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Spatiotemporal Change of Carbon Storage in Forest Biomass: A case Study in Köprülü Canyon National Park

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Abstract

Forest ecosystems, especially protected forest areas play a key role in climate change mitigation. With the declaring Köprülü Canyon as a National Park (NP) since 1973, this region has likely become an important carbon (C) sink. To quantify this potential, understand its implication to the national C budget, comprehend the forest dynamics and evaluate these issues in future park planning, we estimated the changes in forest biomass C storage between 1965 and 2008. Based on the two periods of forest inventory, we used Biomass Expansion Factors (BEFs) to estimate the forest biomass C pool.

The quantitative evidences presented here showed that there were drastic changes in C stock in above and below ground forest ecosystem increased nearly by 46% from one period to the other due mainly to the increase of growing stock and quality of forest ecosystem structure. Köprülü Canyon NP has accumulated 3.21 Tg C increasing from 3.56 Tg C in 1965 to 1.98 in 2008, at a rate of 0.28 Gg C yr^{-1} ha^{-1} between two periods. These certain C stock changes are also reflection of forest dynamics resulting in compatible with temporal changes with a net increase of 530.0 ha (1.84%) of forested areas or stands. On the other hand, such rate of increase in C was not influenced negatively by total number of patches increased from 238 to 672 almost tripled, and the mean patch size of the land cover/land use classes dropped markedly from 1615.0 ha to 425.3 ha. in the same period. In conclusion, landscape dynamics and effects of land use/land cover changes on the amount of C storage are necessary for national park planning.

Keywords: Carbon storage, Land use/Land cover change, GIS, landscape metrics, Forest dynamics.

Orman Biyokütlesindeki Karbon Miktarının Zamansal ve Konumsal Değişimi: Köprülü Kanyon Milli Parkı Örneği

Özet

Orman ekosistemleri, özellikle de korunan alanlar iklim değişiminde çok önemli role sahiptir. Köprülü Kanyon'un 1973 yılında Milli Park (MP) olarak ilan edilmesiyle, bu bölge önemli bir karbon (C) havuzu haline gelmiştir. Bu potansiyeli ortaya koyabilmek, milli C bütçesine katkısını tespit etmek, orman dinamiğini kavrayabilmek ve bu konuları gelecekteki park planlamalarında değerlendirebilmek amacıyla, orman biyokütlesindeki 1965 ile 2008 yılları arasında meydana gelen C depolama miktarı tahmin edilmeye çalışılmıştır. İki periyot için yapılan orman envanterine bağlı olarak, orman biyokütle C havuzunu tahmin edebilmek amacıyla Biyokütle Çevrim Faktörü (BEF) kullanılmıştır.

Elde edilen bulgular toprak altı ve toprak üstü C depolama miktarında, temelde orman ekosistemindeki hacim ve gelişim çağlarında meydana gelen iyileşmeye bağlı olarak bir periyottan diğerine, toprak üstü tutulan karbon miktarında olduğu gibi % 46'ya varan belirgin değişimin olduğunu ortaya koymaktadır. Köprülü Kanyon MP'da 1965 yılında 3.21 Tg C olan karbon depolama miktarı, iki periyot arasında yıllık 0.28 Mg C yr^{-1} ha^{-1} artışla 2008 yılında 3.56 Tg C'a artmıştır. Bu belirgin değişim, aynı zamanda orman alanlarındaki 530.0 ha. (1.84%) artış nedeniyle orman dinamiğindeki değişimin bir yansımasıdır. Diğer taraftan, C depolama miktarındaki bu orandaki değişim, aynı dönemde toplam parça sayısının 238'den 672'e neredeyse üç katına çıkmasına ve ortalama parça büyüklüğünün 1615.0 ha'dan 425.3 ha'a belirgin olarak düşmesine karşın, olumsuz olarak etkilenmemiştir. Sonuç olarak, milli parkların planlanmasında, C depolama miktarı üzerinde önemli derecede etkili olan orman dinamiği ve arazi kullanım/arazi örtüsü değişiminin incelenmesi gerekli olmaktadır.

Anahtar Kelimeler: Karbon depolama, Arazi kullanımı/Arazi örtüsü değişimi, CBS, Konumsal indeksler, Orman dinamiği.

