JOURNAL OF FOREST SCIENCE, *62*, 2016 (11): 501–510

doi: 10.17221/49/2016-JFS

Horizontal and vertical distribution of carbon stock in natural stands of Hyrcanian lowland forests: A case study, Nour Forest Park, Iran

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ABSTRACT: The Nour Forest Park located in the north of Iran is the most important Hyrcanian lowland forest which plays a significant role in the local/national carbon cycle. Since the forest is protectively managed, the distribution of C pools in the forest may give proper information for climate change negotiations. We investigated variations in above- and belowground C pools between three natural stand types that occur in the forest – *Alnus glutinosa-Parrotia persica* (AI), *Acer velutinum-Parrotia persica* (MI), and *Ulmus glabra-Carpinus betulus* (EH). The carbon stocks of trees, herbs and litter were measured in each stand based on a completely randomized design using nested plots. Soil organic carbon (SOC) stock was measured at two depths (0–20 and 20–40 cm). The mean organic carbon concentration of 20.61 ± 0.012% and of 31.13 ± 0.024% was directly measured for herbs and litter, respectively. The results of the paired *t*-test showed that there was no significant difference in SOC between the first depth (0–20 cm) and the second depth (20–40 cm) in AI stand though SOC was significantly different between the two depths in MI and EH stands. The carbon stock of above- and belowground biomass was not significantly different between the three stands, and carbon stock of litter was higher than that of herbs in each stand. Also, there were significant differences in the different carbon pools in each stand type; however, the different stand types did not differ in the proportion of carbon stored in different pools and in total carbon (i.e. C summed across all pools; $P > 0.05$). The findings in the different forest types showed that there was no high carbon stock variability suggesting that the horizontal and vertical distribution of carbon stocks in the forest could be in a balance, implying that the protective management could be a determining factor for the carbon balance in the forest. Regarding this issue, it is necessary to verify the variation of carbon stocks in non-protective and active forest management.

Keywords: above- and belowground biomass; carbon pool; climate change; ecosystem; soil organic carbon

With increasing carbon emission and global warming, there are more interests to estimate carbon stock in forest ecosystems. Forests play a major role in carbon uptake from the atmosphere for climate change mitigation. Iran is categorized as a country with low forest cover, and only 7.6% of its land is covered by forest ecosystems. Hyrcanian forests located in the north of Iran are the mainly industrial and ecological part of the country which considerably contributes a majority of carbon pools on a national scale. There are only small remnants of lowland forests in the plains of the Hyrcanian eco-region in Iran and Nour Forest Park constitutes the largest remaining patches.

Land-use changes in Iran have been more rapid in the last 50 years and are expected to extend and accelerate in the future (Bahrami et al. 2010; Haghdoost et al. 2013). A land-use change in natural ecosystems alters the carbon cycle balance by affecting vegetation covers and soil organic carbon

(SOC) stock. The degradation of lowland Hyrcanian forests in the south of the Caspian Sea in Iran is one of the land-use changes which occurred more than 40 years ago. Deforestation of these forests has led to elimination of endemic species diversity and agricultural development.

Carbon stocks of forest biomass and soil have broad geographical patterns and their distribution is associated with climate and vegetation type (Dixon et al. 1994). The spatial distribution of biomass and the amount of carbon stock are required for forest carbon budgets (Soenen et al. 2010). Aboveground biomass contributes the majority of carbon biomass and is highly important for carbon inventory in most mitigation projects under the Kyoto Protocol (Taghavi Bayat et al. 2012). Allometric equations or regressions including stem diameter and tree height are the common models used in forest ecosystems to quantify biomass and carbon sequestration estimation (Basuki et al. 2009; Djomo et al. 2010; Taghavi Bayat et al. 2012). Belowground carbon is attributed to belowground biomass and SOC. Measuring belowground biomass is usually hard and expensive, so root to shoot ratios are commonly developed to convert above- to belowground biomass (Green et al. 2007). Forest ecosystems store more than 70% of all SOC (Jandl et al. 2007), and the soil carbon pool is determined by the balance between carbon input by litterfall and the release of carbon during decomposition (Jandl et al. 2007). Hence, SOC can vary in stands with different composition and structure. Nour Forest Park has different stands including native tree species such as ironwood (*Parrotia caspica* C.A. Meyer.), maple (*Acer velutinum* Boissier), hornbeam (*Carpinus betulus* Linnaeus), elm (*Ulmus glabra* Hudson) and alder (*Alnus glutinosa* Linnaeus) which are commonly distributed with various abundances in different stands. Therefore, the necessity of the study mainly focused on ecological services looking at carbon stock seems crucial.

