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Determination of Total Carbon Storage using Sentinel-2 and Geographic Information Systems in Mixed Forests

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ABSTRACT

In terrestrial ecosystems, forests have great importance in terms of carbon storage. Determination of carbon storage potential of forests is a key parameter for monitoring global climate change and global warming. The aim of this study was to predict the carbon storage of mixed stands (MS) of coniferous and broadleaf by supervised classification generated from Sentinel-2 satellite image and to calculate the total carbon storage (TCS) of the MS using carbon coefficients. The results demonstrated that the TCS values of the MS in the study area varied between 50.52 and 175.32 ton/ha. The TCS values per hectares of the pure coniferous stands, pure broadleaf stands and MS were 173.52, 143.52 and 74.21 ton/ha, respectively. Carbon storage amounts per hectare of MS were found to be low because the tree species included in the mixture decreased the growing stock volume value per hectare. The structure of the MS in the study area played an effective role in obtaining these results. As a result of this study, calculating the carbon amounts of MS with remote sensing techniques will make a contribution to the interpretation of the carbon capacities of different stand structures.

Keywords: Supervised classification, Total carbon storage, Mixed forest, Sentinel-2 satellite image.

Karışık Meşcerelerde Sentinel-2 ve Coğrafi Bilgi Sistemleri Kullanılarak Toplam Karbon Depolamasının Belirlenmesi

ÖZ

Karasal ekosistemlerde, ormanlar karbon depolaması açısından büyük öneme sahiptir. Karbon depolama miktarlarının belirlenmesi, küresel iklim değişikliğinin ve küresel ısınmanın izlenmesi için önemli bir parametredir. Bu çalışmanın amacı, iğne yapraklı ve geniş yapraklı karışık meşcerelerin Sentinel-2 uydu görüntüsü ile gerçekleştirilen kontrollü sınıflandırma ile karbon depolamasını tahmin etmek ve karbon katsayılarını kullanılarak karışık meşcerelerin toplam karbon depolama kapasitelerini hesaplamaktır. Elde edilen sonuçlar, çalışma alanındaki karışık meşcerelerin toplam karbon depolama değerlerinin 50.52 ve 175.32 ton ha^{-1} arasında değiştiğini göstermiştir. Saf iğne yapraklı meşcerelerin, saf geniş yapraklı meşcerelerin ve karışık meşcerelerin hektardaki toplam karbon depolama değerleri sırasıyla 173.52, 143.52 ve 74.21 ton ha^{-1}'dur. Karışıma dahil olan ağaç türlerinin hektardaki hacim değerlerinin düşmesi nedeniyle karışık meşcerelerin hektardaki karbon depolama miktarları daha az bulunmuştur. Ayrıca, çalışma alanındaki karışık meşcerelerin yapısı bu sonuçların elde edilmesinde etkili bir rol oynamıştır. Bu çalışmanın sonucu olarak, karışık meşcerelerin karbon miktarlarının uzaktan algılama verileri ile hesaplanması, farklı meşcere yapılarının karbon kapasitelerinin yorumlanmasına katkıda bulunacaktır.

Anahtar Kelimeler: Kontrollü sınıflandırma, Toplam karbon depolama, Karışık orman, Sentinel-2 uydu görüntüsü.

1. Introduction

As a result of rapid population growth, industrialization and urbanization in the world, demand for natural resources has increased rapidly. Many problems have arisen, such as the destruction of forest ecosystems, climate change, desertification and degradation of biodiversity, in response to

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increasing and increasing demand over time. Global climate change is one of the most important problems facing the world in the last century. As a result of the destruction of forest ecosystem for agriculture and urbanization by opening of new settlements and destroying forests for firewood need, greenhouse gases in the atmosphere and especially CO_2 amount increased (IPCC, 2001). Forest ecosystem is the most important carbon pool in terms of keeping 82.5 % of organic carbon in terrestrial ecosystem (Cusack et al., 2014; Kauranne et al., 2017; Hao et al. 2019). Therefore, the forest ecosystem plays an important role in mitigating negative impact of global warming and maintaining climate stability (Watson et al. 2000). The amount of carbon in a forest ecosystem is determined accurately by ground measurements. However, it is very difficult and time consuming to compute the amount of carbon in wast forest areas with ground measurements (Lu 2007). Country specific coefficients are used to calculate the amount of carbon that the forest are stored in Turkey. These coefficients were determined separately for pure coniferous stands (PCS), pure broadleaf stands (PBS) of productive and degraded forests (Asan,1995; Asan, 1999; Sivrikaya et al., 2007; Yolasığmaz and Keleş, 2009; Tolunay, 2011; Kadıoğulları and Karahalil, 2013; Mısır, 2013; Gonzales et al., 2014; Karahalil et al., 2018). Although the coefficients have been developed for coniferous and deciduous forests, no coefficient has been developed for mixed forests. There have been some studies on the amount of carbon stored ground measurements of mixed stands with Turkey (Durkaya et al., 2012; Kaptan et al., 2019). However, there are not many studies in which remote sensing data for estimating the amount of carbon stored in mixed stands are evaluated together with ground measurements. Remote sensing methods can accurately reflect the distribution characteristics of the amount of carbon stored in forest ecosystems on a regional scale due to real-time, low-cost, continuous and large area data acquisition. Thus, it can improve the accuracy of estimating the amount of carbon stored by the forest ecosystem. In this respect, remote sensing has become a significant tool for predicting carbon storage capacity (Safari et al., 2017; Van et al., 2018). Therefore, remote sensing data has been widely used in conjunction with ground measurements to determine the amount of carbon stored in forest ecosystems (Gonzalez et al., 2010). The aim of this study was to determine coniferous and broadleaf areas in the mixed stands (MS) by supervised classification generated from Sentinel-2 satellite image and to calculate the total carbon stocks (TCS) of the MS using carbon coefficients in Ilgaz Forest Management Enterprise.

