

# Temporal and Spatial Change of Carbon Storage in Alara Forest Planning Unit

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## Abstract

*Aim of study:* Land use and carbon stock changes of Alara Forest Planning Unit (FPU) between the years of 1997 and 2017 were investigated.

*Area of study:* Alara Forest Planning Unit (FPU) of Alanya Forest Enterprise (FE) within the boundaries of Antalya province, southwest Turkey.

*Material and methods:* Data obtained from the forest management plans for the periods of 1997-2006, 2008-2017 and 2018-2037 were used in the study. Biomass conversion and expansion factors (BCEF), root to shoot ratios (R) and carbon factors (CF) were used for carbon stock estimation.

*Main results:* Total forest area of the Alara FPU decreased from 7497 ha to 7344 ha, while total carbon stock of the forest lands increased by 12.7%, from 1997 to 2017.

*Highlights:* Despite the reduction of total forest area from 1997 to 2017, carbon stocks of all biomass pools in forest ecosystem raised with the increase of productive forest lands and growing stock.

**Keywords:** Alara Forest Areas, Global Warming, Climate Change, Land Use, Carbon Stock Change

## Alara Orman İşletme Şefliği Karbon Stoğunun Zamansal ve Konumsal Değişimi

### Öz

*Çalışmanın amacı:* Bu çalışmada, Alara Orman İşletme Şefliği (OİŞ) için 1997 ve 2017 yılları arasında arazi kullanımının ve karbon stoğunun değişimi incelenmiştir.

*Çalışma alanı:* Bu çalışma, Antalya ili sınırları içerisinde yer alan Alanya Orman İşletme Müdürlüğü bünyesindeki Alara Orman İşletme Şefliği için gerçekleştirilmiştir.

*Materyal ve yöntem:* 1997-2006, 2008-2017 ve 2018-2037 orman amenajman planlarından elde edilen veriler bu çalışmada kullanılmıştır. Çalışma alanı içerisindeki karbon stoğunun tahmini için biyokütle çevirme ve genişletme faktörleri (BCEF), kök/sak oranları (R) ve biyokütleyi karbona çevirme katsayıları (CF) kullanılmıştır.

*Temel sonuçlar:* 1997 ve 2017 yılları arasında, Alara OİŞ içerisinde yayılış gösteren ormanların alansal olarak büyüklükleri 7497 hektardan 7344 hektara düşmesine rağmen, ormanların depoladıkları karbon stoğunda %12.7 lik bir artış gözlenmiştir.

*Araştırma vurguları:* 1997 yılından 2017 yılına kadar geçen sürede toplam ormanlık alanlarda azalma olmasına karşın, verimli orman alanlarının ve dikili servetin artışı ile orantılı olarak orman ekosistemi içerisindeki tüm bileşenlerin depoladıkları karbon miktarlarında artış gözlenmiştir.

**Anahtar Kelimeler:** Küresel Isınma, İklim Değişikliği, Arazi Kullanımı, Karbon Stok Değişimi

## Introduction

Global warming is defined as an increase in the temperature of the earth and thought to be provoked by the human activities such as industrialization, urbanization, deforestation, overuse of fossil fuels, etc. It's estimated that mean temperature of the earth, which is already 1 °C above pre-industrial levels, will increase by 1.5 °C between approximately

the years of 2030 and 2052 (IPCC, 2018). Expected climate change could lead to uncertainty in natural systems, especially in forests. Climate is one of the most important factors affecting growth of the forest trees in mountain environments, and so expectation about climate change concerns the forest sustainability (Socha, 2008). Also, the respiration and photosynthesis rates of trees



are expected to be affected in the coming years (Saxe et al., 2001). These concerns and warnings underline the importance of examination of natural balance between environment and climate, and hence investigation of relation between environment and climate change over time.

