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Douglas-Fir Stump Decomposition:
Modeling Carbon Residence Times

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Abstract

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Stumps are a significant portion of the woody debris in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation forests in western Washington State. Very few studies have attempted to quantify the amount of carbon that is held in stumps or the rate at which that carbon is lost. This study assessed carbon and nitrogen concentration and stump density in a chronsequence of thinned or harvested Douglas-fir plantation forests. Using a negative log transformation of density versus age, a model for stump decay was determined. Stumps were found to have a decay rate (k) of 0.019 year^{-1} , starting at an average density of 0.35 g cm^{-3} at one year of age and declining to a density of 0.26 g cm^{-3} over 15 years. The carbon concentration of stumps decreased steadily over time, while the nitrogen content remained constant. Stumps contain up to 33% of total tree-based carbon and 22% of total ecosystem carbon in Douglas-fir plantation forests.

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Chapter 1. Introduction

Forests are a prominent component of the global carbon cycle, containing approximately 80% of the world's aboveground carbon stores (Sedjo, 1992). In temperate forests the potential amount of carbon sequestered is more than half a gigaton of carbon annually. In the United States, 0.15 gigatons of carbon is sequestered in the 145 million hectares of forested lands (USDA, 2000). More than 20 billion tons of this carbon can be found in the Pacific coast region of the United States, with around 200 thousand pounds acre⁻¹ carbon storage in Douglas-fir forests (Birdsey, 1992). According to the Washington State Department of Natural Resources (WSDNR) there are 3.8 million hectares of forested lands in western Washington. Of this, over 1.5 million hectares is controlled by private industry (WSDNR, 2007). Forested lands, including Douglas-fir plantations and other private forest, in western Washington State are an important contributor to carbon sequestration in the United States.

Forest soil carbon is essential for soil microbial activity and nutrient storage. Decomposition of woody material is one of the major routes by which organic matter enters soil (Lukac and Godbold, 2011). Decomposition rates are affected by physical, chemical and biological processes. Means et al. (1985) reported that microclimate can have an effect on decomposition. Moisture and temperature specifically affect the rates of decay but other factors such as altitude, slope, aspect and soil type may also play a role. Laiho and Prescott (2003) suggest that climate may not be as much a factor, however, since tree species prefer areas that have specific climates. Decomposing woody material partially defines a soil's structure, nutrient content, water holding capacity and supports many soil organisms including fungi, bacteria, amphibians, insects/invertebrates and, in turn, birds and mammals. Decomposition also results in some release of CO₂ from soils. The rate of decomposition of stumps, and other woody material,

could be an important factor in carbon sequestration of plantation forests (Palviainen et al., 2010).

Stumps are a significant feature of a logged landscape, whether in a forest that was previously clearcut or one that has undergone thinning. Stumps can make up as much as 20% of the total carbon stores in some forests (Palviainen et al. 2010). However, very few studies have attempted to quantify the amount of carbon that is held in stumps or the rate at which the stumps decompose (Tobin, 2007; Shorohova et al., 2008).

Stumps, through decomposition, are a factor in forest soil development and productivity in terms of water storage, development of soil structure and nutrient cycling (Tobin et al. 2007). In addition, stumps have been theorized to have a higher rate of decay in comparison to other woody material due to increased moisture and greater surface area contact with the soil (Shorohova, et al., 2008). Before a tree is cut, the 'stump' portion is the connection between roots and shoots or crown. This portion of the tree serves as the main conduit for the transfer of water and nutrients to the bole and branches as well as the transfer of organic compounds to the roots. Stumps interact with soil biogeochemically and their decomposition is influenced by site environmental properties as well as soil nutrient availability and microbial abundance. Many microorganisms obtain their energy through the breakdown of cellulose and lignin thus relying on decomposing woody material in order to survive and reproduce (Harmon et al., 1986; Edmonds and Eglitis, 1989).

In western Washington, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the key species harvested for timber. Many studies have looked at the role of woody debris in carbon cycling of Douglas-fir forests including decomposition rates (Maser and Trappe, 1984; Edmonds and Eglitis, 1989; Stone et al., 1998; Holub et al., 2001; Weedon et al., 2009). Some studies have

noted a decrease in decay rates of Douglas-fir wood due to compounds which restrict the infestation of mycelium into the debris after death (Schafer and Cowling, 1966). However, these studies did not examine the decomposition rates of Douglas-fir stumps, thus stump decomposition rates are largely unknown. Understanding the role of Douglas-fir stumps in carbon cycling of managed forests will fill a current gap in our knowledge.

Recent studies have attempted to quantify decay by using a resistograph and other arborist tools rather than using the traditional method of taking a cross section of the log or other material and measuring density by displacement. The resistograph measures changes in torque that correlate to changes in density, providing a relative unit of torque that could be converted to density. The resistograph has been shown to be a useful tool in determining density of coarse woody debris (Kahl et al., 2009), (Makipaa and Linkosalo, 2001). It has also been found that density determined using a resistograph has a high correlation with decay (Costello, and Quarles 1999) (Kahl et al., 2009) (Rinn et al., 1996). By looking at the decrease in density using a measure of resistance of Douglas-fir woody material, decomposition rate can be calculated (Harmon et al., 2000). [This relationship can also be directly related to respiration and carbon sequestration.]

This study created a model of stump decomposition and examined changes in carbon storage over time by assessing density of stump material, stump size, volume, nitrogen content, and carbon content of Douglas-fir stumps on tree farms in a chronosequence in Western Washington State. This model contributes to the understanding of changes in the ecosystem carbon pool over time and the potential of stumps to serve as a carbon sink in Douglas-fir plantation forests and fills the gap in current life cycle analysis of these forests. Various physical

and environmental factors were assessed for relationships and effects on decomposition rate and C storage in stumps.

Chapter 2. Methods

In order to assess the decay rates and changes in carbon storage of Douglas-fir stumps over time, measurements were taken at five western Washington Douglas-fir plantation sites which were thinned or harvested in 1992, 1999, 2006, 2010, 2012 or 2013. Sample plots were within the Stand Management Cooperative (SMC) sites, a silvicultural research coalition of state, federal, and private forest enterprises. Through the SMC, long term records of individual trees and characteristics of each site were available. All of these sites were dominated by Douglas-fir, though one site did have some western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Each site was a second or third generation plantation forest. General site characteristics such as the location, elevation, slope, average daily temperature, average temperature range and average yearly rainfall are provided in Table 1. Sites descriptions represent some of the environmental and geographical characteristics of the location. Low represents elevations below 200 m, and high represents sites at or above 300 m. Dry represents an average of less than 80 cm yr⁻¹ of rain, moist represents an average rainfall of 140 cm yr⁻¹, wet represents a site with an average of 175 cm yr⁻¹ of rain and very wet represents a site with average rainfall greater than 240 cm yr⁻¹. Most thinning dates corresponded to a single plot at a site. Site properties such as soil type, soil texture, established trees per hectare, thinning level, estimated trees per ha (at time of sampling), the years the site was thinned, the average stump diameter on the site and the number of samples taken per plot can be found in Table 2.

Measurements were taken on stumps ranging from 14 to 58 cm in diameter, with an average stump diameter of 39 cm. Stumps measured had been cut between 1 and 22 years ago (Figure 1). Each stump measured was tagged and given a sample number. Stumps were then measured for average height, diameter at sample height, current light exposure, bark thickness, knife penetration depth, moisture content and bark cover. Knife penetration depth is determined by thrusting a knife into the exposed stump and used to measure decay class (Tobin, et al, 2007). Some stumps were also measured for the depth to which the main cylinder of the stump extended below ground.

Stumps were measured for density by proxy with an IML F300 resistograph. Stumps were first stripped of their bark at both the south and east sides. After the bark was removed, a resistograph measurement was taken on those sides at 15 cm from the top of the stump. Two resistograph measurements were taken on each stump, at the south and the east sides. The two resistograph readings per tree were then averaged to control for variability within the stump (Kahl et al. 2009). This average reading was then used to represent the stump's resistance. The readings for each stump were then converted to density. Four of the 164 resistograph readings collected were determined to be outliers using SPSS and discarded.

The conversions of resistance readings to stump density were made by taking cross sections (cookies) of stumps that were sampled and relating the displacement density of those cross sections to the readings. The density of each cross section was determined using water displacement to obtain volume and dried at 65°C until there was no change in weight (Means et al., 1985). Each cross section was taken from a stump at the same level as the resistograph reading was taken. Each of cross section was taken at one site (low, moist, west sloping), with 29 total cross sections taken from stumps aged four, eight and fifteen years. The resistograph

readings taken from these cross sectional portions of stump were regressed against the densities of the stump, determined using cross sections. In addition, resistograph readings from Douglas-fir wood blocks were used as an upper boundary to convert resistance to density (Figure 2). The resultant equation was cross-validated with two of the paired resistance-cross section density pairs. The difference between the calculated density and the actual density of these was only around .01.

A standard 9.5 x 1 cm drill bit attached to a cordless drill was used to excavate material for CHN analysis. Excavation was done at the same location on the stump where resistograph readings were taken (the south and east sides). A maximum depth of 9.5 cm of wood was excavated. The wood samples were taken from the south side and east sides of each stump.

