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An Analysis of Pre-settlement Biomass and Vegetation in Northwest Whatcom County, Washington, circa Late 19th Century.

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An Analysis of Pre-settlement Biomass and Vegetation in Northwest Whatcom County, Washington, circa Late 19th Century.

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By
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Introduction:

Much of ecology, especially terrestrial ecology, studies how a given system changes over time. Pressures from preservationists and demands for timber products have focused ecological attention on Pacific Northwest forest ecosystems, and much of the debate has been over how change affects "old-growth" forests. Old-growth forests have a number of distinguishing characteristics including species composition, size of trees and forest structure that make them unique (Waring and Franklin 1979, Franklin et al. 1981). Old-growth forests west of the Cascade mountain range are dominated by Douglas fir (*Psuedotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) trees approximately 200-750 years old. The climax community consists of the shade tolerant western red cedar (*Thuja plicata*) and western hemlock species that grow up in the understory and gradually phase out Douglas fir (Waring and Franklin 1979; Franklin, et al. 1981).

A great deal of recent media attention has created the notion that before the arrival of Euro-American settlers, most of western Washington was heavily forested with old-growth forests such as those described above. While by and large this was true, there were some notable exceptions. One such example is south Puget Sound, where there were large expanses of prairie and grasslands (Franklin and Dyrness 1988). Ecosystems such as these, as well as the forests, were maintained by environmental and anthropogenic factors that would periodically reset their successional clocks.

One of the most important of these environmental factors is fire, which plays an ecological role in forest structure and composition. Douglas fir dominated forests of the western Washington lowlands have a fire frequency of approximately 217 years (Agee 1993). The occurrence of fires is largely dependent on the general climate which in the Pacific Northwest is characterized by mild temperatures and heavy precipitation. Therefore, the lightning storms that naturally ignite fires in this part of the world are fairly infrequent. Even so, when fires do occur in this system, they are often large and cause high mortality (Agee 1993). Shade intolerant Douglas fir is often the first dominant species in post-fire succession, eventually giving way to the successional intermediate western red cedar, and western hemlock as the climax species in very old forests (Di Domenico 1982; Agee 1993).

The ability of fire to control vegetation was recognized by the Native American tribes that inhabited the Puget Sound region and utilized the forest for products such as tools and fuel. There is also documentation (White 1980; Agee 1993) that native peoples used fire as a means of maintaining land as prairie or young successional forest. However, there is no valid information on Native American use of fire in western Whatcom County.

More recently, there are other anthropogenic actions that have affected the vegetation of the western Whatcom County lowlands. Although northern Puget Sound was first seen by explorers in 1791, no Euro-American had established residence in western Whatcom County until stories of land thick with timber brought the first settlers to the region in 1852 (Carhart 1926). Logging was the first industry of this region and it began on the shore of Bellingham Bay, then expanded north, south and east. Mines, and later, farming that took advantage of the fertile Nooksack River floodplains, added to the area's population (Carhart 1926). We can assume the attitudes and actions of western Whatcom County's first settlers were similar to those of the settlers on Whidbey Island to the south as documented in White (1980). These settlers harvested the timber for profit and then tried to use the cleared land for farming. A 1898 landuse map of Washington State (Plummer et al. 1898) confirms this by showing that the vast majority of western Whatcom County had either been cleared or burned since the arrival of the first settler four decades earlier.

Among other results, the natural or human caused changes in historic vegetation patterns and land use practices can contribute to global climate change. One way to examine the effects of these changes is by considering biomass which is important to the study of carbon budgets and balances. Much interest has been generated in the study of carbon cycles as the theory of global warming gains greater attention. The global carbon cycle centers around the flow of CO_2. Carbon dioxide is one of the main greenhouse gases that works to hold solar radiation in the earth's atmosphere and thereby contributes to the global warming effect. Traditionally, CO_2 cycles between the atmosphere and terrestrial system as plants take up CO_2 during photosynthesis. During the process of photosynthesis, plants take up CO_2 from the atmosphere and incorporate the carbon into sugars and other organic compounds. Carbon is eventually returned to the atmosphere as CO_2 by the respiration of plants and animals, including soil microbes that decompose organic material (Schlesiger 1997).

