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Estimating the aboveground carbon sequestration and its economic value (case study: Iranian Caspian forests)

Zohreh MOHAMMADI[1], *Soleiman MOHAMMADI LIMAEI*[1]*, *Peter LOHMANDER*[2], *Leif OLSSON*[3]

[1]*Department of Forestry, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Iran*

[2]*Optimal Solutions, Umeå, Sweden*

[3]*Department of Information Systems and Technology, Faculty of Sciences, Technology and Media, Mid Sweden University, Sundsvall, Sweden*

**Corresponding author: limaei@guilan.ac.ir*

Abstract

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The aim of the study is to estimate the aboveground carbon sequestration and to determine the economic value of forests in carbon sequestration as a way of mitigating climate change. This research was conducted at Asalem forests in the north of Iran. In order to estimate the amount of annual carbon sequestration, the annual volume growth of stand was determined using the diameter increment data and tariff. The amount of carbon sequestration was estimated based on wood density and using the allometric equation. The carbon model was obtained for each species. The value of sequestrated carbon in stumpage and the net present value of carbon sequestration were determined in order to estimate the economic value of carbon sequestration. Results indicated that the annual volume growth per hectare and the carbon stored are 6.023 $m^3 \cdot yr^{-1}$ and 2.307 $t \cdot ha^{-1}$, respectively. Finally, the carbon sequestration value of stumpage and the net present value of carbon sequestration are 11,023.753 and 790.361 (10,000 $IRR \cdot t^{-1} \cdot ha^{-1}$), respectively. Our results are very useful in estimating the total economic value of Asalem forests and other Iranian Caspian forests in the future.

Keywords: allometric equation; economic value of carbon; density of wood; forest inventory