This process of measuring stump characteristics, taking two resistograph readings and excavating material with a conventional drill, was then repeated on every fourth stump below ground. In order to obtain a below ground sample, a 30-40 cm pit was dug at the south side of the stump. However, the belowground material was only taken from the south side of each stump and the collected material was analyzed for C and N separately.

Samples were refrigerated until dried at 70°C for 48 hours weighed in the lab. The dried material was then ground to 2 mm and analyzed for CHN using a Perkin Elmer Series II CHNS/O Analyzer 2400.

The total volume of each stump was calculated by using diameter and height measurements. The below ground volume was added to this, however, the depth of each stump below ground was not measured on all stumps and thus this number was calculated by using the average depth. As a result, the final volume of these stumps was calculated by adding 30 cm to the total height of the stump.

Age of stump was calculated by subtracting the year that the tree was cut from 2014 (the year sampled). Additional site parameters were added to the data from the SMC database with information about each site and plot, including the date planted, aspect, soil type, average rainfall, average temperature, temperature range and elevation.

The final stump density data was compared to all known factors first using a Pearson correlation to establish the potential factors influencing decay. Plots of the density versus stump age were then generated to assess what type of model may be more accurate. Density was transformed using the natural log and a stepwise linear regression model of the potential significant factors against the natural log of density was performed using IBM SPSS 19. Carbon and nitrogen concentrations vs stump age and carbon and nitrogen content versus stump age were also plotted using IBM SPSS 19.

Chapter 3. Results

3.1 Carbon Pools in Stumps of Douglas-fir Plantation Forests

Carbon concentrations in stumps remained relatively constant both by site and by age (Table 3). Concentration ranged from 0.11 to 0.68 g g⁻¹ with a standard deviation of 0.05 g g⁻¹ and a standard deviation of less than 0.005 g g⁻¹ for stumps aged 2 years or younger. Carbon concentration was slightly higher in material from stumps age 8 to stumps aged 15 and 22 years (Figure 3).

Nitrogen concentration increased in the stump samples over time (Figure 3) with the mean concentration increasing from 0.02mg g⁻¹ at 1 year of age to 0.35mg g⁻¹ at 22 years since cut (Table 3). There was a gradual increase in standard deviation of nitrogen concentration with stump age, from about 0.02mg g⁻¹ at 1 year since cut to 0.1 mg g⁻¹ at ages 4 and 16 g g⁻¹ at age 15.

Carbon to nitrogen ratios decreased over time. The average C to average N ratio for stumps aged 1 year was about 2400 whereas this ratio for stumps aged 22 years was only about 140 (Figure 3). There was a very high standard deviation of C: N ratios by age.

There was generally a lower concentration of carbon with more variation in belowground stump material in stumps aged 4 years and older. Nitrogen concentration was higher in belowground samples younger than 8 years of age. Carbon to nitrogen ratios are much lower for the belowground stump material than the above ground stump material. There was a slight difference between samples taken above and samples taken belowground in carbon concentration ($p=.05$) and nitrogen concentration ($p=.04$) (Table 4).

The average Douglas-fir plantation stump has about 98 kg of carbon depending on the age of the stump and the volume, with a standard deviation of 67 kg. At 1 year since cutting the average stump in this study had about 15 kg of carbon. This decreased to about 7 kg of Carbon at age 15. The average total stump volume (including belowground material) was about 625 m³ with a standard deviation of about 430 m³. The 15-year-old stumps were at the lower end of this size range and the 1-year-old and 22-year-old stumps at the upper end of this size range (Table 5).

3.2 Factors Affecting Density

There was a general decline in the measured density of stumps over time as well as an increase in variation (Figure 5). Calculated densities ranged from 0.05 to 0.40 g cm⁻³. The average calculated densities, moisture content, carbon nitrogen concentration, carbon concentration, and carbon to nitrogen concentration are in Table 3.

The major factor affecting stump density is age. Elevation, the presence of red rot (also referred to as brown rot), and canopy cover also had high coefficients of correlation; other

factors such as diameter, average precipitation, temperature fluctuation, bark cover, bark thickness, and the presence of insects did not have a high correlation.

The stepwise linear regression determined that age ($p=0.000$) was the primary predictor of the negative natural log of density, with the resultant model [1]:

$$[1] \quad -\ln Y = 0.977 + 0.019t \quad \text{or} \quad Y_t = Y_0 e^{-0.019t}$$

where D is density and t is time since cut (age); The coefficient -0.019 could also be expressed as the decomposition factor k . Elevation, temperature, slope and the presence of red rot were also significant for determining density, however slope correlated very highly with temperature and red rot correlated with very highly age. Elevation and slope (or temperature) were included in subsequent models; slope ($p=0.011$) explaining the greatest amount of additional variance, despite the low correlation with density. None of the models with these additional factors increased the adjusted r^2 by more than 0.04 from the model utilizing age as the only factor.

A stepwise linear regression model at the low, moist, west sloping study site examined loss of density over time while excluding some of the variability created by environmental factors such as such as average precipitation, temperature, and slope. Age was determined as primary major factor in determining decay at this site with the resultant model [2]:

$$[2] \quad \ln Y = -0.926 - 0.021t \quad \text{or} \quad Y_t = Y_0 e^{-0.021t}$$

where Y is density, t is time since cut (age) and -0.021 is the k factor of decay. Moisture content and the presence of red rot were also significant factors in determining density, however, they all correlated highly with each other and none explained much of the remaining variance in stump density. The relationship of stump density to stump age is plotted in Figure 6.

Stumps within the first decay class were around 1 to 2 years old. Stumps within the second class were around 4 years old, stumps within the third class were around 8 years old and

stumps in the fourth and fifth decay classes were 15 and 22 years old respectively, with many class 5 stumps aged 15 years.

There was no significant difference in density for stump material collected above ground vs material belowground (Table 4).

Chapter 4. Discussion

Determining density by using the resistograph resulted in density data that were slightly lower than other decomposition studies of Douglas-fir boles (Harmon et al., 1985; Means et al., 1985). This could be due to calculating the relationship of density to resistance with fewer data points at the upper-end of the density range. It could also be because we were unable to obtain resistograph data from stumps that were freshly cut or because of the age of the trees when they were cut, as some of the Douglas-fir decay studies examined old growth logs. However, the densities ranges of this study were within the standard deviation range of densities for Douglas-fir in Harmon et al.'s study (1985) on Douglas-fir and decomposition classes.

The rate of Douglas-fir stump decay per year (k) found by modeling the natural log of density against age in this study ($k=0.019$) is very close to the k of Douglas-fir logs determined by Stone et al. (1998), and the fine root decomposition rate for Douglas-fir found by Chen et al. (2002). This is especially interesting as Stone's average sample diameter was the same as this study's (34cm) and with a larger standard deviation. The k for this study is in between the value for large diameter Douglas-fir logs established by other studies (Edmonds et al 1985; Erikson et al., 1985). Yet, other studies found the decay constant to be much higher (Means et al., 1985; Edmonds et al. 1989).

The plot of density by age over all sites for this study was consistent with the findings of Edmonds et al. (1989), Erikson et al. 1985 and Harmon et al. (2000), that decay does not start

for up to five years. The results from the low, moist west-sloping site show that at 8 years, however, decay has generally begun. The lag time could be explained by the fact that many stumps could potentially be alive for long periods after they have been cut; using stored nutrients or due to root grafting with live trees. Delayed death or root grafting could explain some of the higher densities on one site, where it was noted that the cambium had grown-up over a portion of many stumps after those stumps were cut.

Despite having a site with several ages and age classes with which to base a model of decay on for Douglas-fir stumps, there was still a lot of unexplained variation. However, other studies have reported high variation in wood density (Means, 1998). Some of the unexplained variation in the model found in this study may be due to the use of the resistograph. For example studies have found the genetics of individual trees to be a factor in the amplitude of resistograph readings and in turn could have impacted our density measurements/calculation. The trees on the sites in this study were most likely genetically different (Isik and Li, 2002; Gwaze and Stevenson, 2008). Additionally, moisture content of wood has been cited as increasing drill resistance (Kahl, 2009). Moisture content may explain why some of the trees aged 15 years still registered a very high resistance as the water content of trees of that age was, on average, 400% higher than that of the other ages. Resistograph reading changing due to wood moisture may also explain why moisture content was found to be a potentially significant factor affecting density (Shorohova et al., 2008).

The factors that determine decay are hard to predict beyond age (Barker, 2008). This study had several factors that were highly correlated with decay and are likely to still be influential in the decay process. However, due to the mild weather across the region, the minor changes in elevation across sites and other characteristic that were similar among study sites, it is

hard to determine which factors in addition to age influence the rate of stump decomposition. With more variability factors such as elevation and temperature could become more significant for generating a model of decay in Douglas-fir stumps. This study found factors such as red rot to negatively correlate with density, suggesting that classification systems based on appearance could accurately determine the rate of decay. However, determining the decay constant through age classification of woody material in other studies did not yield a model that explained as much of the variation (Means et al. 1985; Edmonds et al. 1986; Stone, et al. 1998 and Harmon et al. 2000).

