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Variation of specific gravity (bulk density) in conifer stumps with reference to sampling technique and decay class

Gabagomotse J. Mafoko

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VARIATION OF SPECIFIC GRAVITY (BULK DENSITY) IN CONIFER STUMPS WITH REFERENCE TO SAMPLING TECHNIQUE AND DECAY CLASS

By

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B.S., Utah State University, 1998

Presented in partial fulfillment of the requirements for the degree of Master of Science in Forestry

The University of Montana

2003

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ABSTRACT

Mafoko, Gabagomotse J., M.S., February 2003

Forestry

Variation of bulk density (specific gravity) in Conifer Stumps with Reference to Sampling Technique and Decay class

Director: Professor R.H. Wakimoto

Specific gravity of wildland fuels in relationship to fire has not received wide research. I studied variation of bulk density in conifer stumps with reference to sampling technique and decay class. Stumps were sampled at Lubrecht Experimental Forest in western Montana and the Baker City watershed management area in eastern Oregon. Data were collected on height, diameter, decay class, species, and radius from the pith or heart of the stump. Two types of samples were collected from each stump. Samples were taken using a 5.08 cm diameter drill bore; wood chips were collected and boring depths were recorded. Stumps “cookies” were also cut from each stump. Blocks were cut from the cookies to determine specific gravity. All samples were oven-dried at 100°C for thirty-six hours to get a constant weight. After oven drying the samples, mass, volume, and specific gravity were determined. Stumps comparable to those sampled were visually observed during a prescribed fire to see how they ignited in a fire situation. I observed ignition and smoldering. The research observation also showed that decayed stumps ignited first and flamed while the pitchy stumps needed more fuel around the stump to ignite and catch fire. Whenever they ignited they smoldered for at least several hours. I found that specific gravity for stumps in Baker City, Oregon, decreased as the boring proceeded towards the center of the stump while in western Montana the stumps showed the reverse pattern of decay. I also found the specific gravity of conifer stumps from both study sites decreased with increasing decay pattern. I also observed that within-stump-variation in specific gravity was large. The species sampled are Douglas-fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa), western larch (Larix occidentalis), California red fir (Abies magnifica), and white fir (Abies concolor).

Overall, I found no significant regression between bore sampled specific gravity and block sampled specific gravity. When data was stratified by species, no significant relationship between decay class and specific gravity of the stump was found.

Keywords: specific gravity, ignition, smoldering, conifer stump
ACKNOWLEDGEMENTS

This endeavor started many years ago when I was still young. Every time when there were fires, I would wake in the middle of the night and watch the fire-lighted Tswapong Hills. Somehow I always liked the scene, but when the fire had passed, the repercussions were sad to watch. The normally blue sky would turn gray with smoke from smoldering stumps and logs. Deep down in my heart I would think, “one day I should be able to help control these fires one way or the other”. That is how I ended up studying fires and making them part of my life.

Thanks for the endless support, encouragement, and love of my family members, especially Phatsimo and Gaone, my mother and every one in the family who supported me to make a “dream comes true”. It would be an incomplete acknowledgement if I could not gratify the resting souls of the old man and woman, my grandfather and grandmother, for they made it their resolution that I start my elementary school even though I was beyond the school going age. My grand father repeatedly pestered the principal of the school to accept me into his school. The old man did not leave until I was offered a place to start school.

I would also like to extend my sincere thanks to my undergraduates’ assistants, Bernard Phillimon and Kebagaisitse Mapena. These guys never tired while we collected data in freezing cold and baking sun of Lubrecht Forest. Additionally, thanks go to Frank Maus and Hank Goetz of Lubrecht Experimental Forest for allowing me to use their equipment to locate good study sites. Many thanks to Miguel da Cruz, a Ph.D. (Fire Management Science) student who tirelessly helped me with statistical analysis and computations. Colin Hardy, a Ph.D., student and Fire Behavior Leader, of the Rocky Mountain Fire Science Lab in Missoula, also deserves thanks for the support and great creative ideas he offered me. He supplied me with equipment that I could use to collect data in the field. Thanks go to Ronald Babbitt for the fire chemistry and financial support, which he provided. I also thank Stephen Baker and Mike Chandler at the Fire lab for always availing themselves to help me with my project needs.

Finally, I would to unconditionally thank my advisor Dr. Ronald Wakimoto for his wise guidance, support, and encouragement throughout my graduate experience. Ron always found a word to say for the things I thought were not doable. Two people I should thank my best friends Todd Brandoff and his wife, Kerry, and Mark and his wife, Megan, for the great support they always gave me. Lastly, I would like to thank my committee members, professors Earl Willard and Tunde Adeleke. One person I should also thank is Dr. Edwin Burke for his explanation of the specific gravity concept to me. I also acknowledge my fellow graduates students in the Bull Pen. I am very grateful to the many people whose efforts and support made this thesis a success.
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Chapter 1.0: Introduction: Smoldering Combustion

1.1 Combustion

Agee (1993) describes combustion as a rapid oxidation process dependent on fuel, heat, and oxygen. He further states that the process can be described in four stages of preheating and distillation; distillation and the burning of volatile fractions; burning of the residual charcoal; and cooling. Thus, combustion involves both endothermic and exothermic process. For any combustion to take place there must be fire first; the processes require the same reactants in order to take place (Buckmaster and Lozinski, 1996). So, combustion is consumption of fuels by oxidation, evolving heat and generally flame and/or incandescence (Philpot, 1968).

It is the smoke from smoldering that causes concern for forest managers and health authorities (Allen, 1974). The smoke has some adverse effect on the health of the public in general; therefore, any smoke deposited into the atmosphere from forest fires must be given attention (Williams, 1977). Forest managers should know how much smoke from smoldering is put into the air, so that they can make management plans. This study was also trying to observe the smoke released into the air from smoldering stumps. I believe that most of the fire smoke is from smoldering combustion. This needs to be studied so that it can be better managed (Baker, 2002. Pers. Comm).
1.2 Stump Description

Raile (1982) described a stump as the tree bole from the ground level to any height less than or equal to 4.5 feet. Stumps vary in weight (mass), height, percent moisture content, volume and shape, but all these characteristics must be considered when collecting data on stumps. To calculate specific gravity for a stump one needs to know the mass and volume of that particular stump. It is very important to know certain stump characteristics in order to more precisely calculate specific gravity (Sandberg and Pickford, 1979). The big question is “where does the fire part come in here?” The answer is that “stumps mostly catch fire and continue smoldering for some hours after the fire has passed and they have the potential of starting new fires if not checked on time.” So research must be conducted to understand how stumps ignite and what conditions are conducive for ignition and smoldering.

![Figure 1.1](image.png) Figure 1.1 shows a stump that caught fire and burned to ashes at Lubrecht Experimental Forest in Montana. The stump was very rotten and dry with some pine needle litter on the top and on the sides.
Figure 1.2 shows the same stump as figure 1.1. This photo was taken after 30 minutes of burning. After 2 hours the whole stump was consumed by fire.

1.3 Specific Gravity description

Webster’s dictionary (1988) defined specific gravity as the ratio of the density of a substance to density of a substance taken as a standard when both densities are obtained by weighing in the air. It is always calculated using an oven-dry weight or mass. Specific gravity is also defined as the ratio of the density weight (unit volume) of object (such as wood) to the density of water at 4°C as reference (Helms 1998). Volume can be determined at any moisture content level, but that moisture content must be specified. Hence, specific gravity is defined in physics as the ratio of a material to the density of water at 4°C (Helms 1998). Water has a density of 1g/cm³ or 1000 kg/m³ at that standard temperature (Haygreen and Bowyer 1996). A modification of this definition for wood is that the mass is always determined in the oven-dry condition. Thus, specific gravity has no units since it is expressed as a ratio. In the metric system, specific gravity can be
visualized by thinking of it as grams of dry wood substance per cubic centimeter (Oberg, 1989). The advantage of using the metric system is that the calculation of specific gravity is simplified because 1 cm³ of water weighs precisely 1 gram (Orbeg, 1989). Specific gravity can thus be calculated directly by dividing the oven-dry weight in grams by the volume in cubic centimeters (Haygreen and Bowyer, 1996).

