is typically carried out by the fire chief or experienced forest engineers assigned to the task (Figure 6c).

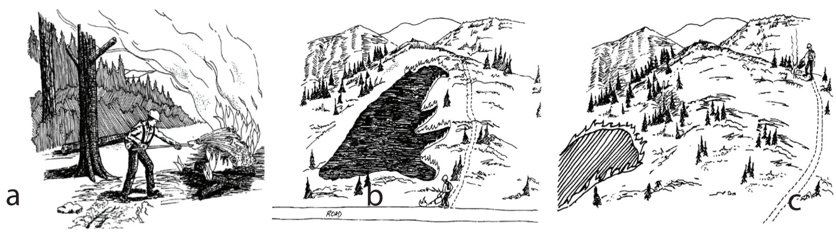

Figure 6. Fire suppression attack techniques:(a) direct attack technique, (b) parallel, (c) backfire (URL-4, 2024)

4. Occupational Safety and Health in Wildfire Suppression

Today, with the development of technology and the increasing societal awareness of human health, the topic of Occupational Safety and Health (OSH) has gained significant importance in the workplace. OSH is a branch of science that focuses on eliminating or minimizing the occupational risks employees face due to the physical environmental conditions of the workplace and the nature of the tasks performed. It also addresses the workers' health problems. In other words, it is defined as the branch of science that examines the conditions affecting the safety of all elements (employees, businesses, production processes, and the environment) impacted by the activities carried out by an institution (URL-2, 2024). Wildfire suppression classified in Hazardous Works Class requires careful attention to OSH (Turkish Ministry of Labor and Social Security, 2012). Approximately 66% of those who died while engaged in wildfire suppression in Türkiye between 1968 and 2022 were wildland firefighters (GDF, 2022a).

There are many studies in the literature on the occupational safety hazards that workers involved in wood harvesting are exposed to, as well as the injuries and deaths resulting from these hazards (Wempe and Keefe, 2017; Ünver-Okan and Acar, 2017; Wempe et al., 2019). While several studies focus on the short-term effects of fires on wildland firefighters' health (Adetona, 2016; Rahn et al., 2016; Broyles et al., 2017; Groot et al., 2019; West et al., 2020; Koopmans et al., 2022), there are few studies investigating their long-term effects (Grant and Runkle, 2022; Navarro et al., 2022). Some of the main health problems experienced by firefighters during or immediately after a fire include headaches, dizziness, skin irritation, burns, injuries, fatigue, and lack of concentration. Some of the long-term problems they experience include cardiovascular diseases, decreased lung function, hearing loss, and cancer (Navarro et al., 2022). These issues usually arise from fire, work environment, task, or machine exposure. Therefore, it is important to identify the dangers that negatively affect wildland firefighters and to develop measures to minimize them.

Wildland firefighters may be exposed to serious injuries or occupational diseases, which can result in death, early retirement, or termination of employment (Liu et al., 2023). The World Health Organization (WHO) has outlined the objectives of Occupational Safety and Health (OSH) (Cuenca-Lozano and Ramírez-García, 2023). Various legal regulations have been established to achieve these objectives, such as the International Labour Organization (ILO) conventions (Articles 155 and 161) (ILO, 2001), the European Union (EU) "Occupational Health and Safety Framework Directive" numbered 89/391/EEC (URL-3, 2024), the "Labor Law" numbered 4857 (10.06.2003; Article 77) (Turkish Labor Law, 2003), and the "Occupational Health and Safety Law" numbered 6331 (Official Gazette dated 30.06.2012 and numbered 28339) (Occupational Health and Safety Law in Turkey, 2012).

Under these regulations, employers are held responsible for identifying workplace risks, conducting risk assessments, taking necessary precautions, raising workers' awareness about their tasks and associated risks, providing training on OSH issues, and supplying the necessary personal protective equipment (PPE). Additionally, Article 4 of the OHS Law No. 6331 explicitly states that employers' responsibilities in this area are not eliminated if they outsource services for risk assessment (Occupational Health and Safety Law in Turkey, 2012). Furthermore, wildland firefighters are required to work safely and comply with safety instructions under these legal regulations. These responsibilities and obligations emphasize the importance of conducting risk analyses across all sectors.

5. Hazards and Risks in Wildfire Suppression

The hazards that workers are exposed to in various forestry activities, such as wood harvesting and nursery work, have been identified by considering factors such as the working environment, the tasks performed, the characteristics of the workers, and the machinery and methods used. These identified hazards are classified as physical, chemical, biological, ergonomic, and psychosocial according to their characteristics (Knecht et al., 2023; Ünver and Ergenç, 2021). However, apart from a limited number of studies that determine the general hazards to which fire crews and fire tower workers are exposed, based on literature reviews or personal experiences (Sayın et al., 2014; Bozkurt, 2017; Başkar-Doğan, 2021; Kaakkurivaara et al., 2022), there are no specific studies focused on wildland firefighters.

Crews attacking forest fires, directly or indirectly, may be exposed to many dangers (Page and Butler, 2017). These hazards may arise from various factors such as fire behavior, topographic conditions, forest types, or work organization. Even a small risk that may be overlooked in wildfire suppression operations can cause significant harm to firefighters, including death, disability, injury, or occupational diseases (Broyles, 2013; Navarro et al., 2019; Koopmans et al., 2022; Navarro et al., 2022). Therefore, it is essential to thoroughly identify the risks wildland firefighters may be exposed to, conduct risk assessments, and develop preventive measures.

Wildland firefighters work under various risks such as the area, weather conditions, work difficulty, tools and machines, work organization, or worker characteristics. Based on a literature review, observations before, during, and after forest fires, and face-to-face interviews with wildland firefighters and OSH experts, a total of 36 hazards were identified. These hazards are classified into six main groups according to their characteristics: physical, chemical, biological, technical, psychological, and organizational.

Twelve physical hazards that wildland firefighters are exposed to due to their work environment and tasks during wildfire suppression have been identified (Table 1).

Table 1. Physical hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Ground Conditions	Slipping, tripping, or falling may occur on steep, uneven, and vegetated terrain, potentially causing injuries, fatigue, psychological stress, and difficulty concentrating.	Wear personal protective equipment, carry maps showing land features (topography, vegetation, and roads), regularly take breaks, and maintain physical conditioning.
Wind	Winds with variable speed and direction can alter fire behavior and conditions, becoming a physical threat. This situation can lead to entrapment and burns if one becomes caught in the fire. Additionally, foreign objects entering the eyes, increased body temperature, high smoke density, loss of concentration, and fatigue may also occur.	Continuously monitor weather reports during the fire, establish escape routes and safe zones, observe fire behavior, wear full personal protective equipment, and take regular breaks.
Relative humidity	Relative humidity can affect fire behavior by altering the fuel conditions and causing breathing difficulties, sweating, shivering, and restlessness.	Continuously monitor weather reports during the fire, establish escape routes and safe zones, observe fire behavior, wear full personal protective equipment, and take regular breaks.
Rainfall	Rainfall positively impacts fire behavior and reduces its potential harmful effects. However, it increases the risks of slipping, tripping, falling, and vehicle and equipment accidents due to wet ground conditions. It can also cause chills and reduce concentration.	Wear full personal protective equipment, take regular breaks, and stay aware of your surroundings.