2. Material and Methods

2.1. Study area

Ilgaz Forest Management Enterprise, which is selected as a case study area, is located in the Ankara Regional Directorate of Forestry (Figure 1). It is bounded by 498234-572705 on the East longitudes and 4496441-4548108 on the North latitudes (WGS 1984, UTM Zone 36N). The study area is 205169.61 ha. Total of productive forest area is 41527.16 ha. and covers 20% of the study area. The PCS, PBS and MS area are 36118.22, 3235.14 and 2170.80 ha., respectively. PCS and PBS are covered by pure stands of *Pinus nigra* (Çk), *Pinus sylvestris* (Çs), *Abies* (G), *Quercus* (M), *Populus* (Kv), *Fagus* (Kn) and *Carpinus* (Gn). MS in the region consist of Çk-Gn-M, Çk-Kn, Çk-Kv, Çk-M, Çs-Kn-Gn, Çs-Gn, Çs-Kv, Çs-Kn and G-Kv. Forests dominated by broadleaved trees consist of M-Çk, Kv-Çk and Kn-Çs. Elevation ranges from 533 to 2541 m and average slope is 19.92%. Annual mean, minimum and maximum temperatures in the region are 10.6, -25.0 and 42.4 °C, respectively. Annual total mean precipitation is 418.59 mm.

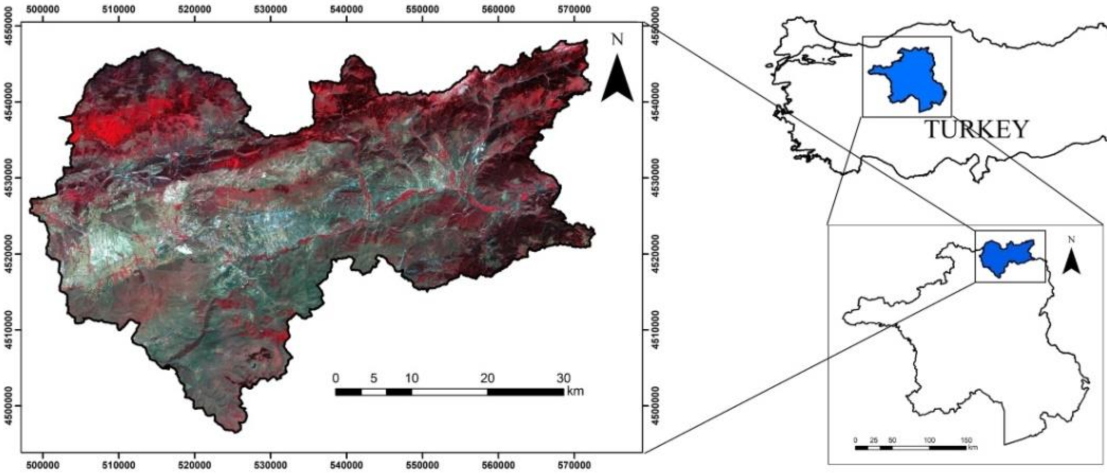

Figure 1. Location of the study area.

2.2. Remote sensed data and processing

The Sentinel-2 satellite image (acquired date 15 June 2018), was freely downloaded from the United States Geological Survey Earth Explorer data portal (USGS, 2000), was used in this study. The four bands of (Band 2, 3, 4 and 8) of Sentinel-2 satellite image with 10 m spatial resolution were used. The atmospheric and geometric corrections were made to make the image ready for analysis. The satellite image was cut according to the outer boundary of the study area.

2.3. Supervised classification

The supervised classification method (maximum likelihood technique) was used in this study. The forest cover type map was used as ground data in supervised classification. Ground data were collected as signatures for Sentinel-2 satellite image. Then, the training signature polygons were equally distributed to coniferous, broadleaf and other area (opened, settlements, agriculture etc.) classes with 15 points. Image processing and classification were carried out using Erdas Imagine (2014). A vector layer for MS was generated from the stand map. Using this layer, MS were extracted from the classified image. As a result of this process, the coniferous and broadleaf areas in MS were determined (Figure 2).

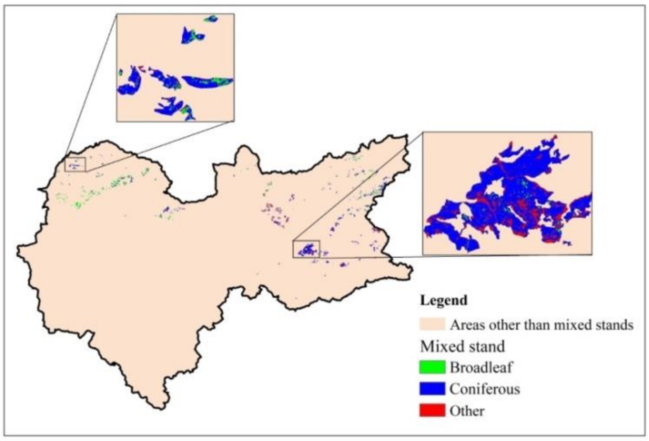

Figure 2. Coniferous and broadleaf areas within the MS.