Carbon sequestration is the long-term storage of carbon or carbon dioxide in the forests, soils, oceans or underground in depleted oil and gas reservoirs, coal seams and saline aquifers. Globally, forests play a major role in the carbon cycle because they account for a greater part of the carbon exchange between the atmosphere and terrestrial biosphere than any other ecosystem type (Lal, Singh 2003). Forest biomass accounts for approximately 90% of all living terrestrial biomass on the earth, and young forests take up CO at higher rates than most other ecosystems (Dixon 1997). The world's forests have been estimated to contain up to 80% of all aboveground carbon and 40% of all belowground (soils, litter, and roots) terrestrial carbon (Dixon et al. 1994). Estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest. It also gives us an idea of the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned (Lu 2006). Several models have been developed for the determination of biomass and carbon based on plant diameter (Mbow et al. 2013), but these models are species specific and focus on the amount of carbon stored in the forest trees. General equations can be inaccurate when used to estimate biomass of individual tree species. Species and site-specific allometric equations are more accurate and precise, and are therefore recommended for estimating the biomass of highly valued species (Litton, Kauffman 2008). This requires that appropriate allometric models specific for a given forest type are in place (Molto et al. 2013). Allometric models use the easy to measure individual tree parameters such as DBH and total tree height from forest inventories to estimate volume aboveground biomass. Another important explanatory variable for a biomass-estimating allometric model is wood basic density which is determined from wood samples in a laboratory as a ratio of dry mass to the green volume (Chave et al. 2005). Kenzo et al. (2009) harvested 136 trees from 23 species to measure the aboveground biomass in various tropical secondary forest trees in Sarawak, Malaysia. They also developed allometric relationships between the stem DBH, stem diameter at ground and leaf, stem and total root biomass. Mugasha et al. (2016) developed site-specific and general models for estimating total tree volume and aboveground biomass in Tanzania forests. Biomass allometric models which include basic wood density are highly recommended for the improved estimate accuracy when such information is available. Ryan et al. (2011) carried out a study to quantify the forest carbon stock in Miombo woodland in Mozambique. They developed a new site-specific allometric equation, between stem diameter and tree stem, based on destructive harvest of 29 trees. The choice of allometric equations has a significant effect on the biomass calculations since the forest biomass estimates vary with age of the forest, site class and stand density and generate an abundant supply of forest credits that could be used by companies to help offset their emissions as required by their emission caps (Stavins, Richards 2005). One of the important ecological roles of the forests, and one that currently provides the greatest potential to realize an economic return is carbon sequestration. Therefore, a viable market for forest carbon involves far more than simply planting and maintaining forests. Scientific and economic evidence identifies serious concerns in trying to meet carbon dioxide emission caps in part through markets for forest-sequestered carbon (Scarborough 2007). Understanding the economic value of carbon sequestered in forests is important in addressing the risk of global climate change that has presented a profound challenge to the international community (Jepkemei 2010). Jepkemei (2010) evaluated the potential economic value of carbon sequestration of Kakamega forest as well as the potential of the forest to participate in carbon trading. In addition, the study investigated the status of the carbon stock in the forest, based on the biomass stock. The study adopted the Tobit model to estimate the determinants of the total amount carbon that can be sequestered by trees in farms. The Tobit model is an econometric model in which the dependent variable is censored. It is also called the censored regression model or the limited dependent variable regression and it was proposed by Tobin (1958). The study confirms the huge atmospheric CO_2 amount that can be offset by the Kakamega forest, indicating the potential of Kenya to participate in carbon trading for both its economic and environmental benefit. Gren and Carlsson (2013) estimated the economic value of carbon sequestration in forests under multiple sources of uncertainty. The replacement cost method is used where the value of carbon sink is calculated as associated cost savings from replacement of more expensive mitigation options for achieving a given emission target. There are some studies that dealt with estimating of carbon sequestration in forest such as Schlesinger (1997), Thornley and Cannell (2000), Van Tuyl et al. (2005), Kindermann et al. (2008), Zhou and Luo (2008), and Lichstein et al. (2009). There are a few studies that dealt with estimation of aboveground carbon sequestration, its modelling and its economic values in Iranian Caspian forests, for example Kabiri Koupaei (2009) using an allometric method. Nejadi and Rahbar (2012) carried out with the aim of valuating carbon sequestration in shrubs and trees to find out their real economic role in human's life in Latyan Watershed. Mohammadi Limaei et al. (2014) used a goal programming technique to determine the optimal harvest volume for the Iranian Caspian forest. They used the allometric method to determine the aboveground stand sequestrated carbon. Nabavi and Keivan Behjou (2012) estimated total carbon stored in trees (branches, leaves, crown and trunk) and its economic value in Shafarood forest of Caspian forests using String methods and volume growth. Ostadhashemi (2014) estimated the aboveground biomass and carbon storage in multi-species plantations using the method of species-specific equations and three other generic methods in Caspian forest. Badehian et al. (2014) estimated the economic value of carbon sequestration in mixed and pure beech stands in Kheyroud Kenar forest, north of Iran, using damage cost avoided methods. Unfortunately, in Iran the decisions are taken based on the traditional economic approaches and the environmental economics is not regarded in the policy and decision-making process. Hence, it is essential to make decisions in line with the country's sustainable development by the usage of the findings obtained from several studies. The aim of the study is to assess the economic value of Asalem forests in the north of Iran in carbon sequestration as a way of mitigating climate change through a reduction of carbon dioxide in the atmosphere.

MATERIAL AND METHODS

Study area. This research was conducted in Nav district No. 3 at Asalem forests, Guilan province in northern Iran. The altitude ranges from 450 to 2,150 m a.s.l., latitude is 37°41'20"N to 37°35'30"N, and longitude is 48°48'00"E to 48°42'40"E (Fig. 1). The total area of these forest districts is 3,770 ha. Compartment No. 320 of this district with the respective latitude and longitude 37°39'30"N to 37°39'05"N and 48°45'57"E to 48°45'30"E was selected. This compartment has an area of 43 ha, and the minimum, average, and maximum altitude is 1,050, 1,120 and 1,210 m a.s.l., respectively. The general aspect is northern, and the slope at hillside is from 30 to 60%. In this district, forest types in the central part are beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* Linnaeus) with Cappadocian maple (*Acer cappadocicum* Gledhill), and alder (*Alnus subcordata* C.A. Meyer) (Anonymous 2006).

First of all, a survey was conducted in order to find a natural forest without any harvesting activities or so called less untouched forest. Hence, a forest reserve area (compartment No. 320, district No. 3) in Asalem region in watershed No. 7 (Nav) from the west of Hyrcanian forests, northern Iran, was selected. According to studies by Amanzadeh (2015) in this compartment, three forest types including hornbeam-beech, beech-hornbeam and mixed hardwood were detected. Therefore, the results of his data collection were used in order to find 3 sample plots in the same aspect and forest types (Schütz 2006). The area of sample plots was 1 hectare. In each sample plot, full callipering was conducted and the parameters such as tree total height (m), DBH of all trees with diameter larger than 7.5 cm were measured. Based on collected data, numbers per hectare of each species were calculated in each diameter class. Using the local tariff of Chooka for healthy trees (positive volume table of Chooka) and number per hectare in each diameter class, volume per hectare for each diameter class was measured (Bayat et al. 2014) (Table 1).

