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Spatial dynamics of carbon storage: a case study from Turkey

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Abstract Forest ecosystems have an important role in carbon cycle at both regional and global scales as an important carbon sink. Forest degradation and land cover changes, caused by deforestation and conversion to non-forest area, have a strong impact on carbon storage. The carbon storage of forest biomass and its changes over time in the Hartlap planning unit of the southeastern part of Turkey have been estimated using the biomass expansion factor method based on field measurements of forests plots with forest inventory data between 1991 and 2002. The amount of carbon storage associated with land use and land cover changes were also analyzed. The results showed that the total forested area of the Hartlap planning unit slightly increased by 2.1 %, from 27,978.7 ha to 28,282.6 ha during the 11-year period, and carbon storage increased by 9.6 %, from 390,367.6 to 427,826.9 tons. Carbon storage of conifer and mixed forests accounted for about 70.6 % of carbon storage in 1991, and 67.8 % in 2002 which increased by 14,274.6 tons. Land use change and increasing forest area have a strong influence on increasing biomass and carbon storage.

Keywords Biomass · Biomass expansion factor · Carbon storage · Land cover

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Introduction

Climate change has become an important environmental issue due mainly to the greenhouse effect of CO_2 (Dixon et al. 1994; Kun and Dongsheng 2008). Forest ecosystem is considered as an important carbon sink in terms of regulating atmospheric CO_2 and have a significant role in carbon (C) cycle as both carbon sources and sinks. Because forests store massive quantities of carbon in flora and soil, they exchange large amounts of carbon with the atmosphere through respiration, photosynthesis, decomposition and combustion (Hu and Wang 2008).

Forest biomass is the most important part of living terrestrial vegetation biomass (Dixon et al. 1994; Zhao and Zhou 2005). The quantity of carbon storage in forest ecosystem accounts for two-thirds of the total carbon fixed annually in terrestrial ecosystems. Therefore, forest ecosystems have an important contribution in reducing the impact of global CO_2 emissions, thereby maintaining climate stability (Haripriya 2002; Hashimotio et al. 2000; Kun and Dongsheng 2008). The Kyoto Protocol by the United Nations Framework Convention on Climate Change (UNFCCC) recognized the role of forest ecosystem and its positive effects in carbon storage. However, forest resources of the world are decreasing gradually, and global warming may be getting worse (van Mantgem et al. 2009). Countries which are under the UNFCCC are responsible for monitoring, estimating and reporting carbon stocks in forest biomass with respect to Articles 3.3 and 3.4 under Forest Management (UNFCCC 2008). Hence, Turkey, as one of the signatories of the Kyoto Protocol, is committed to estimate forest biomass and carbon storage accurately.

Land cover changes have certain effects on carbon storage in forest ecosystem, contributing to climate change (Ostle et al. 2009), with 25 % of the anthropogenic flux of carbon dioxide to the atmosphere (Houghton et al. 2001). Most of the land-cover change studies figured out valuable information about biomass, which is a fundamental component of the carbon cycle, allowing us to acquire precise knowledge of carbon storage in forest ecosystems. Since the Kyoto Protocol has been established, changes in carbon storage due to land cover change have been evaluated. However, estimating carbon storage influenced by land cover change is a primary challenge (Muñoz-Rojas et al. 2011).

Forest inventory data are valuable resources and practical and the best approach for spatially explicit estimates of forest biomass and carbon pool in forest ecosystem at a national or regional scale. These data, generally collected at a landscape scale, provide true ground-based estimates of biomass and carbon stock and are statistically representative of land use change and disturbance (Brown and Schroeder 1999; Hu and Wang 2008). Few studies were carried out to develop allometric equations and biomass expansion factor (BEF) for species such as beech, alder, Scots pine, oak, Calabrian pine and chestnut species in Turkey (Saracoglu 1998; İkinci 2000; Durkaya et al. 2010a,b,c). For example, BEF was calculated at a planning unit level using field survey data (Sivrikaya et al. 2007; Sivrikaya et al. 2009; Keleş et al. 2012). Researchers generally prefer to use BEF instead of allometric equation as allometric equations have not been developed for every tree species native to Turkey.