This study aims: (*i*) to estimate the carbon stock of above- and belowground pools in each stand type of the forest, (*ii*) to compare the total carbon stock among the studied stands in Nour Forest Park. The results of this study may help better understanding the contribution of Nour Forest Park (and of lowland Hyrcanian forests more generally) to the carbon budget and may provide reasons for their protection against deforestation and degradation.

MATERIAL AND METHODS

Study area. This study was conducted in the Nour Forest Park (36°32'–36°36'N and 52°08'–53°02'E) which has 3,600 ha in the Nour county in Mazandaran province, in northern Iran (Fig. 1). The forest area is generally flat and is located at 20 m below

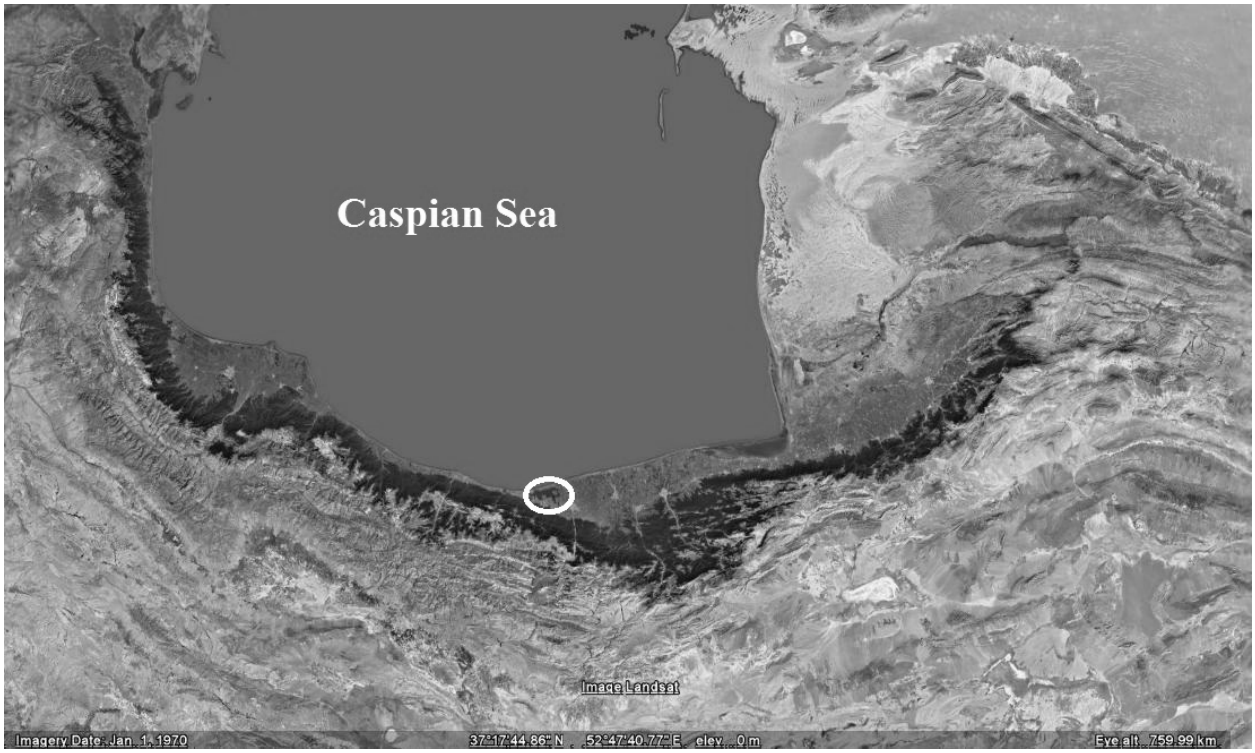

Fig. 1. Location of Nour Forest Park (36°32'–36°36'N, 52°08'–53°03'E) in the Hyrcanian region in the north of Iran

sea level. Meteorological parameters were directly measured between 1985 and 2014 at Nowshahr meteorological station which indicated that mean annual precipitation and temperature of this studied area were 1,293.5 mm and 16.1°C, respectively (Vahedi 2016). Surface soils are alluvial, deep and not well drained with clay loam texture. The soils were developed from the same parent material in the whole forest. The natural stands of *Alnus glutinosa-Parrotia persica* (AI), *Acer velutinum-Parrotia persica* (MI) and *Ulmus glabra-Carpinus betulus* (EH) are commonly broadleaved mixed-species stands in the Nour Forest Park. There are native tree species in each stand in a mixture with other ones which are ash (*Fraxinus excelsior* Linnaeus), Caucasian walnut (*Pterocarya fraxinifolia* Lamarck), Persian poplar (*Populus caspica* Linnaeus), oak (*Quercus castaneifolia* Linnaeus) and common fig (*Ficus carica* Linnaeus).