2.4. Calculation of carbon storage capacity

In order to determine the carbon storage capacity of the forest ecosystem, it is necessary to determine the existing biomass in the forest ecosystems. The most practical and best approach to determine biomass is use of inventory data. First, the growing stock volume (GSV) per hectare of the stands was obtained from forest management plans (Anonymous, 2018). Then biomass (aboveground and belowground) were calculated with conversion coefficient depending on GSV and then the carbon storage capacity was calculated with biomass conversion coefficient (Asan,1995; Asan, 1999; Yolasığmaz and Keleş, 2009; Tolunay, 2011; Sivrikaya and Bozali, 2012; Değermenci and Zengin, 2016; Seki et al., 2017). The forest cover type maps were used to obtain spatial attribute data of PCS, PBS and MS. For this study, GSV data of 8184 PCS, 739 PBS and 481 MS were used. TCS amounts of 9404 stands were calculated by Eq. 1 (Table 1).

Table 1. TCS coefficients (Tolunay, 2011).

Parameter	PCS	PBS
AGB	GSV x 0.446 x 1.212	GSV x 0.541 x 1.310
BGB	AGB x 0.29	AGB x 0.24
AGC	AGB x 0.51	AGB x 0.48
BGC	BGB x 0.51	BGB x 0.48
DWB	AGB x 0.01	AGB x 0.01
DWC	DWB x 0.47	DWB x 0.47
LC	Area (ha) x 7.46	Area (ha) x 3.75
FSC	Area (ha) x 76.56	Area (ha) x 84.82

TCS: total carbon stocks, PCS: pure coniferous stands, PBS: pure broadleaf stands, AGB: above ground biomass, BGB: below ground biomass, AGC: above ground carbon, BGC: below ground carbon, DWB: dead wood biomass, DWC: dead wood carbon, LC: litter carbon and FSC: forest soil carbon.

$$Total\ carbon\ storage = AGC + BGC + DWC + LC + FSC \quad (1)$$

The process steps performed in this study are as follows (Figure 3). Firstly, coniferous and broadleaf areas in the MS were determined by supervised classification. Then, GSV of coniferous and broadleaf areas in each MS was separately obtained from forest management plan. Finally, TCS amounts of MS were calculated through these carbon coefficients.

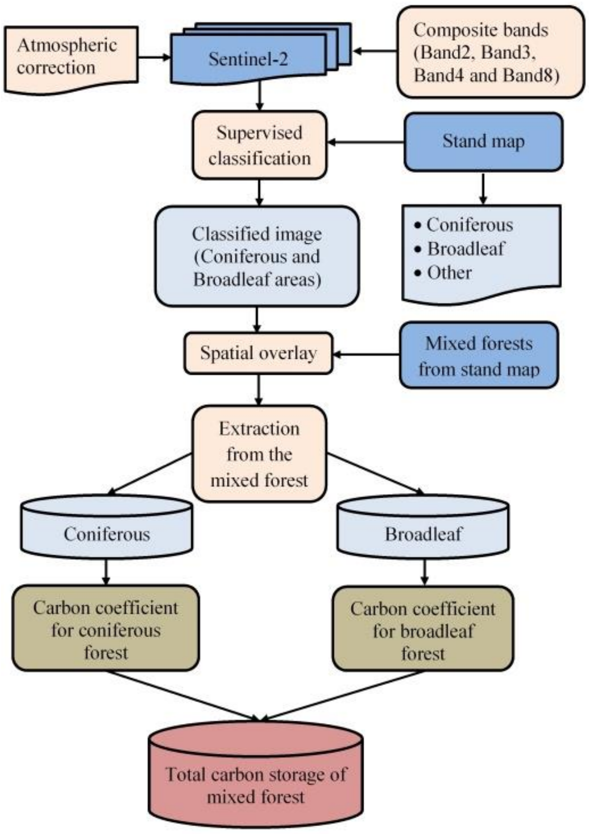

Figure 3. Flowchart for calculation TCS amount of the MS.

3. Results and Discussion

In the first stage of the study, the Sentinel-2 satellite image was classified using maximum likelihood method. Therefore, coniferous, broadleaf and other (opened, settlements, agriculture etc.) areas were successfully mapped. These classes were estimated using supervised classification with a 0.97 kappa statistics value and 98.95% overall accuracy assessment (Table 2).

In the second stage, the TCS capacity of each stand type in the study area was calculated using the stand volume and carbon coefficients (Table 3). TCS for MS was calculated by collecting the amount of coniferous and broadleaf carbon inside MS. In addition, TCS values of PCS and PBS were calculated. Therefore, TCS capacity amounts maps for PCS, PBS and MS were generated by GIS (Figure 4). The TCS amounts of each class were divided by their total area and the mean carbon values per hectare were calculated. The results obtained from this study showed that MS were the least carbon storage amount (74.21 ton/ha). Although the TCS amounts of the PCS and PBS found close to each other, PCS was 30 tons more than PBS per hectare. According to these results, PCS was the capacity to store the highest amount of carbon in the unit area and MS was low carbon storage capacity.

