Developing volume-to-biomass factors for small diameter tree species in Central Oregon

Progress Report 3

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1.0 Introduction

The Coordinated Resource Offering Protocol (CROP) is a multi-year, multi-agency project to address natural resource issues in Central Oregon. The goals of the project are to: 1) reduce the risk of catastrophic wildfire in communities through the restoration of fire-adapted ecosystems and the development of defensible spaces; 2) restore the structure, function and processes of forest and rangeland ecosystems in the project area; 3) to establish and nurture healthy, diverse markets for the by-products of fuel treatment and ecosystem restoration, and provide opportunities for sustainable jobs and income in local communities; and 4) provide individuals and stakeholder groups in Central Oregon with opportunities and the capacity to engage in collaboration so that multiple values are incorporated into ecosystem management (Aycock 2005).

The specific objectives of this project include:

- Developing a set of planning protocols to coordinate and levelize supply offerings from the Deschutes and Ochoco National Forests and the Prineville District of the BLM;
- Produce and disseminate annual supply projections and economic data for the region in order to promote investments in woody biomass utilizing enterprises
- Increase acres treated on National Forest and other lands

The Central Oregon Intergovernmental Council (COIC) is manager of the CROP effort. To help meet the project's objectives COIC and the US Forest Service funded a destructive sampling study of small diameter vegetation in the fall of 2006. The central question that this study is trying to help answer is how can the existing methods for estimating small diameter woody material be improved across the CROP project area so that woody material estimates can be as accurate as possible. COIC and the USFS want to be sure levelized supply offerings are as accurate as possible so that private investments in small diameter wood products, and biomass energy, can be successful.

1.1 Existing databases

There are two sources of information about small diameter woody material in the CROP project area: COIC's database and the USFS FIA data. The COIC database contains a record of all the properties currently enrolled in the CROP effort. It has information on species, number of acres, treatment history, available green weight tonnage, WUI designation, etc. The green weight tonnage estimates are based on information provided by Natural Resource Team Leaders (NRTL). In most cases they are estimates based on visual inspections of each site, and not based on specific inventory measurements. The second source of information is the USFS FIA data. The FIA data contains a large amount of information about forest stands in the CROP project area, but it includes data outside of the CROP boundaries. Therefore to use the FIA data some data extraction and analysis would be required to insure that only the stands that were part of the CROP data boundaries were analyzed. Due to time constraints, it is not feasible to run that analysis at this time. The COIC database will therefore be used at least in the short term. The analysis and products described below will help COIC improve their existing CROP database and estimates of green tonnage.

2.0 Analysis summary

From January to March 2007 Matt Delaney and Leo Yanez analyzed the destructive sampling data that was collected in late 2006. The primary purpose of the analysis was to develop mathematical relationships between the raw destructive sampling data and volume (in cubic feet) of small diameter tree species.

The raw destructive sampling data that was collected between October and December of 2006 consisted of the following information:

- 110 ten trees all <12 inches in dbh were cut and weighed using a field scale. Species harvested were:
    - Douglas Fir
    - White Fir
    - Ponderosa Pine
    - Lodgepole Pine
    - Juniper
- Branch weight, bole weight, and total green weight were measured in the field
- Sub-samples were collected for moisture content determination
- Analysis of the sub-samples occurred at Oregon State University in Corvallis
- Moisture content ratios were applied to green weight raw data to calculate oven dry weight of the harvested trees
- In addition to measuring green weight in the field, the field crew also took detailed volume measurements, which included:

    i. Dbh
    ii. Total tree length
    iii. Two measurements of bark thickness at dbh
    iv. Diameter including bark at 17.5 feet
    v. Diameter including bark halfway between 17.5 feet and the top of the tree

vi. Stump height and stump diameter (not including bark)

The preliminary results of the destructive sampling effort were reported to COIC in early January 2007, which included a summary table showing the species harvested and their diameters (Table 1). The other raw data can be found in Appendix 2 and 3.

Table 1. Number of trees harvested by species during field work.

Species	n	Low dbh	High dbh
Douglas fir	51	0.5	11.9
White fir	14	0.9	11.1
Lodgepole Pine	18	0.5	11.3
Ponderosa Pine	16	1.3	11.4
Juniper	11	0.15	11.9
Total	**110**		

3.0 Development of volume-to-biomass factors

After the sub-samples that were collected in the field were analyzed at OSU, the green weights of the harvested trees were converted to oven-dry pounds. The average moisture content for all 110 samples was 48%.

Wood discs were also collected at dbh for most harvested trees and their density determined by first measuring volume and then oven-drying the samples and measuring mass on a laboratory balance. The results of the wood disc density calculations were compared to the FIA density values of the same species. Our density results were within +/-10% of the FIA wood density values for all species except for Ponderosa Pine (Table 2). But after discussing the results with Leo Yanez, we decided to use the USFS density values because it is a larger data set than our study. In addition, the wood disc density samples that were collected during the destructive sampling included bark. In most cases including bark in the wood disc density measurements did not impact results significantly but the difference was enough to warrant using the FIA database density values.

Table 2. Density values of harvested wood discs and wood density by species from FIA data.

Species	Density from wood discs (g/cm³)	Density from FIA database (g/cm³)
Douglas fir	0.45	0.46
White fir	0.41	0.37
Juniper	0.47	0.54
Lodgepole pine	0.44	0.38
Ponderosa pine	0.42	0.38

The moisture content ratios were applied to the green pounds of the branches and needles collected in the field. Wood density was applied to the bole weights to calculate oven dry pounds. Both results were added together to calculate total dry weight of all 110 harvested trees. Since the field measurements included detailed measurements of volume, Leo Yanez used USFS equations and form class functions to estimate bole volume of all the 110 trees in cubic feet (Figure 1).