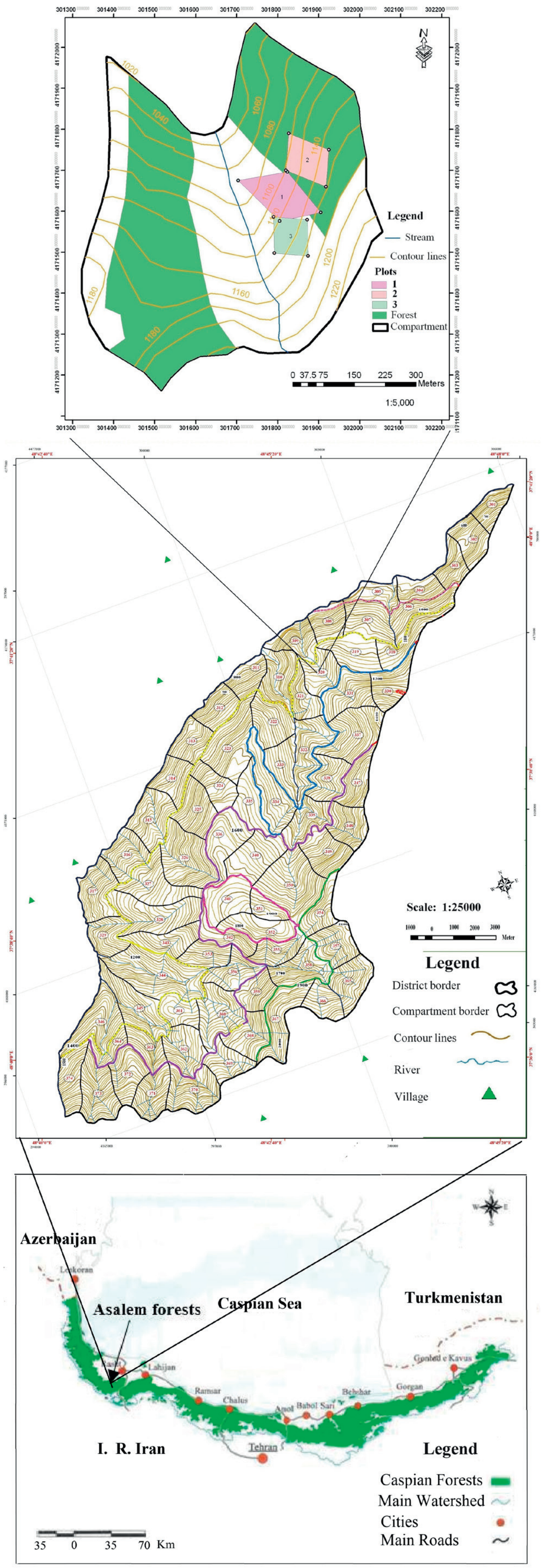

Fig. 1. The study areas, Asalem forests, Guilan province

Table 1. Results of inventory in the study area

Plot No.	Altitude (m a.s.l.)	Species type	Average diameter (cm)	No. of trees per hectare	Volume ($m^3 \cdot ha^{-1}$)
1	1,120	beech and hornbeam with others	38.440	209	588.680
2	1,170		29.600	306	419.989
3	1,170		32.710	235	351.169

others – maple (*Acer velutinum* Boissier), ash (*Fraxinus excelsior* Linnaeus), lime tree (*Tilia platyphyllos* Scopoli), wych elm (*Ulmus glabra* Hudson), alder (*Alnus subcordata* C.A. Meyer), Cappadocian maple (*Acer cappadocicum* Gledhill), sweet cherry (*Prunus avium* Linnaeus)

The amount of carbon sequestration is estimated based on wood density (Parsa-Pajouh 1995). In a study by Kabiri Koupaei (2009), allometric equations of tree crowns based on DBH were estimated for mixed beech-hornbeam stand in Kheyroud Kenar forest, north of Iran. Regarding the similarity of species composition and weather conditions between that area and our study area, the estimated allometric equations by Kabiri Koupaei (2009) were applied in this research (Table 2).

