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USING IMAGE ANALYSIS IN ESTIMATING BLUE STAIN DEFECTS ON FIRE-KILLED BRUTIAN PINE (*PINUS BRUTIA*)

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ABSTRACT

Stain fungi results in a limited deterioration in softwood trees with a high portion of sapwood, such as pines. Discoloration due to stain fungi reduces the economical value of the timber. Besides, stain defects cause reduction in the efficiency of pulp produced from deteriorated timber. Stain defects on sapwood and heartwood of sample timber segments cut from various places (bottom, middle, and top) of a fire-killed Brutian pine (*Pinus brutia*) were estimated using both image analysis and chemical method of 1% NaOH solubility. Various image analysis techniques were applied in analyzing the images and their performances were evaluated. Supervised classification provided satisfactory results in estimating stain defects. A chemical method of 1% NaOH solubility also provided good results in determining the presence of stain in timber segments. The results indicated that the percentage of stain defects decreased from bottom to top portion of a tree in both sapwood and heartwood.

KEY WORDS: blue stain, image analysis, 1% NaOH solubility, *Pinus brutia*, forest fire

INTRODUCTION

In Turkey, approximately 1.6 million hectare of forested areas has been burned from 1937 to 2003. Over 6000 hectare of forests was burned as a result of 1978 recorded forest fires in 2003. The volume and economic value of fire-killed and fire-damaged tree declines due to deterioration. Two types of deterioration have been defined: limited and general deterioration (Lowell et al. 1992). Limited deterioration generally does not affect the strength of the wood but results in a reduction in economic value of timber. General deterioration makes the wood unsuitable for use and results in a reduction of timber volume. Lowell et al. (1992) produced a synthesis of the deterioration agents (insects, stain fungi, decay fungi, etc.) responsible for volume and value loss. Insect and stain fungi damages to the trees after forest fire are classified as limited deterioration, while decay fungi damage is generally classified as general deterioration.

Stain fungi damage is the most important form of softwood deterioration that results in a reduction in economic value of timber especially in the first year after fire (Lowell et al. 1992). Value loss is greater in tree species with a high portion of sapwood, such as the pines. Most of the sapwood staining fungi is blue stain fungi of the genus *Ophiostoma* Syd. & P. Syd. (Farr et al. 1989). Fungal spores enter the sapwood through a break in the bark such as an insect bore hole, weather check, branch stub and broken top. They are also carried in on the body of an insect (Lowell et al. 1992). The deterioration rate of a fire-killed tree also varies based on its position in a tree. From bottom to top portions of a tree, blue stain defects on timber decrease as sapwood volume decreases (Lowell et al. 1992).

There have been many studies on the subject of the deterioration; however, there are little researches have been conducted on estimating defects of blue stain fungi on the fire-killed tree. There are varieties of chemical methods to estimate the general stain defects (Bjurman 1989, Wazny et al. 1989, Laks et al. 1991, Morrell and Sexton 1992). A chemical method of TAPPI T 212 om-02, standard test method for determination of one percent sodium hydroxide (1% NaOH) solubility of wood and pulp, has been widely used to determine the presence of stain defects in woods (Anonymous 1992). 1% NaOH solubility increases as stain defects increase in wood, which causes a reduction in the efficiency of pulp production (Kirci 2003).

An automated system based on processing and analysis of digitized images can be also used to estimate stain defects considering percentage of wood discoloration due to blue stain fungi. Sexton et al. (1993) investigated the performance of using image analysis for automatically assessing the fungal discoloration on wood. The image analysis technique provided satisfactory results in assessing stain defects. In another study conducted by Ross and Solheim (1997), the areas of healthy and occluded sapwood of Pole-size Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were determined successfully using image analysis in order to evaluate the pathogenicity of blue stain fungi associated with the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins).

The purpose of this paper is to estimate stain defects on wood specimens obtained from various places of a fire-killed Brutian pine (*Pinus brutia*), which is cut within six months after a forest fire. Both image analysis and chemical method of 1% NaOH solubility were used to estimate stain defects and their performances were presented. In the analysis, sapwood and heartwood were evaluated separately.