Sampling method. Three stand types of AI, MI and EH were used for collecting samples in the Nour Forest Park. Five nested sampling quadrats were established based on a completely randomized block design in each stand type. There were five replications for each stand type in the forest though five plots were randomly allocated in each stand. Quadrats of regular shape with dimensions of 20 × 20, 1 × 1 and 0.5 × 0.5 m in turn were used as plots for measuring tree biomass, vegetation and litter (Barnes et al. 1998; Kirby, Potvin 2007; Singh et al. 2011; Haghdoost et al. 2013). The inventory of all tree species was performed in the entire plot (20 × 20 m), and all vegetation was assessed in subplots of 1 m^2 that were located at the corners and centre of the plots. In each plot, tree height, DBH, crown diameter in two perpendicular directions (length and width crown diameters measured perpendicularly to each other), height to the base of the crown and percentage of foliage density within the crown or canopy were measured (Haghdoost et al. 2013). Subplots of 0.5 × 0.5 m were established in each 1 m^2 plot located at the corners and centre of the main plot (Kirby, Potvin 2007). All herbaceous plants were harvested and the entire leaf litter was collected. In each 0.5 × 0.5 m subplot, soils were dug up to a depth of 40 cm and soil samples were taken from 0–20 cm and 20–40 cm depth layer. The soil samples were then stored per layer, mixed accordingly and transported to the laboratory. Soil samples were air-dried and sieved (2-mm mesh) for laboratory analyses. All other materials < 2 mm were included in the soil samples for the soil carbon analysis (Peichl, Arain 2006). Soil samples were analysed by a local laboratory for their carbon concentration. Soil organic carbon concentration is received after oxidation with a dichromate-sulphuric acid mixture, heated at 120°C (Walkley, Armstrong Black 1934). Bulk density was determined by excavating with a cylinder (MacDicken 1997).

Analysis of tree biomass and carbon estimation. The allometric relation of Ponce-Hernandez et al. (2004) was used for estimating above- and belowground biomass in each natural stand. In order to estimate the tree aboveground biomass, trees were sorted according to their morphology including the stem and crown form (Fehse et al. 2002; Haghdoost et al. 2013). To estimate stem biomass, basal area (*BA*) and stem volume (V_s) of each tree were calculated (Eqs 1 and 2):

$$BA = (\pi/4) \times DBH^2 \quad (1)$$

$$V_s = BA \times h \times F_{fa} \quad (2)$$

where:

h – tree height,

F_{fa} – average form factor.

Based on the tree species architectures in the Hyrcanian forests, the average form factor of 0.5 was considered in Eq. 2 (Namiranian 2003).

To calculate crown volume (V_c), Eq. 3 was used (Ponce-Hernandez et al. 2004; Haghdoost et al. 2013):

$$V_c = [(\pi \times Db^2)/12] \times CF <=> Db = (L + W)/2 \quad (3)$$

where:

Db – average diameter of the crown,

CF – correction factor reflecting the proportion of branches and foliage within the crown volume,

L – crown length,

W – crown width.

The actual proportion of the volume occupied by branches and foliage was estimated by standing beneath the canopy or crown beside the trunk, and obtaining a careful visual appreciation of the canopy structure (Haghdoost et al. 2013). Biomass (stem and crown) in kilograms was calculated by multiplying the sum of stem and crown volumes by the wood density (*WD*) of each tree species using Eq. 4:

$$\text{Biomass} = (V_s + V_c) \times WD \times 1000 \quad (4)$$

The tree species-specific wood density values were used in the study based on the lists for Hyrcanian forests in the north of Iran reported by Parsapajouh (2015). The specific wood density values for each tree species observed in each stand type in the Nour Forest Park are summarized in Table 1.

Total tree aboveground biomass was obtained by summing the stem and crown biomass. Belowground biomass of each tree was estimated by the root to shoot ratio suggested by Ponce-Hernandez et al. (2004). Haghdoost et al. (2013) reported that 30% of aboveground biomass of broadleaved species represents root biomass. The carbon stock in each biomass component of trees (above- and belowground biomass) was obtained by multiplying the biomass by a conversion factor that represents the average carbon concentration in biomass.