Table 1 continued

Heat	Working at high temperatures for extended periods can lead to discomforts such as edema, cramps, fainting, weakness, rashes, heat stress, and heat stroke. These conditions can also cause fatigue and decreased concentration.	Drink water regularly and carry electrolyte supplements. Wear full personal protective equipment, take regular breaks, and choose cool, shaded areas for resting.
Flame	Injury or death may result from burns to the body.	Wear personal protective equipment, keep a safe distance, and stay aware of your surroundings.
Dust	Foreign objects entering the eye can cause vision loss, allergic reactions, redness, and burning. If inhaled or swallowed, these substances can lead to short-term or long-term health issues, including cancer, upper respiratory tract problems, and lung disorders such as coughing and difficulty breathing.	Wear personal protective equipment and undergo regular health screenings.
Falling and Burning Objects	Burning, hung-up, or felled trees used in suppression efforts can fall suddenly and cause injuries. Additionally, burning fine materials and ash can cause injuries to the body and eyes.	Wear personal protective equipment, identify and mark hazardous trees, maintain a safe distance, and stay aware of your surroundings.
Noise	Headache, hearing loss, restlessness, nervousness, loss of focus, weariness, irritability, and fatigue may result from the noise generated during wildfire suppression efforts.	Wear personal protective equipment, undergo regular health screenings, and take regular breaks.
Vibration	Risks depend on the equipment used such as vascular, bone, joint, nerve, muscle, and circulatory disorders	Wear full personal protective equipment and undergo regular health screenings.
Carrying heavy loads	The weight carried during work varies depending on the weight and usage characteristics of the equipment. This can lead to various injuries and musculoskeletal disorders.	Obtain the necessary training and certifications for equipment use, follow equipment use procedures, take regular breaks, and undergo regular health screenings.
Power Transmission Lines	Risks such as electric shock, injury, or death may arise from power transmission lines breaking or falling during a fire.	Wait for the power to be shut off, maintain a safe distance, and stay aware of your surroundings.

In wildfire suppression, physical hazards include ground conditions (slope, roughness, etc.), weather conditions (wind, relative humidity, precipitation, wind, etc.), fire-related hazards (dust, heat, flame, ash, etc.), and work-related conditions (noise, vibration, carrying heavy loads, etc.).

The most significant and long-term effects of these hazards are those caused by fire.

Three chemical hazards that wildland firefighters are exposed to during wildfire suppression have been identified (Table 2).

Table 2. Chemical hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Smoke and Inhaling Particles	Wildland fire smoke contains fine particulate matter and toxic chemicals that can harm health. These can lead to poisoning, upper respiratory and lung disorders, asthma, allergies, cardiovascular disease, and even death.	Wear personal protective equipment, avoid prolonged exposure to smoke and wind, undergo regular health screenings, and take frequent breaks.
Exhaust Fumes	The exhaust fume from the equipment can have harmful health effects, such as poisoning and eye burns.	Wear personal protective equipment, undergo regular health screenings, and take frequent breaks.
Contact with Fuel, Oil, or Different Chemicals	Contact with chemicals used in wildfire suppression equipment and vehicles as well as those used in suppression efforts can cause various skin disorders, poisoning, and burns.	Wear personal protective equipment and obtain the necessary training and certifications for equipment use.

The chemical hazards class includes smoke resulting from the combustion of living and dead fuels (Naeher et al., 2007; Navarro et al., 2019; Ning et al., 2022), exhaust gases from construction equipment or chainsaws, and contact with fuel, oil, or extinguishing chemicals. The main harmful substances released from smoke are toxic compounds such as carbon monoxide (CO), carbon dioxide (CO_2), hydrogen cyanide (HCN), irritants (particulates, formaldehyde, acrolein), and polycyclic aromatic hydrocarbons (PAH) (Broyles, 2013; Baxter et al., 2014). These compounds, to which wildland firefighters are exposed at high levels through inhalation or contact, can cause a wide range of health problems in both the short and long term (Swiston et al., 2008; Neitzel et al., 2009; Finlay et al., 2012; Brosseau et al., 2014; Brosseau et al., 2019).

Three biological hazards that wildland firefighters are exposed to during wildfire suppression have been identified (Table 3).

Table 3. Biological hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Thorny or Poisonous Plants	Plants affected by the fire can cause various injuries and poisoning.	Wear personal protective equipment.
Insects	Various allergic reactions and poisonings may occur as a result of insect bites in areas affected by the fire.	Wear personal protective equipment, have first aid supplies available, and obtain the necessary training and certifications.
Animals	Animal attacks from animals escaping a fire or moving toward it may result in injury, death, or various diseases.	Gain essential knowledge of animal behavior, have first aid supplies available, and obtain the necessary training and certifications.

During wildfire suppression, biological hazards refer to the dangers firefighters may be exposed to from plants and animals in the fire area. The main hazards include direct contact with harmful plants, insect bites, and attacks by wild animals fleeing from or moving toward the fire. Biological hazards can have immediate effects or may manifest after a certain period. Workers may become infected by bites from various insects or wild animals, with symptoms appearing later.

Four technical hazards that wildland firefighters are exposed to due to their tasks and machines during wildfire suppression have been identified (Table 4).

Table 4. Technical hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Tools	The tools used in wildfire suppression (rake, hoe, chainsaw, hose apparatus, etc.) pose risks such as injury, disability, or death.	Wear personal protective equipment, perform regular maintenance on tools, maintain a safe distance and stay aware of surroundings, have first aid supplies available, and obtain the necessary training and certifications.
Vehicle	Wildfire suppression equipment may malfunction, overturn, or cause an accident, potentially resulting in injury or death.	Wear full personal protective equipment, have first aid supplies available, ensure drivers and operators obtain the necessary training and certifications, follow equipment usage procedures, avoid using vehicles on slopes exceeding their limits, operate tankers either empty or fully loaded, perform regular vehicle maintenance, install necessary lighting and warning signs around vehicles, maintain a safe distance and stay aware of your surroundings, and ensure work organization and communication between crews.

Fire or Explosion	The tools or equipment used may cause a fire or explosion, leading to injury or death.	Wear full personal protective equipment, perform regular maintenance on tools and vehicles, ensure that drivers and operators have the necessary training and certifications, and keep tools and equipment at a safe distance from the fire.
Water or Chemicals	Various injuries or deaths may occur due to pressurized water released from ground vehicles or water and chemicals dropped from aircraft during suppression efforts.	Wear full personal protective equipment, perform regular maintenance on tools and vehicles, ensure drivers and operators have the necessary training and certifications, follow equipment usage procedures, maintain a safe distance, stay aware of your surroundings, and ensure proper work organization and communication between crews.

Technical hazards generally arise from tools used during wildfire suppression, such as hand tools, chainsaws, water trucks, or equipment, as well as from operators or firefighters. Dangers posed by vehicles include their location, invisibility, hitting workers or other vehicles, or someone falling from the vehicle. Additionally, due to lack of maintenance, malfunctioning vehicle parts, or inadequacy of operators, hazards such as firefighters being hit by pressurized water may occur.