Introduction

The accumulation of CO_2 in the atmosphere due to fossil fuel use, deforestation and other anthropogenic sources is changing the global climate (Harries et al., 2001; IPCC, 2001). Forests play an important role in regional and global C cycles because they store large quantities of C in vegetation and soil and exchange large quantities of C with the atmosphere through photosynthesis and respiration (Cannell et al., 1992; Dixon et al., 1994). The net flux between the forests and the atmosphere is estimated nearly 0.7 GtC/yr (Foley and Ramankutty, 2004). On the other hand, forests could be sources of atmospheric C when they are disturbed by human and natural disturbances (Brown et al., 1996; Brown et al., 1999; Brown and Schroeder, 1999). 20-30% of the total emissions initiates from land use sector, including forestry and agriculture.

In an effort to overcome above challenging task, the world public opinion tried to develop some mechanisms such as Kyoto Protocol aimed at fighting global warming by achieving stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In meeting GHG reduction targets, these precautions recognize the use and management of forests for C sinks.

Detailed forest ecosystem C budgets are helpful for improving our understanding of terrestrial C cycle and for supporting the decision making process (Liu et al., 2006). Forest inventory data are the most practical and best approaches for estimating forest biomass and C pool on a national or regional scale because these data are generally collected at a landscape scale from population of interest, the regional forest resource, and are designed to be statistically valid (Brown and Lugo, 1992; Schroeder et al., 1997; Brown et al., 1999; Brown, 2002). Researchers use different methods such as individual under and below ground models (Mohren, 1987; Dewar, 1991; Mery and Kanninen, 1999; White et al., 2000; Laclau, 2003; Masera et al., 2003; Yavuz et al., 2010) or Biomass Expansion Factors (BEFs) (Dewar and Cannell, 1992; Kilbride et al., 1999; Fukuda et al., 2003; Penman et al., 2003; Tobin and Nieuwenhuis, 2007) to estimate the C stock of forest ecosystems. BEFs are generally based on a combination of measurements for broad species groups or specific species in different countries. The use of these BEFs is foreseen by the IPCC guidelines (Houghton et al., 2001; Van Camp et al., 2004). Besides C budgets, the topic of land use/land cover and carbon storage change has been very important in local and global scales over the last two decades. This is because changes in forest cover have had important effects on biodiversity, soil conservation, water quantity and quality, and especially world climate (Iida and Nakashizuka, 1995; Johnson et al., 1997; Chen et al., 2001; Dupouey et al., 2002; Upadhyay et al., 2007; Liu et al., 2006). Landscape-based metrics is another widely used tool to assess landscape condition and monitor status and trends over a specified time interval (Jones et al., 1997; Kadıoğulları and Başkent, 2008). Protected areas which are by definition designated with the primary aim of conserving biodiversity, generally constitute legal restrictions on land use change and potentially play an important role in maintaining terrestrial carbon srocks .It has been estimated that globally, ecosystems within protected areas store over 312 Gt carbon or 15% of the terrestrial carbon stock (Campbell et al., 2008). Land cover composition and changes are major topics in protected area management because understanding the historical dynamics of forest ecosystems including ecosystem structure and function provides a vital role in sustainable use and effective design and planning of protected areas (Cannell et al., 1992; Dixon et al., 1994). Current understanding of the global carbon cycle suggests that managing protected areas to increase the sequestration of GHG provide credible policy options (Dixon and Turner, 1991; Winjum et al., 1993, Brown et al., 1996). Thus, managers of parks, ecological reserves, recreation and conservation areas and other protected areas may have a role to play in reducing the GHG emissions.

As a country located in the Mediterranean Basin, Turkey is one of the country's most vulnerable to climate change effects. Large areas of forest in the Mediterranean region have suffered tremendous degradation and habitat loss by human activities such as fire, logging, overgrazing, conversion to agriculture and urbanization, and introduction and spread of exotic species (Evrendilek and Doygun, 2000). Interaction of these human-induced disturbances and inherent climatic constraints like long summer drought renders sequestration in or release from Mediterranean forest ecosystems of C especially responsive to changes in land-uses and cover, management practices, atmospheric composition, and water and nutrient availability. While protected areas generally reduce deforestation relative to unprotected areas, they do not entirely eliminate land use change within them (Clark et al., 2008; Karahalil et al., 2009). Therefore, the contribution of protected areas in the Mediterranean forest ecosystems to the global C cycle has received scant attention in the past. Thus, it is necessary to quantify the role of Mediterranean forest ecosystems especially protected areas, which are among the most heavily utilized by man and for the longest periods of time, in the global C budget.