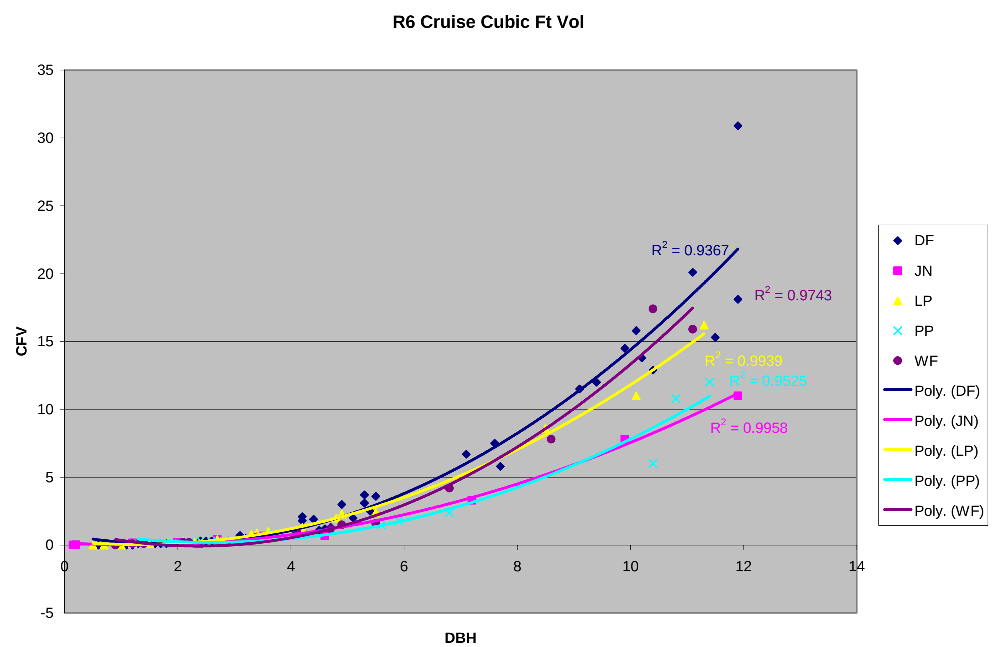

Figure 1. Volume estimates (in cubic feet) by species and dbh (DF=Douglas fir, JN=Juniper, LP=Lodgepole Pine, PP=Ponderosa Pine, and WF=White fir)

For each of the 110 trees harvested there were three estimates:

1. An estimate of green mass by component (bole, branches, and total)
2. An estimate of oven dry mass by component (bole, branches, and total)
3. An estimate of volume in cubic feet

Using SPSS statistical software Leo Yanez analyzed the relationship between volume and biomass of the 110 tree samples. The software used volume as an input value and calculated a factor to make a prediction of biomass (using the destructive sampling raw data). The results were individual conversion factors, by dbh and volume to predict biomass. Factors were calculated for each species for:

- Branch green biomass
- Bole green biomass
- Total green biomass
- Branch oven dry biomass
- Bole oven dry biomass
- Total oven dry biomass

With these factors we constructed volume to biomass tables for each of the five tree species harvested (Appendix 1). The volume-to-biomass tables can be used by the NRTL's to make better estimates of green tonnage for the CROP database. Since the tables also provide estimates of biomass in oven-dry tons, COIC can supply that information to investors as well. Oven dry tons are often used when making carbon calculations as well as during some processing of woody material (for example in biomass energy plants).

4.0 Application of volume-to-biomass factors

During my discussions with Cindy Glick at the start of the field work, she asked if we could help develop a new protocol that the NRTL's could use for estimating small diameter tree volume and biomass. The best way to estimate small diameter vegetation of a particular stand of trees is to develop a stand table. A stand table is basically a description of the number of trees per diameter class on a per acre basis. So for example, if site X is a stand of small ponderosa pine a stand table would estimate how many of a particular size are present (e.g. 200 stems per acre with a dbh of 3 inches or 100 stems per acre with a dbh of 5 inches). Once we had an estimate of stems per acre by species and by diameter range we could apply our developed factors to come up with an estimate of volume and biomass.

The best way to develop a stand table is to install measurement plots. A 1/100th acre or 1/10th acre plot could be used for this effort. A field technician would go to a site and install plots (approximately 1 per 20 acres) along a transect in a representative area and tally the number and diameter of individual trees. Then with the tally sheet, we could work up an estimate of number of trees per diameter class. After that was developed, we would apply our equations to make an estimate of volume, biomass, and carbon. But even in the absence of plot installation and developing stand tables, our existing volume-to-biomass tables will give NRTL's better guidance on mass and volume of the five major tree species present in the CROP project area.

5.0 Conclusions

This study is one of many studies that are trying to address how best to thin stands of western forests to enhance overall forest health, reduce the risk of catastrophic wildfires, and provide market opportunities for the by-products of fuel treatments. The destructive sampling work that was undertaken as a part of this work addresses several key issues having to do with volume and biomass estimation of small diameter trees. Unlike most other studies it involved actual field collection of tree samples so the relationship between volume and biomass could be examined using direct measurements. This data has also helped USFS evaluate current volume tables for the five tree species that were collected. Previous to this study, the USFS used the volume of Ponderosa Pine as a default value for all tree species <5 inches in dbh. But now that we have actual volume estimates for Douglas Fir, White Fir, Ponderosa Pine, Lodgepole Pine, and Juniper <5 inches dbh better estimates of volume can be calculated.

