Economic Analysis of Residual Tree Damage Following Selective Logging in a Caspian Hardwood Forest

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Abstract: This study evaluated the logging damage to residual trees following logging operations by opportunity and replacement cost approaches. A total density of 5.1 trees/ha and 17.3m^3/ha of wood were harvested. On average, 9.8 trees were damaged for every tree extracted including 8 trees killed or severely damaged. The results of showed that selective cutting can damage residual trees US$47369.25. The results of this study also suggest that logging practices need to be accompanied by close supervision of field personnel and post logging site inspections to be implemented properly.

Keywords: Selective cutting, skidding, opportunity cost, replacement cost.

1. INTRODUCTION

The economic understanding of damages to residual trees is important as it ensures the constancy of forest ecosystems following selective logging. Economic questions of forestry can be studied with suitable models that contain description of forest stand growth, harvesting technology, and economic parameters [1]. While many studies were conducted to evaluate physically feasible machine solutions and to improve harvesting economics, the conservation of environment became even more and more essential in public discussion. Long-term field experiments with selective cutting in uneven-aged coniferous forests have showed that inappropriate forest structures and poor conditions for natural regeneration may cause low volume production, and hence, low profitability [2, 3]. This increased interest is partly due to expected enhancements for landscape aesthetics and biodiversity, and partly to expected benefits for regeneration costs, timber quality and profits [4]. Several authors have claimed that near-natural forest management is capable of developing more sustainable forestry practices that protect the ecological structures and functions, as well as satisfies the economic needs of the forest owner. The philosophy behind this ‘‘near-natural’’ stand management is to adopt silvicultural principles in accordance with the ecological processes in the forest and let them merge with economic rationalization. Uneven-aged forest management with selective cutting and natural regeneration has been the dominating silvicultural regime in Caspian forests in Iran for 20–30 years. The loss of Caspian forests to competing land uses has placed significant pressures on forest managers to adopt management practices that can provide a competitive flow of economic benefits while concomitantly protecting critical ecological variables [5]. In Caspian forests, logging operation is generally performed by using selective cutting methods including single-tree and group selection. Chainsaw and cable skidder are two main forest machines for harvesting in the region. However, logging operations result in serious residual stand damage during felling, winching and skidding operations [6]. Iranian law now requires the development of forest management plans that seek sustainable timber harvesting on all of Iran’s permanent production forest lands. Today, Iranian forest management plans are based on the removal of isolated mature trees on a sustained yield basis, with the goal of improving the overall commercial value of the forest. Despite noteworthy advances, damage to future crop trees during selective logging is thought to be one of the largest silvicultural challenges facing sustainable forest management in the region. Numerous studies have quantified the levels of residual tree damage in selection-managed stands, including both the damage caused by falling trees and that caused by skidders used to remove the trees. These studies show that 25%-35% of residual trees are injured at some point in the course of logging [7]. A critical step toward sustainable forestry in the region is ensuring the sustaining residual trees following logging. Although the economic costs of damaging to residual trees following logging operations are probably large, quantification of these costs is missed in Caspian forests. Economic costs analysis may ultimately justify the institution of financial incentives or imposing regulations on the forest product industry to adopt sustainable management practices. The main objectives of this

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study were to evaluate residual tree damage following selective logging and quantify current harvest costs associated with conventional logging by opportunity and replacement cost approaches.

2. MATERIAL AND METHODS

2.1. Site Description

The study was conducted in compartments 228, 231 and 232 in Chafroud forests in the north of Iran. The altitude ranged was from 1250 to 1450 m above sea level and the average annual precipitation was 1450mm. The forest was uneven-aged Fagetum (fagus orientalis *Lipsky*) with the average growing stock 320m^3/ha. The average slope of the compartments was 30 to 40% and the aspects of the slopes were Northwestern and northern. The total volume of production was 2699m^3 and the skidding was done from the stump area to the roadside landing by ground-based skidding system. Dominant canopy species include beech (*Fagus orientalis)*; hornbeam (*Carpinus betulus)*; maple (*Acer velutinum*), alder (*Alnus subcordata)* and elm (*Ulmus glabra)*. Table **1** shows the characteristics of the study area.