Total carbon content of trees (the sum of above- and belowground biomass of trees) was calculated as the product of dry mass and assumed carbon concentration of 50% (MacDicken 1997; Dube et al. 2009; Zhu et al. 2010; Singh et al. 2011) in the present study.

Analysis of herb and litter biomass C estimation. Herbaceous biomass was estimated by harvesting in 1 × 1 m subplots at the peak productive season in mid-April to June in 2013. The above- and belowground parts were separated, cleaned, and oven-dried at 60–65°C for 72 h in the laboratory (Zhu et al. 2010; Singh et al. 2011). The same process was used to obtain litterfall biomass in 0.5 × 0.5 m subplots. Litter and herbs were separately combusted at 400°C, and the carbon concentration of herbaceous vegetation and litter layer was measured using Eq. 5 (Allen et al. 1986):

$$\text{Ash\%} = (W_3 - W_1)/(W_2 - W_1) \Rightarrow \text{C\%} = (100 - \text{Ash\%}) \times 0.58 \quad (5)$$

where:

W_1 – weight of crucibles,

W_2 – weight of oven-dried ground samples + crucibles,

W_3 – weight of ash + crucibles,

C% – organic carbon concentration.

Analysis of soil organic carbon. After soil sampling and measuring the data, the soil organic carbon stock was calculated using Eq. 6:

$$SOC = C\% \times BD \times D \quad (6)$$

where:

SOC – soil organic carbon stock per hectare,

BD – soil bulk density (g·cm^{-3}),

D – soil depth layer (cm).

Statistical analysis. The normality of the variables was checked using the Kolmogorov-Smirnov test, while Levene's test helped to examine the equality of the variances. One-way ANOVA with PROC GLM was used in SPSS Statistics (Version 17.0, 2008) to compare above- and belowground biomass C and SOC stock between the different natural stands. Duncan's test was used to separate the averages of the dependent variables that were significant. A paired *t*-test was used to compare all soil features between two different depths. An independent t-test sample was used to compare C concentration and C stock between herbs and litter.

Table 1. The specific wood density of tree species in the Hyrcanian forests of Iran (Parsapajouh 2015)

Species	Wood density (g·cm^{-3})
Alnus glutinosa Linnaeus	0.49
Parrotia caspica C.A. Meyer	0.81
Acer velutinum Boissier	0.61
Carpinus betulus Linnaeus	0.79
Ulmus glabra Hudson	0.64
Fraxinus excelsior Linnaeus	0.65
Pterocarya fraxinifolia Lamarck	0.43
Populus caspica Linnaeus	0.47
Quercus castaneifolia Linnaeus	0.75
Ficus carica Linnaeus	0.68

RESULTS

Biomass C stock

There were 431, 303 and 385 trees per hectare in total in AI, MI and EH forest stands, respectively (Table 2). Except abundant-dominant tree species in each stand, there was some discrepancy in the number of individuals per tree species distributed in the different stands. The results of ANOVA indicated that the mean DBH ($F = 0.889^{ns}$) and mean tree height ($F = 2.353^{ns}$) were not significantly different ($P > 0.05$) between the studied stands (Table 2), im-

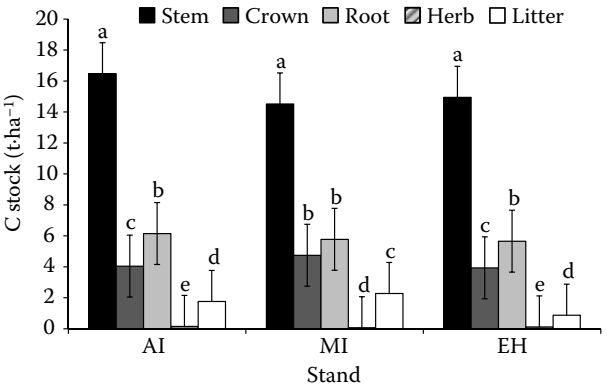

Fig. 2. Carbon stock of stand-specific biomass in Nour Forest Park (no significant difference between C stocks of crown and roots in *Acer velutinum-Parrotia persica* stand)

AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*

Table 2. Number of tree species (*N*) per hectare, mean DBH ± standard error, and mean height (*h*) ± standard error characterized in each of the forest stands

