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# Carbon Stocks of Fine Woody Debris in Coppice Oak Forests at Different Development Stages

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**Abstract:** Dead woody debris is a significant component of the carbon cycle in forest ecosystems. This study was conducted in coppice-originated oak forests to determine carbon stocks of dead woody debris in addition to carbon stocks of different ecosystem compartments from the same area and forests which were formerly elucidated. Weight and carbon stocks of woody debris were determined with recent samplings and compared among development stages (diameter at breast height (DBH, $D_{1.3m}$)), namely small-diameter forests (SDF) = 0–8 cm, medium diameter forests (MDF) = 8–20 cm, and large-diameter forests (LDF) = 20–36 cm). Total woody debris was collected in samplings; as bilateral diameters of all woody debris parts were less than 10 cm, all woody parts were in the "fine woody debris (FWD)" class. The carbon concentrations of FWD were about 48% for all stages. Mass (0.78–4.92 $Mg \cdot ha^{-1}$) and carbon stocks (0.38–2.39 $Mg \cdot ha^{-1}$) of FWD were significantly ($p > 0.05$) different among development stages. FWD carbon stocks were observed to have significant correlation with $D_{1.3m}$, age, basal area, and carbon stocks of aboveground biomass (Spearman rank correlation coefficients; 0.757, 0.735, 0.709, and 0.694, respectively). The most important effects on carbon budgets of fine woody debris were determined to be coppice management and intensive utilization. Also, national forestry management, treatments of traditional former coppice, and conversion to high forest were emphasized as having substantial effects.

**Keywords:** biomass; ecosystem compartments; forest management; *Quercus*; Turkey

## 1. Introduction

Oaks (*Quercus* sp.) have a vast distribution, cover about 50% of entire forest area in North America, Asia and Europe, and offer significant ecosystem services [1–3]. After beech species, oaks are the most valuable deciduous species in Europe, and are widespread in both Mediterranean and temperate climates [1,4]. Oak species are considerably important for Turkish forestry, as oak forests have the second largest area after pine species, and contribute to 26.4% of the Turkey's forested area [5]. Moreover, Turkey is one of the world's notable oak hotspots in terms of forest area and species richness, which reaches to 5.89 million hectares [5] with 24 taxa, respectively.

Coppicing has traditionally been used as a silvicultural management system in many European deciduous forests. Indeed, coppice management has a history of approximately 6000 years in western and central Europe, and coppice forests cover an area of 8.5 million hectares in only five European Union countries in the Mediterranean region [6]. Short rotation times have profound effects on the forest ecosystem under coppice forest management systems. Therefore, coppice management has a much higher disturbance frequency on community structure and ecosystem function than high forest systems (high forests originate from seed or planted seedlings in which single-stemmed trees, singling stems are used to promote a high forest structure and more rapid development of large-diameter trees) [6–8]. In coppice management, the living tree biomass is removed from the forest ecosystem with the clear cuttings and therefore nutrient cycling is interrupted with losses of organic matter and carbon. For this reason, most coppice forests are converted to high forest systems [7]. When such stands are converted to high forest, either by planting or by promotion through thinning, the aged stools typically remain for decades as the stands grow to maturity [9]. Comparing rotations, the difference between coppice and high forests is simply that the young stage recurs every 10–20 years in coppice forests but 5–200 years in high forests [8]. Therefore, coppices contain no snags or large down logs, whereas high forests normally contain substantial amounts of both. Moreover, coppices generally contain all age classes at one time, since the rotation is short [8]. For high forest, only large woods under consistent management for some time are likely to have an even representation of age classes [8]. In Turkey, more than nine million hectares of forest areas composed of deciduous tree species (mostly oak forests) have been managed as coppice forests for many years and a large part of these areas started to become converted to high forest systems with the decision of Turkish General Directorate of Forestry in 2006 [10,11].

Carbon in forest ecosystems has a very important role in the global carbon cycle. Estimation of carbon storage in forest ecosystems plays a key role, particularly in combating climate change [12]. Also, the ability of forests to function as net carbon sinks may be enhanced through carefully planned forest carbon sequestration projects [13]; on the other hand, quantifying the dynamics of forest detritus C accumulation and turnover under a scenario of global climate warming is critical to predicting the future inventory of C stocks [14]. In addition, there is a great need for knowledge and correct carbon estimations in different ecosystem compartments (such as aboveground parts, ground cover, dead wood, woody debris, forest floor, and soil) in forests [12,15]. Highly accurate data is needed to help generate correct estimations and minimize potential mistakes [12]. The importance placed on carbon storage estimation is likely one of the most notable recent changes in forest management [16]. The number of research studies considering carbon budgets of different ecosystem compartments in forest ecosystems are still insufficient in Turkey [17].