Table1: Characteristics of Study Area

Characteristics	Comp.228	Comp.231	Comp.232
Forest district	Chafroud	Chafroud	Chafroud
Altitude	1200	1450	1250
Aspect	Northwestern	Northern	Northern
Area	42	66	48
Average field slope (%)	40	30	30
Silvicultural system	Selective cutting	Selective cutting	Selective cutting
Kind of timber	Beech	Beech	Beech

2.2. Residual Tree Damage

The stands were harvested *via* manual felling with a Chainsaw and cut-to-length system with a rubber tired skidder throughout a 6-month period from the winter of 2010 to the spring of 2011. The Chainsaw operator had 10 years of experience, whereas the skidder operator had 8 years. On our 152 hectare study site, data were collected after selective logging from the remaining trees. Table **2** (from Krueger, 2004) was selected to evaluate the amount of damages to residual trees. Damage to the residual trees recorded according to the cause of damage (i.e. felling, winching and skidding) and the location and severity of wound.

2.2.1. Assessing Tree Damage Associated with Felling Operations

Approximately 30 single tree fall sites were selected at random form in the region and tree damage incurred at each site was tallied. Damage to the residual trees recorded according to the location and severity of wound (Table **2**, from Krueger, 2004).

2.2.2. Assessing Tree Damage Associated with Skidding Operations

All skid trails in each of the three compartments were mapped and delineated into four classifications: (1) primary skid trails, where more than 10 trees had been skidded, (2) secondary skid trails, where 2–10 trees had been skidded, (3) and tertiary skid trails, where only one tree had been skidded (from Jackson *et al*. (2002)). The lengths of individual skid trails were measured, and tree damage was tallied along the entire length of all primary, secondary, and tertiary according to the cause of damage and the location and severity of the wound (Table **1**, from Krueger (2004)). To adjust for differences in pre-harvest tree density among stands and individual skid trail lengths, the percentage of trees damaged per unit length of skid trail constructed was calculated.

Table 2: Classification of Damages to Residual Trees along Skid Trails and Logging Gaps (Modified from Krueger, 2004)

Damage Type	Bole	Root	Crown
Severe	Snapped at base, bent, or severely leaning	Uprooted	Loss of entire crown, less than entire but more than two-thirds of crown
Moderate	Exposed and damage cambial tissue	Exposed and damaged cambial tissue	Loss of less than two-thirds but more than one-third of crown
Minor	Exposed cambial tissue but no damage, bark scrape	Exposed cambial tissue but no damage, root scrape	Loss of less than one-third of crown

2.3. Experimental Design and Statistical Analysis

We were interested not only in quantifying damage due to selective logging but also in quantifying and comparing damage according to disturbance type. We used factorial experiment based on randomized block sampling in the study site, so that the compartments were blocks and harvesting treatment (felling, winching and skidding) and slope (0-20, 20-40 and >40%) were factors. Analysis of variance (ANOVA) and Duncan multiple tests were employed to test for differences in residual tree damage among different logging operations and different slope classes within the forest.

2.4. Economic Analysis

To evaluate the damages to residual trees caused by logging operations (felling, winching and skidding) following selective logging used two economic approaches including opportunity cost and replacement cost methods. With an opportunity cost approach, value is based on what an individual sacrificed to obtain a set of goods, services or assets. With a replacement cost approach, value is based on what one would have to pay to replace a set of goods, services and assets. Economic analysis of current study developed based on wood value of the tree, so other values of a tree is not considered in the study. To compute the value of standing wood, logging costs (US$ per cubic meter) subtracted from wood market price per cubic meter. For each extinct tree, computed the volume and then volume of tree multiply in standing tree value. The value of trees that extinct following logging operations was determined as replacement cost. For computing opportunity cost, the volume of extinct tree in logging year in the future was predicted, and then subtracted from tree volume in study year. Then the surplus volume multiplied in standing value of the tree.