Species	AI			MI			EH			Total
	N per ha	mean DBH (cm)	mean *h* (m)	*N* per ha	mean DBH (cm)	mean *h* (m)	*N* per ha	mean DBH (cm)	mean w*h* (m)	
Alnus glutinosa Linnaeus	225			12.5			29.8			267.3
Parrotia caspica C.A. Meyer	140.5			99.5			49.5			289.5
Acer velutinum Boissier	12.3			101.8			25			139.1
Carpinus betulus Linnaeus	5.4			32			111.2			148.6
Ulmus glabra Hudson	–	41.2	24.9	1.7	41.25	25.05	128.5	39	23.1	130.2
Fraxinus excelsior Linnaeus	11.5	± 3.4[a]	± 1.7[a]	12.1	± 3.7[a]	± 1.3[a]	9.5	± 4[a]	± 1.3[a]	32.8
Pterocarya fraxinifolia Lamarck	8.3			14.2			10.5			33
Populus caspica Linnaeus	12.5			15.9			12.5			40.9
Quercus castaneifolia Linnaeus	3.2			1.1			6.4			10.7
Ficus carica Linnaeus	12.1			12.2			1.9			26.3
Total	430.9			303			384.9			1,118.8

mean values with the same letter in each row do not differ significantly

AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*

plying that mean DBH (cm) and tree height (m) were homogeneous in all stands.

Despite the variation of tree species and number of trees per hectare in the studied stands, the aboveground trees-compartment-specific biomass including stem and crown was not significantly different between the three stands (Table 3). The root biomass was not significantly different between the stands either (Table 3). The results of Duncan's test within each stand showed that the C stock of stems significantly contributed the majority of total biomass (Fig. 2). According to Fig. 2, there were significant differences between the biomass proportions (stem, crown, root, herbs, and litter) within each stand; however, in the MI stand there was no significant difference between the biomass of crowns and that of roots.

The results of Levene's test in the output of independent *t*-test samples showed the equality of variance associated with the distribution of C concentration (%) of herbaceous vegetation and of litter in the studied stands ($F = 0.03$, P-value = 0.287, which is greater than 0.1) (Table 4).

Moreover, the result of the *t*-test showed that the C concentration was not significantly different between litter and herbaceous vegetation within AI and MI stands; however, in EH stand there was a significant difference between C concentrations of litter and herbaceous cover (Fig. 3). Moreover, the results documented that the C stock was significantly different between herbs and litter layers in all the three stands (Table 4). The C stock of litter layer was significantly higher in comparison with the C stock of herbs within each stand (Fig. 2). However, the analysis of variance showed that the C stock of herbs and litter was not significantly different between the three stand types. Furthermore, Duncan's test showed that herbaceous vegetation significantly contributed the least C stock within each stand (Fig. 2).

Soil organic carbon stock

Soil features including bulk density, organic C concentration and SOC stock were not significantly different at the two soil depths (0–20 and 20–40 cm;

Table 3. Carbon stock of tree biomass compartments, herbs and litter under different stands

Stand type	Tree biomass compartments			Herbs		Litter	
	stem	crown	root				
	C stock (t·ha^{-1})			C (%)	C stock (t·ha^{-1})	C (%)	C stock (t·ha^{-1})
AI	16.47[a]	4.04[a]	6.15[a]	20.34[a]	0.1496[a]	26.93[a]	1.76[a]
MI	14.52[a]	4.75[a]	5.78[a]	22.82[a]	0.0625[a]	35.57[a]	2.28[a]
EH	14.95[a]	3.93[a]	5.66[a]	18.64[a]	0.1088[a]	30.91[a]	0.88[a]

mean values with the same letter in each column do not differ significantly

AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*

Table 4. The results of the independent sample *t*-test between C concentration of herbs and litter layer in the Nour Forest Park

	F-value	Mean residual (95% conf. int.)	*t*-value
C concentration (%)	0.030^{ns}	10.53 (4.01–17.05)	3.42^{**}
C stock (t·ha^{-1})	0.425^{ns}	1.25 (0.66–1.84)	4.49^{**}

ns – not significant ($P > 0.05$), conf. int. – the lower and upper limit of the confidence interval of a difference between herb and litter C concentration, $^{**}P < 0.01$

$P > 0.05$) in AI stand (Table 5). But organic C (%) and SOC stock were significantly different at the two soil depths in MI and EH stands (Table 5). Accordingly, the result of the paired *t*-test showed that the bulk density was not significantly different between the two different soil depths in the three stands (Table 5). The result of ANOVA confirmed that bulk density, organic C (%) and SOC stock associated with each soil depth did not differ significantly between the three stands (Table 6).