The objective of our study was to temporally and spatially provide estimates of the carbon storage for Hartlap forest planning unit by using BEFs and forest inventory data between 1991 and 2002 with GIS technology. The temporal and spatial distributions of carbon storage were mapped with ArcGIS 9.3. Total aboveground (AGB) and belowground biomass (BGB) and carbon storage of forest ecosystem in various periods were evaluated with respect to land cover changes in the study area.

Area description

Hartlap forest planning unit, selected as a case study area, covers a total of 48,700.7 ha. It is located in the mountainous areas near Kahramanmaraş city in the southern part of Turkey (274 000–316 000 E, 4137 000–4163 000 N, UTM ED 50 datum Zone 37 N). It is characterized by mid-slope terrain with an average slope of 48 %. The altitude varies from 350 to 2,259 m above sea level (Fig. 1). The main vegetation type in the study area is forest and the dominant tree species are *Cedrus libani* A. Rich., *Pinus brutia* Ten, *Pinus nigra* Arn., *Fagus orientalis* Lipsky, *Abies cilicica* Carr., *Quercus* sp., and *Pinus pinea* L. Yavşan Plateau Natural Park and old-growth cedar stand are located in the planning unit. The case study area and Yavşan plateau are quite important for biodiversity conservation. In fact, *Ajuga relicta* grows only in Yavşan plateau and nowhere else. The main soil types are sandy clay loam, clay loam and sandy loam. The mean annual temperature of the study area is 16.7 °C, and the mean annual precipitation is about 727.2 mm (Bozali 2003).

Data and methods

Data

In this study, forest inventory data in association with forest cover type map in 1991 and 2002 and topographic map (1:25,000 scale) were used to estimate forest biomass in Hartlap forest planning unit. Forest inventory in Turkey has been carried out on a 10-year cycle using field surveys and remote sensing data. All forest inventories were carried out with respect to forest management guidelines by the General Directorate of Forestry (GDF). Diameters at breast height (DBH; 1.3 m) over 8 cm were measured for all trees in each sample plot. The volume of each tree was estimated using a stand table and growing stocks of each plot was calculated by adding the volumes of all individual trees within the sample plot. Growing stock of each forest type was then calculated to estimate the total growing stock in forest management plan.

Fig. 1 Location of the study area

Forest cover type map of the area was generated using a combination of ground measurement or field survey and aerial measurement with remote sensing data. The aerial photographs in 1991 and 2002 were interpreted together with the field survey data and the forest cover type map was produced in raster format.

The area and growing stocks per hectare of each forest cover type were obtained from Hartlap forest management plans (Anonymous 1991, 2002) and forest cover type maps for 1991 as raster format and 2002 as digital format from Kahramanmaraş Regional Directorate of Forestry. Forest cover type map for 1991 was first scanned, saved and then registered to the digital topographic maps. Rectified forest cover type maps were digitized using GIS (ArcGIS 9.3™) with maximum root mean square (RMS) error under 5 m. Attribute data such as area and growing stocks per hectare of each forest cover type were entered into the computer to create the spatial database of the area.

Methods

Biomass and carbon storage estimation

The amount of forest timber biomass and carbon storage in the aboveground and belowground of the forest were estimated using forest inventory data and BEFs for each stand type. Carbon storage was estimated for hardwood and softwood species separately based on ABG and BGB from 1991 to 2002. To predict AGB of trees with a minimum DBH of 8 cm, a BEF (described as the proportion of AGB of all living trees) was used for softwoods and hardwoods.

The total biomass was estimated using the simple formula by Asan et al. (2002) and GFRA (2010) as the sum of AGB and BGB:

$$\mathrm{AGB} = \mathrm{GS} \times \mathrm{BEF} \times \mathrm{ODWC}$$

$$\mathrm{BGB} = \mathrm{AGB} \times \mathrm{PRBC}$$

where GS is the growing stock per hectare, BEF is the biomass expansion factor and ODWC is the oven-dry weight coefficient. BEF is 1.24 for hardwood stands and 1.22 for softwood stands. ODWC is 0.638 for hardwood stands and 0.496 for softwood stands; PRBC is proportion of root biomass coefficient. The BGB was calculated according to the AGB. PRBC is 0.29 for productive softwood stands, 0.40 for degraded softwood stands, 0.24 for productive hardwood stands and 0.46 for productive hardwood stands. Carbon storage was calculated using carbon biomass conversion factors, which were 0.48 and 0.51 for hardwoods and softwood, respectively, in the planning unit for 1991 and 2002.