3. RESULTS

3.1. Statistical Analysis of Damages to Residual Trees

Total number of trees damaged per tree harvested by damage classification and cause of damage show that the most common types of damage to residual trees in winching areas and skid trails included uprooted stems and damaged cambial tissue, while the most common types of damage to residual trees in logging gaps included crown damage (Table **3**). Statistical analysis shows that the numbers of extinct trees per one harvested tree were significantly different

Table 3: Total Number of Trees Damaged per Tree Harvested by Damage Classification and Cause of Damage

		Skid Trails			Winching Areas	Logging Gaps
		Primary	Secondary	Tertiary		
Bole Damage						
	Uprooted	0.12	0.08	0.06	0.56	0.32
	Snapped, bent, leaning	0.78	0.19	0.12	0.17	0.49
	Damaged cambial tissue	1.03	0.60	0.34	0.29	0
	Exposed cambial tissue	0.71	0	0.08	0	0.18
	Bark scrape	0.09	0.06	0.06	0.15	0.27
Crown Damage						
	All	0	0	0	0	1.35
	2/3<3/3	0	0	0	0	1.88
	1/3<2/3	0	0	0	0	0.43
	0<1/3	0	0	0	0	0
Root Damage						
	Damaged cambial tissue	2.54	0.87	0.44	0.83	0
	Exposed cambial tissue	0	0	0	0.11	0
	Root scrape	0.04	0	0.05	0	0.12

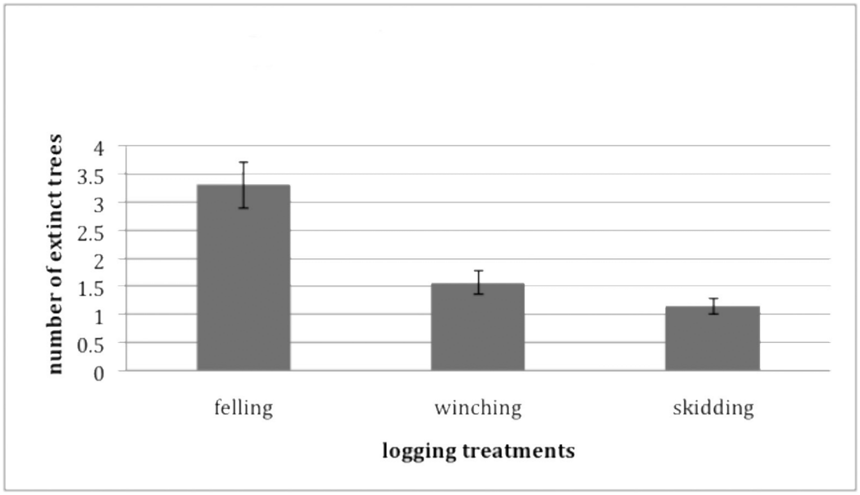

Figure 1: Number of destroyed residual trees in different logging treatment (Felling, Winching and Skidding).