The allometric equation is below as Eq. 1:

$$Y = b_0 X^{b_1} \tag{1}$$

where:
Y – dependent variable,
b_0, b_1 – coefficients,
X – independent variable.

In order to determine the crown dry weight per kilogramme, the parameter values of b_0 and b_1 of crown weight from Table 2 and DBH were substituted in Eq. 1. Then, the amount of crown weight is multiplied by the number of trees of each species in different diameter classes. The trunk weight ($kg \cdot ha^{-1}$) of trees in different diameter classes is calculated using the wood density and stand volume. The biomass weight of standing trees is calculated by total weight of trunk (trunk biomass) and crown dry weight (crown biomass) in $kg \cdot ha^{-1}$. The 50% amount of the dry weight of biomass is considered equivalent to the carbon stored in order to estimate the carbon stored of stands in kg (Snowdon et al. 2002). Then, the carbon ($t \cdot ha^{-1}$) is calculated by dividing the amount of calculated carbon by 1,000.

Determination of carbon model for different tree species. At this stage, the related carbon model is obtained for each species using Eq. 2, as the carbon stored ($t \cdot ha^{-1}$) is dependent on the volume of different diameter classes (m^3):

$$\frac{\text{ton C}}{\text{ha}} = \frac{\text{ton wood}}{\text{volume wood}} \times \frac{\text{ton C}}{\text{ton wood}} \times \frac{\text{volume wood}}{\text{ha}} \tag{2}$$

where:
ton C – total amount of carbon stored in stands ($t \cdot ha^{-1}$),
ton wood – total dry weight of the trunks of trees ($kg \cdot ha^{-1}$),
volume wood – total volume of stands ($m^3 \cdot ha^{-1}$).

The density of wood ($kg \cdot m^{-3}$) is determined by dividing the weight of trunk (ton wood) by the wood volume ($m^3 \cdot ha^{-1}$). Then, the carbon model is determined using Eq. 3 for different tree species in stands:

$$\frac{\text{ton C}}{\text{ha}} = \text{density of wood} \times 0.5 \times \frac{\text{volume wood}}{\text{ha}} \tag{3}$$

Finally, the relationship between the volume per hectare and the carbon stored per hectare determined for different species as the carbon stored –

Table 2. Estimated parameters of allometric equations of tree crowns for mixed beech-hornbeam forest (Kabiri Koupaei 2009)

Species	Dependent variable	Independent variable	Parameter		R^2
			b_0	b_1	
Beech	V (m^3)	DBH (cm)	0.00025	2.400	0.981
	B_{Cr} (kg)		0.003	2.802	0.934
Hornbeam	V (m^3)		0.00032	2.357	0.922
	B_{Cr} (kg)		0.013	2.493	0.955
Others	V (m^3)		0.00027	2.381	0.983
	B_{Cr} (kg)		0.005	2.696	0.933

others – maple (*Acer velutinum* Boissier), ash (*Fraxinus excelsior* Linnaeus), lime tree (*Tilia platyphyllos* Scopoli), wych elm (*Ulmus glabra* Hudson), alder (*Alnus subcordata* C.A. Meyer), Cappadocian maple (*Acer cappadocicum* Gledhill), sweet cherry (*Prunus avium* Linnaeus), V – trunk volume, B_{Cr} – crown weight, b_0, b_1 – coefficients, R^2 – correlation coefficient

Y (t·ha^{-1}) is dependent on the volume of different diameter classes – X (m^3) and $a(i)$ is the amount of wood density × 0.5 for each species (Eq. 4):

$$Y = a(i)X \tag{4}$$

Estimation of carbon sequestration value of stumpage. The sequestrated carbon value of stumpage or above ground (V_{cs}) is determined using Eq. 5:

$$V_{cs} = p_c \times \bar{v} \tag{5}$$

where:
p_c – carbon price per hectare (IRR),
$\bar{v}$ – average volume in compartment (m^3·ha^{-1}).

Estimation of net present value of carbon sequestration. The carbon sequestration value of stumpage is determined using the net present value (NPV) of perpetuity or a constant stream of identical cash flows over time until infinity. In order to estimate the amount of annual carbon sequestration, the annual volume growth of stand was determined using the diameter increment data and tariff. The annual volume growth for each species was calculated. The annual carbon stored is determined using Eq. 6:

$$C_a = \frac{c_t \times g}{\bar{v}} \tag{6}$$

where:
C_a – annual carbon stored (t·ha^{-1}),
c_t – total carbon stored (t·ha^{-1}),
g – annual volume growth per hectare (m^3).