Specific gravity (SG), also known as bulk density, affects combustion in such a way that when the wood has high specific gravity it does not ignite easily and quickly but once ignited and the conditions are right for burning the wood continues to burn or smolder for several hours, days or months. This is so because wood particles are mostly tightly packed in this case (Haygreen and Bowyer, 1996). On the other hand, when wood has low specific gravity and it is dry, it would easily ignite and burst into flames, would in the class, mostly does not burn for a long time because the wood is loosely packed and in most cases it will be too decayed to sustain long hours of burning (Johnson and Miyanishi, 2001). Wood that has high specific gravity has high heat capacity when they burn and therefore they take a long time to flame and smolder while wood with low specific gravity has low heat capacity and therefore will smolder for a short period of time (Cheney and Sullivan, 1997).

Wood density varies greatly within any species because of a number of factors. These factors can include location in a tree, location within the geographic range of the species, site condition, (soil, water, and slope), and genetic source (Maeglin and Wahlgren, 1972). Table 1.1 shows the average and green specific gravity for some important species found in the western United States.
Table 1.1. Range of specific gravity for important species (Maeglin and Wahlgren 1972)

<table>
<thead>
<tr>
<th>Species</th>
<th>Average green SG</th>
<th>Normal range of SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas-fir</td>
<td>0.45</td>
<td>0.36-0.54</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>0.38</td>
<td>0.31-0.45</td>
</tr>
<tr>
<td>White fir</td>
<td>0.37</td>
<td>0.30-0.44</td>
</tr>
<tr>
<td>California red fir</td>
<td>0.36</td>
<td>0.31-0.46</td>
</tr>
<tr>
<td>Western larch</td>
<td>0.48</td>
<td>0.38-0.54</td>
</tr>
<tr>
<td>Western hemlock</td>
<td>0.42</td>
<td>0.34-0.50</td>
</tr>
<tr>
<td>Western white pine</td>
<td>0.35</td>
<td>0.28-0.42</td>
</tr>
<tr>
<td>Quaking aspen</td>
<td>0.35</td>
<td>0.28-0.42</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>0.38</td>
<td>0.26-0.55</td>
</tr>
<tr>
<td>Grand fir</td>
<td>0.35</td>
<td>0.24-0.55</td>
</tr>
<tr>
<td>Black cottonwood</td>
<td>0.31</td>
<td>0.28-0.40</td>
</tr>
</tbody>
</table>

1.4 Problem Statement

There are many stumps and logs that form part of the fuel bed on the ground. They are generally placed in the 1000-hour fuel category (woody material, with a diameter of 7.62 cm +, generally drying out within 40 days) (Teie 1994). These fuels have not been fully assessed to determine if they can ignite, catch fire and smolder in the event of a fire. We do not know under what conditions they smolder, or what conditions really are conducive for smoldering. After doing a literature search, I found that there has been very little work on smoldering combustion of stumps by other researchers. My study observed the effects of decay and fire behavior on stump ignition and burning rates.
In addition I attempted to come up with a useful method or measurement tool that could be applied to determine variation of specific gravity of stump wood on site in the field. The method should be user friendly and less laborious to apply in the field. My specific objective was to study the variation of specific gravity in conifer stumps in reference to sampling technique and decay class of the burning wood.

1.5 Study Objectives

- Observation of conifer stumps ignition
- Comparison between specific gravity sampling techniques
- Specific gravity variation with stump size
- Specific gravity variation with decay class
- Interspecies specific gravity comparison
- Within stump specific gravity variability
- Compare average specific gravity of stumps with decay class

1.6 Research Hypothesis

1. Comparison between sampling technique

Null hypothesis: There is no difference between the mean specific gravity estimated by the block method and the mean specific gravity estimated by the bore method.

\[ H_0: \mu_1 = \mu_2 \]

Alternative hypothesis: There is a difference between the mean specific gravity estimated by the disk method and the mean specific gravity estimated by the bore method.

\[ H_a: \mu_1 \neq \mu_2 \]
Because I compared samples from the same stump (bore versus block) I used a paired sample t-test.

2. Specific gravity variation with stump diameter

Null hypothesis: There is no difference between the mean specific gravity estimated for small (Ø < 35 cm) and large (Ø > 35 cm) stumps.

\[ H_0: \mu_1 = \mu_2 \]

Alternative hypothesis: There is a difference between the mean specific gravity estimated for small (Ø < 35 cm) and large (Ø > 35 cm) stumps.

\[ H_a: \mu_1 \neq \mu_2 \]

Because I compared samples from different independent stumps I used an independent samples t-test.

3. Specific gravity variation with decay class

Null hypothesis: There is no difference between the mean specific gravity estimated by decay class.

\[ H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 \]

Alternative hypothesis: There is a difference between the mean specific gravity estimated by decay class.

\[ H_a: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \]
Since I made multiple comparisons between samples from different independent stumps, I used the Scheffe multiple comparison test based on the t statistics.

4. **Interspecies specific gravity comparison**

Null hypothesis: There is no difference between the mean specific gravity for the various species.

\[ H_0: \mu_1 = \mu_2 = \mu_3 \]

Alternative hypothesis: There is a difference between the mean specific gravity for the various species.

\[ H_a: \mu_1 \neq \mu_2 \neq \mu_3 \]

Because I conducted multiple comparisons between samples from different independent stumps, I used the LSD multiple comparison test based on the t statistics.

5. **Within stump specific gravity variability**

Null hypothesis: There is no difference between the mean specific gravity with stump radial depth.

\[ H_0: \mu_1 = \mu_2 = \mu_3 \]

Alternative hypothesis: There is no difference between the mean specific gravity with stump radial depth.

\[ H_a: \mu_1 \neq \mu_2 \neq \mu_3 \]

Because I conducted multiple comparisons between samples from the same stump, I used the LSD multiple comparison test based on the t statistic.

All hypotheses were tested at the level of significance of 0.05.
1.7 Discussion of Study Sites

There is a climatic difference between the two sites. I used two study sites, Baker City, Oregon and Lubrecht Forest. The vegetation growth rate is different because of the different rainfall patterns of the two sites. It is drier and colder on the Baker City site (eastern side of Oregon) compared to Lubrecht Forest (western Montana) because of the rain shadow effect on the east side of the Cascade Mountains. But Baker City area still gets more rain when compared to areas in western Montana (Hardy, 2002. Pers. Comm.). The Baker City study site had an elevation of 2134 m (7000 ft). Given this elevation it is bound to be cold most of the time. From a personal observation, the stumps at the Baker City site were decayed from the inside outward, and the trees were of large diameter. Some trees were present due to lack of logging activities in the area since it is a municipal watershed. The stumps in that area were three years old (Goetz, 2002. Pers. Comm.). The stumps at Lubrecht Experimental Forest were small in diameter and the decay started from outside inward. Age of the stumps ranged from ten to fifteen years old. At Lubrecht Experimental Forest, the average temperature is warmer than that of the Baker City site. Lubrecht Forest also receives more precipitation, although it has an average elevation of 1281 m (4200 ft) (Maus, 2002. Pers. Comm.).

Fuel load on the ground around stumps also plays a very important role in fire behavior and smoldering combustion of stumps. It increases the chance of ignition since more dry fuel around the stump will help the stump to get ignited and catch fire. The amount of moisture in the air (relative humidity) will determine fire behavior and smoldering characteristics of the stump (Baker, 2002. Pers. Comm.). The higher the relative humidity in the air, the less the chance of fire ignition. Low relative humidity
leads to high probability of fire ignition. Fire travels faster uphill than down hill due to predominant direction of wind movement. Slope gradient will also influence the speed of the fire. A fast moving fire will more likely not ignite most of the stumps while a slow moving fire will have a chance of igniting most of the stumps. The whole scenario of the up and down slope winds is related to the convective winds. There are local diurnal winds present in all sloping surfaces. They flow upslope during the day as a result of surface heating, and down slope at night due to surface cooling (Pyne et al., 1996).

