Artvin Çoruh Üniversitesi
Orman Fakültesi Dergisi
ISSN:2146-1880, e-ISSN: 2146-698X

Yıl: 2023, Cilt: 24, Sayı: 2, Sayfa: 224-233

Artvin Coruh University
Journal of Forestry Faculty
ISSN:2146-1880, e-ISSN: 2146-698X

Year: 2023, Vol: 24, Issue: 2, Pages: 224-233

ofd.artvin.edu.tr

Spatiotemporal changes of carbon storage in Çaltepe Forest Planning Unit

Çaltepe Orman Planlama Birimindeki karbon depolamasının zamansal ve konumsal değişimi

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Eser Bilgisi / *Article Info*
Araştırma makalesi / *Research article*
DOI: 10.17474/artvinofd.1362794

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Geliş tarihi / *Received*
19.09.2023
Düzeltme tarihi / *Received in revised form*
06.10.2023
Kabul Tarihi / Accepted
06.10.2023
Elektronik erişim / *Online available*
15.10.2023

Anahtar kelimeler:
İklim değişikliği
Karbon havuzu
Arazi kullanım değişiklikleri
Mekansal-zamansal örüntüler
Orman ekosistemi

Keywords:
Climate change
Carbon pool
Land use changes
Spatiotemporal patterns
Forest ecosystem

Abstract
Forest ecosystems play a crucial role in mitigating climate change as they are the largest carbon sinks. The objective of this study was to reveal the potential effects of forest dynamics on carbon sequestration and to contribute to planning studies. In this study, the changes in biomass and carbon storage areas in the 1999 and 2014 planning periods of the Çaltepe Forest Planning Unit. This calculation was carried out using widely accepted guidelines and coefficients, and the spatial distribution of biomass and C storage was mapped using GIS. As a result, the total biomass of the forested area increased by 53.42% in the period 1999-2014, from 781039.2 Mg to 1198263.51 Mg. On the other hand, the total amount of carbon storage increased from 1146019.35 Mg to 1448400.56 Mg in the period 1999-2014, an increase of about 26.39%. The contributions to the carbon (C) pool came from soil organic carbon with 60.12% and 53.28% of total C storage; from aboveground with 26.64% and 32.38%; from belowground with 7.66% and 9.27%; from litter with 5.33% and 4.77%; and from deadwood with 0.25% and 0.30% in 1999 and 2014, respectively. The average annual C sequestration was 1.95 Mg ha^{-1} yr^{-1}, of which 1.06 Mg ha^{-1} yr^{-1} occurred in aboveground, 0.53 Mg ha^{-1} yr^{-1} in soil, 0.3 Mg ha^{-1} yr^{-1} in belowground, 0.05 Mg ha^{-1} yr^{-1} in litter and 0.01 Mg ha^{-1} yr^{-1} in deadwood. Results have shown that; to increase the amount of biomass and carbon sequestration capacity in forest areas, it is necessary to increase maintenance activities, select appropriate species in afforestation areas, and ensure sustainable carbon management by reducing social pressure on forests. As long as the sustainability of carbon pools on land is ensured, the effects of climate change will be mitigated.

Özet
Orman ekosistemleri, en büyük karbon yutakları olmaları nedeniyle iklim değişikliğinin azaltılmasında önemli bir paya sahiptirler. Bu çalışmada amaç, orman dinamiklerinin karbon birikimi üzerindeki potansiyel etkilerini ortaya koymak ve planlama çalışmalarına katkıda bulunmaktır. Bu çalışmada Çaltepe Orman Planlama Birimi'nin, 1999-2014 yılları arasında biyokütle ve karbon depolama alanlarındaki değişimleri analiz edilmiştir. İlgili hesaplamalar, yaygın olarak kabul edilen kılavuzlar ve katsayılar kullanılarak yapılmış, biyokütle ve C depolamanın zamansal ve konumsal dağılımı CBS kullanılarak haritalanmıştır. Sonuç olarak, 1999-2014 döneminde ormanlık alanın toplam biyokütlesi %53.42 oranında artarak 781039.2 megaramdan (tondan) 1198263.51 megagrama (tona) yükselmiştir. Diğer taraftan, 1999-2014 döneminde toplam karbon depolama miktarı, yaklaşık %26.9 oranında artışla, 1146019.35 Mg'dan 1448400.56 Mg'a yükselmiştir. 1999 ve 2014 yıllarında C havuzuna katkı sırasıyla %60.12 ve %53.28 ile toprak organik karbonundan, %26.64 ve %32.38 ile toprak üstünden, %7.66 ve %9.27 ile toprak altından, %5.33 ve %4.77 ile ölü örtüden ve %0.25 ölü örtüden ve %0.30 ile ölü odundan gelmiştir. 1.06 Mg ha-1 yıl-1'ı toprak üstü, 0.53 Mg ha-1 yıl-1'ı toprak, 0.3 Mg ha-1 yıl-1'ı toprak altı, 0.05 Mg ha-1 yıl-1'ı ölü örtü ve 0.01 ha-1 yıl-1'ı ölü odun karbonu olmak üzere, araştırma alanının yıllık ortalama C tutulumu 1.95 Mg ha-1 yıl-1 olarak hesaplanmıştır. Sonuçlar göstermiştir ki; orman alanlarında biyokütle miktarını ve karbon tutma kapasitesini artırmak için bakım faaliyetlerinin artırılması, ağaçlandırmada uygun türlerin seçilmesi ve ormanlar üzerindeki sosyal baskının azaltılarak, sürdürülebilir karbon yönetiminin sağlanması gerekmektedir. Karasal alanlardaki karbon havuzlarının sürdürülebilirliği sağlandığı sürece iklim değişikliğinin etkileri de azaltılmış olacaktır.