On the other hand, carbon change studies for Turkish forest ecosystems have not provided a wide variety of information so far except for some studies (Yolasığmaz, 2004; Evrendilek et al., 2006; Keleş and Başkent, 2007; Keleş et al., 2007; Başkent et al., 2008; Asan, 2009; Görücü and Eker 2009; Tolunay, 2011; Keleş et al., 2012; Sivrikaya and Bozali, 2012) Furthermore, there is no recorded studies for protected areas other than Asan et al. (2002) and Sivrikaya et al. (2007).

The objective of our study was to quantify C budget of Köprülü Canyon NP (National Park) one of the protected areas located in the Mediterranean conifer forests that has not been studied in detail, by producing temporally and spatially applying biomass expansion factors to forest inventory data between 1965 and 2008. Total above and belowground carbon densities of the forest ecosystem in two periods were evaluated in the context of growing stocks and forest canopy as well as land use changes in the study area.

Study area

The study area is the Köprülü Canyon NP surrounding the city of Antalya and Isparta located in the southern Mediterranean Region of Turkey (324500-343000 E and 4143000-4110000 N, UTM ED 50 datum Zone 36N) (Figure 1).

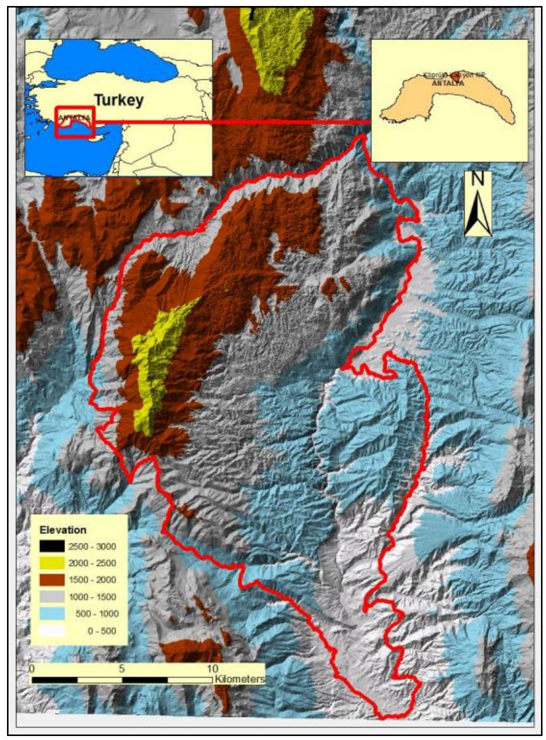

Figure 1. Location of the Köprülü Canyon national park

Köprülü Canyon NP is characterized by dominantly steep and rough terrain conditions with an average slope of 55.7% and an altitude from 200 to 2500 m above sea level with a total area of 35452.8 ha. The vegetation type of the study area is primarily composed of the association of Calabrian pine (*Pinus brutia (L) Link*), Anatolian Black pine (*Pinus nigra* subsp. *pallasiana*), juniper (*Juniperus sub.*), Lebanon cedar (*Cedrus libani*), Graveyard cypress (*Cupressus sempervirens var. horizontalis*), Syrian fir (*Abies cilicica*) and oak (*Quercus sub.*) species (Table 1).

Köprülü Canyon forests, typical Mediterranean ecosystems, provide many goods and services to public, such as water, soil protection, carbon sequestration, recreation, and especially the biodiversity. Thus, changes in carbon stock, may have important consequences for all forest functions. The Park has outstanding landscape features such as the typical forest stands of Mediterranean region as unequal and valuable forest stands, habitats for wildlife, valuable sites for culture, interesting phenomena of geomorphology, springs of the Köprüçay River, habitat of wild goats and water fauna. Because of these outstanding features "General Directorate of Nature Conservation and National Parks" of Turkey declared Köprülü Canyon as a NP in 1973 as 15th national park of Turkey (URL1, 2011).