Mapping carbon storage

Aboveground and belowground carbon storage in Hartlap planning unit were monitored using forest cover type maps of Hartlap (1991 and 2002). The scale of forest cover type maps as well as topographic map was 1:25,000. First of all, forest cover type map was digitized with a maximum RMS error under 3 m and spatial database established using ArcGIS 9.3™. Stand type, crown closure and forest development stages take place in spatial database. The volume of each stand type was added to the database to estimate biomass and carbon storage. Aboveground and belowground carbon storages based on biomass were calculated using GIS database with stand type volumes and stand type areas with respect to carbon storage formula. Aboveground and belowground carbon storage maps (m^3/ha) in 1991 and 2002 for Hartlap planning unit were produced by reclassifying the forest cover type maps.

Results and discussions

Biomass in different land covers

According to BEF between growing stock and biomass of the forest cover types, the spatial and temporal changes in forest biomass and carbon storage of different forest cover types were analyzed based on the forest inventory data. A short explanation of each land cover class is given in Table 1. In terms of land cover, degraded forest accounted for most of the total forest area for 1991 and 2002 with 55.9 %, and 63.3 %, respectively (Table 2). Conifer forest accounted for 16.3 % and 15.8 % of the total forest stand area for the years 1991 and 2002, respectively, and it was the second most common major land cover type. Stem volume and biomass of three land cover types (mixed forest, broadleaf forest and degraded forest) increased annually. Stem volume and biomass of the degraded forest attained the highest growth rate, 26.2 % and 32.9 %, respectively, from 1991 to 2001. The most forest stand biomass in the study area was provided by conifer forest and mixed forest in 1991 and mixed forest and conifer forest in 2002. Biomass of these two land cover types accounted for two periods (1991 to 2001) about 70 % and 67 % of total forest stand biomass, respectively. Biomass of these two land cover types increased by 27 754.8 tons, accounting for 36.4 % of the forest stand biomass increment. A broad level analysis showed that regional forest biomass increased by 9.8 %, from 779,633.2 to 855,959.0 tons (Table 3).

According to land cover class between 1991 and 2002, the total forested area of the Hartlap planning unit slightly increased by 2.1 %, from 27,978.6 to 28,282.6 ha during the 11-year period (Fig. 2). The areas of conifer forest, broadleaf forest, and mixed forests decreased by 1.9 %, 46.1 %, and 4.2 %, respectively. The area of degraded forest increased by 14.5 %. In other words, productive forest area decreased by 15.9 %, from 12,336.0 to 10,373.8 ha (Table 2). As an overall change between 1991 and 2002, the percentage of forest areas in the Hartlap planning unit increased from 57.5 in 1991 to 58.1 in 2002 based on forest cover type maps. This translates to an average 0.1 % annual rate of forest improvement.

A broad level analysis showed that there was a net increase of 304 ha in forest area and 317.4 ha productive forest changed into water bodies due to dam construction. Actually, forest area increased by more than 304 ha (nearly 620 ha). Increasing forest area and decreasing non-forest areas in the Hartlap could be explained by the following reasons. First, most of the rural inhabitants have moved to urban areas in search for higher education and better life as the rural areas do not meet next generation's expectations. Therefore, most of the non-forest areas near and inside the forest ecosystems were abandoned, and non-forest areas have been naturally converted to forest cover. Second, extensive forest plantations were carried out by the forest department on degraded forest areas, forest openings and non-forest areas. This activity has contributed to the increase in forest area. Third, the GDF exerted great efforts to protect and develop the current forest ecosystem (Keleş et al. 2012; Sivrikaya et al. 2007) and rehabilitate degraded areas as fast as possible.

