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Post-Fire Salvage Logging for Fire-Killed Brutian Pine (*Pinus brutia*) Trees

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Abstract: The volume and economic value of the fire-killed and fire-damaged timber can dramatically decrease due to the impacts of deterioration agents after fire. Insect and stain fungi damages cause significant reductions in economic value of timber especially in the first year after fire. The fire-killed and fire-damaged trees should be quickly extracted to recover their economic values. The logging cost is the main factor that affects the net value of the trees after fire. Therefore, logging system should be carefully planned to maximize the net value recovered from the fire-killed and fire-damaged trees. In this study, the cost efficiency of ground-based logging systems in extracting fire-killed and fire-damaged trees was analyzed in a partially burned Brutian Pine (*Pinus brutia*) forest, located in Kahramanmaras. Besides, to select the optimum skidding distance with minimum logging costs, the logging systems were examined with respect to various skidding distances and associated forest road lengths.

Key words: Fire-killed trees, deteriorating agents, logging cost, skidding distance

INTRODUCTION

To recover the economic value of the fire-killed or fire-damaged trees, their timber should be immediately salvaged after fire since they are vulnerable to major deteriorating agents such as insects, decay fungi and stain fungi. The deterioration types are divided into two groups: limited deterioration which reduces the economic value of timber and general deterioration which reduces the volume of the fire-killed timber (Lowell *et al*., 1992). Decay fungi damage is generally classified as general deterioration, while insect and stain fungi damages are classified as limited deterioration.

Beetles are the initial deteriorating agents that attack fire-damaged trees and result in mortality. The most common beetles that attack the sapwood and heartwood of the fire-damaged timber are buprestid (flatheaded or metallic) beetles and cerambycid (roundheaded or long-horned) beetles (Lowell *et al*., 1992). The beetles usually develop galleries under the bark, thereby opening up the tree to other deteriorating agents. In order to detect the presence of beetles in a damaged-tree, the bark along the bole of the tree should be removed to see the signs of beetle activity such as tunnels and wood dusts.

Lowell *et al*. (1992) reported that the most important form of softwood deterioration is stain fungi damage that results in a reduction in economic value of timber especially in the first year after fire. Fungal spores can penetrate into the sapwood through a break in the bark, branch stub and broken top. Insects also introduces stain and decay fungi into the sapwood (Furniss and Carolin, 1977). The value loss from deterioration is greater in pine trees due to higher percentage of sapwood (Smith *et al*., 1970). Most of the staining fungi encountered in sapwood of pine trees is blue stain fungi of the genus *Ophiostoma* Syd. and P. Syd. (Farr *et al*., 1989).

Akay *et al*. (2006) conducted a study where a model was developed to estimate the value of fire-killed Douglas-fir timber based on time since death and yarding distance of helicopter logging. First, the model calculated the average volume loss from deterioration in timber and then, the net value was estimated by subtracting the total logging costs from the total mill value of the recoverable fire-killed timber. For each year during the four years after the fire, the net value of each tree was calculated for each yarding distance (Table 1). The results indicated that recoverable value was very sensitive to yarding distances. However, the model could not examine the economic trade off in case where new forest road could be constructed to decrease the yarding distance.

Since late 1970's, the studies have indicated that fire-killed trees and logs perform vital role for forest ecosystem after fire (Franklin and Maser, 1988). They help restore biodiversity of forest ecosystem by performing ecological functions for forest soils, streams, vegetation,

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Table 1: Net value ($) per tree with average diameter of 45 cm, as function of years after fire and helicopter yarding distances

Years after fire	Distances (km) 0.4	1.2	2	2.8
0	40	36	22	8
1	26	19	13	7
2	16	10	3	0
3	6	0	0	0
4	0	0	0	0

wildlife, fish, insects, microbes and fungi (Harrod *et al.*, 1998). Therefore, some of the fire-killed trees and logs should be left in the burned watershed to ensure forest recovery, rehabilitation and restoration after fire.