In order to better analyze the relationships between forest types in terms of carbon amounts, TCS amounts were calculated at stand level (Table 4-5). Since the coefficients used in the calculation of carbon depend on the GSV, carbon amounts of stands were directly related to GSV value. The structure and form of MS did not contain as GSV as PCS and PBS in the study area. The cause of these results that GSV of the MS in the study area was low compared to PCS and PBS.

Table 2. Confusion matrix for broadleaf, coniferous and other classes.

Class	Broadleaf	Coniferous	Other	Total
Broadleaf	22898 (97.49%)	286 (0.88%)	99 (0.06%)	23283
Coniferous	369 (1.57%)	31519 (96.51%)	517 (0.31%)	32405
Other	221 (0.94%)	853 (2.61%)	165440 (99.63%)	166514
Total	23488	32658	166056	222202
Overall accuracy		98.95%		
Kappa coefficient		0.97		

Table 3. Descriptive statistics for carbon storage amounts of different forest cover types.

Forest cover type	Min	Max	Mean	S.D.	Variance	C (ton/ha)
PCS	31.28	15830.71	804.12	1235.09	1525441.33	173.52
PBS	49.08	9521.65	1076.78	1554.06	2415100.45	143.52
MS	0.57	3832.87	331.17	496.48	246496.62	74.21

PCS: pure coniferous stands, PBS: pure broadleaf stands, MS: mixed stands.

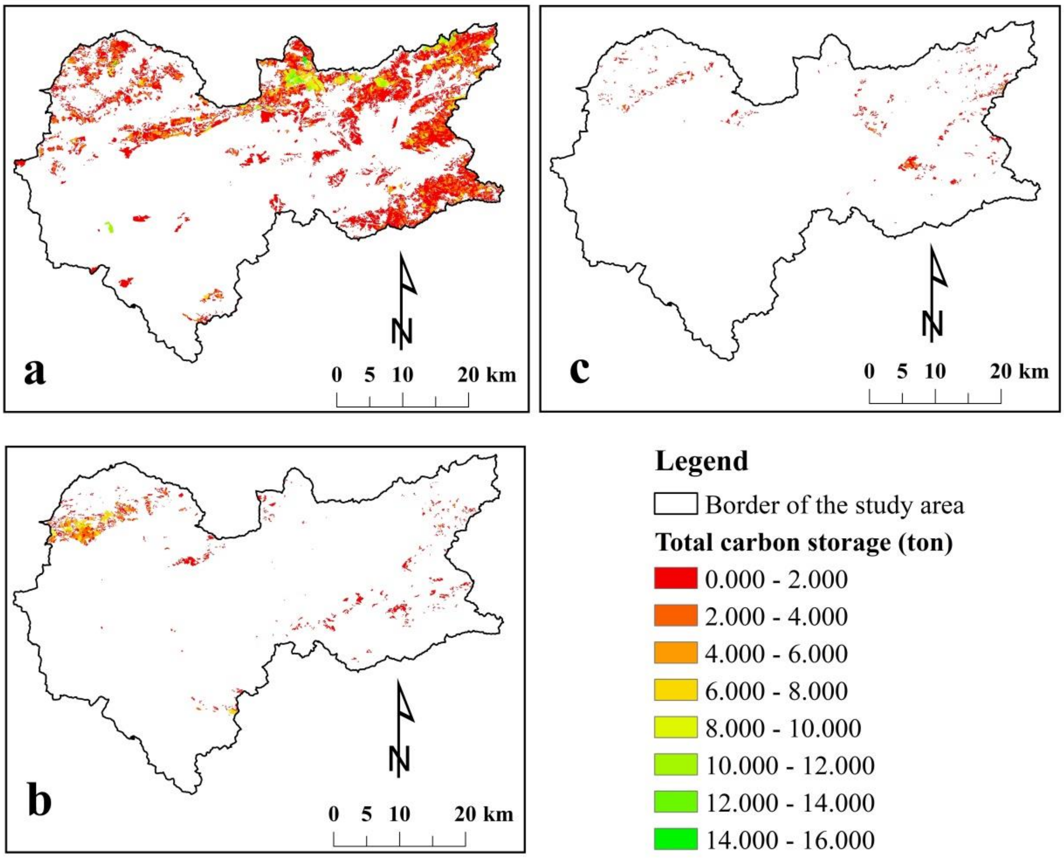

Figure 4. TCS amount maps of the forest cover types a) PCS, b) PBS and c) MS

Table 4. TCS amounts at stand level for PCS.

