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VALUATION OF CARBON SEQUESTRATION AND ESTIMATION OF CO_2 EMISSION IN THE HYRCANIAN FORESTS OF IRAN

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Abstract

The aim of this study was to estimate the aboveground carbon sequestration and the amount of CO_2 emissions at logging operation in Hyrcanian forests of Iran. Required data, such as forest standing stock, annual growth increment of trees, wood density and timber harvesting, were collected from secondary sources. Allometric equation was used for estimating the carbon sequestration. The amount of CO_2 emission was calculated. Results showed that the annual growth per hectare and the amount of carbon sequestration per growth were 3.37 $m^3 \cdot yr^{-1}$ and 1.14 $t \cdot ha^{-1}$, respectively. Results also indicated that the value of aboveground sequestrated carbon and its net present value were 71,217.63 (10,000 $IRR \cdot ha^{-1}$) and 12,668.28 (10,000 $IRR \cdot ha^{-1}$), respectively. Finally, the amount of carbon emission per hectare was calculated, as it was 0.01078 $t \cdot ha^{-1}$ per year. The results of emission and carbon sequestration per hectare of the forest show that not only logging per hectare of forest will eliminate annual carbon sequestration, but also leads to an increase in CO_2 into the atmosphere due to harvest activity.

Key words: aboveground biomass, allometric models, NPV, sustainable forest management, wood density.

Introduction

Forest ecosystems services are extremely vital for human beings. In this regard, carbon storage is one of the most important ones. An important criterion for considering the importance of ecosystem services is to assess their economic value. The monetary value of carbon sequestration in forests remains unknown, whereas many ecosystem services have been measured in this way. As a result, market prices do not reflect the true value of these services. In fact that many decisions made by the government or the private sector are based on market price information for these services, the lack of real value of carbon sequestration leads to erroneous decisions about forest ecosystem management (Brack 2019).

In forest ecosystems, carbon exists in various forms. Different approaches have been used to provide forest carbon estimation and inventory (Andersson et al.

2009). Two fundamental forms need to be distinguished – carbon in the soil and carbon in the plant biomass (Lal 2005). Carbon in biomass means aboveground biomass and belowground biomass. Woody debris is also added as plant biomass. The carbon content of wood vegetation is quantified by a coefficient of 0.5. Therefore, the amount of carbon is often assessed by stand's biomass amount using a transformational assessment (Tyrrell et al. 2009). These variations are influenced by climate, species, site productivity, and silviculture (Jarvis et al. 2005). By measuring the amount of carbon, we can estimate the stored carbon (Zhang et al. 2009).

There are numerous other ways to estimate carbon store and flux. In the case of access to actual tree values (diameter of the breast height 'DBH' and height) relative to the target population, biomass equations are preferred (Zhang et al. 2009). Allometric models employ distinct tree parameters including DBH and total tree height (ht) from forest inventory for estimating the aboveground biomass volume. A further principle explanatory variable for an allometric model to estimate biomass is the basic density of wood, which is evaluated based on dry mass to green volume ratio of wood samples in the laboratory (Cole and Ewel 2006).

Allometric correlations of tree size parameters (DBH, stem diameter at ground surface and tree height) and the biomass of stem, leaf and total root in different trees from tropical secondary-forest in Sarawak, Malaysia, were established by Kenzo et al. (2009).

Moreover, site-specific and general models were developed by Mugasha et al. (2016) to estimate the aboveground biomass and total tree volume using allometric models. Their findings show that tree allometry differs significantly between site-specific ht-DBH models of the studied forests, which seems appropriate for tree height estimation. Allometric biomass models that include basic density of wood are strongly recommended to enhance the accuracy of estimates where this information is available.

Miah et al. (2020) used allometric models to determine the aboveground biomass for five homestead tree species in Bangladesh. Their results showed that for most of the species a combination between DBH at 1.3 m above the ground and ht is the explanatory variable that is required.

The need to quantify carbon stocks in various types of forests is equally significant for emerging carbon market mechanisms including emissions reduction and deforestation. To achieve this, suitable allometric patterns are required for a particular type of forest (Molto et al. 2013). Allometric models use separate tree parameters including DBH and ht of the forest inventory and wood basic density for estimating the volume of carbon stored in the stock of aboveground biomass (AGB). This factor is determined as the dry mass to green volume ratio of wood samples in the laboratory (Chave et al. 2014).

The ht-DBH models were developed for four major types of forests (such as plain forests) by Mugasha et al. (2013). Due to the significant changes in ht at various forest areas depending on climate function and other environmental factors, a local ht-DBH model should be developed to better estimate the volume of tree or biomass (Feldpausch et al. 2012).