Two psychological hazards that wildland firefighters are exposed to during wildfire suppression have been identified (Table 5).

Table 5. Psychological hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Mental and Emotional Stress	Wildfire suppression is inherently a high-stress job that requires long hours, which can impact mental and emotional health. This situation leads to stress, tension, haste, and low motivation all of which increase the risk of accidents and injuries.	Access mental health resources and counseling, share your concerns and improve communication to address them.
Inattention and Fatigue	Inattention and fatigue increase the risk of accidents, injuries, and death.	Take regular breaks and work shifts.

Psychological hazards refer to the effects on workers' mental health as a result of working continuously for long periods (fatigue, demoralization, carelessness) or the difficulty of the work (haste, stress, tension). The most effective and least harmful management of wildfire suppression can be achieved through good work organization.

Twelve organizational hazards that wildland firefighters are exposed to due to organizational errors during wildfire suppression have been identified (Table 6).

Table 6. Organizational hazards to which wildland firefighters are exposed

Hazards	Risks	Precautions
Unclear Escape Routes and Safe Zones	Failure to identify escape routes and safe zones in the event of potential danger may lead to risks such as stress, injury, and death.	Plan and construct in fire-prone areas, keep existing ones well-maintained and clean, mark their locations on maps, place signs indicating escape routes and safe zones, and train wildland firefighters in safety procedures.
Inadequate Forest Roads and Firebreaks.	Inadequate forest roads and firebreaks, or those not meeting standards, limit wildland firefighters' ability to use appropriate techniques and make it difficult to suppress the fire. This can lead to various negative outcomes, such as mental health issues, injury, or death.	Plan and construct fire-prone areas, improve the standards of existing ones, keep them clean, and mark their locations on maps.
Vehicle and Crew Optimization	It is important for vehicles and crews to reach the fire area as quickly as possible and to position them according to proper techniques to optimize resource use and minimize risks. Otherwise, delays in wildfire suppression, fatigue, and injuries may occur.	Position vehicles and crews in designated areas based on fire sensitivity, maintain reasonable distances in the fire area as needed, activate warning lights, and minimize personnel presence in the area.
Insufficient Information Flow	Since wildfire suppression is a labor-intensive and stressful operation, the flow of information must be flawless. Otherwise, risks such as accidents, injuries, and death may occur.	Establish a communication network to keep vehicles and crews informed, perform periodic maintenance on equipment, and provide training on issues such as designated channels, commands, chain of command, duties, and responsibilities.
Insufficient Safety Measures	Failure to take safety precautions against potential risks may result in accidents, injuries, or death.	Conduct risk analyses and take necessary precautions.
Insufficient Breaks	Inadequate rest can lead to fatigue, weariness, exhaustion, lack of concentration, stress, and physical strain. This increases the risk of accidents and injuries.	Work in shifts, take a regular meal, water, and rest breaks, and adjust break times according to the task's intensity or the wildland firefighter's condition.

Long Hours of Continuous Work	Fires can last for days or even weeks. Additionally, during consecutive fires, crews from different regions must assist each other and work for extended periods without breaks. This can lead to accidents and injuries due to negative factors such as fatigue, exhaustion, loss of attention, and stress.	When wind speed, fire intensity, and spread rate are low, change shifts every 6 to 8 hours, create a suitable environment for sleeping or resting, and alternate between difficult and easy tasks.
Inability to Provide First Aid	Medical personnel are often absent in fire areas, and even when present, their numbers are usually insufficient. For this reason, a lack of first aid can result in permanent injury or death.	Ensure crews include personnel with first aid knowledge.
Lack of or Non-Use of Personal Protective Equipment	Personal protective equipment is designed to eliminate risks or, at the very least, minimize potential damage. Therefore, not having or not wearing this equipment can increase the severity of accidents and injuries and may even result in death.	Make it legally mandatory for each crew to have and use personal protective equipment appropriate for the task and to provide training on its proper use.
Inadequate Nutrition and Dehydration	Not consuming enough food and water while working can lead to negative effects such as fatigue, fainting, and injury.	Provide food, water, and electrolyte supplies.
Confusion of Authority	Improper distribution of authority and responsibility can lead to poor work organization and may result in negative outcomes such as injury or death.	Distribute authority and responsibilities legally and establish rules to prevent outside interference.
Unqualified Worker	Workers who are not suitable for the job may experience negative effects such as excessive strain, anxiety, tension, excitement, embarrassment, defiance, loss of confidence, psychological issues, and musculoskeletal disorders due to improper working posture.	Clearly define the job and working conditions and select wildland firefighters suited to these requirements during hiring.

Organizational hazards include pre-fire planning in fire-prone areas (planning of firebreaks, escape routes, and vehicle intervention points), addressing the needs of firefighters during wildfire suppression (food, water, PPE, first aid supplies), managing time according to working hours and workload (breaks, working hours), and issues such as confusion of authority and inadequacies in the flow of information.

6. Conclusion

Due to climate change, the fire regime conditions prevailing in terrestrial ecosystems have changed. This has led to an increase in the number of forest fires, the size of the burned area, and the intensity of the fires. Moreover, even forest ecosystems where fires were not previously considered a problem are now being affected by fire.

The effects of wildland fires, one of the main causes of deforestation, are generally evaluated from economic, ecological, and social perspectives. However, fire management involves comprehensive work carried out before, during, and after a fire. Wildfire suppression is one of the most critical aspects of this process. Many wildland firefighters are exposed to significant risks during wildfire suppression. Today, with the growing awareness of society regarding Occupational Safety and Health (OSH) and the obligations imposed by legal regulations, risk analysis for all activities has become a priority.

The frequency of work accidents in developing or underdeveloped countries is much higher than in developed countries. Some of the main reasons for this include the lack of or non-compliance with regulations regarding occupational safety, the disregard of risks, and inadequate training. The first stage of risk analysis is to identify the hazards that workers may be exposed to, assess the risks that may occur, and develop solution suggestions. The measures taken as a result of the risk analysis will contribute to an increase in work efficiency, a reduction in accidents at work and occupational illnesses, and a decrease in health costs for employees and compensation payments by the institution. Additionally, conducting legally required risk analyses helps ensure compliance with regulations stipulated by law.

The table of hazards and risks that wildland firefighters may be exposed to, created in this section of the book, will contribute to the risk analysis for firefighters, the implementation of necessary precautions, and the effective planning of wildfire suppression. It will also serve as a tool for recording the risks that arise.

References

1. Adetona, A.M. 2016. Wildland firefighter work task-related smoke exposures at prescribed burns and their effect on proinflammatory biomarkers and urinary mutagenicity. PhD Thesis. The University of Georgia. Athens, Georgia.

2. Alamgir, M., Campbell, M.J., Sloan, S., Engert, J., Word, J., Laurance, W.F. 2020. Emerging Challenges for Sustainable Development and Forest Conservation in Sarawak, Borneo. PLoS ONE 15, Article e0229614.

3. Atmış, E., Tolunay, D., Erdönmez, C. 2023. Numerical Analysis of Forest Fires. Forest Fires Part I-II, Turkish Foresters Association, ISBN: 978-605-71791-4-2.