Topography can also play a major role in stump ignition because it includes the elements of slope steepness, aspect, elevation, and configuration of the land. Variations in topography can cause dramatic changes in fire behavior as a fire progress over the terrain. Topography does not change over time but it does affect the way in which fuels and weather change. The fire environment triangle symbolizes this interaction among the elements clearly. Topography modifies general weather patterns, producing localized weather conditions that in turn affect fuel type and moisture content of the fuel, including the stumps (Pyne et al., 1996). Refer to the fire environment triangle figure1.3:
Figure 1.3 The fire environment triangle illustrates the influencing forces on fire behavior: fuel, weather, and topography. The fire in the center signifies that the fire itself can influence the fire environment. Based on Countryman (1972) but reproduced from Pyne et al., (1996).

1.8 Purpose and Importance of the Study

The purpose of this study was to observe how stumps ignite and to find a suitable method that can be used in the field to determine specific gravity of stump wood material more easily and less laboriously. My intention was to have in place a precise tool that could reduce the workload with the current applications. At the same time I studied the variability of stump wood specific gravity in comparison to decay class.
Chapter 2.0: Literature Review.

2.1 Combustion Process Overview

Flaming and smoldering or glowing combustion involve different processes and are quite different in appearance (Shafizadeh, 1968). Flaming combustion dominates at the startup phase, with the fine fuels and surface materials supplying the volatile fuels required for the rapid oxidation reactions to be sustained in a flaming environment. More carbon buildup on the solid fuel surfaces means that pyrolytic reactions no longer produce sufficient gases to sustain the fuel envelope, and this is when smoldering starts (Wilson, 1985). For combustion to continue, oxygen must diffuse to the surface of the fuel allowing oxidation to take place at the solid fuel surface and providing for heat feedback to accelerate the pyrolytic reactions and volatilization of the fuel gases from the solid fuel (Pyne et al., 1996). The plant material that burns in a wildland fire is produced by the process of photosynthesis, the chemical process by which carbon dioxide, water, and the sun’s energy are combined to produce cellulose, lignin, and other chemical components (Pyne et al., 1996). Both fire and decay reverse that process since they consume the stored energy to release heat. Decay is a slow process, with barely noticeable release of heat energy over a long period of time, while fire is a rapid release of the heat energy stored by photosynthesis (Spurr and Barnes, 1980). The process of photosynthesis to store chemical energy in vegetation transforms radiant energy from the sun. When the vegetation is burned, the chemical energy is transformed to thermal energy, radiant energy, and kinetic energy in the rising air in the convection column over the fire (Sussot, 1980). This relationship between photosynthesis and combustion can be simply visualized by comparison of very simple formulae the below:
Photosynthesis:

\[
\text{CO}_2 + \text{H}_2\text{O} + \text{solar energy} \rightarrow (C_6\text{H}_{10}\text{O}_5)_n + \text{O} \quad (\text{Cheney and Sullivan, 1997})
\]

Combustion:

\[
(C_6\text{H}_{10}\text{O}_5)_n + \text{O} + \text{Ignition temperature} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{heat}
\]

Smoldering has been defined as “a self-sustaining, low temperature combustion process involving pyrolysis of the substrate ahead of a solid-phase combustion front” (Shafizadeh et al., 1982). It is characterized by thermal degradation and charring of the solid material with evolution of smoke (Moussa et al., 1977). Smoldering sometimes involves emission of visible glow, so smoldering has also been referred to by some as glowing combustion (Williams, 1977; Johnson, 1992). However, Drysdale, (1985) makes a distinction between glowing combustion and smoldering and, although glowing combustion “is associated with the surface oxidation of carbonaceous materials,” it differs from smoldering in that “thermal degradation of the parent fuel does not occur, nor is it required.” On the other hand, if glowing combustion specifically refers only to the process of surface oxidation of a solid, it may be viewed as the final stage of the smoldering process (Simmons, 1995). Only porous materials, which form a carbonaceous char upon thermal degradation, are capable of self-sustained combustion (Drysdale, 1985). Duff (the partly decayed organic matter of the forest floor) as well as organic peat soils are capable of such sustained smoldering (Frandsen, 1987, 1991; Hawkes, 1993; Hungerford et al., 1995). Cheney and Sullivan (1997) describe smoldering as “a fire that burns without flame and barely spreading”.
Pyne and others (1996) have also supported the findings of the other researchers in the work of smoldering. They concluded that smoldering or glowing combustion, although not as visually dramatic as flaming combustion, is an important component of wildland fires. Surface fires frequently ignite ground smoldering fires. If surface fires initiate ground fire in the organic soil horizons, smoldering may continue for months or even years. Smoldering ground fire is important in suppression and prescribed fire control activities since it has the potential for reigniting surface fuel after the main front has passed (Simmons, 1995). A large portion of smoke production can come from smoldering combustion. The effect of heat from smoldering fire on roots, organisms, and tree cambium can be significant (Johnson and Miyanishi, 2001).

Smoldering generally occurs in fuel arrays that are more tightly packed than those that sustain flaming combustion. Decomposing plant matter tends to smolder because biological degradation removes some cellulose cell wall material, leaving a higher lignin content. Lignin does not burn with flames and therefore encourages smoldering (Simmons, 1995). The steady combustion wave has three distinct regions (see figure 2.1 below).
Figure 2.1 above shows the beginning of smoldering process. A little flame can be observed on the far right corner of the figure and there is much smoke bellowing out of the smoldering stump.

Figure 2.2 shows the intermediate smoldering combustion stage of a stump. Approximately, 95 percent of the stump has burned and the remaining char is just burning by smoldering.
Figure 2.3 above shows the final stage of smoldering and it normally ends with a hole on the ground. The remaining wood is where the stump base was sitting. It should be noticed that smoldering could continue laterally into the soil due to root spread. This situation may start new fires on the other side of the firebreaks.
2.2 Phases of Combustion

There are three phases of combustion, preheating, flaming, smoldering, and/or glowing (see figure 2.4 below), (Johnson and Miyanishi, 2001). These three phases compete for available fuel and are markedly different phenomena that contribute to the diversity of combustion products. The fuel characteristics (including arrangement, distribution by size class, moisture, and chemistry) dominate in affecting the duration of flaming and the efficiency of smoldering combustion (Babbitt, 2002. Pers. Comm.). Open combustion occurs through a diffusion flame process in which the fuel from the interior of the flame (oxygen-deficient area) diffuses outward, and the oxygen from the free-air diffuses inward. (Johnson and Miyanishi, 2001).

Figure 2.4 above shows the three phases of combustion, they compete for available fuel. From Johnson and Miyanishi, (2001).
The different combustion phases in figure 2.4 all require fuel and oxygen to carry on. Glowing or smoldering will not occur if there is no fuel or not enough oxygen. Flaming combustion and preheating require some oxygen and fuel to carry on the process. Preheating occurs through radiation of heat towards the fuel (Pyne et al., 1996).

Figure 2.5 above shows a representation of steady smoldering along a horizontal cellulose rod. From Moussa and others (1977). Propagation arrow shows the direction of smoldering along a downed wood. Smoldering always proceed towards the unburned wood material.

2.3 Pyrolysis

Pyrolysis is defined as the chemical breakdown of solid fuel under the influence of heat and usually in an oxygen-deficient environment. The pyrolytic decomposition of cellulose is generally believed to follow one of two paths dependent on whether the pyrolysis is occurring under high-temperature or low-temperature conditions. Usually under low temperature conditions (200-280°C), the cellulose undergoes dehydration with the evolution of char, H₂O, CO₂, CO, and other compounds (Moussa et al., 1977). Under
higher temperature conditions (280-340°C), the pyrolysis proceeds in the production of levoglucosan, a volatile fuel that supports a gas-phase flame (Kilzer and Broido, 1965).

