Evaluation of animal logging in the mixed broadleaved mountain forest: Economic and environmental impacts

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Abstract

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This investigation assessed the economic and environmental impacts of small-scale wood logging by mules in the mixed broadleaved mountain forest. To develop a time prediction model, all measurements of time are replaced by their decadic logarithms. Unit cost was calculated by two methods: (*i*) as usual, division of the system cost by average productivity per hour, (*ii*) on the basis of the developed logarithmic models. To investigate the residual damage a 100% inventory method was employed in pre- and post-hauling, alongside the mule trail. A core sampling technique of bulk density was used for determining the degree of soil compaction, and soil disturbed widths were measured at a 5-m interval in the mule hauling direction. In this research, computed unit cost was 17.2 EUR·m^{-3} and estimated unit cost by the logarithmic model was 16.2 EUR·m^{-3}. This result highlights the time consumption which estimated by the developed model was at a close ratio with real time (average at 95%). In terms of environmental impact, the results indicated that 5.7% of regenerations and 0% of trees were damaged. Also we found that the increased bulk density was not significant ($P = 0.903$) and only about 0.2% of the total area was disturbed.

Keywords: productivity and cost; logarithm; mule; residual damage; soil damage

It is possible to agree that animal logging still has its place even nowadays, when highly mechanized timber harvesting systems are available (Toms et al. 2001; Akay 2005). Even in industrialized countries, animals (especially horses) still play an important role in forestry exploitation of timber. In many developing countries, animal logging was used for many years for hauling firewood, pulpwood and saw logs (Ghaffariyan et al. 2009), which is still performed as a small-scale harvesting method (Jourgholami 2012) because mechanized harvesting machines are very expensive to purchase and maintain (Akay 2005). In industrialized countries, the number of horse loggers is so small and they do not contribute large wood volumes to the market, as well as only few people want or are able to work with draught animals (Magagnotti, Spinelli 2011a; Malatinszky, Ficsor 2016). Nonetheless, animal-powered logging still occupies a niche in Alabama and China as a small-scale harvesting alternative (Wang 1997; Toms et al. 2001) and in Hungary 26% of forest districts regularly uses horses for skidding (Malatinszky, Ficsor 2016). Due to the development of efficient machines and high volume demands for the forest products, mechanization of logging developed very fast, leaving behind the traditional animal logging (Shrestha, Lanford 2001; Engel et al. 2012). Whilst wood extraction by draught animals offers many additional benefits such as low impact on the soil, standing trees and

seedlings, simplified technologies in timber logging and the lowest greenhouse gas emissions (Ficklin et al. 1997; Wang 1997; Jourgholami, Majnounian 2010; Magagnotti, Spinelli 2011a; Engel et al. 2012; Spinelli et al. 2012; Borz, Ciobanu 2013; Malatinszky, Ficsor 2016). However, a few researchers such as Ghaffariyan et al. (2003) and Naghdi et al. (2009) found a greater impact on the soil, and researchers such as Ahmadi (1996), Ghaffariyan et al. (2009) and Jourgholami and Majnounian (2010) found a greater impact on seedlings.

The most recent works have stated that animal logging is more economical than machines (Ghaffariyan 2008; Ghaffariyan et al. 2009; Gilanpour 2010; Spinelli et al. 2012; Malatinszky, Ficsor 2016), and their integration with tractor skidding is cheaper than direct tractor skidding (Magagnotti, Spinelli 2011a, b). In contrast, Jourgholami (2012) and Mousavi Mirkala et al. (2015) found the higher unit cost of mule logging (13.8 and 12.12 EUR·m^{-3}). The hourly production of animal logging is low (Rasti 2008; Ghaffariyan et al. 2009; Gilanpour 2010; Jourgholami et al. 2010; Jourgholami 2012; Borz, Cibanu 2013; Mousavi Mirkala et al. 2015; Malatinszky, Ficsor 2016) and is influenced by logging distance, logging trail slope and number of logs per load, kind of extracted wood, load volume and weather conditions (Nurminen et al. 2006; Ghaffariyan et al. 2009; Jourgholami 2012; Borz, Cibanu 2013; Mousavi Mirkala et al. 2015; Malatinszky, Ficsor 2016).