Manual and mechanized operations in forestry management activities involve fossil fuel usage and there will be emission of CO_2 into the atmosphere. To perform a complete and precise assessment of the net carbon balance in the forestry ecosystem, quantification of CO_2 emissions from forestry operations is essential (Liski et al. 2001). This amount is generally estimated according to the quantity of fuel consumption during each operation and each fuel's specific emission (Berg and Karjalainen 2003). The quantity of fuel usage during each operation can be calculated directly from real data of the machinery operation (Berg and Lindholm 2005). It maybe also obtained indirectly from the effective working time required for performing the operation and the relevant machine fuel usage per hour work (Schwaiger and Zimmer 2001). Dias et al. (2007) developed and exerted a methodology to evaluate CO_2 emissions of fossil fuel from operations carried out in Portuguese eucalyptus and maritime pine stands. These results suggest that tree logging represents for about 40 % of the total CO_2 emissions per year from these stands. Mohammadi Limaei (2020) investigated the efficiency of forest management units considering economics and carbon dynamic. Carbon sequestration and CO_2 emissions were considered in efficiency analysis of forest management units in Hyrcanian forests or Caspian forests of Iran.

In forestry studies, there is less attention to carbon sequestration by trees, as well as CO_2 emissions during the harvesting and transportation of raw materials. Ignoring the amount of carbon sequestration of trees and carbon emissions from logging operations in forest areas may adversely affect the appropriate forest management plans. Hence, in this study, the role of the Shafarood forest in Iran in mitigating climate change through carbon sequestration is investigated. In addition, forest management has been evaluated by considering CO_2 emissions during the logging operations. The results of this study assess the potential economic value of carbon sequestration in Iranian Hyrcanian forests and its potential to contribute to the carbon trade. Moreover, based on the inventory data, we examined the status of the carbon stock and subsequently determined the carbon model using allometric equations in Iranian Hyrcanian forests.

Material and Methods

Study area

This study was performed in Shafarood district No. 7 at Bargah Zamin forests, Guilan province in north of Iran. The altitude ranges from 1000 to 2050 m a.s.l., the latitude is 37°21'50" N, and the longitude is 48°59'00" E (Fig. 1). This forestry district has a total area of 1064 ha and the harvesting site is 437.5 ha. The volume per hectare in this district is 303.96 $m^3 \cdot ha^{-1}$. Forest types in the central part of this district are Oriental beech (*Fagus orientalis* Lipsky), Caucasian alder (*Alnus subcordata* C.A.Mey.), common hornbeam (*Carpinus betulus* L.), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey.) and other industrial species such as Persian maple (*Acer velutinum* Boiss.), large-leaved lime (*Tilia platyphyllos* Scop.), common ash (*Fraxinus excelsior* L.), wych elm (*Ulmus glabra* Huds.), sweet cherry (*Prunus avium* L.), Cappadocian maple (*Acer cappadocicum* Gled.). For brevity, only the generic names of these species are used henceforth. The average annual rainfall is 989.7 mm and the average annual temperature is 15.2 °C. The wood volume per hectare of tree species such as beech, hornbeam, oak, alder, and other species are 170, 77.42, 3.16, 37.11 and 16.26 $m^3 \cdot ha^{-1}$, respectively. The

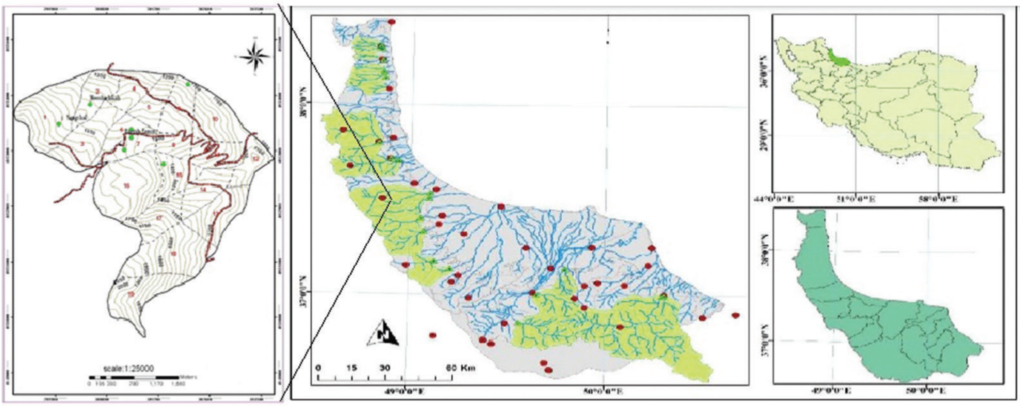

Fig. 1. Geographical location of the study area in Shafarood watershed in the west of Hyrcanian forests, north of Iran.

growth rate in the region is 3.37 $m^3·ha^{-1}$. The amount of harvested timber in Shafarood forests was 1073 m^3 per year for the whole district and 2.45 $m^3·ha^{-1}$ per year (Shafarood forestry plan booklet 2011). In Iran, the policy of harvesting 50 % of the growth rate was on the agenda as a pillar in forest rehabilitation management. The reason for this was that the forest exploitation policy will be in order to create a breathing space in the occurrence of maximum growth potential and volume. This policy was implemented for one or two 10-year periods, and will continue if the volume and growth do not reach to the target. Currently, there is a logging ban in Hyrcanian forests of Iran due to socio-economics problems and environmental issues.