2.4 Decay of stumps

Stump decomposition plays a major part in smoldering of stumps. Stumps that are dry and very decomposed ignite very easily, but do not burn long when it comes to smoldering except when they have absorbed water. On the other hand, pitchy and sound stumps smolder for long hours after the fire, but do not ignite easily (Fogel and Cromack, 1977). Wood decay process requires several years to occur. Fogel and Cromack (1977) found that wood shape, nutrient content, and size play a major role in wood decay. Fungi have been found to be the most prevalent wood decay-causing agent. There is a symbiotic relationship between the fungi and the live plant and the fungi have to produce more hyphae and attach themselves to the plant roots. These thread-like structures are used to feed the fungi but at the same time they give the plant roots more water-absorbing surface (Haygreen and Bowyer, 1996). Decay of stumps starts in different forms depending on the moisture content, growth rate of the tree and the amount of rainfall in the area. For example, in wet areas of Oregon, stumps start decaying in the center and proceeds outward while in Montana dry areas decay is first noticed from the outside of the stump (Hardy, 2002. Pers. Comm.). Both decay and sound wood (stumps) display different burning characteristics, since they have varying different specific gravity. Decayed wood has low specific gravity while pitchy wood has high specific gravity (Haygreen and Bowyer, 1996).
2.5 Decay Fungi

There are different fungi that cause wood decay. Fungi causing wood deterioration and other cellulosic materials are just simple plants that contain no chlorophyll yet they have to find nutrient to survive (Fogel and Cromack, 1977). Unable to produce their own food, fungi must derive their energy from other organic materials (Thomas, 1979). The carbohydrate and lignin components of wood provide food for a wide range of fungi. The hyphae (mycelium) of the fungi produce enzymes that break down the carbohydrate materials, and sometimes lignin, into simple sugar-like compounds that can be metabolized by the fungi for their energy need (Haygreen and Bowyer, 1996).

The fungi that break down wood may be listed as decay, soft-rot, stain, or mold according to the form of degradation they cause. Wood decay fungi cause a noticeable amount of softening or weakening of wood, often to the point that its physical characteristics are changed or destroyed completely. Wood so affected is referred to as rotten or decayed. Very wet wood is mostly attacked by a soft-rot fungus that usually penetrates it slowly. Soft-rots gradually degrade wood from the outside surface to the inside (Haygreen and Bowyer, 1996). Staining fungi that mostly inhabit wood often create a bluish or blackish color and are detrimental to its appearance and value, but they do not have a serious effect on the strength of the wood or the physical integrity of the wood itself (Haygreen and Bowyer, 1996). Molds and mildews can only occur on exposed surfaces but may not do any significant damage to wood strength (Corbett, 1975). Most decay fungi belong to the botanical class Basidiomycetes, named for spore-bearing structure, the basidium. A few are Ascomycetes and several hundred species of
fungi may be involved in wood decay in North America. The most common genera include *Poria, Gloeophyllum, Polyorus, Lentinus, and Coniophora*. The species in these genera vary widely according to the species of wood, moisture content, and temperature that best suit their growth conditions (Corbett, 1975). Some of these fungi can be seen more in wood, especially in post and stumps inclusive. The decay fungi found on living trees rarely cause any damage to the wood products after harvesting but if the wood is left in a wet area or is not well dried they can continue to grow since the conditions will be favorable (Triska et al, 1979).

Furthermore, decay fungi may be categorized as brown rots commonly known as brown cubical rots or white rots. The brown rots selectively attack the cellulose and hemicellulose of the cell, and have very little effect on lignin (Haygreen and Bowyer, 1996). Wood seriously damaged by these fungi will have an abnormally brownish or reddish color. Checks perpendicular to the grain will normally develop on brown-rotted wood and when dried they will break into cubical pieces (Haygreen and Bowyer, 1996). Decay rots (Brown rots) mostly attack two thirds of the wood and leave out the wood with lignin (Haygreen and Bowyer, 1996). All cell wall layers of wood will be degraded but the cellulose-rich wood will be attacked first.

White rots on the other hand have the ability to destroy both lignin and cellulosic components of the cell although lignin is usually consumed at a much faster rate (Haygreen and Bowyer, 1996). White rots may slightly alter the colour of the wood, and give it a whitish or bleached color. White rots erode the cell outward from lumen by decomposing successive layers of the cell wall, much as water erodes riverbank (Hawkes, 1993). This means that the cell wall becomes progressively thinner outward. In this
event the white rot wood does not tend to shrink, check, or collapse, as is the case with brown rots. White-rotted wood usually retains its original shape but may eventually give in and becomes a fibrous and spongy mass, the thing that makes most stumps retain moisture. Studies and experiments are still being conducted to understand the variability in the mode of action of the white rot fungi (Haygreen and Bowyer, 1996).

Most of the decay fungi are known to attack wood only in the presence of existing moisture, but a few known as water conducting fungi have the power to transport water to the wood material they want to attack (Corbett, 1975). The two commonly known fungi species that conduct water to the affected areas are *Poria incrassata* and *Serpula lacrymans* (Haygreen and Bowyer 1996). Brown rots on the other hand cannot transport water to the affected sites and therefore need water for their development (Browning, 1963). Refer to the figure 2.6 for brown cubical rots.
Figure 2.6 illustrates brown cubical rots; the cubes and checks can be seen clearly against the wood grain. The cubes are very spongy and retain moisture for long periods of time (Haygreen and Bowyer 1996).

2.6 Decay fungi and wood breakdown

A suitable host is required for the production and germination of fungi. They can then undergo sporulation when conditions are not conducive for germination (Sollins, 1992). Infection can start from a spore, growth of hyphae, or colonization from a nearby infection source. Stringy long slender fibrous hyphae grow in length along the surface of wood and find their way into the wood by penetrating through exposed grain ends or cut ends of wood cells (Sollins, 1992). Hyphae would then extend progressively from cell to cell through pit pairs or thorough bore holes created in the cell walls by it (hyphae). Hyphae produce enzymes that breakdown cell walls to make bore holes so that they can be penetrate easily. A group of hyphae growing colonially are called mycelium. Mycelium grows within the wood by producing more frequent boreholes and
progressively degrading the cell wall (Oberg, 1989). The more growth the mycelium attains the more wood material get consumed until the wood finally loses its strength and weight. Fruiting bodies called *sporocarps* eventually develops, producing large members of spores that are mostly wind dispersed or could be dispersed by other agents of dispersal (Haygreen and Bowyer 1996). It is not easy to prevent wood from getting infected with spores, since spores can be airborne and germinate easily if they land on wood with suitable conditions for growth. In order for the fungi to consume cellulose, hemicellulose, or lignin as food, fungi must first breakdown cell components into simple molecules that can be easily metabolized by the fungi. These biochemical changes are achieved through the catalytic action of enzymes produced by the hyphae (Browning, 1963). The enzymes are produced at the tips of hyphae for creating boreholes and are also produced alongside the vegetative elements. For diffusion of enzymes into the cell wall and for breakdown products to enter the hyphae it is necessary for some water to be present (Fogel et al., 1973). Water acts as a catalyzing agent for enzymes.