Data and Methods

Carbon storage estimation through forest biomass

Forest biomass is the basic variable in the estimation of the amounts of carbon stored by the forest ecosystems. Biomass expansion factors and conversion factors provide a robust and simple method of converting from forest tree stem volume to total forest biomass. These factors generally constructed on the basis of nationally specific data in order to take account of regional differences in growth rates, management practices, etc. Generically, BEFs describe multiplication factors which are used to expand growing stock or growing stock biomass to account for non-merchantable biomass components (needles, branches, lop and top, bark, stump, roots, etc.) (Milne et al, 1998; Kilbride et al., 1999; Schoene, 2002). Or more practically, when used in conjunction with conversion factors, BEFs convert readily available estimates of merchantable stem wood volumes (m3 ha^{-1}) to total biomass carbon values (Mg C ha^{-1}) which can then be used to estimate carbon budgets (Birdsey, 1992; Kauppi et al., 1992; Kurz and Apps, 1993; Krankina et al., 1996; Brown et al., 1999; Kilbride et al., 1999; Fang et al., 2001; Fukuda et al., 2003; Backéus et al., 2005; de Wit et al., 2006; Sivrikaya et al., 2007; Keleş et al., 2007; Hu and Wang, 2008; Keleş et al., 2012). The use of these BEFs is also foreseen by the IPCC guidelines in those cases where no biomass information is readily available (Houghton et al., 2001; Van Camp et al., 2004).

In this paper, carbon storages of softwood and hardwood species were estimated separately. Biomass for each species was calculated using biomass conversion factors from the literature (Tolunay, 2011). Tolunay (2011) used for the prediction of carbon stocks in the above ground, below ground, litter, dead wood and soil parts of the forested landscape. To predict above ground biomass, timber volume of softwoods and hardwoods were multiplied by species-specific wood density and biomass expansion factors (Table 1). Total dry weight biomass of a tree was converted to total stored carbon by multiplying by 0.51 for softwoods and 0.48 for hardwoods and maquis. The root biomass was predicted according to the above-ground biomass. For this reason, the above-ground biomass was multiplied by predetermined root to shoot ratios. Litter, dead wood and soil carbon values were estimated using according to species specific carbon factors (Table 2). These equations also will be used in an *"integrated approach to management of forests in turkey, with demonstration in high conservation value forests in the Mediterranean region"* GEF V project to calculate GHG emission and carbon inventories under General Directorate of Forestry and UNDP (United Nations Development Program).

Mapping carbon storage

Stand type maps for the years 1965 and 2008 were firstly digitized and rectified. Stand type maps, generated in 1965 through the stereo interpretation of aerial photographs and field survey were obtained from the GDF forest management plan (GDF, 1965). The stand type maps were first scanned and then registered to the 1:25.000 scale topographical maps with UTM projection (ED 50 datum) using first order nearest neighbor rules with a maximum root mean square error (RMSE) under 10 m. using GIS (ArcGIS 10.0). Rectified stand type maps were digitized with a 1:3000 to 1:5000 screen view scale. Afterwards, associated attribute data were entered into the computer to create the spatial database of the area. The 2008 stand type map was derived from interpreting aerial photographs, high-resolution satellite images and field survey. 656 sample plots were taken to generate the final stand type map (Karahalil et al., 2009).

GIS techniques were used to acquire, build and manage spatial database of the study area. Using carbon factors described in details above applied to the stand volumes, carbon values were produced according to stand types. Finally, grouped carbon maps produced for the two periods.

Table 1. Some data and coefficients used in the calculation (P:Productive, D:Degraded)

Tree Species		1965		2008		WD (Mg m^{-3})	BEF
		Volume (m^3)	Area (ha)	Volume (m^3)	Area (ha)		
Juniper	P	10058.10	234.64	52766.15	289.93	0.460	1.195
	D	3428.91	776.26	56062.51	9343.75		
A. Pine	P	749218.12	3727.93	876038.08	2496.30	0.470	1.071
	D	19237.31	2050.69	28948.07	2894.81		
C. Pine	P	840691.11	7137.87	1167243.56	7632.66	0.478	1.349
	D	12644.47	1345.35	32287.90	3228.79		
Cedar	P	66285,13	459.55	-	-	0.430	1.195
	D	4318,40	552.36	-	-		
Cypress	P	43039,11	425.80	27271.50	195.45	0.446	1.195
	D	-	-	583.99	97.33		
Oak	P	-	-	1633.17	39.55	0.570	1.324
	D	43861.85	9656.15	4960.28	620.03		
Mixed F.	P	175900.66	1042.61	663877.33	2462.91	0.446	1.195
	D	6133.15	757.96	-	-		
Maquis		3017,05	603.41	-	-	0.541	1.230

Table 2. Some coefficients used in the calculation

Tree Species	Above-ground biomass (Mg ha^{-1})	Root to Shoot	Carbon Factor	Litter (Mg ha^{-1})	Soil (Mg ha^{-1})	Dead Wood
Coniferous	<50	0.40	0.51	7.46	76.56	% 1 of Above Ground Biomass
	50-150	0.29				
	>150	0.20				
Deciduous	<75	0.46	0.48	3.75	84.82	
	75-150	0.23				
	>150	0.24				

Results and Discussion

As of 1965, it was estimated that forest ecosystems in Köprülü Canyon NP forest contained 3.21 Tg of carbon. Though 0.74 Tg of whole carbon storages in forest ecosystem are above and underground, the rest (2.47 Tg) are litter, dead wood and soil (Table 3).