PCS	Area (ha)	TCS (ton)	TCS (ton/ha)	PCS	Area (ha)	TCS (ton)	TCS (ton/ha)
Çkb1	120.56	11266.88	93.46	ÇsÇkc3	248.44	41795.40	168.23
Çkb2	690.51	70489.15	102.08	ÇsÇkcd1	213.37	27915.93	130.83
Çkb3	818.00	94585.27	115.63	ÇsÇkcd2	368.45	66615.70	180.80
Çkb3Y	3.17	359.74	113.49	ÇsÇkcd3	263.32	58234.35	221.15
Çkbc1	1335.30	134934.96	101.05	ÇsÇkd2	63.45	11204.31	176.59
Çkbc2	1688.65	197154.34	116.75	Çsd/a	2.77	255.45	92.27
Çkbc2Y	6.42	753.51	117.37	Çsd/bc3	21.27	3344.22	157.21
Çkbc3	1216.16	196011.77	161.17	Çsd/Gbc3	32.21	6477.77	201.12
Çkc2	935.83	128611.82	137.43	Çsd1	158.01	22033.15	139.44
Çkc2Y	12.14	1918.13	158.06	Çsd1/a0	83.12	9861.66	118.65
Çkc3	1709.65	319918.32	187.13	Çsd1/ab2	42.60	6646.16	156.02
Çkcd1	2039.20	277093.91	135.88	Çsd1/Gbc2	57.58	11462.30	199.06
Çkcd1/a	12.03	1750.71	145.55	Çsd1/Gbc3	89.61	22798.37	254.41
Çkcd2	3142.50	532194.80	169.35	Çsd2	602.74	140659.64	233.37
Çkcd3	2052.42	485086.41	236.35	Çsd2/Gbc3	135.15	34946.60	258.58
ÇkÇsbc2	128.97	16831.36	130.51	Çsd3	61.55	14878.98	241.72
ÇkÇsbc3	16.09	2436.56	151.46	Çse1	58.11	8954.14	154.09
ÇkÇsc2	74.52	10766.61	144.48	ÇsGbc3	53.90	8856.07	164.31
ÇkÇsc3	148.39	24655.51	166.16	ÇsGc3	76.93	14759.85	191.85
ÇkÇscd2	511.88	96897.47	189.30	ÇsGcd1	212.02	29950.15	141.26
ÇkÇscd3	457.73	96467.97	210.75	ÇsGcd2	586.31	104411.49	178.08
ÇkÇsd1	202.93	27885.79	137.42	ÇsGcd3	987.80	192055.30	194.43
ÇkÇsd2	112.41	19707.88	175.32	ÇsGd2	60.91	14751.93	242.19
ÇkÇzbc2	172.45	20404.95	118.32	ÇsGd3	36.77	10193.26	277.20
ÇkÇzbc2-T	16.33	1931.67	118.32	Çzbc2	164.04	17331.06	105.65
Çkd/a0	66.61	6569.05	98.62	Çzcd1	36.51	4274.53	117.08
Çkd1	375.58	52171.75	138.91	Gbc2	172.59	20399.46	118.20
Çkd1/a	56.50	7848.94	138.91	Gbc3	105.74	18269.70	172.79
Çkd1/a0	25.63	3560.54	138.91	Gc2	33.99	6247.19	183.77
Çkd1/bc2	233.27	35921.18	153.99	Gc3	242.08	52754.10	217.92
Çkd2	779.14	160068.14	205.44	Gcd1	213.31	28598.41	134.07
Çkd3	440.72	110833.78	251.49	Gcd2	418.51	74706.41	178.51
ÇkGcd2	18.20	3461.07	190.16	Gcd3	591.26	142459.87	240.94
ÇkGcd3	79.85	17087.06	214.00	GÇsbc3	88.25	13833.97	156.75
Çsab3	8.31	853.06	102.66	GÇsc2	56.64	8924.85	157.58
Çsb2	483.18	52649.19	108.96	GÇsc3	177.94	31342.36	176.14
Çsb3	205.03	23703.32	115.61	GÇscd2	313.54	65601.05	209.23
Çsbc1	178.12	19205.49	107.82	GÇscd3	874.83	203342.02	232.43
Çsbc2	308.33	36896.97	119.67	GÇsd3	27.50	8875.39	322.71
Çsbc3	241.06	32922.16	136.57	Gd2	31.88	7497.14	235.20
Çsc2	187.22	27871.50	148.87	Gd3	52.63	18539.41	352.29
Çsc3	308.14	51181.87	166.10	GA	801.05	204622.13	255.44
Çscd1	829.54	101659.47	122.55	GC	699.18	152854.54	218.62
Çscd1/a0	20.90	2730.55	130.62	GÇkA	15.64	3086.29	197.37
Çscd2	1489.50	268558.28	180.30	GÇsA	399.78	93516.85	233.92
Çscd3	823.46	171859.23	208.70	GÇsC	280.22	50665.53	180.81
ÇsÇkb3	131.25	15469.45	117.86	GÇsD	174.77	49331.83	282.26
ÇsÇkbc3	56.10	8684.03	154.79	GD	538.05	127833.78	237.59
ÇsÇkc2	122.01	17476.12	143.24	Total	36118.22	6267327.76	173.52

[1]PCS: pure coniferous stands, PBS: pure broadleaf stands, MS: mixed stands

[2]In table 4, crown closure was classified into three classes; 1 (low coverage of 11-40%), 2 (medium coverage of 41-70%) and 3 (full coverage of 71-100%). The development stage was classified into four classes; a (regenerated area, average dbh <8 cm); b (immature area, average dbh 8-19.9 cm); c (mature area, average dbh 20-35.9 cm) and d (over mature, average dbh 36-51.9 cm).

[3]Çk: Black pine, Çs: Scots pine, G:Fir, Çz: Red pine, 1.2.3: Crown closure classes, a. b. c. d: Development stages, Y: Fire, T: Stony and rocky, Çsc2: Scots pine stand, mature development stage (20-35.9 cm), medium coverage. (41-70%).

Table 5. TCS amounts at stand level for PBS and MS.

