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Assessment of Woody Biomass Energy Resources in the Cordova Area

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I. EXECUTIVE SUMMARY

The Native Village of Eyak (NVE) is investigating the feasibility of using woody biomass to heat various public buildings in Cordova. Potential sources of biomass include waste cardboard, wood waste generated at a community burn pile, alder along logging roads and standing green trees. This document focuses on quantifying the standing green tree biomass resource with some added information on the potential for alder harvest. The inventory of the standing green tree biomass resource utilizes a United States Forest Service (USFS) satellite image classified for vegetation together with tree measurement plots installed by State Division of Forestry (DOF) and NVE personnel. The project area generally coincides with the extent of the classified satellite image which covers much of the Copper River Delta. From this extent, a subset of potentially accessible biomass based on access, volume and topography was delineated. It is this area that is analyzed and reported on in detail. Three major landowners in the area include the Eyak Corporation, U.S. Forest Service and State of Alaska.

	Project Area Acres	Accessible Area Acres
Owner Classification		
Eyak Corporation	50,745	50,132
Chugach Alaska Corporation	40,868	527
National Forest	1,108,265	149,502
State	12,484	9,350
Private	2,201	182
Totals	**1,214,563**	**209,693**
Vegetation Type		
Sitka Spruce	85,324	9,558
Western Hemlock	38,665	13,271
Sitka Spruce-Black Cottonwood	2,239	879
Black Cottonwood	16,649	13,712
Subtotal Timberland	**142,878**	**37,420**
Shrubland	333,481	79,701
Harvested	4,832	4,832
Wetland	230,863	38,631
Non-Forest Other	29	28
Barren	146,843	23,209
Water	355,638	25,871
Totals	**1,214,563**	**209,693**
	Project Area Volume	**Accessible Area Volume**
Total Net Volume		
Cubic Feet (≥ 5"diameter)	**644,822,705**	**142,616,749**
Cords (≥ 5"diameter)	**7,164,697**	**1,584,631**
Tons (≥ 5"diameter)	**12,471,553**	**2,904,116**
Board Feet (≥ 9"diameter)	**2,748,695,864**	**604,933,059**

TABLE 1. INVENTORY VOLUME AND ACREAGE SUMMARY.

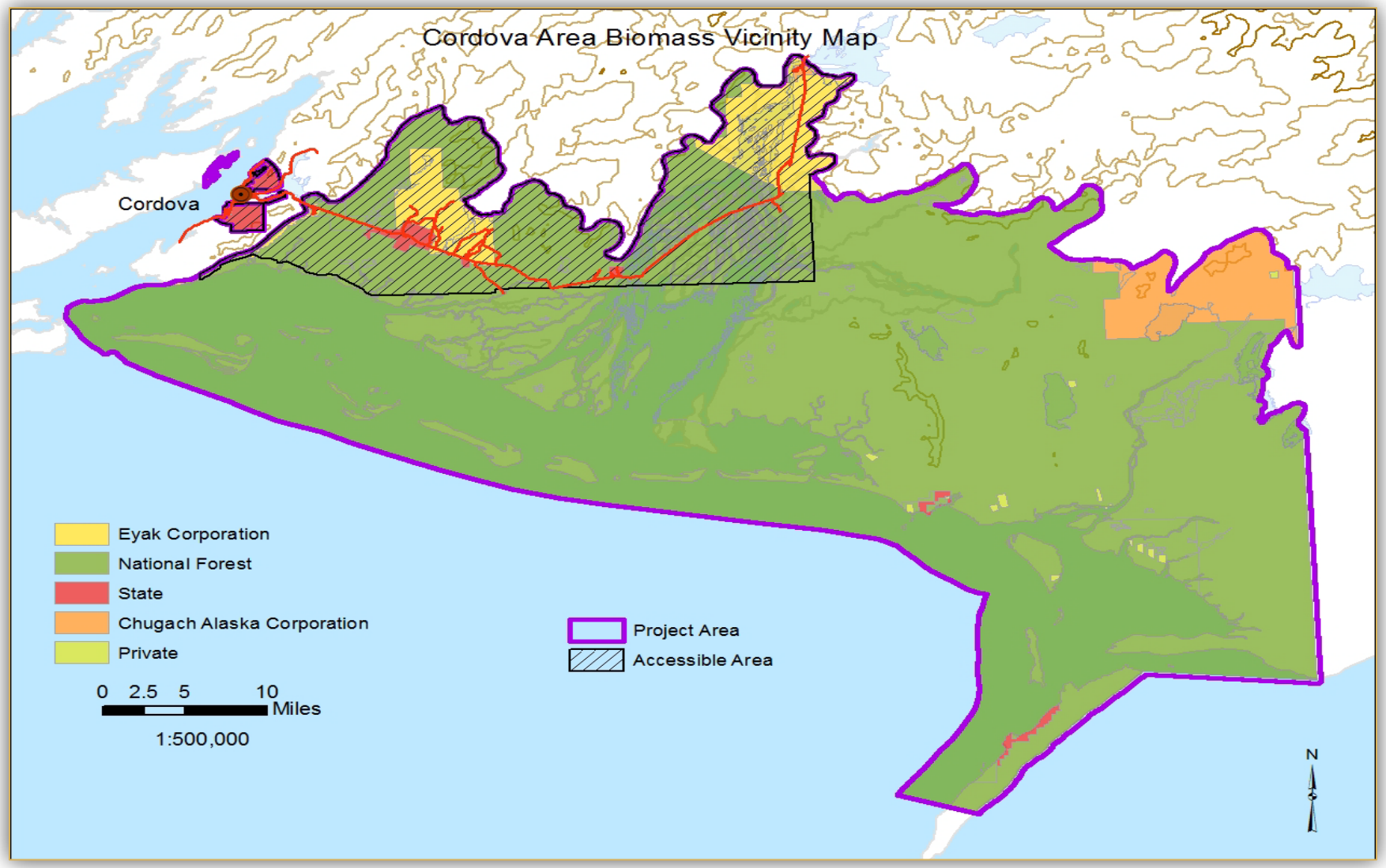

FIGURE 1. CORDOVA AREA BIOMASS VICINITY MAP.

II. OBJECTIVES

The objective of this report is to provide reliable forest inventory data to assist in determining the feasibility of proposed biomass development projects in the Cordova area. A geographic information system (GIS) dataset was utilized for the analysis and allows interactive querying of the spatial data.

III. METHODS

Forest inventory information was collected through a stratified random sampling design. The project area was divided into subpopulations (timber types) in order to account for variation in species composition. Each timber type was then treated as a random sample population. The number of stands sampled within each timber type was based on the overall area occupied and achievement of acceptable statistics within the available field work funding constraints. A total of 32 individual timber stands were field sampled during the first week of October, 2012. These field samples comprise 320 individual measurement plots. The sample timber types were selected randomly and access to the stands was by foot. Field measurements were made in the selected stands to provide estimates of volume, stocking, defect and growth by individual tree species.

A. BASE IMAGERY

Natural color .6 meter resolution digital satellite imagery scenes were used for the project. This mosaic was recently acquired by the USFS and made available to NVE. These scenes were utilized for the field sampling phase and provided a means to accurately navigate to individual sample stands. Timber type polygons, ownership boundaries, roads and sample stands were overlaid onto the base imagery.

B. VEGETATION CLASSIFICATION

The USFS contracted out the vegetation classification and it is still on going. NVE acquired a draft classification map that forms the basis of the acreage estimates in this study. Upon completion of the field work DOF made some edits to the classification to more accurately identify the major timber types. An additional timber type, mixed hemlock-spruce, was added to the coverage. This timber type acreage was combined with the hemlock acreage during data analysis. DOF also classified timber stands on state lands near the town of Cordova that were not included in the draft map. Since the inventory acreage results are generated from the GIS coverage, subsequent changes to the classification map by the USFS can easily be captured and

revisions can be made. For the most part the classification proved reasonably accurate in identifying the major timber types in the Cordova area.

C. Field Inventory Design

The variable plot radius sampling method was used for field data collection of poletimber and sawtimber size trees. The basal area factor utilized was 40 square feet. In each timber stand sampled, ten plots were spaced uniformly on a traverse located systematically through the stand. The traverse was located in such a manner as to attempt to sample the variation within a stand. To minimize travel time, plots were generally located with a maximum interval of 330 feet. Tally trees were selected or rejected with a relascope prism. On five of the ten plots, species, tree vigor, crown ratio, defect type and estimated defect percentage, were recorded and tree diameter, total tree height, bark thickness, and ten-year growth were measured (measure plots). Tree diameters were measured 4.5 feet above ground, commonly known as "diameter breast height" or dbh. Co-dominate and dominant trees were cored at dbh to determine average age and site index of the sample stand. On the other alternating five plots, only the number of trees by species and size class selected by the relascope were recorded (count plots). Count plots generally serve to lower the sample error by increasing the overall plot numbers, but economize time spent in the field collecting data. Only trees five inches dbh and greater were measured utilizing the variable plot sampling method.

The fixed plot sampling method was used for field data collection of trees less than five inches dbh. At every other plot in the ten plot traverse (measure plots) seedling and sapling size trees were measured. Species and quality were recorded and tree diameter and total tree height were measured. The fixed plot was a circular 1/250th acre plot (7.45 foot radius).

D. Data Summary

Upon completion of the field work, sampled stand data were entered into TCruise, a timber inventory software program. The inventory software calculated volume attributes for the individual sampled stands. These stands were then grouped into strata and re-processed in TCruise. The inventory contains four separate sample strata for which estimates of gross and net volume per acre have been calculated. The strata contain field data from 32 individual timber stands containing 320 plots (*Table 4*). Total inventory volume was calculated by multiplying the average per acre volume figures for each stratum by the number of acres each sample stratum represents. These calculations were performed in a Microsoft Access database and utilize the GIS acreage figures. Output reports written in Access display numerous stand attributes from the associated database tables and queries.