Collecting data

Data such as tree species types, wood density, DBH and stock are essential to use in the allometric model. The wood density of beech, hornbeam, alder, oak, and the other species (maple, ash, elm, etc.) are 0.670, 0.700, 0.58, 0.64, and 0.62 $t·m^{-3}$, respectively (Parsa-Pajouh 1995). Therefore, their average wood density is 0.642 $t·m^{-3}$. Nevertheless, inventory form sample plots are very difficult and costly. Therefore, required data such as volume per hectare, DBH, species types and harvested timber have been collected from Shafarood forestry plan booklet (2018). Annual growth data was collected from previous research in the study area (Bonyad 2005).

Estimation of stored carbon

The estimation of carbon sequestration quantity in tree species was performed based on inventory and wood density. Then, the carbon model was estimated. Finally, the coefficients of each variable, related to the carbon equation, was determined. Kabiri Koupaei (2009) estimated the allometric equations of tree canopies based on DBH for beech-hornbeam mixture in Kheirud Kenar forest in Iranian Hyrcanian forests. Due to species composition similarity and climatic status between our study region and that area, we used allometric equations estimated by Kabiri Koupaei (2009) (Table 1).

Table 1. Estimated parameters of tree crown in allometric equations for beech-hornbeam mixed forest.

Species	Dependent variable	Independent variable	Parameter		R^2
			b_0	b_1	
Beech	V, m^3	DBH, cm	0.00025	2.4	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	2.492	0.955
Other industrial species	V, m^3		0.00027	2.381	0.983
	B_{Cr}, kg		0.005	2.696	0.933

Note: These parameters were provided based on the findings by previous studies (Kabiri Koupaei 2009).

The allometric equation (1) is presented below:

$$Y = b_0 \cdot X^{b_1}, \quad (1)$$

where: Y is dependent variable, b_0 and b_1 are coefficients, and X is independent variable.

The quantity of carbon stored in the biomass is determined based on the dry weight of the biomass (Parsa-Pajouh 1995). In forest trees, 50 % of the dry weight of the mass is assumed to be equal to the weight of stored carbon (Tyrrell et al. 2009). First, the dry weight of the biomass was obtained through volume and volumetric biomass. The dry weight of the biomass for the ground cover of forest trees includes the crown of forest trees and the trunk of forest trees.

The trunk weight of the mass trees in various diameter classes was obtained by using the volume and volumetric mass of the identified species. The canopy mass of forest trees (kg) was also calculated using the number of trees and allometric equations. The weight of the mass trees was obtained by adding the mass of the trunks and crown of the trees (kg·ha^{-1}). Subsequently, the amount of calculated carbon is divided by 1000 to calculate the amount of carbon (t·ha^{-1}).

Prediction of carbon model for various tree species

Carbon model for each species is obtained using equation (2) (Kabiri Koupaei 2009). The amount of stored carbon (t·ha^{-1}) depends on the volume of various diameter classes (cm).

$$QC = \frac{DW}{V_1} \cdot \frac{qc}{DW} \cdot V_t, \quad (2)$$

where: QC is total quantity of carbon stored in the stands per hectare (t·ha^{-1}), DW is quantity dry of weight of tree trunks per m^3 (t·m^{-3}), V_1 is one m^3 of wood volume, and V_t is total volume of stands per hectare (m^3·ha^{-1}).

Wood density (WD, t·m^{-3}) is calculated by dividing the trunk weight (ton wood) per the volume of wood (one m^3). $\frac{qc}{DW}$ is the ratio of quantity of carbon (qc) per quantity of dry weight of trees trunks (DW) = 0.5. Then, the carbon model is determined by using equation (3) for various species of trees in stands.

$$QC = WD \cdot 0.5 \cdot V. \quad (3)$$

The relationship between stored carbon and volume per hectare was determined for various species by equation (4).

$$Y = a(i)X, \quad (4)$$

where: Y (t·ha^{-1}) is related to the volume of various diameter classes, $a(i)$ represents the quantity of wood density, and X (m^3) = 0.5.

The value of sequestrated carbon in stumpage or aboveground (V_{cs}) is calculated by equation (5) (Mohammadi et al. 2017).

$$V_{cs} = P_c \cdot \bar{v}, \quad (5)$$

where: P_c is carbon price per ton (Iranian Rials or IRR) and $\bar{v}$ is average volume in compartment (m^3·ha^{-1}).