INTRODUCTION

According to estimates, the world's forests cover 4 billion hectares (ha), or around 31.2% of all land (FAO 2011, FAO 2015, URL-1). One of the most important elements of terrestrial ecosystems is forests, which provide a variety of products (wood products, fuel, etc.) and services (according to Lindquist et al. 2012, includes carbon sequestration, climate change prevention, and wildlife habitats) (Dixon et al. 1994, Pan et al. 2013, Hui et al. 2017).

According to many experts, as the net greatest carbon sink and one of the most important parts of terrestrial ecosystems, the forest ecosystem is crucial to the global carbon cycle (Liu et al. 1997, Fang et al. 1998, Wang et al. 2001, Kuuluvainen and Gauthier 2018, Zhao et al. 2019, Sun and Liu 2020, Başkent 2022). Since the forests generate more fixed carbon in terrestrial ecosystems, it is more productive than any other terrestrial ecosystems (Fang et al. 2001). Additionally, geographical and socioeconomic factors have significant effects on how biomass is distributed spatially in ecological public forests (Liu et al. 2023). Because forests are so important for the worldwide cycle of carbon and climate change mitigation, science and policy need to understand the different types and distributions of forests as well as analyze the carbon balance of forest ecosystems present and in the future (Nabuurs et al. 2010).

Climate change has been identified as one of the world's most serious threats (Hui et al. 2017). Because, global warming is described as an increase in the earth's temperature caused by human activities such as industrialization, urbanization, deforestation, and the excessive use of fossil fuels. The earth's mean temperature, which is now 1 ºC above pre-industrial levels, is expected to rise by 1.5 ºC between 2030 and 2052. (IPCC 2018, Seki and Atar 2021). This upward trend in average global surface temperature, along with changes in precipitation and nitrogen deposition, is expected to significantly impact forest ecosystems' growth, forest dynamics, and carbon storage (Zuidema et al. 2013). Forecasting forest ecosystem carbon dynamics requires understanding the cumulative consequences of various climate changes, such as global warming, increased CO_2, and precipitation changes (Hui et al. 2017). Therefore, it is necessary to determine the carbon storage capacities of forest areas most accurately.

For environmental regulations and management methods, accurate and current data on forest biomass is essential (Herold et al. 2019). Many countries agreed to promote climate change action in the Paris Climate Agreement, for example, by preventing emissions from deforestation and forest degradation (Rozendaal et al. 2022). On the other hand, the Intergovernmental Panel on Climate Change (IPCC) good practice guidance for national greenhouse gas accounting requires that the participating countries monitor forest carbon stocks and emissions (IPCC 2006, IPCC 2019).

In countries with advanced forestry techniques, extensive research has been done on the estimation of the carbon storage capacity of forest ecosystems, such as the United States (Lal 2005, Tian et al. 2015, Domke et al. 2016, Domke et al. 2017), Canada (Liu et al. 1997, Bhatti et al. 2002, Sage et al. 2019), Europe (Neumann et al. 2016, Vanguelova et al. 2016, Rodríguez Martín et al. 2016) and Russia (Warnant et al. 1994, Krankina et al. 1996, Filipchuk et al. 2018). In addition, various researches have been carried out in this field for several decades in Türkiye (Asan 1995, Sivrikaya et al. 2007, Yolasığmaz and Keleş 2009, Sivrikaya and Bozali 2012, Bulut 2012, Kadıoğulları and Karahalil 2013, Sivrikaya et al. 2013, Değermenci and Zengin 2016, Yolasığmaz et al. 2016, Çelik et al. 2017, Durkaya et al. 2017, Seki et al 2017, Yolasığmaz et al. 2017, Durkaya and Durkaya 2018, Günlü et al. 2019, Kocaman and Durkaya 2020, Mumcu Küçüker 2020a, 2020b, Seki and Atar 2021, Sönmez et al. 2022, Değermenci 2023).

