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Estimation of biomass, carbon storage and economic value of felled trees in the Yasouj-Dena road construction project

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Abstract
Roads are among the most important factors for the development of various communities. In designing a road (Tarmac), it is necessary to carefully consider environmental issues in addition to technical ones. Felling trees in road building projects changes forest and rangeland ecosystems and also ends the important roles they play in carbon sequestration. To estimate the biomass and carbon storage of felled trees in the Yasouj-Dena (30sakht) road construction project, 20 sample plots (1000 $m^{2)}$ were selected at a distance of 10 m from the cut down trees in Deh Bar Aftab Village, Boyer-Ahmad County and the quantitative variables of oak trees (diameter at breast height, diameter of shoot clumps, height and crown cover) were measured. Using the related allometric equations previously developed for the provincial forests, the biomass and carbon storage of the tree species with the two different vegetative forms (high forest trees and coppice trees) were estimated. The results indicated that the total biomass of both high forest and coppice trees was about 982 tons. The high forest trees and coppice trees had the capacity to sequester approximately 347 and 144 tons of carbon per hectare, respectively. Therefore, considering the coefficient of 3.67, the amount of carbon dioxide absorbed by these high forest and coppice trees was 1802 tons. Given the global carbon price, the estimated value of carbon sequestration in the trees removed from nature for the Yasouj-Dena road construction project was more than IRR 2.3 billion (23 Meliard Rials).

Keywords: Allometric equations, Deh Bar Aftab village, Highforest, Vegetative form

1. Introduction
In designing road networks and taking measures in nature, the necessary needs should be satisfied while the ecological characteristics of the region and lands also need to be taken into consideration (Deljouei et al., 2018). In designing roads, environmental issues must be carefully taken into account in addition to the technical aspects. Inclusion of the environmental aspects such as geological ones and soil erodibility increases the accuracy level of designing road networks and reduces the possible losses (Bhuiyan et al., 2011). If roads are not designed and constructed practically and methodically, they will have many direct or indirect negative effects on the environment. This point is so important that disregarding environmental principles can, in the long run, even result in total destruction of a watershed (Demir, 2007). Decision-making is especially more important when it comes to the selection of suitable routes causing minimum possible environmental damages and guaranteeing the sustainability of forest ecosystems. If careful studies are carried out by the related experts, it will be possible to construct roads while

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minimizing degradation (Sadeghi et al., 2012). Roads on a small to medium scale open a corridor in the forest habitat when trees are cut down creating extensive changes in the amount of the received sunlight, moisture and soil physical and chemical properties in the long run (Forman et al., 2002). We know that the presence of trees and their canopies influence air currents, air temperature and relative humidity, water regime, soil moisture, and exchange of materials (Barnes et al., 1997). Consequently, any change in forest canopy can have considerable effects on forest ecosystems. This is especially important for Zagros forests given their basic role in water storage and livelihood of people (Ahmadiyan et al., 2015). Oak trees in Zagros mountains have two vegetative forms (Highforest trees and coppice trees (or sprout clumps)) that have various functions (Pourhashemi et al., 2015). One of these functions is carbon sequestration in forest ecosystems (Askari et al., 2021). Cutting down these trees in road construction projects and in other human activities changes forest and rangeland ecosystems and also impairs their important role in carbon sequestration, which will have harmful effects in the long run. Biomass is the mass of live or dead organic matter. Plant biomass is divided into above ground and below ground parts. The above ground biomass (AGB) includes all living biomass above the soil while below ground biomass includes all biomass of live roots excluding fine roots (less than 2 mm diameter) (Deo, 2008). Biomass estimation was used to quantify a forest since they can reflect the changes of the forest carbon stocks (Basuki et al., 2009), vegetation biomass stores a larger amount of global carbon than does the atmosphere. Carbon sequestration (storage) happens in the various stages of carbon cycle including photosynthesis, plant growth, carbon density and accumulation in soils, and likewise carbon emission resulting from respiration of living organs, destruction of trees, microbial decomposition of litter, soil carbon oxidation and land degradation (IPCC, 2005). Atmospheric carbon sequestration using synthetic methods such as filtration entails high costs (Cannell, 2003). Therefore, atmospheric carbon must be sequestered in various methods in order to both decrease atmospheric carbon dioxide and strike a balance between the storage of greenhouse gases (Naghipour Borj et al., 2009). Carbon sequestration in plant biomass and the soils under this biomass is the simplest, and economically the most practical possible method to reduce atmospheric carbon dioxide. In fact, one of the various advantages of forests is carbon sequestration in trees and various plant organs (McNulty et al., 2018). Application of appropriate biomass estimation methods and transparent and consistent reporting of forest carbon inventories are needed in both scientific literature and the Green House Gases inventory measures (Somogyi et al., 2006). Different approaches have been applied for AGB and BGB (Belowground Biomass or root) estimation based on field measurements, remote sensing and GIS (Lu, 2006). The traditional techniques based on field measurements are the most accurate but have also proven to be very costly and time consuming (de Gier, 2003). A sufficient number of field measurements are a prerequisite for developing AGB estimation models and for evaluating the AGB estimation results. Accurate assessment of above-ground woody biomass is important for sustainable forest management and also for understanding the role of forest as source or sink of carbon. The best way to improve the assessment accuracy is to develop predictive equations based on the locally collected data (Deo, 2008). Total above- and below-ground biomasses were calculated according to allometric equations for various biomass components of Highforest and Coppice oak trees. The above-ground biomass of plants is intimately interconnected to that of the below ground, and both compartments capture resources and interact with neighboring trees and other vegetations.