Estimating the net present value for carbon sequestration

The amount of carbon emitted from the stump is calculated based on net present value (NPV) of the shelf life or stable flow of the same cash flows at any time. For estimating carbon sequestration per year, the annual base volume growth for each species was calculated by diameter increment data and tariff. Annual stored carbon is calculated using equation (6) (Mohammadi et al. 2017):

$$C_a = \frac{c_t \cdot g}{\bar{v}}, \quad (6)$$

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

To determine the annual volume growth in stand, the growth data of previous research by Bonyad (2005) and the volume data per hectare of the forestry plan booklet of the region (Shafarood forestry plan booklet 2011) were used. Then, according to the logarithmic functions between the growth and the volume of different species, the amount of annual volume growth was determined.

The net present value for carbon sequestration or NPVc (10,000 IRR·ha^{-1}) is calculated using equation (7):

$$NPV_c = \frac{C_a \cdot P_c}{i}, \quad (7)$$

where: P_c is carbon price per ton (IRR·t^{-1}) and i is real rate of interest.

The real interest rate is calculated from the average between the deposit interest rate and the interest rate of loan after subtracting the inflation. Numerical data of nominal interest rate and inflation rate was collected from the Central Bank of Iran during 2017–2019 (Central Bank of Iran 2019).

Estimate of CO_2 emission

No appropriate data was available on CO_2 emissions from logging in the Hyrcanian forests of Iran. Consequently, the quantity of CO_2 emissions was estimated during the logging operation using chainsaw in various forest management plans. Dias et al. (2007) calculated the average CO_2 emission in operation during the logging by means of chainsaw including cutting and processing (felling, limbing, bucking and debarking), extraction and loading logs onto trucks in Portugal for eucalypt and maritime pine stands. Their results showed that the average CO_2 emission in operation was 0.0044 t·m^3. As a result, wood production in various forest management units was multiplied to 0.0044 t and the quantity of carbon emission was estimated. It is important to note that the Hyrcanian temperate forests with mixed hardwood species are completely different from eucalypt and pine stands in Portugal, but the similarity of forest logging using chainsaw in both regions was the major reason for using the results of Dias et al. (2007) as a reference for estimating the CO_2 emission in the present study.

Analysis of Variance

One way Analysis of Variance (ANOVA) performed using Excel software to investigate, whether a significance differences exists among the average carbon sequestration in different diameter classes for five tree species in this study.

Carbon model

Carbon coefficients were determined by dividing the amount of carbon for each tree to the volume of that tree species and used as the coefficient of variables in the equation of stored carbon in the forest aboveground. Using these coefficients, the stored carbon equation was determined using equation (3) and then the amount of aboveground carbon was determined using equation (4). This amount was 102.87 $t{\cdot}ha^{-1}$.

Carbon models of beech, hornbeam, alder, oak, and others in the study region are shown in Table 2. According to the Table 2, because the density of wood is different among the species, the X coefficients in various carbon models change from 0.29 to 0.35.

Table 2. Numerical values of various variables used in the estimation of carbon model in study area.

Species	*QC*, $t{\cdot}ha^{-1}$	*DW*, $t{\cdot}m^{-3}{\cdot}ha^{-1}$	*V*, $m^3{\cdot}ha^{-1}$	*WD*, $t{\cdot}m^{-3}$	Carbon model
Beech	57.86	115.72	172.72	0.67	Y=0.335X+0.0000004
Hornbeam	27.54	55.07	78.66	0.7	Y=0.3501X+0.000008
Alder	0.93	1.86	3.21	0.58	Y=0.29X+0.000004
Oak	12.08	24.15	37.71	0.64	Y=0.32X+0.0003
Other industrial species	4.46	8.91	14.32	0.62	Y=0.3107X+0.0002

Statistical analysis

Results of ANOVA between the average carbon sequestrations in various species at different diameter classes is shown in Table 3. Results indicated that there is a significant difference at significance level of 0.01 in the average carbon sequestration among all species in different diameter classes.

Table 3. Results of ANOVA between the average carbon sequestrations among various tree species in different diameter classes.

Source of variation	SS	df	MS	*F*	*p*-value	F_{crit}
Between groups	85.74	5	17.15	38.6667	2.71226E-26	2.27
Within groups	74.50	168	0.44			
Total	160.21	173				

The value of aboveground carbon sequestration

To calculate the aboveground stored carbon in Shafarood forests, the average world price per ton of carbon was used. The price of carbon per ton equals to 27.02 USD (World Bank 2020). Depending on the exchange rate in the free market, this is equivalent to 6,923,064.4 IRR. As a result, the value of carbon sequestration in stumpage using equation (5) is 2779.55 USD equal to 71,217.63

(10,000 IRR·ha^{-1}).

