Environmental impact of postfire logging in a Maritime pine stand in Tuscany (Central Italy)

Sanzio Baldini[1], Giacomo Certini[2], Fulvio Di Fulvio[3], Gianluca Giovannini[4], Enrico Marchi[5]

Abstract

Public and scientific debate on postfire logging and rehabilitation activity has intensified in recent years. Scientific research has shown contrasting results on the effects of recovering activities over burned areas, depending on forest types and fire characteristics. On both economical and ecological basis, postfire logging and rehabilitation activities may have positive or negative effects, such as faster species recovery and restoration of nutrient levels, or longer species recovery and altered natural evolution.

In this paper, the Authors describe the results of a study carried out in Tuscany (central Italy) with the aim to assess the environmental effects of postfire rehabilitation activities. Logging damages, regeneration processes, and effects on soil were examined. The study was carried out in a burned 16-years-old *Pinus pinaster* (Maritime pine) stand, that originated after a previous forest fire. The results show that postfire logging may damage natural early regeneration and increase soil compaction, especially when heavy machinery is used all over the stand. Even if logging productivity is lower, the use of environmentally-sound logging systems is recommended.

Introduction

Intense wildfire causes significant and fairly predictable changes in soil, vegetation structure and fauna (Megahan and Molitor, 1975; Durgin, 1985; DeBano, 1991; Smith, 2000).

In the last years, public and scientific debate about the management of forests after fire has intensified. Scientific research on the effects of recovering activities over burned areas has shown contrasting results and approaches (Spanos and others, 2005; Newton and others, 2006; Baird, 2006). On the one hand, some authors and land managers argue that post-fire logging, beyond wood harvesting and potential economic return, has also positive ecological effects such as faster species recovery, quick restoration of soil nutrient levels, reduction of pest population, etc. On the other hand, opponents of postfire logging argue that wood removal has negative ecological

[1] Full professor, Dipartimento di Tecnologia, Ingegneria e Scienze dell'Ambiente e delle Foreste, Università della Tuscia, Via Camillo de Lellis, Viterbo, Italy. baldini@unitus.it.

[2] Researcher, Dipartimento di Scienza del Suolo e Nutrizione della Pianta, Università di Firenze, Piazzale delle Cascine 18 – 50100 Firenze, Italy. giacomo.certini@unifi.it.

[3] Consultant, Dipartimento di Tecnologia, Ingegneria e Scienze dell'Ambiente e delle Foreste, Università della Tuscia, Via Camillo de Lellis, Viterbo, Italy. f.difulvio@unitus.it.

[4] Researcher, Dipartimento di Scienze e Tecnologie Ambientali Forestali, Università di Firenze, Via S. Bonaventura 13 – 50145 Firenze, Italy. gianluca.giovannini@unifi.it.

[5] Associate professor, Dipartimento di Scienze e Tecnologie Ambientali Forestali, Università di Firenze, Via S. Bonaventura 13 – 50145 Firenze, Italy. enrico.marchi@unifi.it.

effects, such as increased soil erosion, longer species recovery, altered natural evolution, etc (Donato and others 2006a, 2006b; Lindenmayer and others 2004; McIver and Starr 2001). However, the environmental impact of these activities depends on several factors, like fire behaviour, burned area features, postfire logging systems (Potts and others 1985; Chou and others 1994a, 1994b).

As studies on environmental effects of postfire logging are still limited, to adopt a general pro- or anti-postfire logging position without evaluating the local environmental and ecological conditions would be misleading.

Natural regeneration is the main mechanism for rehabilitation of burned stands of Mediterranean pines (Sulli and Zanzi Sulli, 1989). Logging is known to damage early regeneration (McIver and Starr, 2001). Forest fire produces various negative effects on soil (Certini, 2005). Postfire management often exacerbates these effects, chiefly compacting the soil or promoting erosion (Marques and Mora, 1998; McIver and Starr, 2001). More information on these topics is required, especially for fire-prone environments, such as Mediterranean areas.

The aim of this investigation was to assess postfire logging productivity as well as the environmental effects of postfire rehabilitation activities on regeneration and soil in a *Pinus pinaster* Ait. (Maritime pine) stand.

