141. Jahrgang (2024), Heft 4, S. 243–262

Austrian Journal of Forest Science
Centralblatt für das gesamte Forstwesen

Evaluating the Spatio-Temporal Change of Forest Carbon Stocks in Northern Türkiye

Bewertung der räumlich-zeitlichen Veränderung des Kohlenstoffvorrates in Wäldern in der Nordtürkei

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Keywords: Land use classes, forest planning system, forest ecosystem service, forest management plans

Schlüsselbegriffe: Landnutzungsklassen, Waldbewirtschaftung, Waldökosystemdienstleistungen, Waldwirtschaftspläne

Abstract

Forests represent important carbon pools among terrestrial ecosystems and play an important role in mitigating the impact of global warming. Changes in land use and forest planning systems affect the spatio-temporal distribution of forest carbon stocks. In this study, the total carbon stocks of the forest stands were calculated, and spatial and temporal changes of the carbon stock were investigated for the 1996, 2009, and 2018 planning periods in Ilgaz Forest Enterprise, Türkiye. Growing stock volume (GSV) was obtained from the forest management plans of Ilgaz Forest Enterprise. GSV-based carbon conversion coefficients were used to calculate the total carbon stock of the forest stands. Mapping the total carbon stock of forest stands was done using stand maps from forest management plans. Our results indicate that changes in land use contributed to enhanced forest carbon stock in the study region. Forest stands stored a total of 7.56, 9.65, and 10.22 MtC over the planning periods of 1996, 2009, and 2018, respectively. While the forest carbon stocks per hectare was

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113.4 tC ha^{-1} in the planning period of 1996, it was 125.1 tC ha^{-1} in 2018. This was an increase of +11.7 tC ha^{-1} over 22 years. In the 22-year planning period covering 1996 and 2018, the increase in productive forest areas, expansion of protection-oriented functions, and the moderate silvicultural treatments applied to the forest stands positively affected on the carbon stock increase in the study region.

Zusammenfassung

Wälder sind wichtige Kohlenstoffspeicher terrestrischer Ökosysteme und spielen eine wichtige Rolle bei der Abschwächung der Auswirkungen der globalen Erwärmung. Landnutzungsänderungen und forstliche Nutzung und Planung wirken sich auf die räumlich-zeitliche Verteilung der Kohlenstoffvorräte der Wälder aus. In dieser Studie wurden die Kohlenstoffvorräte der Waldbestände und deren räumlichen und zeitlichen Veränderungen für die Planungszeiträume 1996, 2009 und 2018 im Forstunternehmen Ilgaz in der Türkei untersucht. Das Bestandesvorrat (GSV) wurde aus Waldbewirtschaftungsplänen des Forstunternehmens Ilgaz ermittelt. Zur Berechnung des Waldkohlenstoffvorrats der Waldbestände wurden GSV-basierte Kohlenstoff-umrechnungskoeffizienten verwendet. Die Kartierung des Waldkohlenstoffvorrats wurde mittels Bestandeskarten aus den Waldbewirtschaftungsplänen erstellt. Die Ergebnisse zeigten, dass Landnutzung zur Erhöhung des Waldkohlenstoffvorrats beitragen kann. In den Planungszeiträumen 1996, 2009 und 2018 speicherten die Waldbestände insgesamt 7.56, 9.65 und 10.22 MtC Kohlenstoff. Während der Waldkohlenstoffvorrat pro Hektar im Planungszeitraum 1996 113.4 tC ha^{-1} betrug, waren es im Jahr 2018 125.1 tC ha^{-1}. So weit stieg der Vorrat um +11.7 tC ha^{-1} während 22 Jahren an. Im 22-jährigen Planungszeitraum von 1996 bis 2018 wirkten sich die Zunahme produktiver Waldflächen, der Ausbau schutzorientierter Funktionen und moderate waldbauliche Maßnahmen in den Waldbeständen positiv auf die Entwicklung des Kohlenstoffvorrats in den Waldbeständen aus.

1 Introduction

The world that we have been living in for thousands of years has seen significant transformations recently, and scientists are struggling to understand the reasons behind this abnormal change. Global climate change, mainly induced by land use change, deforestation, and increased fossil fuel consumption, is the main reason behind this change. The amount of carbon dioxide in the atmosphere has risen from 280 parts per million to 377 parts per million (31%) over the century (Stocker *et al*. 2014). Considering the increasing world population and energy consumption, the application of different climate scenarios reveals that this share will continue to increase in the future if no adequate measures are taken (Masson-Delmotte *et al*. 2018). Supposedly, we have reduced the amount of greenhouse gases released into the atmosphere to their normal level. Still, as of today, it may take decades for the system to repair itself and return to its pristine state. One of the greatest contributions in improving this possibility is undoubtedly forest ecosystems (Nunes *et al*. 2020; Raihan 2024).