The logging operation is the most expensive forest operation in producing wood products (Acar *et al.*, 2000). Logging operation is generally divided in three stages including secondary hauling, loading and unloading and primary hauling (Aykut, 1985). The secondary hauling includes felling, bucking and transporting logs from stump to landing (i.e., skidding, forwarding, yarding etc.), while primary hauling is transporting forest products from landing to the mills. In the ground-based logging operations, skidding distance is generally the most important factor on logging cost (Acar and Dinc, 2001).

The purpose of this study is to estimate the recoverable value of fire-killed timber in a partially burned Brutian Pine (*Pinus brutia*) forest in Kahramanmaras, Turkey. To maximize the net value, the economic analysis is performed for a ground-based logging system where various skidding distances and forest road lengths are also evaluated.

MATERIALS AND METHODS

Study site: The study area of 15 ha was located in a partially burned Brutian pine forest, which is located approximately 40 km northwest of the city of Kahramanmaras. The fire could not penetrate into the wood, while inner and outer barks were burned completely. The average stand age, average tree diameter and a dominant tree height were measured as 30 years, 36 cm and 15 m, respectively. The canopy structure of the stand was moderately closed. The average ground slope and stand density was about 65% and 206 trees per hectare, respectively. Timber volume to be extracted from the study area was estimated as 144 m^3 per hectare in which 10% of the trees, including fire-damaged trees and snags, was assigned to be left in the area for restoration of biodiversity in forest ecosystem. In the fire-killed and fire-damaged trees, the signs of following deteriorating agents were encountered.

Deteriorating agents: Buprestid beetles (Buprestis tarsensis Mars.) were identified into the fire-killed Brutian pine trees, which were cut from the study site (Fig. 1). The sizes of mature buprestid beetles were up to 14-15 mm. The covers of their wings were in bright metallic color and there were lengthwise and parallel lines along the wings. Tosun (1977) conducted a study where buprestid beetles were identified in death Brutian pine samples, which were collected from Duzlercami Kazdagi Forest located in one of the Mediterranean cities of Antalya. In Kahramanmaras region, the samples of buprestid matures were also encountered in Kilavuzlu Forest in June, 1996 (Kanat, 1998).

The blue stain defects were encountered on sample timber segments obtained from various places (bottom, middle and top) of a fire-killed Brutian pine tree within six months after fire (Fig. 2) (Akay and Tutus, 2006). The stain defect on sapwood and heartwood of sample timber segments were estimated using both digital image processing techniques and chemical method of 1% NaOH solubility. Image analysis provided objective

Fig. 1: Buprestid beetles damage on bark of a fire-killed Brutian pine tree

Fig. 2: Blue stain defects were encountered on sample timber segments obtained from a fire-killed Brutian pine tree

Table 2: The estimated percentage of blue stain defects on apwood and heartwood separately

	Sapwood			Heartwood		
Sample	Bottom segment	Middle segment	Top segment	Bottom segment	Middle segment	Top segment
Clear wood	28.52	36.18	72.36	76.17	69.17	95.23
Blue stain defects	49.77	38.17	3.39	23.83	30.83	4.77
Background elements	21.71	25.65	24.25	-	-	-

measurements of wood discoloration in sapwood and heartwood portions of sample timber segments (Table 2). Supervised classification method provided the best result in using image analysis. Chemical method of 1% NaOH solubility also provided good results in determining the presence of stain defects in sapwood and heartwood of each segment.

Logging operation: In the logging operation, it was assumed that felling and bucking was done by loggers using chainsaws and skidding was done by using forest tractor and manpower. To find the optimum skidding distance with minimum logging costs, the skidding distances were evaluated with respect to the length of a temporally forest road section. The average skidding distances from 50 to 200 m was evaluated by 10 m increment, while reducing associated road section lengths from 200 to 50 m by 10 m reduction. In this study, it was assumed that the forest service crew performed felling, bucking and skidding operations, while loading, hauling and unloading was done by the purchasers of the forest products.