DISCUSSION

Total carbon stock in the natural stands of the Nour Forest Park ecosystem was assessed in different carbon pools including trees, herbs, litter and soil. The results showed that in all stands, the carbon stock of trees had the majority contribution to the aboveground carbon stock, and most of the biomass allocation was concentrated in the stem. Many studies on the aboveground biomass of forests in different biomes reported that the tree stem (total stem, trunk, bole) accounts for the majority of total tree weight and carbon stock (Vann et

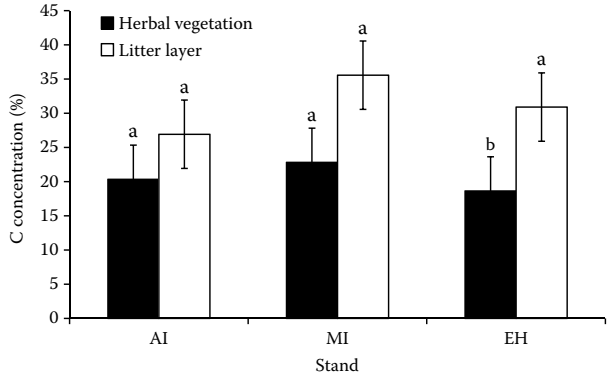

Fig. 3. Stand-specific carbon concentration of herbaceous vegetation and litter (significant difference only in *Ulmus glabra-Carpinus betulus* stand)

AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*

Table 5. The results of the paired *t*-test of soil features between the first (0–20 cm) and second (20–40 cm) soil depth

Stand type	Soil feature	Mean residual (95% conf. int.)	*t*-value
AI	bulk density (g·cm^{-3})	0.10 (–0.22–0.43)	1.34^{ns}
	organic C (%)	0.25 (–0.66–1.17)	1.21^{ns}
	SOC stock (t·ha^{-1})	10.62 (–13.09–34.33)	1.92^{ns}
MI	bulk density (g·cm^{-3})	0.16 (–0.12–0.45)	2.49^{ns}
	organic C (%)	0.28 (0.11–0.44)	7.37^{*}
	SOC stock (t·ha^{-1})	11.61 (5.22–18.005)	7.82^{*}
EH	bulk density (g·cm^{-3})	0.12 (–0.05–0.29)	2.96^{ns}
	organic C (%)	0.30 (0.18–0.41)	11.33^{**}
	SOC stock (t·ha^{-1})	12.95 (9.57–16.34)	16.47^{**}

AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*, SOC – soil organic carbon, conf. int. – the lower and upper limit of the confidence interval of a difference between herb and litter C concentration, ns – not significant ($P > 0.05$), $^{*}P < 0.01$, $^{**}P < 0.05$

al. 1998; Peichl, Arain 2006; Basuki et al. 2009; Marshall et al. 2012). The results of this study indicated that the stem biomass of trees was not significantly different between the studied stands. Comparison of the carbon stock of tree compartments in the different stands showed that the carbon stock of crown and roots was not significantly different in MI stand, implying that the crown had a higher contribution to tree aboveground biomass in the stand. That might be due to the composition and structure of these stands in the studied forest. As the product of square DBH and tree height (DBH^2h) is a surrogate of tree volume (Henry et al. 2010), and because it has a major role for representing the biomass distribution in a tree, the distribution of tree species with different DBH classes and tree height can be the main key for a difference in the amount of biomass and carbon stock in the tree layer in each of the studied stands. Although the abundance (number of trees per hectare) of dominant and co-dominant tree species was different in the three stands, the mean DBH and total *h* of trees in the stands were not significantly different. The standard form factor of 0.5 for the stem volume of trees (Cannell 1984; Peichl, Arain 2006) used in the standard biometric equation in this study (Eq. 2) can be a determining variable which influences the amount of stem carbon stock. As tree species in natural forests have different architecture and various growth trend, it is expected that the form factor of stems might be highly significantly different in forests. However, according to Namiranian

Table 6. Soil features under different stands at two different depths

Stand type	Soil depth					
	0–20 cm			20–40 cm		
	bulk density ($g \cdot cm^{-3}$)	organic C (%)	SOC stock ($t \cdot ha^{-1}$)	bulk density ($g \cdot cm^{-3}$)	organic C (%)	SOC stock ($t \cdot ha^{-1}$)
AI	1.55[a]	1.32[a]	41.08[a]	144[a]	1.06[a]	30.46[a]
MI	1.53[a]	1.14[a]	35.88[a]	1.36[a]	0.89[a]	24.26[a]
EH	1.73[a]	1.37[a]	47.4[a]	1.61[a]	1.08[a]	34.44[a]

mean values with the same letter in each column do not differ significantly; AI – *Alnus glutinosa-Parrotia persica*, MI – *Acer velutinum-Parrotia persica*, EH – *Ulmus glabra-Carpinus betulus*, SOC – soil organic carbon