E. Acreage Summary/GIS Analysis

Topographic features were examined to determine potentially accessible biomass. Areas where steep topography, extensive wetlands or numerous rivers existed were deleted from the operable area. When the operable subset was finally drawn, most of the area east of the Copper River was deemed inaccessible and was not included. The resulting subset area represents land with reasonable access to biomass resources. The operable area polygon was then queried in the GIS to determine vegetation area by land ownership. After the GIS operable vegetation and ownership layer was created a digital elevation layer was overlaid and values extracted to determine average slope of the individual vegetation polygons. Much of the land area near Cordova lies either in the Copper River Delta which is relatively flat to steep slopes that create more difficult harvest operations. By classifying the acreage and volume by slope classes more accurate estimates of operable biomass resources can be made. Relatively low slopes such as those less than 15% can generally be accessed by ground based harvest systems. As slope increases from this level greater investments in logging machinery are required for harvest and access construction activities.

F. Description of Strata

The four volume strata are described below. Generally the inventory project area is comprised of Sitka Spruce dominated stands with lesser amounts of Western Hemlock and Black Cottonwood. The composition of hemlock increases with elevation and cottonwood increases where riparian areas exist. The Copper River forms the dividing line between mostly spruce dominated lands to the west to a more cottonwood and mixed forest to the east.

1. STRATUM 1, SITKA SPRUCE

This stratum is found throughout the project area. Sitka spruce (Picea sitchensis) occurs in pure stands and in mixed stands with Western hemlock, and Black cottonwood. It is common on the low elevation, wet, well-drained alluvial fans and outwash plains. On these sites many of the stands are quite young (approximately 55 years) and appear to be a primary colonizing forest on recently deposited alluvial outwash. There is little downed large woody debris and soil depths are quite shallow over river cobbles. These young stands have rapid growth rates and given their easy access would be prime candidates for use as a sustainable biomass resource. Other low elevation areas however have a more typical uneven age older forest ranging in the 200 year and greater class. At higher elevations and steeper slopes, the stands become more mixed with Western hemlock. Ages here are again more typical of an uneven age older forest.

FIGURE 2. STRATUM 1 SITKA SPRUCE (EVEN AGED YOUNG GROWTH).

FIGURE 3. STRATUM 1 SITKA SPRUCE (UNEVEN AGED).

2. Stratum 2, Western Hemlock

This stratum is found throughout the project area but in lesser amounts than stratum 1. Within the accessible area however it occupied greater acreage. Western Hemlock (Tsuga heterophylla) occurs in pure stands but generally was mixed with Sitka spruce. Stand ages were variable. Biomass use could be applied as a thinning and improvement tool in some areas with removal of the more defective trees.

FIGURE 4. STRATUM 2 WESTERN HEMLOCK .

3. Stratum 3, Mixed Sitka Spruce/Black cottonwood

This stratum is found near riparian areas and on recently deposited alluvial outwash. It is dominated by Sitka spruce with lesser amounts of cottonwood. Most stands that were sampled were quite young and mostly comprised of poletimber or sapling sized trees. Some of the sites were underlain with river cobbles and gravel with an extremely thin top soil layer. Much of the stratum is too young at this time for efficient biomass use.

FIGURE 5. STRATUM 3 MIXED SITKA SPRUCE/BLACK COTTONWOOD.

4. Stratum 4, Black Cottonwood

This stratum is found near riparian areas and on recently deposited alluvial outwash. It is dominated by cottonwood but also has lesser amounts of Sitka spruce mixed in. Stand ages were variable and ranged from around 55 years to an underdetermined amount of probably 150 or so. Ages were unable to be determined in some stands due to large trees containing extensive amounts of rot. The younger stands are growing rapidly and would be prime candidates for use as a sustainable biomass resource.

FIGURE 6. STRATUM 4 BLACK COTTONWOOD.

G. Forest Volume Definitions

Estimates of timber volume on forested lands have been calculated with three different measurements; cubic foot volume, board foot volume and green tons. The cubic foot measurement includes all timber greater than or equal to five inches dbh and is divided among the live and dead poletimber and sawtimber components of the forest. The board foot measurement is commonly used to determine the amount of lumber that can be sawn from a log. Because the measurement is based on actual boards that can be sawn from a log, it disregards all material wasted in the process such as slabs and sawdust. The board foot measurement only includes timber equal to or greater than 9 inches dbh. Although the focus of the inventory is on biomass use some stands may contain material more suited to milling. It is this possibility of merchandizing some of the trees to a use other than biomass that this measurement is included.

1. Cubic and Board Foot Measurements

Volume calculations for both cubic and board foot measurements are based on volume equations produced by the USFS for the Chugach National Forest. The National Volume

Estimator Library (NVEL) equations (A01DEMW000) are used. The NVEL volume equations are available on the internet as a Microsoft Excel add-in function. Board foot volume is reported in Scribner Decimal C scale and is based on 16-foot log segments (short log scale) and is reported to a 6-inch top. Cubic volume is reported in Smalian's rule and includes volume to a 4-inch top. In terms of calculations for wood energy resources, the cubic foot value is important in that it can readily be converted into cords and the measurement relates well to delivered wood in round log form. The equations were entered into TCruise, for processing of the volume calculations.

2. TON MEASUREMENTS

Computation of green tons is somewhat less straight forward because published volume tables by ton are much less available. In past DOF inventory projects for the Copper River Basin and the Tanana Valley computation of green tons was derived from weight ratios produced for Alaska wood species (Sturgeon 1979. *Wood As A Fuel.*). *Wood As A Fuel* lists the weight of green cord wood which can be converted into pounds per cubic foot. Thus the inventory cubic foot values can be converted to a green ton basis. A cord of wood is assumed to contain 90 cubic feet of solid wood.

Species	Pounds per Cubic Foot	Tons per Cord
Sitka Spruce	34	1.53
Western Hemlock	50	2.25
Black Cottonwood	43	1.935

TABLE 2. INVENTORY SPECIES AND WEIGHT FOR POLETIMBER AND SAWTIMBER.

IV. RESULTS

Selected results of the analysis are displayed in the following tables. "Timberland Area" refers to those portions of the land area that have been associated with forest inventory volume strata and have woody biomass estimates. It does not include shrubland vegetation types.

A. VOLUME PER ACRE OF TIMBERLAND

Table 4 lists volume per acre by strata. As can be seen in the data the spruce and hemlock strata have similar volumes per acre. Appendices B and C provide detailed per acre volume figures by strata. Overall the average volume per acre weighted by accessible acres is 3,811 cubic feet per acre or 78 tons per acre or 16,166 board feet per acre. Utilizing an average conversion of 90 cubic feet of solid wood per cord, roughly 42 cords per acre are present.

Stratum	Description	Net CF/Acre	Net Cords/Ac.	Net Tons/Ac.	Net BF/Ac.
1	Sitka Spruce	4,958	55	90	21,700
2	Western Hemlock	4,672	52	102	18,321
3	Sitka Spruce-Black Cottonwood	656	7	12	1,137
4	Black Cottonwood	2,381	26	50	11,186
	Average Timberland	3,811	42	78	16,166

TABLE 3. TIMBERLAND NET VOLUME PER ACRE BY STRATA.

B. Sampling Error by Volume

Sample error was calculated for the gross cubic foot estimate by strata and size class (*Table 4*). The sample error percent is given within one standard deviation of the mean. This means that there is a 68% chance (one standard deviation) that the volume of the individual size class components are within plus or minus the error percentage indicated. Sample error is relatively high for the mixed spruce-cottonwood stratum 3. This is indicative of the variation of the sawtimber and poletimber component within the mostly sapling sized dominated stands. The other 3 strata which comprise the majority of the useable volume are below the target design sample error value of 10%. Overall sample error for all strata combined was 4.8%.

		Poletimber		Sawtimber		Combined	
Stratum	Number Of Plots	Gross CF/Ac	% Sampling Error	Gross CF/Ac	% Sampling Error	Gross CF/Ac	% Sampling Error
1	160	891	10.3	4,294	7.6	5,185	6.5
2	50	963	16.6	4,066	9.3	5,029	8.2
3	60	409	20.1	263	52.9	672	24.0
4	50	135	74.9	2,524	7.7	2,659	8.2
Summary	320	694	8.2	3,226	5.5	3,920	4.8

TABLE 4. GROSS CUBIC FOOT VOLUME SAMPLING ERROR.

C. Log Grade

Log grade estimates were made during field sampling. Although log grade has little meaning in terms of biomass utilization, it gives an idea of potential value added products that could be made available in the course of biomass harvest. Generally log grades of #1 or #2 are the higher value logs that could have additional value as an alternative to biomass and could possible meet export grades. Although a significant area of Eyak Corporation lands was previously harvested for export, markets are less available at this time. Local use of sawlog quality material however could still be a possibility.

Log grade was only tallied for the sawtimber sized trees ($\geq$ 9 inches dbh). A grade of one through five was given for each of the first two 32-foot log segments. Blank grades are where logs were deemed culls. Log grades use Puget Sound grading rules which contain specifications for various species including Sitka spruce, Western hemlock and Black cottonwood (*Table 5*). Table 6 lists log grade results. Log grade by species was not computed by volume but provides grade estimates in straight percentage terms of trees measured in the field. This gives a reference point for the overall grade distribution. Blank table entries indicate that a particular log was cull and did not have useable volume. Sitka spruce contained the most trees where the first 32 foot log was classified as a # 2 log grade (26% of measurements) which has a minimum top diameter of 12 inches. Most of the hemlock and cottonwood were in grades of #3 or higher indicating smaller trees with top diameters less than 12 inches or lower quality utility grade logs.