The remarkable changes were determined in degraded forest areas. The degraded forest area, whose crown closure is smaller than 10 %, increased by 2,266.2 ha. In 1991, degraded forest was 15,642.6 ha while it was estimated as 17,908.8 ha in 2002. The

Table 1 Land cover class descriptions

Land cover classes	Description
Broadleaf forest (BF)	Forest areas with pure broadleaf trees whose stand crown closure is greater than 10 %
Conifer forest (CF)	Forest areas with pure conifer trees whose stand crown closure is greater than 10 %
Mixed forest (MF)	Mixed (BF-CF, CF-BF) forest areas whose stand crown closure is greater than 10 %
Degraded forest (DF)	Forest areas whose stand crown closure is less than 10 %
Forest openings (FO)	Treeless and open areas which are being accepted as forest area in Turkey
Non-forest (NF)	Agricultural lands, settlements areas and pasture lands

Table 2 Land cover change in Hartlap planning unit from 1991 to 2002

Land Cover	Area (ha)		%	
	1991	2002	1991	2002
Broadleaf forest (BF)	3,683.6	1,984.3	7.6	4.1
Coniferous forest (CF)	4,555.1	4,465.0	9.4	9.2
Mixed forest (MF)	4,097.4	3,924.5	8.4	8.1
Degraded forest (DF)	15,642.6	17,908.8	32.1	36.8
Forest openings (FO)	1,982.1	3,128.7	4.1	6.4
Non-forest (NF)	18,739.9	17,289.4	38.5	35.5
Total	48,700.7	48,700.7	100.0	100.0

GDF has previously started a new conversion project to increase both productivity of forest area and expansion of high forest areas. Thus, most of the coppice forests in Turkey (productive and degraded) were converted to high forests due to the recently initiated conversion policy efforts of GDF with an expectation of considerable increase in productive forest areas. Analyzing the study area from this point of view, most of the coppice forest managed as coppice method converted to high forest during 11-year period. However, 1,788.8 ha of productive coppice forest was converted to degraded forest due to failure of high forest activities carried out in productive coppice forest areas. These changes would indicate a much lower quality of forest structure in Hartlap planning unit.

Aboveground, belowground and total carbon storage

It was estimated that total carbon storage (both above and below the ground) of forest ecosystems in Hartlap planning unit was 390,367.6 tons in 1991. While aboveground carbon storages in forest ecosystem was 77.1 % (300,998.3 tons), the rest (89,369.3 tons) was belowground. However, total carbon storage in forest ecosystems was 427,826.9 tons with 328,233.4 tons aboveground and 99,593.5 tons of carbon belowground in 2002. Within the period 1991–2002, carbon storage increased by 9.6 %, from 390,367.6 to 427,826.9 tons in the Hartlap planning unit (Table 3). The spatial distributions of carbon storages of Hartlap planning unit in the 1991 and 2002, and carbon change are shown in Figs. 3 and 4.

The results show that forest ecosystems would play a crucial role in increasing carbon budget if the forest ecosystems are managed carefully. Changing forest biomass and carbon storage during 11-year period in Hartlap forest can be explained by (a) a recovery and grow of understory trees towards the overstory and high growing stock potential; (b) a shift of forest stands towards older age classes; (c) converting coppice forest to high forest having more growing stock; and (d) land cover change and land abandonment.

Comparable results from some other studies carried out in Turkey are also presented. The research by carried out in two different planning units in Northeast part of Turkey by Sivrikaya et al. (2007) showed a net increase in carbon storages (105,446 tons) from 1972 to 2002 in Artvin forest planning.

Table 3 Biomass and carbon storage of different land cover types from 1991 to 2002

Land Cover	Biomass (ton)		Aboveground carbon (ton)		Belowground carbon (ton)		Total carbon (ton)		Growing stock (m^3)	
	1991	2002	1991	2002	1991	2002	1991	2002	1991	2002
BF	110,477.4	118,164.6	42,768.3	45,736.1	10,269.2	10,975.4	53,037.5	56,711.5	112,602.9	120,453.9
CF	301,769.3	271,023.9	119,311.8	107,143.8	34,593.0	31,074.9	153,904.8	138,218.7	386,588.6	347,201.7
MF	243,468.4	301,968.5	95,594.2	118,756.3	26,174.0	32,972.6	121,768.2	151,728.9	290,890.3	366,944.6
DF	123,918.1	164,802.0	43,324.0	56,597.2	18,333.1	24,570.6	61,657.1	81,167.8	130,274.6	164,434.7
Total	779,633.2	855,959.0	300,998.3	328,233.4	89,369.3	99,593.5	390,367.6	427,826.9	920,356.4	999,034.9