(2003), the standard form factor of 0.5 for broad-leaved tree species in the north of Iran can be used in the standard biometric equation of stem volume if there is no information or measurement for tree architecture in forests. Although species- or site-specific allometric equations could have been used for tree biomass estimation on the local scale, no allometric equations were developed because of the highly protective management in the forest.

This study assumed the 50% carbon concentration of wood biomass to estimate the carbon stock in the various compartments. In reality, there is a variation in carbon concentration within trees and among species and also between slowly growing and fast growing species (Loaiza Usuga et al. 2010). That means there are some errors associated with this assumption that can be corrected by better knowledge of carbon concentration in the tree species in the stands. In fact, the 50% carbon concentration based on the literature might be a source of estimation uncertainty, and may produce under- or overestimation of total tree carbon stock. Carbon stock of root biomass was 30% of the total tree aboveground carbon stock, which is a common ratio of roots to shoots related to the forest ecosystems (Ponce-Hernandez et al. 2004). The root to shoot ratio decreases with increasing aboveground biomass and stand age (Peichl, Arain 2006; Green et al. 2007). As tree rooting in forest ecosystems depends on the age of trees, it can be the main factor for the discrepancy of root biomass among the trees. Based on quite homogeneous DBH and tree height of the stands in this study which showed approximately similar age of the stands though the age of the stands was not directly reported in the results, it was expected that the age of the stands could not be a key factor for the significance of root biomass variation in the studied stands. As noted, the root carbon stock was not significantly different between the three stands because the mean biophysical traits (mean DBH and *h*) were significantly similar in the stands. Development of root biomass not only depends on tree species, but also is related to stand architecture, composition and tree biophysical traits. So, there could be a strong probability that the significantly similar difference in the root carbon stock in the stands could be in association with these characteristics.

Contrary to the carbon concentration of trees, the carbon concentration of both ground layers (herbs and litter) was directly calculated in the study. The results showed that the carbon concentration in ground components is within a range of 19–36% of dry biomass in the studied stands. Some studies in the literature used a standard carbon concentration of 50% for herbs and litter (Peichl, Arain 2006; Zhu et al. 2010; Singh et al. 2011). However, applying this standard carbon concentration may cause errors (Peichl, Arain 2006; Green et al. 2007). According to the results of the present study, using the 50% carbon concentration in the dry biomass for herbs and litter may estimate the carbon stock value between 24 and 31%. Thus, the carbon pool estimates may be improved by using the specific carbon concentrations for individual components of biomass. The results showed that there was a significant difference in the carbon concentration between herbs and litter in EH stand only, while it was similar in AI and in MI stands. Higher organic carbon contributions from litterfall may be attributed to higher microbial activity, moisture conditions, organic matter quality and quantity of litter (i.e. leaf area index) (Rigobelo, Nahas 2004). The codominant tree species in AI and MI stands is *P. persica* with the most abundant number; however, dominant and codominant tree species (*U. glabra* and *C. betulus*) are different in EH stand. Hence, the quality and quantity of litterfall from the trees cause the higher organic carbon concentration in EH stand. There was no significant difference in the carbon stock of herb layer and of litter layer between the three natural stands. However, there was a significant difference in carbon stocks between both layers within each stand. Loaiza Usuga et al. (2010) concluded that there were high carbon stocks in the litter layer

with respect to the humus layer and in the materials with a medium rate of decomposition in different tropical forests. Forest ground vegetation biomass is generally highly variable, which depends on forest management, stand-specific canopy coverage and soil conditions, which affect light, water and nutrient availability for the development of ground vegetation in temperate forests (Peichl, Arain 2006; Haghdoost et al. 2013). Haghdoost et al. (2013) studied the total carbon stock in different stands and land uses, and concluded that natural forests had the lowest carbon stock in the herb layer due to the thick litter layer on the forest floor that constrained the growth of grasses. They also reported that the natural forest had greater carbon storage in litter because of greater litter production due to the old age of stands. It can also be attributed to slower litter decomposition due to the characteristics of dominant/codominant tree species of the stands, though the microclimate, wind speed and season of litterfall (autumn) can have respective effects as well (Peichl, Arain 2006).