In the steep terrain of Hyrcanian forests (about 40% of this forest area), where the ground-based system cannot be used, and due to the cutting regime (group and/or single-tree selection) the cut volume is not high to use a cable yarding system, anima logging can be an alternative to wood extraction in this region. In this context, it is necessary to determine wood transportation efficiency considering the cost and as well as the ecological impact. Therefore, the aim of this research was to: (*i*) assess economic and environmental impacts of mule logging in the mixed broadleaved mountain forest, (*ii*) predict time consumption models by a new approach.

MATERIAL AND METHODS

Site description. This study was carried out in compartment 27 of the Wood Industry of Farim forests (a part of the Hyrcanian forests) which is located between 35°58'40" to 36°15'00"N and 53°04'20" to 53°24'55"E. The total surface of this compartment is 59 ha, of which 24.5 ha are a protection area without utilization. The forest lies on the north and northwestern aspect at an altitude ranging from 445 to 2,250 m a.s.l. The slope gradient is classified in 3 classes 0–30, 30–60 and 60–80%. The original vegetation of this area is an uneven-aged mixed forest dominated by oriental beech (*Fagus orientalis* Lipsky) and hornbeam (*Carpinus betulus* Linnaeus). The silvicultural system was applied as a combination of group selection and single tree selection. The soil type is forest brown soil, and at the time of measurement soil moisture content was 16.4%. The average annual rainfall recorded at the closest national weather station was 845.5 mm and the mean annual temperature is 11.5°C. The measurements were carried out during the warmest month of the year in July (26.2°C).

Data collection. To estimate productivity and cost a continuous time-study technique was applied. The work cycle and time elements were broken down in four phases:
(*i*)   Loading: starts when the worker lifts up the lumber by hand and ends when the pieces of lumber were fastened with a to the mule;
(*ii*) Hauling: starts when the teamster and mule with loaded wood leave the stump area and ends when the mule and teamster are on the landing area;
(*iii*) Unhooking: starts when the teamster starts to open the rope and ends when the lumber was unloaded on the ground;
(*iv*) Returning: starts when the teamster and mule leave the landing area and ends when the mule stops in the stump area.

Time for each work element and accumulated time were measured with a deci-minute stopwatch in minutes and seconds. For each mule work cycle, time recording started when the mule leaves the landing and ended when the wood was unloaded at the landing and the mule was ready to start the next cycle. All work phases were recorded without any special arrangements, and any time which was not spent in the work cycle elements was recorded as delay time. Further, important variables of the time consumption such as size of a piece of wood (width, thickness and length), number of pieces of wood, terrain slope, hauling distance and volume were recorded for each trip. The volume for each piece of lumber was estimated by using wood dimensions. The volume per turn and total volume were estimated by multiplying the mean volume of wood by the number of pieces. Acceptable required sample is 30 for scientific inventories (Zobeiry 2000); regarding

Fig. 1. Layout of mule paths: path 1 (a), path 2 (b)

the sample referred to in this study a decision was taken 30 observations to consider required samples, when required samples were 34 with 95% probability level of 10% accuracy.

In this study, the mule logging crew was used for forestry exclusively, who consisted of two mules and three workers, both mules were young and they were in good body condition and no wound was identified on the mule body. In each work cycle a mule and two persons were involved, i.e. mules and people did not work steadily. All extracted wood was in-field produced lumber and its dimensions were 1.2–2.8 m in length, 23–30 cm in width and 12–14 cm in thickness. Each turn, one or two pieces of lumber were fastened to the saddle of mules (wood hauled on the saddle, Fig. 1). All flitched lumber from the two in-field processing places was extracted to the two landing areas in 98 cycles. The mule paths are described in Table 1. Path 2 was exclusively prepared for animal logging (permanent path) and mules moved only on the trail (Fig. 1b), while path 1 was a part of the forest stand which was identified by the worker before wood extraction by the mule (Fig. 1a).

In the study area, system cost for mule logging was based on the contract. The contract system cost was the total cost of: (*i*) fixed cost (including the animal purchase, animal equipment such as saddle, mule shoes and logging ropes, animal support costs, medicine and vaccination cost), (*ii*) operating cost (such as cost of maintenance and repair of the animal equipment), (*iii*) labour cost (such as wage of worker and some fringe benefits).