Similarly, Paletto et al. [18] stated the necessity of carbon estimations in forest ecosystems, and also emphasized that woody debris, which was often formerly seen as only a source of habitat for fungi or insect nests, is now considered an important part of forest ecosystems. Amanzadeh et al. [19] reported that we have still limited information about woody debris, although it has increasingly received a considerable amount of attention in recent years. Nonetheless, studies to determine carbon stocks of woody debris are still inadequate [20]. The number of woody debris studies is also very limited in Turkey [21–23]. Woody debris is important for carbon and one of the major carbon pools that should be calculated in the preparation of national inventories of greenhouse gases [24,25]. In this context, fine woody debris (FWD) is also very important in carbon balances of forest ecosystems, even though it corresponds to relatively low rates within the overall carbon budget. Also, FWD potentially represents a considerable portion of the total volume of dead wood in temperate broadleaf forests, especially in managed woodlands [26]. In general, FWD has a fast decomposition rate, and therefore the small carbon stocks of FWD do not reflect the true size of the carbon fluxes. For example, Harmon et al. [27] stated that 4.1% of FWD carbon stocks accounted for 13% of heterotrophic respiration [28]. In addition, FWD is a source of nutrients for organisms and soil, is important for biodiversity, increases the soil water holding capacity, creates micro-habitats, and is a significant part of decomposing organic matter and nutrient cycling [16,29].

This study was carried out in Demirköy and İğneada regions in Kırklareli, Turkey, where coppice-originated oak forest ecosystems and coppicing are important. The main objective of the study was to determine the amount of woody debris, carbon concentrations, and carbon stocks in coppice-originated oak ecosystems, which are globally important ecosystems and are especially important in region of study. The study also aimed to determine the contribution of woody debris carbon to the total carbon stocks in ecosystems according to different development stages in order to show the variation of these factors based on conversion of the coppice forests to high forest systems.

## 2. Materials and Methods

### *2.1. Study Area*

This study was conducted in the Demirköy-İğneada region of Kırklareli province in northwestern Turkey (Figure 1). The mean annual precipitation is 837 mm in Demirköy and 867 mm in İğneada. The mean annual temperature is listed as 12 °C in Demirköy and 13 °C in İğneada. The prevailing wind directions are northeast and southwest [30].

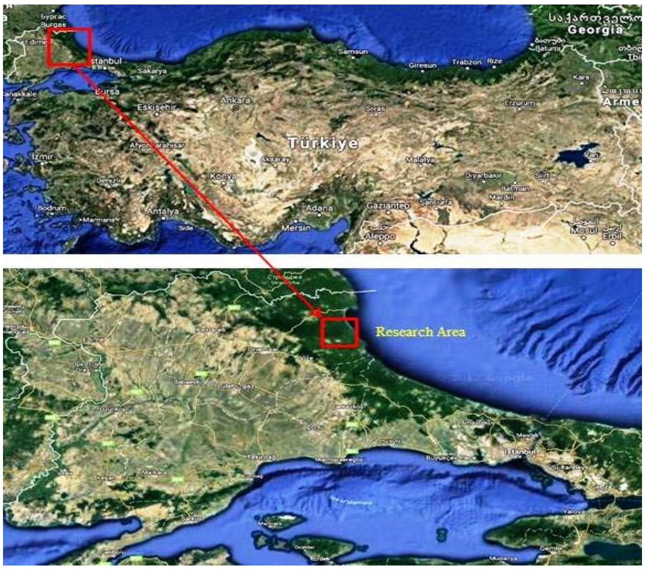


**Figure 1.** Map of the research area [31].

### *2.2. Experimental Design and Sampling*

The procedure of sampling was set on the pure coppice-originated oak forests at different development stages, in two main regions (Demirköy and İğneada), and on the main soil types (based on parent material) of each region based on a former study [10,11]. The main parent materials for dominant soil types in the research area are mainly granitoid in Demirköy and sandstone in İğneada. Soils in the research area are generally deep, well-drained, loamy texture, and slightly acidic (5–6 pH). Sample plots were distributed at the elevations ranging between 125 and 381 m [10,11]. According to Forest Management Legislation, Turkish Ministry of Forest and Water Affairs, development stages are (diameter at breast height ($D_{1.3m}$)) small-diameter forests (SDF) = 0–8 cm, medium diameter forests (MDF) = 8–20 cm, and large-diameter forests (LDF) = 20–36 cm [11]. Eighteen sample plots (20 × 20 m) were selected for each development stages, and 54 sample plots were sampled in total. Diameter at stump height ($D_{0.3m}$), diameter at breast height ($D_{1.3m}$), and heights of all trees were measured in the sample plots (Table 1).

