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IMPACTS OF SOCIO-ECONOMIC FACTORS ON CARBON DYNAMICS IN BLACK SEA FORESTS: A CASE STUDY FROM AKÇAABAT FOREST PLANNING UNIT*

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Abstract: Forest ecosystems play a crucial role in mitigating the negative impacts of global climate change as an essential carbon sink. Land use and land cover change, mainly deforestation, degradation, and afforestation, have significantly affected carbon (C) stock. This study analyzed the effects of land use and land cover changes on forest C dynamics and its spatial distribution based on demographic, socio-economic, and landscape structure in the Akçaabat forest planning unit. Moreover, forest C dynamics in aboveground, belowground, deadwood, litter, and soil were calculated separately based on forest inventory data in 1984, 2008, and 2018. While the total C stock increased by about 38.04% between 1984 and 2008, it increased only by about 4.64% between 1984 to 2018 due mainly to not including of non-state-owned areas covered with forest trees (about 4369.40 ha) in the forest management plans developed based on land cadastre in 2018. The most considerable contribution to the C pool was from the soil by about 73.39%, 72.32% and 61.60% in 1984, 2008 and 2018, respectively. Deciduous cover types, young and full covered forests, had the highest average C density with 442.61 Mg ha⁻¹ 49.65 Mg ha⁻¹ and 144.47 Mg ha⁻¹, respectively. Over three decades, the conversion from degraded, forest opening, and non-forest areas to productive forests as well as increasing the quality of forest structure characterized by increasing mixed forest, young or mature development stages, and full covered forests has contributed positively to the C stock. This increase in the quality of the forest can be explained by conversion abandoned agriculture areas to forested areas with migration, reduction of social pressure on forested areas based on decreasing forest crime, and increasing forest crime, and increasing aware awareness and increasing awareness and sensitivity to the environment based on economic development. Analyzing the spatio-

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temporal patterns and driving factors of carbon dynamics are critical in developing appropriate planning strategies to control climate change.

KARADENİZ ORMANLARINDAKİ SOSYO-EKONOMİK FAKTÖRLERİN KARBON DİNAMİKLERİ ÜZERİNE ETKİSİ: AKÇAABAT ORMAN İŞLETME ŞEFLİĞİ ÖRNEĞİ

Öz: Önemli bir karbon havuzu olan orman ekosistemleri, küresel bir iklim değişikliğinin olumsuz etkilerini azaltmada önemli bir rol üstlenmektedir. Arazi kullanım ve arazi örtüsü değişikliği, özellikle ormansızlaşma, orman yapısının bozulması ve ağaçlandırma, karbon (C) stokunu önemli ölçüde etkilemektedir. Bu çalışma, Akçaabat orman planlama birimindeki demografik, sosyo-ekonomik ve orman yapısı gibi faktörlere bağlı olarak arazi kullanım ve arazi örtüsü değişikliklerinin orman C dinamikleri ve konumsal dağılımı üzerindeki etkilerini incelemiştir. Ayrıca, 1984, 2008 ve 2018 yıllarında toprak üstü, toprak altı, ölü odun, ölü örtü ve topraktaki C dinamikleri, orman envanteri verilerine göre ayrı ayrı hesaplanmıştır. 1984 ve 2008 yılları arasında toplam C stoku %38.04 oranında artarken, 2018'de sadece %4.64 oranında artmıştır. Karbon stokundaki artışın düşmesinin temel sebebi arazi kadastrusu dikkate alınarak hazırlanan 2018 yılı amenajman planında kadastro dışı ağaçlı alanlar (yaklaşık 4369.40 ha) orman dışı alan olarak değerlendirilmesidir. Karbon stokuna en önemli katkı 1984, 2008 ve 2018 yıllarında sırasıyla %73.39, %72.32 ve %61.60 oranlarında topraktan sağlanmıştır. En yüksek ortalama karbon yoğunluğu 442.61 Mg ha⁻¹ 49.65 Mg ha⁻¹ ve 144.47 Mg ha⁻¹ ile geniş yapraklı, gençlik gelişim çağındaki ve tam kapalı ormanlardan sağlanmıştır. Otuz yılı aşkın bir süredir, boşluklu kapalılığa sahip alanlar, orman içi açıklıklar ve orman dışı alanlardan verimli ormanlara dönüşümün yanı sıra, karışık orman, genç veya olgun gelişim aşamaları ile tam kapalı ormanların artmasıyla karakterize edilen orman yapısının kalitesini artırması, karbon stokuna olumlu katkılar sağladı. Ormanın kalitesindeki bu artış, terkedilmiş tarım alanlarının göçle ormanlık alanlara dönüştürülmesi, orman suçlarında azalmaya dayalı ormanlık alanlar üzerindeki sosyal baskının azaltılması ve ekonomik kalkınmaya dayalı olarak çevreye duyarlılığın artırılması ile açıklana-

bilir. Karbon dinamiğinin zamansal ve konumsal değişimi ve bu değişime etki eden faktörlerin analizi, iklim değişikliğini kontrol etmek için uygun planlama stratejilerinin geliştirilmesinde kritik önem taşımaktadır.

1. Introduction

Climate change is a crucial environmental threat affecting populations due to the greenhouse effect of CO₂.¹ Developments related to climate change in recent years have shown that forest ecosystems have an essential role in global climate change and the carbon (C) cycle. C sequestration in forest ecosystems has attracted many researchers and policymakers due to large C capacity in forest ecosystems account for 75% of the atmospheric CO₂.² Forest ecosystems are the most important terrestrial ecosystems³ that absorb large amounts of C from the atmosphere and store them in their living biomass, soil, litterfall, and deadwood. According to the Kyoto protocol, each signature country, is responsible for monitoring, estimate, and submit C stock change.⁴ On a global scale, total carbon stock in forest ecosystems came from mostly forest biomass, and soil accounted for 53% and 39%, and the rest was from deadwood and litterfall.⁵ Besides, of stocked about 1.9 Gt C⁶ in forest ecosystems in Turkey, 62.6% and 32.3% were obtained from soil organic matter and living tree biomass, respectively.⁷

Forest C storage capacity depends mainly on the quality of forest ecosystem structure and composition. Recently, the forested areas in the world are decreased, and the forest structures deteriorated, resulting in climate change and global warming in the entire world due to natural or anthropogenic effects and land-use land cover changes. The amount of C stock in forest biomass has decreased over the last 25 years due mainly to the conversion of forest areas to agricultural and settlement areas and the destruction of forest areas.⁸

¹ Meng et al., 2016.

² Ketizmen, 2011.

³ Watson et al., 2000.

⁴ UNFCCC, 2008.

⁵ FAO, 2015.

⁶ Anonymous, 2016.

⁷ Tolunay et al., 2018.

⁸ FAO, 2015.

Forest stand characteristics (tree species, diameter, basal area, height, age, and growing stock), soil characteristics (soil depth, texture, and pH), climate characteristics, and topographic characteristics affect the amount of fixed C.⁹

The effects of Land Use and Land Cover Change (LULCC) on C stock are regarded as an essential mechanism in controlling climate change.¹⁰ The role of forest ecosystems was highlighted both as sources and sink.¹¹ Forest C stock can increase by afforestation, rehabilitation, restoration, and sustainable planning. However, decrease the quality of forest structure, a decrease in forest areas, conversion of forested areas to non-forest lands such as agricultural land, natural events such as pest outbreaks or wildfire damage, and an increase of C emissions can decrease C storage.¹² Some researches indicated silviculture and forest management interventions enhance to increase forest C sink and reduce emissions.¹³ Nosetto et al. (2006) demonstrated that afforestation activities increased by 50% of C storage.