Therefore, the system cost was calculated based on the contract which was 18.7 EUR·h^{-1}. As usual, the unit cost was calculated by the division of the system cost by average productivity per hour (gross and net production). Moreover, on the basis of the contract the cost of single trip to extracted 0.15 m^3 (on average) and/or 1.8 (on average) pieces of wood was 2.6 EUR.

Model prediction. Normally researchers who use the time study in forest harvesting operations predict a time consumption model by using the original times which are gathered by time studies in the field. But in this paper, all time study numerical data is transformed to their logarithmic data based on 10 and the time consumption model was developed on the basis of logarithmic time data.

Why do we use logarithms? Logarithm modelling is indeed the most reliable method for predicting the consumption of woodworking time by mule. Today's concept of logarithms might make it seem strange that logarithms were really developed out of comparing velocities of arithmetically and geometrically moving points (VILLARREAL-CALDERON 2008). There are two reasons for this unusual and slightly more difficult method:

(*i*) Specialists in mathematical statistics know that logarithms often fit better to time studies than numerical data (SACHS 1984);

(*ii*) Numerical data produce unsolvable contra-

Table 1. Path description

| Path | No. of cycles | Path length (m) | | | Direction | Slope (%) |
		minimum	mean	maximum		
1	48	33	76	84	downhill	−17
2	50	30	85	99	uphill	+23

dictions and problems that do not occur with logarithmic data (Erler 1984, 2012), e.g. in time study numerical data, arithmetic mean and performance mean are different but in the logarithm of data, both performance mean and arithmetic mean are congruent. For example, to do a task by two employees, one employee needs 5 min and his colleague needs 15 min (their arithmetic mean is 10 min). The fast worker's performance is 12 times per hour while his slower colleague's performance is only 4 times per hour (their performance mean is 8 times per hour). If this performance mean is recalculated to arithmetic mean, it would be 7.5 min. This result highlights the two different arithmetic means to do a task, 10 min as the average time consumption and 7.5 min as the time for average performance, which can cause a lot of problems in the interpretation of the statistics (Erler 2012).

To solve this problem we present a solution, as the first, when all collected numerical data of the time study are transformed to their logarithmic data based on 10. After calculating statistical parameters for the logarithmic data, they are recalculated into numerical figures again. The recalculated mean in our example is located between the two means (7.5 min < recalculated mean < 10 min). Therefore, in this study the cost is calculated by two methods:

(*i*) As usual the unit cost is calculated by the division of the system cost by average productivity per hour;

(*ii*) We transformed all the time study data to their logarithms on the base 10, and using logarithmic data we developed a logarithmic time prediction model – on the basis of linear regression in SPSS software (Version 19, 2011). Finally, by the used logarithmic model, we simulated the unit cost for 11 skidding cycles depending on hauling distance and number of pieces of wood under maximum, mean and minimum of the influence parameters.

Residual damage. To assess damage to residual standing trees a 100% inventory method was employed in pre- and post-hauling alongside the mule path. Inventory was executed within 6 m from each side of the mule trail centreline (12 m width). All trees greater than 12 cm in DBH and regenerations within 6 m from each side of the centreline of the mule path were surveyed. Seedlings were classified according to the height in three classes: (*i*) 0.5 m > *h*, (*ii*) 0.5 m < *h* < 2 m, (*iii*) 2 m < *h* < 10 m, diameter less than 12 cm.

After finishing the logging operation, a field study was carried out again to analyse the residual dam-

age. The total number of damaged trees and seedlings was counted alongside the mule hauling direction. The damage to seedlings was recorded by seedling height (as mentioned in the pre-harvesting part) and damage intensity which was classified in two classes: (*i*) severe (broken top, crushed sapling, most parts of the stem are damaged or the seedling is destroyed), (*ii*) light (some parts of the stem and leaves are damaged). The damage to standing trees was recorded by the number of damaged trees, number of injuries on the tree, damage location (root and uproot) and damage intensity which was classified in two classes: (*i*) light (in light injury the wound size was small and damage was caused to scratched or squeezed bark), (*ii*) deep (in deep damage the wound size was large and/or bark of the tree was removed and damage was on the cambium layer or wood).