Since roads in Zagrosian forests of Iran are usually built without taking environmental considerations into account, and trees are cut down at night without being marked by specialists (*i.e.*, the principles of silviculture are not observed), there are no documented studies on estimating the carbon storage of felled trees in forest ecosystems in road construction operations. In addition, the majority of the existing studies have only focused on the effects of non-asphalt forest roads on the flora and fauna of the related area. Salimi et al. (2011) studied the effects of the types of forest roads and the chemical properties of the surrounding soil on the growth of the Caucasian alder (*Alnus subcordata* C. A. Mey.) in Darab Kola forest, Mazandaran Province. They concluded that there were not many differences in the environmental effects of first-grade and second-grade forest roads. Naghdi et al. (2014) also investigated the effects of forest roads on vegetation and some soil physical and chemical properties in Shafarood forests and reported that forest roads effectively influenced the ecosystems adjacent to the forests and that it was necessary to minimize forest disturbances and degradation in road constructing projects. Naseri & Rostamian (2021) studied the Influence of forest road on tree and shrub biodiversity indices in Irano-Turanian forests. The results showed that the third-grade forest roads are used during some seasons of the year due to the limited infrastructure and pavement, and thus the adverse effects of human presence would be limited. Therefore, increased distance from third-grade forest road in the study area did not affect the richness, diversity, and evenness of tree and shrubs species.

This research, the first one of its kind in Iran, intended to estimate the biomass and carbon storage of felled trees in the Yasouj-Dena road construction project and also to calculate the economic value of the cut down trees along the road with respect to carbon stock.

2. Materials and Methods

2.1. Research region

Trees were cut along the 23-kilometer road, but most felled trees were in the Deh Bar Aftab Village in the Sarrud-e Shomali rural district, 15 kilometers northwest of the central district of Yasouj County (the capital of Kohgiluyeh and Boyer-Ahmad Province) with longitude 51°31′ and latitude 30°45′ (Figure 1). This village is close to the Eastern Dena Protected Area. The mean altitude is 2030 m and the annual rainfall is 653 mm. Monthly mean minimum temperature is 7.5 C and Monthly mean maximum temperature is 21.9. The soil type of study area is clay loam and silt loam texture. Trees diversity consists of *Quercus brantii* L. *Crataegus azarolus* L. and *Pistacia atlantica* Desf. Forest density in total study area is 147 per hectare.