Population dynamics,¹⁴ socio-economic developments,¹⁵ and increased environmental awareness are driving forces on LULCC induced climate change. Whereas the increase in rural populations who need forest products for their livelihoods increases the pressure on forests directly on the basis of the number of forest crime, decreasing rural population based on the abandonment of agricultural lands and increasing environmental awareness on the basis of increase welfare level affect positively on forested areas, then C stock change.¹⁶

The historical dynamics of forest structure is a significant challenge in the management of forest resources.¹⁷ The changes in forest structure in terms of tree species, canopy cover, development stages and stand ages under complex socio-economic conditions strongly influence C storages in forest ecosystems.¹⁸ Numerous studies on the impact of spatiotemporal changes in forest ecosystems on biomass C have been conducted.¹⁹ In recent years, while several studies have reported on the effects of LULCC on Soil Organic Carbon (SOC) stocks and SOC sequestration,²⁰ only limited research attention has been paid to the effects of land-use changes on various C pools.²¹ Additionally, a few studies suggested negative relationships between forest carbon stock and the human population.²² However, almost no studies have been indicated the influence of socio-economic dynamics.

The overall objective of this research was to analyze the effects of driving factors on spatiotemporal patterns of forest C dynamics in the Akçaabat forest planning unit. The specific objectives were to determine (1) contribution of various C pools in successive periods (1984, 2008 and 2018) to forest C stock, (2) the influence of forest dynamics (land cover type, development stages, age class, and canopy cover), rural population dynamics and socio-economic structure such as forest crime change on C stocks and (3) the effects of forest ownership based on land cadastre on C stock (4) the spatial distribution maps of forest C dynamics in the study area between 1984 to 2018.

⁹ Tolunay, 2011.

¹⁰ Houghton and Hackler, 2000; Liu et al., 2006; IPCC, 2007.

¹¹ Brown et al., 1996; Folland et al., 2001.

¹² FAO, 2010.

¹³ Baskent and Kucuker, 2010; Kucuker and Baskent, 2010; Noormets et al., 2015.

¹⁴ Ramankutty et al., 2002.

¹⁵ Yang et al., 2014.

¹⁶ Tuyoglu, 2020.

¹⁷ Cannell et al., 1992; Dixon et al., 1994.

¹⁸ Zhou et al., 2008; Ren et al., 2011.

¹⁹ Sivrikaya et al., 2007; Yang and Guan, 2008; Hu and Wang, 2008; Muñoz-Rojas et al., 2011; Sivrikaya et al., 2013; Guo et al., 2013; Günlü et al., 2019; Yang et al., 2017.

²⁰ Wellock et al., 2011; Ruiz Sinoga et al., 2011; Novara et al., 2012; Ren et al., 2014; Muñoz-Rojas et al., 2015.

²¹ Zhou et al., 2008; Arevalo et al., 2009; Kaul et al., 2009; Chen et al., 2019.

²² Wang et al., 2001; Yang et al., 2014; Değermenci and Zengin, 2016; Yang et al., 2017; Günlü et al., 2019.

2. Material and Methods

2.1. Study Area

In the present study, the Akçaabat forest planning unit was selected as the study area. The planning unit situated in Trabzon city in north Turkey covers an area of 32,958.8 ha, 26.8% of which is forested. The altitude ranges from 0 m on the coast of the Black sea to 1990 m asl. The forested areas are characterized by steep terrain with an average slope of 50%. The vegetation type of the area is primarily composed of the association of beech (*Fagus orientalis*), hornbeam (*Carpinus betulus*), alder (*Alnus glutinosa*), oak (*Quercus* sp.), spruce (*Picea orientalis*), scots pine (*Pinus sylvestris*), chestnut (*Castanea sativa*) and stone pine (*Pinus pinea*).

2.2. Forest Inventory Data

Forest inventory data in association with topographic maps and the forest cover type maps at 1/25000 scale in 1984, 2008 and 2018 prepared by General Directorate of Forestry were used to evaluate temporal and spatial patterns of forest C dynamics in the Akçaabat forest planning unit. Growing stock per hectare of each stand type was obtained from the Akçaabat forest management plans in 1984, 2008, and 2018.²³ Unlike the forest cover type map in 1984, the maps in 2008 and 2018 were provided from Trabzon Regional Directorate of Forestry as a digitalized format. Thus, the forest cover type map of the study area in 1984 was digitized with ArcGIS 10TM with maximum root mean square error under 5 meters and built a spatial database.

2.3. Estimation of Carbon Stocks

Because deadwood (DW), litterfall and soil in forest ecosystems in addition to above

and belowground biomass (AGB, BGB) make a serious contribution to forest C stock, forest C stock was calculated as the total amount of C stored in these C pools. To calculate forest C stock change between periods Stock-Difference Method was used because forest inventory in Turkey is based on periodic measurement. While C stock in biomass was predicted based on growing stock inventory data, litter and soil C stock was estimated based on area inventory data. Annual C stock change between two periods and the C stock in the AGB and BGB were calculated based on Agriculture, Forestry and Other Land Use (AFOLU) guidelines (IPCC, 2006) with the following Equation [1] and [2].

$$\Delta C = (Ct_2 - Ct_1) / (t_2 - t_1) \quad (1)$$

$$CLB = (GS \times BCEF_1) \times (1 + R) \times CF \quad (2)$$

Where ΔC is the annual change in forest C stock (t/ha/yr), Ct_1 and Ct_2 are the C stocks in t_1 and t_2 years, respectively. CLB is the C stock in the living biomass (t), GS is the growing stock volume (m^3), $BCEF_1$ is the factor for conversion and expansion of stem volume to AGB (t/ m^3), R is the root to shoot ratio, CF is the carbon fraction of dry matter (tC). $BCEF_1$ is determined by multiplying of wood density (WD) and biomass expansion factor (BEF) coefficients.²⁴

AGB was calculated with a multiplying of growing stock volume and BCEF. The BGB was estimated by multiplying AGB and R coefficient. For this purpose, the species-species WD and BEF coefficients reported for each tree species in Turkey's forests were derived from Tolunay (2013) and R and CF ratios given for temperate zone forests in Agriculture, Forestry and Other Land use (AFOLU) derived from IPCC (2006). The used parameters were listed in Table 1 and Table 2.

²³ Anonymus, 1984, 2008, 2018.

²⁴ IPCC, 2006.

Tree species	WD (t/m ³)	BEF	BCEF (t/m ³)
<i>Pinus sylvestris</i>	0.426 ^a	1.247	0.531
<i>Pinus pinea</i>	0.470 ^b	1.310	0.616
<i>Picea orientalis</i>	0.358 ^a	1.132	0.405
<i>Alnus glutinosa</i>	0.407 ^a	1.103	0.449
<i>Quercus sp.</i>	0.570 ^a	1.322	0.754
<i>Castane sativa</i>	0.480 ^c	1.320	0.634
<i>Fagus orientalis</i>	0.530 ^a	1.305	0.692
<i>Carpinus betulus</i>	0.630 ^c	1.482	0.934
Coniferous	0.446 ^d	1.212 ^c	0.541
Deciduous	0.541 ^d	1.310 ^c	0.709

^a As et al. (2001); ^b Erten and Sozen (1997); ^c IPCC (2003); ^d the generalized coefficients of coniferous and deciduous²⁵

Table 1. WD, BEF and BCEF values of tree species in the study area²⁶

Vegetation Types	Aboveground Biomass	Root to Shoot Rate	Carbon Fraction
Coniferous	<50	0.40	0.51
	50-150	0.29	
	>150	0.20	
<i>Quercus sp.</i>	>70	0.30	0.48
Deciduous	<75	0.46	
	75-150	0.23	
	>150	0.24	

Table 2. R and CF coefficients for different vegetation types according to AFOLU guidelines²⁷

C stock of deadwood in the forest was estimated with the following formula (Equation [3]). In this s and CF were used as 1% and 0.47, respectively.

$$DWC = AGB \times s \times CF \quad (3)$$

Where DWC is C stock in deadwood carbon pool (ton), s is the ratio of deadwood biomass to aboveground biomass.