This study aimed to look into how the forest ecosystem's land use has changed and how it has affected regional carbon storage in the Çaltepe FPU in Kastamonu, Türkiye.

MATERIAL AND METHOD

Case Study Area

In the North of Türkiye, Çaltepe FPU covered around 15125.5 ha in size, 91% of which is covered in forest. The study area is geographically located in UTM WGS 84 Zone 36N, between latitudes 41° 17’ 33’’– 41° 24’ 14’’ N and longitudes 33° 54’ 36’’– 34° 03’ 43’’E (Fig. 1). Its elevation varies between 410 and 2394 m above sea level the forested areas are characterized by mid-slope terrain with an average slope of 46%. The most common trees in area are Black Pine (*Pinus nigra* J.F.Arnold), Scotch Pine (*Pinus sylvestris* L.), Fir (*Abies nordmanniana* (Stev.) subsp. *equi-trojani* (Asc-hers. & Sint. Ex Boiss) Coode et Cullen), Beech (*Fagus orientalis* Lipsky), Oak (*Quercus* sp.) and Hornbeam (*Carpinus* sp.). Using the long-term data set of the Kastamonu meteorological station as a reference, the mean temperature is 10 °C, and annual rainfall is 482.8 mm yr^{-1} (URL-2).

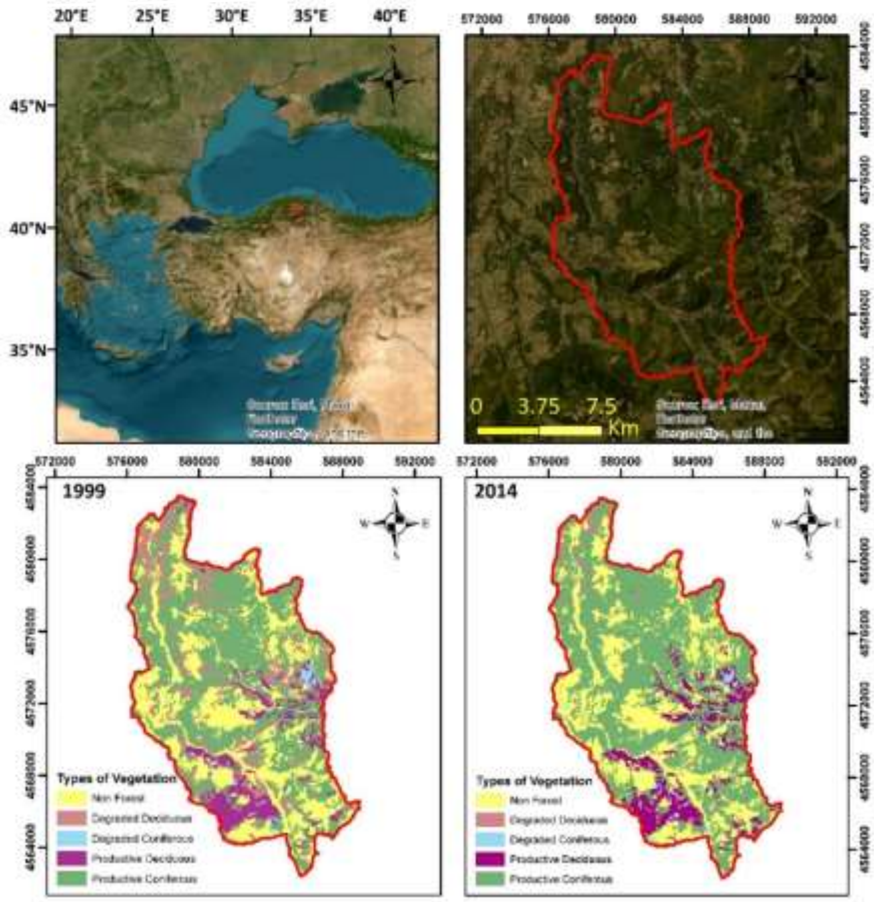

Figure 1. Geographical location of the study area and vegetation types maps as of 1999-2014

Forecasting the Biomass and Carbon Stocks

Firstly, the volume, biomass, and carbon values of the stands obtained from the forest management plans were found with the help of the coefficients prepared for the coniferous and deciduous forests of Türkiye. The coefficient of deciduous trees was used for deciduous tree species and the coefficient of conifers was used for coniferous tree species, the same in mixed stands. Then, the biomass and carbon stocks of each stand were calculated separately by multiplying them by the areas of the stands. Eq. 1-10 was used to make amount of biomass and carbon calculations and find the total carbon amount (Table 1-2).