In general, 1 $m^2$ subsampling plots are adequate for the sampling of woody detritus [32]. We selected five randomized 1 $m^2$ subsampling plots for woody debris in each sample plots. All downed woody debris parts which were greater than 1 cm in diameter were collected because woody parts less than 1 cm in diameter are generally collected in forest floor samplings. The most commonly used lower limit for coarse woody debris (CWD) seems to be 10 cm [26,33,34]. FWD was defined as woody debris below 10 cm [15,32]. Despite the original aim of collecting all woody debris, including coarse parts, and separating these parts those that were 1–10 cm and those that were greater than 10 cm, all sampled and measured woody debris parts were in the fine woody debris (FWD) class. Bilateral diameters of woody parts were measured with electronic calipers with 0.01 cm sensitivity, the length of each part was measured with a measuring tape, and the parts were weighed in the field. Increment cores were taken from five randomized live trees with a stem diameter at breast height

(DBH, $D_{1.3m}$) to determine the mean ages of trees. Ages of trees were found by counting annual year rings from the cores.

**Table 1.** Stand characteristics of coppice-originated sample plots in different development stages (data were taken and transferred from [10,11]). SDF, small-diameter forests (0–8 cm); medium MDF, diameter forests (8–20 cm); LDF, large-diameter forests (20–36 cm).

| Stand Characteristics | Development Stages | | |
|---|---|---|---|
| | SDF | MDF | LDF |
| *n* (number of sample plots) | 18 | 18 | 18 |
| $D_{0.3m}$ (cm) | 4.72 ± 1.26 | 20.31 ± 3.32 | 30.66 ± 3.45 |
| $D_{1.3m}$ (cm) | 2.25 ± 0.84 | 15.15 ± 2.66 | 25.23 ± 2.45 |
| Height (m) | 2.60 ± 0.58 | 15.19 ± 3.67 | 22.25 ± 0.77 |
| Age (year) | 14 ± 4 | 60 ± 10 | 75 ± 13 |
| Stand density (tree number/ha) | 6267 ± 2504 | 1106 ± 218 | 589 ± 83 |
| Basal area ($m^2$/ha) | 3.80 ± 2.98 | 20.12 ± 4.95 | 30.05 ± 6.94 |

### *2.3. Analyse*

Woody debris samples were dried at 70 °C until constant weight. Some representative small parts for each sample plot were mixed to obtain a composite sample and they were ground. Carbon concentrations were analyzed with LECO TruSpec 2000 Analyzer [35] in three replicates for each of the plots.

A research study was previously carried out in the research area that considered biomass and carbon based on the sampling of different ecosystem compartments of coppice-originated oak forests [10,11]. Local biomass models were developed for presently sampled plots by using models of this former study (Table 2). The biomasses of living tree components were estimated with these models and data from measurements on $D_{1.3m}$ and tree height of the sample plots in the present study. At the same time, carbon concentrations of living tree components were taken from [10], live tree biomass was calculated by multiplying these carbon values with the unit area value in order to evaluate the relationship between carbon stocks of woody debris and living tree biomass (Table 3). These estimated values were considered in order to evaluate the relationships with carbon stocks of woody debris.