The unit cost of logging operations can be calculated based on hourly cost of equipment and production rate (Lambert, 1990): The hourly cost of the equipment with operator is called the machine rate, which is usually divided into ownership costs, operating costs and labor costs (Sessions, 1992). The production rate (P) can be calculated by dividing the average volume of wood per cycle (V) by the time per cycle including delays as follows (Kellogg *et al*., 1986):

$$P(m^3\ h^{-1}) = \frac{V(m^3\ cycle^{-1})}{\frac{hours}{cycle} + \text{delay and other } (h\ cycle^{-1})} \quad (1)$$

Then, the unit cost of logging operations can be calculated by dividing the machine rate by the production rate (Lambert, 1990):

$$UC = C/P \quad (2)$$

UC = the unit cost of logging ($\$\ m^{-3}$)

C = machine rate for the equipment ($\$\ h^{-1}$)

RESULTS AND DISCUSSION

In the economic scenario of the logging operation, two main forest products including logs and firewood were extracted from the logging site. The proportions of total log and firewood productions were estimated as 70 and 30%, respectively. The market values of the undamaged trees were \$93.28 and \$78.36 per m^3 for logs and firewood, respectively. The average value loss in the fire-damaged and fire-killed trees was estimated as 20% for logs, while it was 5% for firewood. The average unit costs of felling and bucking for log and firewood were \$7.26 and \$11.98 per m^3, respectively. The unit cost of road section with quality surfacing was estimated as \$55 per m.

The unit cost of skidding was minimized in a case where the average skidding distance of 50 m was combined with temporally road length of 200 m (Table 3). The unit costs of skidding logs and firewood were estimated as \$2.51 and \$4.13 per m^3, respectively. In a study conducted by Acar and Dinc (2001), the unit costs of skidding with forest tractor was estimated as \$2.97 per m^3 in a study area where the average ground slope and tree diameter were \$61 and 43 cm, respectively.

The results indicated that increase in skidding distance increased the unit cost of skidding for both log and firewood productions. Akay *et al*. (2004) reported that skidding distance was the most effective variable increasing the cycle time in skidding operation, which then lead to significant increase in skidding cost. The unit costs of logging in extracting firewood were about 39% more expensive than that of extracting logs.

After leaving about 216 m^3 of the fire-damaged trees and snags for recovering forest ecosystem, the amount of log and firewood extracted from logging site were about 1360 and 583.2 m^3, respectively. The total costs of felling and bucking were \$9,873.60 and \$6,986.74 for all combinations of skidding distances and road lengths. The total costs of logging and road construction and total value of were listed in Table 4. The net value was computed by subtracting the total costs from the total market value of the fire-killed timber.

The maximum net value of the recovered timber, \$111,214.06 (\$57.21 per m^3), was provided by the logging operation with the shortest skidding distance and longest temporally road section. The logging system with the

Table 3: The unit cost summary of logging operations for log and firewood products

Skidding distance (m)	Road length (m)	Skidding costs ($m^{-3}) Log	Skidding costs ($m^{-3}) Firewood	Logging costs ($m^{-3}) Log	Logging costs ($m^{-3}) Firewood
250	-	12.56	20.71	19.82	32.69
200	50	10.04	16.58	17.30	28.56
190	60	9.54	15.73	16.80	27.71
180	70	9.04	14.91	16.30	26.89
170	80	8.54	14.09	15.80	26.07
160	90	8.04	13.27	15.30	25.25
150	100	7.53	12.42	14.79	24.40
140	110	7.03	11.60	14.29	23.58
130	120	6.53	10.78	13.79	22.76
120	130	6.02	9.93	13.28	21.91
110	140	5.53	9.11	12.79	21.09
100	150	5.02	8.29	12.28	20.27
90	160	4.52	7.47	11.78	19.45
80	170	4.02	6.62	11.28	18.60
70	180	3.51	5.80	10.77	17.78
60	190	3.00	4.96	10.26	16.94
50	200	2.51	4.13	9.77	16.11