MS	Area (ha)	TCS (ton)	TCS (ton/ha)	PBS	Area (ha)	TCS (ton)	TCS (ton/ha)
Çkbc2/GnMcra3	22.95	1791.76	78.09	GnKnab3	116.18	14792.63	127.33
Çkc2/GnMza3	37.81	3807.46	100.71	Knab3	258.55	27519.29	106.44
Çkcd1/GnMza3	20.94	1655.31	79.04	Knb2	40.09	4626.22	115.41
Çkcd1/Kna3	12.04	759.63	63.11	Knb3	611.20	82323.99	134.69
Çkcd1/KnGnab3	34.36	6023.45	175.32	Knbc2	194.05	26044.07	134.21
Çkcd1/MzGna	14.93	2415.09	161.73	Knbc3	1034.98	165971.92	160.36
ÇkKvbc3	17.47	1753.81	100.40	Knc2	58.97	9425.64	159.83
ÇkMmb2	51.39	5357.16	104.25	Knc3	79.67	14414.64	180.93
ÇkMmb2	299.01	15106.24	50.52	Kncd3	81.23	17285.50	212.81
ÇkMmbc2	41.58	3158.21	75.95	KnGnab3	70.82	7644.00	107.94
ÇkMzbc2	221.79	11759.16	53.02	KnGnbc3	35.75	6527.24	182.57
Çscd1/Knab3	14.52	768.81	52.94	Kvbc3	212.41	30140.06	141.90
Çscd2/Gnab3	20.06	2357.70	117.51	Kvc3	77.39	14156.20	182.91
Çsd/Knb3	28.21	3832.87	135.88	Mzb2	57.35	5956.54	103.86
Çsd2/KnGna	18.98	2970.50	156.54	MzGnab3	189.96	19152.86	100.83
ÇsKnbc3	83.72	5487.25	65.55	MzGnb3	50.33	8296.93	164.85
ÇsKncd2	62.38	6210.95	99.57	MzGnbc2	44.33	7126.08	160.76
ÇsKvbc2	28.57	2471.83	86.52	MzMcrbc2	21.87	2892.02	132.21
ÇsKvbc3	53.13	6187.06	116.45	Total	3235.14	464295.84	143.52
ÇsKvc3	50.43	6008.91	119.15				
GKvc3	27.26	1593.64	58.46				
KnÇsbc2	90.87	7997.88	88.02				
KnÇsbc3	38.53	2536.46	65.84				
KvÇkbc3	291.04	24542.26	84.33				
MmÇkab2	588.85	34549.63	58.67				
Total	2170.80	161103.02	74.21				

[1]PCS: pure coniferous stands, PBS: pure broadleaf stands, MS: mixed stands

[2]In table 5, crown closure was classified into three classes; 1 (low coverage of 11-40%), 2 (medium coverage of 41-70%) and 3 (full coverage of 71-100%). The development stage was classified into four classes; a (regenerated area, average dbh <8 cm); b (immature area, average dbh 8-19.9 cm); c (mature area, average dbh 20-35.9 cm) and d (over mature, average dbh 36-51.9 cm).

[3]Çk: Black pine, Çs: Scots pine, Gn: Hornbeam, Kn: Beech, Kv: Poplar, Mz: Sessile oak, Mcr: Hungarian oak, Mm: Gall oak, 1.2.3: Crown closure classes, a. b. c. d: Development stages, ÇkMzbc2: Black pine-Sessile oak mixed stand, mature development stage (8-35.9 cm), medium coverage. (41-70%).

Walle et al. (2001) compared the mixed broadleaved stands in terms of carbon pools. TCS values were calculated 324.8 (ton/ ha) in the oak (*Quercus robur* L.)-beech (*Fagus sylvatica* L.) stand and 321.4 (ton/ha) in the ash (*Fraxinus excelsior* L.) stand. Lee et al. (2009) estimated carbon content in pure and MS of pine (*Pinus densiflora*) and oak (*Quercus* spp.) species. Total carbon contents of the pine, oak and MS were 199.6, 192.5 and 169.1 (Mg C/ha^{-1}), respectively. In natural forests, mixed stands had low carbon retention than pure stands. The results obtained from these studies were consistent with our results. However, the findings of studies in plantation areas were not consistent with these results.

Redondo-Brenes and Montagnini (2006) estimated the TCS amounts of pure and mixed plantations in 3 different areas. Carbon content values were 47.7-55.3 (Mg C/ha^{-1}) for pure-mixed in first plantation, 66.2-90.8 (Mg C/ha^{-1}) for pure-mixed in second plantation and 35.8-47.3 (Mg C/ha^{-1}) for pure-mixed in third plantation. Wang et al. (2013) assessed carbon storage of coniferous, broadleaved and mixed plantation areas. Carbon storage values were 71.0, 73.3 and 83.7 (ton/ha) for the coniferous, broadleaved and mixed plantation, respectively. It was clear from these results that the natural structure of MS has certain effects on the amount of carbon stored. While the MS in plantation areas yields higher amounts of carbon storage than pure stands, the MS store lower levels of carbon storage in natural forests.

In some studies, it was seen that mixed plantation areas showed better development than pure plantation areas (Piotto et al., 2003; Alice et al., 2004). As a result of this, MS in plantation areas accumulates more aboveground biomass and carbon compared to pure plantation areas (Montagnini and Porras, 1998; Kanowski and Catterall, 2010). Redondo-Brenes and Montagnini (2006) reported that the MS in plantation areas demonstrated higher diameter values, better site conditions, nutrition of trees and less insect damage, biomass and carbon sequestration than pure plantation areas. Especially in plantation areas, MS improve the carbon stocks in soil and litter (He et al. 2013). This enhancing effect contributed to the increase of total carbon in MS. Various studies indicated that MS in plantation areas was likely to generate more fertility and improve soil properties (Forrester et al. 2006; Wang et al., 2009; Richards et al. 2010). Stand types, composition of species and site characteristics greatly affect carbon stored in forest ecosystems (Zhou et al., 2000). Owing to limited studies on natural MS, evaluating the success of MS was especially hard with regards to biomass production and carbon stock.