### 2.7 Conditions Suitable For Decay

Moist conditions are mostly required for wood decay to take place. Therefore, there is very little danger of wood decay if wood moisture is below fiber saturation point and just a few fungi can grow slowly under moisture contents less than fiber saturation point (Haygreen and Bowyer, 1996). Although there are other physiological requirements for fungi growth besides moisture there is very little that can be done to control them. At temperature ranging from 21°C – 33°C fungi grows rapidly and are inhibited at temperatures below 0°C – 38°C (Cheney and Sullivan, 1997). It is not easy to
kill fungi by dropping temperatures below zero degree Celsius because they will simply become dormant, when temperatures rise to the suitable level fungi will become active again. Fungi also need oxygen for their growth, and tend to prefer an acidic environment. They require a pH range 4-6 for best growth (Cheney and Sullivan, 1997)

2.8 Decay Class Description

Stump decay class is a tool developed by wildlife scientists in Washington State under the PNW of USDA Forest Service, (Thomas 1979). The classification was developed in order to have a mechanism in place that can be applied in the field to have a standardized decay class level for all the stumps and logs. The decay class scale ranges from 1 to 5, with 1 being the least decayed or an intact stump, with bark, still standing and all parts of the stump are still present, while 5 is the most decayed stump or log that is detached from the ground (Thomas, 1979). These decay classes were meant for consistently classifying decay level for stumps and logs in the field. Most of the stumps and logs in our study areas ranged from 2-3-decay class level. It was not easy to come up with a decay class 5 stump or log, since there would be basically nothing left of the wood material that we could work with. Descriptions of these classes can be seen in Figure 2.7 and Table 2.1 and Table 2.2.
Figure 2.7 describes the different stages a log has to go through during decomposition levels. There are five decay class stages. When they fall, trees and snags immediately enter one of the first four log decomposition classes. Reproduced from Thomas, (1979).

Decay classes as shown by table 2.2 are divided into 5 levels, and each level describes exactly what the stump status is. For example, a decay class 1 stump wood would be characterized by intact bark, needles present, fine twigs, sound wood, and round stump or log (Thomas, 1979). Basically, most of the original wood parts are still present in the stump.
Table 2.1. A 5-class system of log decomposition based upon work done on Douglas-fir (adapted from Fogel et al. 1973, but reproduced from Thomas 1979).

Table 2.1 is self-explanatory in the sense that it depicts each level of decay clearly and tells what things to expect in that decay level. Decay class 1 and 2 do not show any big change in the wood original status. The wood is still intact except for the twigs that are broken off, otherwise the stump or log still has its original identity.

Table 2.2 shows decay classes for stumps and large downed ponderosa pine wood debris (1000hr+) but the decay class can still be used for other stump species, (Thomas, 1979).
Table 2.2 shows the same version of the decay classification, but in a different way for ponderosa pine. It gives the view on more comparative information for the decay class. The two tables can be used interchangeably even though they were developed for different species (Ottmar, 2002. Pers. Comm.).
Chapter 3.0: Methods

3.1 Data collection

Stumps were randomly selected on the marked site. Tree species, stump top diameter, stump bore height, and diameter at bore height were recorded. Decay class was determined and recorded on a scale of 1-5 as described by Thomas (1979).

Stump ages ranged from eight to fifteen years in Montana sites (Maus, 2002. Pers. Comm.). In order to be selected each site had to have enough stumps for sampling and enough fuel for ignition during a prescribed fire. I looked for a variety of decayed and pitchy stumps for comparison purposes. It was not easy to get samples from very decayed stumps and logs since they did not hold together during drilling or “cookie” cutting. Most the decayed stumps and logs were attacked by brown cubical rot that made the wood too soft to hold together after sawing. The white rot material on the other hand, held together well but the affected wood was hard to bore. Some data were collected from the Baker City watershed management area, where most of the conifers had enjoyed long periods of growth time without logging. The stumps sampled were only three years old according to the US. Forest Service district personnel in Baker City, Oregon.

The data collection started with stump selection. Core samples were drilled from the stumps as the first step. The bore tip had a diameter of 5.08 cm. I drilled into the side of the stump at intervals of three divisions of equal depth to collect core samples. For example, a 15 centimeters stump radius was divided into three sections of 5 cm each, and a sample was collected at every 5 cm into the stump. For a diagram of this scenario please refer to figure 3.1. The boring depth was divided into three equal sections of 1/3 cm of the length of the radius of the stump. The equal division of radius was used to
attain consistent mass for each core sample. The boring was performed from the side of the stump while the “cookie” or disc was cut from the stump after the decayed stump was removed. Then, the sample cookies were cut. The “cookie” was cut at the same height as the boring to produce comparable wood samples. The boring extended all the way to the pith of the stump wood. The samples were then taken to the lab where they were weighed for wet weight and then oven-dried. The other variables that were recorded were wet volume and wet weight.

Figure 3.1 Illustrates a hypothetical stump; it shows how the boring into the stump was carried out.
Figure 3.2 shows the testing of the drilling (boring) equipment to see if would work. Attached to the stump is a vacuum cleaner to suck out the bore chips into the collecting can. The bore is run by a power saw mechanism. Testing the equipment is Colin Hardy from the Missoula Fire Lab.

Stump cookies were taken back to the lab and blocks were cut for more precise specific gravity determination. The blocks from the stump were cut into small cubes of 5.08x5.08x5.08 cm. These measurements were to approximate the size of the drill bit hole made when collecting bore samples. In the lab I determined moisture content of the samples by first oven-drying them for at least thirty-six hours at 100°C. All the samples were treated the same way to make conditions constant in order to reduce variation. Block sampling method is the standard method.

Volume for each core sample and each cube was calculated through the following procedures:

For blocks: Use the specific gravity scale that uses water displacement in a beaker (Haygreen and Bowyer, 1996).
For bore samples: Use the cylinder:

\[ V = \pi \cdot r^2 \cdot h \] (Lyman, 1993)
Where $V =$ volume of the cylinder; $r =$ radius; and $h =$ height of cylinder

To find the specific gravity of a block or core sample, I determined the sample mass per volume of the wood. Knowing the volume we can now calculate the specific gravity of the sample. The following formula can be applied,

$$SG = \frac{m}{V}$$

Where $SG$ is the specific gravity, $m$ is the sample oven-dry mass and $V$ the sample volume.

Once data were collected they were entered into a computer program that was used to generate scatter plots, histograms, bar charts, and regression analysis. The relationships between specific gravity and decay class, as well as the testing of the other hypotheses, were conducted using SPSS 11.0 software (Norusis, 1997).
Chapter 4.0. Results

4.1 Data Analysis and Specific Gravity

I sampled 54 stumps from the following species: Douglas-fir, N=15 (*Pseudotsuga menziesii*), Ponderosa pine, N=17 (*Pinus ponderosa*), Western larch, N=1 (*Larix occidentalis*), California red fir, N=1 (*Abies magnifica*), and White fir, N=12 (*Abies concolor*). There were too few stumps of California red fir and western larch on the sites selected to be used in testing for specific gravity variation, but the data will be included for comparison.

Bock samples of the three species, Douglas-fir, ponderosa pine, and white fir, displayed a wide range of specific gravity (see table 4.1). The specific gravity range found for Douglas-fir was 0.41 – 0.85, ponderosa pine was 0.36 – 0.72, and white fir was 0.67 – 0.77. There were only two good samples (N= 2) for white fir used since the samples would not hold together when cut into cookies. Only two samples remained intact from Baker City, Oregon to Missoula, Montana. These data may not be very representative of the white fir specific gravity due to small sample size. Stump diameters ranged from 20 – 50 cm for all the species with average diameter being around 34 cm. Diameters of species can be seen in figure 4.1.
Table 4.1. Range of variability of the main variables used in the study for Douglas-fir, ponderosa pine and white fir.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Douglas-fir</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>15</td>
<td>24.00</td>
<td>48.00</td>
<td>34.3600</td>
<td>7.31503</td>
</tr>
<tr>
<td>Decay Class</td>
<td>27</td>
<td>1</td>
<td>4</td>
<td>2.52</td>
<td>1.122</td>
</tr>
<tr>
<td>Block Specific Gravity (g/cm³)</td>
<td>24</td>
<td>.41</td>
<td>.85</td>
<td>.6086</td>
<td>.12806</td>
</tr>
<tr>
<td><strong>Ponderosa pine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>16</td>
<td>24.00</td>
<td>54.00</td>
<td>37.3875</td>
<td>8.68576</td>
</tr>
<tr>
<td>Decay Class</td>
<td>23</td>
<td>1</td>
<td>4</td>
<td>2.65</td>
<td>.885</td>
</tr>
<tr>
<td>Block Specific Gravity (g/cm³)</td>
<td>18</td>
<td>.36</td>
<td>.72</td>
<td>.5488</td>
<td>.11326</td>
</tr>
<tr>
<td><strong>White fir</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>12</td>
<td>22.98</td>
<td>48.00</td>
<td>29.7450</td>
<td>6.66293</td>
</tr>
<tr>
<td>Decay Class</td>
<td>12</td>
<td>1</td>
<td>4</td>
<td>2.75</td>
<td>.866</td>
</tr>
<tr>
<td>Block Specific Gravity (g/cm³)</td>
<td>2</td>
<td>.67</td>
<td>.77</td>
<td>.7190</td>
<td>.07007</td>
</tr>
</tbody>
</table>
Even though most samples had a specific gravity of approximately 0.60 g/cm³ there were a few samples that had a specific gravity greater than 0.70 g/cm³. See figure 4.2 for more clarifications. Each histogram represents a species specific gravity based on block samples.
Figure 4.2 Block average specific gravity by species.