The litterfall and soil C stocks were predicted by multiplying the size of forest area and country-specific litter or soil organic C

content in Equation [4] and Equation [5], respectively. The country-specific coefficients for tree species groups in degraded and productive areas were listed in Table 3.²⁸

$$LC = F \times r \quad (4)$$

$$SOC = F \times r \quad (5)$$

LC is litter carbon pool (ton), SOC is soil organic C pool (ton), F is the size of forest area (ha) and r is carbon content (t C).

Vegetation types	Carbon in Litterfall (t/ha)		Soil Organic Carbon (t/ha)	
	Productive	Degraded	Productive	Degraded
Coniferous	7.46	1.86	76.56	19.14
Deciduous	3.75	0.93	84.82	21.20

Table 3. Country specific litterfall and soil organic carbon contents (t/ha) according to vegetation types and productivity²⁹

²⁵ Tolunay, 2013.

²⁶ Tolunay, 2013.

²⁷ IPCC, 2006.

²⁸ Tolunay and Çómez, 2008.

²⁹ Tolunay and Çómez, 2008.

3. Results and Discussion

3.1. Temporal Change in Carbon Pools from 1984 to 2018

Total C storages in forest ecosystems in the Akçaabat forest planning unit changed from 1071.86 Gg in 1984 to 1479.67 Gg and 1121.57 Gg in 2008 and 2018, respectively. Thought the net C accumulation was about by 407.79 Gg (38.04%) between 1984 and 2008, it was only about by 49.69 Gg (4.64%) between 1984 and 2018. The result can be explained by a dramatic increase in the growing stock of the forested area over the periods. AGB and BGB changed from 578,612 tons in 1984 to 1,201,734 tons in 2008 and to 1,399,632 tons in 2018. Total C density increased from 86.87 Mg ha⁻¹ in 1984 to 111.46 Mg ha⁻¹ in 2008 and 126.87 Mg ha⁻¹ in 2018. In addition, annual forest C accumulation rates were 1.46 Gg yr⁻¹ and 1.18 Mg ha⁻¹ yr⁻¹ between 1984 and 2018 (Table 4). When compared the annual forest C accu-

mulation rate in the current study with previous studies made for different forest ecosystems in Turkey, it was shown that the calculated rate was higher than the rates in almost all studies. For instance, Tolunay (2011) calculated C accumulation rate for Turkey forests as 0.21 Mg ha⁻¹yr⁻¹. Sivrikaya et al. (2007) estimated this rate as 0.67 Mg ha⁻¹yr⁻¹ in Artvin planning unit and 0.04 Mg ha⁻¹yr⁻¹ in the Camili planning unit. While Sivrikaya and Bozali (2012) found it as 0.11 Mg ha⁻¹yr⁻¹ in Türkoğlu planning unit, Sivrikaya et al. (2013) calculated it 0.07 Mg ha⁻¹yr⁻¹ in Hartlap planning unit. The main reason for predicting higher rate C accumulation in our study most probably is to including of deadwood, litterfall, and SOC stocks as well as above and below biomass stock. Besides, preferring species-species coefficients of WD and BEF rather than general coefficients for tree groups. Also, Tuyoglu (2020) predicted it 0.08 Mg ha⁻¹yr⁻¹ in the Hisar planning unit.

Carbon Pools	Total Carbon (Gg C)			Carbon Density (Mg ha ⁻¹)			Carbon Accumulation Rate (1984-2018)	
	1984	2008	2018	1984	2008	2018	Gg C yr ⁻¹	Mg ha ⁻¹ yr ⁻¹
AGB	206.58	299.8	332.09	16.74	22.58	37.57	3.69	0.61
BGB	76.75	106.95	95.4	6.22	8.06	10.79	0.55	0.13
DW	1.97	2.86	3.15	0.16	0.22	0.36	0.03	0.01
Litterfall	40.36	56.52	39.58	3.27	4.26	4.48	-0.02	0.04
SOM	746.22	1013.54	651.35	60.47	76.35	73.68	-2.79	0.39
Total	1071.86	1479.67	1121.57	86.87	111.46	126.87	1.46	1.18

Table 4. Temporal changes in carbon dynamics in different carbon pools

Spatial distribution maps of C stock in Akçaabat forest planning unit for 1984, 2008, and 2018 are shown in Figure 1. According to the maps, about 62.02%, 59.69%, and 73.18% of the total area in 1984, 2008 and 2018, respectively, did not contain C budget due to lack of growing stock. Of the whole area, about 13.45%,

13.08%, and 11.45% stored C under 2.0 Gg, between 2.1-5.0 Gg and over 5.0 Gg, respectively, in 1984 (Figure 1a). While the area rates in these C level ranged for about 24.76%, 11.48% and 4.07% in 2008 (Figure 1b), the rates ranged for about 16.27%, 7.91% and 2.64, respectively in 2018 (Figure 1c).

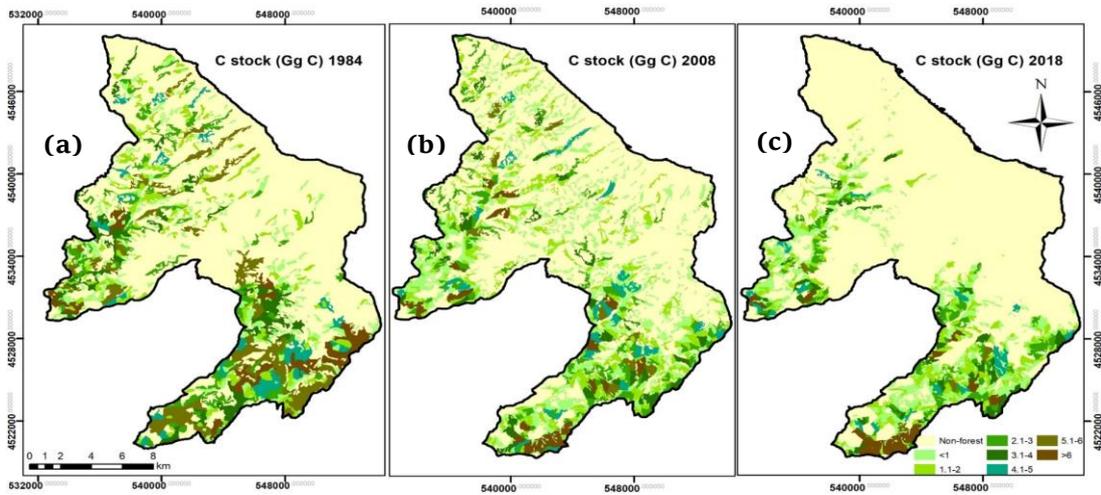


Fig. 1. Spatial distribution maps of C stock in 1984 (a), 2008 (b) and 2018 (c)

Spatial distributions of the total C density of the Akçaabat Planning Unit in 1984, 2008, and 2018 are shown in Figure 2. The results showed that the area mainly clumped into 100-150 Mg ha⁻¹ of total C

density with 17.52%, 25.96%, and 13.53%, respectively in 1984, 2008, and 2018. Besides, about 13.81% of the total area in 1984 clumped into under 0-50 Mg ha⁻¹.