The annual volume growth is 3.37 m^3·ha^{-1}. Therefore, the annual stored carbon per growth was determined by equation (6) and it was 1.14 t·ha^{-1}. Moreover, the NPV of carbon sequestration was calculated using equation (7). The real interest rate was 6.23 %. The results indicated that the NPV of carbon sequestration was 494.43 USD or equal 12,668.28 (10,000 IRR·ha^{-1}·yr^{-1}).

The amount of wood harvested is 2.45 m^3·ha^{-1}. Hence, the ratio of carbon sequestration will be 0.83 t·ha^{-1} by using equation (6). The NPV of carbon sequestration was 359.98 USD or equal 9215.488 (10,000 IRR·ha^{-1}·yr^{-1}) by using equation (7).

Estimation of CO_2 emission

The amount of carbon emission estimated by Dias et al. (2007) was equivalent to 0.0044 t·m^3, the carbon emission rate was 0.01078 t·ha^{-1} per year. The carbon emission was 4.72 t in this entire study area per year (the harvesting site is 437.5 ha). The quantity of CO_2 emissions in this study for various species during logging operation was estimated. Results indicated that CO_2 emissions for beech, alder, hornbeam, oak and the other species were 0.0061, 0.0028, 0.00011, 0.0013, and 0.0005 t·ha^{-1} CO_2 per year, respectively.

Discussion

The results indicated that the amount of volumetric growth and carbon sequestration in this area is 3.37 m^3·ha^{-1} and 1.14 t·ha^{-1} per year. The forest ecosystem is composed of several elements, each of which is involved in carbon sequestration. Technically, the amount of carbon sequestration is only based on the growth of the volume of trees in the aforementioned mass, which is in terms of the current situation, not the potential, and at the same time, the shrubs have not been calculated. The amount of volumetric growth and carbon sequestration in the study of Mohammadi et al. (2017) in Asalem forests of northern Iran were 6.023 m^3·ha^{-1} and 2.307 t·ha^{-1}. The volume per hectare and density of trees may be the reason of disproportionate distribution and changes in biomass and carbon sequestration in these forests. The average volume per hectare in study area by Mohammadi et al. (2017) was 453.28 m^3·ha^{-1} and in this study area is 303.96 m^3·ha^{-1}.

Various forests can offer similar services, although the value of them may be dependent upon the species. The quantity of CO_2 stored per hectare of forested land is dependent upon local climate, species selection, distribution of age, hydrology, soil type, stocking density and management regime (Lopes and Cunha-e-Sá 2014).

In this study the amount of forest biomass carbon sink of 102.87 t·ha^{-1} per year worth about 71,217.63 (10,000 IRR·ha^{-1}). Nabavi and Behjoo (2012) calculated the total stored carbon in the leaves, branches, crown and trunk of trees in Shafarood forest by string methods and volume growth and its economical value was calculated as it was 5,601,545 IRR·ha^{-1}·yr^{-1}. Apparently, the diversity among species and case study has resulted the difference in economic value per hectare. In present study, the types of species were beech, alder, hornbeam, oak and others. Furthermore, we estimated crown and trunk weight, while Nabavi and Behjoo (2012) calculated total carbon stored in leaves, branches, crown and trunk of trees. Therefore, forest management methods affects the quantity of carbon stored in soils, biomass and forest products, and the amount of emissions into the atmosphere (United Nations Economic and Social Council 2014). Moreover, it provides several job opportunities in the area, as well as social, economical, environmental and health benefits. Hence, it can be considered as an economic income source for sustainable forest management to increase the participation of the local community on climate change mitigation and biodiversity protection, and to produce wood biomass (Nejadi and Rahbar 2012, Mohammadi et al. 2017).

Allometric models used in this paper for quantifying biomass carbon will significantly improve capacity to directly estimate the aboveground carbon sequestration at the Shafarood forest in the north of Iran. The species investigated in this study are very important for economically, environmentally and social aspects in the region. The estimated carbon stored models in this study can be applied for carbon balance. These results are consistent with results of Vaidya et al. (2017). Their findings show that different generalized allometric equations were developed to estimate biomass carbon. Under future UNFCCC commitment periods, each country will have to provide detailed statements on its overall carbon budget.

Aabeyir et al. (2020) developed allometric models for assessing modelling aboveground biomass in Ghana's savannah forests. Their study showed that wood density and DBH were the major predictors that had a significant effect on the variability of aboveground biomass modelling. Thus, the allometric model of their research provide an appropriate local allometric tool filling an important gap in estimating of aboveground biomass modelling for Ghana's tropical forests (Aabeyir et al. 2020).