With increasing global awareness about climate change and its effects, carbon pools of the earth have received increasing importance in recent years. It seems possible to reduce, or at least delay the global warming by decreasing greenhouse gases emission and increasing carbon dioxide absorption from the atmosphere. Forests have been considered to be one of the most important carbon pools responsible for locking up carbon in the living biomass, soil, litter and dead wood (Vogt, 1991; Dixon et al., 1994). Moreover, forests have been managed over a long rotation ages, and this situation provides long-term carbon sequestration in the ecosystem. In epitome, forests are of great importance in storing large amount of carbon over the long-term.

The calculation and/or estimation of the forest carbon stock is an important issue to determine the role of forests in Earth's carbon cycle. Another issue as important as determination of the amount of carbon stored in forest ecosystems is to investigate the carbon stock change of forest biomass.

Especially, relationship between land use and carbon storage is one of the major point that is to be considered during decision making process of forest management. The objectives of this study were to investigate land use change, and hereby carbon stock change of forests of Alara FPU located in Antalya region.

## Material and Methods

### Study Area

This study was conducted in Alara Forest Planning Unit (FPU) of Alanya Forest Enterprise (FE) within the boundaries of Antalya province, southwest Turkey. Alara FPU was divided into 2 different FPUs in the year of 2019. Nevertheless, Alara FPU was examined as one unit (as before) for the last period. The study area has humid and semi-humid Mediterranean climate, with annual average temperature of 18.8 °C and mean annual precipitation of 1058.3 mm. Elevation of the studied area ranges from 0 to 785 m above sea level, with an average of 254 m, and slope varies between 0 and 86%. The total area of the studied FPU is 12683 ha, and forests cover approximately 58% of this FPU. The main species of the studied FPU is Brutian pine (*Pinus brutia* Ten.) which occupies over 95%. The geographic location of the Alara FPU is given in Figure 1.



Figure 1. Geographic location of the study area

**Data**

Forest inventories of the Alara FPU were carried out in the years of 1997, 2007 and 2017, on account of forest management plans for the periods of 1997-2006, 2008-2017 and 2018-2037, respectively. Average growing stocks ( $m^3/ha$ ) of each stand type and total area of these stands were used for biomass and carbon stock calculations (GDF, 1997;

GDF, 2007; GDF, 2017a). Information on total area and growing stock by group of tree species (coniferous, deciduous and maquis) for the years of 1997, 2007 and 2017 is given in Table 1. Beside, Figure 2 illustrates the land use changes of the study area between 1997 and 2017. All geographic maps were produced by using ArcMap 10.6 Software provided by Esri (Esri, 2021).

Table 1. Descriptive information of the study area for the consecutive periods

Stand form	Group of Species	1997		2007		2017	
		Area (ha)	Growing stock ( $m^3$ )	Area (ha)	Growing stock ( $m^3$ )	Area (ha)	Growing stock ( $m^3$ )
Productive	Coniferous	5674	962815	6288	957801	6432	1108619
	Deciduous	-	-	-	-	-	-
Degraded	Coniferous	1790	13291	1352	10470	646	6230
	Deciduous	33	258	18	72	-	-
Maquis		-	-	-	-	266	-
Total		7497	976364	7658	968343	7344	1114849

Note: Productive means the forest stands having crown closure more than 10%, while degraded means the forest stands having crown closure equal and less than 10%