Another significant development from this study was evaluating how the USFS calculates volume. Estimating tree volume can vary significantly based on the mathematical formula used to estimate the volume of a bole (Figure 2) from Harmon and Sexton (1996).

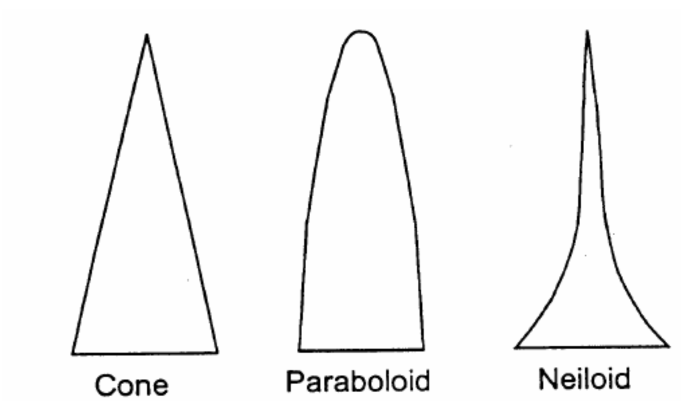

Figure 2. Illustration of the different mathematical formulas used to estimate tree volume (Harmon and Sexton 1996).

Since our destructive sampling work included detailed measurements of the bole of each harvested tree, Leo Yanez was able to compare existing Forest Service methods for estimating tree volume. The first method he employed was to plug in the raw bole measurement data by species into the Region 6 cruise volume equation. The second method used standard FIA cruise formulas to estimate volume. The third and final volume estimate was done using Behre hyperbola values. The estimate of volume using the standard FIA cruise formulas differed by 29% from the Behre hyperbola method. The Region 6 cruise volume method differed from the Behre hyperbola values by much less (7 %). Having information from this 110 tree harvest effort from across Central Oregon allowed the USFS to improve their methods of estimating small diameter volume.

5.1 Carbon opportunities

COIC is interested in exploring carbon project opportunities to help meet some of the CROP project's objectives. The goal of reducing wildfire risk and enhancing forest health can be assisted with carbon financing. The idea of using forest treatments to obtain carbon sequestration (or avoided emissions) is a subject being studied by the US Department of Energy's Westcarb program. The Westcarb project is part of a nationwide effort initiated by the DOE to provide solutions to the buildup of carbon dioxide in the atmosphere. Their project has multiple objectives, particularly exploring geological and technology solutions to sequestering carbon but the effort includes 'forest treatment/wildfire risk reduction' pilot projects. One of these projects is in Northern California (Shasta County) and the other is taking place in southern Oregon (Lake County). One of the organizations involved in the Westcarb study is Winrock International. As part of their work, they are establishing forest carbon baselines for project areas in Shasta and Lake Counties. They have installed dozens of fuel plots in areas that were going to be treated (thinned) to calculate a pre-treatment carbon stock and plan to install post-treatment fuel plots to quantify impacts on carbon. Final results of their study are expected sometime in 2009. Our destructive sampling effort and the resulting volume-to-biomass factors can provide COIC and the USFS a method of developing their own carbon baselines. The approach is slightly different than the fuel plot approach, but it can be used to achieve the same objectives from a carbon point of view. For example, with the improved tables in Appendix 1, the NRTL's will be better equipped to estimate existing green tonnage of small diameter material that is available for extraction. After treatments, the NRTL's can return to the same forest stand and assess the biomass and carbon impacts of a treatment activity (i.e. how much tonnage is present after treatment). And since our study examined the breakdown of biomass amongst tree components (bole, branches, needles) full carbon accounting of treatments can be made, e.g. what was extracted in boles versus what was left behind as slash. These kinds of assessments will be general and most likely require closer scrutiny but the destructive sampling study has laid the ground work for these kinds of evaluations, which will be helpful when examining carbon project potential in Central Oregon.

Appendix 1. Volume-to-biomass tables for five tree species in Central Oregon

Table A. Volume-to-biomass by dbh for Douglas fir

Dbh (inches)	Volume Cubic feet (ft^3)	Green Branches and needles (lbs)	Green Bole (lbs)	Green Total (lbs)	Oven-dry Branches and needles (lbs)	Oven-dry Bole (lbs)	Oven-dry Total (lbs)
1	0.1	2.5	2.1	4.6	1.2	1.0	2.1
2	0.3	14.2	17.3	31.4	6.6	8.2	14.8
3	0.6	28.3	34.5	62.8	5.7	16.4	22.2
4	1.1	41.0	61.1	102.2	20.5	29.8	50.3
5	2.2	65.8	126.0	191.7	31.9	61.3	93.2
6	3.8	97.4	215.6	312.9	46.5	104.4	150.9
7	5.8	135.8	330.0	465.7	64.1	159.3	223.4
8	8.2	181.0	469.1	650.2	84.8	225.9	310.8
9	11.1	233.1	633.1	866.2	108.6	304.2	412.9
10	14.4	292.1	821.8	1113.9	135.5	394.3	529.8
11	18.1	357.9	1035.3	1393.2	165.5	496.0	661.5
12	22.2	430.5	1273.5	1704.1	198.5	609.4	808.0