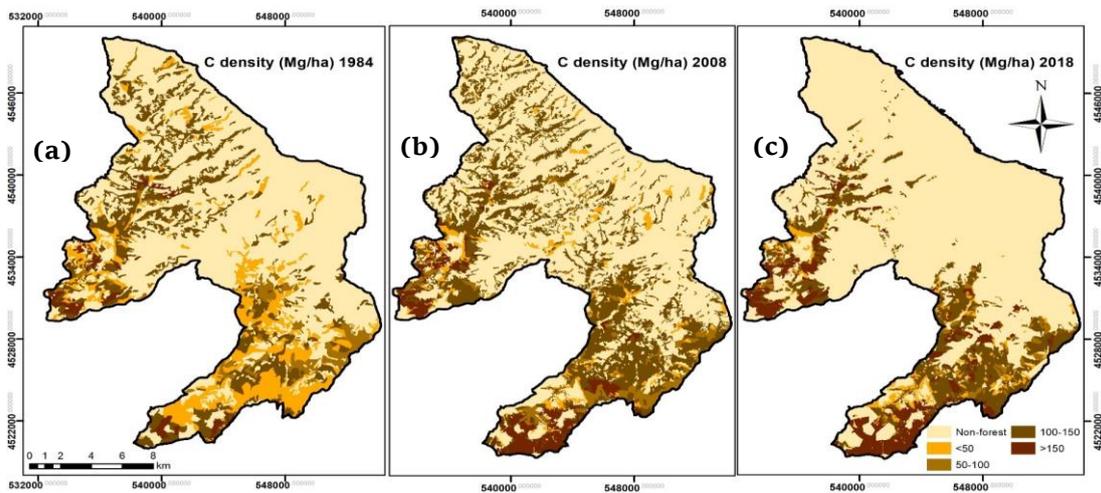


Fig. 2. Spatial distribution of C density in 1984 (a), 2008 (b) and 2018 (c)

The carbon stocks in each C pool gradually increased in successive inventory years, except for a reduction in BGB during 2008-2018, in litterfall and soil organic material (SOM) during 1984-2018. SOM contributed more than the other C pools, which accounted for 69.62%, 68.50%, and 58.07% of total C stock in the forest ecosystem in 1984, 2008, and 2018, respectively. The highest forest biomass C was obtained in 2018 by about 38.11% of total C stock due to higher growing stock. In contrast, forest

biomass C in 1984 and 2008 was accounted for approximately 26.43% and 27.49%, respectively. C accumulation rates in each C pools for aboveground, below-ground, deadwood, litterfall, and SOM were accounted for by 3.69 Gg yr⁻¹, 0.55 Gg yr⁻¹, 0.03 Gg yr⁻¹, -0.02 Gg yr⁻¹, and -0.27 Gg yr⁻¹ between 1984 and 2018 (Table 4, Figure 3a). The C densities in each C pool showed an increasing trend from 1984 to 2018 except for a slight decrease in SOM from

2008 to 2018. The most considerable contribution of total C density was from SOM, which accounted for 60.47 Mg ha⁻¹, 76.35 Mg ha⁻¹, and 73.68 Mg ha⁻¹ in 1984, 2008, and 2018, respectively. C densities in aboveground biomass ranged from 16.74 Mg ha⁻¹ in 1984 to 22.58 Mg ha⁻¹ in 2008 and 37.57 Mg ha⁻¹ in 2018 (Table 4, Figure 3b). The results showed that estimating C stock in forest ecosystems without the other carbon pools, especially SOM, can cause underestimate of C dynamics. Chen et al. (2019) demonstrated that the more considerable contribution to C storage in forest ecosystems was from soil and biomass pools accounting for 95.4% for Hunan province, China. Similarly, Zhou et al. (2008) figured out that C stock in litterfall and understory vegetation contributed to approximately 38%-44% of total C stock.

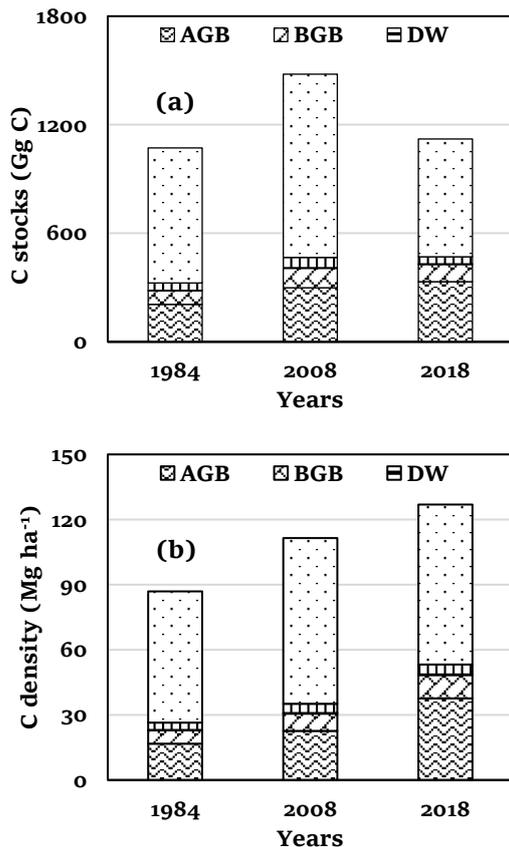


Fig. 3. Temporal change of forest C stocks (a) and C densities (b) based on different carbon pools. (AGB: Aboveground biomass, BGB: Belowground biomass, DW: Deadwood, and SOM: Soil Organic Material)

3.2. Driving Factors on Carbon Dynamics

3.2.1. Total Carbon Storage in Different Land Use/Cover Classes

Temporal change of total C stock for the different land cover types is shown in Figure 4. While the total C stock of coniferous forest showed an increasing trend, the total C stock of deciduous forest showed a decreasing and then increasing trend. However, while total C stock was increasing in degraded areas, it was increasing and decreasing in a mixed forest. The changing forest areas for land cover types from 1984 to 2018 resulted in a changing trend in total C stock. Among various land cover types, deciduous forest in 1984 with 564.58 Gg and mixed forest in 2008 and 2018 with 925.99 Gg and 474.46 Gg, respectively, were the largest contributor to total C stock. The contribution of pure coniferous and deciduous forests to total C stock was about 74.47%, 35.12%, and 54.92% in 1984, 2008 and 2018, respectively. Besides, mixed forests contributed to total C stock accounted for 14.4%, 62.58%, and 42.3% in 1984, 2008 and 2018, respectively. It can be explained by the larger forest area in these cover types (Figure 4a). Though the forested area in the study is importantly decreased from 12339.16 ha in 1984 to 8840.08 ha in 2018, total C stock increased from 1071.88 Gg to 1121.57 Gg. The main reason for a low increase is that in the forest management plan developed based on land cadastre in 2018, approximately 4369.40 ha of land, non-state forest areas covered with forest trees, are not registered as forested areas and excluded in the forest management plan. The total C density of all land cover increased from 1984 to 2018. While the highest C density obtained in the coniferous forest, the lowest C densities were obtained in degraded areas in 1984, 2008, and 2018 (Figure 4b). The results showed that conifer and mixed forests have the highest contribution of C stock due to growing stock in these areas.