**Table 2.** Equations for biomass estimation of different living tree components (*n* = 145) (developed from [10] using study data).

| Aboveground Biomass Components | Models | A | b | $R_{adj}^2$ | Standard Error of the Estimate | F Values | Significance |
|---|---|---|---|---|---|---|---|
| Leaf | $B_l = a \times ((D_{1.3m})^2H)^b$ | 0.1273 | 0.4824 | 0.891 | 0.540 | 1178.99 | 0.000 |
| Branch | $B_{br} = a \times ((D_{1.3m})^2H)^b$ | 0.0603 | 0.7193 | 0.928 | 0.639 | 1868.65 | 0.000 |
| Bark | $B_{ba} = a \times ((D_{1.3m})^2H)^b$ | 0.0391 | 0.7287 | 0.944 | 0.570 | 2415.93 | 0.000 |
| Stem over bark | $B_{sb} = a \times ((D_{1.3m})^2H)^b$ | 0.1398 | 0.7938 | 0.966 | 0.474 | 4137.22 | 0.000 |
| Stem under bark | $B_s = B_{sb} - B_{ba}$ | | | | | | |
| Aboveground biomass | $B_{ag} = B_l + B_{br} + B_{ba} + B_s$ | | | | | | |

**Table 3.** Carbon concentrations of aboveground biomass components in the research area (*n* = 145) (developed from [10,11]).

| Aboveground Biomass Components | Carbon (%) |
|---|---|
| Leaf | 48.68 |
| Branch | 49.19 |
| Bark | 47.97 |
| Stem | 48.54 |

### 2.4. Statistical Evaluation

Weight, carbon concentration, and carbon stocks of FWD obtained from the sample plots were compared among development stages (SDF, MDF, and LDF). The data were not normally distributed according to Kolmogorov-Smirnov test ($p = 0.05$), therefore, the differences between the development stages were tested by Kruskal-Wallis analysis. After the determination of significantly changed parameter according to the Kruskal-Wallis test results, Mann-Whitney U test was used at 0.05 significance level by paired comparisons of development stages (SDF-MDF, SDF-LDF, and MDF-LDF) to determine which of the development stages was significantly different in regard to the tested parameters. Also, Spearman rank correlation analysis was performed to determine the relationships between carbon stocks of FWD and different stand parameters (age, $D_{1.3m}$, basal area, and carbon stocks of aboveground biomass). IBM-SPSS Statistic20 for Windows computer software package was used for the statistical evaluation [36].

## 3. Results

No dead downed woody parts and/or snags with diameters greater than 10 cm were found in the study area (Table 4). For this reason, all sampled dead woods were classified as fine woody debris (FWD). In a total of 54 plots, the average FWD weight in the unit area was approximately 3.16 Mg·ha$^{-1}$. The FWD weights in SDF, MDF, and LDF stands were 0.78, 3.79, and 4.92 Mg·ha$^{-1}$ respectively. FWD weight was significantly lower ($p \leq 0.05$) in stands with younger development stages. Although the FWD weights in development stages were statistically different, there were no statistically significant differences between the FWD carbon concentrations. The average FWD carbon concentration was 48.43%. FWD carbon stocks in the SDF, MDF, and LDF stands were 0.38, 1.83, and 2.39 Mg·ha$^{-1}$, respectively, and the average FWD carbon stock was 1.53 Mg·ha$^{-1}$. The FWD carbon stocks in the stands belonging to the SDF development stage were significantly lower than the other two groups ($p \leq 0.05$) (Table 5).

**Table 4.** Mean diameters, lengths, and weights of FWD in different development stages of coppice oak forests (±standard deviation) (mid-diameter of all samples >1 cm, mean values are sample based (each sample of FWD)).

| Development Stages | Base Diameter (cm) | Top Diameter (cm) | Length (cm) | Weight (g) |
|---|---|---|---|---|
| SDF | 2.34 ± 0.81 | 2.27 ± 0.81 | 21.59 ± 10. 77 | 78 ± 42.82 |
| MDF | 2.10 ± 1.01 | 1.92 ± 0.94 | 20.56 ± 9.84 | 379 ± 45.37 |
| LDF | 2.22 ± 1.38 | 2.09 ± 1.21 | 16.73 ± 8.43 | 492 ± 52.83 |

**Table 5.** Weight, C concentration, and C stocks of fine woody debris according to the development stages of coppice oak forests (±standard deviation).

| Characteristics of FWD | Means-Development Stages | | | Kruskal Wallis (Asymp. Sig) | Mann Whitney U-Asymp. Sig. (2-Tailed) | | |
|---|---|---|---|---|---|---|---|
| | SDF | MDF | LDF | | SDF-MDF | SDF-LDF | MDF-LDF |
| Number of plots | 18 | 18 | 18 | | | | |
| Weight (Mg·ha$^{-1}$) | 0.78a ± 0.51 | 3.79b ± 1.96 | 4.92c ± 1.16 | 0.000 | 0.000 | 0.000 | 0.015 |
| Carbon concentration (%) | 48.47a ± 1.21 | 48.32a ± 1.30 | 48.41a ± 1.27 | 0.844 | 0.704 | 0.728 | 0.613 |
| Carbon stocks (Mg·ha$^{-1}$) | 0.38a ± 0.25 | 1.83b ± 0.93 | 2.39c ± 0.58 | 0.000 | 0.000 | 0.000 | 0.018 |

Notes: Values within lines followed by the same letter (a, b, c) are not statistically different at 0.05 significance level.