The climate crisis, increasing population, and varied needs have changed people's perceptions of forests. While getting wood products remains the fundamental aim of forest operations, this perspective has changed due to the effects of international processes (UNCED 1992). Forests are no longer seen as wood stores but also as an ecosystem with ecological and social functions. The forest management guideline on the planning of forests in Turkey has been revised in 2008. According to the regulation, forest management plans are prepared with an "ecosystem-based functional planning" system in accordance with the principles of sustainable forest management (GDF 2008). While forest management plans were prepared based on the principle of intensive wood production, forests are divided according to their economic, ecological, and socio-cultural functions as of this regulation. Although the stand characteristics are the same, forest management plans are implemented using appropriate silvicultural treatments based on the assigned forest ecosystem services. At the stage of determining the forest ecosystem services, society should demand a potential function in the forest ecosystem. As a result of the demand of the society and the evaluation of the relevant stakeholders, forest ecosystem services are determined as the operational purpose with a participatory approach (Başkent *et al*. 2008; Başkent 2018, Vatandaşlar 2021).

Forests have critical functions in terms of improving the climate and play an active role in the regional and global carbon cycle (Guo *et al*. 2013; Zhang *et al*. 2023; Wei *et al*. 2023). Anthropogenic and natural disturbances like climate anomalies, population density, insect damage, forest fires, or atmospheric pollutants have an impact on the amount of carbon storage in forests (Wang *et al*. 2001; Yang *et al*. 2017). The amount of carbon stored is also affected by forest stand characteristics such as forest type, age, tree species, and compositions (Ren *et al*. 2011; Putz *et al*. 2023). Also, the characteristics of the forest stands are directly related to the current forest management system and silvicultural treatments. Therefore, appropriate forest planning systems and correct silvicultural treatments are required to maximize the amount of carbon stored by the forest stands (Sharma 2010; Ruslandi *et al*. 2017; Başkent & Kašpar 2023; Lee *et al*. 2023).

Ecological and socio-cultural-based functions are protected areas where silvicultural treatments are applied at low and medium levels. Protection-based forest ecosystem functions such as nature protection, erosion prevention, aesthetics, ecotourism, and recreation improve the development of stand structure (Keleş *et al*. 2017). This process in protected forests also provides a driving force for carbon storage (Ali & Yan 2017). In addition to forest ecosystems, land use and land cover change in terrestrial ecosystems are also effective on the amount of carbon stored (Chang *et al*. 2022; Orlov *et al*. 2023). One of the biggest causes of carbon losses is land use change, and the effect of greenhouse gas emissions due to deforestation and land use changes on global climate change is 17% (Miles & Kapos 2008; Jia *et al*. 2022; Girma *et al*. 2023). In mitigating climate change, minimizing carbon emissions caused by land use changes is one of the environmentally friendly, effective, and cost-effective ways. In this regard, increasing forest areas, intensifying afforestation practices, and rehabilitation of non-productive areas can contribute to the carbon storage capacity of stands in forest ecosystems (Tian *et al*. 2022; Tao *et al*. 2023). The main objectives of the present study were

(i) to determine the spatio-temporal distribution of stand carbon stocks and land use classes in 1996, 2009 and 2018 planning periods, and
(ii) to examine the interaction of stored carbon stocks change with land use classes and planning systems such as classical planning focused on wood production and functional planning.

2 Materials and methods

2.1 The study area

The study area covers Ilgaz Forest Enterprise, and these areas are located in the Black Sea backward region of Turkey (Figure 1). Ilgaz Forest Enterprise is in the Ankara Regional Directorate of Forestry, and it is bound by 32° 59′ 50″-33° 50′ 10″ on the eastern longitudes and 40° 37′ 39″-41° 26′ 19″ on the northern latitudes. The study area is 206,293 ha. The total productive and non-productive forest area is 47,927 and 33,838 ha, respectively. The total area covered by forest is 81,765 ha, which is 40% of the study area. The dominant tree species are *Abies nordmanniana* ssp. *bornmuelleriana* (Fir), *Pinus nigra* (Black pine), *Pinus sylvestris* (Scots pine), *Fagus orientalis* (Beech), *Quercus infectoria* (Oak), *Quercus petraea* (Oak), *Populus tremula* (Poplar) and *Juniperus excelsa* (Juniper) in the region. The altitude is between 540 and 2,544 m, and the mean slope is 20%. Annual minimum, maximum, and mean temperatures are -8, 31, and 9 °C, respectively. Annual total mean precipitation is 513 mm (Anonymous 2018).