In the present study, the results of allometric relations showed a high significant correlation coefficient. This slight interspecific difference in the allometric relationships of the stem and total biomass with DBH may be obtained from the similarity of wood density among Shafarood forest trees as it is 0.6–0.7 $t{\cdot}m^3$. Kenzo et al. (2009) demonstrated that secondary-forest trees have a less density of wood (0.2 to 0.5 $t{\cdot}m^3$) in comparison with trees from the tropical rain-forest in late succession, which extend from 0.2 to 0.8 $t{\cdot}m^3$ within the tropical rain timberlands of South-East Asia (Whitmore 1990, Suzuki 1999). In reality, the particular gravity of tree species under our consideration has changed inside a little run from 0.29 to 0.53 $t{\cdot}m^3$. Moreover, Hashimoto et al. (2004) have explained the details of similar allometric relations among their tropical secondary-forest trees, which was also similar in wood density, in South-East Asia. Aabeyir et al. (2020) also have similar allometric relationships in Ghana's tropical forests, West Africa. The density of wood in their study was between 0.5–0.89 $t{\cdot}m^3$.

By comparing carbon sequestration by forests with its artificial methods, we can mention, refining carbon with artificial methods such as filters involves heavy costs. Therefore, in order to reduce the atmospheric carbon dioxide and balance the content of greenhouse gases, the atmospheric carbon must be absorbed and deposited in various forms. Carbon sequestration in plant biomass and soils under this biomass is the simplest and most economically viable solution to reduce the atmospheric carbon dioxide (Nelson et al. 1999). Refining carbon with synthetic methods, such as filters, is costly, at around 600 $\${\cdot}t^{-1}$ in the United States (Service 2018).

Therefore, if this carbon was to be refined artificially, it would cost $ 61,722 or

1,581,441.084 (10,000 IRR·ha^{-1}) per hectare (considering the average of $ 600 per ton of carbon and 256,220 IRR per dollar in 2021). Hence, the damage caused by harvesting of these species in the Hyrcanian forests in terms of carbon sequestration is significant.

The ANOVA test used to determine if the means of carbon sequestrations for various tree species in different diameter classes are significantly different from each other. Results indicated that there is a significant difference at the average of carbon sequestrations in various tree species at different diameter classes at the significance level of 0.05 (tables 1 to 3). Hence, the results of this research is in line with finding of Färe et al. (1989) that failure to credit plants for reducing pollution may seriously distort the classification of plant performance.

Based on the findings of this study, the amount of CO_2 emissions in the logging operation was 0.01078 t·ha^{-1} per year and carbon sequestration quantity was about 0.083 t·ha^{-1}. Comparing the amount of emissions and carbon sequestration per hectare of forest, it can be mentioned that the amount of CO_2 emissions in logging operations is lower than carbon emissions from other activities in the forest such as transportation operations, wood processing, uncontrolled logging and unsupervised selective wood cutting (Pearson et al. 2014). The volume of harvested wood in this study is equivalent to 2.45 m^3·ha^{-1} with a carbon sequestration of 0.83 t·ha^{-1}. Hence, by harvesting this amount of wood, its deposition function is eliminated in the atmosphere. Furthermore, the machine activities for cutting 2.45 m^3·ha^{-1} cause the emission of 0.01078 t·ha^{-1} excess CO_2. Although the fact that the amount of carbon emission by the machines is low, but because of being seen it is necessary to be mentioned.

The economic value of 2.45 m^3 of wood is equal to 860 USD based on USD to IRR exchange rate in the market in 2020 and the economic value of its carbon sequestration is 359.98 USD. This is the only value of the tree's aboveground carbon sequestration, which accounts for 30 % of total, and the rest of it (70 %) such as belowground, soil and dead organic matter are not estimated in this study (Pache et al. 2021). Carbon sequestration is only one of the tree services whose value has been estimated in this study and the value of other tree services have not been considered such as soil conservation, water storage and recreational values, etc. Hence, the suggestion is to determine the value of other services also in Hyrcanian forests and determine optimal forest policy based on environmental, economic and social values.

Conclusion

Estimating the monetary value of carbon sequestration as an important forest service is a very important issue. Despite the various studies on economics values of carbon sequestration, it is still required more investigation as this value is highly related to geographical locations and species diversity of forests. In addition, market prices are not reflecting the values of forest ecosystem services. However, a large number of decisions from the public and private sectors are made in response to market information, non-quantified carbon sequestration value could result in poorly informed decisions on forest management. Overall, the amount of carbon storage in forests is declining due to forest degradation and loss in Hyrcanian forests of Iran. The results of this study may serve as a guideline for policy makers for sustainable forest management considering carbon dynamic.