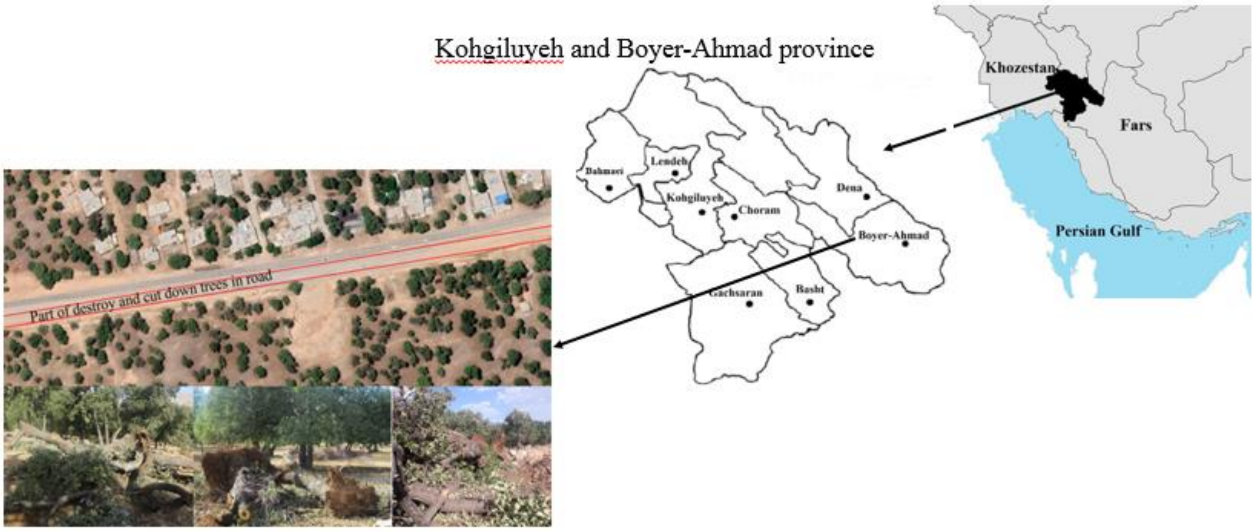

Figure 1. Study area in Iran and local scale and part of destroyed trees.

2.2. Methodology

Since there was no documented information on the quantitative parameters of the felled trees in the region, and as suggested by the experts to use the experience of the specialists, 20 sample plots 1000-m^2 were randomly selected and sampled along every two kilometers of the road at a road-distance of 10-m to study the structure and also the accurate quantitative characteristics of the cut down trees (Deljouei et al., 2018). After recording the quantitative parameters, allometric equations (previously developed for the forests in Kohgiluyeh and Boyer-Ahmad Province (Askari et al., 2017) were used to estimate the biomass and carbon storage of the felled trees. Among the various types of equations, the exponential model made the best prediction for the highforest trees, and breast-height diameter (BHD) was the appropriate variable for predicting biomass. Table 1 presents Y (biomass in tree organ in kg), X (the independent variable of BHD), R^2 (the coefficient of determination), F (the F statistic), Std. Error (standard deviation) and Sig. (significance at the 0.001 level).

Table 1. The biomass estimation model ($Y=a \times X^b$) for highforest oak trees based on independent variable BHD.

component	a	b	R^2	Std. Error	F	Sig
Trunk	0.089	2.047	0.96	0/276	172	***
Main branches	0.014	2.695	0.98	0/282	286	***
Sub-branches	0.114	1.762	0.97	0/208	225	***
Twig	0.078	1.468	0.97	0/159	266	***
Foliage	0.050	1.738	0.97	0/214	207	***
Stump	0.154	1.436	0.90	0/311	67	***
ABG	0.324	2.027	0.99	0/163	488	***
Root	0.975	1.620	0.98	0/133	467	***
Total	1.107	1.832	0.99	0/144	507	***

***: Significant differences at 0.001 probability level.

In addition, the exponential model was the most complete predictor among the various equations for estimating the biomass of coppice trees, and the mean canopy diameter was the best, among the studied variables, for estimating the biomass of the highforest trees, Table 2 lists Y (biomass of tree organ in kg), X (the independent variable of mean crown diameter or MCD), F (the F statistic), Std. Error (standard deviation of the model), and Sig. (significance at the 0.001 level).

Table 2. The estimation model ($Y=a \times X^b$) for coppice oak trees based on the independent variable MCD.

component	a	b	R^2	Std. Error	F	Sig
Trunk	1.099	2.105	0.96	0/204	159	***
Main branches	0.569	2.578	0.97	0/211	223	***
Sub-branches	0.355	2.498	0.96	0/233	173	***
Twig	0.434	1.468	0.95	0/178	128	***
Foliage	0.308	1.845	0.98	0/109	425	***
Stump	1.381	1.549	0.84	0/310	37	***
ABG (kg)	3.835	2.141	0.96	0/202	168	***
Root	6.462	1.783	0.95	0/178	149	***
Total (kg)	9.936	1.966	0.96	0/185	168	***

***: Significant differences at 0.001 probability level.

Considering the growth structure of oak trees, the sample trees were divided into seven separate parts: trunk, main branches, sub-branches, twigs, Foliage, stump and root. The branches longer than 5 cm, 1-5 cm long and shorter than 1 cm long were considered as the main branches, sub-branches and twigs, respectively (Bakhtiarvand, 2012; Iranmanesh, 2014).