Material and method

Study area

The study site is Calambrone, 43°35’ N 10°17’ E, on the coast of Tuscany (Province of Pisa), central Italy. Here, fires in the last 60 years have occurred with a 15 to 20 years frequency. It is a flat area about 400 m far from the seashore. The soil developed on quartzo-feldspatic marine sands and its typical horizon sequence is O (about 5 cm thick), A (12-13 cm thick), and C. The climate is typically Mediterranean, with mean annual precipitation of 912 mm and mean annual diurnal temperature of 14.4 °C (average of the period 1951-1995). The forest belongs to Pisa Municipality Administration and is included in the Regional Park of Migliarino-San Rossore-Massaciuccoli.

For this study a stand of Maritime pine affected by a wildfire in 2005, was selected. Most of the area was a 16-years-old Maritime pine stand (thicket) that took origin from a previous forest fire developed in 1989. There were also patchy distributed groups of adult Maritime pines and Italian Stone pines, that survived at the previous forest fires, and stumps of hardwoods like Holm Oak (*Quercus ilex* L.), Cork Oak (*Quercus suber* L.) and other species of Mediterranean Macchia.

The fire started in the afternoon of August 8, 2005, and was put out the day after. The total burned area was about 21 ha. About 18 ha were forest vegetation. The present study was carried out over 16 ha of burned forest area. In details, we had four burned plots: plot C, no logging (1.1 ha); plot WS, winching and skidding (1.14 ha); plot CC, forwarder-mounted chipper fitted with a container (4.85 ha); and plot CL, forwarder and chipper at the landing (~9 ha). All fellings were carried out by chainsaw.

In January 2006, the burned trees were still standing up. A survey in four 20-m diameter sample plots showed that the density of the young stand was between 6,500 and 9,300 tree ha^{-1}. Mean diameter of the young Maritime pines was 6.6 cm (standard deviation 2.93). Mean diameter of the adult trees survived at the 1989 forest fire, was between 22 and 56 cm. Basal area ranged between 45 and 50 m² ha^{-1}, including all the trees. The average height of young Maritime pines and adult trees was 8 m and about 14 m, respectively *(Figure 1)*.

To study postfire productivity, two cutting systems and two extraction systems (WS and CC) were applied. To study effects on natural regeneration and soil, all three extraction systems were investigated.

Figure 1- The burned Maritime pine stand in January 2006.

Postfire logging productivity

In plot WS, two cutting methods were applied: chainsaw with felling frame (0.68 ha, *Figure 2*), and traditional chainsaw without felling frame (0.46 ha, *Figure 3*). The chainsaw was a STIHL 025 (2.3 kW). The felling frame was a prototype mounted on a chainsaw to facilitate the felling of trees with a cut diameter less than 15 cm, and to allow the operator to remain in erect posture *(Figure 2)*. Average cut diameter at the butt end was 9.2 cm (N=150, standard deviation 2.97). Felling was carried out by a team of two workers in March 2006. Felled trees were arranged in bunches with the butt ends pointed toward a forest road.

Working times of cutting, movement from a tree to the next one (passage), supportive work, and delays were recorded by an operator using a series of chronometers. Half-way diameter and length of the logged trees were determined (N=150). To determine the wood density, weight and volume were measured on samples collected from butt end, half and top of 10 trees.

The wood extraction was made by applying the full tree system. Burned trees were skidded to the landing, without processing, by using a wheeled tractor (FIAT 780 DT 52 kW) with a single drum forest winch. This is an economical and simple technology, that is suitable for a situation where wood has a very low value and reduces soil compaction in the stand. Two workers fixed bunches of trees, by using chains, to the sliders on winch cable. The winch was operated by a third worker (the driver). Bunches of trees were winched to the tractor, then skidded to the forest road.

In order to study the effect of logging on natural regeneration, winching and skidding were made in two periods: April 2006, i.e. immediately after felling (WS*a*), and January 2007 (WS*b*).

Figure 2- Felling operation performed by chainsaw with felling frame

Figure 3- Felling operation performed by traditional chainsaw

In plot CC, felling was carried out by traditional chainsaw in March 2006. Still in March 2006, chipping of full trees was carried out directly in the stand with a portable drum chipper (BRUKS 803 CT 300 kW) and a container with a capacity of 15 m^3 (bulk volume) mounted on an eight-wheel drive forwarder (HEMEK CICERON D81 150 kW). This machine was equipped also with a hydraulic grapple to move trees from stumps to infeed rollers *(Figure 4)*. Chips were trasported by the forwarder to a landing situated along a public road, then loaded on a truck and directed to a thermoelettric power plant.