4. Başkar-Doğan, Ö. 2021. Occupational HEALTH & safety in forest fires. Master's Thesis, Tarsus University Institute of Graduate Education. Tarsus.

5. Baxter, C.S., Hoffman, J.D., Knipp, M.J., Reponen, T., Haynes, E.N. 2014. Exposure of Firefighters to Particulates and Polycyclic Aromatic Hydrocarbons. Journal of Occupational and Environmental Hygiene 11(7): 85-91.

6. Bhosle, A.S., Gavhane, L.M. 2016. Forest Disaster Management with Wireless Sensor Network. International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT). 3-5 March. Chennai, India. Proceedings Book. 287-289.

7. Bozkurt, A. 2017. Applications of occupational health and safety in forestry works: A case study of Karabuk Forest Directorate). Master's Thesis. Bartin University Institute of Science. Bartin, Türkiye.

8. Brosseau, L.M., Kardous, C.A., Shaw, P.B., Krieg, E.F. 2019. Noise exposures and perceptions of hearing conservation programs among wildland firefighters. Journal of Occupational and Environmental Hygiene 16(12): 775-784.

9. Brosseau, L.M., Bejan, A., Parker, D.L., Skan, M., Xi, B.M. 2014. Workplace Safety and Health Programs, Practices, and Conditions in Auto Collision Repair Businesses. Journal of Occupational and Environmental Hygiene 11: 354-365.

10. Broyles, G., Butler, C.R., Kardous, C.A. 2017. Noise exposure among federal wildland firefighters. The Journal of the Acoustical Society of America 14 (2): 177-183.

11. Broyles, G. 2013. Wildland Firefighter Smoke Exposure. National Technology & Development Program 1351 1803. U.S. Department of Agriculture Forest Service. Atlanta, Georgia. 22.

12. Cuenca-Lozano, M.F., Ramírez-García, C.O. 2023. Occupational Hazards in Firefighting: Systematic Literature Review. Safety and Health at Work 14: 1-9.

13. Dantas, V. L., Hirota, M., Oliveira, R.S., Pausas, J. G. 2016. Disturbance maintains alternative biome states. Ecology Letters 19(1): 12-19.

14. Doerr, S.H., Santín, C. 2016. Global trends in wildfire and its impacts: perceptions versus realities in a changing world. Philosophical Transactions of the Royal Society B-Biological Sciences 371: 1-10.

15. EFFIS (European Forest Fire Information System), 2021. JRC Technical Report Forest Fires in Europe, Middle East North Africa.

16. Finlay, S. E., Mofft, A., Gazzard, R., Baker, D. L., Murray, V. 2012. Health Impacts of Wildfires. Plos Current 4: e4f959951cce2c. doi: 10.1371/4f959951cce2c. PMID: 23145351; PMCID: PMC3492003., 32.

17. Flannigan, M., Cantin, A.S., de Groot, W.J., Wotton, M., Newbery, A., Gowman, L. M., et al. 2013. Global Wildland Fire Season Severity in the 21st Century. For. Ecol. Manage. 294: 54-61. doi:10.1016/j.foreco.2012.10.022

18. GDF (General Directorate of Forestry). 2022a. Evaluation Report for Forest Fire Fighting Activities in 2022. General Directorate of Forestry, Ministry of Agriculture and Forestry, Department of Forest Fire Fighting. Ankara. 137.

19. GDF (General Directorate of Forestry). 2022b. Forest Statistics. General Directorate of Forestry. Ankara.

20. Grant, E., Runkle, J.D. 2022. Long-term health effects of wildfire exposure: A scoping review. The Journal of Climate Change and Health 6: 100-110.

21. Groot, E., Caturay, A., Khan, Y., Copes, R. 2019. A systematic review of the health impacts of occupational exposure to wildland fires. International Journal of Occupational Medicine and Environmental Health 32(2): 121-140.

22. Heikkilä, T.V., Grönqvist, R., Jurvelius, M. 2010. Wildland fire management. Handbook for trainers. Ministry for Foreign Affairs of Finland and FAO. Rome, Italy.

23. ILO (International Labour Organization). 2001. Guidelines on occupational safety and health management systems. ISBN 92-2-111634-4. International Labour Organization (ILO-OSH). Geneva. 28.

24. Kaakkurivaara, T., Borz, A.A., Kaakkurivaara, N. 2022. Risk Factors and Occupational Safety Failures in Forest Work in the Southeast Asian Region. Forests 13(2034): 1-16.

25. Knecht, H., Balanay, J.A.G., Langley, R., Marcom, R.T., Richards S.L. 2023. Systematic Review of Biological, Chemical, Ergonomic, Physical, and Psychosocial Hazards Impacting Occupational Health of United States Forestry Workers. Journal of Forestry XX: 1–12. Doi: 10.1093/jofore/fvad052

26. Koopmans, E., Cornish, K., Feyfe, T.M., Bailey, K., Pelletier, C.A. 2022. Health risks and mitigation strategies from occupational exposure to wildland fire: a scoping review. Journal of Occupational Medicine and Toxicology 17(2): 1-17.

27. Liu, R., Shi, H., Gu, X. 2023. Occupational health and safety risk assessment: A systematic literature review of models, methods, and applications. Safety Science 160: 106050.

28. Martinez-de Dios, J.R., Arrue, B.C., Ollero, A., Merino, L. 2008. Computer vision techniques for forest fire perception. Image and Vision Computing 26: 550-562.

29. Naeher, L.P., Brauer, M., Lipsett, M., Zelikoff, J.T., Simpson, C.D., Koenig, J., Smith, K.R. 2007. Woodsmoke Health Effects: A Review. Inhalation Toxicology 19: 67-106.

30. Navarro, K.M., Butler, C.R., Fent, K., Toennis, C., Sammons, D., Ramirez-Cardenas, A., Clark, K.A., Byrne, D.C., Graydon, P.S., Hale, C.R., Wilkinson, A.F., Smith, D.L., Alexander-Scott, M.C., Pinkerton, L.E., Eisenberg, J., Domitrovich, J.W. 2022. The Wildland Firefighter Exposure and Health Effect (WFFEHE) Study: Rationale, Design, and Methods of a Repeated-Measures Study. Annals of Work Exposures and Health. 66(6): 714-727.

31. Navarro, K.M., Kleinman, M.T., Mackay, C.E., Reinhardt, T.E., Balmes, J.R., Broyles, G.A., Ottmar, R.D., Naher, L.P., Domitrovich, J.W. 2019. Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. Environmental Research Letters 173: 162-468.

32. Neitzel, R., Naeher, L.P., Paulsen, M., Dunn, K., Stock, A., Simpson, C.D. 2009. Biological monitoring of smoke exposure among wildland firefighters: A pilot study comparing urinary methoxyphenols with personal exposures to carbon monoxide, particular matter, and levoglucosan. Journal of Exposure Science and Environmental Epidemiology 19: 349-358.