Table 3. Carbon stocks (Gg) of in the carbon pools of Köprülü Canyon NP in 1965 and 2008

Species		Above-ground		Below-ground		Litter		Dead wood		Soil		Total	
		1965	2008	1965	2008	1965	2008	1965	2008	1965	2008	1965	2008
Jun.	P	2.82	14.79	0.81	4.28	1.75	2.16	0.02	0.12	17.96	22.19	23.36	43.54
	D	0.96	15.71	0.38	6.28	5.79	69.70	0.01	0.13	59.43	715.3	66.57	807.1
A. Pine	P	192.3	224.8	55.77	65.21	27.81	18.62	1.79	2.09	285.4	191.1	563.0	501.8
	D	4.94	7.43	1.97	2.97	15.29	21.59	0.04	0.06	157.0	221.6	179.2	253.6
C. Pine	P	276.4	383.8	80.17	111.3	53.24	56.93	2.04	2.84	546.4	584.3	958.2	1139.1
	D	4.15	10.61	1.66	4.24	10.03	24.08	0.03	0.07	103.0	247.1	118.8	286.1
Ced.	P	17.37	0	5.03	0	3.42	0	0.14	0	35.18	0	61.14	0
	D	1.13	0	0.45	0	4.12	0	0.01	0	42.28	0	47.99	0
Cyp.	P	11.69	7.41	3.39	2.14	3.17	1.45	0.09	0.06	32.60	14.96	50.94	26.02
	D	0	0.15	0	0.06	0	0.72	0	0.01	0	7.45	0	8.3
Oak	P	0	0.59	0	0.13	0	0.14	0	0.00	0	3.35	0	4.21
	D	15.88	1.79	7.30	0.82	36.21	2.32	0.12	0.01	819.0	52.59	878.5	57.53
Mix. For.	P	47.81	180.4	13.86	52.33	7.77	18.37	0.40	1.51	79.82	188.5	149.6	441.1
	D	1.66	0	0.66	0	5.65	0	0.01	0	58.03	0	66.01	0
Maq.		0.96	0	0.44	0	1.02	0	0.01	0	48.03	0	50.46	0
Total		578.0	847.4	171.8	249.7	175.2	216.0	4.71	6.9	2284.2	2248.1	3214.5	3568.6
%		17.98	23.74	5.34	6.99	5.45	6.05	0.14	0.19	71.06	63.00	100.0	100.0