The biomass of the aboveground tree components in three different development stages and the carbon stocks of these components are given in Table 6. Except from the leaf biomass and their carbon stocks, the biomass and biomass carbon stocks of other tree components were significantly different among the three development stages. In terms of leaf biomass, MDF and LDF stands were similar, whereas leaf biomass in SDF stands were considerably less than the others. Aboveground biomass carbon stocks were calculated as 8.40 Mg·ha$^{-1}$ in SDF, 64.63 Mg·ha$^{-1}$ in MDF, and 100.30 Mg·ha$^{-1}$ in LDF stands (Table 6).

**Table 6.** Biomass and biomass carbon stocks of living tree components according to development stages (Mg·ha$^{-1}$, ±standard deviation).

| Biomass and Biomass Carbon Stocks of Living Tree Components | Means-Development Stages | | | Kruskal Wallis (Asymp. Sig) | Mann Whitney U-Asymp. Sig. (2-Tailed) | | |
|---|---|---|---|---|---|---|---|
| | SDF | MDF | LDF | | SDF-MDF | SDF-LDF | MDF-LDF |
| Plot number | 18 | 18 | 18 | | | | |
| Leaf biomass | 3.16 ± 2.04 a | 7.03 ± 1.44 b | 7.53 ± 1.21 b | 0.000 | 0.000 | 0.000 | 0.327 |
| Branch biomass | 3.46 ± 2.64 a | 23.70 ± 7.12 b | 34.65 ± 6.70 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Bark biomass | 1.13 ± 0.72 a | 15.55 ± 5.93 b | 41.53 ± 6.00 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Stem under bark biomass | 9.51 ± 7.88 a | 86.71 ± 28.46 b | 122.92 ± 29.51 c | 0.000 | 0.000 | 0.000 | 0.002 |
| Stem over bark biomass | 10.64 ± 8.49 a | 102.26 ± 33.74 b | 164.45 ± 33.77 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Aboveground biomass | 17.26 ± 13.15 a | 133.00 ± 42.23 b | 206.63 ± 41.63 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Leaf carbon mass | 1.54 ± 1.00 a | 3.43 ± 0.70 b | 3.67 ± 0.59 b | 0.000 | 0.000 | 0.000 | 0.327 |
| Branch carbon mass | 1.70 ± 1.30 a | 11.66 ± 3.50 b | 17.05 ± 3.29 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Bark carbon mass | 0.54 ± 0.35 a | 7.46 ± 2.84 b | 19.92 ± 2.88 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Stem under bark carbon mass | 4.61 ± 3.82 a | 42.09 ± 13.81 b | 59.67 ± 14.32 c | 0.000 | 0.000 | 0.000 | 0.002 |
| Stem over bark carbon mass | 5.16 ± 4.12 a | 49.55 ± 16.35 b | 79.59 ± 16.37 c | 0.000 | 0.000 | 0.000 | 0.000 |
| Aboveground carbon mass | 8.40 ± 6.40 a | 64.63 ± 20.52 b | 100.30 ± 20.22 c | 0.000 | 0.000 | 0.000 | 0.000 |

Notes: Values within lines followed by the same letter (a, b, c) are not statistically different at 0.05 significance level.

Statistically positive correlations were found between the FWD carbon stocks and mean $D_{1.3m}$, age, and basal area values in a correlation analysis (Table 7). Similarly, as the aboveground biomass carbon stocks increase, the FWD carbon stocks also significantly increase (Table 7).

**Table 7.** Spearman rank correlation coefficients between variables.

| | $D_{1.3m}$ (cm) | FWD Carbon Stocks | Age | Basal Area |
|---|---|---|---|---|
| **FWD Carbon Stocks (Mg·C·ha$^{-1}$)** | 0.757 * | | | |
| **Age (year)** | 0.760 * | 0.735 * | | |
| **Basal area (m$^2$·ha$^{-1}$)** | 0.957 * | 0.709 * | 0.729 * | |
| **Aboveground biomass carbon stocks (Mg·C·ha$^{-1}$)** | 0.959 * | 0.694 * | 0.733 * | 0.992 * |

Notes: "*" is statistically different at 0.05 significance level.