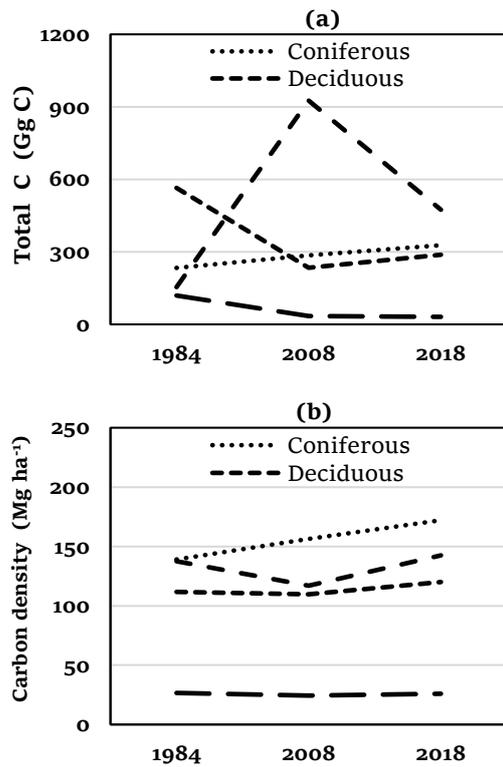


Fig. 4. Temporal change of total C (a) and C density (b) in land cover types

To explain the total C stock change for each land cover class, both the change in the quality of forest ecosystem structure and the size of forested areas from 1984 to

2018 were analyzed. Though the total area of the planning unit increased about 470 ha due to the extended boundary of the planning unit from 32,488.16 ha in 1984 to 32,958.78 ha, the forested lands decreased about 3499.08 ha from 12339.16 in 1984 to 8840.08 ha in 2018. Even though reducing of forested areas, the change in the quality of forest ecosystem structure contributed positive effect on carbon stocks between 1984 and 2018. Conversion from degraded and coppice areas to high and productive pure and mixed forests by about 24.60% and 26.01%, respectively, from forest opening areas to productive pure, mixed and degraded areas, by about 10.45% 4.93% and 7.70%, respectively, of non-forest lands to productive pure, mixed and degraded forests by about 1.45%, 1.34%, and 1.45%, respectively contributed carbon contents (Table 5). Besides, the conversion of deciduous and coniferous forests to the mixed forest by about 26.28% and 6.25%, respectively, caused the change of main carbon sink from the deciduous forest in 1984 to the mixed forest in 2018. Previous studies supported that conversion of some areas to forested areas resulted in a significant increase in total C stock.³⁰

1984 \ 2018	Deciduous	Coniferous	Mixed	Degraded	Forest opening	Non-forest	Total (ha)
Deciduous	1353.61	2.88	1324.82	216.42	87.77	2056.2	5041.7
Coniferous	4.15	1008.75	103.49	42.43	22.98	474.51	1656.31
Mixed	110.55	2.32	435.01	34.04	6.21	531.26	1119.39
Degraded	713.01	384.31	1160.15	580.15	120.79	1502.73	4461.14
Forest opening	7.87	17.05	11.77	18.36	13.17	170.36	238.58
Non-forest	200.62	85.71	265.95	286.96	245	18720.21	19804.45
Total (ha)	2389.81	1501.02	3301.19	1178.36	495.92	23455.27	32321.57

Table 5. Transitions between lands cover types from 1984 to 2018

³⁰ Sivrikaya et al., 2007; Sivrikaya et al., 2013; Sivrikaya and Bozali, 2012; Chen et al., 2019; Tuyoglu, 2020.

3.2.2. Total Carbon Storage in Different Development Stages

As shown in Figure 5, the total C storage of regenerated forest (“a” development stages) decreased consistently. In contrast, the total C storage of young (“b” development stages) slightly increased initially and then decreased after 2008. Total C pool of regenerated forests changed from 7.06% in 1984 to 4.82% in 2008 and 2.30% in 2018, respectively. Total C pool of young forests changed from 56.28% in 1984 to 59.07% in 2008 and 33.59% in 2018, respectively. Unlike the constant increase in total C storage of mature forest (“c” development stages) from 21.24% in 1984 to 32.39% in 2008 and to 57.26% in

2018, respectively, the total C storage of over-mature forest decreased initially and then increased from 4.29% in 1984 to 1.43% in 2008 and 4.07% in 2018, respectively (Table 6).

While the most considerable contribution to total C stock occurred from the young forest in 1984 and 2008 accounted by 56.28% and 59.07%, respectively, it was from mature forest 2018 accounted for 57.26% (Figure 5a). While over-mature forests contributed to the lowest total C stock in 1984 and 2008 with 4.29% and 1.43%, respectively, regenerated areas contributed to the lowest total C stock in 2018 due to the size of the forested land.

Development Stage *(Criteria Average dbh)	Total Carbon (Gg C)			Carbon Density (Mg ha ⁻¹)			Carbon Accumulation Rate (Gg C yr ⁻¹)
	1984	2008	2018	1984	2008	2018	1984-2018
a	75.69	71.29	25.77	94.61	88.28	86.41	-1.47
b	603.27	874.01	376.77	118.69	112.1	122.08	-6.66
c	227.68	479.23	642.19	132.33	151.5	159.22	12.19
d	45.96	21.16	45.66	184.01	186.85	209.22	-0.01
Degraded	119.28	33.98	31.18	26.59	24.38	25.90	-2.59
Total	1071.88	1479.67	1121.57	86.87	111.46	126.87	1.46

* a (regenerated): dbh<8cm, b (young): 8-19.9 cm, c (mature): 20-35.9 cm, d (over-mature): >36 cm

Table 6. Temporal changes of C dynamics in development stages

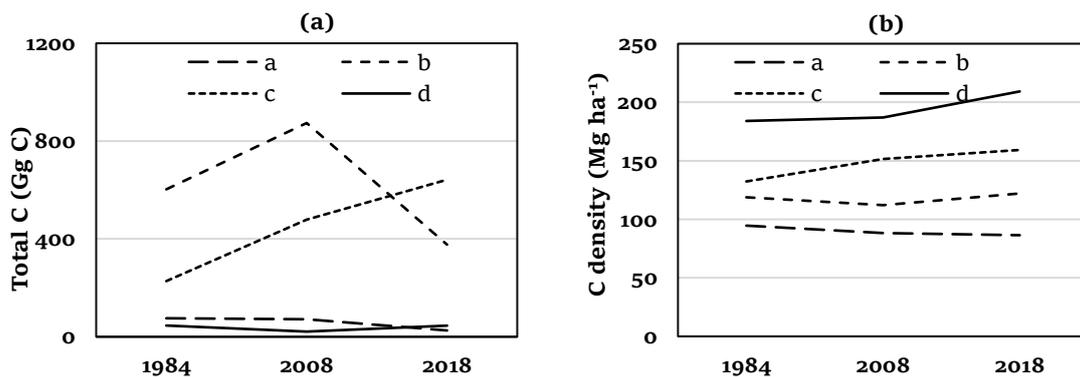


Fig. 5. Temporal change of total C (a) and C density (b) in development stages

Figure 5b showed that the C densities of mature and over-mature forests were increasing trends, while the C density of the regenerated forest was decreasing. However, the C density of the young forest

showed a decreasing and then an increasing trend after 2008. While the most considerable contribution to total C densities was obtained by over-mature forest in successive periods with 184.01 Mg ha⁻¹, 186.85

Mg ha⁻¹, and 209.22 Mg ha⁻¹, the lowest contribution was received by regenerated forest with 94.61 Mg ha⁻¹, 88.28 Mg ha⁻¹ and 86.41 Mg ha⁻¹ due to growing stock (Table 6). The average total C densities for each development stage were 89.77 Mg ha⁻¹, 117.62 Mg ha⁻¹, 147.68 Mg ha⁻¹, and 193.36 Mg ha⁻¹ by regenerated, young, mature and over-mature development stages respectively. While the area was mostly clumped into young forests by about 56.28% in 1984 and 59.07% in 2008, the area was stamped into the mature stage with 57.26% in 2018. Conversions of development stages from 1984 to 2018 showed that regenerated forest converted

to the young, mature and over-mature forest about by 60.9%, young areas converted to mature and over-mature forests about by 24.77%, mature areas converted to the over-mature forest by about 7.88%, degraded areas converted to the high productive forest about by 50.61% and forest opening and non-forest areas converted to the high productive forest about by 2.94% (Table 7). The positive transitions from degraded, coppice, forest opening areas, and non-forest areas to productive high forests, increasing forestland through afforestation, and changing to older development stages have more growing stock led to increasing forest coverage and total C stock in forest ecosystems.