References

Aabeyir R., Adu-Bredu S., Agyare W.A., Weir M.J. 2020. Allometric models for estimating aboveground biomass in the tropical woodlands of Ghana, West Africa. Forest Ecosystems Journal 7: 1–23. DOI:10.1186/S40663-020-00250-3

Andersson K.P., Plantinga A.J., Richards K.R. 2009. The national inventory approach for international forest-carbon sequestration management. Oxford Scholarship Online. DOI: 10.1093/acprof:oso/9780199573288.001.0001

Berg S., Karjalainen T. 2003. Comparison of greenhouse gas emissions from forest operations in Finland and Sweden. Forestry 76: 271–284. DOI: 10.1093/forestry/76.3.271

Berg S., Lindholm E.L. 2005. Energy use and environmental impacts of forest operations in Sweden. Journal of Cleaner Production 13: 33–42. DOI:10.1016/j.jclepro.2003.09.015

Bonyad A. 2005. The final report of the research project, measurement and statistical analysis of forest growth in three elevation profiles in Shafarood watershed. 197 p. (in Persian).

Brack D. 2019. Forests and Climate Change. Background study prepared for the fourteenth session of the United Nations Forum on, Forests. Available at: https://www.un.org/esa/forests/index.html. (Access date, 28 February, 2020).

Chave J., Réjou-Méchain M., Búrquez A., Chidumayo E., Colgan M.S., Delitti W.B., Duque A., Eid T., Fearnside P.M., Goodman R.C. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology 20: 3177–3190. DOI:10.1111/gcb.12629

Cole T.G., Ewel J.J. 2006. Allometric equations for four valuable tropical tree species. Forest Ecology and Management 229: 351–360. DOI: 10.1016/j.foreco.2006.04.017

Dias C.A., Luís A., Isabel C. 2007. Carbon dioxide emissions from forest operations in Portuguese eucalypt and maritime pine stands. Scandinavian Journal of Forest Research 22: 422–432. DOI:10.1080/02827580701582692

Färe R., Grosskopf S., Lovell C.K., Pasurka C. 1989. Multilateral productivity comparisons when some outputs are undesirable: a nonparametric approach. The Review of Economics and Statistics 71(1): 90–98. DOI:10.2307/1928055

Feldpausch T.R., Lloyd J., Lewis S.L., Brienen R.J., Gloor M., Monteagudo Mendoza A., Lopez-Gonzalez G., Banin L., Abu Salim K., Affum-Baffoe K. 2012. Tree height integrated into pantropical forest biomass estimates. Biogeosciences 9: 3381–3403. DOI:10.5194/bg-9-3381-2012

Hashimoto T., Tange T., Masumori M., Yagi H., Sasaki S., Kojima K. 2004. Allometric equations for pioneer tree species and estimation of the aboveground biomass of a tropical secondary forest in East Kalimantan. Tropics 14: 123–130. DOI: 10.3759/tropics.14.123

Jarvis P.G., Ibrom A., Linder S. 2005. Carbon forestry–Managing forests to conserve carbon. The carbon balance of forest biomes 1: 331–349.

Kabiri Koupaei K. 2009. Carbon sequestration and its spatial pattern in the above-ground woody compartment of a pure and mixed beech stand: A case study of Gorazbon Forest, north of Iran, University of Tehran, Iran. 102 p.

Kenzo T., Ichie T., Hattori D., Itioka T., Handa C., Ohkubo T., Kendawang J.J., Nakamura M., Sakaguchi M., Takahashi N. 2009. Development of allometric relationships for accurate estimation of above-and below-ground biomass in tropical secondary forests in Sarawak, Malaysia. Journal of Tropical Ecology 25(4): 371–386. DOI:10.1017/S0266467409006129

Lal R. 2005. Forest soils and carbon sequestration. Forest Ecology and Management 220: 242–258.

Liski J., Pussinen A., Pingoud K., Mäkipää R., Karjalainen T. 2001. Which rotation length is favourable to carbon sequestration? Canadian Journal of Forest Research 31: 2004–2013. DOI:10.1139/x01-140

Lopes A.F., Cunha-e-Sá M.A. 2014. The economic value of Portuguese forests–the effect of tree species on valuation of forest ecosystems. AERNA Congress, September 4–6, 2014. 13 p.

Miah M.D., Islam K.N., Kabir M.H., Koike M. 2020. Allometric models for estimating aboveground biomass of selected homestead tree species in the plain land Narsingdi district of Bangladesh. Trees, Forests and People 2, 100035. DOI: 10.1016/j.tfp.2020.100035

Mohammadi Limaei S. 2020. Efficiency analysis of forest management units considering economics andcarbon dynamic: A data envelopment analysis (DEA) approach. Austrian Journal of Forest Science 137: 199–221.

Mohammadi Z., Mohammadi Limaei S., Lohmander P., Olsson L. 2017. Estimating the aboveground carbon sequestration and its economic value (case study: Iranian Caspian forests). Journal of Forest Science 63: 511–518. DOI:10.17221/88/2017-JFS

Molto Q., Rossi V., Blanc L. 2013. Error propagation in biomass estimation in tropical forests. Methods in Ecology and Evolution 4: 175–183. DOI:10.1111/j.2041-210x.2012.00266.x.