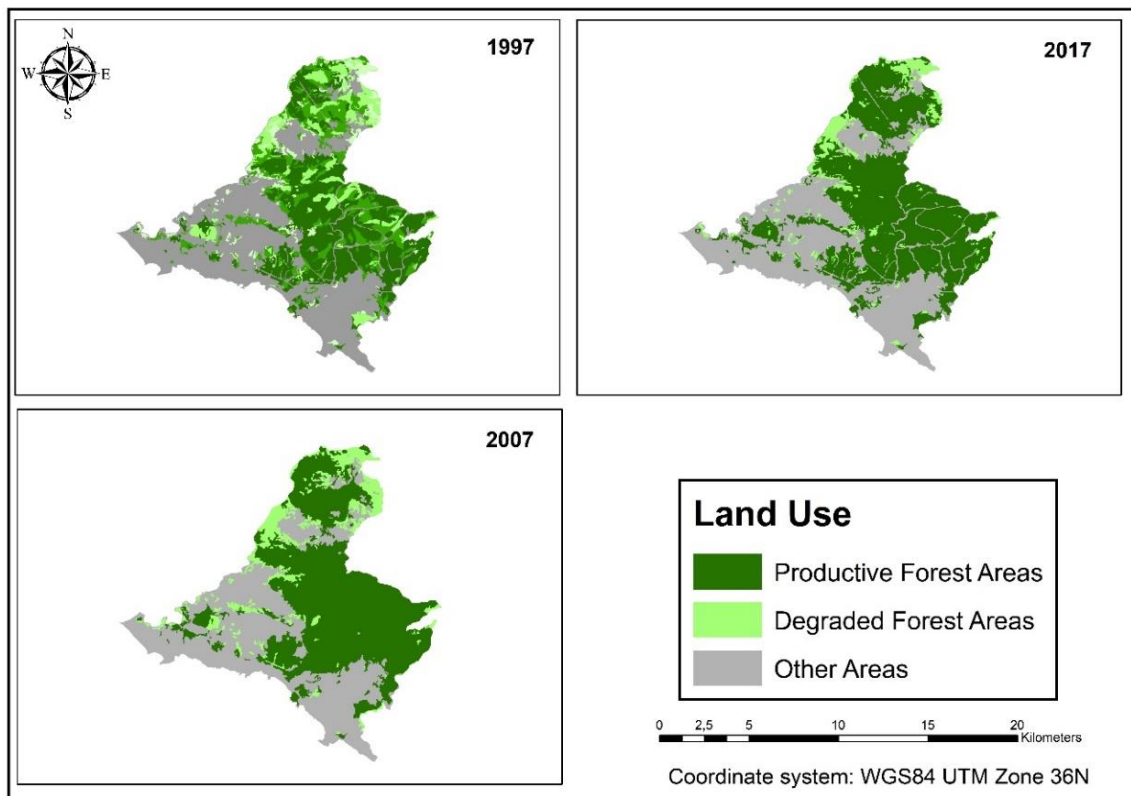


Figure 2. Land use change of the study area

*Biomass and Carbon Stock Calculations*

First step for estimation of carbon stock in living tree biomass is to convert growing stock volume to stem biomass. For this conversion, stem volume of a tree is multiplied by basic wood density (*WD*). The stem biomass is multiplied by biomass expansion factor (*BEF*) to calculate above-ground biomass (*AGB*) value, while below-ground biomass (*BGB*) value is obtained by using root to shoot ratios (*R*). Subsequently, carbon stock in the living tree biomass is calculated using carbon factor (*CF*) (IPCC, 2003). If it's desired, *AGB* can be estimated directly from the stem volume using biomass conversion and expansion factor (*BCEF*), recommended in AFOLU (IPCC, 2006).

The formula for calculation of carbon stocks in living tree biomass is given as follows:

$$C = V \times BCEF_1 \times (1 + R) \times CF$$

where *V* is the growing stock volume ( $m^3$ ),  $BCEF_1$  is the conversion and expansion factor ( $Mg/m^3$ ), *R* is the root to shoot ratio (dimensionless), *CF* is the carbon factor, and *C* is carbon stock (*Mg*).

There are various studies on determination of tree biomass in Turkey. Tolunay (2013) compiled the studies on this topic, and recalculated *BEF* and *BCEF* coefficients for Turkey. In this study, *BCEF* coefficients for coniferous and deciduous tree species groups calculated in Tolunay (2013) were used (Table 2).