The tree biomass is calculated by summing the biomass of trunk, main branches, sub-branches, twigs, Foliage, stump and root. According to the available equations and some previous researches, the carbon storage of a tree is 50% of its biomass (Ismail et al., 2019). The amount of carbon dioxide absorbed from the atmosphere by the trees is determined by using the coefficient of 3.67 after calculating the biomass and carbon Storage of the felled trees of both vegetative forms (Hunt & Colin, 2009; Li et al., 2006). Considering the global carbon price (USD 47.2 per ton) (Yazdani & Abbasi, 2010) and the exchange rate of the USD (about IRR 280,000 on Nov. 16, 2021), the value of the carbon absorbed in the felled trees along the road construction route was calculated.

Finally, after recording the data, their normality was checked using the Kolmogorov-Smirnoff test, and Duncan's multiple range tests were used for comparison of the means. All statistical analyses were performed in SPSS 22 and the diagrams were drawn using EXCEL 2007. It must be mentioned that, in interviews with the county officials and the experts in the Natural Resources and Watershed Management Organization of the Kohgiluyeh and Boyer-ahmad province, it was found that about 1024 oak trees were cut down in the 23-km long road construction project. However, according to the provincial and national media reports, the number of the cut down trees was by far larger; thus the information obtained from county and provincial officials was used as the estimation basis in this research.

3. Results

Table 3 presents density in percentage of coppice trees (shoot clumps) and high forest trees and other quantitative characteristics of the studied habitat. According to the information presented in this table, highforest oak trees are dominant in the studied habitat, and the mean quantitative parameters are higher compared to those of the Zagros forests.

Table 3. Descriptive statistics measured in the study area.

Growth form	*MCD (m)	Mean DBH* (cm)	Mean Height (m)	Density (%)	*CC% (m^2)
Highforest	3.0±8.64	16.3±37.62	2.7±9.48	69	47.1±64.49
Coppice	2.4±9.63	11.7±37.24	2.6±10.36	31	34.8±76.39

*MCD: Mean Crown Diameter DBH: Diameter at breast height CC: Crown Cover

According to the ANOVA results, the differences between the mean biomass storage of the various organs were significant, but the differences between the biomass of small organs such as leaf (foliage), twigs and stumps were not (Figure 2). It was found that the roots had the largest amount and the foliage and twigs the smallest amount of biomasses. The mean biomass of a felled coppice tree was about 980 kg in total study area.

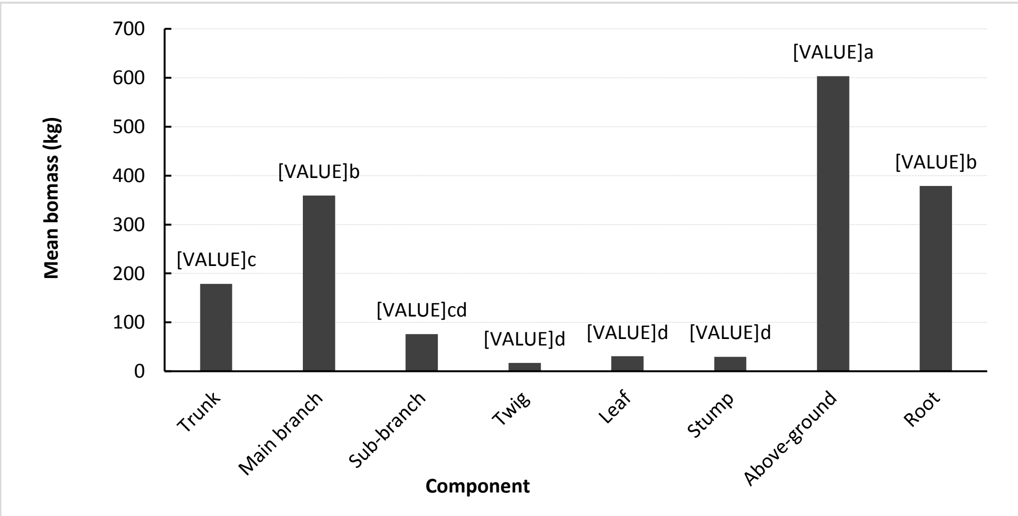

Figure 2. Mean biomass of various organs in Highforest oak trees (Different letters indicate statistically significant differences).