Mugasha W.A., Bollandsås O.M., Eid T. 2013. Relationships between diameter and height of trees in natural tropical forest in Tanzania. Southern Forests: a Journal of Forest Science 75: 221–237. DOI:10.2989/20702620.2013.824672

Mugasha W.A., Mwakalukwa E.E., Luoga E., Malimbwi R.E., Zahabu E., Silayo D.S., Sola G., Crete P., Henry M., Kashindye A. 2016. Allometric models for estimating tree volume and aboveground biomass in lowland forests of Tanzania. International Journal of Forestry Research 4: 1–13. DOI:10.1155/2016/8076271

Nabavi S.F., Behjoo K. 2012. Determination of the economic value of forest by focused on potential of carbon sequestration, case study (Guilan forests). Proceedings of the 1st National Conference on Organic vs. Conventional Agriculture, Ardabil, October 17–19, 2012. 5 p.

Nejadi A., Rahbar F. 2012. Economic valuation of annual carbon sequestration potential for woody and shrubby land cover. Journal of Environmental Science and Technology 5: 389–396. DOI: 10.3923/jest.2012.389.396

Nelson B.W., Mesquita R., Pereira J.L., De Souza S.G.A., Batista G.T., Couto L.B. 1999. Allometric regressions for improved estimate of secondary forest biomass in the central Amazon. Forest Ecology and Management 117: 149–167. DOI:10.1016/S0378-1127(98)00475-7

Pache R.G., Aabrudan I.V., Daniel Nita M. 2021. Economic Valuation of Carbon Storage and Sequestration in Retezat National Park, Romania. Forests 12(1), 43. DOI: 10.3390/f12010043

Parsa-Pajouh D. 1995. Wood Technology. University of Tehran Press. 404 p.

Pearson T.R.H., Brown S., Casarim F.M. 2014. Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters 9, 034017.

Schwaiger H., Zimmer B. 2001. A comparison of fuel consumption and greenhouse gas emissions from forest operations in Europe. In Karjalainen T., Zimmer B., Berg S., Welling J., Schwaiger H., Finér L., and Cortijo P. (Eds), Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products. Achievements of the working group 1 of the COST action E9. Discussion Paper 10. Joensuu: European Forest Institute. 3353 p.

Service R.F. 2018. Cost plunges for capturing carbon dioxide from the air. a report from Science in Portland. Science news website. DOI: 10.1126/science.aau4107 (Access date, 7 June, 2018)

Shafarood Forestry plan booklet 2011. Forestry Planning of District 7 of Shafarood, Watershed Number 9. Guilan Department of Natural Resources and Watershed Management. 235 p. (in Persian).

Shafarood Forestry plan booklet 2018. Guilan

Department of Natural Resources and Watershed Management. 214 p. (in Persian).

Central Bank of Iran 2019. Nominal interest rate and inflation rate. Available at: http://www.cbi.ir/ default_en.aspx (Access date, 23 December, 2020).

Suzuki E. 1999. Diversity in specific gravity and water content of wood among Bornean tropical rainforest trees. Ecological Research 14: 211–224.

Tyrrell M.L., Ashton M.S., Spalding D., Gentry B. 2009. Forests and Carbon: A Synthesis of Science, Management, and Policy for Carbon Sequestration in Forests. Yale School of the Environment Publications Series 42. Available at: https://elischolar.library.yale.edu/fes-pubs/42

United Nations Economic and Social Council 2014. Revised recommendations of the United Nations Economic Commission for Europe to the United Nations Framework Convention on Climate Change on how carbon capture and storage in cleaner electricity production and through enhanced oil recovery could be used in reducing greenhouse gas emissions. Prepared by the Group of Experts on Cleaner Electricity Production from Fossil Fuels. 6 p.

Vaidya P., Verma K., Bhardwaj S., Brahmi M., Sharma D., Gupta R. 2017. Allometric models for estimating tree biomass and soil carbon stocks of small scale plantations in subtropical-subtemperate regions of Western Himalayas. Indian Forester 143: 411–416.

Whitmore T.C. 1990. An introduction to tropical rain forests. Clarendon Press. 296 p.

World Bank 2020. Carbon Pricing Dashboard. Available at: https://carbonpricingdashboard.worldbank.org (Access date, 21 February, 2021).

Zhang X., Zhao Y., Ashton M.S., Lee X. 2009. Methods of measuring carbon in forests. In Tyrell M.L., Ashton M.S., Spalding D., Gentry B. (Eds). Forests and carbon: a synthesis of science, management, and policy for carbon sequestration in forests Yale School of Forestry & Environmental Studies 23: 183–221.