The net present value of carbon sequestration – NPV_c (10,000 IRR·t^{-1}·ha^{-1}) is determined using Eq. 7:

$$NPV_c = \frac{C_a \times p_c}{i} \tag{7}$$

where:
p_c – carbon price per ton (IRR),
i – real rate of interest.

RESULTS

Carbon model

The biomass weight of standing trees is determined by total weight of trunk (trunk biomass) and crown dry weight (crown biomass) per hectare. The 50% amount of the dry weight of biomass is considered equivalent to the carbon stored in order to estimate the carbon stored of stands in kilogrammes (Snowdon et al. 2002). Which means that you assume that "ton carbon" per "ton stem wood" = 0.5 = 50% or ton C/ton wood = 0.5 for each species in Eq. 2. Furthermore, the carbon content of the crown is calculated with the same factor, 50%. Then, the "volumes" in different places are "stem volumes" and the "carbon per hectare" is based on "stem volume plus crown volume". That means that "ton carbon" is more than what it becomes from the calculation using Eq. 3 (Table 3). The results showed that if the density of wood is known, then we can determine the carbon model. Carbon models are determined using Eq. 4 for different species in stands. Finally, the related carbon models of hornbeam, beech and other species in the study area are shown in Eqs 8–10, respectively (Table 3).

Carbon sequestration value of stumpage

The sequestrated carbon value of stumpage or above ground was determined using Eq. 5. Average volume in the compartment was derived from Table 1, carbon price per ton is equal to 7.6 USD (Goldstein et al. 2014). According to the exchange rate, it is equal to 243,200 IRR (Central Bank of the Islamic Republic of Iran 2016). The results showed that the carbon sequestration value of stumpage is 11,023.753 (10,000 IRR·t^{-1}·ha^{-1}).

Table 3. The values of different variables in order to estimate the carbon model in the study area

Species	Ton C (Eq. 3) (t·ha^{-1})	Ton C (t·ha^{-1})	Ton wood (kg·ha^{-1})	Volume wood (m^3·ha^{-1})	Density of wood (kg·m^{-3})	Carbon model	Eq.
Hornbeam	28.176	32.932	56.352	80.503	0.700	$Y = 0.350X$	8
Beech	102.965	116.471	205.931	307.360	0.670	$Y = 0.335X$	9
Others	10.700	12.386	21.416	34.463	0.621	$Y = 0.310X$	10

others – maple (*Acer velutinum* Boissier), ash (*Fraxinus excelsior* Linnaeus), lime tree (*Tilia platyphyllos* Scopoli), wych elm (*Ulmus glabra* Hudson), alder (*Alnus subcordata* C.A. Meyer), Cappadocian maple (*Acer cappadocicum* Gledhill), sweet cherry (*Prunus avium* Linnaeus), ton C – total amount of carbon stored in stands, ton wood – total dry weight of the trunks of trees, volume wood – total volume of stands, density of wood – weight of trunk (ton wood) divided by wood volume, Y – dependent variable, X – independent variable

Net present value of carbon sequestration

Results indicated that the annual volume growth is 6.023 $m^3 \cdot ha^{-1}$. The annual carbon stored was determined using Eq. 6. The results showed that the annual carbon stored is 2.307 $t \cdot ha^{-1}$. The NPV of carbon sequestration was determined using Eq. 7. The real rate of interest in the capital market was assumed to be equal to 7.1%. The results showed that the net present value of carbon sequestration is 790.361 (10,000 $IRR \cdot t^{-1} \cdot ha^{-1} \cdot yr^{-1}$).