According to the collected data (Table 3), about 69% of the felled trees (707 trees) were high forest trees. Therefore, the total biomass of the cut down trees along this transportation road was more than 694 tons in the total study area (Figure 3).

As for the coppice trees also, comparison of the means of biomass for the different organs showed that the differences between them were significant, whereas the differences were not significant for the small organs such as foliage, twigs and stumps (Figure 4). The mean biomass of a felled coppice tree was about 910 kg.

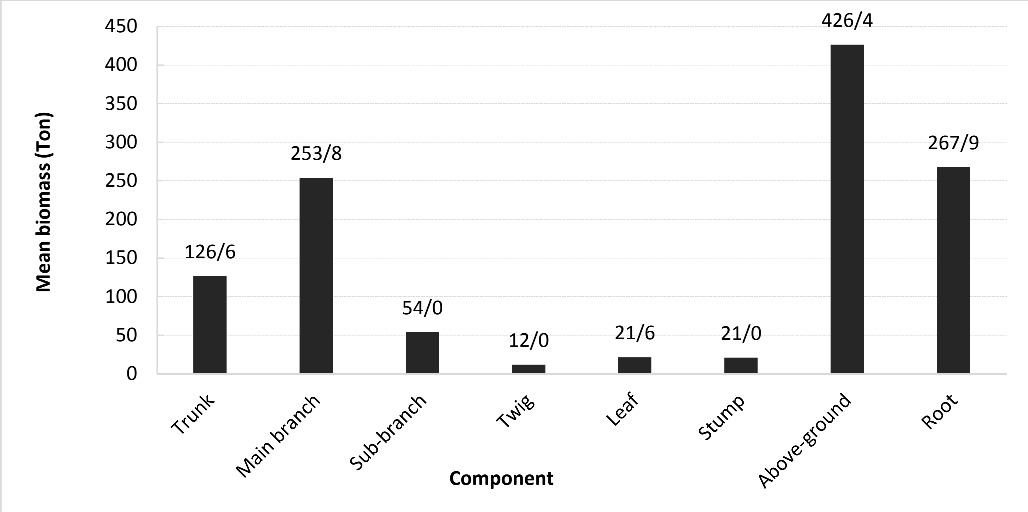

Figure 3. Total biomass of various organs in Highforest felled trees on the transportation road.

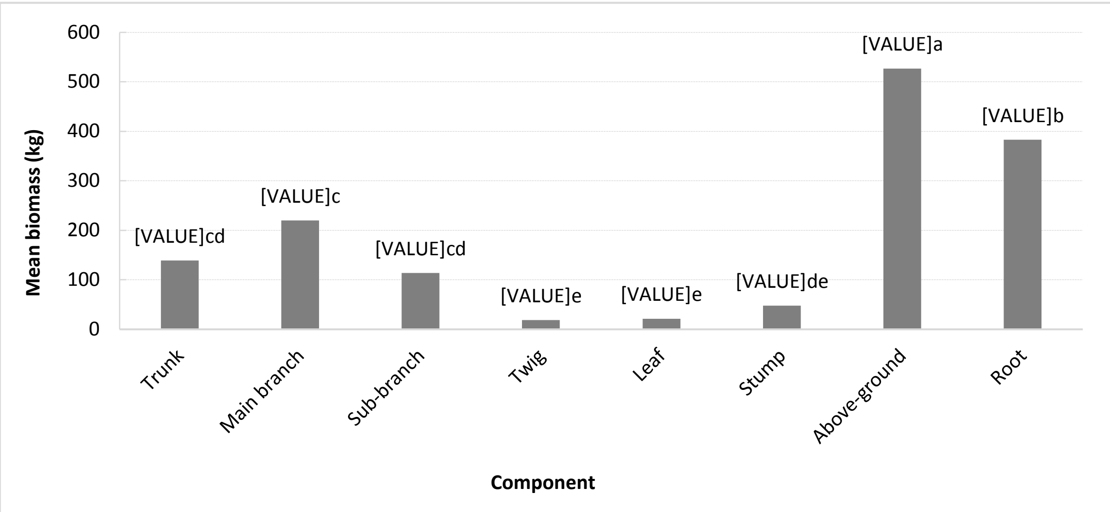

Figure 4. Mean biomass of various organs in oak coppice trees (Different letters indicate statistically significant differences).