4. Conclusions

The carbon storage capacities of MS were determined in this study. Sentinel-2 satellite image was used to obtain coniferous and broadleaf areas in MS. This process was successfully performed using supervised classification technique (Kappa coefficient = 0.97). When the results obtained are evaluated, the TCS values of the MS in the study area vary between 50.52 and 175.32 ton/ha. Since the spatial resolution of the satellite image used in the study is not very high, it can cause errors in determining the areas of the tree species in the MS. This may affect the value of the total amount of carbon calculated for MS. Because, if the mixture is based on the individual trees and not in groups or clumps, it will hard to distinguish the softwoods or hardwoods especially stands at the development stage “a” or “b”. The structure of the mixture will not effectively have determined, due to the minimum mapping unit of 100 m^2. Therefore, the use of high resolution satellite images with different classification techniques in future studies will increase the success results. In addition, this study should be expanded for different regions, natural and plantation forest areas help to interpret the carbon amounts of MS. Also, we need to observe and assign the long-term changes stand structure, biomass generation and carbon storage in forest areas.

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References

Alice, F., Montagnini, F., Montero, M., 2004. Productividad en plantaciones puras y mixtas de especies forestales nativas en La Estacio´n Biolo´gica La Selva, Sarapiquı´, Costa Rica. Agron. Costarricense 28 (2), 61–71.

Anonymous, 2018. Ilgaz Forest Enterprise, forest management plan, Turkish General Directorate of Forestry, Ankara.

Asan, Ü.,1995. Global İklim Değişimi ve Türkiye Ormanlarında Karbon Birikimi.İstanbul Üniversitesi,Orman Fakültesi Dergisi, 45(1-2):23-37.

Asan, Ü., 1999. Climate Change, Carbon Sinks and The Forests of Turkey. Proceedings of the International Conferenceon Tropical Forests and Climate Change:Status, Issues and Challenges(TFCC ’98),Phillippines,pp.157-170.

Cusack, D. F., Axsen, J., Shwom, R., Hartzell-Nichols, L., White, S., and Mackey, K. R., 2014. An interdisciplinary assessment of climate engineering strategies. Front. Ecol. Environ. 12, 280–287.doi: 10.1890/130030

Değermenci, A.S. and Zengin, H., 2016. Ormanlardaki karbon birikiminin konumsal ve zamansal değişiminin incelenmesi: Daday planlama birimi örneği. Artvin Çoruh Üniversitesi, Orman Fakültesi Dergisi, e-ISSN: 2146-698X, 17 (2):177-187.

Durkaya, B., Durkaya, A. and Macaroğlu, K., 2012. Bartın yöresi karışık meşcerelerinin biyokütle stok değişimlerinin irdelenmesi. Bartin Orman Fakültesi Dergisi, 14(21), 28-36.

Forrester, D.I., Bauhus, J. and Cowie, A.L., 2006. Carbon allocation in a mixed-species plantation of Eucalyptus globulus and Acacia mearniss. For Ecol Manag 233:275–284.

Gonzalez, P., Asner, G.P.,Battles, J.J., Kefsky, M.A., Waring, K.M. and Palace, M. 2010. Forest carbon densities and uncertainties from Lidar, QuickBird and fielde measurements in California . Remote Sens. Environ. 114, 1561-1575.

Gonzales, P., Kroll, B. and Vargas, C.R. 2014. Tropical rainforest biodiversity and aboveground carbon changes and uncertainties in the Selva Central, Peru, Forest Ecology and Management, Vol. 312, No. 15, pp.78–91.

Hao, H., Li, W., Zhao, X., Chang Q. and Zhao, P. 2019. Estimating the Aboveground Carbon Density of Coniferous Forests by Combining Airborne LiDAR and Allometry Models at Plot Level. Frontiers in Plant Science, 10.

Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K. and Johnson C.A. 2001. Climate Change 2001, The Scientific Basis, Contribution of working group 1 to the Third Assessment Report of the IPCC, Cambridge University press, Cambridge.

He, Y., Qin, L., Li, Z., Liang, X., Shao, M. and Tan, L. 2013. Carbon storage capacity of monoculture and mixed-species plantations in subtropical China. Forest Ecology and Management, 295, 193-198.

Kadıoğulları, A.İ. and Karahalil, U., 2013. Spatiotemporal change of carbon storage in forest biomass: a case study in Köprülü Canyon National Park, Kastamonu Üniversitesi Orman Fakültesi Dergisi, 13 (1): 1-14.

Kaptan, S., Aksoy, H. and Durkaya, B. 2019. Akgöl Orman İşletme Şefliği ormanlarının biyokütle ve karbon stok değişimlerinin incelenmesi. 8th International Vocational Schools Symposium.

Kanowski, J., Catterall, C.P., 2010. Carbon stocks in above-ground biomass of monoculture plantations, mixed species plantations and environmental restoration plantings in north-east Australia. Ecol. Manage. Restor. 11 (2), 119–126.