33. Ning, J., Yang, G. S., Liu, X., Geng, D. Y., Wang, L., Li, Z., Zhang, Y., Sun, L. ve Yu, H. 2022. Effect of fire spread, flame characteristic, fire intensity

on particulate matter 2.5 released from surface fuel combustion of Pinus koraiensis plantation– A laboratory simulation study. Environment International 166: 1-14.

34. Occupational Health and Safety Law in Türkiye, 2012. No. 6331. Official Gazette Number: 28339, Official Gazette Date: 20.06.2012. Ankara. 25.

35. Page, W.G., Butler, B.W. 2017. An empirically based approach to defining wildland firefighter safety and survival zone separation distances. International Journal of Wildland Fire 26: 665-667.

36. Pausas, J.G., Keeley, J.E. 2019. Wildfires as an ecosystem service. Frontiers in Ecology and the Environment 17(5): 289-295.

37. Pheko, N. 2021. The effects of fire on ecosystem functions: A study with the purpose of improving fire management in Lesotho. GRO LRT [Final Project] https://www.grocentre.is/static/gro/publication/833/document/pheko2021.pdf

38. Rahn, M., Broyles, G., McHale, T., Brown, C., Edwards, T., Hale, K., Swan, R. 2016. Wildland Firefighter Exposure Study: Evaluating Core Temperature, Heart Rate and Hydration. Wildfire Research Report 5 USA. 35.

39. Sayın, S., Güney, C.O., Sarı, A. 2014. Occupational health and safety in forest fires. SDU Faculty of Forestry Journal 15: 168-175.

40. Swinston, J.R., Davidson, W., Attridge, S., Li, G.T., Brauer, M., van Eeden, S.F. 2008. Wood smoke exposure induces a pulmonary and systemic inflammatory response in firefighters. European Respiratory Journal 32: 129-138.

41. Şahan, C., Kaya, İ. 2022. Evaluation of Forest Fires in Turkey and European Countries in Terms of Some Variables. ODÜSOBIAD 12(1): 1-14. Doi: 10.48146/odusobiad.1013462

42. Turkish Labor Law, 2003. No. 4857. Official Gazette No: 25134, Official Gazette Date: 10.06.2003. Ankara. 137.

43. Turkish Ministry of Labor and Social Security, 2012. List of workplace hazard classes according to the Workplace Hazard Classes Communiqué on Occupational Health and Safety.

44. Tyukavina A., Potapov, P., Hansen, M.C., Pickens, A.H., Stehman, S.V., Turubanova, S., Parker, D., Zalles, V., Lima, A., Kommareddy, I. 2022. Global Trends of Forest Loss Due to Fire From 2001 to 2019. Front Remote Sens 3:825190. Doi: 10.3389/frsen.2022.825190

URL-1. 2024. https://www.ogm.gov.tr/tr. Access date: 07/07/2024.

45. URL-2. 2024. https://www.afac.com.au/docs/default-source/fire-and-hazard-notes/012.pdf?sfvrsn=10&download=false. Bushfire CRC. Access date: 28/08/2024.

46. URL-3. 2024. Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. OJ L 183, 29.6.1989, 1. https://www.legislation.gov.uk/eudr/1989/391/contents. Access date: 8/10/2024.

URL-4, 2024. Wildland Fire Suppression Tactics Reference Guide. PMS: 465, NFES: 1256. https://www.coloradofirecamp.com/suppression-tactics/how-to-attack.html. Access date: 28/08/2024

47. Usta, Y. 2023. The effects of prescribed burning on seed germination, seedling growth and development and soil properties in pure Anatolian black pine and Scots pine stands. PhD Thesis. Karadeniz Technical University Institute of Science. No: 794209. Trabzon, Türkiye.

48. Ünver, S., Ergenç, İ. 2021. Safety Risk Identification and Prioritize of Forest Logging Activities Using Analytic Hierarchy Process (AHP). Alexandria Engineering Journal 60 (1): 1591-1599.

49. Ünver-Okan, S., Acar, H.H. 2017. Evaluation of Satisfaction Levels from Workwears of Forest Fire Workers. J. of Faculty of Forestry-Istanbul University 67(1): 93-102.

50. Wempe, A.M., Keefe, R.F. 2017. Characterizing Rigging Crew Proximity to Hazards on Cable Logging Operations Using GNSSRF: Effect of GNSS Positioning Error on Worker Safety Status. Forests 8 (10): 357.

51. Wempe, A.M., Keefe, R.F., Newman, S.M., Paveglio, T.B. 2019. Intent to Adopt Location Sharing for Logging Safety Applications. Safety 5 (1): 7.

52. West, M.R., Costello, S.L., Sol, J.A., Domitrovich, J.W. 2020. Risk for heat-related illness among wildland firefighters: job tasks and core body temperature change. Occupational and Environmental Medicine 77(7): 433-438.

53. Xanthopoulos, G. 2007. Olympic flames. Wildfire 16(5): 10-18.

54. Xu, R., Yu, P., Abramson, M.J., Johnston, F.H., Samet, J.M., Bell, M.L., Haines, A., Ebi, K.L., Li, S., Guo, Y. 2020. Wildfires, Global Climate Change and Human Health. The New England Journal of Medicine 383(22): 2173-2181.

55. Yuan, W., Cai, W., Nguy-Robertson, A.L., Fang, H., Suyker, A.E., Chen, Y., Dong, W., Liu, S. Zhang, H. 2015. Uncertainty in Simulating Gross Primary Production of Cropland Ecosystem from Satellite-Based Models. Agric. For. Meteorol. 207: 48-57.

Chapter 6

PRESCRIBED BURNING FOR SITE PREPARATION

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1. Introduction

The first stage of forest regeneration is site preparation (Löf *et al.*, 2012; Kushla, 2017). The purpose of site preparation is to prepare the area for the species that will form the final stand (Grebner *et al.*, 2013). A regeneration process that lacks site preparation often results in unacceptably low seedling establishment and performance, including seed germination, seedling density, survival, growth, and development (Löj *et al.*, 2015). This leads to significant economic losses and ecosystem degradation (Stanturf *et al.*, 2001; Birch *et al.*, 2010; Löj *et al.*, 2015). In forestry practices, various site preparation techniques are used to prevent such negative effects (Grebner *et al.*, 2013; Löj *et al.*, 2015). Chemical, mechanical and prescribed burning are generally employed as site preparation techniques (Löf *et al.*, 2012; Kushla, 2017; Barry *et al.*, 2024). These techniques can be used individually or in combination (Löj *et al.*, 2015).

The preferred site preparation techniques in the regeneration process vary by country (Ammer *et al.*, 2011; Löf *et al.*, 2012). Chemical techniques involving the use of various herbicides are generally not preferred due to environmental concerns (Thiffault and Roy, 2011). Mechanical site preparation (MSP) techniques, which involve the use of specific tools, are the most commonly employed methods (Perrow and Davy, 2008; Cardoso *et al.*, 2020). Prescribed burning, based on the principle of utilizing the changes that fires cause in ecosystem structure and composition, is another site preparation technique (Weber and Taylor, 1992; Löj *et al.*, 2015; Cardoso *et al.*, 2020). Studies revealing the fire-ecosystem interaction have facilitated the use of fire as a management tool in forestry practices (Harper *et al.*, 2018).