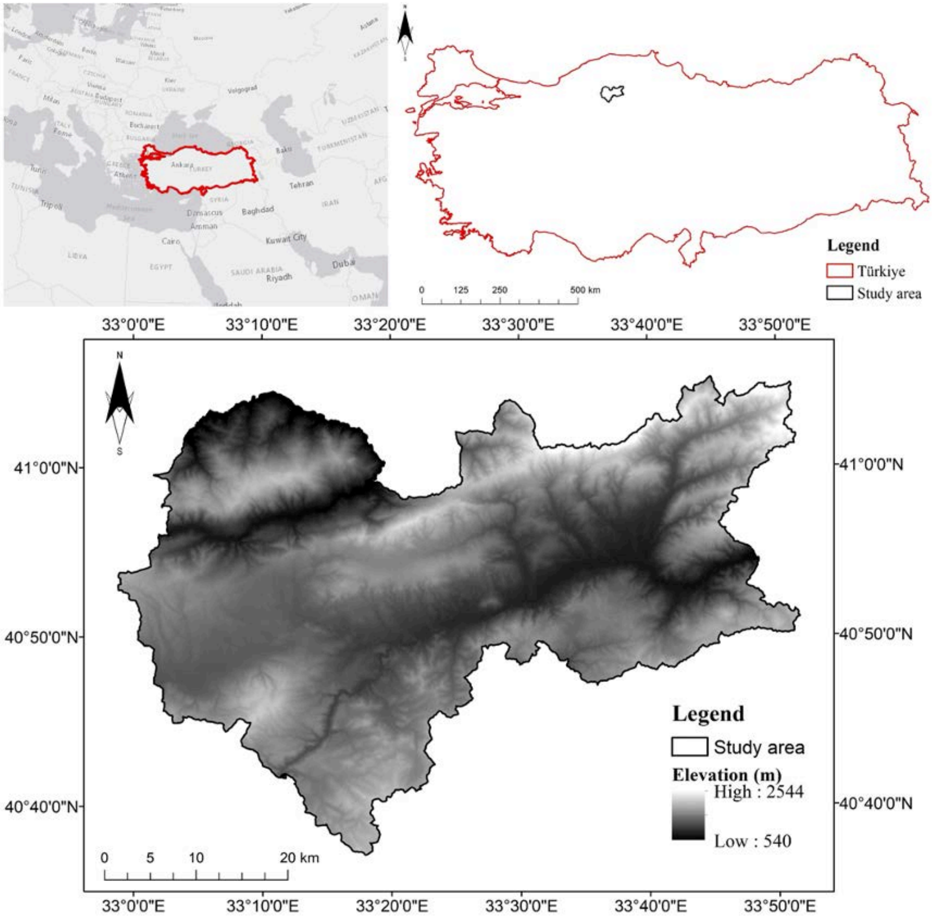

Figure 1: Location of the study area.

Abbildung 1: Standort des Untersuchungsgebietes.

2.2 Field measurements

The data acquired from the forest management inventory that was carried out under the control of the General Directorate of Forestry were used in the study. Field measurements were made in 2,158 sample plots systematically with 300 × 300 m intervals. For each sample area, circular sample plot sizes of 400, 600, and 800 m² were used. Sample plot sizes were determined as low (400 m²), medium (600 m²), and full (400 m²) according to the crown closure. Diameters at breast height of 1.30 m, age, and height were measured in all trees with a diameter of 8 cm or more in each sample plot (GDF 2017). Following the field measurements, the finalized stand maps of the region were added to the forest management plans of 1996, 2009, and 2018.

2.3 Forest management plan and stand map

Forest management plans and stand maps of Ilgaz Forest Enterprise prepared by the Turkish General Directorate of Forestry were used in the study. Areal distributions of main forest ecosystem services, including economic, ecological, and socio-cultural functions, were determined by using forest management plans for the 1996, 2009, and 2018 planning periods. In stand maps, land use classes such as productive forests, unproductive forests, clearings in forests, pastures, settlements, and agricultural areas were updated for each planning period. According to 1996, 2009, and 2018 planning periods, land use classes were mapped using stand maps, and their spatial distributions were determined (Anonymous 1996; Anonymous 2009; Anonymous 2018).

2.4 Calculation of the total carbon stock

Forest management plans, stand maps (Anonymous 1996; Anonymous 2009; Anonymous 2018), and carbon conversion coefficients (Tolunay 2011) were used to calculate the carbon stored by the stands. Growing stock volume (GSV m^3 ha^{-1}) of forest stands were obtained from forest management plans. GSV was calculated after field measurements made for preparing and updating forest management plans. GSV represents the volume of standing and barked stems for forest stands and is the amount of tree volumes with a breast diameter of 8 cm and above. Above-ground biomass (AGB), above-ground carbon (AGC), below-ground biomass (BGB), below-ground carbon (BGC), forest soil carbon (FSC), litter carbon (LC), dead wood biomass (DWB), and dead wood carbon (DWC) were calculated based on GSV-based carbon conversion coefficients developed by Tolunay (2011) (Table 1). The total carbon stocks of the productive/non-productive coniferous and broadleaf stands were calculated by the sum of AGC, BGC, DWC, LC, and FSC (Eq. 2), and the total carbon stock map was created through the stand map.

Table 1: GSV-based carbon conversion coefficients (Tolunay 2011) for calculation of the total carbon stock.

Tabelle 1: GSV-basierte Kohlenstoffumrechnungskoeffizienten (Tolunay 2011) zur Berechnung des gesamten Kohlenstoffbestands.