Table 1. The formulas for determining total total carbon stocks (Mg/ha)

$Ct=(V*BCEF_1) * [CF (1 + R) + 47*10^{-4}] + LC + SC$	(1)
$TB=(AGB) * (1+R)$	(2)
$AGB=V*BCEF_1$	(3)
$BGB=AGB*R$	(4)
$AGC=BGB*CF$	(5)
$BGC=BGB*CF$	(6)
$DWB=AGB*0.01$	(7)
$DWC=DWB*0.47$	(8)
LC=Coniferous Productive 7.46(Mg/ha), Coniferous Degraded 1.86(Mg/ha), Deciduous Productive 3.75(Mg/ha), Deciduous Degraded 0.93(Mg/ha)	(9)
SC=Coniferous Productive 76.56(Mg/ha), Coniferous Degraded 19.14 (Mg/ha), Deciduous Productive 84.82 (Mg/ha), Deciduous Degraded 21.20 (Mg/ha)	(10)

Where C is the total carbon stock (Mg), CF is the carbon factor, R is the root-to-shoot ratio (dimensionless), V is the growing stock volume (m^3), $BCEF_1$ is the conversion and expansion factor (Mg/m^3), AGB: aboveground biomass (Mg), BGB belowground biomass (Mg), AGC: above ground carbon stock (Mg/ha), BGC below ground carbon stock (Mg/ha), TB: Total biomass (Mg), Litter carbon (LC) is the litter carbon amount, Soil carbon stock (SC) is the Forest soil carbon amount (Mg), DWB is the dead wood biomass amount (Mg), DWC is the dead wood carbon amount (Mg).

Table 2. Formulas and coefficients used to program total biomass and carbon

Group of species		WD (Mg/m^3)	BEF_1	$BCEF_1$	AGB (Mg/ha)	R	CF	Litter (LC) (Mg/ha)	Soil (SC) (Mg/ha)
Coniferous	Productive	0.446	1.212	0.541	<50 50-150 >150	0.40 0.29 0.20	0.51	7.46	76.56
	Degraded	-	-	-	-	-	-	1.86	19.14
Deciduous	Productive	0.541	1.310	0.709	<75 75-150 >150	0.46 0.23 0.20	0.48	3.75	84.82
	Degraded	-	-	-	-	-	-	0.93	21.20

WD, BEF1 and BCEF1 (Tolunay 2013), AGB, R and CF (IPCC 2006), LC and SC (Tolunay and Çömez 2008)
Note: As there is not enough research on the soil carbon of degraded forests in Türkiye, the values given in Tolunay and Çömez (2008) are multiplied by 0.25 for degraded forests, as suggested in GDF (2017b). When calculating the DWB, it was assumed to have 1% biomass of AGB, and DWC was estimated by multiplying the DWB value with a coefficient of 0.47 (FRA 2010)

Mapping of Carbon Storage Capacity

For the study area; the standing volume per hectare, the amount of tree species, and the field data in the stand description tables in the forest management plan for the period 1999-2014 were transferred to the computer. Biomass and carbon maps were produced by processing the calculated biomass and carbon storage amounts into the attribute tables of the stand maps belonging to the relevant periods in ArcGIS Desktop 10.8™ software.

RESULTS

Çaltepe FPU's in the general forested area did not change significantly between 1999 and 2014, but there was an increase in the standing volume and diameter increment of the young forest, which increased from 1086797 m^3 to 1671582 m^3 (+53.8%) and 48964 m^3 to 73531 m^3 (+50.1%), respectively. Over the course of 15 yrs, it is obvious that the primary factors behind this trend of growth are the consistent maintenance of forests, efforts towards rehabilitation, and the implementation of afforestation programs. The most significant reduction occurred in degraded forest areas, which decreased from 1.978 ha in 1999 to 545 ha in 2014. This decrease corresponds to a 72.47% decrease in degraded forest areas (Table 3). On the other hand, the forest areas of Çaltepe FPU observed a significant rise in V, amounting to 584784 m^3 (equivalent to a 53.81% increase) during the period extending from 1999 to 2014 (as indicated in Table 3 and Fig. 2). The main reasons for this increase are the high amount of annual increment in young stands and while degraded forest areas are decreasing, productive forest areas are increasing.

Table 3. Descriptive information on the forests of the study area in consecutive periods

Types of vegetation		1999 Standing volume (m^3)	1999 Standing volume increment (m^3)	1999 Area (ha)	2014 Standing volume (m^3)	2014 Standing volume increment (m^3)	2014 Area (ha)
Coniferous	Productive	988196	44677	7062.5	1550691	67650	8488.9
	Degraded	16214	350	1832	3504	54	437.1
Deciduous	Productive	80048	3889	1246.5	116420	5743	1309.8
	Degraded	2331	48	146	967	84	107.4
Total		**1086798**	**48964**	**10287**	**1671582**	**73531**	**10343.2**

When the carbon storage status of Çaltape FPUs between 1999 and 2014 is analyzed, it is seen that the above-ground and below-ground carbon stocks, as well as the amount of soil, litter, dead wood, and total carbon, have been on a consistent upward trend (Table 4). Since the carbon stock in living tree biomass (above and below ground combined) is significantly related to tree volume, the trends in the graphs of both show similar trends. Based on the calculations conducted, it has been ascertained that the cumulative carbon stocks in Çaltepe FPU exhibited a notable growth of 26.39% throughout the period spanning from 1999 to 2014.