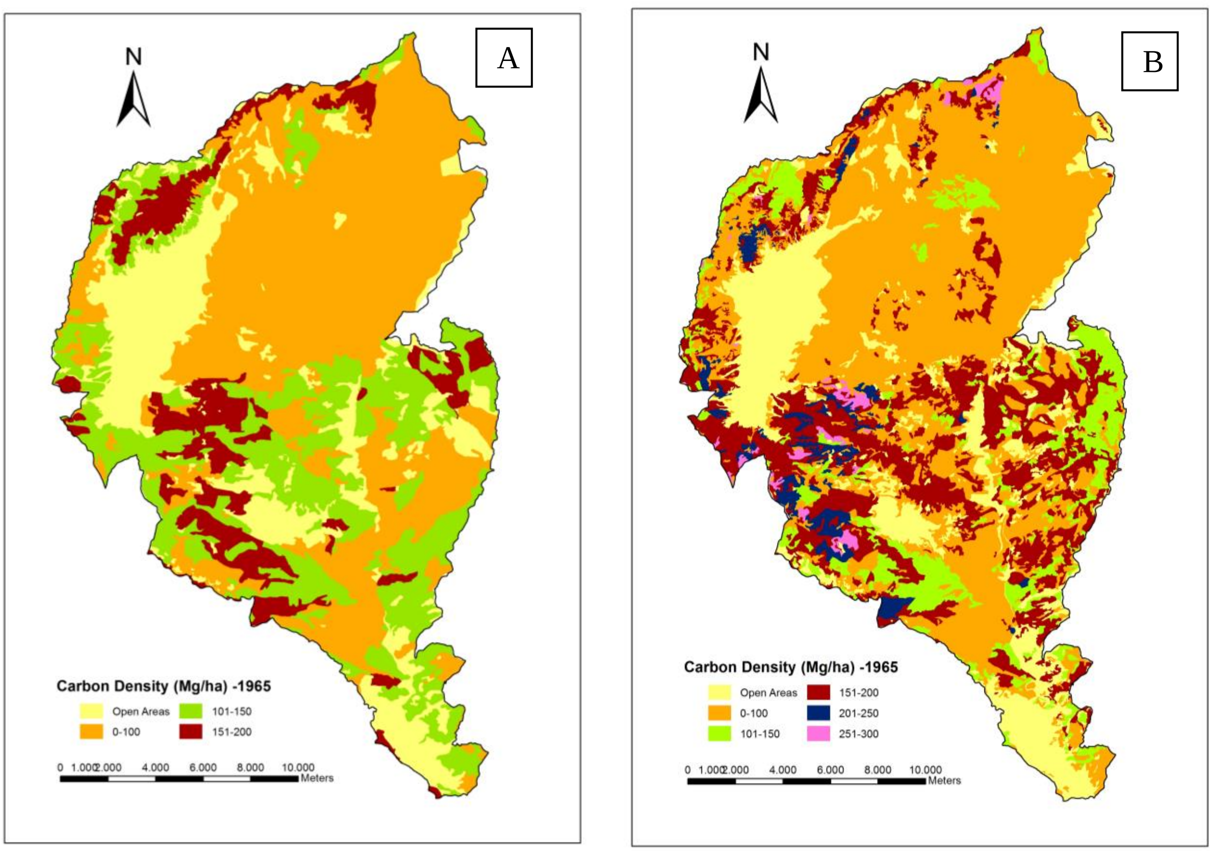

Figure 2. Carbon density maps of Köprülü Canyon NP forest in the years of a) 1965 and b) 2008

It was estimated that forest ecosystems contained 3,56 Tg of carbon with 1.08 Tg above and belowground and 2.48 Tg litter, dead wood and soil in the year of 2008. While 17.98% of carbon stored in aboveground biomass in the year 1965, it was increased to 23.74% in the year 2008. On the other hand, carbon stored in the soil decreased from 71.06% to 63.00% in that period.

The spatial distribution of carbon densities of Köprülü Canyon NP Forest in 1965 and 2008 are shown in Figure 2. As a result, carbon storages increased by about 11% over 43 years (Figure 2). This value is about 46% (0.34 Tg) in total above and below ground carbon budgets.

Investigation of carbon storage increase is important for better park planning in Köprülü Canyon NP. The stand type maps were further analyzed to see any changes in forest structure. In terms of crown closure change, between 1965 and 2008 years, crown closure of 1 (11%-40%) decreased about 21% (900 ha) of landscape, crown closure of 2 (41%-70%) decreased about 37% (2.650 ha) of landscape and crown closure of 3 (>70%) increased about 208% (3.600 ha) of landscape. Generally changes of crown closures show that, between 1965 and 2008 years, 3 crown closure areas increased, 1 and 2 crown closure areas decreased and quality of forest structure is increased.

Furthermore, the total standing timber volume (growing stock of forest) affecting the amount of carbon storage increased by 47% (from 1.97 million m^3 in 1965 to 2.91 million m^3 in 2008). This change largely due to declaring Köprülü Canyon as a NP in 1973 and having forest management and maintenance activities stopped by the park administration since that time, although there were designed forest management plans for the year 1984 and 2008. All the changes in forest structure indicate that the quality of forest ecosystem structure during a 43-year period has increased, hence, the amount of carbon storage in Köprülü Canyon NP forest increased (Table 1 and Table 3).

The rate of land use and land cover changes affecting the amounts of carbon sequestrations in the atmosphere has become an important indicator of human disturbance (Kennedy and Spies, 2004; Wakeel et al., 2005; Cayuela et al., 2006). Thus, there is a strong need to display and correlate temporal changes in Köprülü Canyon for the above reasons. Forest improvement accounted for 530 ha and this translates to a net increase of 1.84% of forested stands between 1965 and 2008 (Table 1).

Understanding forest dynamics is also critical to design the sustainable management of NPs as spatial configuration of forest cover types are crucial factors of ecosystem conditions and functions. Especially, these changes may affect to not only in forest management activities but also in environmental concerns like carbon balance, water production and other forest values. So, spatial changes must be displayed to comprehend the causes in carbon storage increase. The total number of patches increased from 238 to 672 between 1965 and 2008, almost tripled. MPS (Mean Patch Size) of the land cover/land use classes dropped markedly from 1615.0 ha to 425.3 ha. (Karahalil et al., 2009). These changes showed that landscape fragmentation increased and the forest has become more susceptible to harsh disturbances.