Variable	PCS	NPCS	PBS	NPBS
AGB	GSV × 0.446 × 1.212	GSV × 0.446 × 1.212	GSV × 0.541 × 1.310	GSV × 0.541 × 1.310
BGB	AGB × 0.29	AGB × 0.40	AGB × 0.24	AGB × 0.46
AGC	AGB × 0.51	AGB × 0.51	AGB × 0.48	AGB × 0.48
BGC	BGB × 0.51	BGB × 0.51	BGB × 0.48	BGB × 0.48
DWB	AGB × 0.01	AGB × 0.01	AGB × 0.01	AGB × 0.01
DWC	DWB × 0.47	DWB × 0.47	DWB × 0.47	DWB × 0.47
LC	Area (ha) × 7.46	Area (ha) × 1.86	Area (ha) × 3.75	Area (ha) × 0.93
FSC	Area (ha) × 76.56	Area (ha) × 19.14	Area (ha) × 84.82	Area (ha) × 21.20

GSV: growing stock volume, AGB: above-ground biomass, AGC: above-ground carbon, BGB: below-ground biomass, BGC: below-ground carbon, DWB: dead wood biomass, DWC: dead wood carbon, LC: litter carbon, FSC: forest soil carbon, PCS: productive coniferous stand, NPCS: non-productive coniferous stand, PBS: productive broadleaf stand, NPBS: non-productive broadleaf stand

$$\text{Total carbon stock (tC } ha^{-1}) = AGC + BGC + DWC + LC + FSC \quad (2)$$

3 Results

The spatial distribution of the main forest ecosystem services in the study area changed between 1996 and 2018 (Table 2). Especially in 1996 planning, it is seen that economic functions are dominant, and in other planning periods, these areas have transitioned into ecological and socio-cultural functions. While stands with ecological functions covered an area of 12.2% in 1996, this ratio was extended to approximately half of the area in other periods. While socio-cultural functions were not considered in the planning in 1996, they covered an area of 1.6% in 2009 and 10.2% in 2018.

Table 2: Areal distribution of the main forest ecosystem services in terms of planning periods.

Tabelle 2: Flächenmäßige Verteilung der wesentlichen Ökosystemleistungen des Waldes nach Planungszeiträumen.

Main forest function	1996		2009		2018	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Economic	61,050	29.6	23,236	11.3	30,608	14.8
Ecological	25,053	12.2	117,509	57.0	101,752	49.3
Socio-cultural	-	-	3,259	1.6	21,092	10.2
Non-forest area	120,190	58.2	62,289	30.1	52,841	25.7
Total	206,293	100.0	206,293	100.0	206,293	100.0

It has been observed that productive areas increase in forest areas within the land use classes (Table 3). During the 1996-2018 period, the area of productive forests increased by 7.4%. A partial decrease was observed in non-productive forest areas. Compared to the 2009 period, there was an increase in productive and non-productive forest areas in the 2018 period. It was determined that the grassland areas had an area of 18.3% in 1996. However, there were neither grassland nor swamp areas in the region in other planning periods. In addition, there was a decrease in settlement and agricultural areas during the planning periods.

Table 3: Areal distribution of the land use classes in terms of planning periods.

Tabelle 3: Flächige Verteilung der Bodennutzungsklassen nach Planungszeiträumen.

Land use classes	1996		2009		2018	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Productive forest	32,533	15.8	45,463	22.0	47,927	23.2
Non-productive forest	34,141	16.6	31,748	15.4	33,838	16.4
Forest openings	19,463	9.4	66,749	32.3	71,705	34.8
Grassland	37,764	18.3	-	-	-	-
Swamp	397	0.2	-	-	-	-
Water	174	0.1	189	0.1	228	0.1
Sand land	-	-	321	0.2	455	0.2
Settlement and agriculture	81,234	39.3	61,766	29.9	51,719	25.1
Other area (road, rocky, energy line etc.)	587	0.3	57	0.1	421	0.2
Total	206,293	100.0	206,293	100.0	206,293	100.0

In 1996, some of the non-productive forest areas were converted into productive forest areas in other periods (Figure 2). The grassland class, which had a significant area in 1996 (37,764 ha), was classified as the forest openings in the 2009 and 2018 planning periods. The swamp area, which was founded locally in 1996, has changed into forest openings and water area in other periods. Some parts of the non-productive forests and forest openings in the 1996 period were classified as sand land in other periods.