Logs will meet the minimum exterior characteristics. Diameter refers to top of log diameter.	
1. Sitka Spruce, Hemlock	
Grade No. 1	
Gross Diameter:	24 inches
Surface:	75% clear
Grade No. 2	
Gross Diameter:	12 inches
Surface:	Sound, tight knots not to exceed 2 ½ inches in diameter. Any larger knots must be well distributed.
Grade No. 3	
Gross Diameter:	6 inches
Surface:	Sound, tight knots not to exceed 3 inches in diameter. Any larger knots must be well distributed.
Minimum volume	50 board feet NET scale
Grade No. 4	
Gross Diameter:	5 inches
Minimum volume	10 board feet NET scale
2. Cottonwood	
Grade No. 1	
Gross Diameter:	10 inches
Surface:	Not to exceed 4 knots per log
Grade No. 2	
Gross Diameter:	6 inches
Grade No. 4	
Gross Diameter:	5 inches
Minimum volume	10 board feet NET scale
3. All Species	
Grade No. 5 Utility Logs	
Shall be logs that do not meet the minimum requirements for sawmill grades, but are suitable for the production of firm useable chips to an amount not less than 50% of GROSS scale.	
Gross Diameter:	4 inches
Minimum volume	10 board feet NET scale
Note: A log that is burned or charred or is not mechanically barkable, shall not qualify as a Utility log.	

TABLE 5. PUGET SOUND GRADING RULES.

	Grade 1st Log	Grade 2nd Log	# Of Trees Measured	% Of Trees
Cottonwood				
			11	16%
	1	2	3	4%
	1	4	2	3%
	1	5	3	4%
	2		10	14%
	2	1	1	1%
	2	4	8	11%
	2	5	7	10%
	4		8	11%
	5		13	19%
	5	5	4	6%
Total for Cottonwood			70	
Hemlock				
			5	6%
		5	1	1%
	2	2	1	1%
	2	3	6	7%
	3		10	11%
	3	3	1	1%
	3	4	10	11%
	3	5	2	2%
	4		16	18%
	4	4	2	2%
	4	5	6	7%
	5		22	25%
	5	4	1	1%
	5	5	6	7%
Total for Hemlock			89	

TABLE 6. LOG GRADE BY SPECIES.

Sitka Spruce			
		16	5%
1	2	7	2%
2	2	26	9%
2	3	43	15%
2	4	5	2%
3		30	10%
3	2	1	0%
3	3	22	8%
3	4	14	5%
3	5	14	5%
4		56	19%
4	4	3	1%
4	5	2	1%
5		45	15%
5	3	3	1%
5	4	3	1%
5	5	3	1%
Total for Sitka Spruce		293	
Grand Total Trees Measured		452	

TABLE 6. CONTINUED, LOG GRADE BY SPECIES

D. Site Index

Tree height has been found as the most reliable indicator of site productivity. In essence, the taller the tree the more productive is the growing site. When height is combined with tree age, the measurements can be reported as a site index number. This number gives the height in feet of a particular stand at a reference base age. Site index of spruce and hemlock uses a base age of 100 years whereas site index of cottonwood uses a base age of 50 years. Site index reflects the combined effect of all environmental factors and is therefore a good index of stand productivity. Site index calculations for spruce and hemlock are based on site index equations produced for Alaska: U.S. Forest Service research paper PNW-53. Site index calculations for cottonwood are based on site index equations U.S. Forest Service research paper NOR-2.

	Site Index (Feet)
Stratum 1 Sitka Spruce	
Sitka Spruce	103
Western Hemlock	76
Stratum 2 Western Hemlock	
Sitka Spruce	78
Western Hemlock	61
Stratum 3 Sitka Spruce – Black Cottonwood	
Sitka Spruce	---
Black Cottonwood	---
Stratum 4 Black Cottonwood	
Sitka Spruce	---
Black Cottonwood	76
Species Average	
Sitka Spruce	98
Western Hemlock	68
Black Cottonwood	76

TABLE 7. SITE INDEX BY STRATUM AND SPECIES.

E. Timberland Area Age Class

Timberland productivity can also be examined in terms of overall age class distribution. Typically as trees become older productivity declines. Cottonwood generally begins to decline after year 80 or 90 when rot becomes more frequent. Spruce and Hemlock can be much longer lived, but generally starts to decline after year 225 or so. At this age the conifers become more susceptible to rot and insect damage. Table 8 shows the average stand age by strata. Stratum 1 average age is relatively young and reflects the numerous spruce stands that are growing on recently deposit alluvial outwash. Stratum 2 ages are more typical of the hemlock and spruce mixed stands that occur on various topographic features in the area. Stratum 3 is the youngest and is comprised of a significant amount of sapling size trees. Stratum 4 is comprised of stands that are growing near the riparian areas where flooding is frequent. These stands for the most part are being replaced by flooding before they reach old age.

Stratum		Average Age
1	Sitka Spruce	107
2	Western Hemlock	168
3	Sitka Spruce-Black Cottonwood	32
4	Black Cottonwood	62

TABLE 8. AVERAGE AGE BY STRATA.

F. REGENERATION

Another measure of productivity is whether individual timber stands are being replaced by regeneration. Coastal Alaska tree species comprise a combination of even and uneven-aged stand types and are replaced through natural regeneration following wind, flooding or insect outbreaks. Past timber harvest has occurred in the Cordova area and also influences stand development. In the absence of disturbance, stands are slowly replaced by understory regeneration. In many cases such as the dense spruce and hemlock stands, regeneration is poor because of thick moss cover and cold soils. There may be a high tree count of small hemlock seedlings, but regeneration of quality crop trees is poor. These stands are slow to regenerate unless a stand replacing disturbance such as an extreme wind event occurs. In other cases stands are actively being replaced even in the absence of disturbance. These stands typically are the mixed spruce-cottonwood stands that contain a shallow moss layer conducive to seed germination. Table 9 gives numbers of trees per acre less than 5 inches by species and stratum. Trees are of desirable and acceptable quality as determined in field. Undesirable trees not expected to become future crop trees are not included in the table. Stratum 3 contains the greatest number of seedlings and saplings which is typical of a newly developing forest.

Stratum 1 Sitka Spruce	Trees/Acre
Black Cottonwood	16
Sitka Spruce	244
Western Hemlock	53
Total Trees Per Acre	313
Stratum 2 Western Hemlock	
Sitka Spruce	270
Western Hemlock	230
Total Trees Per Acre	500
Stratum 3 Sitka Spruce – Black Cottonwood	
Black Cottonwood	108
Sitka Spruce	850
Western Hemlock	42
Total Trees Per Acre	1,000
Stratum 4 Black Cottonwood	
Sitka Spruce	460
Total Trees Per Acre	460

TABLE 9. NUMBER OF TREES PER ACRE LESS THAN 5 INCHES DBH.

G. Growth and Mortality Estimates

Growth estimates have been determined through projections made with the timber cruise software TCruise. Periodic annual gross growth has been projected utilizing the past 10-year diameter growth increment and bark thickness measurements collected in the field. These measurements sampled trees 5-inch dbh and greater across all diameter classes. By collecting both the growth increment and bark thickness measurement, the software is able to discount changes in bark thickness that would affect the accurate determination of diameter growth. Growth was computed by a regression approach for both diameter and height. The desired growth projection interval used was 10 years (i.e. 2012-2022). The increased volume growth was then divided by 10 to calculate an annual growth rate. This volume figure was then divided by the growing stock base (live tree volume) to calculate a percentage growth rate. The trees were grown out initially by ten years instead of just one year to smooth growth rates because some of the 10-year diameter growth increments were too small to be accurately projected for just one year. Diameter-height relationships, diameter growth and calculated bark thickness ratios (Husch et al. 2002. *Forest Mensuration, Fourth Edition.*) are shown in Appendix D. In the field sampling protocol dead standing trees estimated to have died within 5 years were sampled to include potentially useable volume and to develop mortality estimates. Field work tree measurement results however, did not sample any recently dead trees and thus percent mortality estimates are zero for the inventory. Some standing dead trees were observed but were all significantly older than 5 years. The average net annual growth for the project area is 155 cubic feet per acre which is equivalent to 1.7 cords per acre or 3 tons per acre (*Table 10*).

	Strata	% Annual Net Growth	CF Per Acre Per Year Growth	Cords Per Acre Per Year Growth	Tons Per Acre Per Year Growth
1	Sitka Spruce	3.42%	170	1.9	3.1
2	Western Hemlock	2.12%	99	1.1	2.2
3	Sitka Spruce-Black Cottonwood	6.75%	44	0.5	0.8
4	Black Cottonwood	4.18%	100	1.1	2.1
	Timberland Average	**3.44%**	**155**	**1.7**	**3**

TABLE 10. GROWTH AND MORTALITY ESTIMATES.

H. Volume of Timberland by Landowner

In Tables 11 and 12 strata volume figures have been multiplied by acreage to calculate total volume on the entire project as well as accessible area lands.

	Stratum	Acres	Cords	Tons	Board Feet
1	Sitka Spruce	85,324	4,700,847	7,680,168	1,851,527,422
2	Western Hemlock	38,665	2,007,059	3,935,624	708,366,728
3	Sitka Spruce-Black	2,239	16,317	27,388	2,546,818
4	Black Cottonwood	16,649	440,406	828,240	186,231,668
	Total Timberland	**142,878**	**7,164,68**	**12,471,52**	**2,748,690,957**

TABLE 11. PROJECT AREA TIMBERLAND NET VOLUME BY STRATA.

	Stratum	Acres	Cords	Tons	Board Feet
1	Sitka Spruce	9,558	526,589	860,333	207,408,222
2	Western Hemlock	13,271	688,901	1,350,860	243,139,221
3	Sitka Spruce-Black Cottonwood	879	6,406	10,752	999,845
4	Black Cottonwood	13,712	362,716	682,132	153,379,100
	Total Timberland	**37,420**	**1,584,612**	**2,904,078**	**604,926,387**

TABLE 12. ACCESSIBLE AREA TIMBERLAND NET VOLUME BY STRATA .