Table 4 and Fig. 5 presents the carbon stock pools (aboveground, belowground, litter, soil, and dead wood) contributed by various forest ecosystems in Çaltepe FPU.

The primary carbon sink within forest ecosystems is the soil, representing approximately 53.28% to 60.12% of the total carbon storage. Additionally, it is notable that the biomass of trees found in the forest area, both aboveground and belowground, contributes around 26.65-32.38% and 7.66-9.27% respectively, of the total carbon content. The other ecosystems, litter, and deadwood, account for about 5.33-4.77% and 0.25-0.3% of total carbon, respectively. During the 15 yrs extending from 1999 to 2014, the average annual C sequestration of the research area was calculated as 1.95 Mg ha^{-1} yr^{-1}, including 1.06 Mg ha^{-1} yr^{-1} of aboveground, 0.53 Mg ha^{-1} yr^{-1} of soil, 0.3 Mg ha^{-1} yr^{-1} of belowground, 0.05 Mg ha^{-1} yr^{-1} of litter and 0.01 ha^{-1} yr^{-1} of dead wood carbon (Table 4, Fig. 3).

Table 4. Biomass (Mg) and Carbon stocks (Mg) in the forest lands of Çaltepe FPU in 1999 and 2014

		Biomass (B) (Mg - %) Carbon stocks (C) (Mg - %) 1999	2014	Accumulation Biomass (Mg) Carbon (Mg)	Change (%)	Mg C/yr^{-1}
Aboveground	B	602023.89 (77.08%)	924546.99 (77.16%)	322523.1	53.57	-
	C	305379.98 (26.64%)	469001.85 (32.38%)	163621.9	53.58	1.06
Belowground	B	172995.07 (22.15%)	264471.05 (22.07%)	91475.98	52.88	-
	C	87796.05 (7.66%)	134251.12 (9.27%)	46455.07	52.91	0.30
Litter	B	-	-	-	-	-
	C	61095.18 (5.33%)	69151.83 (4.77%)	8056.65	13.19	0.05
Soil	B	-	-	-	-	-
	C	688918.63 (60.12%)	771650.39 (53.28%)	82731.76	12.0	0.53
Deadwood	B	6020.24 (0.77%)	9245.47 (0.77%)	3225.23	53.57	-
	C	2829.51 (0.25%)	4345.37 (0.30%)	1515.86	53.57	0.01
Total	**B**	**781039.20 (100.00%)**	**1198263.51(100.00%)**	**417224.3**	**53.42**	**-**
	C	**1146019.35 (100.00%)**	**1448400.56 (100.00%)**	**302381.21**	**26.30**	**1.95**