Carbon content decreasing over time could be due to both respiration and translocation of the carbon due to biological activities of fungi, bacterial and other flora and fauna. Carbon concentration staying more or less constant supports the idea that respiration in Douglas-fir logs does not change between decay classes (Marra and Edmonds, 1994). The loss of carbon over time, coupled with stable nitrogen content suggest that while carbon is being lost, nitrogen is neither being fixed nor lost at significant levels.

The general patterns associated with carbon and nitrogen concentrations and C:N ratios in this study were consistent with Palviainen et al. (2010) as well as Edmonds et al. (1989). However, with the high variability of C:N ratios in each age group of stumps, it is hard to determine if the average numbers are representative enough to make inferences on C:N trends.

The carbon concentration of Douglas-fir stumps was higher, on average, than that of fine roots as found by Chen et al (2001). Whereas the nitrogen content of fine roots was far less on average than that of Douglas-fir stumps (Chen et al, 2001). This somewhat agrees with the findings that the belowground portion of the stump had a higher nitrogen concentration than the

above ground portion, though the fine root concentration of nitrogen was an order of magnitude larger than this study's below ground stump material.

Using the model of decay coupled with the average volume of stumps (675m^3), and 900 stumps ha^{-1} on average, indicates that a site should have around $110,000\text{ kg ha}^{-1}$ of carbon when it is initially thinned, decreasing down to $83,000\text{ kg ha}^{-1}$ of carbon by age 15. Considering that an area that has undergone multiple thinning operations such as at the low, moist, west sloping site with trees aged 4 and 15 years the site could have about $93,000\text{ kg ha}^{-1}$ of carbon. Using Thies and Cunningham's (1996) equation for root biomass with the average stump diameter of 0.39 cm, we can estimate the average root biomass of our stumps to be about 83 kg stump^{-1} , resulting in an additional $37,000\text{ kg ha}^{-1}$ of carbon to be accounted for in stumps and roots. This puts the total amount of carbon in a freshly cut stump as high as $147,000\text{ kg ha}^{-1}$ with a single thinning.

Total tree carbon for plantation forests of site class 2 has been estimated at 330 Mg ha^{-1} , with about 185 Mg ha^{-1} above ground and 35 Mg ha^{-1} , with forest floor biomass estimated at 10 Mg ha^{-1} (Vogt, et al. 2015). The model from this study estimated that cut stumps and roots contain up to 147 Mg ha^{-1} . Total soil carbon for forest plantation sites has been estimated at 130 Mg ha^{-1} (James and Harrison, 2014). The total carbon in these Douglas-fir plantation forests can be estimated at 500 Mg ha^{-1} . Stumps may contain up to 33% of the total tree-based carbon on a Douglas-fir plantation site, 22% of the total forest carbon, when accounting for the cylinder alone and up to 29% of the total ecosystem carbon on a forest plantation sites when accounting for both the stump cylinder and the roots.

Chapter 5. Conclusions

Douglas-fir stumps decay at a rate of 0.019 year^{-1} and are a significant carbon sink for a substantial period of time in plantation forests, with up to 33% of the total tree-based carbon and 29% of the total ecosystem carbon stored in stumps and roots. Carbon content decreases with the age of the stump leaving valuable nitrogen in forests where nitrogen is often a limited nutrient. When all other woody debris is removed, stumps help to support a recovering ecosystem while still supplying nutrients to young saplings and the trees that remain. Using a resistograph of decay classification managers can establish levels of carbon on thinned or logged sites as potential sources of carbon credits.

Table 1. General site characteristics.

Stump sample sites ranged from high to low elevation, drier to very wet and from flat to sloping. Average yearly temperatures among sites had a maximum difference of 3°C and an average seasonal difference of about 15°C. Site coordinates are in decimal degrees. Aspect is given with the highly-sloped site.

Site Description	N Coordinates (Decimal Degrees)	W Coordinates (Decimal Degrees)	Average Rain (cm)	Average Daily Temperature (°C)	Seasonal Temperature Range (°C)	Elevation (m)	% Slope
High, wet, level	46'27.500"	122'4.013"	190	19	15	300	5
Low, moist, level	48'19.436"	122'11.303"	130	16.5	14.5	190	0
Low, dry, level	47'53.959"	122'46.302"	80	16	12.2	180	0
Low, moist, west sloping	47'35.465"	121'43.739"	130	17.5	15	200	40, W
High, very wet, level	46'43.311"	123'25.170"	240	16.5	14	350	0

Table 2. Site properties and stump characteristics.

Estimated trees ha⁻¹ corresponds with the level of thinning and the initial number of trees ha⁻¹ and is representative of the number of trees at the site when sampling was conducted.

Site Description	Soil Type	Soil Texture	Established Trees ha ⁻¹	Thinning Level	Estimated Trees ha ⁻¹ (thinned)	Year(s) Thinned	Average Stump Diameter (cm)	Samples taken per plot
High, wet, flat	Cispus cindery loam	Cindery Sandy Loam/Pumice	1060	Light	250	2012	51	5
Low, moist, flat	Tokul gravelly medial loam	Gravelly Loam	1250	Light	250	2013/2010	49	20
Low, dry, flat	Sinclair gravelly sandy loam	Sandy Loam/Gravelly Sandy Loam	1110	Heavy /Moderate	200	2010/1999	30	20
Low, moist, west sloping	Blethen gravelly loam	Sandy Loam/Gravelly Loam	1110	Light to Moderate	220	2010, 2006, 1999 and 1992	34	20
High, very wet, flat	Boistfort silt loam	Silt Loam	1110	Clear Cut	0	1999	77	13

Table 3. Aboveground stump densities, moisture, carbon and nitrogen concentrations, and C/N ratios.

Densities were calculated using the equation in Figure 2 ($Y = 0.24X^{1.69}$ where X is resistance, Y is density (g cm^{-3})).

Age (Years)	Number of Samples	Average Calculated Density (g cm^{-1})	Average Moisture (%)	Average Nitrogen Concentration (mg g^{-1})	Average Carbon Concentration (g g^{-1})	Average C to Average N (g C g N^{-1})
1	21	0.35	70	0.21	0.48	2300
2	4	0.36	110	0.73	0.48	660
4	61	0.36	120	0.80	0.48	600
8	20	0.34	160	1.1	0.48	440
15	53	0.28	600	2.9	0.50	170
22	5	0.27	390	3.5	0.49	140

Table 4. Comparison of above and belowground stump densities, carbon and nitrogen concentrations, and C/N ratios.

Note that the differences in densities between above and belowground samples are minimal.

N = 45

Age (Years)	Below Ground Density (g cm ⁻³)	Above Ground Density (g cm ⁻³)	Below Ground Nitrogen Concentration (mg g ⁻¹)	Above Ground Nitrogen Concentration (mg g ⁻¹)	Below Ground Carbon Concentration (g g ⁻¹)	Above Ground Carbon Concentration (g g ⁻¹)	Below Ground Average C to Average N (g C g N ⁻¹)	Above Ground Average C to Average N (g C g N ⁻¹)
1	0.37	0.34	1.7	0.20	0.48	0.48	280	3200
2	0.32	0.36	1.5	0.50	0.48	0.48	320	960
4	0.39	0.39	1.3	1.0	0.46	0.50	370	500
8	0.38	0.39	2.6	1.1	0.41	0.48	160	440
15	0.29	0.26	3.2	3.3	0.44	0.50	140	150
22	0.34	0.25	3.1	3.2	0.48	0.48	150	150

Table 5. Average stump volume (cm^3), stumps ha^{-1} and kg C ha^{-1} by age and site. Note that volume of stump material determines the carbon content of each site more so than age.

Age (Years)	Site Description	Average Above Ground Stump Volume (cm^3)	Average Below Ground Stump Volume (cm^3)	Average Total Stump Volume (cm^3)	Average Stump Density (g cm^{-3})	Average gC stump $^{-1}$	Stumps ha^{-1}	Average Total Site Carbon kgC ha^{-1}
1	Low, moist, level	62000	26000	88000	0.35	15000	1100	17000
2	High, wet, level	50000	52000	100000	0.36	18000	850	15000
4	Low, dry, level	30000	21000	51000	0.35	8900	900	8000
4	Low, moist, level	37000	25000	61000	0.36	10000	1100	11000
4	Low, moist, west sloping	39000	27000	66000	0.37	12000	900	11000
8	Low, moist, west sloping	20000	24000	44000	0.34	7200	900	6500
15	Low, moist, west sloping	35000	21000	57000	0.27	7800	900	7000
15	Low, dry, level	16000	14000	30000	0.29	4000	900	3600
15	High, very wet, level	80000	44000	120000	0.26	16000	850	14000
22	Low, moist, west sloping	73000	30000	100000	0.27	15000	900	14000



Figure 1. Stump appearance at ages 1, 4, 8 and 15.

Note the lack of rot on the one year old stump, the white fungus on the four year old stump, the change in color on the eight year old stump and the crumbling form of the 15 year old stump.