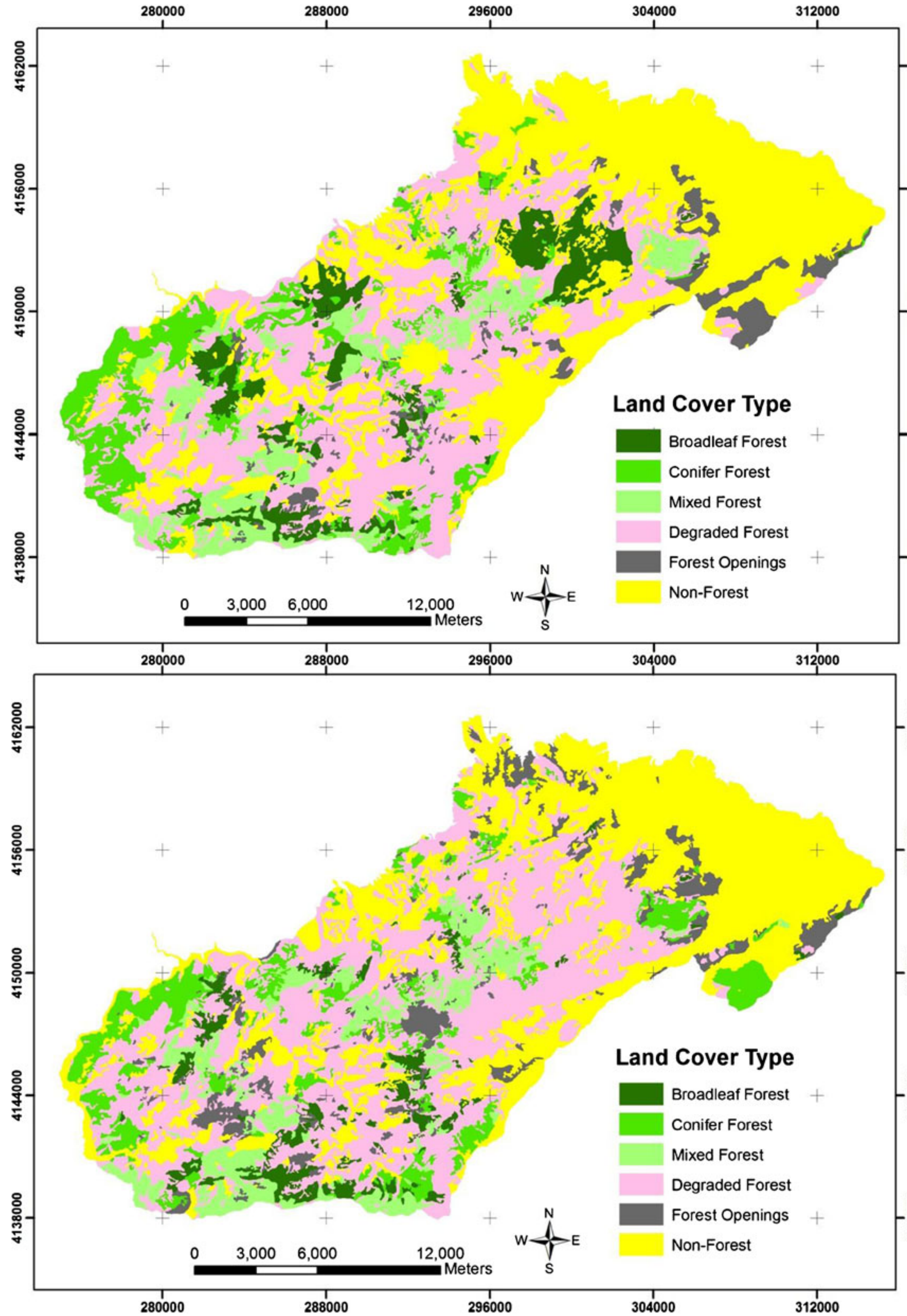


Fig. 2 Spatial distribution and changes of land cover in Hartlap forest from 1991 (*upper map*) to 2002 (*lower map*)