Table 2. *WD*, *BEF<sub>1</sub>* and *BCEF<sub>1</sub>* values given in Tolunay (2013)

Group of species	<i>WD</i> ( $Mg/m^3$ )	<i>BEF<sub>1</sub></i>	<i>BCEF<sub>1</sub></i>
Coniferous	0.446	1.212	0.541
Deciduous	0.541	1.310	0.709

There is a deficiency in the number of studies investigating root biomass in Turkey. Therefore, *R* values, and also *CF* values

given in AFOLU (IPCC, 2006) for temperate zone forests were used in this study (Table 3).

Table 3. *R* and *CF* values given in AFOLU (IPCC, 2006)

Group of species	<i>AGB</i> ( $Mg/ha$ )	<i>R</i>	<i>CF</i>
Coniferous	<50	0.40	0.51
	50-150	0.29	
	>150	0.20	
Deciduous	<75	0.46	0.48
	75-150	0.23	
	>150	0.24	

Tolunay & Çömez (2008) investigated the former studies on litter and soil carbon stocks, and calculated carbon densities per

unit area. These values were used for determination of litter and soil carbon stocks of the study area (Table 4).

Table 4. Litter and soil carbon densities given in Tolunay and Çömez (2008)

Group of species	Litter ( $Mg/ha$ )	Soil ( $Mg/ha$ )
Coniferous	7.46	75.56
Deciduous	3.75	84.82
Maquis	1.70	79.60

Note: As there is not enough research on soil carbon of degraded forests in Turkey, the values given in Tolunay and Çömez (2008) are multiplied by 0.25 for degraded forests, as suggested in GDF (2017b).

Although there is a deficiency in studies evaluating dead wood biomass, the assumption that 1% of the *AGB* is equal to dead wood biomass is adopted (Tolunay, 2011; GDF, 2017b). The calculated dead wood biomass was multiplied by *CF* value (0.47) given in *FRA* (2010) for dead wood carbon stock.

### Results

Investigation of land use change between 1997 and 2017 showed that total area of the forest in the study field decreased from 7497 ha to 7344 ha. Despite the decrease in forest areas, there was a growing stock increase of 138485 m<sup>3</sup> (14%) between 1997 and 2017 (Table 1 and Figure 2). The main reason of

this contrast is reduction in the rate of degraded forest areas, and hereby rises in accumulation of growing stock.

As seen from Table 5, above- and below-ground, litter, soil, dead wood and total carbon stocks of the study area continuously increased from 1997 to 2017, while increase of carbon stocks in total living biomass is seen only between 2007 and 2017. This is the same trend with growing stock, as carbon stock in living tree biomass is highly correlated to tree volume. Total carbon stocks in the forest lands of the study area increased by 4.7%, 7.7% and 12.7% for the periods of 1997-2007, 2007-2017 and 1997-2017, respectively.

Table 5. Carbon stocks (Mg) in the forest lands of Alara in 1997, 2007 and 2017

	1997	2007	2017
Above-ground	269484.0 31.4%	267205.5 29.7%	307358.5 31.8%
Below-ground	78764.2 9.2%	78304.8 8.7%	88233.4 9.1%
Total living tree biomass	348248.2 40.6%	345510.3 38.4%	395591.9 40.9%
Litter	45687.8 5.3%	49438.4 5.5%	49638.8 5.1%
Soil	462151.0 53.8%	501365.2 55.8%	519551.0 53.7
Dead wood	2483.8 0.3%	2462.6 0.3%	2833 0.3%
Total	858570.7 100.0%	898776.5 100.0%	967614.6 100.0%

The contributions of carbon stock pools (above-ground, below-ground, litter, soil and dead wood) of forest ecosystem are given in Figure 3. As seen from the figure, forest soil is the major carbon pool of the forest ecosystems, with approximate percentages of 53.7-55.8%. Beside, above-ground biomass of living trees in the forest area lock up approximately 29.7-31.8% of the total carbon stored in the forest ecosystem. Below-ground biomass, litter and dead wood have approximately 9%, 5% and 0.3% of the total carbon, respectively. The proportion of these pools are seem to be close to each other for the years of 1997, 2007 and 2017. Nevertheless, living tree biomass including

*AGB* and *BGB* has the highest rate in 2017 when compared with 1997 and 2007. This is due to the increase of growing stock of forest trees from 1997 to 2017 in the study area.