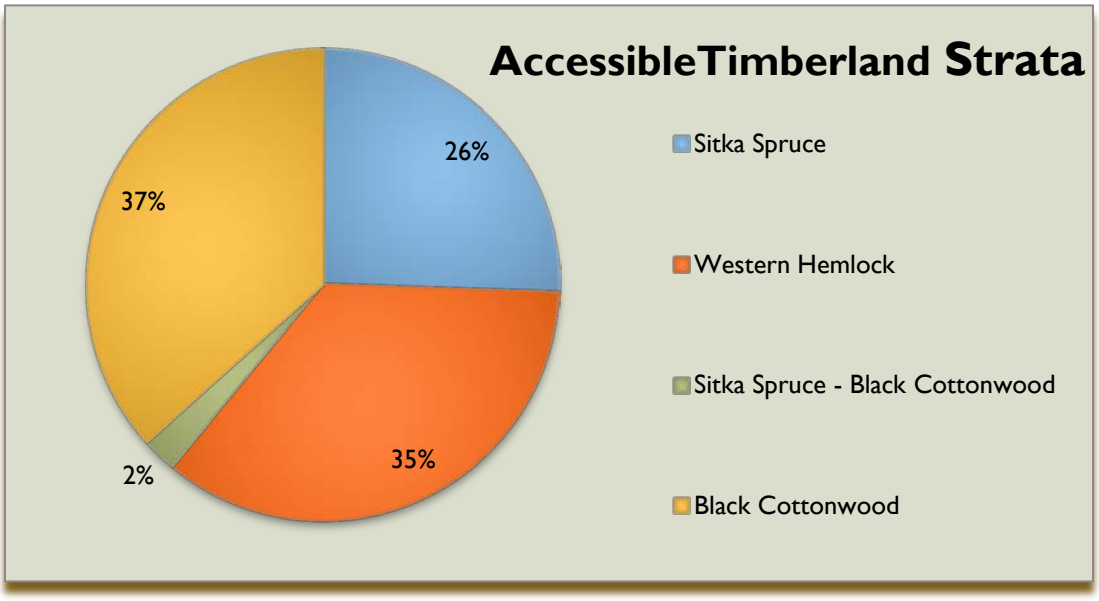

FIGURE 7. ACCESSIBLE TIMBERLAND STRATA DISTRIBUTION BY AREA.

V. ECONOMIC AVAILABILITY OF SUSTAINABLE BIOMASS FUELS

The economics of available biomass were examined with a delivery point to Cordova. The context of the accessible area was analyzed to develop delivered biomass costs and volume estimates by landowner. For any proposed biomass project the scope and extent of the raw resource must be known prior to project development. The success of biomass projects over the long term requires an accurate estimate of economic and sustainable biomass resources. With volume estimates and locations of biomass resources known, harvest scheduling and infrastructure development can be better planned. Although some of the resource for biomass utilization may originate from the brushing and utilization of alder along the Eyak Corporation's logging road system, additional sources will most likely consist of harvested firewood and commercial grade timber. When biomass is used in this form it is referred to as "fuelwood". This is the most expensive of biomass sources (Ashton et al. 2008. *Woody Biomass Desk Guide and Toolkit*). This supply scenario is quite different than the Lower 48 where biomass projects generally rely on a combination of urban wood waste, mill waste, logging residues and increasingly biomass from intensively managed fast growing woody crops.

A. CURRENT DELIVERED COSTS

Delivered firewood costs are generally correlated to distance traveled from the harvest site. The range of costs however can cover a relatively wide spectrum of distances and prices may be constant until the haul distance significantly lengthens. This is because there are many other variables that contribute to the cost of the delivered product including stumpage price, logging costs, transportation and equipment depreciation. In the Cordova area since the accessible area is mostly adjacent to the limited road system the haul distance is a small factor in the overall cost. A far greater affect is terrain which can greatly influence logging costs. The topography ranges from near level in the Copper River Delta to well over 70% slopes on steeper lower and mid slope hillsides. Harvesting timber on level terrain can consist of a simple operation of ground based logging equipment that employs a small dozer, flatbeds, pickup trucks and chainsaw hand felling. On steeper slopes larger and more expensive equipment is needed including tower yarders, dump trucks, front end loaders, and larger dozers.

In the Cordova area individual firewood vendors are not present to establish a base price for delivered wood. Instead delivered costs to other Alaskan communities were examined to arrive at a base price. A biomass analysis study recently prepared by DOF for the Alaska Energy Authority on the Kenai Peninsula researched delivered firewood rates. Firewood generally originates from state beetle killed forest lands. These harvest sites are mostly level and relatively easy to access. In the Kenai area firewood sales originating off of beetle killed

state forest lands sells for about $150.00 per cord. Seward however is more remote and tends to be more expensive than the other Peninsula communities. Here firewood sells for about $225.00 per cord. It is estimated based on harvest costs on past DOF sales that delivered prices are 25% higher on more complex sales such as those on steeper terrain. Coastal sales on state lands on southern southeast Alaska may increase by 50% due to extensive heavy equipment use and mobilization costs associated with mountainous logging terrain. Below in Table 13 delivered prices are displayed by an associated representative slope class.

Delivery Location	Delivered Price/Cord	Configuration	Slope Class
Cordova	$225	Flat Bed	0-15%
Cordova	$285	Log Truck	16-25%
Cordova	$340	Log Truck	>25%

TABLE 13. DELIVERED CORD PRICES BY SLOPE CLASS.

Utilizing the data from Table 13 equations have been established to predict delivered costs for a range of topographic steepness in slope percent from the harvest locations to Cordova. The calculated regression equations for cords and tons respectively are shown below.

Delivered Price Per Cord = 3.4508 * Percent Slope + 205.12

Delivered Price Per Ton = 2.2509 * Percent Slope + 133.98

B. Potential Accessible Biomass Volume by Slope Class

The accessible biomass area has been categorized by slope to provide a more realistic calculation of the economic availability of biomass. The total accessible timberland acreage by ownership class and strata is shown in Table 14 and by ownership and slope class in Table 15. Figure 3 illustrates three slope classes with the accessible biomass area identified surrounding Cordova.

Stratum	Chugach AK Corp	Eyak Corp	National Forest	Private	State	Totals
1		1,814	6,480	45	1,219	9,558
2		2,918	8,124	2	2,227	13,271
3		491	386	0	2	879
4	412	6,868	6,162	2	268	13,712
Totals	**412**	**12,091**	**21,152**	**49**	**3,716**	**37,420**

TABLE 14. ACCESSIBLE ACREAGE BY OWNERSHIP CLASS AND STRATA.

Slope	Owner	Acres	Gross CF	Net CF	Gross Cords	Net Cords	Gross Tons	Net Tons	Gross BF	Net BF
0-15%										
	Chugach Alaska Corp.	412	1,096,371	981,564	12,182	10,906	22,965	20,511	5,177,748	4,611,859
	Eyak Corp.	10,286	34,031,010	31,217,926	378,122	346,866	701,581	641,277	150,181,694	137,046,447
	National Forest	8,169	26,560,435	24,445,502	295,116	271,617	532,249	487,553	119,551,646	109,628,655
	Private	47	237,327	226,640	2,637	2,518	4,339	4,127	1,036,628	993,361
	State	1,287	5,966,789	5,644,316	66,298	62,715	113,089	106,476	25,991,887	24,619,908
	Total	20,201	67,891,932	62,515,948	754,355	694,622	1,374,223	1,259,944	301,939,603	276,900,230
16-25%										
	Eyak	430	2,118,307	1,971,873	23,537	21,910	45,508	42,254	8,463,997	7,839,193
	National Forest	5,548	27,988,898	26,201,745	310,988	291,131	583,673	544,533	113,675,706	106,131,328
	Private	1	5,520	5,128	61	57	121	112	21,781	20,108
	State	927	4,670,432	4,347,856	51,894	48,310	100,738	93,552	18,569,318	17,197,662
	Total	6,906	34,783,157	32,526,602	386,480	361,407	730,040	680,451	140,730,802	131,188,291
>25%										
	Eyak Corp.	1,376	6,525,576	6,111,198	72,506	67,902	133,417	124,463	27,097,870	25,325,034
	National Forest	7,435	36,552,040	34,361,260	406,134	381,792	736,370	689,399	152,315,213	143,060,249
	Private	1	4,695	4,361	52	48	102	95	18,526	17,103
	State	1,503	7,598,961	7,097,379	84,433	78,860	160,837	149,764	30,564,923	28,442,150
	Total	10,315	50,681,272	47,574,198	563,125	528,602	1,030,726	963,721	209,996,532	196,844,536
Grand Total		37,420	153,356,361	142,616,749	1,703,960	1,584,631	3,134,988	2,904,116	652,666,937	604,933,059

TABLE 15. CORDOVA AREA ACCESSIBLE ACREAGE AND VOLUME BY SLOPE CLASS.