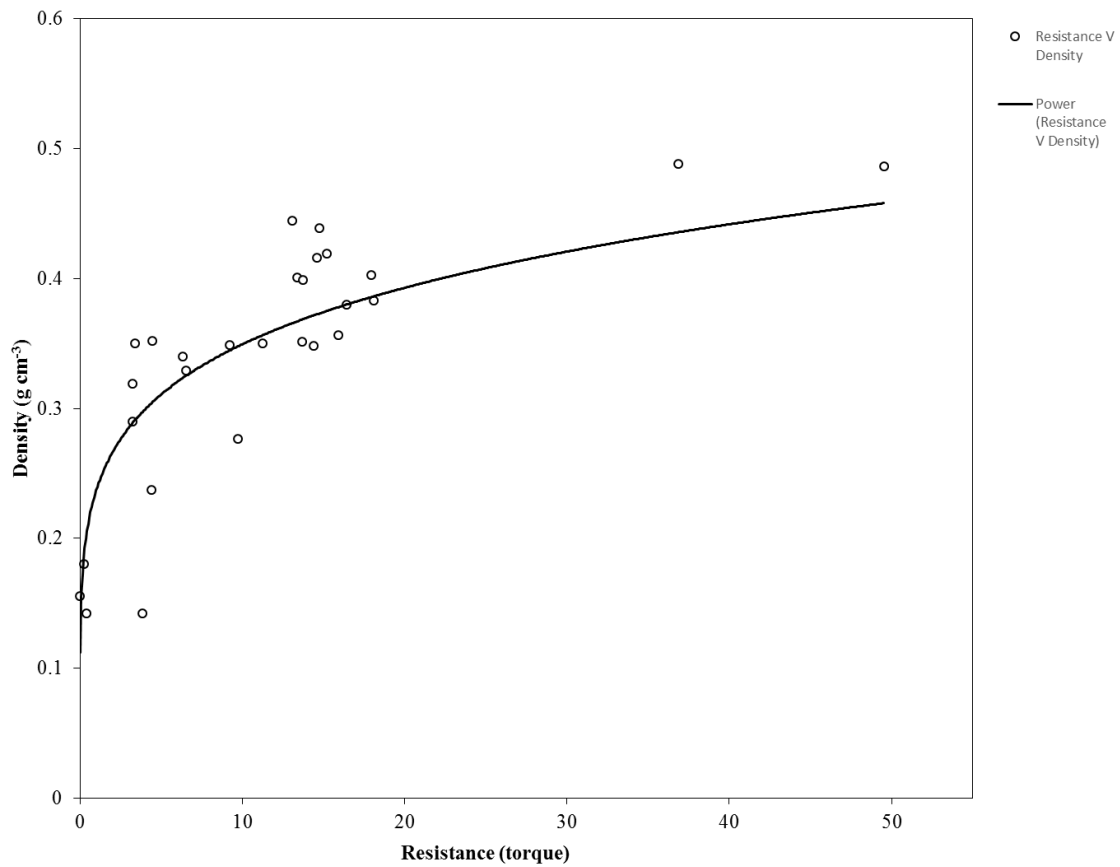


Figure 2. Resistance to displacement density.

Resistance is represented in units of torque registered by the drill as the drill bit passes through the stump material. Each measurement is an average resistance for the two measurements taken per stump. The equation for the line is $Y = .24X^{.169}$, where X is resistance, Y is density (g cm^{-3}) and has an r^2 of .668.

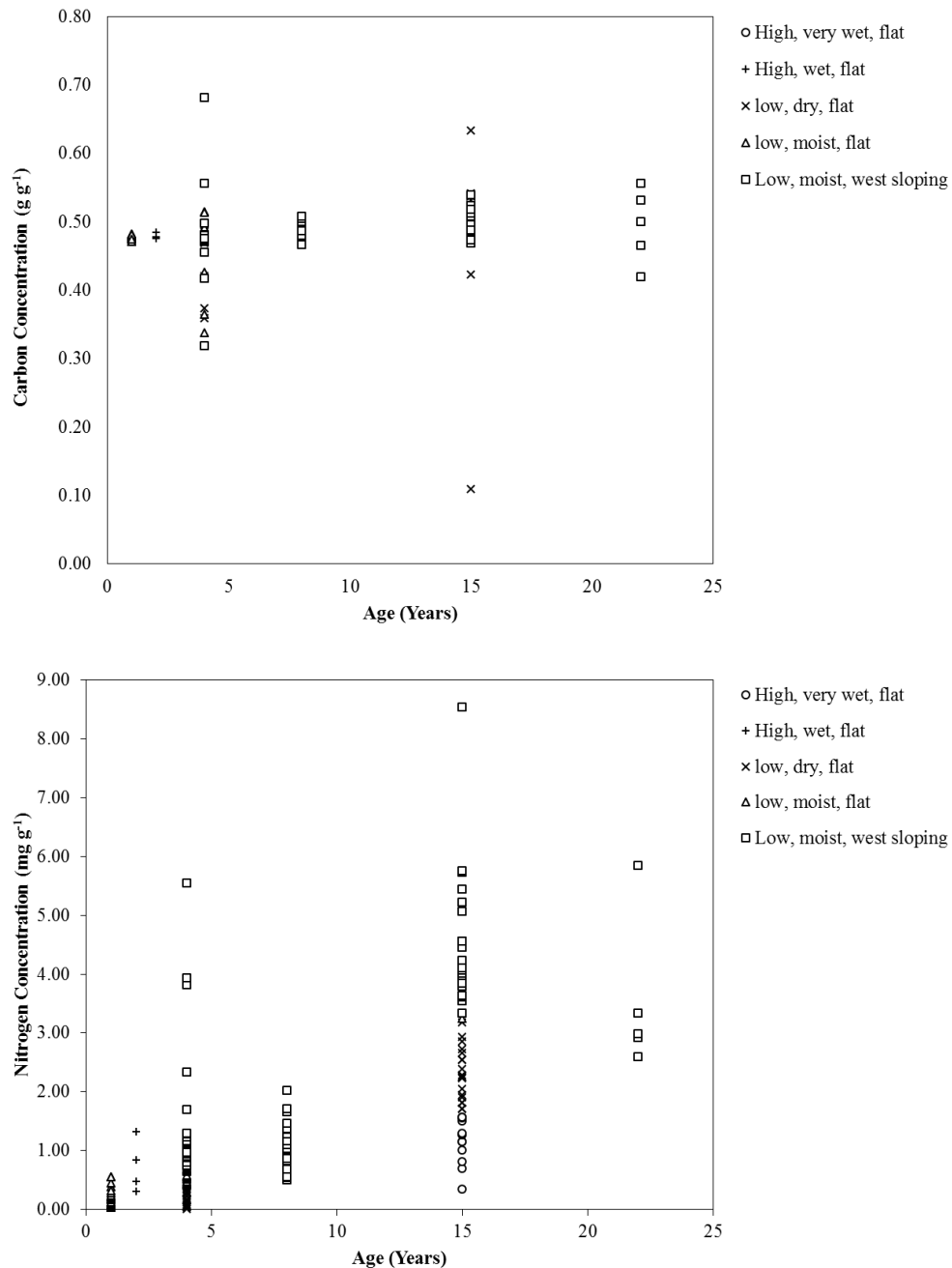


Figure 3. Stump carbon (g g^{-1}) (upper) and nitrogen (lower) concentrations (mg g^{-1}) by stump age (years since cut) and by site (symbol).

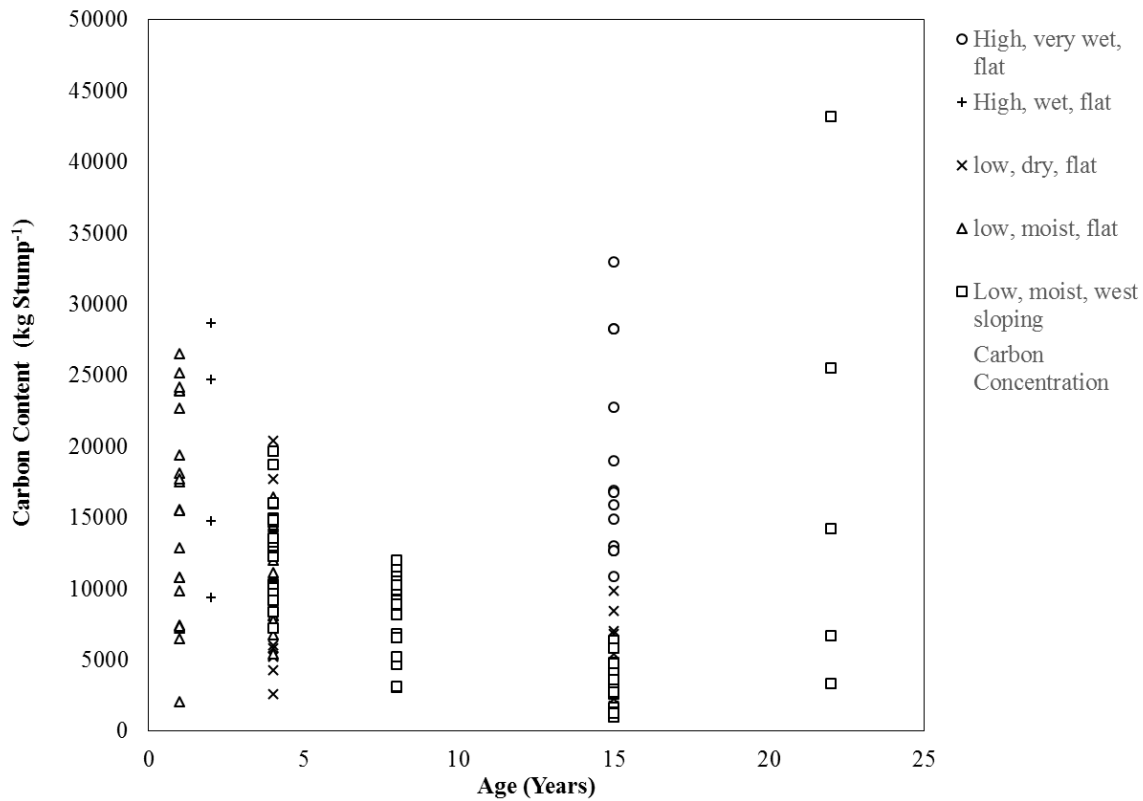


Figure 4. Plot of carbon content (kg stump⁻¹) by age (years since cut). Concentrations are shown per stump, with each site (symbol).