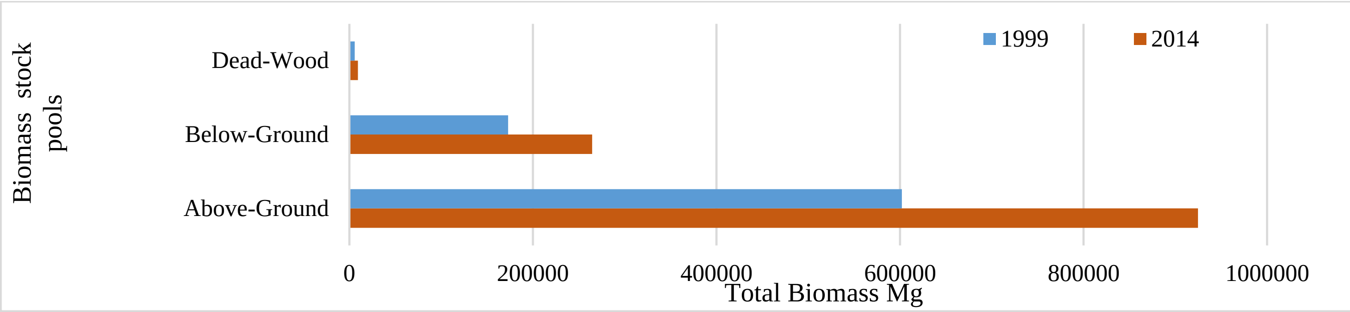

Figure 2. Total biomass stock pools

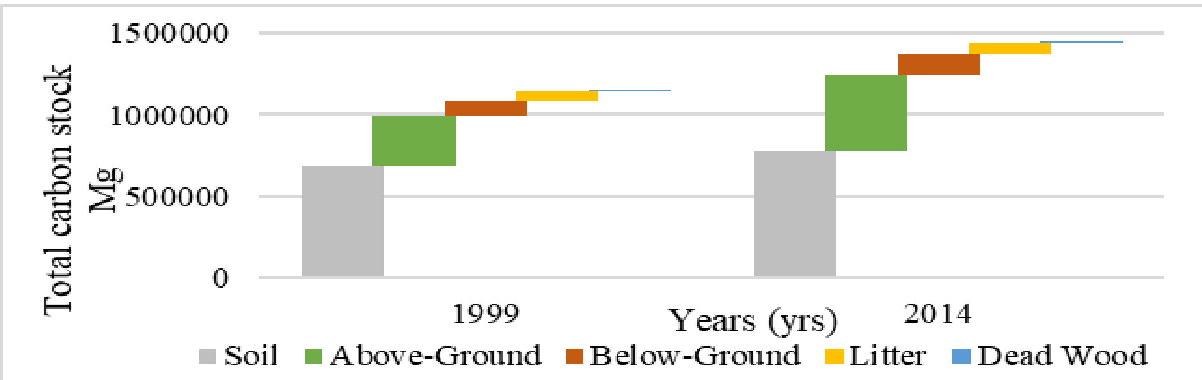

Figure 3. Carbon stock pools

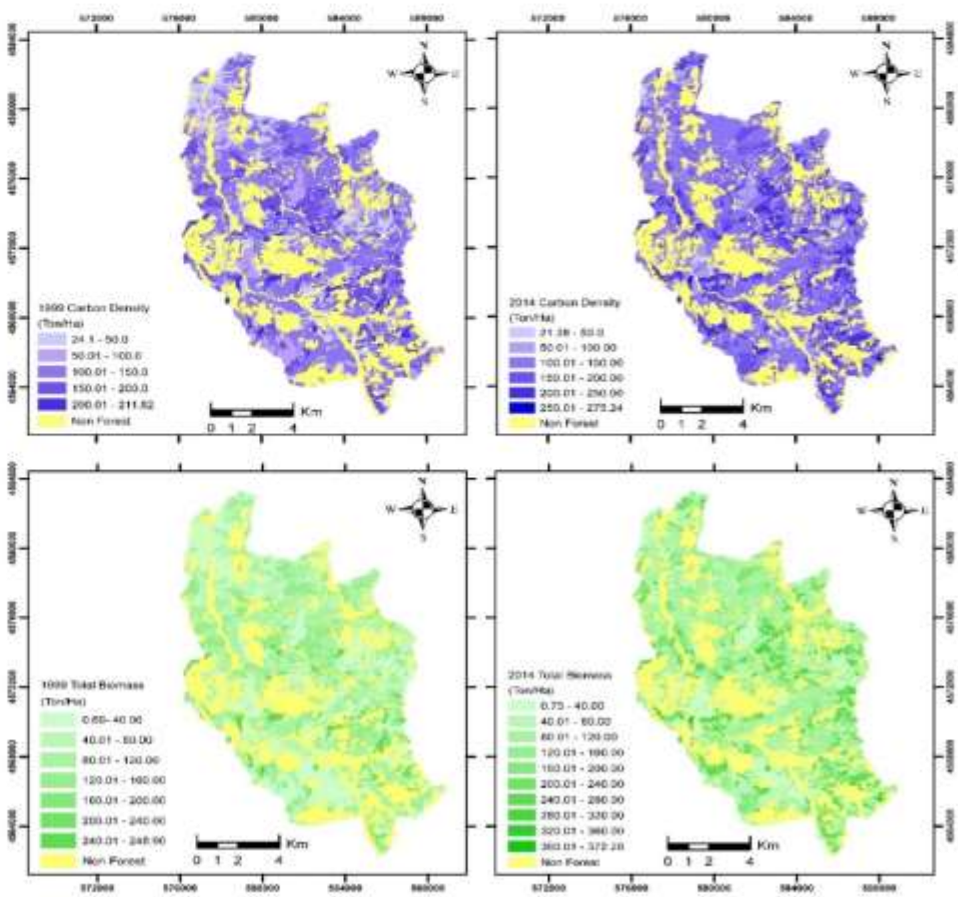

Figure 4. Changes in carbon stock density and biomass of the study area

When this change map of total biomass and carbon sequestration amount is examined, the amount of carbon sequestered per hectare by Çaltepe FPU forested areas increases from light yellow to blue color (Fig. 4). When using a scale of 50 Mg per hectare, a total of 5 classes were established for the yr 1999, while 6 classes were established for the yr 2014. For 1999, the highest rate was 48.7% in 3rd grade (100-150) and the lowest rate was 4% in 4th grade (200-250). For 2014, the highest rate is 62.6% in class 3 (100-150) and the lowest rate is in class 6 (200-250), covering an area of 0.2%. In 2014, the amount of carbon sequestration per hectare also increased areally. Therefore, it was necessary to add the 6th class (200-250) to the scale (Fig. 4-5). The primary cause of this increase is the rise in biomass per hectare and, as a result, the long-term sequestration of carbon.