## 4. Discussion

In the study area, the sampled woody debris is in fine woody debris class (Ø < 10 cm, [32]) in all sample areas. The majority of the FWD in our research area was composed of dead branch fragments. As noted by Fasth et al. [28], the FWD, which is very important for the ecosystem, consists of fragments under 10 cm, most of which is formed by branches.

The FWD weight ranged from 0.78 to 4.92 Mg·ha$^{-1}$ in different development stages. In a study by Swift et al. [37], 93.6 g·m$^{-2}$ was observed for woody debris branches more than 2 cm in diameter, and 0.6 g·m$^{-2}$ was observed for branches of 1–2 cm in diameter in an abandoned oak coppiced woodland. The sum of these values is about 0.942 Mg·ha$^{-1}$, which is close to the values of the MDF stands in our study area. However, Onega and Eickmeier [38] found that the FWD weight (1–10 cm in diameter) was 7.52 Mg·ha$^{-1}$ for broad-leaved forests. Chojnacky and Schuler [39] reported that the amount of FWD in mixed oak forests was 7 Mg·ha$^{-1}$, which is higher than the values observed in the present study. Forest management types, biotic and abiotic disturbances, and silvicultural interventions can also be effective determining factors for the FWD masses in forest ecosystems.

In the research area, the mean FWD carbon concentration was 48% for all stages, and this concentration ratio did not show any significant difference between the development stages. Similar carbon concentration values, especially in the woody parts (branches and stem) of living tree biomass components, were obtained in the research results [11] of a previous study that was conducted on the same study area and considered the same development stages. Lamlom and Savidge [40] stated that, in wood residues, the carbon concentration may vary in a single tree and species. Weggler et al. [41] reported that using a default carbon ratio (50%) caused a high deviation for woody debris compared to species-specific values for various models and calculations in Switzerland. Guo et al. [42] investigated the branches of CWD from five native forests in China and found carbon concentrations were very variable, ranging from 29.4% to 49.0%.

In the development stages, carbon stock of FWD of the study area varied from 0.38 to 2.39 Mg·ha$^{-1}$. Also, the carbon stock of FWD showed a strong linear relationship with $D_{1.3m}$, age, basal area, and carbon mass of aboveground biomass. In addition to these, very different values are presented in the literature for the carbon stock of FWD [14,43]. Similar to the results in our study, Gough et al. [44] provided a carbon stock value of total woody debris of 2.2 Mg·C·ha$^{-1}$ in temperate forest, emphasizing that this value is an important carbon stock and close to the living leaf biomass carbon stock (1.8 Mg·C·ha$^{-1}$). However, in our study, carbon stocks in leaf biomass were calculated as 1.54–3.67 Mg·C·ha$^{-1}$, which is higher than FWD carbon stocks. Krueger et al. [45] found that FWD carbon stocks were between 7.4 and 35.8 Mg·C·ha$^{-1}$ on different geological materials and in managed and unmanaged forests. Woodall and Liknes [14] reported that FWD carbon stocks varied between 2.43 and 4.05 Mg·ha$^{-1}$ from a study conducted in 5528 sample plots around the US. Yoon et al. [46] measured the carbon amount of woody debris that originated only from broad-leaved trees ranging from 5.87 to 6.3 cm in diameter to be 0.28 Mg·C·ha$^{-1}$. The number of studies on woody debris carbon stocks in Turkey is very limited. In a study carried out by [23], it was determined that all woody debris parts were in the FWD class and ranged from 0.46 to 1.49 Mg·ha$^{-1}$ according to stand development stages. On the basis of various assumptions, Tolunay [47] estimated that the average dead wood carbon stock in Turkey's forests was 0.18 Mg·ha$^{-1}$ and that this value decreased to 0.13 Mg·ha$^{-1}$ in coppice forests.