The collected data (Table 3) show that about 31% of the felled trees (317 trees) were coppice trees. Consequently, the total biomass of the cut down trees of this vegetative form along the mentioned transportation road was about 288 tons (Figure 5).

Table 4 also indicates the biomass allocated to the various organs of the highforest trees and coppice. In the highforest trees, the tree crown (the main and sub-branches, twigs and foliage) had 62% and the non-crown regions (the trunk and the stump) had 38% of the biomass on average. In the sprout clumps, the tree crown (the main and lateral branches, twigs and foliage) accounted for 65% and the non-crown regions (the trunk and the stump) for 35% of the total biomass on average.

Considering the results shown in Figures 3 and 5, the total biomass of felled trees for both vegetative forms was about 982 tons. Therefore, if 50% of the dry biomass is considered to be the amount of carbon sequestered by a tree, high forest trees had about 347 tons and coppice trees 144 tons of sequestered carbon in the study area.

Each ton of carbon sequestered by trees results from removing 3.67 tons of atmospheric carbon dioxide. Consequently, the estimated amount of carbon dioxide absorbed from the atmosphere by trees (high forest and coppice trees) was 1802 tons. Since the global carbon price is USD 47.2 per ton, the estimated value of the removed carbon sequestered by the felled trees from nature for the Yasouj-Dena road construction project is more than IRR 2.3 billion.

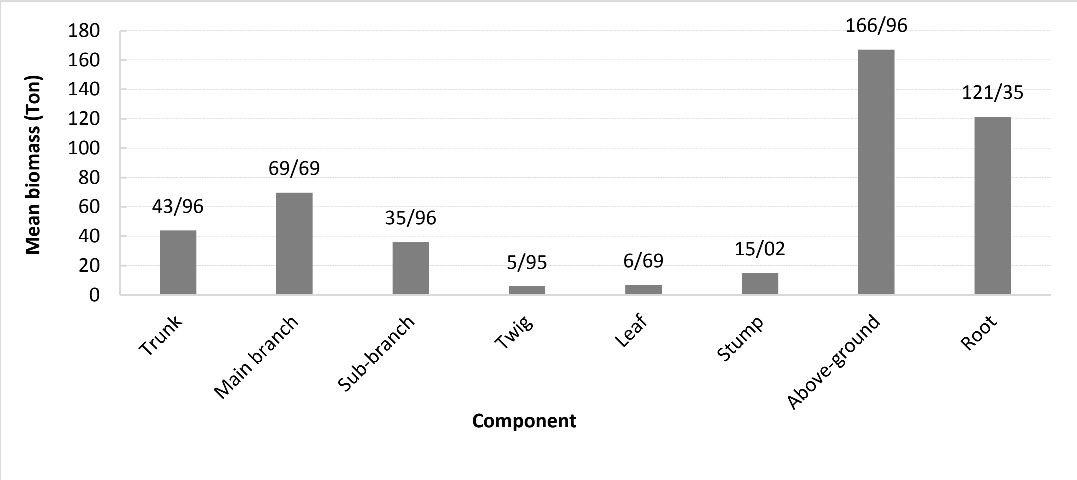

Figure 5. Total biomass of various organs of felled coppice trees along the transportation road.

Table 4. Percentage of biomass allocated to different parts of highforest trees and coppice.