Table B. Volume-to-biomass by dbh for White fir

Dbh (inches)	Volume Cubic feet (ft^3)	Green Branches and needles (lbs)	Green Bole (lbs)	Green Total (lbs)	Oven-dry Branches and needles (lbs)	Oven-dry Bole (lbs)	Oven-dry Total (lbs)
1	0.1	5.6	6.3	11.9	1.8	2.6	4.5
2	0.4	13.7	15.6	29.3	3.9	9.5	10.4
3	0.4	22.3	25.3	47.6	4.5	10.6	15.1
4	0.5	43.0	77.0	120.0	23.2	14.4	37.5
5	1.5	75.5	93.3	168.8	37.6	40.2	77.8
6	3.0	120.5	181.8	302.4	57.6	78.2	135.8
7	4.9	178.7	299.0	477.7	83.3	128.4	211.7
8	7.2	249.9	444.9	694.7	114.6	190.7	305.2
9	10.0	334.2	619.3	953.4	151.5	265.1	416.6
10	13.3	431.5	822.3	1253.8	194.1	351.6	545.7
11	17.1	542.0	1054.0	1596.0	242.3	450.3	692.7
12	21.3	665.6	1314.2	1979.8	296.2	561.2	857.4

Table C. Volume-to-biomass by dbh for Ponderosa Pine

Dbh (inches)	Volume Cubic feet (ft^3)	Green Branches and needles (lbs)	Green Bole (lbs)	Green Total (lbs)	Oven-dry Branches and needles (lbs)	Oven-dry Bole (lbs)	Oven-dry Total (lbs)
1	0.2	5.9	10.8	16.7	3.6	4.5	8.2
2	0.3	10.1	18.4	28.5	6.2	7.7	13.9
3	0.4	14.5	26.3	40.8	8.9	11.1	19.9
4	0.5	33.0	36.3	69.3	12.1	14.4	26.5
5	1.0	59.2	74.4	133.6	25.3	30.3	55.6
6	1.8	93.7	131.9	225.6	44.6	54.7	99.3
7	2.9	136.5	208.8	345.3	70.2	87.4	157.7
8	4.3	187.6	305.1	492.7	102.1	128.5	230.6
9	5.9	246.9	420.8	667.8	140.2	178.0	318.3
10	7.8	314.6	555.9	870.5	184.6	236.0	420.5
11	10.0	390.6	710.3	1100.9	235.2	302.3	537.5
12	12.5	474.8	884.1	1358.9	292.0	377.0	669.0

Table D. Volume-to-biomass by dbh for Lodgepole Pine

Dbh (inches)	Volume Cubic feet (ft^3)	Green Branches and needles (lbs)	Green Bole (lbs)	Green Total (lbs)	Oven-dry Branches and needles (lbs)	Oven-dry Bole (lbs)	Oven-dry Total (lbs)
1	0.1	2.6	4.6	7.2	1.3	2.1	3.3
2	0.3	7.8	13.9	21.6	3.5	9.2	9.8
3	0.5	18.5	33.0	51.5	13.8	14.7	28.5
4	1.2	38.7	73.3	112.0	23.6	33.9	57.5
5	2.2	66.7	133.1	199.8	35.2	61.8	97.0
6	3.5	102.6	212.3	314.9	48.5	98.3	146.8
7	5.1	146.4	311.0	457.4	63.5	143.5	207.0
8	7.0	198.1	429.2	627.3	80.3	197.2	277.5
9	9.3	257.6	566.8	824.5	98.8	259.7	358.5
10	11.8	325.0	724.0	1049.0	119.0	330.7	449.8
11	14.7	400.3	900.6	1300.9	141.0	410.4	551.5
12	17.8	483.4	1096.7	1580.1	164.8	498.7	663.5

Table E. Volume-to-biomass by dbh for Juniper

Dbh (inches)	Volume Cubic feet (ft^3)	Green Branches and needles (lbs)	Green Bole (lbs)	Green Total (lbs)	Oven-dry Branches and needles (lbs)	Oven-dry Bole (lbs)	Oven-dry Total (lbs)
1	0.1	9.7	5.8	15.5	3.5	2.8	6.2
2	0.3	31.0	18.7	49.7	10.4	8.9	19.3
3	0.6	58.1	35.0	93.2	24.8	16.7	41.5
4	0.8	86.9	46.9	133.8	51.5	21.3	72.8
5	1.4	127.0	81.6	208.7	74.2	39.1	113.3
6	2.2	174.5	126.3	300.8	100.5	62.4	162.8
7	3.3	229.3	181.0	410.3	130.5	91.1	221.5
8	4.5	291.4	245.6	537.0	164.1	125.2	289.3
9	5.9	360.9	320.2	681.1	201.4	164.8	366.2
10	7.5	437.7	404.8	842.6	242.4	209.9	452.3
11	9.4	521.9	499.4	1021.3	287.0	260.4	547.4
12	11.4	613.4	603.9	1217.4	335.3	316.4	651.7