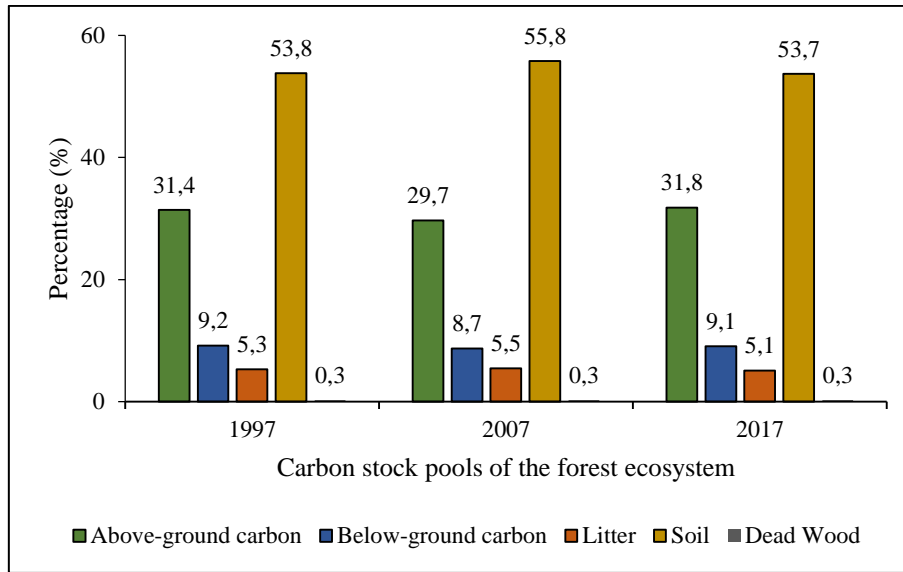


Figure 3. Carbon density changes of the study area

It's investigated that ratios of the productive forests in total forest area have continuously increased during two decades. While 75.7% of the total forest areas were productive in 1997, this ratio reached the 82.1% in 2007 and 87.6% in 2017. In parallel

with land use and forest productivity changes by years, carbon stock densities (Mg/ha) of the study area, as matter of course, has changed. Figure 4 and Figure 5 demonstrates the change of carbon stock densities in the study area.