There are some reasons for such changes. Tourism activities like rafting and recreational uses of forests in NP caused changes in forest landscape structure such as increased forest degradation and fragmentation.

When we compared our results with previously published estimates of some carbon sequestration rates, it is seen that Köprülü Canyon NP is in middle rank among the given references (Table 4).

These results or rates are because of similar reasons when compared to our study. For instance, Sivrikaya et al., (2007) showed that carbon stored in Artvin, Turkey (above and belowground) increased 105.44 Gg between 1972 and 2002 because of increasing of productive forests and decreasing of degraded forests in as well as protection of spruce forests subject to insect attacks. On the other hand, the results showed that carbon stored in Camili, Turkey, (above and belowground) increased 21.55 Gg between 1984 and 2005 because of increasing of forested and productive forest forests have accumulated 81.84 Tg C due to forest expansion and regrowth, increasing from 57.36 Tg C in 1936 to 139.20 Tg C in 2005. Hardwood and softwood forests accounted for 74% and 26% of carbon accumulation during this period, respectively. From 1936 through 2005, forest carbon accumulated at a rate of 1.19 Tg C yr^{-1} from 2.8 million ha land area. This means that 425 kg C yr^{-1}. Similarly, Keleş et al. (2012) presented spatial and temporal changes of carbon storages of forest timber biomass between 1984 and 2005 in Torul. The results indicated that the total amount of carbon stored in the above and belowground forest ecosystems increased nearly 47% (from 1.97 Tg in 1984 to 2.91 Tg in 2005) from one period to the next mainly due increase of forest areas and decreasing of non-forest and degraded forest areas. Hu and Wang (2008) used biomass expansion factors like our study and they found that, since 1936, the Piedmont area (12.379 ha) and the quality of forest ecosystem structure.

Tolunay (2011) found that the annual biomass carbon accumulation increased from 2.20 Tg C $year^{-1}$ in 1990 to 6.82 Tg C $year^{-1}$ in 2005 (an average increase of 4.50 Tg C $year^{-1}$).

Sivrikaya and Bozali (2012) determined temporal and spatial change in carbon storage (aboveground plus belowground) in Türkoğlu planning unit for 1991 and 2002 and carbon storage map was produced. Biomass increased 52021 m^3 and carbon storages also increased 26342 (%19.5) tons during a 11-year period from 1991 to 2002. They found that the main reason for the increase in the amount of biomass and carbon storage is to increase of total forest areas and transition from degraded forest to productive forest.

Table 4 Comparisons of our estimates with previously published estimates of carbon sequestration rates (Mg C ha^{-1} yr^{-1})

Method	Region	Time Period	Carbon seq. rate (Mg C ha^{-1} yr^{-1})	Reference
Forest Inventory (FI)	Camili, Turkey	1984-2005	0.04	Sivrikaya et al., (2007)
Land use change	Conterminous US	1980s	0.08	Houghton et al. (1999)
FI	Türkoğlu, K.Maraş	1991-2002	0.11	Sivrikaya and Bozali (2012)
FI	Turkey Forests	1990-2005	0.21	Tolunay (2011)
FI	*Köprülü Canyon NP*	*1965-2008*	*0.28*	*This Study*
FI	Torul, Turkey	1984-2005	0.29	Keleş et al. (2012)
FI	Conterminous US	1980s	0.31	Turner et al. (1995)
Forest Inventory and Ecosystem Model (FIEM)	Conterminous US	1990-2005	0.38	Woodbury et al. (2007)
FI	Conterminous US	1952-1992	0.4	Birdsey and Heath (1995)
FIEM	Conterminous US	1980s	0.4	Hurtt et al. (2002)
FI	Piedmont	1936-2005	0.44	Hu and Wang (2008)
FI	Artvin, Turkey	1972-2002	0.67	Sivrikaya et al., (2007)

In conclusion, there is net increase in terms of carbon storage, growing stock, area, and canopy in forested areas and accretion in patchiness in Köprülü Canyon NP from 1965 to 2008. The main reason of this result is the declaration of Köprülü Canyon as a NP in

1973. Before the status of NP, the area was subject to excessive timber management, illegal cutting and over grazing activities. After the declaration, a master plan was designed and timber production activities stopped until 1984. In this year, a 10 year forest management plan was prepared according to master plan and moderate timber production was allowed without damaging ecological integrity. However, this plan was unable to reach to the target as it was not put in practice as desired. Forestry activities in terms of regeneration or thinning have not been undertaken since that time. Furthermore, after the announcement of NP, tourism activities developed rapidly resulting in heavy tourism activities. Agriculture and stockbreeding were gradually diminished and the area of forested stands began to improve in that period.