Appendix 2. Tree measurements used to calculate mass and volume

Tree no.	Species	DBH inches-tenths	Top diameter stump (DIB) inches-tenths	Stump height inches	DOB at 17.5 ' inches-tenths	DOB at midpoint 17.5 and top of tree inches-tenths	Bark 1 tenths	Bark 2 tenths	Total height feet	Total height inches	Location
1	PP	5.9	5.4	6"	2.4	1.72	0.4	0.3	23	8	Sisters
2	PP	5.6	5	5 3/4 "	1.3	1.1	0.2	0.4	21	3	Sisters
3	PP	6.8	5.7	5 3/4"	2.8	1.4	0.4	0.5	23	8	Sisters
4	PP	2.2	2.8	flush	no	1.4	0.15	0.2	11	10	Sisters
5	PP	2.6	2.5	flush	no	1.4	0.2	0.2	9	10	Sisters
6	PP	1.8	2.2	flush	no	0.9	0.1	0.08	8	10.5	Sisters
7	PP	2.7	2.7	flush	no	1.8	0.2	0.23	13	9	Sisters
8	PP	1.9	2.5	flush	no	1.2	0.12	0.2	8	9	Sisters
9	PP	3.6	3.8	3 1/2"	no	1.9	0.3	0.3	14	3	Sisters
10	DF	4.1	4.1	1 1/2"	1.8	1.1	0.3	0.3	25	3	Sisters
11	DF	2.6	2.9	flush	no	1.4	0.2	0.2	12	9	Sisters
12	DF	1.4	1.5	4"	no	0.4	0.01	0.01	9	0	Sisters
13	DF	3.1	3.3	flush	0.4	0.2	0.29	0.26	19	10	Sisters
14	WF	1.4	1.8	3"	no	1	0.1	0.15	11	11	Ochoco
15	DF	2.5	2.5	flush	no	1.6	0.2	0.2	16	0	Ochoco
16	WF	1.2	1.4	2 1/2	no	0.6	0.1	0.1	8	4	Ochoco
17	DF	1.7	1.9	2	no	0.7	0.11	0.1	10	10	Ochoco
18	WF	5.5	6.2	flush	0.22	1.7	0.4	0.7	18	2	Ochoco
19	WF	2.2	2.6	4	no	1.2	0.2	0.3	11	1	Ochoco
20	WF	3.4	3.7	10	no	1.9	0.3	0.3	16	10	Ochoco
21	WF	4.7	4.4	10	0.42	0.34	0.4	0.4	19	2	Ochoco
22	PP	2.4	2.1	flush	no	1.3	0.1	0.1	16	9	Ochoco
23	PP	1.3	1.2	1	no	0.6	0.05	0.05	10	5	Ochoco
24	DF	1.1	1	1	no	0.5	0.08	0.08	8	1	Ochoco
25	PP	3.7	3.2	2 1/2	1.98	1.2	0.2	0.4	27	2	Ochoco
26	WF	6.8	5.8	3	4.3	2.5	0.4	0.5	37	10	Ochoco
27	WF	8.6	7.1	4	6.8	3.3	0.6	0.4	45	0	Ochoco
28	PP	4.1	3.8	1	2.3	1.4	0.12	0.4	27	4	Ochoco
29	WF	4.9	5.5	2	1.5	0.8	0.4	0.2	24	0	Ochoco
30	WF	4.1	5	3	1.2	0.7	0.5	0.2	23	0	Ochoco
31	DF	3.2	3.7	flush	0.4	0.2	0.1	0.15	20	1	Sisters
32	DF	4.7	5.3	3 1/2	1.3	0.7	0.25	0.3	24	8	Sisters
33	WF	2.1	2.3	1 1/2	no	1.1	0.15	0.11	12	2	Sisters
34	WF	0.9	1.3	1	no	0.3	0.08	0.1	8	1	Sisters
35	PP	11.4	12.02	4	8.7	4.3	0.5	0.6	48	2	Sisters
36	PP	10.4	11.1	3	4.1	2.3	0.2	0.3	28	2	Sisters
37	DF	10.4	11.9	4	8.7	3.3	0.22	0.21	56	11	Sisters
38	WF	11.1	12.09	5	9.5	4.7	0.2	0.3	56	0	Ochoco
39	WF	10.4	9.2	9 1/2	8.9	5.1	0.3	0.35	65	10	Ochoco
40	PP	10.8	12.05	3	7.6	4.4	0.81	1.2	47	4	Ochoco
41	JN	7.2	9	flush	1	0.4	0.35	0.2	19	9	PrinevilleBLM