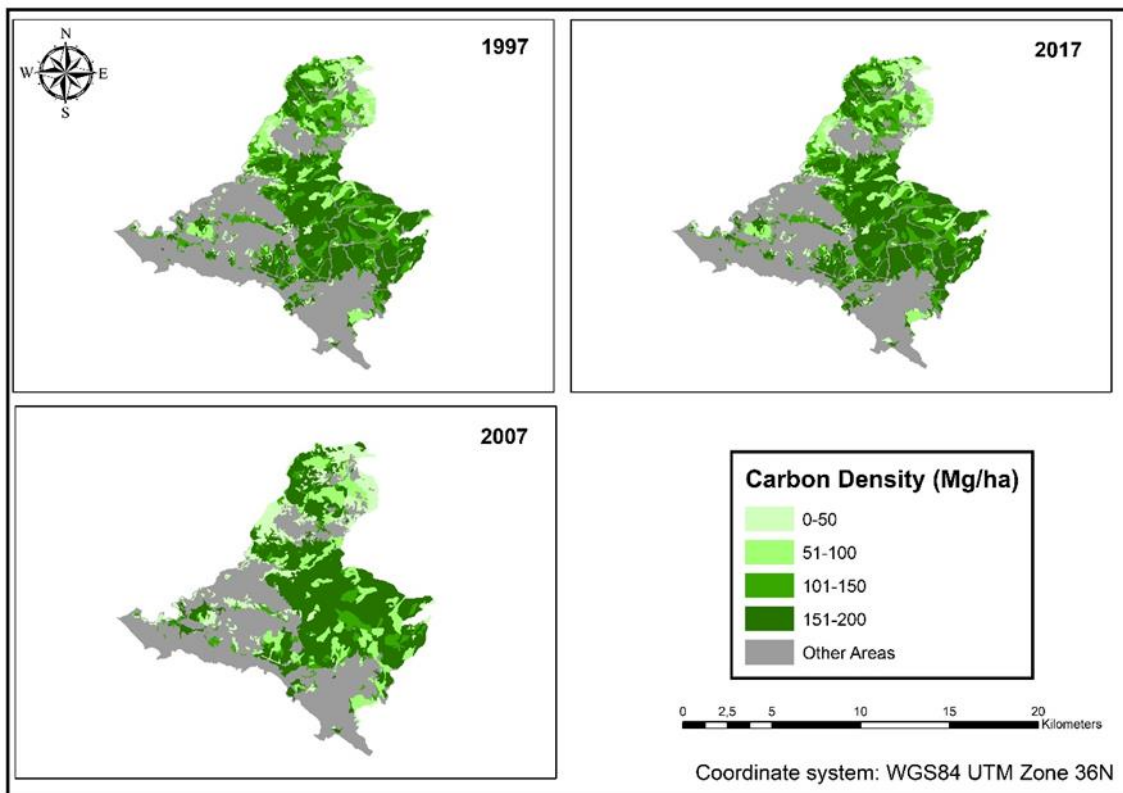


Figure 4. Changes of carbon stock density of the study area



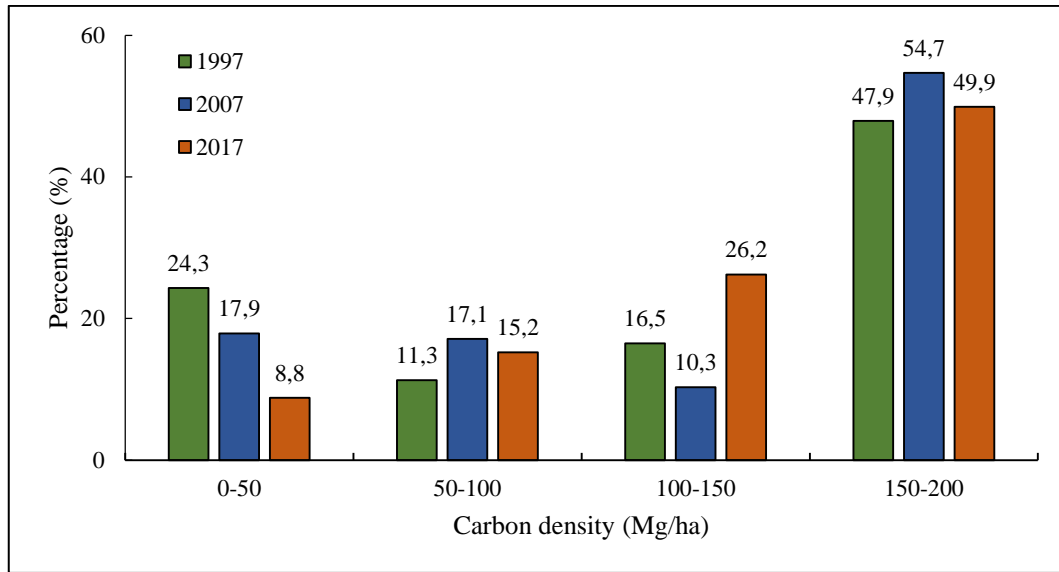


Figure 5. Distribution of carbon density groups in total forest area

### Discussion

Total carbon stock of the forest ecosystem in the study unit (Alara FPU) increased by 12.7% from 1997 to 2017. Despite the reduction of total forest area for this period (from 7497 ha to 7344 ha), carbon stocks of all biomass pools (living tree, litter, soil and dead wood) in forest ecosystem raised with the increase of productive forest lands and growing stock. From this point, it can be concluded that improvement of forest quality, in addition to quantity, lead to more sequestration of carbon in the forest ecosystem.