Soil compaction. To determine the degree of soil compaction a core sampling technique of bulk density was applied. Soil samples were collected from the horizontal face of a soil pit at 10-cm depths of the soil core, at 10 m intervals in the hauling direction of the mule. In this study, 20 bulk density samples in the control and 10 bulk density samples on path 1 were taken [path 2 was a permanent mule path and the soil was compacted prior to this study (Fig. 1b)]. To compute the percentage of moisture, samples were oven-dried at 110 ± 5°C for 24 h. After drying coarse elements such as roots, wood and stones were separated from the soil and parameters such as soil moisture, soil wet and dry density were determined by Eqs 1–3:

$$\gamma_w = \frac{WW}{V} \qquad (1)$$

where:
γ_w – soil wet density,
WW – wet weight of soil samples,
V – volume of the wet weight of soil samples.

$$\gamma_d = \frac{\gamma_w}{1+w} \qquad (2)$$

where:
γ_d – soil dry density,
w – soil moisture content (%).

$$w = \frac{(WW-DW)}{WW} \times 100 \qquad (3)$$

where:
DW – dry weight of soil sample (g).

Soil disturbance occurs when soil A-horizon is puddled and mixed with forest floor organic debris or soil A-horizon is removed and the rest is mixed

Table 2. Measured and estimated time in mule logging

Time consumption	Hauling work phase				
	loading	hauling	unhooking	return	total
Net measured time ± SD (min)	1.45 ± 0.35	2.98 ± 1.23	1.27 ± 0.43	2.59 ± 0.87	8.17 ± 1.98
Measured time (%)	18	36	15	31	
Estimated time (min)	1.41	2.64	1.17	2.56	7.78
Estimated time (%)	18	34	15	33	
Ratio (%)	97	89	92	99	95

SD – standard deviation

with B-horizon. To determine the post-harvesting soil disturbance, distribution area in the entire area of operation such as path 1, in-field processing sites, landing area and tree felling areas are surveyed. Path 2 was a permanent mule trail, therefore it was not considered for soil damage. Disturbed width was measured at a 10-m interval in mule hauling directions.

Statistical analysis. All statistical analyses were performed by SPSS software and $P < 0.05$ was used as the limit for statistical significance. A paired t-test was employed to test the pre- and post-hauling number of healthy residual trees in the mule hauling direction with a 95% confidence level. Before the analysis of soil data, the normality of data distribution was examined by the one-sample Shapiro-Wilk test. The soil dry bulk density changes between the mule path and the control were compared by one-sample t-test. To develop a logarithmic model, linear regression was applied. To do this, hauling distance and slope in return phases, the number of pieces of wood in loading and unhooking phases, distance, the number of pieces of wood and slope in hauling phases were considered as influencing variables. But the logarithmic model was developed just by influencing factors with significant correlation coefficients at a level of significance α = 0.05.

RESULTS

Time consumption and cost

The ratio between the estimated time by the logarithmic model and the measured time by the time study was 99% for return, 97% for loading, 89% for hauling and 92% for unhooking (Table 2). The total time per turn, which was estimated by the prediction model, takes 7.78 min, whilst the measured time in the field was 8.17 min (Table 3). 2.2% of the total time was delay time which was also used for the prediction model, 100% of delay time was for

the operational delay. Inter-time elements, hauling phase took more time than the other time elements, which was about 36% of total time in the time study and about 34% of the total time consumption in the prediction model (Table 2).

The average net and gross production rate was 1.09 and 1.06 $m^3 \cdot h^{-1}$, and the average estimated cost by the logarithmic model, net and gross unit cost were 16.2, 17.2 and 17.6 EUR·m^{-3}, respectively.

Logarithmic time prediction model for simulation of 11 skidding cycles (Eq. 4, $R^2 = 0.56$, $n = 98$):

$$\hat{Y} = 10^{(-0.325+0.009 \times HD)} R +$$
$$+ 10^{(-0.402+0.01 \times HD)+(0.273+0.006 \times S)+(0.115+0.173 \times NW)} H + \quad (4)$$
$$+ 10^{(0.055+0.051 \times NW)} L +$$
$$+ 10^{(-0.220+0.160 \times NW)} UH$$

where:
$\hat{Y}$ – time consumption by the model (min),
HD – hauling distance,
R – return phases,
S – slope,
NW – number of pieces of wood,
H – hauling phases,
L – loading phases,
UH – unhooking phases.