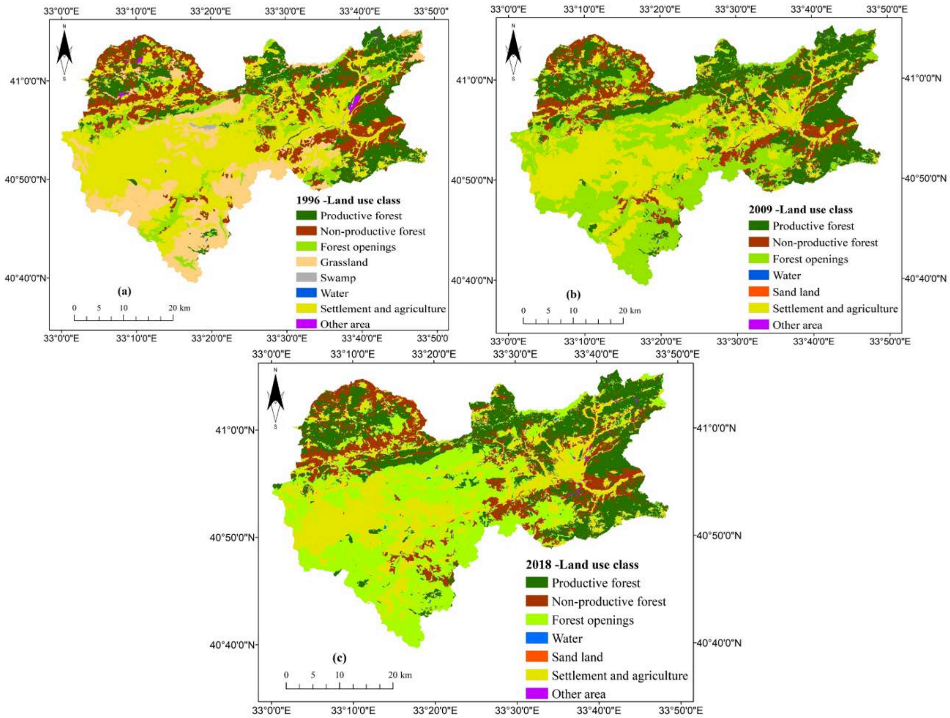

Figure 2: Spatio-temporal change maps of the land use class for study area in (a) 1996, (b) 2009 and (c) 2018 planning periods (Anonymous 1996; Anonymous 2009; Anonymous 2018).

Abbildung 2: Karten zur räumlich-zeitlichen Veränderung der Landnutzung für das Untersuchungsgebiet in den Planungszeiträumen (a) 1996, (b) 2009 und (c) 2018 (Anonym 1996; Anonym 2009; Anonym 2018).

The highest mean and total carbon stock among the planning periods was found in 2018 (Table 4). The mean carbon stock increased from 113.4 to 125.1 tC ha^{-1}, and the total carbon stock increased from 7.56 to 10.22 MtC from 1996 to 2018. Thus, the mean carbon stock increased by 11.7 tC ha^{-1} while the total carbon stock increased by 2.66 MtC in the study area's forests. The forest area increased from 66,673 to 81,765 ha, and there was an increase of 15,092 ha in productive and non-productive forest areas. Productive stands in coniferous forests had more carbon stock. Non-productive stands were more in broadleaf forests, and the carbon stock of non-productive stands was found to be higher than productive stands.

Table 4: Forest carbon stock change (tC ha-1, MtC) over the years of 1996, 2009, and 2018 planning periods.

Tabelle 4: Waldkohlenstoffvorrat Veränderung (tC ha^{-1}, MtC) in den Planungszeiträumen 1996, 2009 und 2018.

Planning period	Forest type	Area (ha)	Forest carbon stock (tC ha^{-1})	Forest carbon stock (MtC)
1996	Coniferous	46,645	125.1	5.83
	Productive	29,687	146.9	4.36
	Non-productive	16,958	86.7	1.47
	Broadleaf	20,028	86.1	1.73
	Productive	2,845	52.7	0.15
	Non-productive	17,183	92.0	1.58
	Total	66,673	113.4	7.56
2009	Coniferous	53,319	142.1	7.58
	Productive	38,452	163.6	6.29
	Non-productive	14,867	86.1	1.28
	Broadleaf	23,892	86.5	2.07
	Productive	7,011	81.3	0.57
	Non-productive	16,881	88.9	1.50
	Total	77,211	124.9	9.65
2018	Coniferous	56,325	141.2	7.95
	Productive	40,934	162.0	6.63
	Non-productive	15,391	86.4	1.33
	Broadleaf	25,440	89.4	2.27
	Productive	6,993	88.7	0.62
	Non-productive	18,447	90.0	1.66
	Total	81,765	125.1	10.22

The broadleaf forest's carbon stock increased by 1% on average between 1996 and 2018 (Figure 3). In coniferous forests, this increase was found to be 4% in the 2009 period and 3% in the 2018 period.

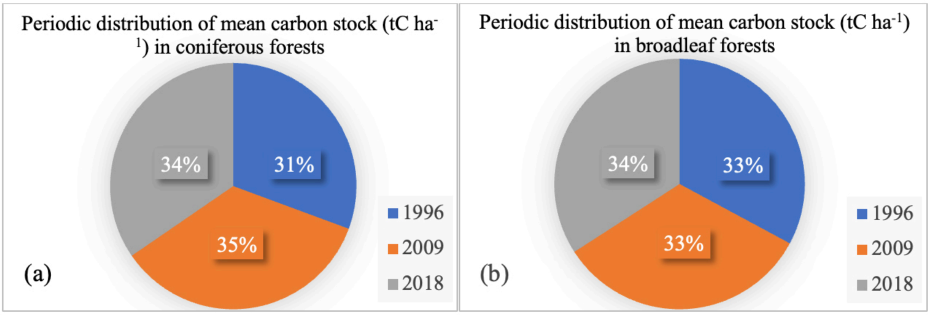

Figure 3: Periodic percentage distribution of mean carbon stock (tC ha^{-1}) per unit area according to (a) coniferous and (b) broadleaf forests in planning periods.