The soil organic carbon stock was significantly different at two different depth layers in MI and EH stands except in AI stand. *Alnus glutinosa-Parrotia persica* organic carbon concentration was significantly similar at the two depths, implying that the sources of organic carbon concentration at both depths were similar. Varamesh et al. (2009) concluded that the concentration of organic carbon at different soil depths depends on the amount of humus, canopy coverage, and vegetation species (Haghdoost et al. 2013). The accumulation of litter in the humus layer induces the higher carbon concentration and SOC stock in the soil surface layer; however, this carbon concentration and SOC stock on the surface might be transferred to the deeper depth by leaching the organic matters. Arevalo et al. (2009) reported that the lack of mixing of the surface litter material with the mineral soil caused the low carbon stocks in the mineral soil at the natural forest site. The patterns of carbon accumulation and loss vary according to location, soil type and tree species (Turner et al. 2005). The present study showed that the second depth of soil (20–40 cm) had lower SOC stocks in MI and in EH stands. In this study, although the SOC stock was significantly different between the two depths within each stand, the value did not vary significantly between the stands. Bulk density can be a useful indicator of soil changes which can be attributed to losses in soil quality, soil aggregation resulting in a loss of the superficial layers, creating compaction and erosion process problems, increasing the loss of physical and chemical soil quality (Alfsen et al. 2001; Jaramillo et al. 2004; Loaiza Usuga et al. 2010). In the present study, soil depth-specific bulk density did not change in the stands. Therefore, it can be considered that the quality, stability, physical and chemical structure of the soil aggregates was similar in the three studied stands. Some studies suggested that SOC stocks differ between the different land uses depending on the inputs of organic matter, soil microclimates, increase/decrease in decomposability of organic matter, of crop residues due to changed litter quality (for example, lowered C:N ratio and lignin content) and soil disturbances (Post, Kwon 2000; Lal 2005; Haghdoost et al. 2013). The result is probably attributed to high homogeneity of soil organic carbon, most likely associated with the similarity in the amount of tree biomass carbon, litter, microclimate on a local scale and invariability in topography due to the flatness of the forest site. High heterogeneity in the edaphic carbon stock on a local scale is associated with the variability in topography, soil structure and texture, parent material, soil depth and microclimate, although it has interrelations with other components like forest floor and tree biomass (Loaiza Usuga et al. 2010). Here, carbon stock in soils contributed the majority of ecosystem carbon storage; however, the ground carbon stock layers (herbs and litter) were the smallest carbon pools. Although the carbon stocks of ground layers were relatively small, plant matter (and litter layer) was the most important source of carbon inputs in the soil (Leake et al. 2006; Loaiza Usuga et al. 2010). Nevertheless, the mineral soil provides a major carbon reservoir and remains an important component of the overall forest ecosystem carbon budget (Peichl, Arain 2006).

Many studies emphasized that previous land use and land management can be among the important issues for the variability of C stock distribution in different pools in the forest (Oliver et al. 2004; Peichl, Arain 2006; Green et al. 2007; Loaiza Usuga et al. 2010; Haghdoost et al. 2013). According to the history of the Nour Forest Park, the total studied area of the forest did not change until new land use 50 years ago, showing a homogeneous variation of carbon pools in different stands.

CONCLUSIONS

The significance of each biomass component and soil mineral layers within each stand showed that the total SOC stock contributed the majority of car-

bon pools within the stands. The findings showed that although the three different stand types were focused on estimating the above- and belowground carbon stock, the amount of carbon pools unexpectedly was not significantly different between the stands. Therefore, the results implied that there was a balance of the local carbon cycle in the Nour Forest Park or at least in the studied stands of the forest. According to the findings in this study, we can conclude that the stand type and composition could not be a key factor for significant variations of carbon pools in the different stands. Furthermore, some studies reported that the stand type and composition, in agreement with this study, were not highly determining factors for variations of the carbon stock in forest ecosystems (Kirby, Potvin 2007; Hollingsworth et al. 2008). Since the forest is protectively managed, the balance of carbon variation would mainly be influenced by the management though biotic and abiotic factors could have been other determining factors for the variations of carbon pools in the stands.

Acknowledgement

We thank Mr. E. Khatibnia, the personnel of the Natural Resources Organization of Nowshahr, for helping us in the field work.

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Received for publication April 30, 2016
Accepted after corrections September 21, 2016

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