1984 \ 2018	a	b	c	d	Degraded	Forest opening	Non-forest	Total(ha)
a	34.89	416.37	70.58	0.12	43.78	10.8	223.29	799.83
b	54.81	967.82	1212.89	39.73	153.27	72.08	2558.28	5058.88
c	18.42	201.78	1008.68	135.03	77.68	30.27	242.41	1714.27
d	8.75	31.57	130.25	13.89	18.16	3.81	37.99	244.42
Degraded	154.19	1122.84	958.16	22.28	580.15	120.79	1502.73	4461.14
Forest Opening	2.9	10.74	20.59	2.46	18.36	13.17	170.36	238.58
Non-forest	20.42	299.66	228.45	3.75	286.96	245	18720.21	19804.45
Total (ha)	294.38	3050.78	3629.6	217.26	1178.36	495.92	23455.27	32321.57

Table 7. Transitions between development stages from 1984 to 2018

3.2.3. Total Carbon Storage in Different Canopy Cover Types

The lowest total C stock obtained in degraded areas whose canopy cover is under 10% with 119.28 Gg, 33.98 Gg, and 31.18 Gg in 1984, 2008, and 2018, respectively, due to low amount of forestland and above-ground forest biomass in degraded areas. Whereas the total C stock in full covered stands whose crown closure is higher than 70% was the highest in 2018 with 574.36 Gg, the total C stock in the middle covered stands whose crown closure between 40%-70% was the highest in 1984 and 2008 with 598.88 Gg and 1015.27 Gg, respectively (Figure 6a). While the total C stock in degraded and low covered forests showed a decreasing trend, the total C

stock in full covered forests showed an increasing trend from 1984 to 2018. The temporal change of total C stock in middle covered forests showed an increasing and then decreasing trend.

The total C density in full covered forests increased from 1984 to 2018, unlike total C density in the rest of canopy cover classes (Figure 6b). The maximum C densities obtained in the full covered areas with 154.82 Mg ha⁻¹ and 157.32 Mg ha⁻¹ in 2008 and 2018, respectively. However, the C densities in the middle and the full covered forests with 123.34 Mg ha⁻¹ and 121.28 Mg ha⁻¹ in 1984 were very close to each other. As expected that the minimum C densities occurred in degraded areas for all successive periods accounted for 26.59 Mg ha⁻¹, 24.38

Mg ha⁻¹, and 25.90 Mg ha⁻¹ (Table 8). The results indicated that full covered forests

play a critical role in C sequestration due to their greater growing stock.

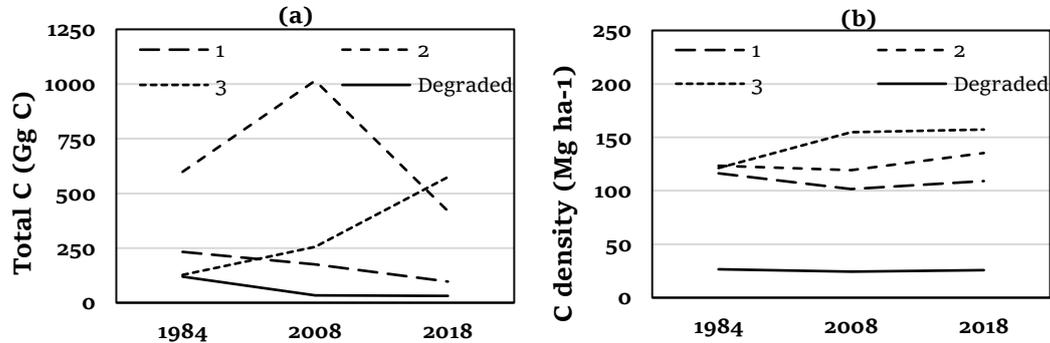


Fig. 6. Temporal change of total C (a) and C density (b) in canopy cover

Canopy Cover (Criteria % Cover)	Total Carbon (Gg C)			Carbon Density (Mg ha ⁻¹)			Carbon Accumulation Rate (Gg C yr ⁻¹)
	1984	2008	2018	1984	2008	2018	1984-2018
1-Low (11%-40%)	232.53	174.92	96.81	116.34	101.64	109.09	-3.99
2-Middle (41%-70%)	598.88	1015.27	419.22	123.34	119.31	135.32	-5.28
3-Full (71%-100%)	127.19	255.5	574.36	121.28	154.82	157.32	13.15
D-Degraded (<11%)	119.28	33.98	31.18	26.59	24.38	25.90	-2.59
Total	1071.88	1479.67	1121.57	86.87	111.46	126.87	1.46

Table 8. Temporal changes of total C dynamics in canopy cover

Transitions from the low covered stands to medium and the full covered stands which accounted for 60.2%, from the medium covered stands to the full covered stands which accounted for 25.13%, from the degraded areas to medium and the full covered productive forest areas which accounted for 43.63%, from non-forest areas to forested areas which accounted for 2.42% from 1984 to 2018 increased the total C stocks (Table 9). Over 34 years, while the extended boundary of the planning unit

from 32,488.16 ha to 32,958.78 ha, the decreasing of forested areas from 12339.16 ha to 8840.08 ha caused a negative effect on total C stock. However, the increase in quality of forest structure in terms of canopy closure and development stages, some management interventions such as afforestation of degraded and bare forest lands and conversion of the abandoned areas to forested areas due to rural migration affect positively to growing stock of existing forests and total C sequestration.

1984 \ 2018	1-Low	2-Middle	3-Full	Degraded	Non-forest	Forest Opening	Total (ha)
1-Low (11%-40%)	179.59	714.89	476.93	119.83	48.64	440.04	1979.92
2-Middle (41%-70%)	225.81	960.02	1209.95	148.12	62.29	2207.82	4814.01
3-Full (71%-100%)	53.18	116.54	408.67	24.94	6.03	414.11	1023.47
Degraded (<11%)	311.15	953.47	992.85	580.15	120.79	1502.73	4461.14
Non-forest	5.31	14.5	16.88	18.36	13.17	170.36	238.58
Forest Opening	98.46	283.21	170.61	286.96	245	18720.21	19804.45
Total (ha)	873.5	3042.63	3275.89	1178.36	495.92	23455.27	32321.57

Table 9. Transitions between canopy cover from 1984 to 2018

3.2.4. The Effects of Forest Ownership Based on Land Cadastre on Carbon Stock

While the boundary of the planning unit has extended from 1984 to 2018 with about 472.62 ha, interestingly, the forested areas decreased in his period based on the current forest management plan. The forested area in the planning unit was 12,339.16 ha, 13,275.13 ha, and 8840.08 ha in 1984, 2008, and 2018, respectively. According to the new guide for preparing forest management plans,³¹ non-state-owned areas covered with forest trees must be shown as only KDA in forest management plans. According to the forest management plan developed based on land cadastre in 2018, the forested area importantly decreased, which accounted for 28.36% between 1984 and 2018. It was obtained that a total of 4369.40 ha area, which has been covered with forest trees, were not considered forested areas based on the cadastral applications. This cadastral area not considered forestland corresponds to approximately 49.43% of the state forested area in the forest management plan for 2018. Because these areas were not included in the current forest management plan due to ownership, showing areas covered with forest trees as non-forest areas resulted in an underestimation of total C stock, and the increase in total C stock between 1984 and 2018 accounted for only 4.64%. According to regulations, if there were actual stand types in the forest management plans developed based on land cadastre in 2018 instead of KDA, the forest presence would have increased by about 50% and the total C stock would be estimated at a higher and real value.