Based on the master plan, a 20 year forest management plan was also prepared in 2008 with the participatory and ecosystem based approach focusing on meeting the needs of the people living in or around the protected areas as well as the requirements of nature conservation and natural resource management. But like the year 1984 forest management plan, the other plan designed in 2008 have not found any chance to come into practice since then because of deficient management policies.

Unlike the positive forest composition and land cover/forest cover type changes the spatial structure of forest configuration was failed (Karahalil et al., 2009). Although there was a net increase in number of patches and smaller patches, and decrease in MPS demonstrated that the forest landscape has gone into a more fragmented structure, that situation did not negatively affected carbon storage because of increase in forested area and total volume.

Conclusions

There is an increasing need to improve the estimates of the amount of carbon in forest ecosystems because of their importance in the global carbon cycle. Besides, under international obligations, for instance according to Kyoto Protocol, countries must produce a national inventory of changes to forest carbon stocks during the first commitment period (2008-2012) due to afforestation, reforestation, and deforestation activities since 1990. So countries tried to estimate C stored in their forest ecosystems.

In this study, a methodology was demonstrated to document carbon storage, using existing databases and GIS technology. A temporal and spatial change of carbon storage amounts in Köprülü Canyon NP in southwestern of Turkey is analyzed. It was estimated that forest ecosystems in Köprülü Canyon NP forest contained 3.21 Tg of carbon in the year 1965 however, that forest ecosystems contained 3.56 Tg of carbon in the year 2008. As a result, carbon storages increased by about 11% over 43 years.

We produced the maps of the carbon storage change depending on inventory database. GIS tool was used to display the spatial and temporal change patterns of carbon storage during the study process. GIS can greatly facilitate the procedure because these systems or methods can be used in the collection, analysis and presentation of resource data. Since 1973, the year of the declaration Köprülü Canyon as a NP, forest acted as a carbon sink with a net accumulation of 0.28 Mg C ha^{-1} yr^{-1} due to the growth of existent forest. Carbon accumulation rate in this region is highly influenced by growing stock, forest canopy and area as well as spatial changes.

For instance, forest improvement accounted for 530.0 ha and 1.84% of the forested area of the Köprülü from 1965 to 2008 have specific effects on the amount of carbon storage beside other certain effects such as the total standing timber volume increased by 46%, and improvements in crown closure increased about 208% (3.600 ha) in dense forests (crown closure > %70). Shortly, we can say that the increasing forest area and the growth of existent forests are likely determined the magnitude and direction of carbon flux of the Köprülü Canyon forests. On the other hand, carbon storage capacity was not affected negatively from configuration of forest resources changed considerably in the study area. Reducing forest loss is therefore of utmost importance for climate change mitigation, and this is reflected in the commitment to include reduced emissions from deforestation and degradation (REDD) in the post-2012 agreements of the United Nations Framework Convention on Climate Change. Achieving these emissions reductions will require effective strategies for reducing land cover change, in which formally protected areas are one promising tool. Recent research indicates that whilst protected areas generally reduce deforestation relative to unprotected areas, they do not entirely eliminate land use change within them (Clark et al. 2008; Karahalil et al., 2009). Therefore, it is important to understand the extent to which protected areas are in fact subject to land use change, and the degree to which improving the effectiveness of existing protected areas could make an effective contribution to reducing emissions from deforestation and forest degradation. There is no doubt that, Turkey has a great opportunity on the promotion of affirmative effect on climate change by occurring of carbon stocks in the forests. Protected forested areas should be evaluated as a huge potential for the carbon sink.

In conclusion, as a major indicator of human disturbances, land use and land cover changes need to be incorporated into carbon budget calculations. The changes in land use and land cover should be analyzed carefully to see both spatial and temporal dynamics over a significant amount of time and relatively larger areas. The changes may cause modification of forest management plans as well as forest policies across the country. Increasing the size and number of protected areas has the benefit of protecting the vegetation, soils, water, wildlife, and/or recreation in the ecosystem while also conserving ecosystem carbon.

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