42	JN	9.9	12.1	3	4.8	2.5	0.22	0.2	33	0	PrinevilleBLM
43	JN	2	3	flush	no	1.1	0.01	0.01	9	8	PrinevilleBLM
44	JN	1.2	2.8	flush	no	0.7	0.01	0.01	9	5	PrinevilleBLM
45	JN	0.2	1.3	flush	no	0.08	0.02	0.01	5	11	PrinevilleBLM
46	JN	0.15	1.02	flush	no	0.1	0.02	0.02	5	1	PrinevilleBLM
47	JN	2.7	4	flush	no	1.2	0.01	0.01	13	2	PrinevilleBLM
48	JN	4.6	4.3	flush	no	2.1	0.02	0.02	16	6	PrinevilleBLM
49	JN	11.9	12.47	5	6.3	3.3	0.15	0.12	35	3	PrinevilleBLM
50	JN	3.5	4.5	flush	no	1.7	0.08	0.01	16	5	PrinevilleBLM
51	JN	4.2	5.5	flush	no	1.5	0.1	0.08	15	8	PrinevilleBLM
52	DF	10.2	12.05	4	9	5.4	0.35	0.25	61	11	Ochoco
53	LP	8.5	7.6	4	6.1	3.3	0.15	0.22	47	11	Crescent
54	LP	5.5	5.5	2	3.8	1.4	0.1	0.11	32	4	Crescent
55	LP	10.1	8.6	3	7.5	4.9	0.11	0.13	44	10	Crescent
56	LP	1.2	1.13	1 1/2	no	0.9	0.01	0.01	11	11	Crescent
57	LP	1	1.6	1	no	0.6	0.02	0.01	7	10	Crescent
58	LP	2.1	2	3/4	0.7	0.45	0.01	0.01	20	10	Crescent
59	LP	2.3	2.1	1	no	1.5	0.01	0.02	15	6	Crescent
60	LP	0.7	0.9	1	no	0.3	0.01	0.01	7	10	Crescent
61	LP	2.7	2.3	2	0.5	0.4	0.01	0.02	19	5	Crescent
62	LP	1.5	1.6	1 1/2	no	1	0.01	0.01	10	1	Crescent
63	LP	4.8	5	2 1/2	3.5	1.8	0.05	0.05	34	5	Crescent
64	LP	11.3	12.8	3	9.5	6.7	0.18	0.13	52	8	Crescent
65	LP	0.5	0.7	1	no	0.2	0.01	0.01	5	3	Crescent
66	LP	3.6	3.3	1	2.4	1.4	0.02	0.02	28	9	Crescent
67	LP	4.2	4.6	1	2.6	1.5	0.02	0.03	28	5	Crescent
68	LP	4.9	5.7	3	3.7	1.9	0.1	0.06	37	6	Crescent
69	LP	3.4	3.3	1 1/2	2.2	1.3	0.02	0.02	28	10	Crescent
70	LP	3.3	3.1	1	2.2	1.4	0.01	0.02	26	10	Crescent
71	DF	9.4	13	2 1/2	7.7	5.2	0.28	0.4	62	5	Sisters
72	DF	11.9	15.3	2 1/2	10.1	6.9	0.5	0.5	62	4	Sisters
73	DF	5.1	5.1	1	3.2	1.8	0.15	0.15	33	2	Sisters
74	DF	3.3	3.4	2	0.18	0.11	0.09	0.12	18	4	Sisters
75	DF	9.9	12.1	2 1/2	8.7	3.8	0.1	0.09	63	2	Mount Hood
76	DF	1.3	1.38	flush	no	0.7	0.05	0.04	11	3	Mount Hood
77	DF	3.3	3.45	flush	0.1	0.08	0.01	0.03	17	9	Mount Hood
78	DF	5.5	5.4	3 4/5	4.3	2.6	0.02	0.02	44	9	Mount Hood
79	DF	7.1	7.15	4	5.8	3.4	0.19	0.11	53	2	Mount Hood
80	DF	11.9	12.085	3	11	7.8	0.25	0.25	92	3	Mount Hood
81	DF	2.4	2.7	1 4/5	no	1.2	0.01	0.01	17	3	Mount Hood
82	DF	4.2	3.49	2 3/5	3.3	2.1	0.09	0.11	34	6	Mount Hood
83	DF	5.3	5.2	3	4.7	4.5	0.1	0.08	39	3	Mount Hood
84	DF	1.5	1.5	2 1/2	no	1	0.01	0.01	11	4	Mount Hood
85	DF	0.7	1.3	1	no	0.5	0.01	0.01	7	5	Mount Hood
86	DF	1	1.19	1	no	0.7	0.01	0.01	8	11	Mount Hood
87	DF	7.6	7.4	3	5.8	4.3	0.1	0.11	51	3	Mount Hood
88	DF	10.1	9.75	4	8.5	5.1	0.23	0.3	67	9	Mount Hood
89	DF	5.3	5.4	2	4.4	3	0.07	0.01	53	9	Mount Hood
90	DF	2.7	3.3	1	0.5	0.4	0.01	0.01	21	3	Mount Hood
91	DF	1.2	3.2	1/2	no	1.3	0.01	0.01	11	8	Mount Hood
92	DF	0.6	0.7	flush	no	0.5	0.01	0.01	6	11	Mount Hood

93	DF	4.2	3.8	1	3.6	2.3	0.03	0.01	45	3	Mount Hood
94	DF	11.1	8.5	12	9.2	6.8	0.6	0.6	62	9	Mount Hood
95	DF	3.1	2.85	1 1/2	2.1	1.5	0.01	0.01	28	1	Mount Hood
96	DF	1.8	1.85	1/2	no	1.4	0.01	0.02	13	6	Mount Hood
97	DF	4.9	3.8	3	4	2.9	0.17	0.19	50	7	Mount Hood
98	DF	4.4	4	1	2.2	1.1	0.02	0.02	31	5	Mount Hood
99	DF	9.1	9.1	2	7.8	4.9	0.3	0.31	63	2	Ochoco
100	DF	7.7	6.75	1	6.1	3.6	0.27	0.27	44	8	Ochoco
101	DF	5.4	5.5	1	3.8	2.1	0.18	0.1	37	3	Ochoco
102	DF	11.5	10.93	8 1/2	10.3	5.9	0.5	0.6	56	7	Ochoco
103	DF	1.6	2	1	no	0.8	0.01	0.01	12	4	Ochoco
104	DF	0.5	1.2	2	no	0.6	0.01	0.01	7	3.5	Ochoco
105	DF	2.9	3.3	2 1/2	no	1.1	0.02	0.02	12	5.5	Ochoco
106	DF	2.2	3	1 2/3	no	0.9	0.02	0.02	12	9.5	Ochoco
107	DF	4.7	6.3	1	2.5	1.1	0.05	0.04	26	1	Ochoco
108	DF	3.3	3.8	1 1/2	0.9	0.4	0.1	0.01	21	2	Ochoco
109	DF	4.6	4.7	2	2	0.8	0.1	0.11	23	5	Ochoco
110	DF	4.5	4.2	1 1/5	1.5	0.7	0.18	0.19	21	6	Ochoco

Appendix 3. Green and oven dry mass of the 110 harvested trees.