4.1.1. Comparison between sampling techniques

The study attempted to find a suitable sampling technique that was less time consuming and less destructive when cutting cookies. The block sampling technique was very time consuming since cookies had to be transported to the lab and then cut into blocks with a band saw.

Table 4.2 compared average specific gravity of the two sampling techniques. Variables compared were bore versus block samples. There was no significant relationship between the two with a p-value of 0.05. There is no significant correlation between the block specific gravity and bore specific gravity. Both variables have a significance level of 0.844 that is too high for our set p-value.
Table 4.2 Correlation between bore average specific gravity and bore average specific gravity.

<table>
<thead>
<tr>
<th></th>
<th>Bore Average Specific Gravity Dry (g/cm³)</th>
<th>Block Average Dry Specific Gravity (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore Average Specific</td>
<td>Pearson Correlation</td>
<td>1</td>
</tr>
<tr>
<td>Gravity Dry (g/cm³)</td>
<td>Sig. (2-tailed)</td>
<td>-.040</td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>.844</td>
</tr>
<tr>
<td>Block Average Dry</td>
<td>Pearson Correlation</td>
<td>-.040</td>
</tr>
<tr>
<td>Specific Gravity (g/cm³)</td>
<td>Sig. (2-tailed)</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>26</td>
<td>54</td>
</tr>
</tbody>
</table>

Figure 4.3 indicates that there is no significant difference between bore and block specific gravities as sampled when samples were paired together for analysis.

Table 4.3 Paired sample t-test and 2-tailed significance value.

<table>
<thead>
<tr>
<th>Paired Samples Test</th>
<th>95% Confidence Interval of the Difference</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>-.0628</td>
<td>.29394</td>
<td>.05765</td>
</tr>
</tbody>
</table>

Table 4.4 compares paired samples from bore samples number 1 to block sample number 1 of the same stump. The other samples were compared in the same way based on the position of the samples. I wanted to see if there was any relation between the paired samples. No significant difference between the samples was found regardless of sample position.
Table 4.4 Sample t-test, and 2-tailed significance value.

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>95% Confidence Interval of the Difference</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td>Pair 1: Bore #1 - Block #1 Specific Gravity (g/cm3)</td>
<td>-0.0476</td>
<td>0.30229</td>
</tr>
<tr>
<td>Pair 2: Bore #2 - Block #2 Specific Gravity (g/cm3)</td>
<td>-0.0444</td>
<td>0.32184</td>
</tr>
<tr>
<td>Pair 3: Bore #3 - Block #3 Specific Gravity (g/cm3)</td>
<td>-0.0964</td>
<td>0.36577</td>
</tr>
</tbody>
</table>

A scattergram of bore average specific gravity versus block average specific gravity is presented in figure 4.3. It shows that there is no relationship between block average specific gravity and bore specific gravity. The regression $R^2$ was very low (table 4.5) and therefore indicates no significant relationship between the variables. From the results of table 4.5 it can be concluded that there is no predictable relationship between the two sampling techniques. The regression line was almost horizontal and the points’ area “cloud’s” only significant relationship between the two sampling techniques.
Figure 4.3 Regression between block specific gravity and bore average specific gravity.

Table 4.5. Regression results comparing the relationship between the two techniques.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.040a</td>
<td>.002</td>
<td>-.040</td>
<td>.26703</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Block Average Specific Gravity (g/cm3)

4.1.2. Specific gravity variation with stump diameter distribution

I tried to check for any strong relationship between stump diameter and specific gravity. Normally, I would expect smaller stumps to decay faster because they have greater sapwood content and surface area per volume. I also expected that weathering processes would increase stump decay. The block data set was used as a standard for all
analysis. As it is depicted by figure 4.4, there is a lightly variable relationship between the block specific gravity and stump diameter. The regression line in Figure 4.4 has an $R^2$ of 0.001 (Table 4.5), and the slope was not significantly different from 0 ($p = 0.878$).

I have tried other data analysis to determine whether there was any relationship between the two sampling techniques. I had no positive results. I tried comparing block average specific gravity and bore specific gravity by species, but there was still no significant relationship between the two sampling techniques.

![Figure 4.4](image)

**Figure 4.4** Relationship between diameter of the stumps and block specific gravity.

Table 4.6 summarizes the comparison made in figure 4.4; $R^2$ of 0.001 shows an almost flat linear relationship that means that there is not much difference from the zero line.
Table 4.6. Regression results comparing the relationship between diameter of the stumps and block specific gravity.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.032a</td>
<td>.001</td>
<td>-.041</td>
<td>.12586</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Diameter (cm)

4.1.3 Specific gravity variation with decay class

I tried to determine if there was any strong relationship between specific gravity and decay class. I would expect to find a strong relationship since specific gravity decreases with increasing wood decay. Since there was no strong relationship in the analysis I needed to look at the species level in order to further reduce variation. Wood specific gravity varies by species, therefore, the following analysis was conducted by comparing species with block number 1 specific gravity, since they are the outside of the stump that led to visual “decay classification.”

Figure 4.5 shows that regression relationship was very weak for the relationship between decay class and block #1 specific gravity for Douglas-fir. A linear regression line indicates that as decay class goes up block specific gravity decreased as expected. And the $R^2$ value was 0.058.
Figure 4.5 Block #1 specific gravity versus decay class for Douglas-fir

Figure 4.6 further shows the comparison of block average specific gravity and decay class for Douglas-fir. The aim here was to test whether there could be any relationship between the two, since there was no significant relationship with other tests. I found no strong relationship between the two. Most of the samples had a specific gravity < 0.70 g/cm³.
Figure 4.6 Block average specific gravity versus decay class.

Decay class versus block average specific gravity for ponderosa pine is displayed by figure 4.7. There was no significant relationship found in the comparison. The regression line had some slope and it was in the right direction. There were more samples with a specific gravity of more than 0.6 g/cm³, especially in decay class 3. There was a lot of variation in the data samples; therefore, I did not get any strong relationship.
Figure 4.7 Regression line between block average specific gravity and decay class. Regression square value is 0.0516.

Figure 4.8 illustrates the relationship between the decay class and block #1 specific gravity for ponderosa pine. Overall, there is a slight relationship between the block average dry specific gravity with a regression square of 0.1683. Even though there was some little improvement from figure 4.7, the relationship is still very weak to conclude that there is any significant relationship between block #1 samples and decay class.
4.1.4 Interspecies specific gravity comparison

Specific gravity within stumps by species was compared to determine if there could be any relationship and variation with different stumps of different species. Before conducting a study it would be difficult to determine if there would be any strong relationship between specific gravity and decay. The use of a box plot (figure 4.9) helped to explain this scenario by each species. Since all the outliers represent a higher block average specific gravity, there is a strong assumption that this could occur as a result of the heartwood that is hard and had higher specific gravity values.
Table 4.7 shows the results of the between species block average specific gravity comparison using t-tests. All tests had a t-value larger than 0.1, meaning that there were no significant differences between species in terms of block average specific gravity. Each species was compared with the other pairwise, to determine if there were any differences between the species. However, there was a significant difference between ponderosa pine and white fir at a significance level of 0.053.
Table 4.7. Between species specific gravity multiple comparisons.