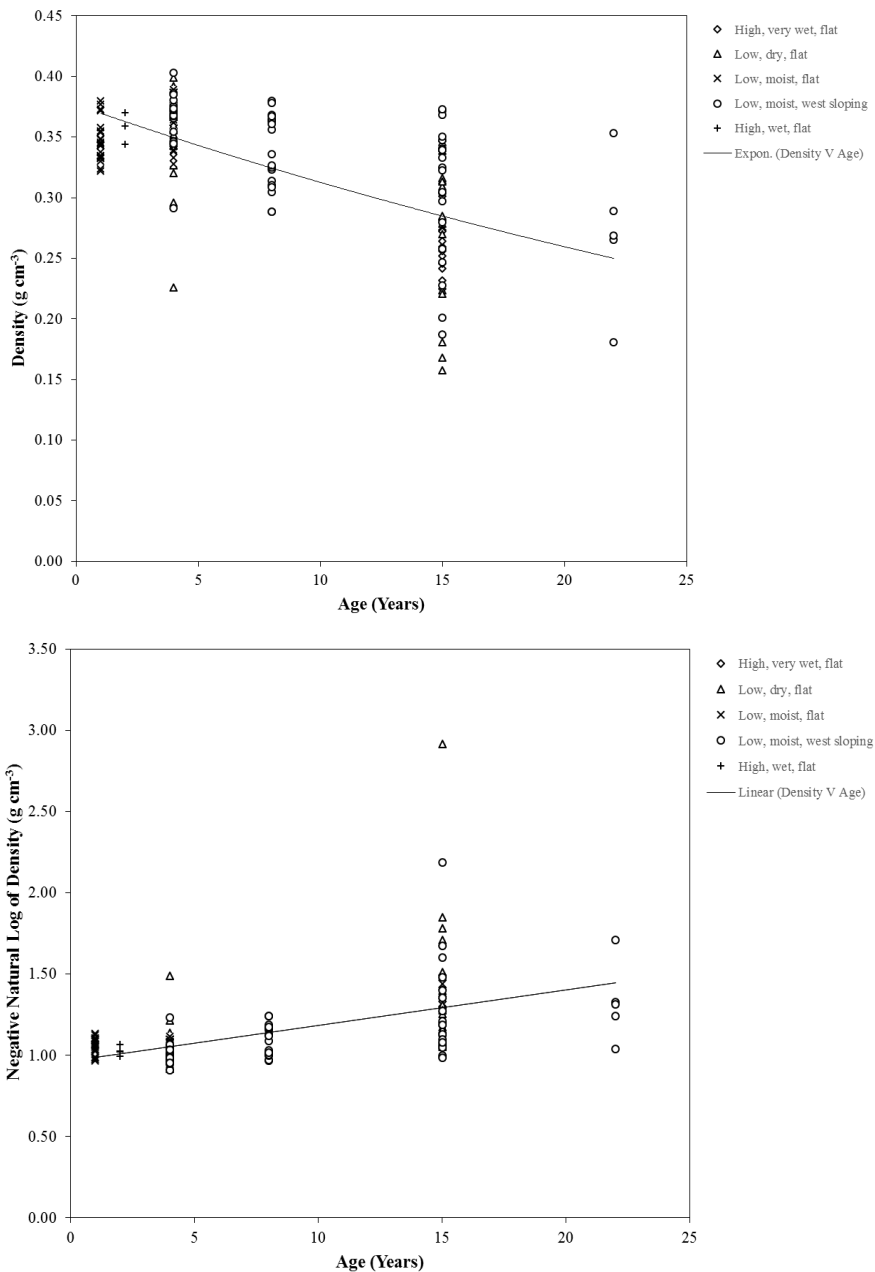


Figure 5. Stump densities (g cm^{-3}) by stump age (years since cut), with trend line, and plot of negative natural log transformed stump densities (g cm^{-3}) by stump age (years since cut). Densities were calculated using the equation which resulted from regressing resistograph units against the densities of cross sections measured using the resistograph ($Y = .24X^{.169}$ where X is resistance, Y is density (g cm^{-3})).

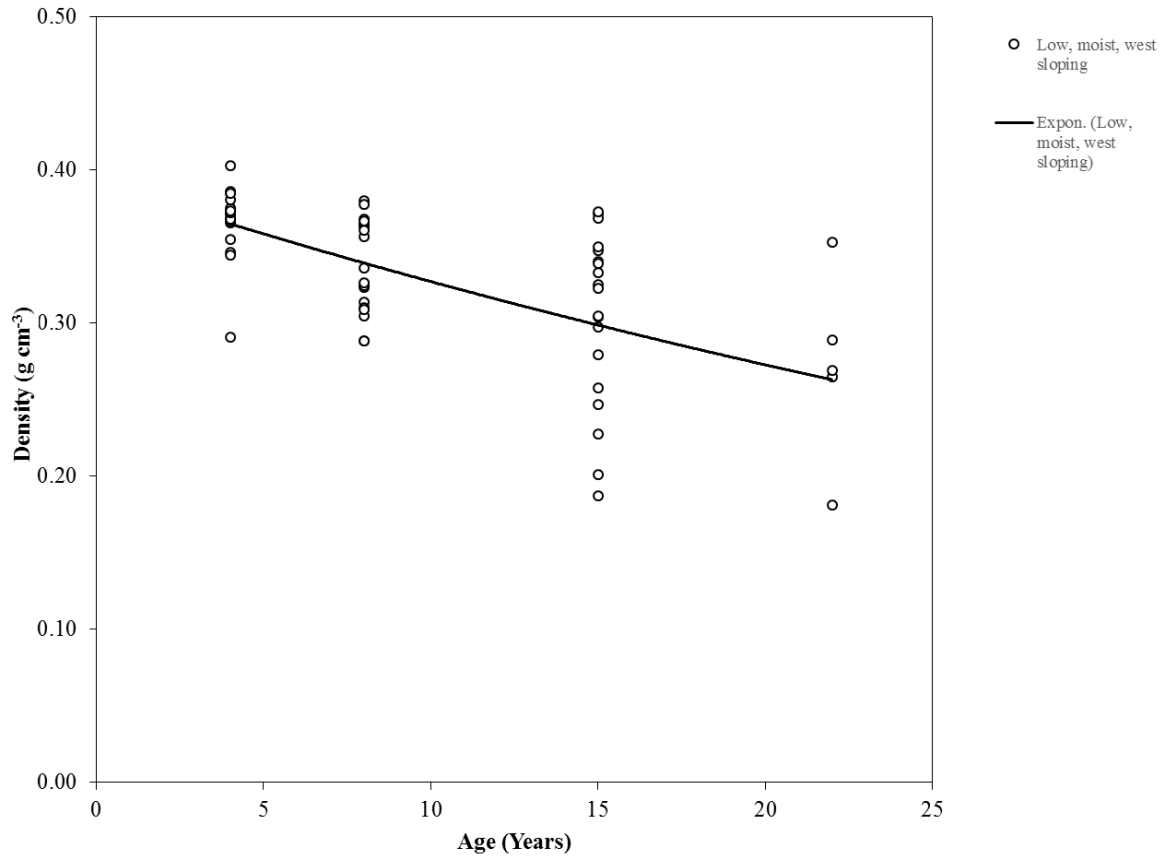


Figure 6. Stump density (g cm^{-3}) by stump age (years since cut) of the low, moist, sloping site.