Tree no.	Species	Code	Dbh (in)	Ht(in)	Oven dry wt total lbs	Green branch (lbs)	Green bole (lbs)	Green total (lbs)	Oven dry branch (lbs)	Oven dry bole (lbs)	Oven dry total (lbs)
10	DF	S2DF10	4.1	303	55.9	49.3	62.7	112	27.6	28.4	55.9
11	DF	S2DF11	2.6	153	20.5	24	17.2	41.2	12.7	7.8	20.5
12	DF	S2DF12	1.4	108	5.0	6.4	3.7	10.1	3.3	1.7	5.0
13	DF	S2DF13	3.1	238	33.1	33.9	30.8	64.7	19.2	13.9	33.1
15	DF	O1DF15	2.5	192	20.4	22.9	19.6	42.5	11.6	8.9	20.4
24	DF	O1DF24	1.1	97	3.7	4.8	2.6	7.4	2.5	1.2	3.7
31	DF	S3DF31	3.2	241	35.2	36.1	35.6	71.7	19.1	16.1	35.2
32	DF	S3DF32	4.7	296	90.9	87.1	85.4	172.5	52.2	38.7	90.9
37	DF	S3DF37	10.4	683	641.8	450.3	822.4	1272.7	269.5	372.3	641.8
52	DF	3ODF52	10.2	743	515.6	193	904	1097	106.3	409.3	515.6
71	DF	3SDF71	9.4	749	447.0	271	660	931	148.2	298.8	447.0
72	DF	3SDF72	11.9	748	757.6	470	1102	1572	258.7	498.9	757.6
73	DF	3SDF73	5.1	398	72.3	49	101	150	26.6	45.7	72.3
74	DF	3SDF74	3.3	220	37.0	39	34.5	73.5	21.4	15.6	37.0
75	DF	MDF75	9.9	758	457.5	291.5	712	1003.5	135.2	322.4	457.5
76	DF	MDF76	1.3	135	2.2	2.9	2.1	5	1.3	1.0	2.2
77	DF	MDF77	3.3	213	28.3	31	33.5	64.5	13.1	15.2	28.3
78	DF	MDF78	5.5	537	123.1	66.5	201.5	268	31.8	91.2	123.1
79	DF	MDF79	7.1	638	259.7	155.5	388	543.5	84.1	175.7	259.7
80	DF	MDF80	11.9	1107	977.0	347	1740.5	2087.5	189.0	788.0	977.0
81	DF	MDF81	2.4	207	13.7	13.5	19.5	33	4.9	8.8	13.7
82	DF	MDF82	4.2	414	60.9	30.5	99.5	130	15.8	45.0	60.9
83	DF	MDF83	5.3	471	158.8	117.5	203.5	321	66.6	92.1	158.8
84	DF	MDF84	1.5	136	5.6	5.5	6.5	12	2.7	2.9	5.6
85	DF	MDF85	0.7	89	2.1	2.5	2.1	4.6	1.2	1.0	2.1
86	DF	MDF86	1	107	2.1	2.5	2.1	4.6	1.2	1.0	2.1
87	DF	MDF87	7.6	615	313.0	223.5	420.5	644	122.6	190.4	313.0
88	DF	MDF88	10.1	813	591.6	359	897.5	1256.5	185.3	406.3	591.6
89	DF	MDF89	5.3	645	123.2	52	210	262	28.1	95.1	123.2
90	DF	MDF90	2.7	255	27.9	29.5	24.5	54	16.8	11.1	27.9
91	DF	MDF91	1.2	140	0.0	2.5	0.9	3.4	1.1	0.4	1.5
92	DF	MDF92	0.6	83	0.7	0.7	0.9	1.6	0.3	0.4	0.7
93	DF	MDF93	4.2	543	80.6	39	132.5	171.5	20.6	60.0	80.6
94	DF	MDF94	11.1	753	557.5	182.5	1017.5	1200	96.8	460.7	557.5
95	DF	MDF95	3.1	337	30.3	16.5	47.5	64	8.8	21.5	30.3
96	DF	MDF96	1.8	162	6.4	5.5	8.5	14	2.5	3.8	6.4
97	DF	MDF97	4.9	607	80.8	9.5	167	176.5	5.2	75.6	80.8
98	DF	MDF98	4.4	377	62.0	51	79.5	130.5	26.0	36.0	62.0
99	DF	ODF99	9.1	758	398.2	198.5	611	809.5	121.5	276.6	398.2
100	DF	ODF100	7.7	536	160.7	54	285	339	31.7	129.0	160.7
101	DF	ODF101	5.4	447	112.3	78	145	223	46.6	65.6	112.3
102	DF	ODF102	11.5	679	702.9	553	935.5	1488.5	279.4	423.5	702.9
103	DF	ODF103	1.6	148	8.9	10.5	7.5	18	5.5	3.4	8.9
104	DF	ODF104	0.5	87.5	1.3	1	1.8	2.8	0.5	0.8	1.3