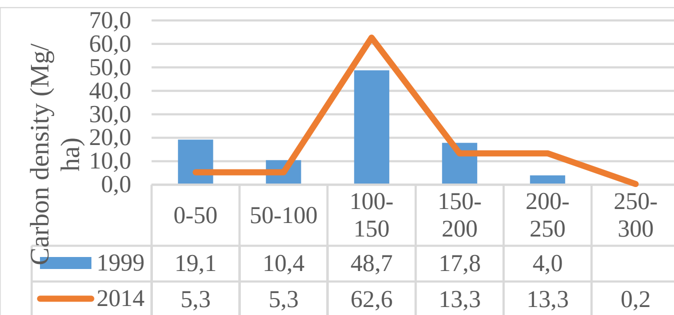

Figure 5. Distribution of carbon density groups per hectare in total forest area

DISCUSSION

The total C storage in the forest ecosystem in Çaltepe FPU ranged from 1146 Mg C in 1999 to 1448 Mg C in 2014 (+26.39%) in which the C densities increased from 248.9 to 372.2 Mg ha−1. The projected increase in carbon storage was attributable to the rise of biomass in the study area between 1999 and 2014, which increased the area covered by forests and the C density of those forests. In studies conducted in different FPUs, spatiotemporal C density variation was found to be below 20% by Asan (1995), Sivrikaya et al. (2007, 2013), Yolasığmaz and Keleş (2009), Sivrikaya and Bozali (2012), Kadıoğulları and Karahalil (2013), Durkaya et al. (2017), Mumcu Küçüker (2020a) and Seki and Atar (2021); between 20-40% by Seki et al. (2017); between 40-60% by Sivrikaya et al. (2007) and Günlü et al. (2019); between 60-80% by Mumcu Küçüker (2020b); Bulut (2012) found between 80-100% and Değermenci and Zengin (2016) found above 100%.

The average annual C sequestration was 1.95 Mg ha^{-1} yr^{-1}, of which 1.06 Mg ha^{-1} yr^{-1} occurred in AGB, 0.53 Mg ha^{-1} yr^{-1} in soil, 0.3 Mg ha^{-1} yr^{-1} in BGB, 0.05 Mg ha^{-1} yr^{-1} in litter and 0.01 in deadwood. The study's estimate of 1.95 Mg ha^{-1} yr^{-1} of forest C sequestration between 1999 and 2014 was greater than past estimations produced for several study locations in Türkiye. For instance, Mumcu Küçüker (2020a, 2020b) estimated this rate as 1.18 Mg $ha^{-1}yr^{-1}$ in the Akçaabat FPU and 1.57Mg ha^{-1} yr^{-1} in the Yeniköy FPU. Sivrikaya et al. (2007) estimated this rate as 0.04 Mg $ha^{-1}yr^{-1}$ in the Camili FPU and 0.67 Mg $ha^{-1}yr^{-1}$ in the Artvin FPU. While Sivrikaya and Bozali (2012) found it as 0.11 Mg $ha^{-1}yr^{-1}$ in the Türkoğlu FPU, Sivrikaya et al. (2013) calculated it as 0.07 Mg ha^{-1} yr^{-1} in Hartlap FPU, Mumcu Küçüker and Tuyoglu (2021) predicted 0.08 Mg $ha^{-1}yr^{-1}$ in the Hisar FPU and Tolunay (2011) calculated the C accumulation rate for all Türkiye forests as 0.21 Mg $ha^{-1}yr^{-1}$.

In some studies on the spatiotemporal variation of C stocks in Türkiye (Sivrikaya et al. 2007, Yolasğmaz and Keleş 2009, Sivrikaya and Bozali 2012), only the C stored in living biomass was found and SC, litter and DW carbon were not taken into account. In this study, in addition to live biomass, C stores in DW, litter, and SC were also taken into account. The total C storage of the four forest C pools, including living biomass (below and above ground), dead wood, dead cover, and SC, increased between 1999 and 2014. The most significant contribution to total C storage came from SC with 60.12% and 53.28% in 1999 and 2014, followed by living (above- and below-ground) biomass with 34.3% and 41.65% in 1999 and 2014.