DISCUSSION

The aim of the study is to assess the economic value of Asalem forests in the north of Iran in carbon sequestration as a way of mitigating climate change through a reduction of carbon dioxide in the atmosphere. Results indicated that the volume growth and the carbon stored were calculated as 6.023 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ and 2.307 $t \cdot ha^{-1} \cdot yr^{-1}$, respectively. Determining the amount of carbon stored and the rate at which forests release and sequester carbon is important for understanding the potentials of such uses of forests (Botkin et al. 1993). Thus carbon sequestration is particularly sensitive to managerial actions that affect the amount and structure of tree crowns, above- and below-ground microclimate, and structure and chemical composition (i.e., C/N ratio) of the forest floor and soil beneath. Measurements of the scale and activities of these terms separately provide a basis for evaluation of the likely impacts of management actions (Jarvis et al. 2005). Approximately 40% of annual carbon is absorbed by volume growth in above ground. Alternatively, credits could be generated from activities that remove CO_2 already in the atmosphere by growing additional forests to sequester carbon. Each ton of carbon sequestered in new forests and certain forestry practices could generate tradable credits (forest carbon credits) that companies could buy as a means of offsetting their emissions or sell to others desiring offsets to their own greenhouse gas emissions (Scarborough 2007). Heal (2000) validated that the use of tradable permits in the European Union Emissions Trading Scheme (EU ETS) market has created a price for the abatement of carbon emissions. If forests have the ability to sequester carbon, then the EU ETS permit price can be multiplied by the amount of carbon sequestrated by each hectare of forest in order to obtain the value of carbon sequestration. The results also showed that the net present value of carbon sequestration and the sequestrated carbon value of stumpage or above ground were estimated to be 790.361 and 11,023.753 (10,000 $IRR \cdot t^{-1} \cdot ha^{-1} \cdot yr^{-1}$), respectively. In addition, carbon sequestration calculations in forest can function as an index of productivity of the woodland habitat with the exception of wood value. Therefore it can be considered in economic equations for sustainable forestry management (Nejadi, Rahbar 2012). The use of market price to estimate the economic value of ecosystem service such as carbon sequestration is criticized for not truly reflecting the value of the ecosystem service (Jerath 2012; Ninan, Inoue 2013). Nabavi and Keivan Behjou (2012) estimated total carbon stored in trees (branches, leaves, crown and trunk) and its economic value in Shafarood forest of Caspian forest using String methods and volume growth. The results showed that the value of carbon stored was determined to be 560.150 (10,000 $IRR \cdot t^{-1} \cdot ha^{-1} \cdot yr^{-1}$). Different forests may provide the same services, but the value of the services may depend on the species. The amount of CO_2 equivalent stored per hectare of forested land depends on local climate, soil type, hydrology, species choice, stocking density, age distribution and management regime (Lopes 2013). In our study, the species type was beech and hornbeam and other species. It seems that the difference in species type and case study has caused that the economic value per hectare is different. In addition, we estimated the weight of crown and trunk in trees, while in this study total carbon stored in trees including branches, leaves, crown and trunk was estimated. Badehian et al. (2014) estimated the economic value of carbon sequestration using the cost avoided damage method in Kheyroud Kenar forest, north of Iran. The results of their study revealed that the average value of mix beech stand is 830 (10,000 $IRR \cdot t^{-1} \cdot ha^{-1} \cdot yr^{-1}$) in terms of the carbon sequestration function. In this study the total of carbon stored was estimated (soil and biomass), while in our study the amount of biomass was estimated. Häyhä (2014) focused on the supply and spatial distribution of ecosystem services in a forest area in the Italian Alps. The ecosystem services were evaluated both in biophysical and economic units. He estimated the economic value of carbon sequestration above ground using an economic indicator of carbon emission permit price. The emission permits regulated by the EU ETS were used to estimate the economic value of carbon sequestration. Average price of 15 $EUR \cdot t^{-1}$ CO_2 was used (Kossoy, Ambrosi 2010). The results showed that the economic value of carbon sequestration was 76 EUR·ha^{-1}·yr^{-1} and the most important areas were located in Fiemme Valley. This study showed the importance of estimating the economic value of carbon sequestration in the forest.

CONCLUSIONS

At the global level, 19% of carbon in the earth's biosphere is stored in plants and 81% in the soil. In all forests, approximately 31% of carbon is stored in the biomass and 69% in the soil. The carbon reservoir in the forest biomass and soil is very large, highlighting the importance of conserving natural forests, and eliminating agricultural practices which contribute to the deterioration of these reservoirs (Karsenty et al. 2003). As it was discussed, carbon is found in several pools in the forest such as living plant biomass, dead wood and litter and soil organic matter. Hence, in the future studies we recommend to use other pools in order to estimate the economic value and the results will be more realistic. For example, soil organic matter is an important source that stores carbon. Our results are very useful in estimating the total of economic value in the study area. This research provides statistical analyses for carbon estimation that can be used to assess the actual and potential role of forests in reducing atmospheric carbon dioxide and also by estimating the value of carbon, we can determine the value of non-marketable forest products, which can help in future decisions and policies in forest management. Hence, the forest decision makers may use the results of this research for planning a multi-objective forest management plan.

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