An operator using a series of chronometers recorded the working times of both winching - skidding and chipping - forwarding.

Figure 4 - Forwarder-mounted chipper

Natural early regeneration

To analyze postfire natural early regeneration of Maritime pine, two surveys were made before (March 2006) and after logging (March 2007) in plots C, WS, and CL. Plot CC was not surveyed as the owners opted to plant.

A digital caliper and drying in an oven at 80°C (until constant weight was reached) were used, respectively, to measure height and aboveground dry weight on 55 seedlings per plot, gathered at random. After checking for normality, data were analysed by ANOVA and Tukey test. In addition, the occurrence of lateral branches, as indicator of mechanical damage to the apical bud, as well as of spring sprouting and secondary needles, as indicator of healthy conditions, was recorded. In plot C and WS, the number of Maritime pine seedlings was counted in 1-m^2 squares distributed along linear transects, for a total of 40 squares per plot.

Soil characteristics

In plot C, CC, CL, and in an unburned plot, as reference of pre-fire conditions, bulk density and organic carbon content were determined. Organic carbon was not measured in plot CC. Sixty samples of top mineral soil were collected at each plot, following an orthogonal grid with meshes of 2 m on the side and using a steel cylinder of known volume. In the unburned plot, before taking the mineral soil, litter layer was removed from a 38x38 cm^2 square and sampled separately. In the laboratory, all samples were air-dried, finely ground by a ball mill and analysed for total carbon by a CHNS analyser (Perkin Elmer 2400). The mineral soil was also analysed for inorganic carbon by a volumetric calcimeter, so as to eventually determine the organic carbon by difference.

The significance of differences between means was assessed by ANOVA and Tukey-Kramer test at a 95 percent confidence level.

Results

Postfire logging productivity

Working times for felling and skidding were analyzed and productivity was calculated. Felling outputs with the two methods (chainsaw with and without felling frame) were very similar. The average productivity (team of two workers) was 2.5 $m^3 h^{-1}$ for the chainsaw with felling frame, and 2.8 $m^3 h^{-1}$ for the traditional chainsaw. With the felling frame, the time to move from a tree to another one was 8 percent lower than the traditional chainsaw, because the frame allowed to cut more trees without moving the chainsaw, thus reducing worker's effort. However, the time for cutting increased 10 percent with the felling frame, maybe because of a lack of practice with this tool, that was new for the workers. The felling frame also determined a reduction in the average height of stumps (4.3 cm a.g.l - N=50, standard deviation 1.29 - *versus* 7.2 cm with the traditional chainsaw - N=50, standard deviation 1.78) *(Figure 5)*. These results suggest that the chainsaw with felling frame may become a valid tool in this type of operations in young stands, if opportunely improved.

The use of a farm tractor with winch in skidding had an average productivity of 1.9 $m^3 h^{-1}$ (team of three workers). The average distance was 16 m for winching, and 35 m for skidding. Each trip was composed by an average number of 17 trees. The average load per trip was low (0.4 m^3), due to the small size of trees *(Table 1)*.

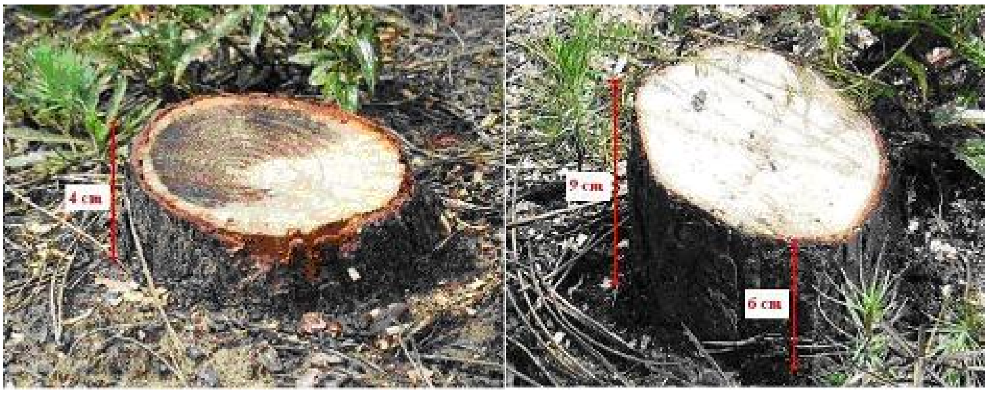

Figure 5 - Stump cutted by chainsaw with felling frame on the left and by traditional chainsaw on the right