Abbildung 3: Prozentuale Verteilung des mittleren Kohlenstoffvorrats (tC ha^{-1}) pro Hektar nach (a) Nadelwäldern und (b) Laubwäldern in den Planungszeiträumen.

In the spatial distribution of TCS, stands with high carbon stock were more common in 2018 (Figure 4). There were the stands with lower TCS levels in the 1996 and 2009 planning periods, and TCS of these stands developed in 2018 planning period especially in the south of the study area.

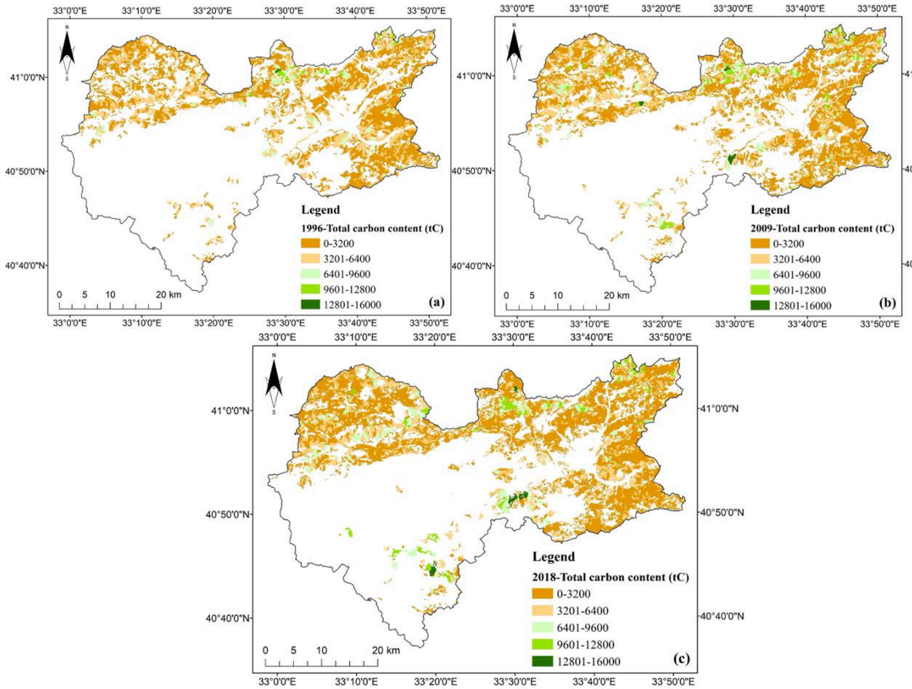

Figure 4: Spatio-temporal change maps of the total forest carbon stocks (tC) for study area in (a)1996, (b) 2009, and (c) 2018 planning periods.

Abbildung 4: Karten der räumlich-zeitlichen Veränderungen der gesamten Waldkohlenstoffvorräte (tC) für das Untersuchungsgebiet in den Planungszeiträumen (a) 1996, (b) 2009 und (c) 2018.

Both the land use and the total carbon stored by the forest stands have changed spatially between 1996 and 2018 (Figure 5). The most visible transition is the conversion of non-forest regions into productive and non-productive forest areas. Furthermore, in certain limited places, both productive and non-productive forest areas have changed into non-forest areas. The total carbon storage capacities of the stands within the forest area also changed. Stands have improved their carbon storage capacity, especially in areas that have turned into productive and non-productive forests. On the other hand, the amount of carbon stored in regions transformed into non-forest areas has decreased to the minimum level.