MATERIAL AND METHODS

Study Site

The study area was selected from a partially burned Mediterranean Forest, which is located approximately 40 km northwest of the city of Kahramanmaras. Forest fire Wood specimens were cut from fire-killed Brutian pine (*Pinus brutia*), within six months after a forest fire. The inner and outer barks of the trees almost completely burned, while fire could not penetrate into the wood. The average stand age, average tree diameter, and a dominant tree height were measured as 30 years, 36 cm and 15 m, respectively. The stand exhibits a moderately closed canopy structure. The cross-sectional segments with minimum 15 cm height were obtained from three different places (bottom, middle, and top) of an average tree representing the stand characteristics. Then, tree barks were separated from the timber segments.

Image Processing and Analysis

The images of the timber segments were captured in plan view, using a digital color camera that was connected to a personal computer. The digital images were acquired with rectangular arrays of 1024x768 pixels and stored on the PC as three-channel (RGB) TIFF files. The field-of-view of the camera covered an area from 28 to 100 mm in length with spatial resolution of 5.0 mega pixels.

The image files were read into a common image processing program, ERDAS IMAGINE 8.5 (Atlanta, GA, USA), for subsequent processing and analysis. In order to eliminate the background areas from further analysis, one of the image interpretation utilities of ERDAS IMAGINE, Subset, was used and background pixels were set to zero. The small cracks located outside edge of the timber segments were also eliminated and set to zero. The techniques used for processing and analyzing the images are indicated in Figure 1.

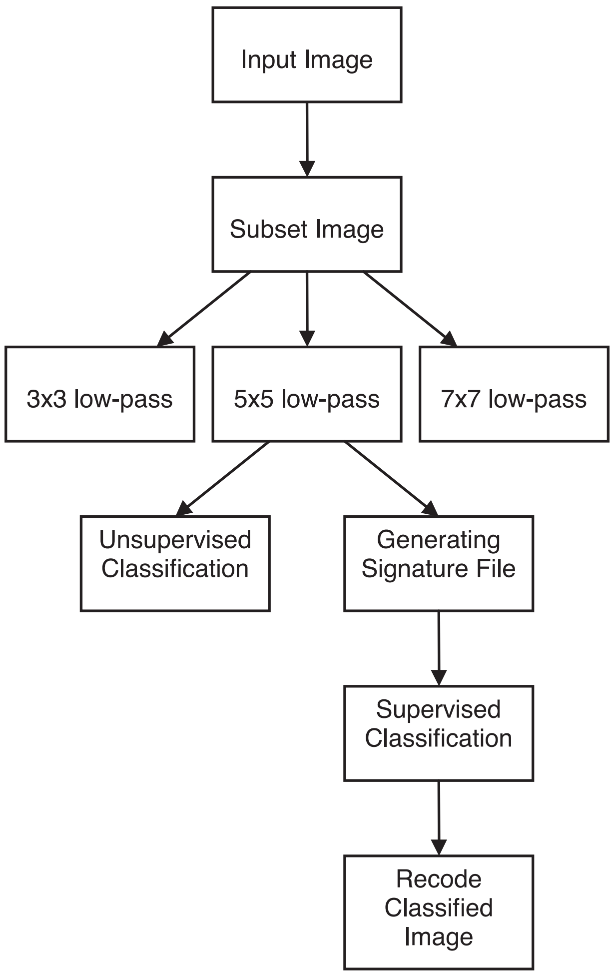

Fig. 1: The flowchart of the techniques used for processing the images

A spatial enhancement tool of ERDAS IMAGINE, Convolution, was first applied using low-pass filtering to reduce spatial frequency of data variation associated with the images. The performances of three different low-pass convolution standards selected from the built-in kernel library (3x3, 5x5, and 7x7) were investigated. Using 5x5 kernel filter removed the data variation well and provided a smooth image for classification process (Figure 2). Then, classification techniques were performed on convoluted images to sort pixels into individual classes, based on their data file values. In classification process, if a pixel meets a certain set of criteria, it is assigned to the class that corresponds to those criteria.