Table 1 - *Summary of winching and skidding operations (plot WS)*

Productivity (team of three workers)	$m^3\,h^{-1}$	1.9
Average load	m^3	0.4
Average tree volume	m^3	0.02
Average tree weight	kg	10.2
Average number of trees per load	No.	17
Average winching distance	m	16
Average skidding distance	m	35

In regard to the working times, much time was spent for attaching loads to winch (33 percent), due to the high number of trees in each load and an average number of three bunches for trip. In contrast, the time for skidding and returning to the winching area was short (17 percent), because of the very short skidding distance.

The average output of chipping in the stand by the mobile chipper (plot CC) was 22.7 $m^3\,h^{-1}$ (bulk volume). If forwarding was included, productivity was reduced to 19.2 $m^3\,h^{-1}$.

Natural early regeneration

Seedling height was lower in both skidded plots (WS*b* and CL) than in the control *(Table 2)*. Aboveground dry weight was significantly lower than the control only in plot WS*b*. In plot CL, a high number of seedlings showed branching, as a likely response to logging damage. In plot WS*b*, the damaged seedlings had not yet developed a branching response at the time of the survey *(Figure 6)*.

When logging was carried out two years after the fire (plot WS*b*), even the seedling phenology was affected. In March 2007, only 4 percent of seedlings were sprouting, while they were 33 percent and 62 percent in the plot logged in 2006 (plot CL) and in the control, respectively. Moreover, no seedling showed secondary (adult) needles, compared to 25 percent and 49 percent of seedlings in plot CL and C, respectively.

The density of seedlings was higher in plot C than in plot WS*b*, both before and after logging *(Table 3)*. Logging reduced the seedling density (-58 percent), even if a strong reduction over time (-47 percent) was recorded also in the control plot.

Tab. 2 – *Characteristics of Maritime pine seedlings in plot C (control with no logging) and in two logged plots (logging was either by winching and skidding, WS*b*, or by forwarder and chipper at the landing, CL) after a fire in August 2005. The survey was carried out in March 2007. Different letters show significant differences among the plots (Tukey test, p<0.01, N=55).*

	Plot C	**Plot WS*b***	**Plot CL**	**ANOVA**
Average height, cm	31.79 b	18.69 a	18.01 a	F=78.60
Standard Deviation	7.68	5.62	5.95	p<0.0001
N. Seedlings with sprouting	61.8 pct	3.6 pct	32.7 pct	
Average aboveground dry weight, g	2.70 b	1.03 a	3.24 b	F=21.88
Standard Deviation	1.56	0.71	2.66	p<0.0001
Average needles dry weight, g	1.61 a	0.59 b	2.27 c	F=24.11
Standard Deviation	0.95	0.43	1.95	p<0.0001
N. Seedlings with secondary needles	25.5 pct	0	49.1 pct	
N. Seedlings with branching	0	1.8 pct	16.4 pct	

Figure 6 – Morphological differences between seedlings collected in different plots (WS*b*, CL, C).

The frequency of the number of seedlings per square was similar in plot C and WS*b (Figure 7)*. However, the frequency of squares with more than 100 seedlings dropped to zero because of skidding.

Table 3 - *Postfire seedling density (No. m^{-2}) in the skidded plot WS*b *(before and after logging by winching and skidding) and in the untreated plot C (same dates).*

	Plot WS*b*		Plot C	
	pre	**post**	**pre**	**post**
Average	50.9	21.8	85.0	45.1
Min	0	0	1	0
Max	276	81	561	320