The simulated cost model shows that the minimum, mean and maximum net cost depending on hauling distance was 10.14, 16.20 and 22.98 EUR·m^{-3} (Fig. 2a). In terms of the number of pieces of wood, the maximum net cost was 28.73, mean 16.20 and the minimum was 10.56 EUR·m^{-3} (Fig. 2b).

Table 3. Results of inventoried and damaged seedlings in each height class

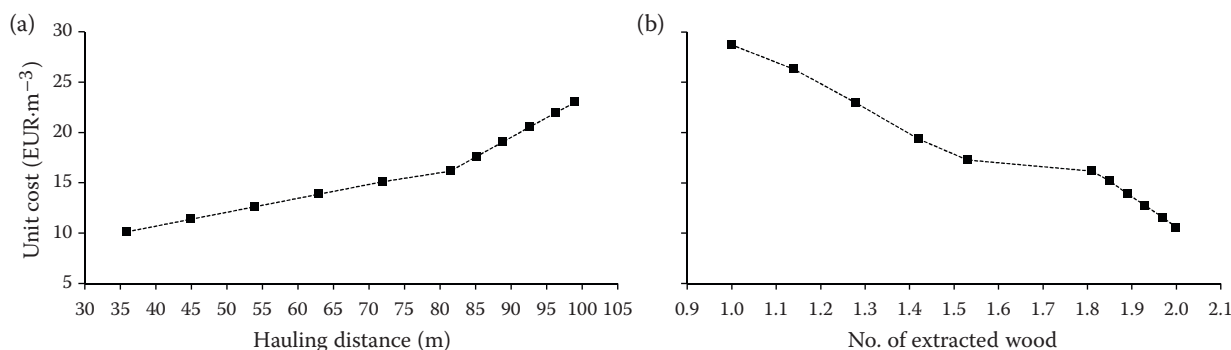| Height class (m)	Inventoried seedlings		Damage	
	quantity	(%)	quantity	(%)
< 0.5	220	70.0	11	5.0
0.5–2	24	7.5	5	20.8
2–10	70	22.5	2	2.9
Total	314	100	18	5.7

Fig. 2. Net cost per cubic meter depending on hauling distance (a), number of pieces of wood (b)

Residual damage

In total, the number of inventoried seedlings was 314, with 18 stems (5.7%) that were damaged (Table 3). About 79% of the seedling damage was severe (29% broken top and 50% crushed sapling) and 21% of damage was light. The statistical analysis showed that the number of healthy individuals of regeneration in pre-harvesting to post-harvesting was not significant ($P = 0.151$). The number of inventoried and damaged seedlings in each height class is presented in Table 3. The highest number of inventoried and damaged seedlings was in the first height class (0.5 m > h). Depending on the percentage of damaged seedlings, the highest damage was in the second height class (0.5–2 m) and the lowest was in the third class (2–10 m, Table 3). The number of inventoried trees was 55 stems and the number of damaged trees was 0 stem (0.00%).

Soil damage

The computed bulk density was 0.953 g·cm^{-3} in the control and 0.956 g·cm^{-3} on the mule hauling path. The bulk density increased by 0.3% to loaded 7.2 m^3 in 48 mule hauling turns, this increase was not statistically significant ($P = 0.903$, $n = 10$, t-statistic = 0.126).The percentage of soil moisture was 19.9% in the control samples, and 16.4% on the mule hauling path. Also, about 1% of the total area was disturbed by mules.

DISCUSSION

According to our assumption all values of estimated time (geometric means) by the logarithmic formula are lower than the time study numerical data (lying between two means). Also, estimated time consumption by the developed model and real time were at a close ratio, on average it was more than 95% (Table 2).