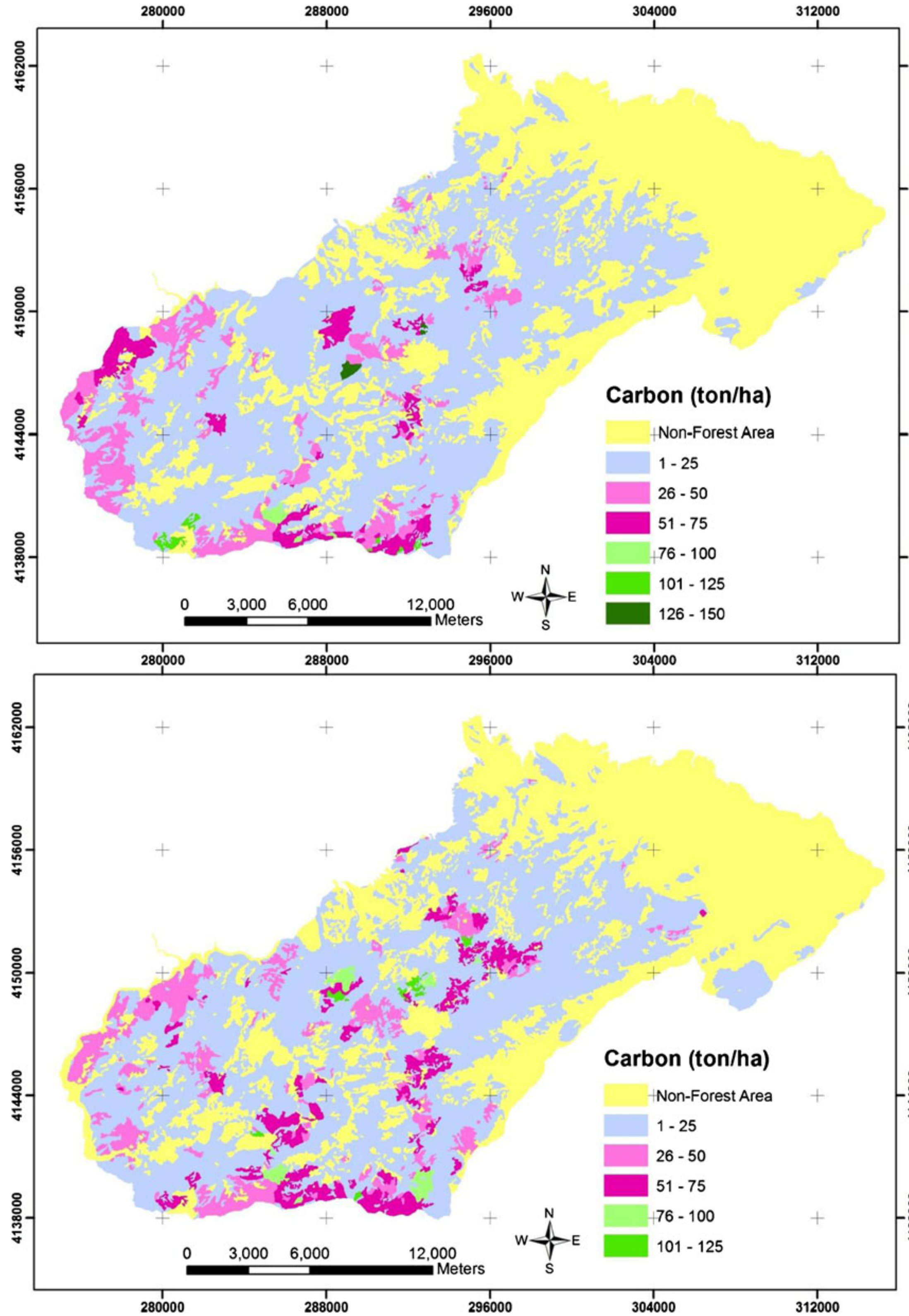


Fig. 3 Spatial distribution and changes of carbon storage in Hartlap forest planning unit from 1991 (*upper map*) to 2002 (*lower map*)