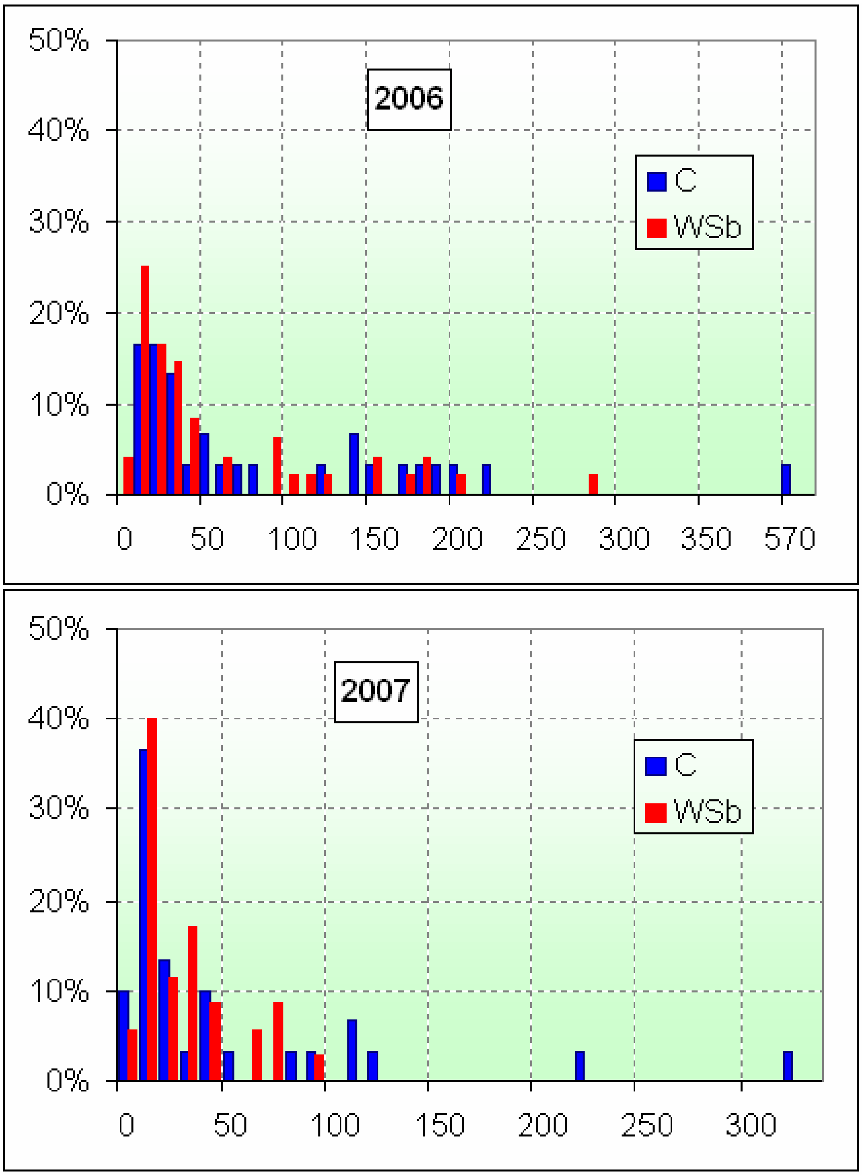

Figure 7 - Frequency of 1-m² squares per class of postfire seedling number, before (2006) and after logging (2007) in a control plot (C) and a plot logged by winching and skidding (WS*b*).

Effects on soil

The bulk density of the mineral soil decreased slightly due to the fire only *(Figure 8)*, as a likely result of the combustion of the interstitial organic matter. However, post-fire management practices appear to play a much more remarkable role in compacting this sandy soil. In particular, winching and skidding did not vary the pre-fire value of bulk density, while the entrance of the forwarder and chipper compacted seriously the soil of the burned area, as the bulk density increased significantly *(Figure 8)*. This marked soil compaction led in a few months to the formation of clearly visible redoximorphic features near the surface, which are symptoms of water stagnation, an unexpected phenomenon indeed in such a type of soil.