Depending on the country, various species of animals (including oxen, donkeys, horses, elephants, lamas, yaks, caribou and mules) have been used for wood logging (Malatinszky, Ficsor 2016), and their logging capacity is different. In this study, the hourly hauling capacity of a single mule was 1.09 m^3·h^{-1}, the hourly production documented by Rasti (2008) was 1.4 m^3·h^{-1}, Ghaffariyan et al. (2009) 1.99 m^3·h^{-1}, Gilanpour (2010) 1.27 m^3·h^{-1}, Jourgholami et al. (2010) 1.2 m^3·h^{-1}, Jourgholami (2012) 1.23 m^3·h^{-1}, Borz and Cibanu (2013) 2.63 m^3·h^{-1} (for horse) and Mousavi Mirkala et al. (2015) 0.202 m^3·h^{-1}. Also, Malatinszky and Ficsor (2016) reported that the daily logging capacity of a single draft horse ranges from 4.5 to 30 m^3. It seems that these ranges of the hourly production were similar to our finding. On average, the net cost of the extraction of one cubic meter of wood was 17.2 EUR·m^{-3} and estimated cost was 16.2 EUR·m^{-3}. This finding was similar to Jourgholami (2012) and Mousavi Mirkala et al. (2015) observations (13.8 and 12.12 EUR·m^{-3}). On the other side, our observation was higher than the reported cost by Ghaffariyan (2008) 1.99 EUR·m^{-3}, Ghaffariyan et al. (2009) 1.28 EUR·m^{-3} and Gilanpour (2010) 2.83 EUR·m^{-3}. Probably, the reason for this large difference could be due to the contract infrastructure. Knowing the factors affecting the production and costs of skidding has an important role in planning and organizing consumed budgeting as well as arranging expenditures to raise profitability (Hejazian et al. 2013). After analysing the data and prediction model, it became clear that the time consumption was affected by hauling distance, number of hauled pieces of wood per turn and terrain slope. Overall, in previous studies the most important factors that affected time consumption were hauling distance, slope, volume per turn, number of logs per load and kind of extracted

wood (Ghaffariyan et al. 2009; Jourgholami 2012; Borz, Cibanu 2013; Mousavi Mirkala et al. 2015). Further, our findings by simulated models imply that (regarding the hauling distance) mule logging was more profitable at a shorter hauling distance (less than 70 m, Fig. 2a). It is to suggest the mule integration with skidder at short distances. Also, Magagnotti and Spinelli (2011b) reported that horse skidding incurs lower unit costs than tractor skidding, when the extraction distance is short or when pre-existing skidding trails are not available (Magagnotti, Spinelli 2011b), and their integration with tractor skidding is cheaper than direct tractor skidding (Magagnotti, Spinelli 2011a). Also, Malatinszky and Ficsor (2016) found that horses are more economic than machines in the thick snow. In terms of the number of pieces of wood, the difference between minimum and maximum cost is high (Fig. 2a), which highlights the higher influence of the number of wood pieces compared to hauling distance (in less 100 m).

Logging in forests often causes physical damage to standing residual trees and soil (Nikooy et al. 2010). The analysis of residual damage data indicated that about 5.7% of the regeneration was damaged. This range of damage to regeneration is similar to results of Gahffariyan (2008), Rasti (2008), Naghdi et al. (2009), Spinelli et al. (2012), their reported damage was 8, 11, 13.3 and 5% of the total seedlings. In contrast, fewer researchers found that damaged seedlings exceeded more than 22% alongside the mule path (Ahmadi 1996; Ghaffariyan et al. 2009; Jourgholami, Majnounian 2010). Researchers who have written for the Forest Resources Association believe that 10% damage is a worthy goal and that damage exceeding 25% in any partial harvest operation is unacceptable (Gillespie 2001). The main cause of the high level of damage is manpower, which can be minimized by the use of proper timber harvesting techniques. Timber harvesting techniques resulted in damage to residual trees, seedlings, and timber products, but the degree of damage caused by the harvesting techniques was significantly different (Eroglu et al. 2009). We found that 79% of the seedling damage was severe and 21% of damage was light, and in regard to pre-harvesting intensity the lowest damage occurred in the third height class and the major portion of damage occurred in the second height class. This result is in conflict with Naghdi et al. (2009) and in agreement with Ghaffariyan et al. (2009). In this research, no damage occurred on the trees, which is quite similar to Jourgholami and Majnounian (2010);

their study showed that 0% of trees was damaged, Ficklin et al. (1997) reported that only 7% of the residual trees (DBH > 5 cm) were damaged by the mule logging system.