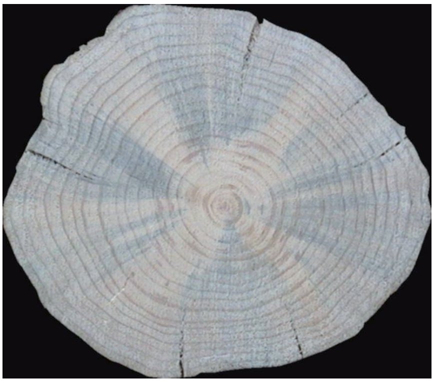

Fig. 2: The convoluted image of bottom segment using 5x5 kernel filter

Unsupervised Classification was first used to identify blue stain defects on timber. To execute unsupervised classification, ERDAS IMAGINE uses the ISODATA algorithm, which applies the classification repeatedly and forms clusters using the minimum spectral distance formula. However, Unsupervised Classification was not completely successful to distinguish blue stain defects from sapwood, small cracks inside of the timber segment, and tree rings on the images. The results of unsupervised classification, executed using ten classes, is shown in Figure 3.

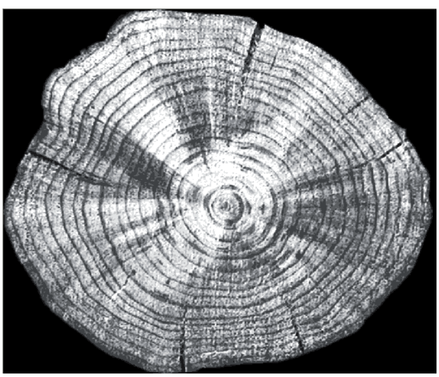

Fig. 3: The classified image of the bottom segment of a fire-killed Brutian pine, using unsupervised classification

Supervised Classification was then performed using Maximum Likelihood technique, which is based on the probability that each pixel belongs to a particular class and the probabilities are equal for all classes. AOI (Area of Interest) tool of ERDAS IMAGINE was used to generate a specific signature file by placing pixels into over 150 parameter classes. Once a reliable signature file was generated, Supervised Classification was performed to identify blue stain defects on timber. Supervised classification provided satisfactory results in terms of differentiating blue stain defects from sapwood, small cracks inside of the timber segment, and tree rings on the images (Figure 4). A GIS (Geographic Information Systems) analysis tool of ERDAS IMAGINE, Recode, was then applied to combine 150 classes into three main classes; blue stain, wood, and background. The cracks located inside of the timber segments were set to zero and assigned to be background in recoding process.

Fig. 4: The classified image of the bottom segment of a fire-killed Brutian pine, using supervised classification

Chemical Method

After image analysis was conducted, the timber segments were prepared for chemical analysis. The specimens were obtained from sapwood and heartwood portions of each timber segments. Then, moisture content and 1% NaOH solubility of the specimens were determined according to American standards TAPPIT T 257 (Anonymous 1992) and TAPPI T 212 om-02, respectively. Therefore, the presence of stain defects in sapwood and heartwood of each segment was determined based on the percentage of 1% NaOH solubility.

RESULTS AND DISCUSSION

Blue stain defects on fire-killed Brutian Pine were estimated using both image analysis techniques and chemical method. In this study, various image processing and analysis techniques were applied and their performances were assessed to determine the one that provided the best results. Using 5x5 low-pass convolution successfully reduced spatial frequency of data variation associated with the images and provided input images for the classification process (Figure 2). Unsupervised Classification could not provide satisfactory results in distinguishing stain defects from other features such as sapwood, small cracks, and tree rings (Figure 3). Therefore, Supervised Classification was performed by selecting over 150 training points from the convoluted image using AOI tool. The results indicated that blue stain defects were successfully identified and distinguished from other features on the timber segment (Figure 4). The accuracy assessment of the supervised classification was performed by selecting 255 sample points from inside of the timber segment on recoded image. It was found that overall classification accuracy of 70.2% was achieved by using supervised classification technique.