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Appendix A: Stump Data

A.1 Volume and Nutrient Data

Sample Number	Age (Years)	Moisture Content (%)	Above Ground Height (cm)	Diameter (cm)	Nitrogen (cg g ⁻¹)	Carbon (g g ⁻¹)
10-116-735	4	143.61	45	37.5	0.01	0.42
10-116-738	4	156.08	40	40	0.00	0.48
10-116-756	4	101.54	40	31.25	0.02	0.48
10-116-768	4	65.09	30	43.25	0.02	0.48
10-116-782	4	61.61	25	34.75	0.02	0.48
10-116-792	4	131.17	31.25	35	0.01	0.48
10-116-798	4	151.31	35	29	0.02	0.49
10-116-811	4	42.45	36.875	33.5	0.05	0.48
10-116-813	4	138.98	31.25	37.25	0.12	0.43
10-116-826	4	108.05	47.5	30.25	0.07	0.68
10-116-829	4	144.57	36.25	40	0.03	0.48
10-116-829.5	4	48.74	55	38.75	0.03	0.49
10-116-848	4	102.94	18.75	34.5	0.00	0.48
10-116-858	4	135.40	38.75	39	0.02	0.48
10-116-864	4	115.41	35.625	25.5	0.01	0.48
10-116-868.5	4	120.70	40	35.5	0.04	0.51
10-116-870.5	4	142.49	36.25	31.5	0.38	0.36
10-116-873	4	130.14	30	31.75	0.01	0.51
10-116-885	4	61.29	50	40	0.03	0.34
13-112-802	1	117.36	57.5	32.5	0.00	0.48
13-112-804	1	50.94	70	46	0.01	0.48
13-112-808	1	62.05	47.5	49.75	0.06	0.48
13-112-812	1	45.28	52.5	26.5	0.01	0.48
13-112-815	1	112.40	42.5	35	0.02	0.48
13-112-820	1	38.62	65	36.25	0.02	0.47
13-112-821	1	90.09	57.5	36.25	0.01	0.48
13-112-824	1	50.40	67.5	43.5	0.01	0.48
13-112-832	1	39.61	63.75	45.75	0.01	0.48
13-112-845	1	74.84	75	38.75	0.01	0.47
13-112-848	1	43.57	60	38.75	0.06	0.48
13-112-857	1	54.02	56.25	14	0.02	0.48
13-112-860	1	101.40	77.5	40	0.05	0.47
13-112-867	1	100.91	40	27.5	0.03	0.47
13-112-869	1	49.43	65	25	0.04	0.48
13-112-872	1	109.35	55	40	0.01	0.48
13-112-882	1	83.13	62.5	28.25	0.00	0.48
13-112-892	1	87.07	45	40.75	0.02	0.48
13-112-897	1	47.73	43.75	26.25	0.03	0.48
13-112-901	1	52.22	65	29.75	0.02	0.47
13-112-902	1	57.41	60	44.25	0.02	0.47
99-116-837	15	219.92	41.25	26.25	0.12	0.48

Appendix A.1 Volume and Nutrient Data

Sample Number	Age (Years)	Moisture Content (%)	Above Ground Height (cm)	Diameter (cm)	Nitrogen (cg g ⁻¹)	Carbon (g g ⁻¹)
12-087-254	2	159.96	35	57.25	0.08	0.48
12-087-255	2	106.39	17.5	48.75	0.13	0.48
12-087-289	2	72.77	26.25	35.25	0.05	0.48
12-087-293	2	116.62	17.5	61.25	0.03	0.48
10-251-507	4	64.29	40	27	0.09	0.48
10-251-511	4	42.53	37.5	32	0.06	0.48
10-251-513	4	58.54	21.25	20	0.12	0.47
10-251-528	4	56.30	30	32.25	0.09	0.47
10-251-543	4	64.16	47.5	38	0.07	0.42
10-251-550	4	68.58	32.5	27.5	0.03	0.47
10-251-574	4	58.12	41.25	23.25	0.08	0.48
10-251-586	4	57.05	47.5	34.25	0.05	0.37
10-251-588	4	45.13	37.5	33.25	0.07	0.48
10-251-599	4	56.95	42.5	45	0.10	0.48
10-251-607	4	123.19	37.5	34	0.06	0.36
10-251-630	4	63.39	40	41.25	0.01	0.47
10-251-639	4	44.87	31.25	24.75	0.04	0.47
10-251-639.5	4	58.95	40	32.5	0.11	0.49
10-251-643	4	43.54	27.5	34.75	0.07	0.49
10-251-667	4	79.14	32.5	38.75	0.06	0.48
10-251-688	4	69.03	35	29.25	0.09	0.48
10-251-694	4	69.64	28.75	34.75	0.13	0.48
10-251-700	4	59.70	27.5	30	0.06	0.48
10-251-713	4	39.94	20	30	0.07	0.48
10-251-764	4	62.43	45	29.75	0.04	0.47
99-251-501	15	159.74	23.75	27.25	0.15	0.48
99-251-512	15	203.08	32.5	35	0.29	0.11
99-251-515	15	116.25	28.75	25.5	0.19	0.49
99-251-536	15	215.35	30	18.75	0.40	0.51
99-251-561	15	302.56	30	30	0.38	0.49
99-251-572	15	188.31	26.25	33	0.27	0.51
99-251-620	15	231.28	25	34	0.41	0.50
99-251-632	15	243.44	25	26	0.46	0.50
99-251-641	15	291.58	26.25	28.25	0.32	0.54
99-251-672	15	185.13	21.25	24.75	0.08	0.42
99-251-748	15	286.27	20	23.75	0.13	0.48
99-254-783	15	196.60	20	28.75	0.29	0.52
99-254-786	15	362.75	17.5	31.25	0.16	0.63
99-254-807	15	291.94	30	35	0.36	0.50
99-254-824	15	90.09	16.25	31.75	0.18	0.54
99-254-824.5	15	304.38	25	25	0.46	0.50
99-254-867	15	81.14	41.25	29.25	0.16	0.54
99-254-922	15	367.09	25	25.5	0.85	0.51
99-254-931	15	421.98	20	31.25	0.27	0.53

Appendix A.1 Volume and Nutrient Data

Sample Number	Age (Years)	Moisture Content (%)	Above Ground Height (cm)	Diameter (cm)	Nitrogen (cg g ⁻¹)	Carbon (g g ⁻¹)
06-367-733	8	128.74	25	30	0.06	0.48
06-367-736	8	93.75	21.25	33.75	0.13	0.50
06-367-747	8	169.22	13.75	32.5	0.07	0.48
06-367-751	8	193.01	22.5	37.75	0.10	0.50
06-367-760	8	228.17	13.75	29.25	0.11	0.48
06-367-769	8	173.24	17.5	21.25	0.12	0.49
06-367-775	8	172.85	22.5	38.75	0.17	0.51
06-367-787	8	125.01	20	36.75	0.17	0.49
06-367-790	8	224.92	22.5	43.75	0.08	0.48
06-367-794	8	188.30	27.5	26.5	0.20	0.47
06-367-798	8	221.03	22.5	37.5	0.12	0.49
06-367-803	8	151.96	17.5	37.5	0.05	0.48
06-367-806	8	129.60	22.5	35.25	0.14	0.48
06-367-817	8	128.58	22.5	38.25	0.09	0.48
06-367-860	8	184.88	17.5	39.25	0.14	0.48
06-367-871	8	86.05	22.5	23.75	0.05	0.47
06-367-875	8	140.04	13.75	31.25	0.10	0.48
06-367-884	8	147.43	22.5	40	0.10	0.48
06-367-889	8	204.13	22.5	42.75	0.15	0.49
10-365-503	4	136.83	48	41.5	0.06	0.47
10-365-507	4	140.05	39	34.25	0.11	0.48
10-365-518	4	371.93	33	33.75	0.10	0.48
10-365-527	4	119.60	42	31.25	0.56	0.50
10-365-529	4	92.44	42	31.25	0.03	0.48
10-365-577	4	172.79	36	31.75	0.03	0.48
10-365-595	4	611.93	54	42.75	0.07	0.47
10-365-602	4	166.22	39	36.75	0.02	0.47
10-365-617	4	166.23	33	32.5	0.03	0.48
10-365-629	4	132.78	42	40.25	0.04	0.47
10-365-640	4	178.57	36	37.75	0.10	0.47
10-365-646	4	194.39	27	35.75	0.11	0.48
10-365-656	4	140.56	33	33.5	0.17	0.47
10-365-669	4	106.05	36	40.25	0.08	0.48
10-365-701	4	198.87	33	31.75	0.05	0.48
10-366-009	4	134.41	27.5	38.25	0.08	0.68
10-366-038	4	114.98	27.5	32.75	0.23	0.46
10-366-050	4	146.39	32.5	41.75	0.13	0.42
10-366-065	4	46.22	30	40.5	0.39	0.56
10-366-071	4	135.48	32.5	47.5	0.05	0.32
92-366-232.5	22	450.80	90	32.75	0.29	0.53
92-366-243.5	22	302.66	60	65	0.33	0.50
92-366-244.5	22	584.84	26.25	27.5	0.59	0.56
92-366-245.5	22	279.92	42.5	55	0.26	0.42
92-366-246.5	22	350.82	30	33.75	0.30	0.47