Soil compaction can be characterized as a breakdown of surface aggregates, which leads to a decrease in the macropore space in the soil and a subsequent increase in the volume of soil relative to the air space, leading to an increase in bulk density and soil resistance to penetration (Han 2006). The results of soil bulk density showed that an increase in soil bulk density was not significantly different compared to control samples, while according to Naghdi et al. (2009), it was significantly higher than in control samples. In the research area of Ghaffaryian et al. (2003, 2009) soil compaction increased by 14.14% (due to 55 passes) and 13.8% (due to 28 passes), but our observation was only 0.30% (due to 48 passes), which is significantly less than in those reports. In our study, bulk density samples were collected from path 1, where designated prior to wood extraction by workers. Depending on the results of these researchers (Ghaffaryian et al. 2003, 2009; Naghdi et al. 2009), their considered mule paths were probably designated as permanent. The important point in this research is that pieces of lumber were fastened with a rope to the saddle of the mule and they were hauled on the saddle instead of skidding on the ground. Therefore, the damaged soil area by a mule is only the mule foot track, which can be a reason for a tiny change in soil bulk density on path 1. Jourgholami and Majnounian (2010) showed that soil disturbance and soil compaction were reduced by mule logging and 4.3% of the total area were disturbed. In recent studies, the soil disturbance area was also reported by Ghaffaryian et al. (2009) 5.72% and less than 3% of the total area by Spinelli et al. (2012). Whereas, in our study the total area that was disturbed by mule logging was less than 1% of the total area, because mules move along the narrow path and soil damage was measured only on path 1, in-field processing areas and landing areas. But e.g. Ghaffaryian et al. (2009), they surveyed all areas of skid trails, processing sites and landing in a compartment to determine the disturbed area.

CONCLUSIONS

In the time study, numerical data produces unsolvable contradictions and problems (Erler 1984), hence researchers can benefit from loga-

rithms to solve this problem. Despite the limited numbers of time study data (98 turns) we found a high ratio (95%) between numerical and logarithmic data. Furthermore, depending on our results, we can conclude that a suitable harvesting method, regarding the environmental impacts on forests in a mountain area, is logging by animals. But if foresters are looking for economic alternatives, absolutely it cannot be animal logging. Also, we propose that animal logging can be more economic if it is used at a shorter distance.

References

Ahmadi H. (1996): Study of logging damages on forest stand [MSc Thesis.]. Tehran, University of Tehran: 148.

Akay A.E. (2005): Determining cost and productivity of using animals in forest harvesting operations. Journal of Applied Sciences Research, 1: 190–195.

Borz S.A., Ciobanu V. (2013): Efficiency of motor-manual felling and horse logging in small-scale firewood production. African Journal of Agricultural Research, 8: 3126–3135.

Engel A.M., Wegener J., Lange M. (2012): Greenhouse gas emissions of two mechanised wood harvesting methods in comparison with the use of draft horses for logging. European Journal of Forest Research, 131: 1139–1149.

Erler J. (1984): Leistungsstreuung und Mittelwertsautomatik. [Ph.D. Thesis] Göttingen, Göttingen University: 70.

Erler J. (2012): Wissenschaftliches Arbeiten. Band: Zumutbare Vorgabezeiten. Reihe: Forstliches Technikmanagement. Tharandt, Fachinstitut für Waldarbeit: 50.

Eroglu H., Öztürk U.O., Sönmez T., Tilki T., Akkuzu E. (2009): The impacts of timber harvesting techniques on residual trees, seedlings, and timber products in natural oriental spruce forests. African Journal of Agricultural Research, 4: 220–224.

Ficklin R., Dwyer P.J., Cutter B.E., Drapper T. (1997): Residual tree damage during selection cuts using two skidding systems in the Missouri Ozarks. In: Pallardy S.G., Cecich R.A., Garret H.H., Johnson P.S. (eds): Proceedings of the 11th Central Hardwood Forest Conference, Columbia, March 23–26, 1997: 36–46.

Ghaffariyan M.R. (2008): Selecting the best skidding system using AHP: A case study in Northern Iran. Forest Science, Sofia, 44: 77–86.

Ghaffariyan M.R., Sobhani H., Mohajer M.R. (2003): A study of site damages (soil and seedling) by traditional logging method. Iranian Journal of Natural Resources, 58: 812–820. (in Persian)

Ghaffariyan M.R., Durstone T., Sobhani H., Mohajer M.R. (2009): Mule logging in northern forests of Iran: A study of productivity, cost and damage to soil and seedlings. Croatian Journal of Forest Engineering, 30: 67–75.