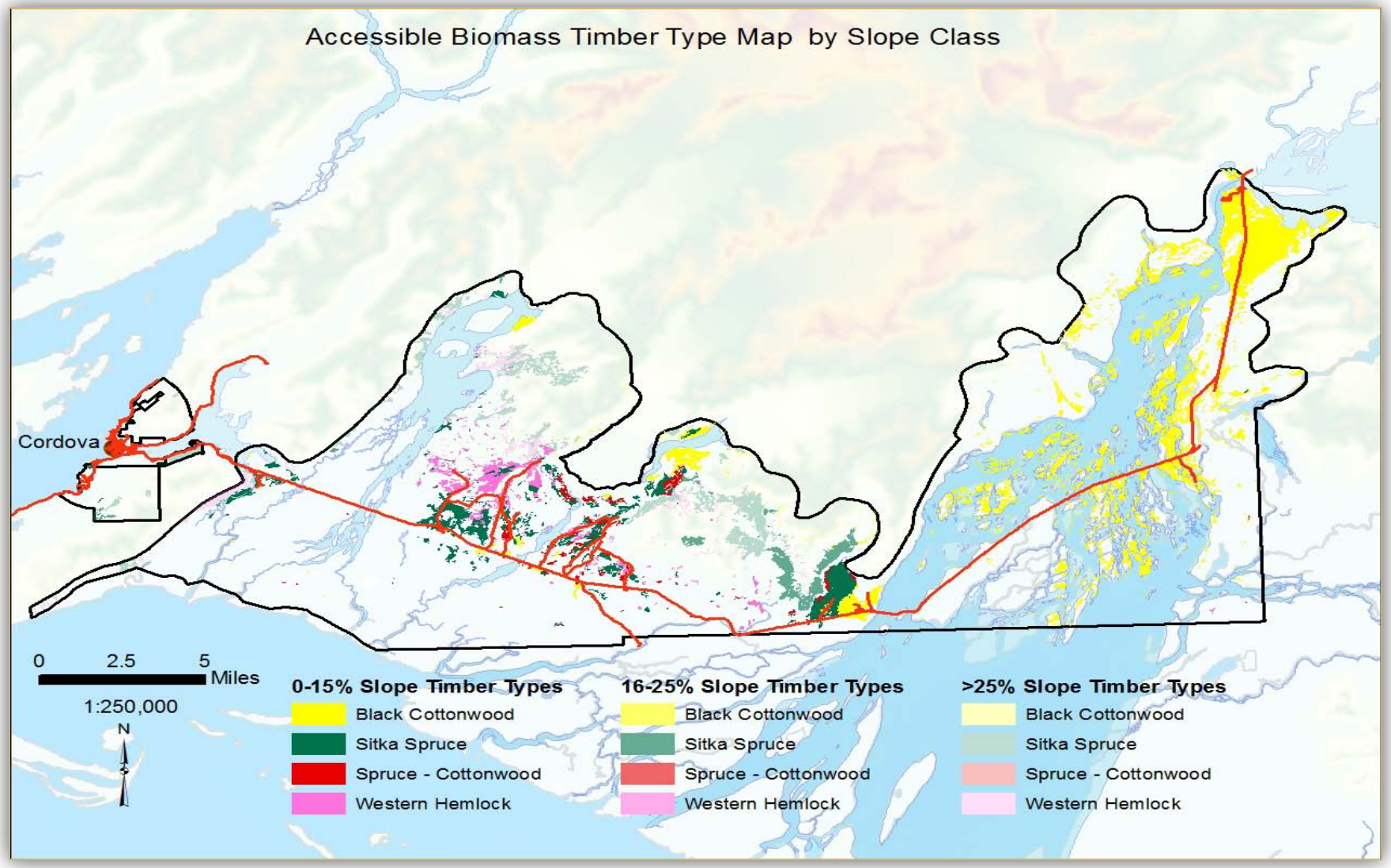

FIGURE 8. ACCESSIBLE BIOMASS TIMBER TYPE MAP BY SLOPE CLASS.

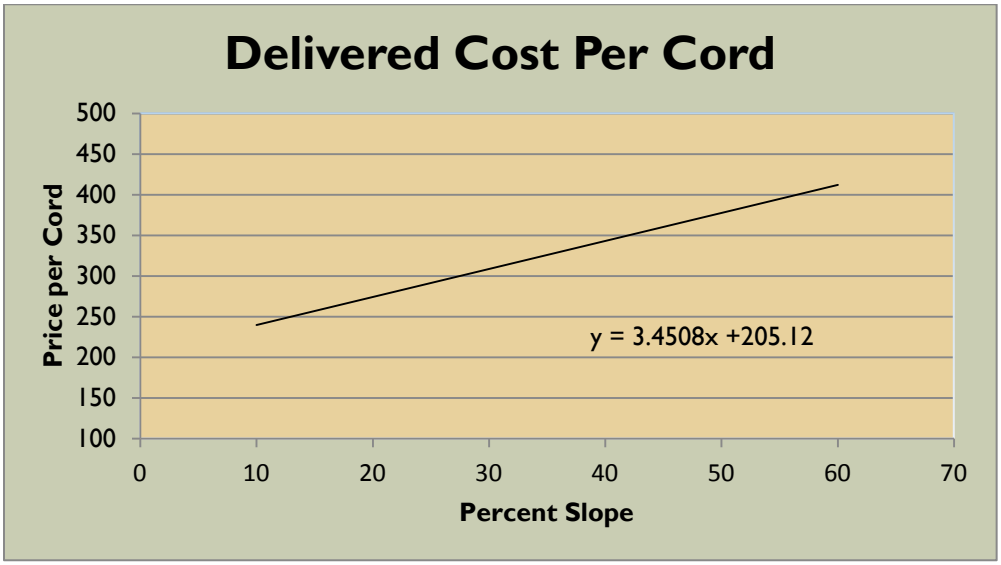

FIGURE 9. DELIVERED COST PER CORD.

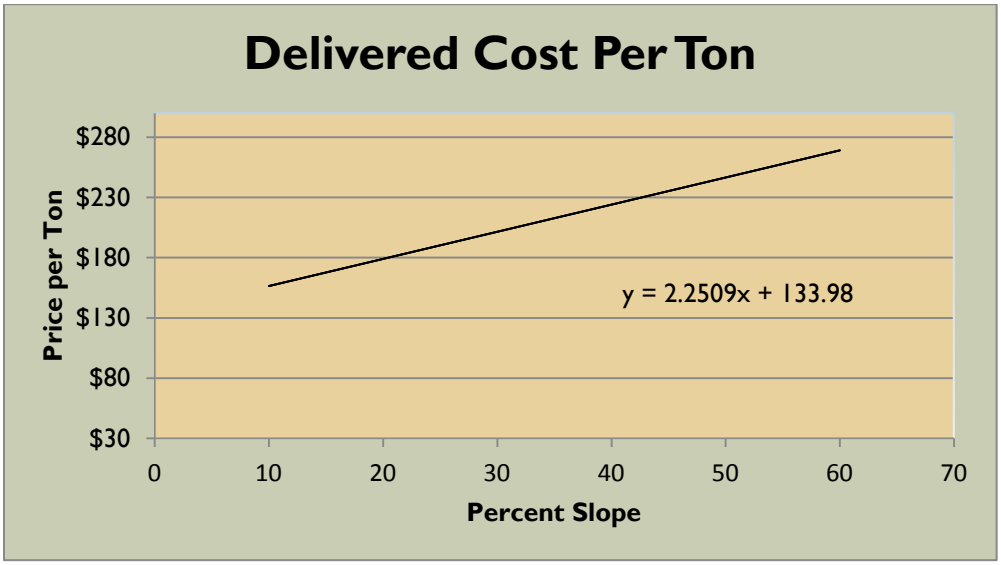

FIGURE 10. DELIVERED COST PER TON.

C. Annual Sustainable Biomass Yield by Slope Class

Volume availability on an annual basis was determined by multiplying the inventory net growth rate percentages with the accessible area volume. By using the growth rates applied to the available volume the harvest is considered sustainable because only the amount of overall tree

growth is harvested each year. The data was then merged into the five land ownership classes (*Table16*).

The delivered cost information was then applied to the annually available operable volume to develop supply curves in cords and tons (*Figures 12 and 13*) for the Cordova area. The delivered cost per cord is converted from the total available cubic feet at a ratio of 90 cubic feet per cord.

Across all slope classes and land owners there would potentially be available on an annual basis a sustainable net volume of approximately 48,209 cords, 87,302 tons or about 19 million board feet. This volume could be available at a cost of up to $340.00 per cord or $222.00 per ton. Maintaining a simpler harvest operation where only slopes between 0 and 15% were accessed, a sustainable net volume of approximately 24,946 cords, 45,154 tons or about 10 million board feet would potentially be available. This volume could be available at about $225.00 per cord or $147.00 per ton.

Slope	Owner	Gross CF	Net CF	Gross Cords	Net Cords	Gross Tons	Net Tons	Gross BF	Net BF
0-15%									
	Chugach Alaska Corp.	45,828	41,029	509	456	960	857	216,430	192,776
	Eyak Corp.	1,190,660	1,088,521	13,230	12,095	24,426	22,246	5,323,049	4,839,714
	National Forest	1,000,083	917,876	11,112	10,199	20,079	18,342	4,518,603	4,129,786
	Private	8,156	7,787	91	87	149	142	35,640	34,140
	State	200,814	189,837	2,231	2,109	3,792	3,567	880,196	833,118
	Total	2,445,541	2,245,050	27,173	24,946	49,406	45,154	10,973,918	10,029,534
16-25%									
	Eyak	48,314	45,014	537	500	1,029	956	194,321	180,219
	National Forest	694,535	652,044	7,717	7,245	14,226	13,305	2,851,945	2,673,293
	Private	117	109	1	1	3	2	462	426
	State	103,419	96,388	1,149	1,071	2,216	2,060	412,879	383,030
	Total	846,385	793,555	9,404	8,817	17,474	16,323	3,459,607	3,236,968
>25%									
	Eyak Corp.	179,493	168,311	1,994	1,870	3,605	3,367	756,825	708,696
	National Forest	1,023,039	963,861	11,367	10,710	20,217	18,965	4,322,190	4,072,023
	Private	100	92	1	1	2	2	393	363
	State	179,317	167,888	1,992	1,865	3,742	3,491	727,411	679,223
	Total	1,381,949	1,300,152	15,354	14,446	27,566	25,825	5,806,819	5,460,305
Grand Total		4,673,875	4,338,757	51,931	48,209	94,446	87,302	20,240,344	18,726,807

TABLE 16. ANNUAL VOLUME AVAILABILITY BY SLOPE CLASS AND OWNER.