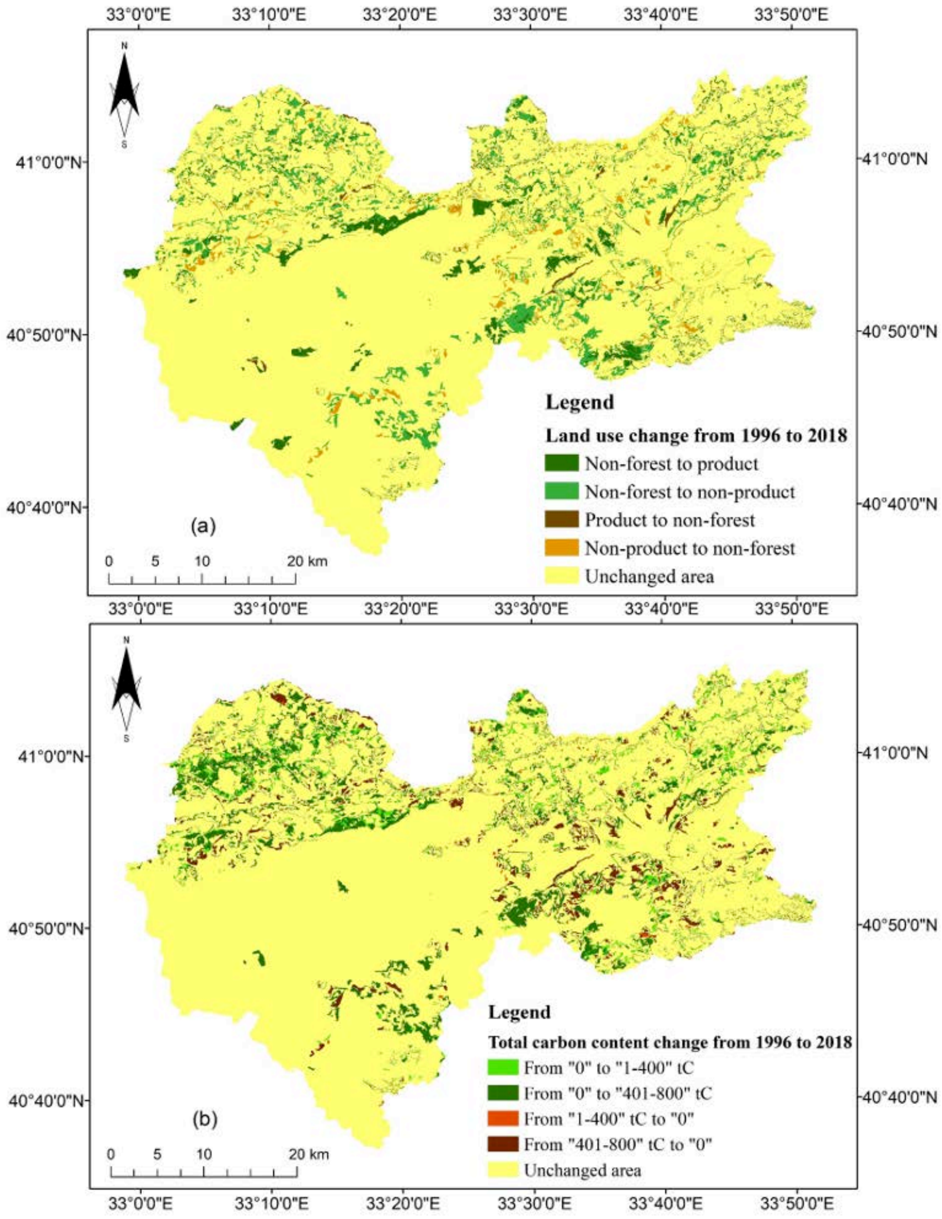

Figure 5: Change of spatial distribution of (a) productive and non-productive forest areas and (b) total carbon stock (tC ha^{-1}) from 1996 to 2018.

Abbildung 5: Veränderung der räumlichen Verteilung (a) produktiver und nicht produktiver Waldflächen und (b) des gesamten Kohlenstoffvorrats (tC ha^{-1}) von 1996 bis 2018.

4 Discussion

As a result of the wood production-oriented management approach in the 1996 planning period, the total and unit area carbon amount accumulated was 7.56 MtC and 113.4 tC ha^{-1}, respectively. In the planning periods of 2009 and 2018, ecosystem-based multiple-use planning had an increasing effect on the carbon amounts stored in the forest stands. The unit area's carbon amount accumulated was 124.9 tC ha^{-1} in 2009 and 125.1 tC ha^{-1} in the 2018 planning period. When the 1996 and 2018 planning periods were compared, 11.7 tC ha^{-1} more carbon was accumulated. Also, a total of 2.66 MtC more carbon was stored in the 2018 planning period. Functional and protection-oriented planning approaches implemented during the 2009-2018 period have positively affected and improved the amount of carbon stock. Especially with thinning implemented in wood production-oriented forest areas, approximately 25-50% of the volume increment can be harvested, while 10-15% is harvested in protection-oriented forest areas envisaged with functional planning system. Assmuth & Tahvonen (2018) reported that it is necessary to postpone thinning and partial cuttings and to increase stand volume throughout the rotation period for optimal carbon storage. Therefore, an increase in the volume, biomass, and carbon amounts stored per unit area has occurred with the extension of the rotation age in the region (Krankina & Harmon 2006; Sartori *et al*. 2024).

The increase in forest areas was effective in the increase in the total carbon amount. While the forest area was 66,673 ha in 1996, it increased to 81,765 ha in 2018. In summary, the forest area increased by 23%, and the total carbon stock increased by 35% from 1996 to 2018 in the study area. The expansion of tree-covered forest areas enhanced the biomass in the area and positively affected the total carbon stock. Similar results were determined in the study of Sivrikaya & Bozali (2012). They evaluated the carbon storage capacity of a planning unit in Türkiye for the years 1991 and 2002, and there was an increase of 12% and 20% in the amount of forest area and stored carbon, respectively. Also, Sivrikaya *et al*. (2013) reported that the increase in the carbon budget of forest ecosystems depends on the growth and development of trees in the understory, the formation of older forests over time, the formation of stands with higher carbon stocks in the forests, and land cover change. When the planning systems and land use classes with our results were examined, it can be stated that increasing stand carbon in the region occurred due to preventing deforestation, protecting and increasing productive forest areas, regenerating forests, and accelerating growth with silvicultural techniques and longer rotation periods (Kline 2006; Kassaye *et al*. 2024).