As mentioned above, there are different values in the literature regarding both FWD quantities and their carbon stocks. This situation can be explained by the national forest management systems or silvicultural treatments. For example, in a research study on Mediterranean oak ecosystems, Paletto et al. [18] noted that carbon found in dead wood in intensively managed oak forests was much lower than forests under other forms of forest management (extensive and multifunctional management) in the Mediterranean region. Fasth et al. [28] emphasized the importance of forest operations on carbon storage potential of FWD, and it is surprising that there are very few studies demonstrating this fact. Lõhmus et al. [48] stated that the amount of small wood fragments (<10 cm in diameter) increases especially in clear-cuts due to falls and direct ground contact of trees. Direct increases in the amount of FWD can also be expected after periodic clear-cuts in coppice forest management. Additionally, Niklas [49] stated that broadleaved trees generally have more complex branching patterns, which may lead to a higher production of fine dead wood. Seidling et al. [50] emphasized that national forest management and legislation came first for woody debris amounts, followed by the structural features of the forests, the silvicultural system, and various ecological site factors after examining the 91 intensive monitoring plots of 11 countries in Europe. In classical forest management, trees that are the source of woody debris are cut before their normal life, and dead wood fragments are collected and removed to guard against disease, insect, and fire threats. Various researchers have similarly emphasized that there are quite notably different effects of forest management and silvicultural practices on woody debris quantities [51–53].

According to our results, FWD carbon stocks increase with the aging of the stands, and there is a strong linear correlation with diameter, age, basal area, and the aboveground biomass carbon stocks of the living trees. The increase in FWD weight can be considered to be a part of normal ecosystem development depending on the increases on the masses of all ecosystem compartments and tree components in a maturing stand. However, Fasth et al. [28] stated that the FWD weight may not change over time because the FWD has a relatively fast decomposition rate, and the amount of FWD can change over time with many factors such as cuts of trees, storm, snow, rain, wind, and insects. The following sequential steps can be expected on the mass or carbon stocks of FWD in coppice management: increase after clear cuts, decrease due to fast decomposition, and increase with the stand development stage. In addition, FWD stocks may differ in stands if regular thinning treatments are applied. It is interesting that our results have a high correlation with diameter, age, and aboveground biomass. This situation is thought to be caused by the national coppice management in Turkey, since most of the oak forests were managed as coppice systems with clear-cuts occurring in 20 year rotations until 2006. As a national and traditional coppice treatment in Turkey, the trees are removed from the forest with their leaves and branches, and the branches are separated outside of the stand. Branches that are larger than 4 cm in diameter are harvested as fuel wood for both coppice and high forest stands. Also, after clear cuttings and harvesting, dead wood and woody residues are gathered by forest villagers for fuel wood. In addition to all these facts, the whole tree mass can be removed from forests following extreme conditions (decline, wind storm, insect, fungi, etc.), which is called "clean forest management", as it is believed that this form of management decreases the risks against fire and pest/disease epidemics. Such an intensive management can likely reduce FWD weight as an expected result in the research area. The increase of FWD carbon stocks with the stand development stages is mostly caused by the conversion of the coppices to high forests. In general, the conversion of all coppices to high forest started in 2006 in Turkey on a country-wide basis. However, local-regional applications of coppice conversions had been initiated in the study area since the 1970s. As a matter of fact, there are stands approaching 100 years old, even though they originated as coppice systems, following the coppice conversion process and after the abandonment of periodical clear cuts. Silvicultural treatments were applied to increase canopy crown in order to promote more seed production for natural regeneration, and no clear cuts occurred under the coppice conversion process. Under these conditions, the diameter of branches increases. However, diebacks can be seen in older stages of coppice originated forests. The special situation for oak forests called "oak decline" is also observed in Turkey [10]. It is believed that these cases are the reason why FWD carbon stocks increase with age, diameter, and the aboveground biomass.

## 5. Conclusions

Woody debris under coppice-originated oak forests was observed as being completely within the fine woody debris class (<10 cm in diameter) in the study area. Stand type-structure, decomposition conditions, and site factors can be effective in regard to carbon balance of fine woody debris. Despite its small rate in ecosystem compartments, fine woody debris is an important part in carbon flux and the carbon cycle as much as carbon pools in forest ecosystems. In our study, FWD carbon stocks increased with the aging of the stands, and there was a strong correlation with diameter, age, basal area, and the aboveground biomass carbon stocks of the living trees. The most important effects on carbon budgets of fine woody debris were coppice management (short rotation times, with 20 year mean clear cut treatments) and intensive utilization (dead woods and woody residues are picked up by forest villagers for fuel wood and charcoal after clear cuttings and harvesting). National forestry management, treatments of traditional former coppice, and conversion to high forest were emphasized as having substantial effects.

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