Despite using different coefficients and handling different units, various studies in

Turkey have reported that carbon stocks of forests have upward trend over time (Table 6). The main reasons of this trend can be explained as increase of the forest area, quality and growing stock. In more detail, the main factors affecting carbon storage and sequestration can be explained as follows: changing forest management strategies, increase of protected forest areas, rehabilitation of degraded forest lands, afforestation and reforestation activities, land use change, migration from forest villages to the town and increase in the public awareness of the forest ecosystem.

Table 6. Some studies on carbon stock changes across Turkey

Study	Study Area (unit)	period	Carbon stock pools	Change (approx.%)
Asan (1995)	Turkey	1960-1995	AGB	+ 13.3
Sivrikaya et al. (2007)	Artvin FPU	1972-2002	Living tree biomass	+ 42.2
	Camili FPU	1984-2005	Living tree biomass	+ 1.6
Yolasiğmaz & Keleş (2009)	Balci FPU	1984-2006	Living tree biomass	+ 17.6
Sivrikaya & Bozali (2012)	Türkoğlu FPU	1991-2002	Living tree biomass	+ 19.5
Bulut (2012)	Saraycık FPU	1970-2009	Forest ecosystem	+ 90.7

Table 6. (Continued)

Kadioğulları & Karahalil (2013)	Köprülü Canyon National Park	1965-2008	Forest ecosystem	+ 11.0
Sivrikaya et al. (2013)	Hartlap FPU	1991-2002	Living tree biomass	+ 9.6
Değermenci & Zengin (2016)	Daday FPU	1970-2012	Forest ecosystem	+ 113.7
Durkaya et al. (2017)	Sarıalan FPU	1986-2005	Forest ecosystem	+ 15.5
Seki et al. (2017)	Taşköprü FE	1989-2009	Forest ecosystem	+ 37.4
Günlü et al. (2019)	Upstream of the Göksu River Basin	1993-2015	AGB	+ 53.8

Note: Living tree biomass includes above- and below-ground biomass; forest ecosystem includes total living tree, litter, soil and dead wood biomass.

In this study and also previous ones, the effects of land use change, silvicultural treatments, and forest management policies on forest carbon stocks have been underlined. Relationship between these effects and the carbon stock change should be investigated with more studies on this subject. Because, to maintain or increase the carbon stock in the forest ecosystems is essential in terms of carbon management.

For higher accuracy in estimation of carbon stock in the forest ecosystems, quantity of the studies on carbon stock in above- and below-ground living tree biomass, and especially in litter, soil and dead wood must be increased (Tolunay, 2011). Besides, there is a great regional diversity which causes the different forest dynamics in Turkey. Growth, and thereby biomass and carbon stock rates of the forest ecosystem are directly affected from this regional difference. Therefore, studies on biomass and carbon stock of natural sources should be investigated at the regional or local scale to obtain more stable estimates (Sakici et al., 2018).

Another important point relevant to the carbon stock monitoring is to establish permanent sample plot design in Turkey. Unfortunately, studies on the determination of carbon stock and its change over time have been conducted based on temporary sample plots in the country, because of the absence of permanent sample plots.

This type of data leads to higher biases and lower accuracy on carbon stock estimates. To avoid these inconveniences, there is an urgent need for permanent sample plots for each species, and each region in Turkey.

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#### Ethics Committee Approval

N/A

#### Peer-review

Externally peer-reviewed.

#### Author Contributions

Conceptualization: M.S., D.A.; Investigation: M.S.; Material and Methodology: M.S., D.A.; Supervision: M.S.; Visualization: M.S., D.A.; Writing-Original Draft: M.S.; Writing-review & Editing: M.S.; Other: All authors have read and agreed to the published version of manuscript.

#### Conflict of Interest

The authors have no conflicts of interest to declare.

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