Multiple Comparisons

<table>
<thead>
<tr>
<th>(I) Species</th>
<th>(J) Species</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
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<td>.03585</td>
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<td>-.0123 - 1317</td>
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<tr>
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<td>.04327</td>
<td>.612</td>
<td></td>
<td>-.0648 - 1090</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-.1104</td>
<td>.08462</td>
<td>198</td>
<td></td>
<td>-.2804 - .0595</td>
<td></td>
<td></td>
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<tr>
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<td>410</td>
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<td>-1287 - .0534</td>
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4.1.5 Within stump specific gravity variability

Tests were performed to determine variation of specific gravity for blocks within the stumps. The box plot (figure 4.10) shows that all outliers were in block #3. I would expect this to happen normally because the heartwood lignifies during tree growth and become very hard. Hence, its specific gravity greatly increases.
The stump in figure 5.4 was ignited at the base and the fire progressed to the top along the sloughed outside of the stump. The fire then curled downward to the base where it originally started. As evidenced by the blackened burn area around the stump, there was adjacent fuel that ignited the stump.

Figure 5.4. Smoldering stump at Lubrecht Experimental Forest after one day of ignition.

Once ignited, pitchy stumps would smolder for several hours or even days. These stumps entered an incomplete combustion stage where there was not enough oxygen to continue flaming combustion. Once in this stage, stumps smoldered and produced large amounts of smoke. Such stumps flamed for a while before smoldering. I observed that for such stumps to ignite there had to be some dry fuel around the stump base. In figure 5.5a the stump shown burned from outside to the inside of the stump. In figure 5.5b the same stump soon stopped flaming and smoldering began since the stump was very pitchy and the wood was tightly packed. In figure 5.5c the stump smoldered for 24 hours. This
I did the same box plot of block specific gravity for ponderosa pine. In figure 4.12 there was an outlier for ponderosa pine, again in the higher specific gravity level region. I expected this to happen since the heartwood solidifies and become very hard, attaining a very high specific gravity. The box plot was used to compare block specific gravity by the position of the sample on the stump for ponderosa pine. Again there was no apparent difference between block positions.

**Figure 4.11.** Box plot for Douglas-fir by block samples
Table 4.7 shows the results of the within stump specific gravity comparison. Paired samples $t$ tests were used. There were significant differences between the specific gravity of block 1 (outside) and block 3 (inside). There was also a weak significant difference ($p=0.065$) between the specific gravity of block 1 (outside) and block 2 (middle). There were no significant differences between the Block 2 and 3 specific gravities. The outliers occurred because the dense heartwood has been filled with resin, as the tree grew older. This phenomenon results in the heartwood being a high specific gravity as compared to sapwood.
Table 4.8. Results of paired sample t-test of within stump specific gravity

<table>
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<th>Paired Samples Test</th>
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<th></th>
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<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>95% Confidence Interval of the Difference</td>
<td>t</td>
<td>df</td>
<td>Sig. (2-tailed)</td>
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<td>Specific Gravity Block #1 versus Block #2 (g/cm³)</td>
<td>-0.0176</td>
<td>0.06852</td>
<td>-0.0363</td>
<td>0.0011</td>
<td>-1.884</td>
<td>53</td>
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<td>Specific Gravity Block #1 versus Block #3 (g/cm³)</td>
<td>-0.0408</td>
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<td>Specific Gravity Block #2 versus Block #3 (g/cm³)</td>
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<td>0.0110</td>
<td>-1.362</td>
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</tbody>
</table>
Chapter 5.0: Observations of Stump fires

In science, it is normally observations that lead researchers and scientists to conduct specific research projects. So it was with this idea that we made observations about stumps and fire. The lack of published information on the smoldering and flaming combustion of stumps made these observations imperative. Stumps make up part of the wildland fuel load yet little research has been carried out concerning their burning behavior. These observations included comments on ignition, flaming, and smoldering. Information concerning ignition and smoldering were the two main focuses in my study, although anything about fire behavior was recorded as well. Prescribed fires for the Lubrecht site were made in the spring of 2002, in the months from May to August, while the Baker City site prescribed fire was in the beginning of the fall, October 2002.

Specific gravity affects combustion in such a way that wood of high specific gravity does not ignite easily and quickly. However, once ignited under flammable conditions for burning, the wood will continue to burn or smolder for several hours, days or even months. This occurs because wood particles are generally tightly packed in this case (Haygreen and Bowyer, 1996). On the other hand, when wood has low specific gravity and it is dry, it ignites easily and bursts into flames. Such wood does not burn for a long time because the wood is loosely packed and, in most cases, it is too decayed to sustain long hours of flaming (Bakhman, 1993). Wood that has high specific gravity has high heat capacity when it burns and takes a long time to burn and smolder; wood with low specific gravity has low heat capacity and will burn and smolder for a short period of time. At times wood with high specific gravity may not even ignite at all since the wood is densely packed together.
5.1 Ignition Stage

It was observed that stumps that were very decayed with fire fuel around their base ignited easily and burned with flaming combustion. The decayed stumps had the outside wood sloughed off. This material made it easy for such stumps to ignite. Decay fungi soften wood and soft wood looses its strength quickly. Well-decayed soft parts that would catch fire first and fire would spread from the soft parts. The decayed stumps that caught fire generally flamed for less than 2 hours. Observed stumps burned out completely in 2 hours. These types of stumps did not produce a lot of smoke when burning because most of them were very dry and the wood particles are less densely packed allowing more oxygen diffusion into the burning wood to produce “clean” flames. Ignition generally started at the base of the stump and made its way to the top face. Then such fires burn down to the bottom of the stump. The observed burning path that was followed by the fire normally followed the soft decayed wood since preheating dried that wood first and enhance burning.
Figure 5.1 Very decayed stump (decay class 3) that has ignited and burst into flames. This particular stump was completely consumed by the fire in less than 2 hours after ignition.

Figure 5.2a shows a decayed stump that was still intact and did not ignite because fire did reach the stump. Figure 5.2b shows a well-decayed stump that ignited and burned with clean flames for only 2 hours. The stump was completely consumed in 2 hours of the ignition. Figure 5.2c is a continuation of figure 5.2c after one hour and thirty minutes of the ignition. All the time the stump experienced complete flaming combustion.
Figure 5.2 Flaming combustion of stumps. Figure 5.2a) the first stump is a decayed stump that has not caught fire; 5.2b) fine fuels next to the stump enhanced ignition of the stump on the side that was very decayed; 5.2c) the whole stump caught fire and busted into flames, within two hours the whole stump was consumed by fire.
5.2 Smoldering

The smoldering of stumps has not been given much attention by researchers. It is one of the causative agents of new fires that start after the main fire has passed. Stumps can smolder for hours and embers can be blown distances to unburned areas, thereby starting new fires (Drysdale 1985). I observed that in most cases the pitchy stumps were the ones that smolder whenever they were ignited. Oxygen does not enter the dense burning wood easily, which produces thick black smoke that bellows from the stumps (Simmons, 1995). The fire fuel load around the stump often determined whether the stump would ignite and catch fire. Lubrecht Forest stumps looked decayed from outside but were very pitchy toward the stump center. For a pitchy stump see figure 5.3.

Figure 5.3. The stump here has signs of being decayed on the outside but when cut the stump was so pitchy and dense that 2 chain blades were ruined cutting this particular stump.
The stump in figure 5.4 was ignited at the base and the fire progressed to the top along the sloughed outside of the stump. The fire then curled downward to the base where it originally started. As evidenced by the blackened burn area around the stump, there was adjacent fuel that ignited the stump.