Forests dominate terrestrial carbon cycle dynamics (Sedjo 1992), and globally, two-thirds of terrestrial vegetation is in temperate regions (Schlesinger 1997). It has been estimated that 86% of the carbon stored aboveground and 73% of the carbon stored in the world's soils are in forest systems (Sedjo 1992). Overall, forests have been estimated to hold approximately 60% of the global carbon stock (Waring and Schlesinger 1985, in Wallin et. al. 1996).

Human activity has done two things to substantially alter the world's carbon budget. First, about 6×10^{15} g C/year are added to the atmosphere as a result of burning fossil fuels, and only about one-third of this is taken in by the world's oceans (Schlesinger 1997). Second, deforestation and the subsequent decay of large volumes of organic matter contribute 0.9×10^{15} g C/year globally to elevated CO_2 levels in the atmosphere (Schlesinger 1997). For example, 187 of the 325 Mg C/ha harvested from an old-growth forest are lost to the atmosphere as the biomass is subjected to paper production, fuel consumption, or decomposition (Harmon et al. 1990). When these factors are incorporated into the global carbon budget, there is a large amount of CO_2 that should be in the atmosphere but is not (Schlesinger 1997). Attempts to identify this missing carbon sink has garnered much attention and current popular theories point to northern temperate forests as the location of this "sink." There are discrepancies, however, as to where exactly this sink is (Wallin et. al. 1996; Sedjo, 1992).

Therefore, the purpose of my study was to accomplish several things. First, to create a picture of average biomass/ha distribution in the western Whatcom County lowlands during the second half of the nineteenth century. This then provides a historical context in which future studies can compare changes in land use, land cover, and a local carbon budget.

Methods:

The area of study included the following townships and ranges: T38N R2E, T38N R3E, T39N R2E, T39N R3E, T40N R2E, and T40N R3E (Figure 1). This area is located in northwestern Whatcom County, Washington. The area extends from the U.S.-Canadian border on the north to the northeastern shores of Bellingham Bay in the south. The area contains the lower portion of the Nooksack River and the northwest portion of Lake Whatcom.

The General Land Office Survey (GLOS) conducted in 1859 by Issac Smith and Jared Hurd covered Township 38 North, Ranges 2 and all of 3 East except interior corners around Lake Whatcom in the southern extreme of the Township; and Township 39 North, Range 2 East (north boundary only) and Range 3 East (west boundary only). The survey team headed by Deputy Surveyor Snow in 1871-72 completed Township 39 North, Range 2 East and the north boundary of section 6, Township 38 North, Range 2 East. Snow also surveyed Township 40 North, Range 2 East in 1872-73. Also in 1872, Samuel Brackens surveyed the north boundary of Township 39 North, Range 3 East. An 1873 survey led by John Tennant covered the remainder of Township 39 North, Range 3 East and sections 35, 36, 22-25, and 27 in Township 38 North, Range 3 East near Lake Whatcom (Di Domenico 1982).

The surveyors were instructed to mark four "witness trees" at each section corner. (Townships are 6x6 mi. and contain 36 1x1 mi. sections.) The nearest tree in each of the four quadrants was to be selected as a witness tree for that point. Half-way along each section line (i.e. every half-mile), another post was to be erected and two trees noted. Trees which lay directly in a surveyor's path were also marked and noted. Where there were no trees, a mound of dirt was to be made as the marker. Many sections in T40N R3E did not have witness tree information because by 1873, much of that land had been cleared by burning (Di Domenico 1982).