Appendix A.1 Volume and Nutrient Data

Sample Number	Age (Years)	Moisture Content (%)	Above Ground Height (cm)	Diameter (cm)	Nitrogen (cg g ⁻¹)	Carbon (g g ⁻¹)
99-365-506	15	365.29	54	23.75	0.57	0.49
99-365-519	15	395.83	18	16.5	0.22	0.48
99-365-525	15	127.98	45	22	0.33	0.51
99-365-530	15	164.07	40.5	21.25	0.17	0.48
99-365-531	15	283.22	22.5	14.5	0.03	0.48
99-365-585	15	355.62	22.5	20.75	0.52	0.49
99-365-597	15	251.76	39	21	0.25	0.49
99-365-616	15	198.01	36	25.25	0.13	0.48
99-365-628	15	394.23	30	23.5	0.33	0.54
99-365-633	15	250.46	36	12.75	0.39	0.52
99-365-651	15	241.20	18	23	0.12	0.49
99-365-679	15	162.00	30	20.25	0.17	0.48
99-365-693	15	377.38	33	23.25	0.54	0.52
99-365-711	15	435.51	27	19.5	0.58	0.50
99-366-510	15	165.77	35	22.5	0.23	0.47
99-366-512	15	167.57	37.5	22.5	0.13	0.49
99-366-539	15	380.83	30	25	0.07	0.47
99-366-590	15	395.85	25	25	0.51	0.51
99-366-631	15	442.31	37.5	20.25	0.41	0.52
99-366-658	15	427.98	22.5	29	0.42	0.49
99-888-10-64339	15	1485.85	40	51	0.40	0.51
99-888-11-26120	15	665.26	32.5	43	0.25	0.52
99-888-12-320037	15	712.89	51.25	62	0.22	0.53
99-888-1-24-23.5	15	355.78	37.5	47	0.16	0.53
99-888-13-20145	15	8831.58	70	49	0.23	0.50
99-888-2-24-256	15	461.22	40	41.5	0.18	0.54
99-888-3-24-257	15	2622.92	52.5	46.5	0.36	0.50
99-888-4-24-25699	15	519.33	35	48	0.19	0.50
99-888-5-25694	15	655.73	25	48.2	0.21	0.52
99-888-6-25734	15	842.94	52.5	55	0.35	0.51
99-888-7-25740	15	2638.46	50	49.5	0.45	0.52
99-888-8-26179	15	518.71	45	43	0.24	0.52
99-888-9-64347	15	823.85	37.5	58	0.10	0.48

Appendix A.2 Density and Class Data

Sample Number	Age (Years)	Average Total Resistance	Calculated Density (g cm ⁻³)	Bark Thickness (cm)	Bark Cover (%)	Knife Test (cm)	Insects (Y/N)	RedRot (Y/N)	WhiteRot (Y/N)	Decay Class
10-116-735	4	12.83	0.36	1.375	95	1	0	0	0	2
10-116-738	4	8.90	0.34	0	100	1	0	0	1	1
10-116-756	4	16.00	0.38	1.125	100	1	0	0	1	2
10-116-768	4	9.32	0.35	2.75	100	1	0	0	1	2
10-116-782	4	12.30	0.36	1.5	100	1	0	0	0	2
10-116-792	4	13.62	0.37	1.5	100	0.5	0	0	0	2
10-116-798	4	18.23	0.39	1.125	100	1	0	0	1	2
10-116-811	4	9.37	0.35	1.125	100	1	0	0	0	2
10-116-813	4	15.15	0.37	1.625	100	0.5	0	0	1	2
10-116-826	4	9.03	0.34	2.75	100	1	0	0	0	2
10-116-829	4	14.13	0.37	1.625	100	0.5	0	0	1	2
10-116-829.5	4	7.58	0.33	2	100	1	0	0	0	2
10-116-848	4	11.09	0.36	1.25	100	1	1	0	1	2
10-116-858	4	14.80	0.37	1.25	90	1	0	0	1	2
10-116-864	4	8.46	0.34	1.5	100	1	0	0	1	1
10-116-868.5	4	8.27	0.34	1.5	100	0.5	0	0	0	2
10-116-870.5	4	12.31	0.36	1.5	100	1	0	0	1	2
10-116-873	4	18.99	0.39	1.625	100	1	0	0	1	2
10-116-885	4	6.89	0.33	1.5	90	1	0	0	0	2
13-112-802	1	14.70	0.37	1.475	100	0.5	0	0	0	1
13-112-804	1	7.73	0.33	1.625	100	0.5	0	0	0	1
13-112-808	1	9.83	0.35	2.075	100	0.5	0	0	0	1
13-112-812	1	9.25	0.34	1.575	100	0.5	0	0	0	1
13-112-815	1	6.22	0.32	1.575	100	0.5	0	0	0	1
13-112-820	1	7.74	0.33	2.25	100	0.5	0	0	0	1
13-112-821	1	11.52	0.36	1.775	100	0.5	0	0	0	1
13-112-824	1	9.09	0.34	2.125	100	0.5	0	0	0	1
13-112-832	1	6.40	0.32	1.775	100	0.5	0	0	0	1
13-112-845	1	7.16	0.33	1.625	100	0.5	0	0	0	1
13-112-848	1	9.00	0.34	1.25	100	0.5	0	0	0	1
13-112-857	1	7.44	0.33	1	100	0.5	0	0	0	1
13-112-860	1	15.73	0.38	1.575	100	0.5	0	0	0	1
13-112-867	1	14.45	0.37	0.75	100	0.5	1	0	1	1
13-112-869	1	7.52	0.33	1	100	0.5	0	0	0	1
13-112-872	1	11.00	0.35	1.5	100	0.5	1	0	0	1
13-112-882	1	10.80	0.35	0.975	100	0.5	0	0	0	1
13-112-892	1	16.38	0.38	3.5	100	0.5	0	0	0	1
13-112-897	1	8.18	0.34	1	100	0.5	0	0	0	1
13-112-901	1	9.94	0.35	1.625	100	0.5	0	0	0	1
13-112-902	1	9.38	0.35	2.5	100	0.5	0	0	0	1
99-116-837	15	8.72	0.34	1.25	90	5	0	1	1	4

Appendix A.2 Density and Class Data

Sample Number	Age (Years)	Average Total Resistance	Calculated Density (g cm ⁻³)	Bark Thickness (cm)	Bark Cover (%)	Knife Test (cm)	Insects (Y/N)	RedRot (Y/N)	WhiteRot (Y/N)	Decay Class
12-087-254	2	11.74	0.36	3.75	85	0.5	0	0	0	1
12-087-255	2	9.14	0.34	1.75	70	0.5	0	0	0	2
12-087-289	2	11.80	0.36	1.875	90	0.5	0	0	1	1
12-087-293	2	14.12	0.37	2.75	100	0.5	0	0	0	1
10-251-507	4	21.07	0.40	2.125	100	1	1	0	1	2
10-251-511	4	11.37	0.36	1.975	100	0.5	0	0	0	1.5
10-251-513	4	9.31	0.35	1.25	100	5	1	0	0	4
10-251-528	4	0.76	0.23	1.625	100	1	1	0	1	2
10-251-543	4	13.28	0.37	1.7	100	1	0	0	1	2
10-251-550	4	8.94	0.34	1.325	100	0.5	1	0	1	1.5
10-251-574	4	3.78	0.30	1.5	100	2	0	0	0	2
10-251-586	4	12.41	0.36	1.55	100	0.5	0	0	1	2
10-251-588	4	11.10	0.36	1.35	100	0.5	0	0	0	1.5
10-251-599	4	13.73	0.37	1.625	100	1	1	0	1	2
10-251-607	4	13.31	0.37	1.625	100	0.5	0	0	0	2
10-251-630	4	21.91	0.40	2.075	100	0.5	1	0	0	1.5
10-251-639	4	16.30	0.38	1.25	100	1	0	0	1	2
10-251-639.5	4	6.71	0.33	1.5	85	2.5	1	0	0	2
10-251-643	4	14.62	0.37	2.125	100	2	0	0	0	2
10-251-667	4	16.73	0.38	2.2	100	0.5	1	0	1	2
10-251-688	4	15.31	0.38	1.775	100	0.5	0	0	1	1.5
10-251-694	4	5.97	0.32	1.25	98	0.5	0	0	1	1.5
10-251-700	4	10.52	0.35	1.625	85	0.5	0	0	1	2
10-251-713	4	9.59	0.35	1.3	100	0.5	0	0	0	2
10-251-764	4	19.71	0.39	1.25	100	1	0	0	0	2
99-251-501	15	11.93	0.36	1.875	100	3.5	0	1	1	4
99-251-512	15	2.18	0.27	1.375	95	5	1	1	0	4
99-251-515	15	4.88	0.31	1.175	100	5.5	0	1	1	4
99-251-536	15	10.00	0.35	1.3	90	6	0	0	0	1
99-251-561	15	8.35	0.34	2.75	90	5	0	0	0	4
99-251-572	15	2.63	0.28	1.6	100	6	0	0	1	3
99-251-620	15	8.72	0.34	1.475	100	10	0	1	0	5
99-251-632	15	5.38	0.31	1	90	4	1	0	1	5
99-251-641	15	5.55	0.32	1.25	95	8	1		1	5
99-251-672	15	3.01	0.29	1.05	90	7.5	0	1	1	5
99-251-748	15	9.44	0.35	2.775	90	5	0	1	1	4
99-254-783	15	0.21	0.18	1.075	100	11	0	1	1	5
99-254-786	15	0.00	0.05	1.65	100	6.5	0	1	1	4.5
99-254-807	15	9.05	0.34	1.675	100	10	0	1	1	4
99-254-824	15	0.72	0.22	1.75	100		0	0	0	
99-254-824.5	15	0.13	0.17	1.25	100	9	0	1	1	5
99-254-867	15	0.09	0.16	1	95	6	1	0	1	4.5
99-254-922	15	5.25	0.31	1.375	95	4.5	0	1	0	4
99-254-931	15	0.66	0.22	1.375	100	7	0	1	1	5