Prescribed burning (also referred to as prescribed fire or controlled burning) is the process of planning and applying fire in a predetermined area under specific weather conditions to achieve a management objective (Waldrop and Goodrick, 2012; Fernandes *et al.*, 2013; Usta *et al.*, 2019). Prescribed burning practices in forest ecosystems are used to achieve various forestry objectives, such as reducing hazardous fuels, disposing of logging debris, preparing sites for regeneration, improving wildlife habitat, managing competing vegetation, controlling insects and diseases, improving forage for grazing, enhancing appearance and access, and perpetuating species and communities that require fire (Wade and Lunsford, 1989; Waldrop and Goodrick, 2012). Prescribed burning is an ideal pretreatment for forest regeneration (Weber and Taylor, 1992; Usta *et al.*, 2019).

This section evaluates the general principles and applications of prescribed burning as a site preparation technique in forest regeneration.

In this context, relevant studies are assessed, and recommendations are provided for implementation in Türkiye's forests.

2. General Principles of Site Preparation Burning

Site preparation burning is the use of fire for forest restoration. The purpose of this burning is to prepare the site for seeding, planting, or natural regeneration (Wade and Lunsford, 1989; Waldrop and Goodrick, 2012). Fire consumes fuels on the soil surface, exposes the mineral soil, enriches the soil with usable plant nutrients, and burns invasive species along with their seeds (Fernandes and Botelho, 2003; Alcañiz *et al.*, 2018; Agbeshie *et al.*, 2022; Usta, 2023). In other words, it creates suitable seedbed conditions for regeneration (Weber and Taylor, 1992). Two site preparation burning methods are commonly used: broadcast burning and pile and windrow burning (Van Lear and Waldrop, 1991).

<u>Broadcast burning</u>: In this method, the logging slash is burned without any treatment, such as piling or windrowing. Burning is carried out throughout the plot. To apply this method, fuel continuity and the establishment of a fire line are required. Burning should be conducted after the logging slash has dried for a certain period (1–2 months on average) and before seed fall, following the first autumn rains. Broadcast burning has several advantages, including:

- It is more economical because the logging slash does not require any treatment.

- The impact on the soil is less (e.g., soil compaction, soil loss, and organic matter loss).

- The fact that some of the logging slash remains unburned and the density of herbaceous plants increases after burning helps reduce the risk of erosion in areas with relatively steep slopes.

- It is quick and saves time.

<u>Pile and windrow burning (pile and burn)</u>: In this method, the logging slash is burned after being piled in specific areas or windrowed parallel to contour lines (Figure 1). This method is preferred when the fuel loading is low, and fuel continuity does not allow for the establishment of a fire line. In other words, it is generally used in cases where broadcast burning cannot be applied. Fuel consumption is higher with this technique. Burning should be completed at the same time as the broadcast burning technique. Pile and windrow burning has several disadvantages, including:

- The impact on the soil is greater.

- Since the logging slash is collected in specific areas, organic matter loss occurs, and site quality in terms of plant nutrients decreases in some locations.

- The burning period is lengthy and time-consuming.

Figure 1. Pile burning method (Photo: Yetkin USTA)

Different firing techniques are used in broadcast burning (Rizza and Berger, 2023). The technique selected is determined by the biology and ecology of the species, the management objective, the topography, fuel characteristics, and weather conditions at the time of burning. Depending on these factors, one technique may be used, or a combination of techniques may be applied (Wade and Lunsford, 1989; Waldrop and Goodrick, 2012).

a) Backing fire: In this technique, the fire is ignited along the firebreaks established around the plot and is allowed to advance into the plot as a backing fire in the direction of the wind (against the prevailing wind direction) (Figure 2). The main purpose of site preparation burning is to improve the conditions of the growing environment. This purpose can be achieved with a surface fire, where fire intensity is low and fuel consumption is high. Additionally, the fire should be confined to the application plot and must not spread to the surrounding area. Therefore, fire safety is crucial. For this reason, burning with the support of a backing fire will create a safety strip devoid of fuel.

Figure 2. Backing fire technique (Photo: Yetkin USTA)

b) Strip-heading fire: In this technique, fires are ignited in strips perpendicular to the prevailing wind direction and in the form of a head fire (Figure 3). The distance between the strips where the fire line is formed is determined by the desired flame length. In the strip-head fire technique, the fire line can be formed as continuous or dotted strips, depending on the conditions, distribution, and continuity of the fuel. The application of this technique, together with the backing fire technique, is crucial for fire safety.

c) Point-source (dot) fire: This technique is similar to the strip-head fire technique. However, in this method, the fire line is created using points (Figure 3). Fires ignited at individual points gradually coalesce over time to form a strip fire line. Point fires can be ignited from the bottom of the fuel or from the top and sides when the risk of fire spread is high. This technique is preferred when low fire intensity is desired.

d) Flanking fire: This technique involves setting several fire lines at right angles to the wind simultaneously. Flanking fire is conducted under conditions where the wind direction and speed remain constant. This technique is often used to support a backing fire or strip-head fire.

e) Heading fire: In this technique, fires are ignited from the upwind side. The fire line can be continuous or spot. In the heading technique, where staged burning is not anticipated, the rate of fire spread and fire intensity are very high. This technique is suitable for use under conditions of high relative humidity.

Figure 3. Strip-head and point-source fire techniques (Photo: Yetkin USTA)

f) Centre and circular (ring) fire: These methods are generally used when a fire line cannot be established due to low wind speeds. For a fire line to be established, the wind speed must be at least 2 km/h (Wade and Lunsford, 1989). This technique utilizes the convection created by interior fires and the inward flow of external fires toward the center.

To ensure fire safety and enable suppression in the event of a fire, firebreaks should be established around the plots where burning applications will be conducted. The firebreak should be wide enough (~3 m) to allow water tankers to enter. Existing roads around the plots can also be utilized if maintained appropriately. To ensure fire safety, a fully equipped tanker and a hand crew (at least five workers) equipped with hand tools should be ready on the firebreak (Figure 4). Simultaneously, weather conditions (temperature, precipitation, relative humidity, wind speed and direction, dew point) during the fire should be monitored in real-time. To avoid any issues related to incoming notifications, relevant authorities should be informed about the time, location, and duration of the burning. All work must be carried out according to a specific plan.

Figure 4. Fire safety (Photo: Yetkin USTA)

3. Use of Site Preparation Burning in Forest Regeneration

There are no natural pine ecosystems in tropical Africa and the Southern Hemisphere (except Sumatra). Pines are pioneer species in these ecosystems and were introduced to the area following events such as the abandonment of agricultural land, landslides, or fires (Goldammer, 1991). Pine species have developed various adaptations (e.g., thick bark, deep root systems, shoot formation) based on the fire regime characteristics of their native areas (Fernandes *et al*., 2008). In the event of a fire in the ecosystem, hardwood species that are sensitive to fire retreat from the area, while species adapted to fire survive and form pure stands. Pure pine ecosystems, including those in South Asia and Central America, have a clear history of fire (Munro, 1966; Goldammer and Peñafiel, 1990; Goldammer, 1991). In these ecosystems, fires are closely linked to and significantly influence the management and sustainability of the ecosystem.