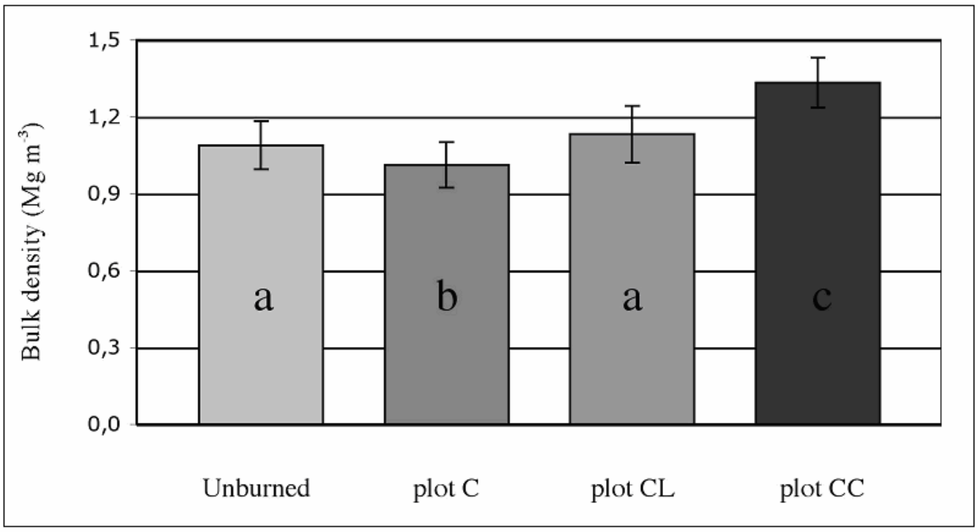

Figure 8 - Bulk density of soil in the unburned stand and the burned unlogged (C) and logged plots (CL & CC). Error bars are the standard deviations and letters within columns indicate significant differences between means at a 95 percent confidence level.

Fire caused the complete loss of litter, which is the main reservoir of soil carbon *(Figure 9)*. However, evidently some of the carbon of the litter remained on top of the mineral soil as charcoal since the latter contains about 20 percent more carbon in the burned area than in the unburned one. Post-fire logging implied a slight and non-significant loss in soil carbon, perhaps due to the ploughing required by the removal of trees.

Discussion

Felling frame may become a valid tool for chainsaw in felling of young burned stands, reducing the efforts and improving the ergonomic condition of operators.

Forwarder-mounted chipper reached a higher productivity than winching and skidding, but soil bulk density significantly increased, since the forwarder-mounted chipper has a full load weight of 30 t and moves across the whole stand. Winching and skidding reached a lower value of productivity, mainly due to the small size of trees, but had a reduced movement across the stand, thus containing the impact on preferential routes.

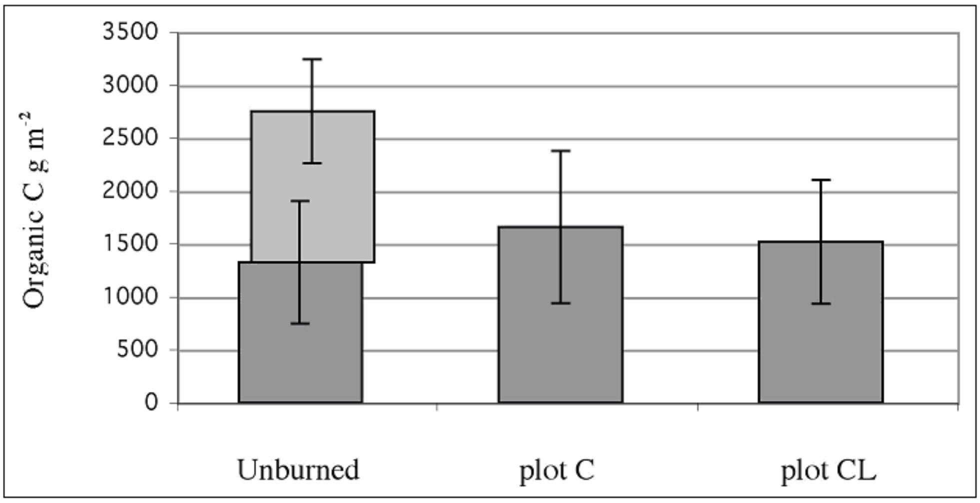

Figure 9 - Soil organic carbon concentration in the unburned stand and the burned unlogged (C) and logged plots (CL). Light grey bar is carbon in the litter. Dark grey bars are carbon in the mineral soil. Error bars are the standard deviations.

Logging damaged early regeneration, by reducing both seedling density and height. Damages were more severe when logging was postponed. However, weed proliferation was also damaged by logging (data not shown). In addition, the control plot has showed natural felling of burned trees, which is also contributing to damage seedlings. Surveys are in progress to evaluate the effects of this phenomenon on natural regeneration.

Seedling density was elevated in both control and logged plots. The high variability and decrease of seedling density over time is considered to be physiological, as it appeared also in the control plot. Two year after fire, density was, in fact, still higher than 200,000 seedling ha^{-1}. Previous studies in burned pine stands in Northern and Central Tuscany showed a high variability in density. Bianchi (1984) recorded about 240,000 seedlings ha^{-1} in a 14 years old Maritime pinewood originated after a fire. Moreover, the author refers about unpublished data on natural seedling mortality over time that show a reduction from about 130,000 seedlings ha^{-1} two years after a fire, to 70,000 plants five years later.