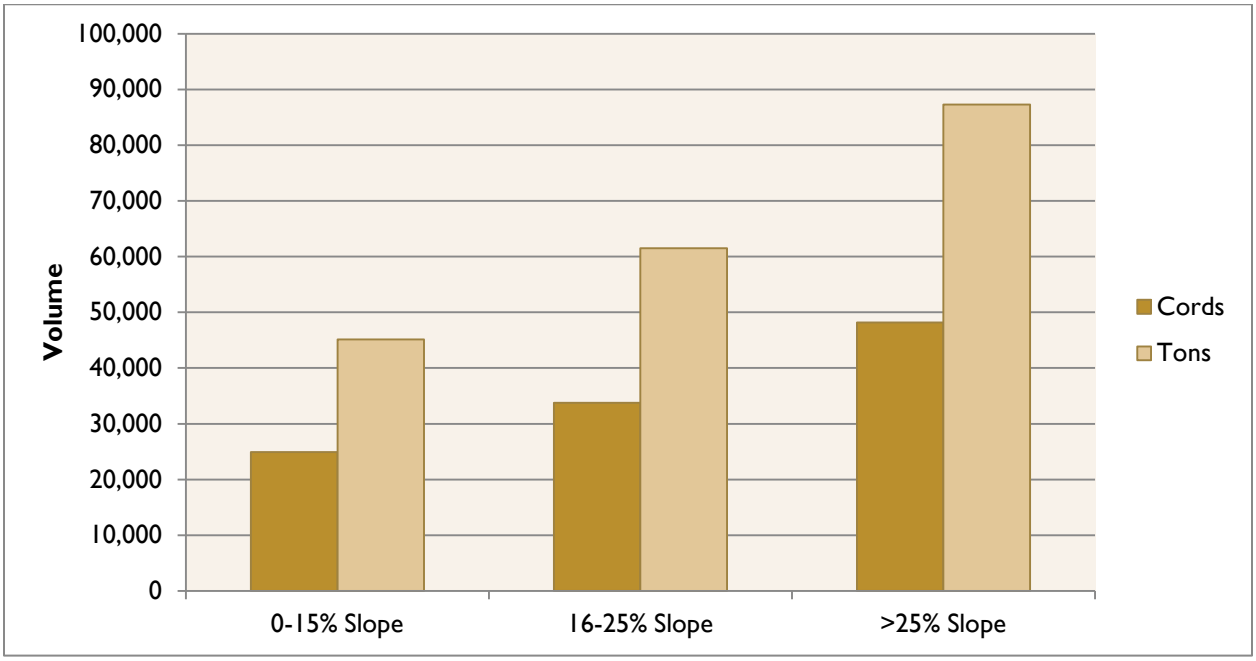

FIGURE 11. CUMULATIVE ANNUAL VOLUME AVAILABILITY BY SLOPE CLASS TO CORDOVA.

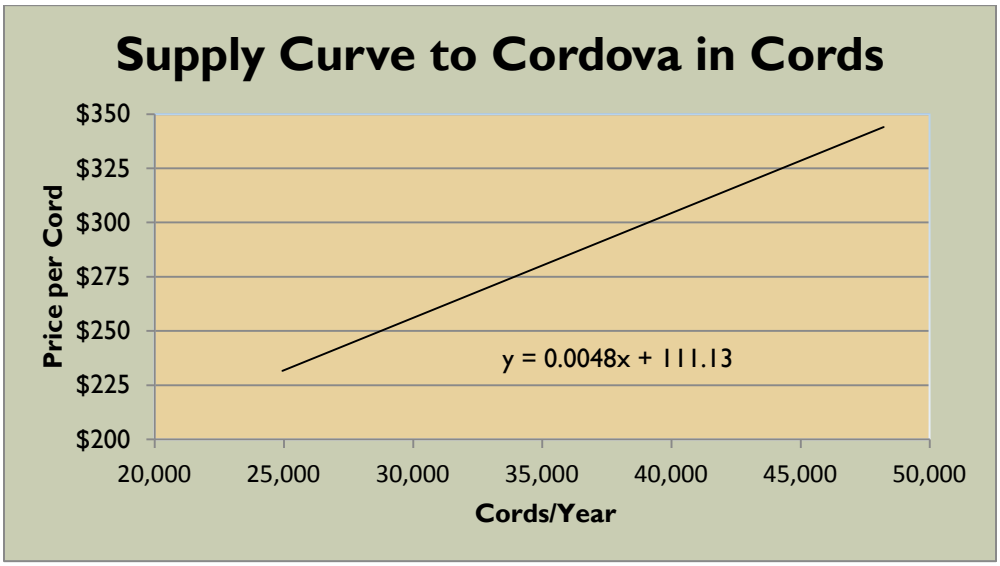

FIGURE 12. SUPPLY CURVE FOR CORDS TO CORDOVA.

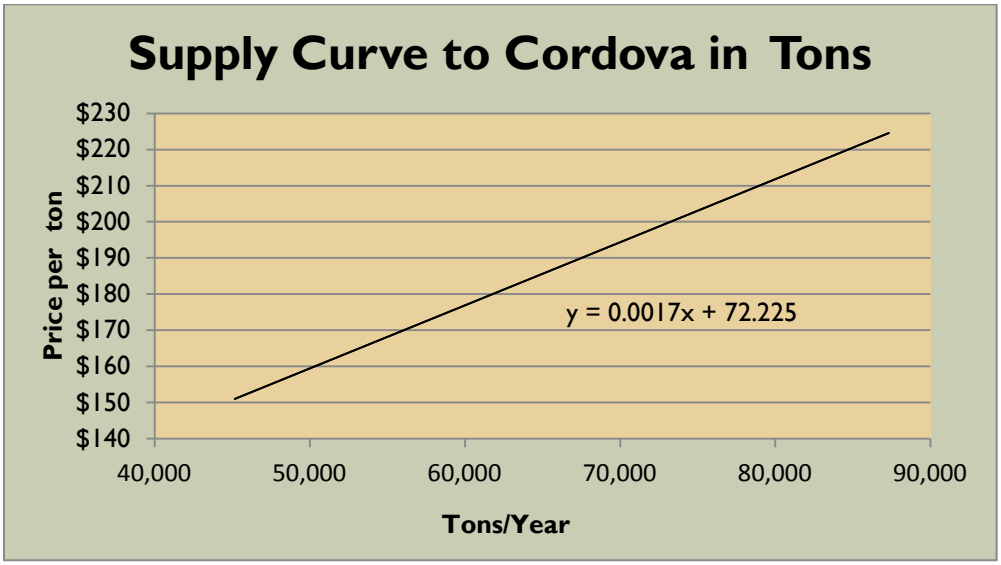

FIGURE 13. SUPPLY CURVE FOR TONS TO CORDOVA.

VI. VOLUME AVAILABILITY FROM PROPOSED EYAK LOGGING ROAD BRUSH CLEARING

Another consideration of potential biomass supply was alder. This may be available as part of brush clearing on grown over Eyak Corporation logging roads. These roads were constructed during export logging operations in the early to mid 1990's and now have significantly grown over with mostly alder. Although sampling was not performed during the timber inventory, field observations of the roads combined with some estimated alder stocking rates were used to calculate a rough idea of available volume. An estimate of land covered by the roads was made by examining the satellite imagery for presence of alder on the road bed. An approximate average width was determined and multiplied by the overall length to calculate acres. The calculations resulted in roughly 386 acres. Small aspen tree weights compiled in a DOF biomass study in Tok resulted in about 3 pounds per tree with an estimated stocking rate of 5,000 stems per acre. If these values are applied to the logging road alder component, a weight of 15,000 pounds per acre or 7.5 tons per acre is present. This value multiplied by the overall acreage equals 2,895 green tons. This amount is quite rough but could be corroborated by installing small fixed plots in various areas of the road system to calculate a stocking rate and then weighing the individual stems. From observations made during the field work, levels of alder stocking appear to be relatively consistent along the roads.

VII. CONCENTRATION OF BIOMASS ON A PORTION OF EYAK CORPORATION LANDS

The following figure identifies a selected land area of Eyak Corporation ownership and the timber volume and sustained yield present. This area was selected from the GIS coverage as the most accessible land under Eyak Corporation ownership. This particular unit of land was examined because it has the most existing logging road infrastructure, is mostly less than 15% slope and is west of the washed out bridge at milepost 36 of the Copper River Highway. The bridge which is used to access other Eyak lands is not scheduled to be replaced until 2015. At a cost of $31 million funding will have to be secured from the state.