Pine species that are naturally distributed in Türkiye and form pure stands include Calabrian pine (*Pinus brutia* Ten.), Scots pine (*Pinus sylvestris* L.), Anatolian black pine (*Pinus nigra* Arn. subsp. *pallasiana* Lamb.), Aleppo pine (*Pinus halepensis* Miller), and Stone pine (*Pinus pinea* L.). Calabrian pine (5.215.292 ha), Scots pine (1.410.177 ha), and Anatolian black pine (4.199.623 ha) constitute 47.2% of the country's forested area (GDF, 2020). Calabrian pine and Anatolian black pine are found in fire-prone areas and are exposed to fires of varying intensities (Turna and Bilgili, 2006; Usta *et al*., 2019; Usta, 2023).

Calabrian pine, Scots pine, and Anatolian black pine are fire-adapted pine species (Eron, 1987; Hille, 2006; Fulé *et al.*, 2008; Christopoulou *et al.*, 2014). These species are either negatively or positively affected by fires, depending on the fire regime characteristics of their ecosystems (Hardesty *et al.*, 2005; Meyers, 2006; Usta *et al.*, 2022; Güney *et al.*, 2024). While these species are negatively affected by high-intensity fires, they can survive low-to-moderate intensity fires due to the adaptations they have developed, and they may even benefit from the changes in stand structure and soil dynamics caused by fires (Hille and Den Ouden, 2004; Keeley, 2012; Drews and Fredericksen, 2013; Lucas-Borja *et al.*, 2016). This demonstrates that fires can be used as forestry management tools in ecosystems dominated by these species, depending on their biology and ecology.

4. Conclusion

Prescribed burning is used as a management tool in silviculture for purposes such as controlling invasive species, stand rehabilitation, and regeneration. Seedling establishment, especially in regeneration studies, is possible with suitable site preparation. For seeds to germinate, they must come into contact with mineral soil, and for germinated or planted seedlings to grow and develop well, the soil must be rich in plant nutrients. Prescribed burning is a practical and economical pretreatment used in site preparation, serving various purposes. In Türkiye's forestry practices, prescribed fire can be used during the site preparation phase of regeneration in Calabrian pine, Scots pine, and Anatolian black pine stands.

The first step for a successful burning application is to thoroughly analyze the area where the burning will be carried out beforehand and to take the necessary precautions. This is essential because the studies conducted on the plots influence a wide range of factors, from achieving the intended purpose of the burning application to ensuring its safe and effective completion. Although burnings are not planned in areas that pose a risk, all necessary fire safety precautions must be taken.

Prescribed fire conditions and applications should be planned from a multi-faceted perspective based on the desired purpose. For example, if burning is carried out outside of a mast year in natural regeneration and the seed quantity is insufficient, it would be advisable to protect seed trees from fires. Additionally, clearing existing seed trees from the area after a few years or supplementing seeds with those of suitable origin can increase regeneration success. In such areas, measures like removing logging slash to a certain distance from seed trees, conducting burning when soil moisture increases after the first autumn rains, and shortening the time between cutting and burning (to reduce the drying period) will help lower fire intensity and minimize damage to trees. However, if there are enough trees around to seed the area, not taking such measures can reduce regeneration costs. Another example is the increase in herbaceous plant density following prescribed burning. Burning in areas close to settlements can lead to grazing damage, disrupting the seed-soil-protection triangle, which is critical for the successful and purposeful completion of the regeneration process. In such cases, it would be more appropriate to use alternative site preparation techniques. Moreover, the use of fire requires the presence of technical personnel with sufficient knowledge and experience. In the absence of expert personnel, fire should definitely not be used. Factors such as whether burning applications are implemented, the timing of the burn, and the specific burning technique should all be carefully planned and executed according to the conditions.

References

Agbeshie, A.A., Abugre, S., Atta-Darkwa, T., Awuah, R., 2022. A review of the effects of forest fire on soil properties. Geoderma. 33, 1419-1441. https://doi.org/10.1007/s11676-022-01475-4.

Alcañiz, M., Outeiro, L., Francos, M., Úbeda, X., 2018. Effects of prescribed fires on soil properties: A review. Sci Total Environ. 613-614, 944-957.

Ammer, C., Balandier, P., Bentsen, N.S., Coll, L., Löf, M., 2011. Forest vegetation management under debate: an introduction. Eur J Forest Res. 130, 1-5. https://doi.org/10.1007/s10342-010-0452-6.

Barry, J.E., Cunningham, K., Walkingstick, T., 2024. Site Preparation Methods for Establishing or Re-establishing Pine Stands. FSA5002. University of Arkansas Division on Agriculture, C.E.S., Access Date: 03/12/2024, USA, pp. 6.

Birch, J.C., Newton, A.C., Aquino, C.A., Cantarello, E., Echeverría, C., Kitzberger, T., Schiappacasse, I., Garavito, N.T., 2010. Cost-effectiveness of dryland forest restoration evaluated by spatial analysis of ecosystem services. Proceedings of the National Academy of Sciences. 107, 21925-21930. https://doi.org/10.1073/pnas.1003369107.

Cardoso, J.C., Burton, P.J., Elkin, C.M., 2020. A Disturbance Ecology Perspective on Silvicultural Site Preparation. Forests. 11, 1-12. https://doi.org/10.3390/f11121278.

Christopoulou, A., Fyllas, N.M., Andriopoulos, P., Koutsias, N., Dimitrakopoulos, P.G., Arianoutsou, M., 2014. Post-fire regeneration patterns of Pinus nigra in a recently burned area in Mount Taygetos, Southern Greece: The role of unburned forest patches. Forest Ecol Manag. 327, 148-156. https://doi.org/10.1016/j.foreco.2014.05.006.

Drews, M.J., Fredericksen, T.S., 2013. The Effect of Experimental Prescribed Fire on White Pine Regeneration. The Open Forest Science Journal. 6, 31-35.

Eron, Z., 1987. Ecological factors restricting the regeneration of Pinus brutia in Turkey. Ecologia mediterranea. XIII, 57-67. https://doi.org/10.3406/ecmed.1987.1189.

Fernandes, P.M., Botelho, H.S., 2003. A review of prescribed burning effectiveness in fire hazard reduction. Int J Wildland Fire. 12, 117-128. https://doi.org/10.1071/WF02042.

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A., Molina, D., 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. Front Ecol Environ. 11, E4-E14. https://doi.org/10.1890/120298.

Fernandes, P.M., Vega, J.A., Jiménez, E., Rigolot, E., 2008. Fire resistance of European pines. Forest Ecol Manag. 256, 246-255. https://doi.org/10.1016/j.foreco.2008.04.032.

Fulé, P.Z., Ribas, M., Gutie´rrez, E., Vallejo, R., Kaye, M.W., 2008. Forest structure and fire history in an old Pinus nigra forest, eastern Spain. Forest Ecol Manag. 255, 1234-1242. https://doi.org/10.1016/j.foreco.2007.10.046.

GDF, 2020. Türkiye Forest Assets. Forestry, General Directorate of Forestry, Ankara, pp. 56 s.