Growth form	Twig	Branches	Trunk and Stump	foliage
Highforest	3.57	53.10	37.78	5.49
Coppice	5.40	55.19	34.88	4.50

4. Discussion

This is the first documented study on estimating the amounts of biomass and carbon stored in felled trees in road building projects (Asphalt roads) in the Zagros forests, and even in all the forests located in Iran. Most of the studies by Shashavand Baghdadi et al. (2011), Keivan-Behjo et al. (2020) and others were on changes in vegetation or changes related to soil physical and chemical properties along the constructed (non-asphalt) roads inside forests. Road construction and the connections between various urban and rural areas have become important necessities of modern life. Despite the need for and the importance of communication roads in the progress, welfare, and comfort of people, many negative environmental effects will ensue if they are not designed and built methodically and scientifically (Nekooimehr et al., 2006). Construction of any road causes changes in the vegetation and the lands in the region, and these changes will inflict heavy losses in most cases (Rafatneia, 1988). Disturbances in river flows, increased river sediments, destruction of fish habitats and habitats of other aquatic organisms, soil disturbances and degradation, reduced soil fertility, landslides, injuries to forest masses, destruction of natural habitats, and extinction of certain animal species are some of these environmental damages (Sadeghi et al., 2012). The extent of damage to the environment, forests and rangelands caused by building roads depends on various factors such as type of the road, topography of the region, and vulnerability of the soils and geological formations (Salavati Dezfuli, 2005). The Yasouj-Dena road construction project passes the Bar Aftab Village in Boyer-Ahmad, which is one of the rich habitats in the province. Table 3 shows that the dominant vegetative form in this habitat is high forest oak trees with mean diameter larger and mean height larger than the corresponding averages in Zagros habitats. High forest trees in the Zagros forests do not cover a considerable area, especially in Southern Zagros where very few high forest trees grow. According to the summation of studies conducted in the Zagros forests, only 7% of the forests consist of high forest trees (Shariatnejad et al., 1996). Consequently, the harmful effects of road construction (degradation and removal of vegetation) in the studied region are more extensive than other regions due to the removal of vegetation and genetic reserves. The Yasouj-Dena road is about 35-km long, but according to the reports published by the provincial authorities, the length of the road to be constructed is about 23 km. In other words, more than 1000 trees were cut down for a 23-km long road. The need to cut down a large number of high forest trees in a short and less traveled route must certainly be explained and clarified by the provincial authorities (in particular, by those at the Natural Resources and Watershed Management Organization in the province). Based on observations, road width in some parts of the road exceeds 30 m whereas few cars travel on this route (the alternative route called the Isfahan road is preferred, and its 5-10 m width is sufficient for the traffic on it). In addition, if the old road would be improved and repaired, it could be used for many years without causing any problems.

Apart from road construction, there is the issue of carbon sequestration, which is one of the important services provided by forest ecosystems. Forest vegetation is considered as the most cost-effective and fastest mechanism for reducing concentration of atmospheric carbon dioxide through its active absorption in the photosynthesis process followed by its storage in the biomass of forest trees (Baes et al., 1977). In this research, the amount of stored carbon in highforest trees was more compared to that of sprout clumps. The results of a study on biomass and carbon stock on land having Persian oak trees (high forest trees and coppice trees) in Lordegan forests in Chaharmahal and Bakhtiari Province suggested that the biomass of the highforest trees was 2.5 times more than that of the coppice trees (Iranmanesh et al., 2014). These results conform to those of this study. Therefore, cutting down trees, especially highforest trees, in forest ecosystems is completely wrong and harmful. Among the above ground organs, the main and lateral branches of highforest trees had the largest biomass and carbon Storages (Figures 2 and 4) because of the structure and vegetative form of Persian oak trees. In this tree species, the lateral branches (growing from the main branches) begin to grow at the maximum height of 2.5 m from ground surface (Iranmanesh, 2014). Therefore, a large part of tree biomass is found in the main and lateral branches that grow from the trunk and are in the tree crown. In sprout clumps also, the main and lateral branches had the largest amounts of biomass (Figures 3 and 5) because there are many branches in this regeneration pattern of oak trees. The results of the research by Bordbar & Mortazavi (2006) in *Eucalyptus* and *Acacia* afforestation in Fars Province showed that the quantity of biomass stored in the trunks was significantly larger than that in other organs. Plant species usually adjust their aboveground and underground biomass in response to environmental changes (Wang et al., 2011). Aboveground and underground biomass is considered the main carbon stock of terrestrial ecosystems. However, contrary to aboveground biomass, studies on underground biomass are very limited due to the difficulty of studying root biomass (Mokany et al., 2006). However, this research overcame this difficulty and root biomass and carbon Storages were also calculated.