The development that occurs, especially with the dynamism of the forest cover in different planning periods, is very important. Many of the regions without tree cover in the study area have turned into productive and non-productive forest areas through afforestation and rehabilitation interventions. As a result of this, forest stands with a total carbon content of up to 800 tC have emerged in these areas, which are poor in terms of stored carbon (Figure 4). Martin *et al*. (2012) compared the amount of carbon stored in managed and protected areas in Alabama, USA. They found that the carbon amount of managed area and protected area were 291 and 1758 kg/year/ha, respectively. Keleş *et al*. (2017) analyzed the forest ecosystem functions according to different planning periods in the Black Sea region of Turkey. The 1986 and 2011 planning periods were examined, and it was determined that the forest areas increased by 12%, and the total stored biomass amount increased by 28% in the 25 years. With the changing planning system of forests, forest ecosystem functions have also diversified to undertake different services. As a result of the diversified functions, the silvicultural treatments applied to the stands have also changed. More moderate treatments were implemented, especially in areas of ecological and social-cultural function. Conservation-based interventions applied to the stands provide the accumulation of more living biomass and carbon in the forests. In addition, forest areas increasing with land use change and transformation of non-productive areas into productive forest stands also have an increasing effect on the total biomass and carbon amount (Başkent *et al*. 2008; Başkent & Keleş 2009; Sivrikaya & Bozali 2012; Mumcu Kucuker 2020; Seki & Atar 2021).

There are actions such as Reducing Emissions from Deforestation and Degradation (REDD), Improved Forest Management (IFM), and Afforestation/Reforestation (AR), which are referred to as forest carbon activities that can improve the amount of carbon stored in forests. These actions, which can be employed for strategies at different scales in a single or integrated manner, have the potential to generate quantitative, realistic, and verifiable contributions to forest carbon. REDD reduces or prevents the conversion and degradation of forests to reduce forest carbon emissions. This activity also considers the harvesting of firewood, fire, and logging. IFM is an activity that increases carbon stocks by revising the management planning systems of forests with practices such as extending harvest rotations and promoting the growth of healthy trees. AR is an activity that increases the carbon stocks of forest stands with afforestation or natural regeneration activities (Virgilio & Marshall 2009). The options that can be applied in the forestry sector to reduce carbon emissions are to prevent deforestation, a conservation-oriented planning approach and increase the use of energy derived from biomass instead of fossil fuels (Krankina & Harmon 2006).

In addition to forest management options, the management of even or uneven-aged forests also significantly affects the amount of carbon stored in forest stands. The amount of carbon stored in even-aged forests is higher than in uneven-aged forests (Bragg & Guldin 2010; Moore *et al*. 2012). Nilsen & Strand (2013) found that the amount of carbon stored in even-aged forests is approximately 3 times higher than in uneven-aged forests. The amount of carbon stored in even-aged forests was estimated to be 199-220 Mg/ha, while it was 76 Mg/ha in uneven-aged forests. The most important reason for this is that the annual volume increment in even-aged stands (24.2 m^3) is higher than in uneven-aged stands (11.3 m^3). Bragg & Guldin (2010) found that the change in biomass over time varies between +14.4 and -24.2 tons/ha/year in even-aged stands, while the change amount is 2.2 tons in uneven-aged forests. Since uneven-aged forests are operated as a group or selection method, the area has a continuous cover regime. Thus, uneven-aged forests always contain a large amount of living biomass. Therefore, the carbon accumulation values of uneven-aged forests draw a much more stable graph. Carbon accumulation amounts in even-aged forests are clearly variable. During the rotation period, an increase in biomass occurs. As biomass is removed from the area by thinning and regeneration treatment applied to the stands, there are periodically sharp decreases in amount of biomass. As production decreases after harvest, carbon loss is balanced by new increments and growth (Kellomäki *et al*. 2019).

5 Conclusions

Variations in the amount of forest carbon stocks were determined for the 1996, 2009, and 2018 planning periods. Land use classes and forest planning systems were used to assess the change in the total carbon stock. In forest management planning, which is based on conservation, it has been revealed that living biomass accumulates in forest areas over time, and the total amount of stored carbon increases. Especially in mitigating climate change, which is a global problem, the carbon storage function of forests has gained more importance. It has been determined that the regeneration of forest stands, accelerating growth, development of tree cover in the understory, postponement of partial cuttings, longer rotation periods, establishment of old stands with dense biomass, increasing forest areas, and preventing deforestation are effective in increasing the carbon budget of forest ecosystems. In the forest management plans prepared in this direction, it is recommended that conservation targets be determined with a participatory approach by involving relevant stakeholders and that conservation-oriented forest services be focused on in addition to production. It is recommended that future studies assess forest carbon stocks in various environmental conditions based on planning and land use systems. Diversifying such research can be better understood the effects of changing land use classes and implementing planning systems on amount of forest carbon stocks.

Acknowledgments

The authors express their gratitude to the General Directorate of Forestry for providing the data.

Conflicts of Interest

The authors declare no conflict of interest.

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