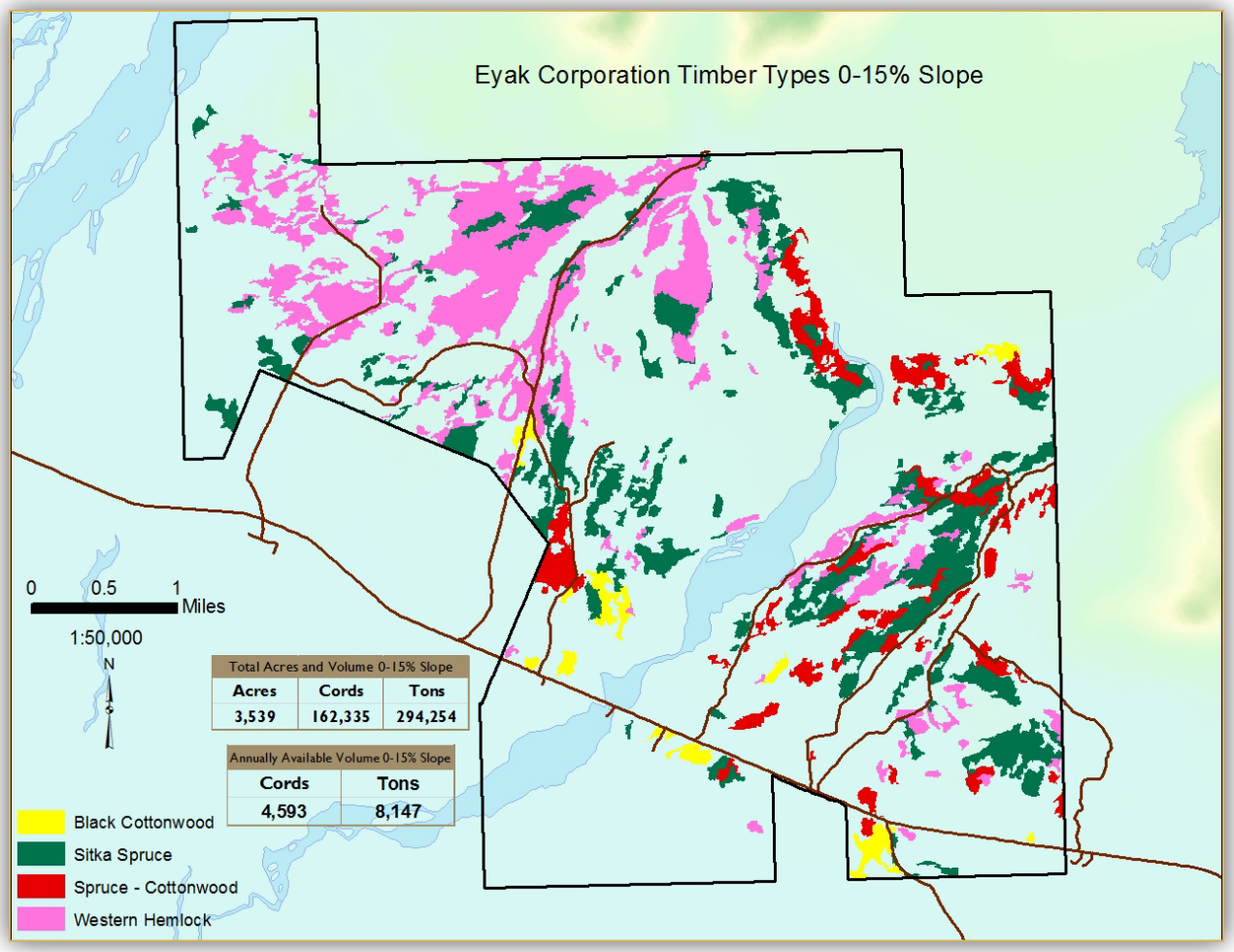

FIGURE 14. EYAK CORPORATION TIMBER TYPES 0-15% SLOPE.

In this particular selection of Eyak Corporation land on 0-15% slopes almost 4,600 cords could be available on an annual sustainable basis. In terms of tons about 8,150 tons could be available on an annual sustainable basis. Other scenarios of volume availability can be performed utilizing the GIS data set.

I. LITERATURE CITED

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Husch, B., T.W. Beers, J.A. Kershaw. 2002. *Forest Mensuration, Fourth Edition*. John Wiley and Sons.

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Appendix A
Acreage Summary by Stratum and Vegetation Type

Vegetation Type			Acres	Field Sampled?
Stratum	*1*	Sitka Spruce		
	Sitka Spruce		9,558	Yes
Summary for 'stratum' = 1 (1 detail record)				
Sum			*9,558*	
Stratum	*2*	Western Hemlock		
	Western Hemlock		3,605	Yes
	Spruce - Hemlock		9,667	No
Summary for 'stratum' = 2 (2 detail records)				
Sum			*13,271*	
Stratum	*3*	Sitka Spruce-Black Cottonwood		
	Spruce - Cottonwood		879	Yes
Summary for 'stratum' = 3 (1 detail record)				
Sum			*879*	
Stratum	*4*	Black Cottonwood		
	Black Cottonwood		13,712	Yes
Summary for 'stratum' = 4 (1 detail record)				
Sum			*13,712*	
Stratum	*10*	Harvested		
	Harvested		4,832	No
Summary for 'stratum' = 10 (1 detail record)				
Sum			*4,832*	
Stratum	*20*	Tall Shrub		
	Sitka Alder - Willow		18,688	No
	Willow		10,006	No
	Sweetgale		4,189	No
	Sitka Alder		33,005	No
Summary for 'stratum' = 20 (4 detail records)				
Sum			*65,887*	
Stratum	*30*	Wet Meadow		
	Aquatic Herbaceous		4,855	No
	Mesic Wet Herbaceous		33,744	No
	Wet Mesic		31	No
Summary for 'stratum' = 30 (3 detail records)				
Sum			*38,631*	
Stratum	*40*	Dry Meadow		
	Dry Graminoid		13,815	No
Summary for 'stratum' = 40 (1 detail record)				
Sum			*13,815*	

Vegetation Type		Acres	Field Sampled?
Stratum *50*	Bare Ground		
Sparse/Unvegetated		23,209	No
Summary for 'stratum' = 50 (1 detail record)			
Sum		*23,209*	
Stratum *60*	Non-Forest Other		
Background		28	No
Summary for 'stratum' = 60 (1 detail record)			
Sum		*28*	
Stratum *70*	Water		
Clear Water		25,872	No
Summary for 'stratum' = 70 (1 detail record)			
Sum		*25,872*	
Grand Total Accessible Area		*209,693*	

Appendix B
Per Acre Summary by Stratum and Species

Trees		Basal Area	Gross CF	Net CF	Gross Cords	Net Cords	Gross Tons	Net Tons	Gross BF	Net BF
Stratum 1										
Cottonwood	17	8	191	175	2	2	4	4	702	636
Hemlock	68	30	685	616	8	7	17	15	2,229	1,982
Sitka Spruce	210	146	4,309	4,167	48	46	73	71	19,675	19,081
Sum	294	183	5,185	4,958	58	55	94	90	22,606	21,700
Stratum 2										
Cottonwood	6	3	66	49	1	1	1	1	266	199
Hemlock	209	126	3,000	2,768	33	31	75	69	12,118	11,033
Sitka Spruce	151	82	1,963	1,854	22	21	33	32	7,461	7,089
Sum	366	211	5,029	4,672	56	52	110	102	19,845	18,321
Stratum 3										
Cottonwood	34	13	252	240	3	3	5	5	774	747
Sitka Spruce	90	24	419	415	5	5	7	7	394	390
Sum	124	37	672	656	7	7	13	12	1,168	1,137
Stratum 4										
Cottonwood	75	88	2,332	2,061	26	23	50	44	11,294	9,959
Sitka Spruce	26	15	327	320	4	4	6	5	1,265	1,227
Sum	101	103	2,659	2,381	30	26	56	50	12,558	11,186

Appendix C
Stand Tables Per Acre by Strata and Species

DBH	# of Trees	BA	Gross CF	Net CF	Gross Tons	Net Ton	Gross BF	Net BF
Stratum	**1**							
Cottonwood								
5	3	1	9	9	0	0		
6	5	1	12	10	0	0		
7	4	1	19	19	0	0		
9	1	1	10	8	0	0		
10	1	1	20	19	0	0	86	82
13	1	2	40	38	1	1	187	180
15	1	1	33	31	1	1	164	153
17	0	1	15	15	0	0	74	74
21	0	1	16	14	0	0	83	75
25	0	0	8	5	0	0	48	31
30	0	0	10	7	0	0	60	42
Totals	17	8	191	175	4	4	702	636
Hemlock								
5	13	2	53	52	1	1		
6	8	2	42	41	1	1		
7	9	2	50	45	1	1		
8	4	2	37	31	1	1		
9	7	3	63	60	2	1	90	87
10	3	2	37	30	1	1	160	133
11	5	3	70	60	2	1	313	268
12	4	2	33	24	1	1	157	115
13	4	2	40	39	1	1	193	192
14	2	2	41	41	1	1	195	194
15	1	1	31	27	1	1	155	137
16	0	0	9	6	0	0	37	25
17	4	2	53	46	1	1	261	225
18	1	1	35	28	1	1	172	140
19	1	1	40	37	1	1	215	200
20	0	1	15	15	0	0	76	75
23	0	1	14	11	0	0	68	55
25	0	1	24	23	1	1	138	136
Totals	68	30	685	616	17	15	2,229	1,982
Sitka Spruce								
5	19	3	59	58	1	1		
6	30	6	106	105	2	2		
7	19	5	106	90	2	2		
8	35	13	306	298	5	5		
9	15	7	169	165	3	3	569	564
10	21	12	274	266	5	5	1,181	1,145
11	19	13	343	328	6	6	1,567	1,499
12	13	11	281	278	5	5	1,373	1,357
13	3	4	113	113	2	2	576	576