**Figure 5.4.** Smoldering stump at Lubrecht Experimental Forest after one day of ignition.

Once ignited, pitchy stumps would smolder for several hours or even days. These stumps entered an incomplete combustion stage where there was not enough oxygen to continue flaming combustion. Once in this stage, stumps smoldered and produced large amounts of smoke. Such stumps flamed for a while before smoldering. I observed that for such stumps to ignite there had to be some dry fuel around the stump base. In figure 5.5a the stump shown burned from outside to the inside of the stump. In figure 5.5b the same stump soon stopped flaming and smoldering began since the stump was very pitchy and the wood was tightly packed. In figure 5.5c the stump smoldered for 24 hours. This
was in sharp contrast to the stump in figure 5.2 which burned to ashes in less than two hours following ignition.

Figure 5.5 Incomplete combustion. This stump did not continue flaming for a long time, but it smoldered for 24 hours after the flames disappeared.
5.3 Decay Pattern

Stump decay displayed some very interesting patterns. Stumps from Lubrecht Forest were decayed from the outside of the stump to the inside. This unusual decay can be deceiving. Upon cutting into stump I found that the center would be very pitchy. Specific gravity of stumps in this area increased from the outside of the stump inwards. In the Baker City site, the stumps showed a different pattern of decay. The stumps looked pitchy on the outside but when cut open I found that the stumps were well decayed inside. The specific gravity of the Baker City stumps increased from the center towards the outside of the stump. In other words decay pattern from the Baker City site was the reverse of that displayed at Lubrecht Forest site. In Baker City I observed, that the stump had a tendency to ignite in the middle if an ember lands on top of the stump. This I attributed to be a result of the decayed stump center. I also observed that decayed stump centers did not ignite easily when wet up from moisture from earlier snow and or rain.
In figure 5.6, these types of stumps are the ones that normally reach complete combustion because it is well decayed. All it takes to get the stump is amber with enough energy to light the decayed stump part. The decayed part is very soft that ignition would start quickly within seconds on landing on the stump. Even though the fuel around the base of this stump was generally pine needles it would not have difficulty catching fire due to its decay class status. See figure 5.6.

Figure 5.6 shows a 15-year-old decayed stump from Lubrecht Experimental Forest. Stumps like this one normally would ignite quickly and burn out completely.
In the case of the stump in figure 5.7, the fuel at the base ignited first and then the bark caught fire and carried fire to the top. The woody material then caught fire at the top. The fire then started burning its way down the stump.

I also observed that pitchy stumps, once ignited would get in the flaming combustion stage, which lasted less than an hour. Once the flames went out, the stump goes to the smoldering combustion stage where continuous bluish smoke would fill the air until the whole stump was burnt out. Such burning may produce underground fires that burn out root systems which may smolder for weeks and even months. Smoldering is a result of incomplete combustion. At times some wood material are left unconsumed by fire, but the fire would burn slowly releasing huge amounts of smoke (Frandsen, 1987).
Chapter 6.0: Discussion and Conclusions

The research here has shown that there is no predictable relationship between block specific gravity, and bore specific gravity, the two sampling techniques tested. Unfortunately this result precludes the use of the fast and less destructive bore method to assess stump specific gravity. Scatter plots demonstrated wide variation in stump wood specific gravity and no relationship between samples taken by the two methods.

The results from the study were important, even though no relationship were found between the variables. In all the cases where data were regressed there was no significant relationship. It is very significant that no significance was found for decay class and block specific gravity. In other words the usual classification scale did not correlate with wood decay and specific gravity.

6.1 Observation Conclusions

During my study I made three major observations concerning ignition, flaming and smoldering of stumps. I found that decayed stumps were easily ignited. Once they were ignited they flamed and produced a minimum of smoke. They generally burn to ashes and left no char. Comparatively, pitchy stumps on the other hand were not easily ignited. They needed more fuel around the stump base for ignition to occur. I realized that once they ignited the fire would consume the outer soft part of the wood first. Pitchy stumps produced large amounts of smoke for a long time. These stumps normally enter flaming combustion first and then flamed out They then enter smoldering stage, which continued for a long time. In this study I found that it was the decayed stumps that had
high flames. These flames consumed such stumps quickly when compared to pitchy ones that stayed flaming for a short time and then smolder slowly. Incomplete consumption was common with decayed stumps and rare in the case of the pitchy stumps. Like I observed smoldering combustion of pitchy stumps, I found that these stumps needed a lot fuel at the base to ignite and required more heat energy input to start burning. Thick black smoke was generally associated with pitchy stumps while the burning of decayed stumps was generally characterized by light blue smoke.

After my observations I attempted to find a suitable sampling technique that would provide information on the specific gravity of a stump without having to saw out the cookies, (Block and Bore Methods). Unfortunately, the bore sampling technique proved be no good since there was no significance relationship between the block and bore samples.

There is no difference between the mean specific gravity estimated by the block method and the mean specific gravity estimated by the bore method because of the great variation in specific gravity in stumps.

6.2. Specific gravity variation with stump diameter

I found that there was no relationship between diameter increase and specific gravity. Specific gravity was not affected by the diameter size but the age of the stump (Haygreen and Bowyer, 1996). I tried to determine if there was any strong relationship between specific gravity and stump decay. I expected to find a strong relationship since specific gravity decreases with increasing wood decay. Variation in specific gravity in stumps was high so I looked at the species level to further reduce variation. Wood
specific gravity varies by species, therefore, (Sollins 1982).” I found no significant
difference between the mean specific gravity estimated for small (Ø < 35 cm) and large
(Ø > 35 cm) stumps.

6.3. Specific gravity variation with decay class

To further understand the relationship between decay class and specific gravity, I
employed the use of scatter plots and t-tests. The results indicated no significant
relationship. The regression line was almost horizontal (no slope) and the R² was too low
to warrant any further analysis. There is no difference between the mean specific gravity
across decay classes.

6.4. Interspecies specific gravity comparison

There is no difference between the mean specific gravity for the various species.
Once again the variation in block specific gravity was so large that no significant
differences were found.

6.5. Within stump specific gravity variability

There is no difference between the mean specific gravity with stump radial depth.
Despite high variation in specific gravity in the stumps I found that outer specific gravity
(block #1) was significantly different from inner specific gravity (block #3) when all
species were combined.
6.6 Study Limitations

There were some problems associated with the study, and they delayed the study progress. These study limitations included: winter snow cover on the ground that made sawing of the stumps very dangerous when stumps were frozen and the saw blade was slipping off just carrying the equipments to the site was very difficult since the vehicle had to be left more half a mile away from the site to avoid getting stuck in snow. A financial constraint was one limitation that restricted the fast progress of the study. Academy for Educational Development (AED) funded students could not be paid by the USDA Forest Service, which limited numbers of free assistants I could hire. The other problem was taking on campus classes and trying to collect field data at the same time was very tedious.
Chapter 7.0: Management Implications and Recommendations

I found in this study that the sampling technique I wanted to develop was not possible to develop within a very short time. The bore technique needs to be well calibrated so that the exact amount of core can be collected. There must be an automatic stopper that will prevent the bore from boring deeper once the required length has been reached. I also found that it was not easy to collect the exact core sample because the amount of human force power needed to push the varied with the wood strength. Once the bore hit a soft spot it would often go beyond the required distance into the wood, therefore collecting more wood chips. More wood chips would increase the weight of the sample and that would affect specific gravity calculations since it is mass per volume.

Although the study results were negative, I still have a feeling that with more time, more precise and accurate equipment the results can be positive. The researcher needs to take an exact measure of the depth of core samples from the stump. I recommend that anyone who may want to conduct a follow up study of the same subject should also take into account the following variables relative humidity, wood moisture content, site aspect and slope gradient. It is very important to know how these variables since they affect fire behavior and the stump burning characteristics during a fire. We need to know how stump moisture content affects the smoldering stumps. One variable that needs to be determined is the rate at which a decayed and a pitchy sound wood would smolder. How resin affects smoldering combustion of stumps should be studied. A simulated fire could be carried out in a lab situation to give the researcher a better chance to observe stump consumption rate.
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