Karahalil, U., Başkent, E.Z. and Bulut, S. 2018. The effects of spatiotemporal changes on forest carbon storage: A case study in Çaykara, Turkey. International Journal of Global Warming, 14(2), 207-223, doi: 10.1504/IJGW.2018.10006060.

Kauranne, T., Joshi, A., Gautam, B., Manandhar, U., Nepal, S., Peuhkurinen, J., et al. 2017. LiDAR-assisted multi-source program (LAMP) for measuring above ground biomass and forest carbon. Remote Sens. 9:154.doi: 10.3390/Rs9020154

Lee, S. K., Son, Y. H., Noh, N. J., Heo, S. J., Yoon, T. K., Lee, A. R., ... & Lee, W. K. 2009. Carbon storage of natural pine and oak pure and mixed forests in Hoengseong, Kangwon. Journal of Korean Forestry Society.

Lu D. 2007. The potential and challenge of remote sensing-based biomass estimation. Int J Remote Sens. 27:1297–1328.

Mısır, M. (2013) 'Changes in forest biomass carbon stock in northern Turkey between 1973 and 2006', Environmental Monitoring and Assessment, Vol. 185, No. 10, pp.8343–8354.

Mitchard, E. T. a, Feldpausch, T. R., Brienen, R. J. W., LopezGonzalez, G., Monteagudo, A., Baker, T. R. 2014. Markedly Divergent Estimates Of Amazon Forest Carbon Density From Ground Plots And Satellites. Glob. Ecol. Biogeogr. 23(8): 935-946.

Montagnini, F. and Porras, C., 1998. Evaluating the role of plantations as carbon sinks: an example of an integrative approach from the humid tropics. Environ. Manage. 22 (3), 459–470.

Piotto, D., Montagnini, F., Ugalde, L. and Kanninen, M., 2003. Growth and effects of thinning of mixed and pure plantations with native trees in humid tropical Costa Rica. For. Ecol. Manage. 177, 427–439.

Redondo-Brenes, A., and Montagnini, F. 2006. Growth, productivity, aboveground biomass, and carbon sequestration of pure and mixed native tree plantations in the Caribbean lowlands of Costa Rica. Forest Ecology and Management, 232(1-3), 168-178.

Richards, A.E., Forrester, D.I., Bahuhs, J. and Scherer-Lorenzen, M. 2010. The influence of mixed tree plantations on the nutrition of individual species: a review. Tree Physiol 30:1192–1208.

Safari, A., Sohrabi, H., Powell, S. and Shataee, S. 2017. A comparative assessment of multi-temporal Landsat 8 and machine learning algorithms for estimating aboveground carbon stock in coppice oak forests. Int. J. Remote Sens., 38, 6407–6432.

Seki, M., Sakıcı, O.E., Büyükterzi, M. ve Sağlam, F., 2017. Taşköprü Orman İşletme Müdürlüğü ormanlarında karbon stoğunun zamansal değişimi, Uluslararası Taşköprü Pompeiopolis Bilim Kültür Sanat Araştırmaları Sempozyumu, 10-12 Nisan 2017, Taşköprü.

Sivrikaya, F. ve Bozali, N., 2012. Karbon depolama kapasitesinin belirlenmesi: Türkoğlu planlama birimi örneği, Bartın Orman Fakültesi Dergisi, 14: 69-76.

Sivrikaya, F., Keleş, S. and Çakır, G., 2007. Spatial distribution and temporal change of carbon storage in timber biomass of two different forest management units, Environmental Monitoring and Assessment, 132:429-438.

Tolunay, D., 2011. Total carbon stocks and carbon accumulation in living tree biomass in forest ecosystems of Turkey. Turkish J. Agric. For. 35, 265-279.

Van, G.N., Shi, Z., van Groenigen, K.J., Osenberg, C.W., Andresen, L.C., Dukes, J.S., Hovenden, M.J., Luo, Y., Michelsen, A. and Pendall, E. 2018. Predicting soil carbon loss with warming. Nature, 554, E4–E5.

Walle, I. V., Mussche, S., Samson, R., Lust, N., and Lemeur, R., 2001. The above-belowground carbon pools of two mixed deciduous forest stands located in East-Flanders (Belgium). Annals of Forest Science, 58(5), 507-517.

Wang, Q., Wang, S. and Zhang, J., 2009. Assessing the effects of vegetation types on carbon storage fifteen years after reforestation on a Chinese fir site. For Ecol Manag 258:1437–1441.

Wang, Q. K., Wang, S. L., and Zhong, M. C., 2013. Ecosystem carbon storage and soil organic carbon stability in pure and mixed stands of Cunninghamia lanceolata and Michelia macclurei. Plant and soil, 370(1-2), 295-304.

Watson, R., Noble, I., Bolin, B. et al. 2000. Summary for policymakers: land-use, land-use change and forestry. In: A special report of the Intergovernmental Panel on Climate Change.Cambridge University Press.

Yolasığmaz, H.A. and Keleş, S. 2009. Changes in carbon storage and oxygen production in forest timber biomass of Balcı Forest Management Unit in Turkey between 1984 and 2006, African Journal of Biotechnology, 8 (19): 4872-4883.

Zhou, Y., Yu, Z., Zhao, S., 2000. Carbon storage and budget of major Chinese forest types. Acta Phytoecol. Sinica 24 (5), 518–522.