105	DF	ODF105	2.9	149.5	24.6	28.5	19.5	48	15.8	8.8	24.6
106	DF	ODF106	2.2	153.5	20.9	27.5	15.5	43	13.8	7.0	20.9
107	DF	ODF107	4.7	313	87.8	70	111	181	37.5	50.3	87.8
108	DF	ODF108	3.3	254	39.9	40.5	40.5	81	21.5	18.3	39.9
109	DF	ODF109	4.6	281	71.0	67.5	76.5	144	36.4	34.6	71.0
110	DF	ODF110	4.5	258	67.7	74	63.5	137.5	39.0	28.7	67.7
41	JN	4BJN41	7.2	237	219.5	231	167	398	140.5	79.0	219.5
42	JN	4BJN42	9.9	396	469.1	442	419	861	271.0	198.1	469.1
43	JN	4BJN43	2	116	21.5	30.2	11	41.2	16.3	5.2	21.5
44	JN	4BJN44	1.2	113	13.1	18	7	25	9.7	3.3	13.1
45	JN	4BJN45	0.2	71	1.1	1.1	0.9	2	0.6	0.4	1.1
46	JN	4BJN46	0.15	61	0.9	1	0.7	1.7	0.6	0.3	0.9
47	JN	4BJN47	2.7	158	36.9	45	26	71	24.6	12.3	36.9
48	JN	4BJN48	4.6	198	112.3	155	60	215	84.0	28.4	112.3
49	JN	4BJN49	11.9	423	628.6	598	586	1184	351.5	277.1	628.6
50	JN	4BJN50	3.5	197	57.6	66	43	109	37.3	20.3	57.6
51	JN	4BJN51	4.2	188	56.2	52	54	106	30.6	25.5	56.2
53	LP	5CLP53	8.5	575	324.8	225	463.5	688.5	119.4	205.4	324.8
54	LP	5CLP54	5.5	388	114.2	86	154.5	240.5	45.7	68.5	114.2
55	LP	5CLP55	10.1	538	441.5	329	605	934	173.4	268.0	441.5
56	LP	5CLP56	1.2	143	1.8	1.8	2.2	4	0.8	1.0	1.8
57	LP	5CLP57	1	94	2.0	2.2	2	4.2	1.1	0.9	2.0
58	LP	5CLP58	2.1	250	14.1	10.2	18.5	28.7	5.9	8.2	14.1
59	LP	5CLP59	2.3	186	11.4	7	17.5	24.5	3.7	7.8	11.4
60	LP	5CLP60	0.7	94	0.9	0.5	1.5	2	0.3	0.7	0.9
61	LP	5CLP61	2.7	233	15.3	9	25.5	34.5	4.0	11.3	15.3
62	LP	5CLP62	1.5	121	4.9	4	7	11	1.8	3.1	4.9
63	LP	5CLP63	4.8	413	86.0	45	139	184	24.4	61.6	86.0
64	LP	5CLP64	11.3	632	594.0	428	1073	1501	118.6	475.4	594.0
65	LP	5CLP65	0.5	63	0.9	1.2	1	2.2	0.4	0.4	0.9
66	LP	5CLP66	3.6	345	50.1	31	84	115	12.9	37.2	50.1
67	LP	5CLP67	4.2	341	78.2	74	96	170	35.7	42.5	78.2
68	LP	5CLP68	4.9	450	93.5	56	150	206	27.0	66.5	93.5
69	LP	5CLP69	3.4	346	34.1	19	57	76	8.9	25.3	34.1
70	LP	5CLP70	3.3	322	35.7	26	57	83	10.4	25.3	35.7
1	PP	S1PP1	5.9	284	95.3	89.3	126.7	216	42.2	53.0	95.3
2	PP	S1PP2	5.6	255	83.2	75.7	112	187.7	36.3	46.9	83.2
3	PP	S1PP3	6.8	284	124.8	105.4	170.3	275.7	53.5	71.3	124.8
4	PP	S1PP4	2.2	142	9.9	9	13	22	4.5	5.4	9.9
5	PP	S1PP5	2.6	118	13.5	12.8	16.3	29.1	6.7	6.8	13.5
6	PP	S1PP6	1.8	106.5	6.9	7.5	7.9	15.4	3.6	3.3	6.9
7	PP	S1PP7	2.7	165	13.0	9.2	20.2	29.4	4.5	8.5	13.0
8	PP	S1PP8	1.9	105	8.9	9.7	10.1	19.8	4.6	4.2	8.9
9	PP	S1PP9	3.6	171	37.1	37.4	40	77.4	20.3	16.7	37.1
22	PP	O1PP22	2.4	201	10.8	6.2	17.8	24	3.3	7.5	10.8
23	PP	O1PP23	1.3	125	2.9	2.2	3.7	5.9	1.3	1.5	2.9
25	PP	O1PP25	3.7	326	35.7	15.8	60.1	75.9	10.5	25.2	35.7
28	PP	O1PP28	4.1	328	46.9	29.3	78.5	107.8	14.1	32.9	46.9
35	PP	S3PP35	11.4	578	649.1	376.2	855.8	1232	290.9	358.3	649.1
36	PP	S3PP36	10.4	338	418.4	431.6	437.4	869	235.3	183.1	418.4

40	PP	O3PP40	10.8	568	489.7	356	752.2	1108.2	174.8	314.9	489.7
14	WF	O1WF14	1.4	143	8.1	11	7.5	18.5	5.1	3.1	8.1
16	WF	O1WF16	1.2	100	5.7	7.9	4.2	12.1	3.9	1.7	5.7
17	WF	O1WF17	1.7	130	9.0	11.9	7.7	19.6	5.8	3.1	9.0
18	WF	O1WF18	5.5	218	100.7	120.6	81.4	202	67.5	33.2	100.7
19	WF	O1WF19	2.2	133	25.9	36.5	17.4	53.9	18.8	7.1	25.9
20	WF	O1WF20	3.4	202	69.1	95	48.8	143.8	49.2	19.9	69.1
21	WF	O1WF21	4.7	230	58.8	59.4	68.9	128.3	30.7	28.1	58.8
26	WF	O1WF26	6.8	454	143.7	90	225.3	315.3	51.9	91.8	143.7
27	WF	O1WF27	8.6	540	338.9	263.6	527.6	791.2	123.9	215.0	338.9
29	WF	O1WF29	4.9	288	88.1	87.6	95.9	183.5	49.0	39.1	88.1
30	WF	O1WF30	4.1	276	57.6	53	71.3	124.3	28.5	29.1	57.6
33	WF	S3WF33	2.1	146	13.8	16.3	13.6	29.9	8.2	5.5	13.8
34	WF	S3WF34	0.9	97	4.2	5.5	3.5	9	2.8	1.4	4.2
38	WF	O3WF38	11.1	672	696.3	555.5	984.5	1540	295.1	401.2	696.3
39	WF	O3WF39	10.4	790	650.0	511.5	1054.9	1566.4	220.2	429.9	650.0