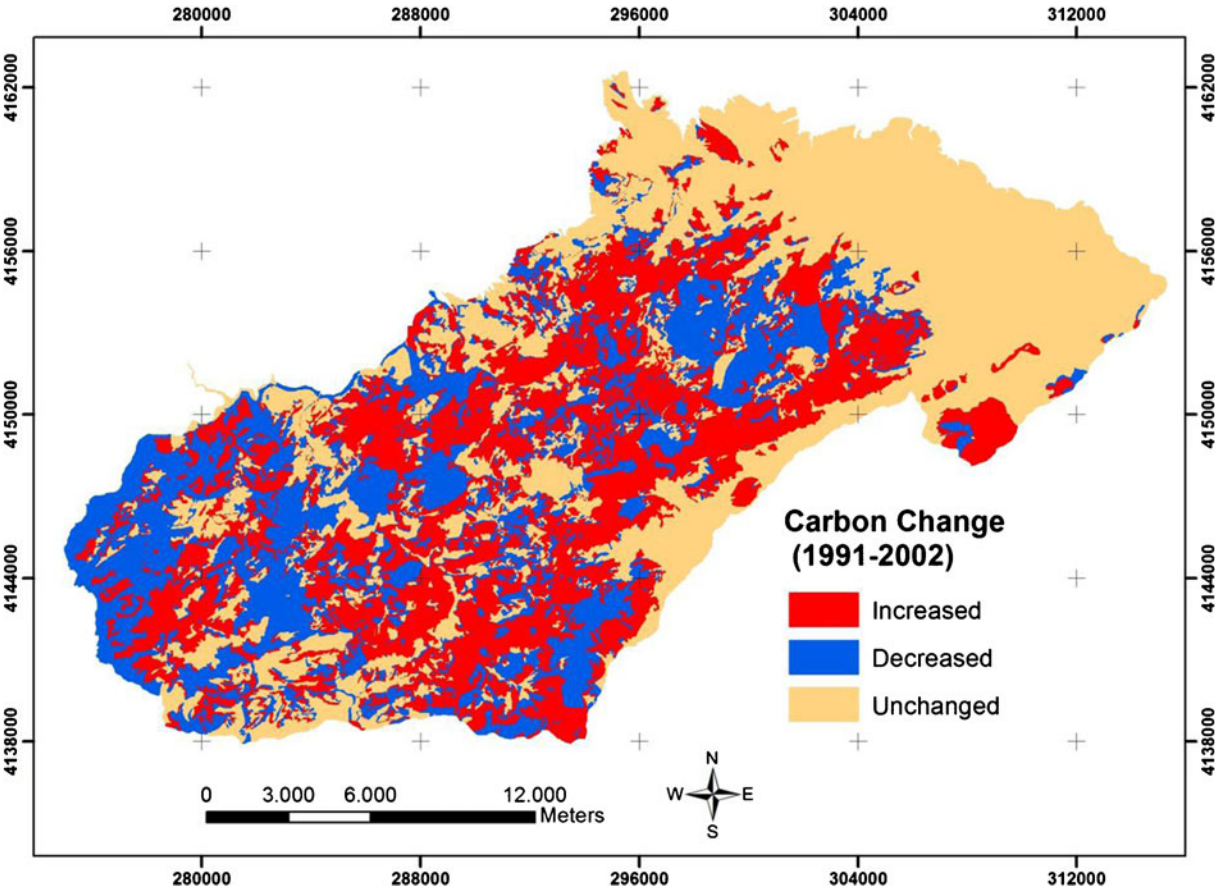
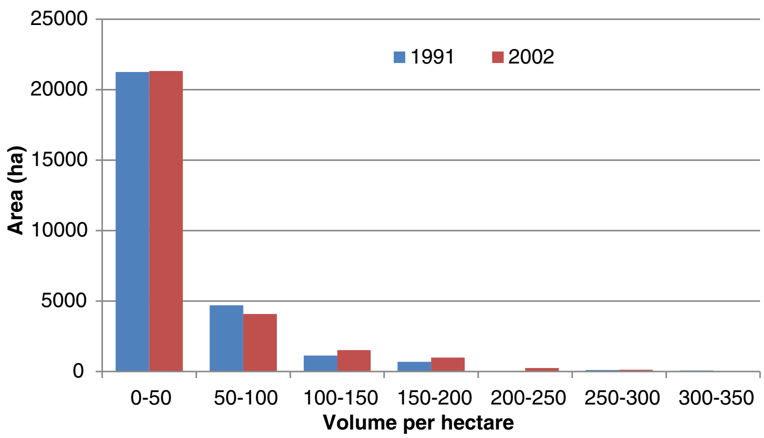