Moreover, the total contribution of C storage (in DC, LC, and SC was about 65.7% and 58.35% in 1999 and 2014, respectively. The results demonstrated that underestimating C dynamics in forest ecosystems can occur from assessing C stock without taking into account the other carbon pools (DC, LC, and SC). Similarly, recent studies in China have revealed that at least 70% of the total carbon stock in forest areas is sequestered in SC (Ren et al. 2014, Cui et al. 2015, Chen et al. 2019). In some of the spatiotemporal carbon exchange studies (Kadıoğulları and Karahalil (2013) 71-63%, Değermenci and Zengin (2016) 64-46%, Durkaya et al. (2017) 42.1%, Seki et al. (2017) 57.8-57.3%, Dinç and Vatandaşlar (2019) 73%, Mumcu Küçüker (2020a) 73.39-61.6%, and (2020b) 58.6-49.3%, and Seki and Atar (2021) 53.8-53.7% carried out in Türkiye, SC was found to be the major carbon pool.

The main reason for such a variety of results in different planning units may be due to many reasons such as differences in the methods used in the studies, periodic differences (10 or longer periods), and differences in the general growth of the species found in the study areas.

Including 210076.97 Mg of total carbon accumulated in living biomass C, 82731.76 Mg of SC, 8056.65 Mg of LC, and 1515.86 Mg of DWC, total C storage in the forest ecosystem rose by around 302.381 Mg between 1999 and 2014. Although the SC in the Çaltepe FPU stores the most carbon, it has been found that the capacity for sequestering carbon in living biomass can increase substantially more than in forest soil over time.

CONCLUSION AND RECOMMENDATIONS

Türkiye is a mountainous country with a vast territory and rugged terrain, as well as comprises several climatic zones including Mediterranean, pontic, sub-humid, or semi-arid. Terrestrial ecosystems have significant diversity, as they are distributed throughout different climatic zones and are subject to numerous land-use modifications. Various factors such as plant species and yield, temperature, soil moisture, soil properties, and nutrients, together with climate change, can affect the dynamics of forest carbon. As the most important part of terrestrial ecosystems, many studies on forests' carbon storage have been carried out in Türkiye at local scales or regional scales. The accumulation of the research data revealed by these studies constitutes the basis for further research studies.

In this study, the temporal and spatial (spatiotemporal) distribution of carbon stock and biomass accumulation change between 1999-2014 in the Çaltepe FPU was analyzed. Using forest inventory data, IPCC (2006) and FRA (2010) guidelines, various coefficients developed by Tolunay and Çömez (2008) and Tolunay (2013), the dynamics of the carbon pool (AGC, BGC, DWC, LC, and SC) were calculated and the total biomass and carbon amounts of Çaltepe FPU were compared periodically. As a result, it was determined that Çaltepe FPU stored 1146019.35 Mg of C, 781039.20 Mg of biomass in 1999 and 1448400.56 Mg of C, 1198263.51 Mg of biomass in 2014. Although there was no significant change in the forest areas during the 15 yrs, there was a standing volume increase of 584784 m^3 (+53.81%) in Çaltepe FPU forests. On the other hand, a significant increase of 26.39% (302381.21 Mg) was observed in the carbon stock of Çaltepe FPU. The annual forest C sequestration rate was 1.95 Mg ha^{-1} yr^{-1} between 1999 and 2014. The results show that the total C storage contribution in the DWC, LC, and SC pools was 65.7% in 1999 and 58.35% in 2014.

The results of this study indicate that the exclusion of certain carbon pools, namely DWC, LC, and SC from calculations, might lead to a significant error in estimating the overall carbon storage of forest ecosystems. Although changes in LULC are very small, forest growth and increments appear to have a significant impact on carbon.

Consequently, it is generally accepted that the main variables that contribute to the increase in carbon storage capacities can be attributed to the progressive growing stock of the Çaltepe FPU biomass over time, afforestation efforts using suitable species, the conversion of degraded forest areas into productive ones, the reduction of social pressures, and the improvement of population and socio-economic conditions.

To reveal the effect of spatiotemporal changes in forest ecosystems on carbon dynamics and to calculate carbon reserves more reliably; biomass and carbon stock equations have not yet been developed for all tree species. With these studies, biomass and carbon calculations, which are of vital international importance, need to be determined more accurately.

To calculate spatiotemporal changes in forest ecosystems more reliably:

- Biomass and carbon equations for all tree species should be completed as soon as possible.
- Forest loss (and consequently reduced carbon storage capacity) due to misuse and deforestation must be prevented.

- Degraded forest areas should be turned into productive areas to trap more carbon in forest soils, mixed forests should be established, silvicultural interventions should be made moderately, non-forested areas should be afforested and soil erosion should be prevented.
- Carbon accumulation needs to be considered and planned in the long term with all its components.

Effective and appropriate forest management practices need to be determined for the ecological sustainability of carbon products and mitigation of climate change impacts.

ACKNOWLEDGEMENTS

The authors gratefully thank Kastamonu Regional Directorate of Forestry for providing forest management plan data. The writers greatly appreciate the feedback from the reviewers.

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