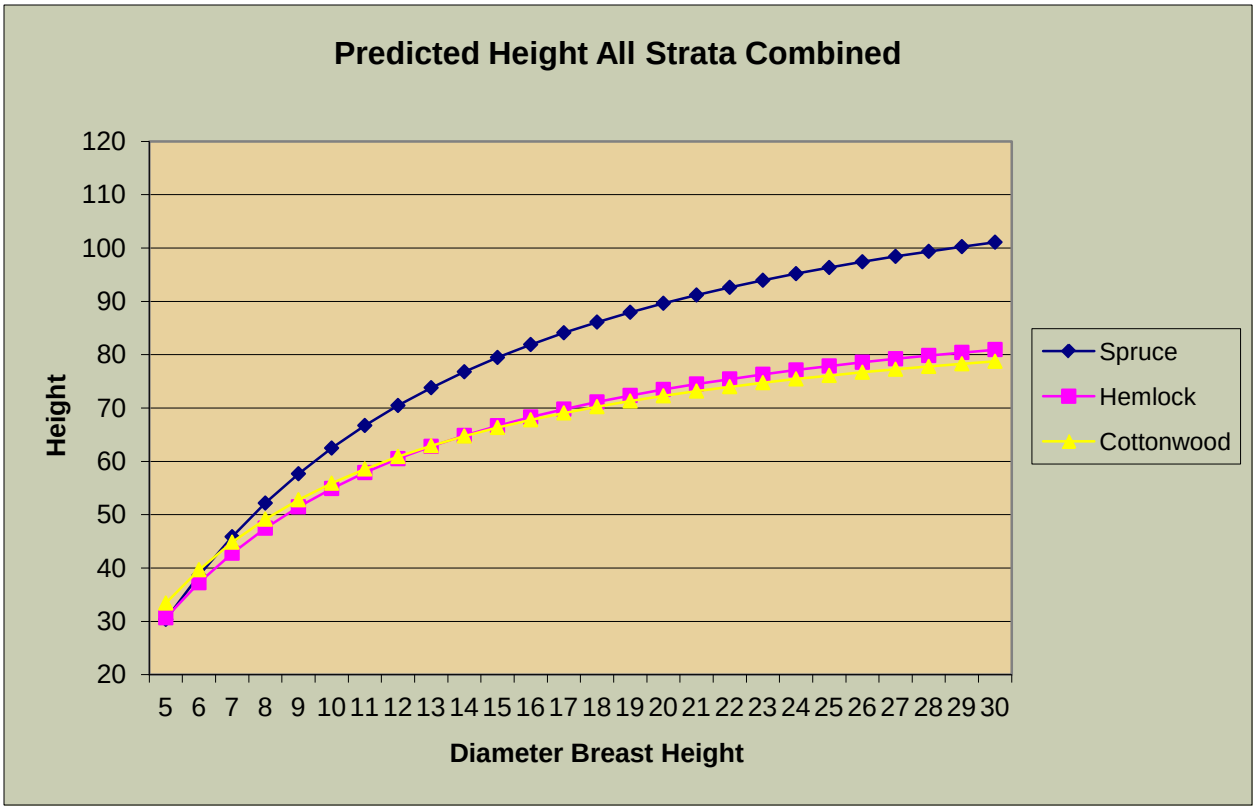
DBH	# of Trees	BA	Gross CF	Net CF	Gross Tons	Net Ton	Gross BF	Net BF
14	6	8	233	224	4	4	1,169	1,124
15	5	7	214	212	4	4	1,075	1,065
16	2	4	120	114	2	2	625	594
17	4	6	216	207	4	4	1,145	1,098
18	3	5	178	178	3	3	967	966
19	3	7	256	248	4	4	1,413	1,370
20	2	4	162	150	3	3	912	851
21	1	3	119	112	2	2	659	626
22	1	2	100	96	2	2	582	557
23	1	3	129	129	2	2	758	758
24	1	3	107	101	2	2	639	606
25	1	4	161	154	3	3	964	921
26	1	2	83	83	1	1	520	520
27	1	4	135	130	2	2	819	791
28	0	1	21	21	0	0	121	121
29	0	1	44	44	1	1	276	275
31	0	1	51	48	1	1	323	307
32	0	1	32	32	1	1	203	202
33	0	2	84	82	1	1	547	535
34	0	1	39	35	1	1	237	218
35	0	1	30	30	1	1	195	194
37	0	1	16	16	0	0	108	108
38	0	1	11	8	0	0	67	50
39	0	1	13	13	0	0	86	81
Totals	210	146	4,309	4,167	73	71	19,675	19,081
Totals for stratum 1	294	183	5,185	4,958	94	90	22,606	21,700
Stratum	**2**							
Cottonwood								
10	6	3	66	49	1	1	266	199
Totals	6	3	66	49	1	1	266	199
Hemlock								
6	49	10	211	208	5	5		
7	20	5	114	112	3	3		
8	22	8	168	158	4	4		
9	18	8	168	153	4	4	639	534
10	25	14	304	276	8	7	1,305	1,188
11	17	11	254	243	6	6	1,155	1,104
12	6	5	120	112	3	3	607	565
13	16	14	364	347	9	9	1,767	1,685
14	7	7	157	150	4	4	726	695

DBH	# of Trees	BA	Gross CF	Net CF	Gross Tons	Net Ton	Gross BF	Net BF
15	6	7	182	144	5	4	872	697
16	2	3	85	80	2	2	441	417
17	7	9	239	208	6	5	1,190	1,038
18	5	6	180	162	5	4	954	861
21	0	1	37	37	1	1	198	197
22	2	2	63	62	2	2	340	332
25	2	4	109	104	3	3	601	571
26	2	4	103	87	3	2	557	472
27	2	3	69	55	2	1	371	292
28	2	3	72	70	2	2	395	386
Totals	209	126	3,000	2,768	75	69	12,118	11,033
Sitka Spruce								
5	39	8	114	108	2	2		
6	16	3	59	55	1	1		
7	13	5	99	93	2	2		
8	17	7	130	110	2	2		
9	7	3	64	58	1	1	155	126
10	14	8	193	184	3	3	845	810
11	5	3	83	83	1	1	388	384
12	7	6	157	146	3	2	726	671
13	8	7	149	149	3	3	676	675
14	4	4	86	86	1	1	406	405
15	2	2	54	54	1	1	263	262
16	4	4	97	97	2	2	493	492
17	6	7	224	221	4	4	1,098	1,087
18	3	5	143	141	2	2	726	715
19	1	2	49	46	1	1	251	235
21	2	3	103	103	2	2	537	537
23	1	2	38	24	1	0	181	116
25	0	2	65	52	1	1	384	308
30	0	2	56	45	1	1	332	267
Totals	151	82	1,963	1,854	33	32	7,461	7,089
Totals for stratum 2								
	366	211	5,029	4,672	110	102	19,845	18,321
	Stratum	**3**						
Cottonwood								
5	5	1	8	7	0	0		
6	8	1	19	15	0	0		
7	11	3	52	50	1	1		
9	3	1	23	23	0	0	106	106
10	2	1	19	20	0	0	82	84
11	4	3	45	44	1	1	173	169
16	1	2	39	35	1	1	174	156
18	0	1	24	24	1	1	124	125
20	0	1	22	21	0	0	115	107
Totals	34	13	252	240	5	5	774	747

DBH	# of Trees	BA	Gross CF	Net CF	Gross Tons	Net Ton	Gross BF	Net BF
Sitka Spruce								
5	19	3	40	40	1	1		
6	21	4	53	56	1	1		
7	25	6	112	112	2	2		
8	10	4	79	73	1	1		
9	8	3	57	57	1	1	43	44
10	3	1	23	23	0	0	104	104
11	3	2	40	40	1	1	170	171
13	0	1	16	14	0	0	77	71
Totals	90	24	419	415	7	7	394	390
Totals for stratum 3								
	124	37	672	656	13	12	1,168	1,137
Stratum	**4**							
Cottonwood								
5	9	1	7	7	0	0		
7	10	3	70	70	1	1		
9	3	2	39	39	1	1	168	170
10	1	1	23	24	0	1	89	93
11	4	3	72	66	2	1	325	299
12	3	3	77	78	2	2	387	393
13	5	5	143	141	3	3	703	694
14	10	11	323	303	7	7	1,616	1,519
15	3	5	130	125	3	3	653	630
16	7	11	327	315	7	7	1,658	1,596
17	7	13	385	376	8	8	1,910	1,865
18	2	3	104	94	2	2	544	493
19	2	3	110	100	2	2	590	539
20	2	4	87	61	2	1	419	306
21	2	4	94	69	2	1	477	364
22	0	1	43	36	1	1	239	201
24	1	2	42	31	1	1	217	157
25	1	2	35	11	1	0	168	53
27	1	5	96	43	2	1	482	217
31	0	2	32	21	1	0	158	104
32	0	2	32	15	1	0	163	77
34	0	2	35	26	1	1	191	139
38	0	2	26	10	1	0	135	50
Totals	75	88	2,332	2,061	50	44	11,294	9,959

DBH	# of Trees	BA	Gross CF	Net CF	Gross Tons	Net Ton	Gross BF	Net BF
Sitka Spruce								
6	15	3	43	43	1	1		
8	3	1	15	15	0	0		
9	2	1	25	25	0	0	99	102
12	3	3	74	75	1	1	340	341
13	0	1	21	22	0	0	100	103
16	2	3	76	76	1	1	362	363
20	1	3	73	64	1	1	363	319
Totals	26	15	327	320	6	5	1,265	1,227
Totals for stratum 4	101103	2,659	2,381	56	50	12,558	11,186	

Appendix D
DIAMETER/HEIGHT RELATIONSHIPS, TEN YEAR GROWTH, AND BARK THICKNESS



Reciprocal dbh height prediction model:

$$ht_{top} = ae^{\frac{-b}{dbh^{c}}}$$

Species	A Coefficient	B Coefficient	C Coefficient
Spruce	128.56	-7.2180	1
Hemlock	98.29	-5.8267	1
Cottonwood	93.46	-5.1435	1

"e" is a numerical constant that is equal to 2.71828

The corresponding Microsoft Excel equation appears as follows:

Height = A Coefficient*POWER (e, B Coefficient/dbh)

Ten Year Radial Growth and Bark Thickness by Species

		Radial Growth (In.)	Single Bark Thickness (In.)
Sitka Spruce	(264 detail records)		
	Average=	0.76	0.59
Hemlock	(64 detail records)		
	Average=	0.33	0.65
Cottonwood	(66 detail records)		
	Average=	0.77	0.84

Bark Thickness Ratio by Species

		DBH	DIB*	Bark Thickness Ratio
Sitka Spruce	(264 detail records)			
	Sum=	3,832.80	3,522.60	0.919
Hemlock	(64 detail records)			
	Sum=	836.70	753.50	0.901
Cottonwood	(66 detail records)			
	Sum=	1,025.20	914.80	0.892
Grand Total				**Average All Species**
	Sum=	5,694.70	5,190.90	0.912

*DIB = Diameter Inside Bark