Spatial distributions of the land cover change between 1984 and 2018 in the Akçaabat planning unit are shown in Figure 9. According to the map, of total area,

1.80%, 13.44%, and 59.25% were unchanged areas from degraded, forestland, and non-forest lands, respectively. Besides, of total area 6.98% converted from degraded areas to forestland, 5.02% converted to non-forest areas, 0.91% converted from forestland to degraded, 9.84% converted from forestland to non-forest areas, 0.94% converted from non-forest to degraded, and 1.82% converted from non-forest to forestlands. Also, this map showed that of total cadastre area (4369.40 ha) in forest cover type for 2018, were not considered a forested area based on the forest management guide, 662.91 ha, 1478.82 ha, and 2219.30 ha were covered with degraded, forestland and non-forest lands in 1984.

The spatial distribution of temporal change for total forest C between 1984 and 2018 in the Akçaabat planning unit is shown in Figure 7. The areas where total C stock increased, decreased and did not change between 1984 and 2018 were indicated with "Increased", "Decreased" and "Unchanged" in the total C balance map. According to the map, increased, decreased, and unchanged areas were 6864.41 ha (21.24%), 6249.35 ha (19.33%), and 19207.73 ha (59.43%), respectively.

While extended boundary of the study area, increasing the quality structure of the forested area in terms of development stage and canopy cover, increasing productive forest areas with the rehabilitation of degraded areas, afforestation of forest opening areas and forestation of abandoned agricultural lands had a positive effect on total C stock, woodlands not considered as forested area through cadastre had the most significant negative impact on total C stock.

³¹ Anonymous, 2014.

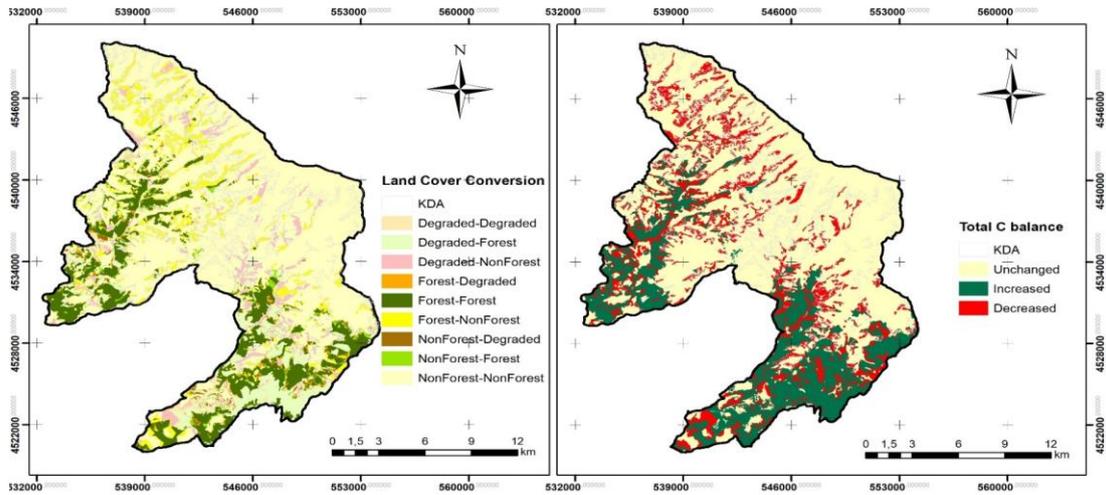


Fig. 7. Land cover conversion (a) and spatial distribution map of total C balance (b) from 1984 to 2018

3.2.6. Demographic Movement, Forest Crimes and Economic Development

The main reason for the increase in the forestland state over 34 years was accurate forest management interventions. Some conversion from degraded forests and forest opening lands to forestland with rehabilitation and afforestation had a great effect on the improvement of the forest areas in the Akçaabat planning unit. Thanks to accurate forest management interventions, a significant proportion of degraded

and forest opening lands accounted for 65.46% and 32.87%, respectively converted to forested areas over 34 years. Also, the increase of the forestland can be explained by demographic and socio-economic changes in the forest village. The rural population in all forest villages was about 64,577 in 1980 and decreased to 47,941 in 2018, with a net decline of 25.76% (Anonymous, 2020a) (Figure 8). Conversion of agricultural areas about 834.7 ha to forested land can be explained by the movement of the rural population.

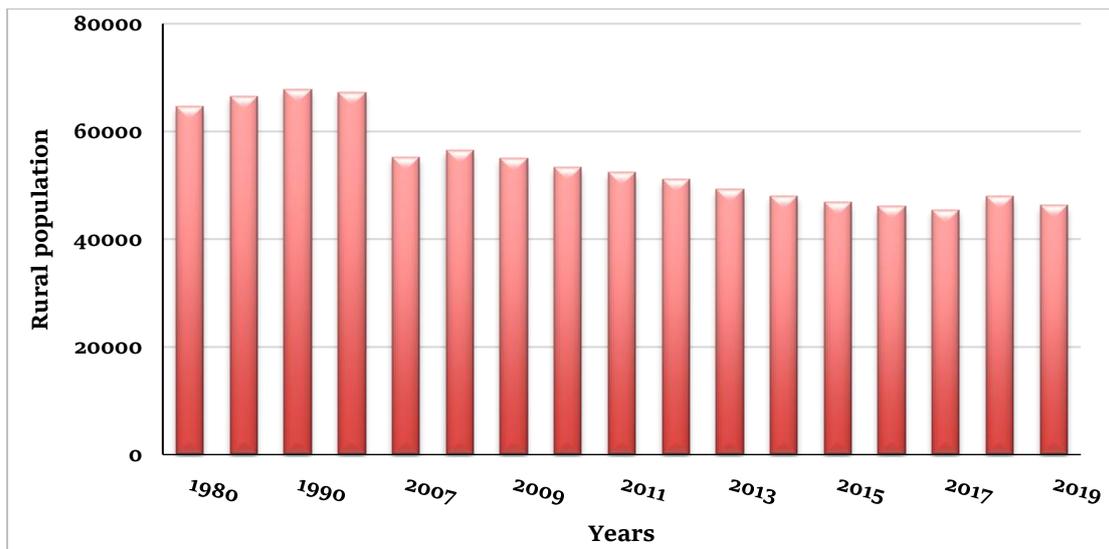


Fig. 8. The number of the rural population in the study area

In addition to the conversion of abandoned agriculture area to forestland, decreasing

social pressure on forested areas due to reducing of rural population resulted in a

significant increase in the productive forests by about 15.39%. In this point, forest crime statistics are great important indicators showing the extent of pressure on forests. The historical distribution of the forest crime statistics in the Akçaabat forest planning unit showed that total amount of forest crimes such as illegal harvesting, transporting, possessing, consumption, grazing, occupation, and utilization, dramatically changed. The average annual crime numbers were 28.8, 55.4, 46.3 and 16.9 in each period of 1980-1990, 1991-2000, 2001-2010 and 2011-2019 with a decline of 41.3%³² (Figure 9). The number of

forest crimes were very high between 1980-2000, but after 2000 it can be seen clearly that there was a severe decrease in the number of forest crimes. The main reason for the number of forest crime numbers to appear quite low between 1980-1990 is that real records could not be shown on the figure 10 due to the loss of all archive records in the forest business as a result of the flood disaster in the Akçaabat in 1990. Therefore, it was estimated that the real number of forest crimes was higher than those shown on the figure 9 at this period.