The results demonstrate that fire caused a slight decrease of the bulk density of this soil, while logging by heavy machinery remarkably increased it. Such a compaction implies water stagnation and formation of redoximorphic features. When logging is carried out by light machinery, no significant change in soil bulk density was recorded compared to the unburned stand.

The effect of fire on soil organic matter was remarkable, but confined to the litter layer, whose carbon mainly volatilized and partly remained as charcoal on top of the mineral soil. The impact of post-fire logging on soil carbon is negligible.

In conclusion, postfire logging may damage natural early regeneration and increase soil compaction, especially when heavy machinery is used all over the stand.

Even if logging productivity is lower, the use of environmentally-sound logging systems is recommended.

References

Baird, B. N. 2006. **Comments on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"**. Science vol 313: 615b.

Bianchi, M. 1984. **Analisi della dinamica di accrescimento nella pineta di Tocchi (Siena).** L'Italia Forestale e Montana vol. XXXIX: 185-199.

Certini, G. 2005. **Effects of fire on properties of forest soils: a review**. Oecologia, 143: 1-10.

Chou, Y. H.; Conard, S. G.; Wohlgemuth, P. M. 1994a. **Analysis of postfire salvage logging, watershed characteristics, and sedimentation in the Stanislaus National Forest.** In: Proceedings of ESRI users conference; 1994; Palm Springs, CA.: 492-499.

Chou, Y. H.; Conard, S. G.; Wohlgemuth, P. M. (1994b) - **Postfire salvage logging variables and basin characteristics related to sedimentation, Stanislaus National Forest, California.** In: Proceeding, GIS '94 symposium; 1994 February; Vancouver, BC. 873-878.

DeBano, L. F. 1991. **The effect of fire on soil properties.** In: Proceedings, Symposium on management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 151-156.

Donato, D. C.; Fontaine, J. B.; Campbell, J. L.; Robinson, W. D.; Kauffman, J. B.; Law, B. E. 2006a. **Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk.** Science vol 311: 352

Donato, D. C.; Fontaine, J. B.; Campbell, J. L.; Robinson, W. D.; Kauffman, J. B.; Law, B. E. 2006b. **Response to Comments on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"**. Science vol 313: 612c-615c.

Durgin, P. B. 1985. **Burning changes the erodibility of forest soils.** Journal of Soil and Water Conservation, May/June: 299-301.

Lindenmayer, D. B., Foster, D. R., Franklin, J. F., Hunter, M. L., Noss, R. F., Schmiegelow, F. A., Perry, D. 2004. **Salvage Harvesting Policies After Natural Disturbance.** Science, vol. 303: 1303.

Marques, M.A.; Mora E. 1998. **Effects on erosion of two post-fire management practices: clear-cutting versus non-intervention**. Soil & Tillage Research, 45: 433-439.

McIver, J.D., Starr, L.A 2001. **Literature Review on the Environmental Effects of Postfire Logging**. Western Journal of Applied Forestry, vol. 16, no. 4: 159-168.

Megahan, W. F.; Molitor, D. C. 1975. **Erosional effects of wildfire and logging in Idaho**. In: Proceedings of a symposium on watershed management; 1975; New York. Society of Civil Engineers: 423-444.

Newton, M.; Fitzgerald, S.; Rose, R. R.; Adams, P. W.; Tesch, S. D.; Sessions, J.; Atzet, T.; Powers, R. F.; Skinner, C. 2006. **Comments on "Post-Wildfire Logging Hinders Regeneration and Increases Fire Risk"**. Science vol 313: 615a.

Potts, Donald F.; Peterson, David L.; Zuuring, Hans R. 1985. **Watershed modeling for fire management planning in the northern Rocky Mountains.** Res. Pap. PSW-177. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 p.

Smith, J.K., ed. 2000. **Wildland fire in ecosystems: effects of fire on fauna.** Gen. Tech. Rep., RMRS-GTR-42-vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Spanos, I.; Raftoyannis, Y.; Goudelis, G.; Xanthopoulou, E.; Samara, T.; Tsiontsis, A. 2005. **Effects of postfire logging on soil and vegetation recovery in a *Pinus halepensis* Mill. forest of Greece.** Plant and Soil 278:171–179.

Sulli, M.; Zanzi Sulli, A. 1992. **Danni da incendio nelle pinete.** In: Proceedings "Giornate di studio sulle avversità del pino" 1989, November; Ravenna (Italy).