Appendix A.2 Density and Class Data

Sample Number	Average Total Resistance	Calculated Density (g cm ⁻³)	Age (Years)	Bark Thickness (cm)	Bark Cover (%)	Knife Test (cm)	Insects (Y/N)	RedRot (Y/N)	WhiteRot (Y/N)	Decay Class
06-367-733	12.73	0.36	8	1	90	3.5	0	0	0	3
06-367-736	3.23	0.29	8	1.375	90	3	0	0	1	2.5
06-367-747	16.41	0.38	8	1.5	100	2	1	0	0	2.5
06-367-751	12.63	0.36	8	1.375	100	2	0	0	0	2.5
06-367-760	12.93	0.36	8	1.5	100	3.75	0	0	0	3
06-367-769	15.94	0.38	8	1	100	2	0	0	1	2
06-367-775	11.25	0.36	8	1.375	90	2.5	1	0	1	3
06-367-787	13.62	0.37	8	1	100	1.5	0	0	0	3
06-367-790	4.44	0.30	8	2	100	2.5	0	0	0	3
06-367-794	5.33	0.31	8	0.75	100	3	0	0	1	3
06-367-798	4.97	0.31	8	1.25	100	3	1	0	0	3
06-367-803	13.40	0.37	8	2.5	100	1	1	0	1	2
06-367-806	7.94	0.34	8	1	100	3.5	0	0	0	3
06-367-817	4.82	0.31	8	1.375	100	1	0	0	1	2
06-367-860	12.14	0.36	8	1.5	100	1.5	0	0	1	2
06-367-871	3.23	0.29	8	0.75	100	2	0	0	1	2
06-367-875	6.32	0.32	8	1.25	100	3.5	0	0	0	3
06-367-884	6.52	0.32	8	1.75	100	3.5	0	0	0	2.5
06-367-889	6.73	0.33	8	2	90	5	1	0	0	3
10-365-503	15.22	0.38	4	1.25	90	1	0	0	1	2
10-365-507	23.36	0.40	4	1.75	100	1	0	1	1	2.5
10-365-518	17.93	0.39	4	1.75	100	1	0	0	1	2
10-365-527	14.44	0.37	4	1.125	100	2	0	0	1	2
10-365-529	13.07	0.37	4	1	100	1	0	0	1	2
10-365-577	3.40	0.29	4	1.375	100	1	0	0	0	2
10-365-595	9.51	0.35	4	1.75	100	0.5	0	0	1	1.5
10-365-602	14.61	0.37	4	1.75	100	1	0	0	1	2
10-365-617	14.74	0.37	4	2	100	0.5	0	0	1	2
10-365-629	9.21	0.34	4	2.25	100	0.5	0	0	0	1.5
10-365-640	14.59	0.37	4	1.5	100	1	1	0	1	2
10-365-646	13.39	0.37	4	2	100	1	0	0	1	2
10-365-656	13.76	0.37	4	1	100	1	1	0	1	2
10-365-669	13.56	0.37	4	1.375	100	1	0	0	1	2
10-365-701	18.11	0.39	4	1.5	100	1	1	0	0	2
10-366-009	10.93	0.35	4	2	100	0.5	0	0	0	2
10-366-038	16.64	0.38	4	1.375	100	0.5	0	0	1	2
10-366-050	14.61	0.37	4	2	100	0.5	0	0	0	2
10-366-065	14.89	0.37	4	1.5	100	0.5	0	0	1	2
10-366-071	17.77	0.38	4	2	100	1	0	0	1	3

Appendix A.2 Density and Class Data

Sample Number	Average Total Resistance	Calculated Density (g cm ⁻³)	Age (Years)	Bark Thickness (cm)	Bark Cover (%)	Knife Test (cm)	Insects (Y/N)	RedRot (Y/N)	WhiteRot (Y/N)	Decay Class
92-366-232.5	1.97	0.27	22	0	0	1	0	0	0	5
92-366-243.5	3.26	0.29	22	1.75	10	4	0	0	1	3
92-366-244.5	0.21	0.18	22	0.75	30	3	1	1	0	4.5
92-366-245.5	10.69	0.35	22	2.75	50	1	0	1	1	4
92-366-246.5	2.14	0.27	22	0.75	40	4	0	1	1	5
99-365-506	9.72	0.35	15	0.625	80	0.1	1	1	1	4
99-365-519	8.60	0.34	15	0.375	90	3.8	0	1	1	4
99-365-525	4.42	0.30	15	0.875	70	5	0	0	0	3.5
99-365-530	6.53	0.33	15	0.75	100	7.5	0	0	0	4
99-365-531	6.28	0.32	15	0.5	80	7.5	0	0	0	4.5
99-365-585	14.41	0.37	15	0.5	100	5	0	0	0	4
99-365-597	3.87	0.30	15	0.875	80	6	0	0	1	4
99-365-616	13.70	0.37	15	1	90	1	1	1	1	4
99-365-628	0.25	0.19	15	0.75	100	5	1	1	0	4.5
99-365-633	0.80	0.23	15	0.5	100	7.5	0	1	0	4.5
99-365-651	7.57	0.33	15	0.5	60	2	0	0	0	3
99-365-679	4.47	0.30	15	0.5	100	3.8	0	0	0	4
99-365-693	1.29	0.25	15	0.5	60	7.5	1	0	0	4.5
99-365-711	10.14	0.35	15	0.5	100	0.1	0	0	0	4
99-366-510	8.44	0.34	15	1	6.5	6.5	0	1	1	4
99-366-512	14.76	0.37	15	0.75	2.5	2.5	1	0	1	4
99-366-539	1.65	0.26	15	1	90	4	1	1	1	5
99-366-590	0.38	0.20	15	0.75	10	8.5	0	1	0	4.5
99-366-631	0.01	0.11	15	0.875	80	15	0	1	1	4.5
99-366-658	2.70	0.28	15	1	80	7.5	0	1	1	5
99-888-10-64339	1.73	0.26	15	1	NA	NA	1	1	0	NA
99-888-11-26120	0.88	0.23	15	1	NA	NA	1	1	0	NA
99-888-12-320037	1.45	0.25	15	1.25	NA	NA	1	1	0	NA
99-888-1-24-23.5	2.36	0.27	15	1.75	NA	NA	1	1	0	NA
99-888-13-20145	4.16	0.30	15	0.75	NA	NA	1	1	0	NA
99-888-2-24-256	1.60	0.26	15	1.25	NA	NA	1	1	0	NA
99-888-3-24-257	1.13	0.24	15	1.25	NA	NA	1	1	0	NA
99-888-4-24-25699	2.30	0.27	15	1.625	NA	NA	1	1	0	NA
99-888-5-25694	1.25	0.25	15	1	NA	NA	1	1	0	NA
99-888-6-25734	2.79	0.28	15	1.25	NA	NA	1	1	0	NA
99-888-7-25740	0.25	0.19	15	1	NA	NA	1	1	0	NA
99-888-8-26179	0.73	0.22	15	1	NA	NA	1	1	0	NA
99-888-9-64347	1.93	0.26	15	1	NA	NA	1	0	0	NA

Appendix B: Illustrative pictures

Appendix B.1: Using the Resitograph



B.2 Stump Below Ground



Appendix B.3 Stump (age 4) with Bark and Partially Excavated for Sampling



Appendix B.4 Stump (age 15) with Bark Removed for Sampling



Appendix C Decay Classification System

		A 5-class system of decay for stumps of Douglas Fir trees*				
Characteristics of Cut Stumps	Decay Class					
	I	II	III	IV	V	
Bark	Intact	Intact	Intact - Broken, some pieces missing	Crumpling, larger pieces missing.	Mostly Deformed, to completely absent.	
Inner Wood	Hard	Sapwood softening	Sapwood Soft	Sapwood Soft, Heartwood softening.	Both Sapwood and Heartwood soft.	
Texture	Intact - Knife does not	Intact to Partly Soft - Knife will Penetrate some of sapwood.	Hollow Areas; Knife Penetrates to inner wood.	Small, soft blocky pieces	Soft and Powdery	
Shape/Size	Round - No change	Round - No change	Round, may have minor shape loss	Stump Reduced in Size, loss of shape	Stump Slumping, Not holding Shape	
Color of wood	Original color	Original color	Original color to faded	Light brown to reddish brown	Red-brown to dark brown	
Stump Structure	Fully Structured	Mostly Structured	Minor Slump	Reduced Size, loss of shape, noticeable slump	Minimally Discernable as a Stump	
Signs of Wood Borer's (Insect Galleries) **	Absent	Minor to No Boring	Minor to Moderate Boring	Moderate to Advanced Boring	Signs of Advanced Boring, borers absent.	
Root Invasion	None	None	Root Invasion Starting - Sapwood	Root Invasion into Heartwood	Roots from other plants bringing soil upward around stump base.	

* Adapted from From Maser and Trappe, The Seen and Unseen World of the Fallen Tree - 1984 and from Tobin, Brian, Kevin Black, Luke McGurdy, and Maarten Nieuwenhuis. 2007. "Estimates of decay rates of components of coarse woody debris in thinned Sitka spruce forests". Forestry. 80 (4): 455-469.