Tab. 1: The estimated percentage of blue stain defects on various places of timber

	Bottom Segment	Middle Segment	Top Segment
Clear wood	41.27%	61.50%	96.56%
Blue stain defects	58.73%	38.50%	3.44%
Total	100%	100%	100%

Tab. 2: The estimated percentage of blue stain defects on sapwood and heartwood separately

	Sapwood			Heartwood		
	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%	--	--	--
Total	100%	100%	100%	100%	100%	100%

In order to estimate the blue stain defects, pixel numbers were obtained for each image and for each separate feature in the image. ERDAS IMAGINE provided the total number of pixels for each main class, which then allowed us to determine the percentage of blue stain defects on various places of timber (Table 1). The highest percentage of stain defects occurred at the bottom of the tree due to lower sapwood content of the timber. The percentage of stain defects on sapwood and heartwood were also estimated separately. The small cracks inside of the timber segments were classified as background elements. The results indicated that the percentage of stain defects were higher at the sapwood than that of heartwood in the bottom and middle portions of the tree, while it was opposite in the top portion of the tree (Table 2). In both sapwood and heartwood, the percentage of stain defects decreased dramatically from bottom to top.

Tab. 3: The percentages of 1% NaOH solubility in sapwood and heartwood of a healthy tree and of three sample timber segments obtained from a fire-killed tree

	Sapwood	Heartwood
Healthy tree	9.41%	10.51%
Bottom segment	11.69%	13.97%
Middle segment	10.84%	12.08%
Top segment	9.76%	10.74%

A chemical method of 1% NaOH solubility was used to estimate stain defects on a fire-killed Brutian pine. The percentages of 1% NaOH solubility in sapwood and heartwood of each timber segment were determined and illustrated in Table 3. The average percentages of 1% NaOH solubility in sapwood and heartwood were also determined for a healthy Brutian pine within the same age, diameter, and height classes. The results indicated that percentage of 1% NaOH solubility in both sapwood and heartwood decreased from bottom to top portions of a tree due to reduction in the amount of sapwood. The percentages of 1% NaOH solubility in heartwood of all three timber segments were higher than that of sapwood, which suggested that the presence of stain defects in chemical structure of the timber were greater in heartwood than that of sapwood. The similar results were found by Usta and Kara (1997) in a previous study where the chemical composition of sapwood and heartwood of Cedrus libani were investigated. According to their results, the percentages of 1% NaOH solubility were 19.50% and 13.89% in heartwood and sapwood, respectively.

The results also indicated that the percentage of 1% NaOH solubility was only slightly higher in both sapwood and heartwood of all three timber segments of fire-killed timber than that of healthy timber. The reason for this little difference was that the specimens were collected from the timber within six months after a forest fire. If the specimens were obtained within a longer period of time after a forest fire, the percentage of 1% NaOH solubility could be much higher due to possible increase in stain defects on timber.

CONCLUSIONS

Image analysis and chemical method were performed to estimate blue stain defects on a fire-killed Brutian pine. Image analysis provided objective measurements of wood discoloration in sapwood and heartwood portions of sample timber segments. Supervised classification was the one that provided the best result in image analysis. However, some refinement can be performed in classification process by treating specimens with selected concentration of chemicals to obtain a digital image with better separation between clear wood and stain defects. Chemical method of 1% NaOH solubility also provided good results in determining the presence of stain defects in sapwood and heartwood of each segment. However, it can not provide an accurate estimation for the amount of stain defects developed in wood. Besides, collecting specimens within six months after a forest fire may be considered as a bias since there would not be sufficient time for stain fungi to develop in woods. In order to improve the accuracy of chemical method, a feature study may consider obtaining specimens within a longer amount of time after a forest fire.

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