Goldammer, G.J., 1991. Tropical Wild-land Fires and Global Changes: Prehistoric Evidence, Present Fire Regimes, and Future Trends. In: Levine, J.S. (Ed.), Global biomass burning: Atmospheric, climatic and biospheric implications. The MIT Press, Cambringe, Massachuesetts, London, England, pp. 45-62.

Goldammer, G.J., Peñafiel, S.R., 1990. Fire in the Pine-Grassland Biomes of Tropical and Subtropical Asia. In: Goldammer, G.J. (Ed.), Fire in the Tropical Biota: Ecosystem Processes and Global Challenges, Ecological Studies, 84. Springer-Verlang, Berlin-Heidelberg, pp. 45-62.

Grebner, D.L., Bettinger, P., Siry, J.P., 2013. Chapter 11-Common forestry practices. In: Grebner, D.L., Bettinger, P., Siry, J.P. (Eds.), Introduction to Forestry and Natural Resources. Academic Press, San Diego, pp. 255-285.

Güney, C.O., Güney, A., Sarı, A., Kavgacı, A., Ryan, K.C., Hood, S.M., 2024. Modeling post-fire mortality of Turkish pine (Pinus brutia Ten.). Forest Ecol Manag. 572, 122265. https://doi.org/10.1016/j.foreco.2024.122265.

Hardesty, J., Myers, R., Fulks, W., 2005. Fire, Ecosystems and People: A Preliminary Assessment of Fire as a Global Conservation Issue. The George Wright Forum. 78-87.

Harper, A.R., Doerr, S.H., Santin, C., Froyd, C.A., Sinnadurai, P., 2018. Prescribedfire and its impacts on ecosystem services in the UK. Sci Total Environ. 624, 691-703. https://doi.org/10.1016/j.scitotenv.2017.12.161.

Hille, M., 2006. Fire Ecology of Scots Pine in Northwest Europe. PhD Thesis. Wageningen University, Wageningen, pp. 179.

Hille, M., Den Ouden, J., 2004. Improved recruitment and early growth of Scots pine (Pinus sylvestris L) seedlings after fire and soil scarification. Eur J Forest Res. 123, 213-218. https://doi.org/10.1007/s10342-004-0036-4.

Keeley, J.E., 2012. Ecology and evolution of pine life histories. Ann Forest Sci. 69, 445-453. https://doi.org/10.1007/s13595-012-0201-8.

Kushla, J.D., 2017. Site Preparation: The First Step to Regeneration. Publication 2823 (POD-09-17). Service, Mississippi State University Extension Service, USA, pp. 6.

Löf, M., Dey, D.C., Navarro, N.F., Jacobs, D.F., 2012. Mechanical site preparation for forest restoration. New Forest. 43, 825-848. https://doi.org/10.1007/s11056-012-9332-x.

Löj, M., Ersson, B.T., Hjältén, J., Nordfjell, T., Oliet, J.A., Willoughby, I., 2015. Site Preparation Techniques for Forest Restoration. In: Stanturf, J.A. (Ed.), Restoration of Boreal and Temperate Forests. CRC Press, Boca Raton, pp. 85-102.

Lucas-Borja, M.E., Madrigal, J., Candel-Pérez, D., Jiménez, E., Moya, D., de las Heras, J., Guijarro, M., Vega, J.A., Fernández, C., Hernando, C., 2016. Effects of prescribed burning, vegetation treatment and seed predation on natural regeneration of Spanish black pine (Pinus nigra Arn. ssp salzmannii) in pure and mixed forest stands. Forest Ecol Manag. 378, 24-30. http://dx.doi.org/10.1016/j.foreco.2016.07.019.

Meyers, R.L., 2006. Living with Fire—Sustaining Ecosystems and Livelihoods Through Integrated Fire Management. The Nature Conservancy, Tallahassee, U.S.A.

Munro, N., 1966. The Fire Ecology of Caribbean Pine in Nicaragua In, 5th Tall Timbers Fire Ecology Conference, Tallahassee, Florida, Tall Timbers Research Station, pp. 67-84.

Perrow, M.R., Davy, A.J., 2008. Handbook of Ecological Restoration: Restoration in Practice, Volume 2. Cambridge University Press, UK.

Rizza, J., Berger, C., 2023. Prescribed Fire Basics: Ignition Techniques and Tools. EM 9387. Oregon State University, Oregon State University, Forestry and Natural Resources Extension Program, USA, pp. 7.

Stanturf, J.A., Schoenholtz, S.H., Schweitzer, C.J., Shepard, J.P., 2001. Achieving restoration success: myths in bottomland hardwood forests. Restor Ecol. 9, 189-200.

Thiffault, N., Roy, V., 2011. Living without herbicides in Québec (Canada): historical context, current strategy, research and challenges in forest vegetation management. Eur J Forest Res. 130, 117-133. https://doi.org/10.1007/s10342-010-0373-4.

Turna, I., Bilgili, E., 2006. Effect of heat on seed germination of Pinus sylvestris and Pinus nigra ssp pallasiana. Int J Wildland Fire. 15, 283-286. https://doi.org/10.1071/WF05069.

Usta, Y., 2023. Saf Anadolu Karaçamı ve Sarıçam Meşcerelerinde Kontrollü ve Amaçlı Yakma Uygulamalarının Tohum Çimlenme, Fidan Büyüme ve Gelişimi ile Toprak Özellikleri Üzerine Olan Etkilerinin Belirlenmesi. Doktora Tezi. KTÜ, Fen Bilimleri Enstitüsü, Trabzon, pp. 153.

Usta, Y., Bilgili, E., Coskuner, K.A., Balcioglu, K., 2019. The Use of Fire as A Management Tool in Anatolian Black Pine and Scots Pine Stands. In, III. International Mediterranean Forest and Environment Symposium (IMFES 2019), Kahramanmaras, Türkiye, pp. 134-138.

Usta, Y., Bilgili, E., Coşkuner, K.A., 2022. Karaçam Ekosistemlerinde Orman Yangınlarının Ekolojik Rolü. In: In: Sevgi, O., Tecimen, H. B., Okan, T. (Ed.), Karaçam. Türkiye Ormancılar Derneği, Ankara, pp. 252-272.

Van Lear, D., Waldrop, A., 1991. Prescribed Burning for Regeneration. In: In: Duryea, M.L.a.D., P. M. (Ed.), Forest Regeneration Manual. Forestry Sciences, vol 36. Springer, Dordrecht, pp. 235-250.

Wade, D.D., Lunsford, J.D., 1989. A guide for prescribed fire in southern forests. Technical Publication R8-TP 11. Region, U. S. Department of Agriculture Forest Service Southern Region, Atlanta, Georgia, pp. 63.

Waldrop, T.A., Goodrick, S.L., 2012. Introduction to prescribed fires in Southern ecosystems. Science Update SRS-054. Station, U. S. Department of Agriculture Forest Service Southern Research Station, Asheville, North Carolina, pp. 80.

Weber, M.G., Taylor, S.W., 1992. The use of prescribed fire in the management of Canada's forested lands. The Forestry Chronicle. 68, 324-334.