Fig. 4 Map of spatial carbon change in the study area from 1991 to 2002

Another study by Sivrikaya et al. (2009) reported that carbon storages increased to 205,766 tons during an 18-year period in Bulanıkdere forest planning unit located in south west part of Turkey. Although forest area decreased approximately by 1 %, total carbon storages increased due to increasing productive forest areas and the area of stands with high growing stocks. Total carbon storage increased while forest area decreased in both studies. In this respect, both studies are quite compatible with each other. Another research by Kauppi et al. (2010)

Fig. 5 Distribution of areas by volume per hectare in Hartlap forest planning unit in 1991 and 2002



carried out in Finnish Lake district showed that the carbon stock in biomass was 0.57 and 1.23 million tons in 1912 and 2005, respectively.

Carbon storage of other types of land cover increased, with the exception of conifer forest. The conifer forest was the main carbon sink in 1991 and mixed forest in 2002. However, degraded forest has the highest growth rate of carbon storage and biomass growth rate due to increasing degraded forest area and growing stock per hectare in degraded forest. Carbon storage of two land cover types (conifer forest and mixed forest) accounted for about 70.6 % of carbon storage in 1991, and 67.8 % in 2002, which increased by 14,274.5 tons during the 11-year period.

While broadleaf forest area decreased, carbon storage in broadleaf forest increased. The main reason of this change is that most of the coppice forest was converted to high forest. Growing stock, biomass and carbon storage of high forest stand are higher than those of coppice forest stand. For example, productive coppice stand (NMBt) has about 15 m^3 growing stock per hectare. However, productive high oak stand (Mb2) has nearly 19 m^3 growing stock per hectare. This means that the area of stands with high growing stocks has increased. Other reason might be the increase of older stands and their high growing stock (Fig. 5). In long-term projection of forest condition, however, the growth rate of forest and the emission control mechanism become one of the key factors in managing the carbon balance in forest ecosystems.

Other notable changes were determined in degraded forest. Even though there was a remarkable increase in degraded forest areas, increasing carbon storages in degraded forest was low. This result can be explained by the fact that degraded forest has low growing stocks. Therefore, carbon storage changes during 11-year period in Hartlap planning unit are not quite important due to degraded stands and their low standing timber volumes.

The importance of accurate estimation of the carbon storage in forest ecosystem is gradually increasing at national and international scales (Zhao and Zhou 2005). Although there are different methods to estimate forest biomass based on field survey data (Houghton et al. 2001), there are many uncertainties in the determination of carbon storage (Schulze et al. 2000). To estimate carbon storage in forest ecosystem, first of all, the forest biomass need to be accurately determined. Here, the most practical and an appropriate approach for estimating aboveground forest biomass and carbon storage is to use forest inventory data. There are generally two methods to estimate forest AGB: BEF and allometric equation. Few studies have developed allometric equations for estimating the biomass of some tree species such as *Pinus brutia*, *Pinus nigra*, *Quercus* sp., *Castanea sativa*, *and Fagus orientalis* in Turkey (Durkaya et al. 2010a,b,c). Allometric equations of some species grown in Hartlap planning unit have not been developed so far. Therefore, BEF was used instead of allometric equations.

Conclusion

A methodology was demonstrated to document biomass and carbon storage with respect to land use cover. The maps of the carbon storages, estimated based on inventory data over various temporal scales, were generated using GIS technology with ArcGIS 9.3. Maps provide a visual representation to forest managers for making decision accurately and easily. The effect of land cover changes on carbon storage in temporal and spatial scale was also described.

This study showed that biomass (above and belowground) and carbon storage in Hartlap increased by 76,326 and 37,459 tons, respectively, due to increasing productive forest areas and converting coppice forest to high forest with more growing stock. On the other hand, forest area increased 304 ha with an average 0.1 % annual rate of forest improvement between 1991 and 2002.

To accurately estimate forest biomass and carbon storage, allometric equations should be developed for each species and be used for a better estimating of carbon storage. Carbon storage pools in forest ecosystems consist of living trees, down dead woods, understory vegetation, forest floor, and soil. In this study, we only estimated the carbon storage in living trees based on AGB and BGB. Other carbon pools need to be taken into account for accurately estimating the total carbon storage of forest ecosystems.

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