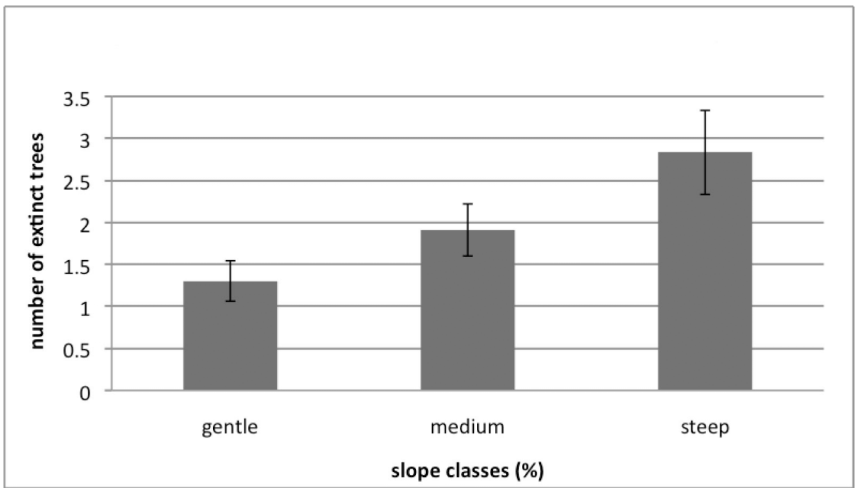

Figure 2: Number of destroyed residual trees in different slope classes.

among logging treatments (Figure **1**). Statistical analysis shows that the numbers of extinct trees per one harvested tree were significantly different among slope classes (Figure **2**).

3.2. Economic Analysis

The value of standing wood was computed US$219 per cubic meter. Table **7** shows the amount of computed opportunity and replacement costs in the study area. The total replacement and opportunity cost was estimated US$1402.42 and US$45966.83, respectively (Table **7**). Generally, the economic value of extinct trees in the study area was estimated US$47369.25. On the other hand, the selective logging can cause damage as much as US$303.65 per hectare.

4. DISCUSSION

The results of this study showed that one of the potential difficulties of selective cutting in any stand is logging damage to residual trees that can result in reducing the tree wood value. Absolutely, much of this

Table 7: Economic Cost of Damages to Stand Trees Per Harvested Tree Due to Selective Logging

Logging Treatment	Diameter at Breast Height (dbh)	Standing Wood Volume	Slope Class (%)	Average Weighted Price (US$/m^3)	No. of Extinct Trees Per Harvested Tree	Standing Wood Value (US$/m^3)	Replacement Cost (US$)	Opportunity Cost (US$)
All operations		3.78			54.41	-	1402.42	45966.83

damage could have been avoided through more careful logging procedures. The results indicated that most of the bole damage was from skidding when tree-length logs scraped against boles of standing trees on primary and secondary skid trails, but most of the crown damage was from felling operation, so, better felling procedures, such as directional felling, could have remedied some of the crown damage. The number of trees that were destroyed by the selective logging operation ranged from 1.15 along skid trails to 3.32 in felling gaps per harvested tree**.** Some damages to residual trees represent damage so great that the log grade decreases by one grade on the butt log. The butt log is the most valuable log in the tree. This again devalues the remaining trees in the residual stand because the trees will probably not heal over and increase to a better log grade anytime in the foreseeable future. The logging wounds provide an opportunity for fungi to enter the tree and instigate the spread of wood decay and rot that will diminish the value of the tree (Shigo 1979, 1986). Table **1** showed that logging treatments and slope gradient have a significant impact on residual trees (P=0.000) following logging operations. Total amount of replacement and opportunity costs in the study area were calculated US$1402.42 and US$45966.83, respectively. On the other hand, the amount of economic cost per harvested trees was measured US$47369.25. Obviously, planned logging operations can cause decreasing damages to residual trees.

CONCLUSIONS

More careful logging would have reduced the amount of residual stem damage and economic costs associated with selective logging in Caspian forests. However, the un-planned logging operations increased the chance of bole and crown damage to residual trees. Future residual trees in selective logging are necessary to reach sustainable forest management in Caspian forests. Selective logging have many advantages in reducing stand density, favoring certain species, increasing diameter growth, and having more pleasing aesthetics when compared to clear-cutting. However, the potential detrimental damage to residual trees should be considered in selective logging. Results showed that selective cutting cause destroying of trees and decrease stand value (opportunity and replacement costs), on the other hand, reduction of butt log grade and the loss of potential tree value should be prime considerations with long-term effects in the future stand in the region.

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