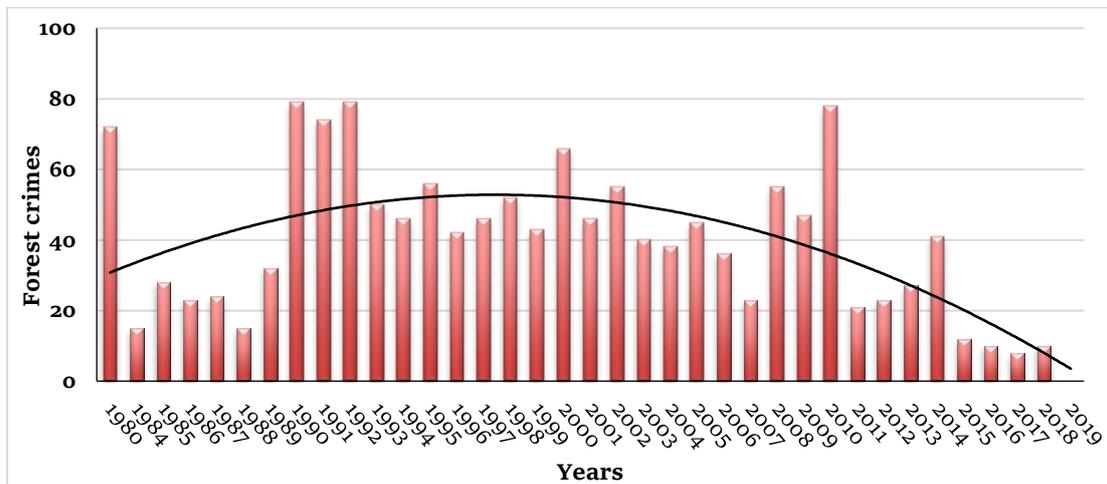


Fig. 9. The number of forest crimes in the study area

The ability of people to look at the forests with a different perspective is related to their educational and financial development. The gross domestic product per capita (GNP) in Trabzon province increased from \$4466 in 2004 to \$7648 in 2018, with a similar trend to GNP in Turkey (Figure 10) (Anonymous, 2020c). It was clear that decreases in rural population and forest crimes and increases in income levels re-

sulted in increasing awareness and sensitivity to the environment over time. Consequently, conversion abandoned agriculture to forested areas explained by migration from county to cities and decreasing social pressure on forest areas explained by reducing the amount of forest crime increased both of forested size and the quality of forest structure, thus total C stock importantly increased.

³² Anonymous, 2020b.

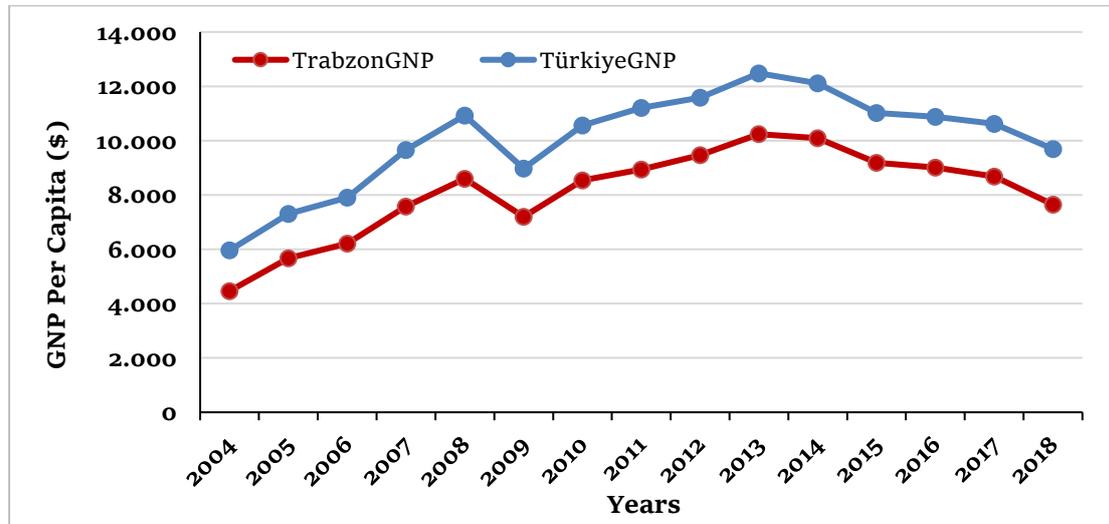


Fig. 10. Gross national products per capita (\$) in Trabzon and Turkey

4. Conclusion

This study analyzed the spatial and temporal change of forest C dynamics on various C pools based on demographic, socio-economic, and landscape structure. To estimate forest C dynamics, forest inventory data, and the latest methodology of IPCC, 2006 guidelines were combined. The method used in the study was expanding growing stock to biomass by BEF due to a lack of allometric equations for tree species in the study area. Unlike many previous studies, species-species WD and BEF coefficients reported for each tree species in Turkey's forests were preferred in this study to avoid the overestimation of C stock. Moreover, C dynamic in above-ground, belowground, dead wood, litter, and soil was calculated separately based on forest inventory data in 1984, 2008, and 2018. In this study, the spatial distribution of C dynamics each planning period and C balance between 1984 and 2018 were mapped by using GIS. The change in the spatial distribution of C dynamics each period was about landscape and socio-economic dynamics. Also, these maps are helpful tools for forest management applications.

Forest C dynamics and its spatial distribution between 1984 and 2018 were influenced by land cover and the quality of forest ecosystem structure in terms of developing stages and canopy cover, tree species, and forest coverage. The forest management policies, planning interventions, irregular human interventions were main drivers on significant changes in the forest structure. For instance, afforestation of forest opening and degraded areas within the scope of forestry policies directly affected total C dynamics and its spatial distribution.

Unlike the previous studies analyzing the change of C dynamics, this study focused on the change of C dynamics based on land cover change associated with forest crime, economic development, and population movement in rural. Temporal and spatial change in the C dynamics can be explained indirectly through a reduction in rural population on forest villages and forest crime statistics and an increase in income levels (GNP). Because land cover changes are mostly affected by forest management interventions, human disturbances, natural and socio-economic factors are the important indicators of awareness and sensitivity to the environment. Based on these socio-economic changes in rural areas, conversion abandoned agriculture areas to

forestland, and the reduction in social pressure on the existing forested areas has increased total C stock.

The results showed that expanding the boundary of the study area and conversion from degraded, coppice, and non-forest areas to highly productive areas increased total C stock. In contrast, conversion from forest lands to degraded or non-forest areas resulted in a reduction of total C stock. The average C densities were higher in deciduous forest with 442.61 Mg ha⁻¹ than the coniferous and mixed forests with 267.37 Mg ha⁻¹ and 132.47 Mg ha⁻¹, respectively. While the deciduous forest was the main carbon sink in 1984, the mixed forest was the main carbon sink in 2008 and 2018 due to the larger area.

The development stages and canopy cover are important indicators to observe C stock. The average C densities in young and mature forests with 49.65 Mg ha⁻¹ and 36.96 Mg ha⁻¹ and full covered forests with 144.47 Mg ha⁻¹ were higher. Temporal change in forest dynamics showed that young and full covered areas increased. These results demonstrated that the quality of forest structure based on C stock increased between 1984 to 2018.

The combined contribution of litterfall and SOM to C stock was about 73.39%, 72.32%, and 61.60% in 1984, 2008 and 2018, respectively. Thus, estimating C in forest ecosystems stock without litterfall and SOM C pools will cause a significant error.

Though total C stock increased from 1984 to 2008 by about 38.04%, the increase was only about 4.64%. The main reason for a decreasing increase in total C stock was to not including of non-state-owned areas covered with forest trees in the forest management plans developed based on land cadaster in 2018. Thus, a total of 4369.40 ha area, which had previously been forested or later covered with forest cover, was not included in the current forest management plan. This administrative approach resulted in an underestimation of total C stock in 2018. Thus, these non-

state-owned lands should be considered as forests for sustainable use.

Climate change is one of the most important global environmental problems. Because living biomass and SOM in forest ecosystems store large quantities of C, these ecosystems can play a significant role in mitigating greenhouse gas emissions. The temporal change in forest structure based on forest management interventions, human disturbances, population dynamics, and socio-economic structure affect C dynamics. Accurate forest management interventions spatial distribution maps can consider as helpful tools to change C stock and to control global climate change.

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