Gilanpour N. (2010): Investigation of productivity and cost of ground base operation and animal skiding for determining the best composition. [MSc Thesis.] Nour, University of Tarbiat Modares: 71.

Gillespie W.H. (2001): Residual stand damage can be a serious logging problem. Available at http://www.wvfa.org/pdf/factsheets/FACT%20SHEET%20No.%2031.pdf

Han S.K. (2006): Impacts on soils from cut-to-length and whole tree harvesting. [MSc Thesis.] Moscow, University of Idaho: 43.

Hejazian M., Lotfalian M., Hosseini S.A., Fallah A. (2013): Analysis and evaluation of ground skidding costs of two stands with respect to production per hour and log quality. Bulletin of Environment, Pharmacology and Life Sciences, 2: 24–29.

Jourgholami M. (2012): Small-scale timber harvesting: Mule logging in Hyrcanian forest. Small-scale Forestry, 11: 255–262.

Jourgholami M., Majnounian B. (2010): Traditional logging method in Hyrcanian forest, impacts to forest stand and soil (case study: Kheyrud forest). Iranian Journal of Forest, 2: 221–229. (in Persian)

Jourgholami M., Majnounian B., Feghhi J., Visser R.J.M. (2010): Timber extraction with mules: A case study in the Hyrcanian forest. African Journal of Agricultural Research, 5: 3108–3115.

Magagnotti N., Spinelli R. (2011a): Integrating animal and mechanical operations in protected areas. Croatian Journal of Forest Engineering, 32: 489–499.

Magagnotti N., Spinelli R. (2011b): Financial and energy cost of low-impact wood extraction in environmentally sensitive areas. Ecological Engineering, 37: 601–606.

Malatinszky A., Ficsor C. (2016): Frequency and advantages of animal-powered logging for timber harvesting in Hungarian nature conservation areas. Croatian Journal of Forest Engineering, 37: 279–286.

Mousavi Mirkala S.R., Nikooy M., Naghdi R., Ghaznavi N., Karamzade S. (2015): Productivity and cost study of mule logging in Astara watershed forests. Journal of Wood & Forest Science and Technology, 21: 161–174.

Naghdi R., Lotfalian M., Bagheri I., Moradmand Jalili A. (2009): Damages of skidder and animal logging to forest soils and natural regeneration. Croatian Journal of Forest Engineering, 30: 141–149.

Nikooy M., Rashidi R., Kocheki G. (2010): Residual trees injury after selective cutting in broadleaf forest in Shafaroud. Caspian Journal of Environment Science, 8: 173–179.

Nurminen T., Korpunen H., Uusitalo J. (2006): Time consumption analysis of the mechanized cut-to-length harvesting system. Silva Fennica, 40: 335–363.

Rasti R. (2008): Comparaison wood production and cost during planned and unplanned mule logging in Kheiroudkenar forest. [MSc Thesis.] Tehran, University of Tehran: 98.

Sachs L. (1984): Applied Statistics. A Handbook of Techniques. New York, Springer-Verlag: 716.

Shrestha S.P., Lanford B.L. (2001): Utilization and cost for animal logging operations. In: Wang J., Wolford M., McNeel J. (eds): Proceedings of the 24th Annual Council on Forest Engineering (COFE) Meeting, Snowshoe, July 15–19, 2001: 148–154.

Spinelli R., Lombardini C., Magagnotti N. (2012): Salvaging windthrown trees with animal and machine systems in protected areas. Ecological Engineering, 53: 61–67.

Toms C.W., Dubois M.R., Bliss J.C., Wilhoit J.H., Rummer R.B. (2001): A survey of animal-powered logging in Alabama. Southern Journal of Applied Forestry, 25: 17–24.

Villarreal-Calderon R. (2008): Chopping logs: A look at the history and uses of logarithms. The Mathematics Enthusiast, 5: 337–344.

Wang L. (1997): Assessment of animal skidding and ground machine skidding under mountain condition. International Journal of Forest Engineering, 8: 57–64.

Zobeiry M. (2000): Forest Inventory (Measurement of Tree and Stand). Tehran, University of Tehran Press: 401. (in Persian)