In this research, the estimated amount of carbon dioxide absorbed from the atmosphere by the vegetation of interest (high forest trees and coppice trees) was 1802 tons. Considering the global carbon price, the value of carbon sequestration in trees removed from nature for the Yasouj-Dena road construction project was more the IRR 2.3 billion. Yousefi et al. (2017) evaluated carbon sequestration and its economic value in the Persian oak tree forests located in Bistoon Protected Region. They concluded that the coppice trees and the high forest trees sequestered 1622 and 1786 kg/ha/year, respectively, and each hectare of these forests had the mean value of IRR 1,780,856 with respect to carbon sequestration. Their results differed from those of this research because high forest trees were the dominant trees in their study. However, the superiority of high forest trees over coppice trees in carbon sequestration was confirmed in their research as it was in our study.

The issue addressed in this research was merely valuation of the amount of sequestered carbon in the felled trees and the values of the other ecosystem services such as market services (sale of timber, charcoal and minor products) and of non-market services including soil formation, water purification, flood control, oxygen production, dust control, soil erosion control, and biodiversity were not determined. If their values were included, the calculated values of all ecosystem services would be much more than the estimated one. In addition, we must bear in mind that these forests, in addition to their monetary value, are important for Iran as its biosphere reserve, economic support, and vital support.

5. Conclusions

Roads are among the most important factors for the development of various communities. In designing a tarmac, it is necessary to carefully consider environmental issues in addition to technical ones. The majority of the existing studies are on the effects of non-asphalt forest roads on the flora and fauna of the related area. The Main road of Yasouj-Dena is about 35-km long, but according to the reports published by the provincial authorities, the length of the road to be constructed is about 23 km. In other words, more than 1000 trees were cut down for a 23-km long road. The amount of carbon dioxide absorbed by felled trees was 1802 tons. Given the global carbon price, the estimated value of carbon sequestration in the trees removed from nature for the Yasouj-Dena road construction project was more than IRR 2.3 billion.

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برآورد زی‌توده و موجودی کربن درختان قطع شده در پروژه راه‌سازی یاسوج به دنا

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چکیده

راه‌های ارتباطی از مهم‌ترین عوامل توسعه جوامع مختلف محسوب می‌شوند. در طراحی جاده لازم است تا علاوه بر مسائل فنی، مسائل زیست‌محیطی نیز به‌دقت مدنظر قرار داده شوند. با قطع این درختان در پروژه‌های جاده‌سازی علاوه بر تغییر در اکوسیستم جنگلی و مرتعی، نقش مهم آن‌ها در زمینه ترسیب کربن نیز حذف می‌گردد. به منظور برآورد مقدار زی‌توده خشک (بیوماس) و ذخیره کربن درختان قطع شده در پروژه راه‌سازی یاسوج به شهرستان دنا (سی‌سخت)، ده قطعه نمونه ۱۰۰۰ متر مربعی در فاصله ۱۰ متری از درختان قطع شده در روستای ده‌برآفتاب بویراحمد انتخاب و متغیرهای موردنظر (قطر برابر سینه، قطر جست‌گروه، ارتفاع و سطح تاج پوشش) آماربرداری شد. به‌منظور برآورد زی‌توده و ذخیره کربن گونه‌های درختی متناسب با فرم رویشی (دانه‌زاد و شاخه‌زاد)، از معادلات آلومتریک مربوطه که قبلاً از جنگل‌های استان تهیه شده بود، استفاده گردید. طبق نتایج بدست آمده، مجموع زی‌توده درختان قطع شده برای هر دو فرم رویشی حدود ۹۸۲ تن می‌باشد. درختان با فرم رویشی دانه‌زاد حدود ۳۴۷ و درختان شاخه‌زاد ۱۴۴ تن در هکتار جذب کربن داشتند. بنابراین با درنظر گرفتن ضریب ۳/۶۷ مقدار دی‌اکسید کربنی که به‌وسیله پوشش درختان (دانه‌زاد و شاخه‌زاد) موردنظر از اتمسفر جذب می‌شد، ۱۸۰۲ تن بود. و با توجه به قیمت جهانی کربن، ارزش ترسیب کربن درختان حذف شده از طبیعت به خاطر پروژه جاده‌سازی یاسوج به شهرستان دنا بیش از دو میلیارد و ۳۰۰ میلیون تومان برآورد گردید.

واژه‌های کلیدی: ارزش اقتصادی، ده برآفتاب، فرم رویشی، معادلات آلومتریک.

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