Table 4: The logging costs and net value summary for alternative logging systems

Skidding distance (m)	Road length (m)	Road cost ($)	Total logging costs ($) Log	Total logging costs ($) Firewood	Total net value ($)	Net value ($ tree^{-})
250	-	-	26955.20	19064.81	98876.60	50.86
200	50	2750	23528.00	16656.19	101962.42	52.45
190	60	3300	22848.00	16160.47	102588.14	52.77
180	70	3850	22168.00	15682.25	103196.36	53.08
170	80	4400	21488.00	15204.02	103804.58	53.40
160	90	4950	20808.00	14725.80	104412.81	53.71
150	100	5500	20114.40	14230.08	105052.13	54.04
140	110	6050	19434.40	13751.86	105660.35	54.35
130	120	6600	18754.40	13273.63	106268.58	54.66
120	130	7150	18060.80	12777.91	106907.90	54.99
110	140	7700	17394.40	12299.69	107502.52	55.30
100	150	8250	16700.80	11821.46	108124.34	55.62
90	160	8800	16020.80	11343.24	108732.57	55.93
80	170	9350	15340.80	10847.52	109358.29	56.25
70	180	9900	14647.20	10369.30	109980.11	56.57
60	190	10450	13953.60	9879.41	110613.60	56.90
50	200	11000	13287.20	9395.35	111214.06	57.21

longest skidding distance and no temporally road section provided the timber in the lowest net value of $98876.60 ($50.86 per m^3). The results indicated that the total economic value loss on fire-killed timber due to deterioration was estimated as $27,663.74 ($14.23 per m^3). The net value and value loss per tree was $39.93 and $9.93, respectively. According to Akay *et al*. (2006), the maximum net value per tree with average diameter of 45 cm was $40 in helicopter logging with yarding distances of 400 m (Table 1).

Since fire-killed and fire-damaged trees were subject to value loss due to deteriorating agents of Buprestid beetles and stain defect, they were extracted from the site before unit cost of logging becomes greater than the market value of the timber. Akay *et al*. (2006) indicated that the economic value of the tree rapidly declines over time after fire. In their study, it was found that yarding cost (at 2.8 km yarding distance) was greater than the market value of fire-killed trees with 45 cm dbh by the end of second year. On the other hand, leaving some number of fire-killed and fire-damaged trees in the burned site is necessary to restore forest ecosystem (Harrod *et al*., 1998).

Post-fire salvage logging after fire should be performed by considering the possible environmental impacts. Ingalsbee (2003) indicated that extracting fire-killed trees may cause significant long-term impact on forest ecosystem structures, functions and processes. Therefore, logging operation should be well planned and implemented by considering not only the maximum net value but also minimal environmental impact. According to Garland (1983), logging systems with planned and designated skid trails may be only slightly more expensive, or even less expensive than logging systems with conventional skidding, but it can significantly reduce the impacts of logging operation on forest ecosystem.

CONCLUSIONS

Limited deteriorating agents can seriously reduce the economic value of the fire-killed and fire-damaged timber. In order to maximize the recoverable value, logging system should be carefully planned and immediately implemented after fire. In skidding operations, the net value is very sensitive to skidding distance; therefore, optimum skidding distance with minimum total logging costs should be determined. This study analyzed the cost efficiency of a ground-based logging system in extracting fire-killed timber from a partially burned Brutian Pine (*Pinus brutia*) forest. In the tree samples collected from the burned study site, Buprestid beetles and stain defects were detected. In evaluating logging system, the economic tradeoff between alternative skidding distances and temporally forest road lengths were investigated. The results from simple logging system configurations indicated that determining optimum skidding distance is the crucial to minimize total costs of logging operation. The analysis can be extended to evaluate the economic efficiency of alternative logging systems including cable logging, forwarding, etc. The future studies can also focus on application of logging systems by considering the minimal environmental impact on the burned forest site.

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