The way in which the surveys were conducted resulted in a systematically

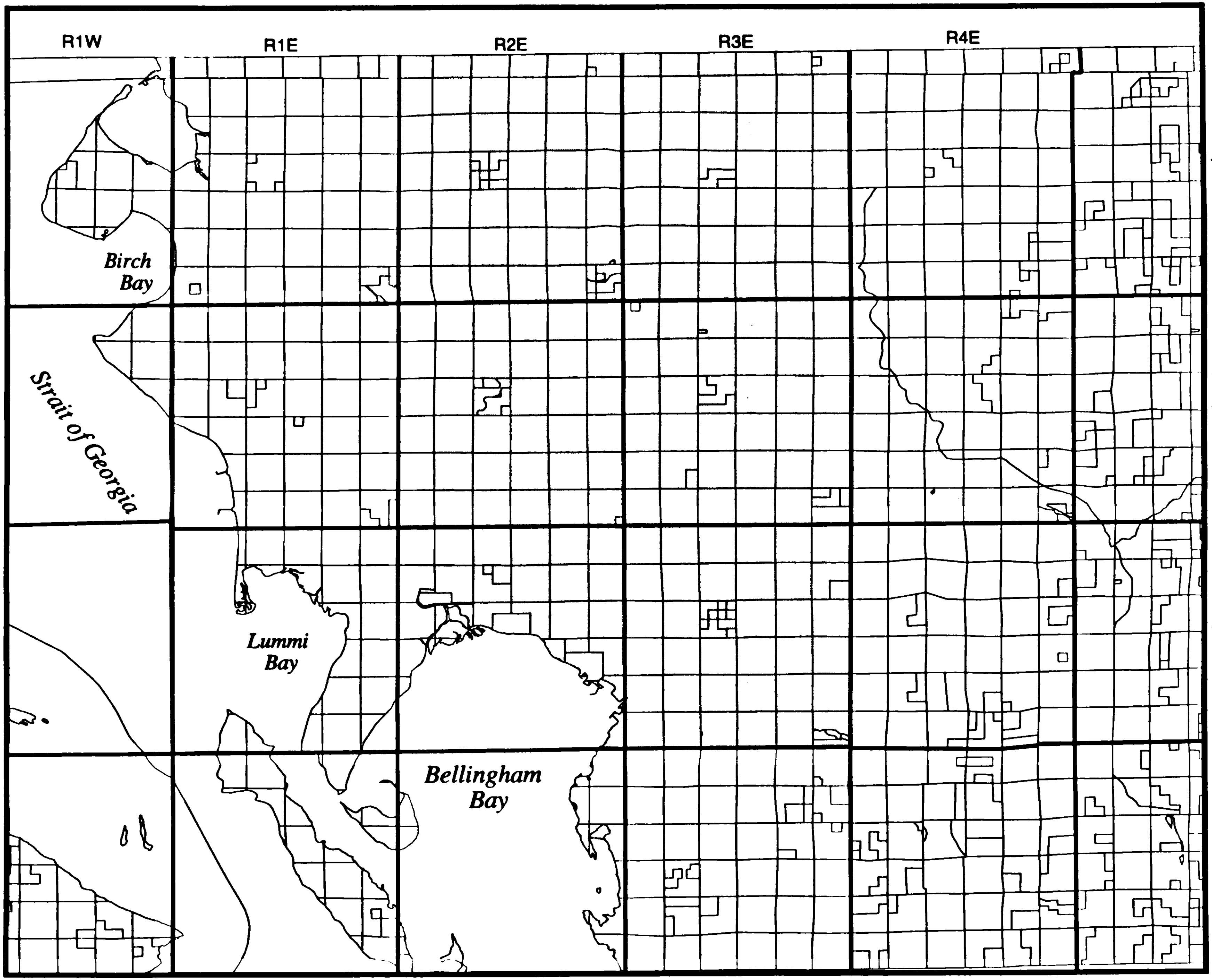

Figure 1. Study Area

gathered set of data on vegetation, soil, and topography characteristics. Information regarding section and corner point location, species, stem diameter at breast height (inches), and distance from each point to the witnessed trees was utilized in this study. This information was transcribed into a Microsoft Excel 7.0 spreadsheet from the original survey notes. These notes were on microfilm in the Pacific Northwest Collection, Washington State Archives Building, Bellingham, WA.

Eighteen tree species were identified from the surveyors' notes (Appendix A). The biomass of each species was calculated using equations and regression coefficients found in Harmon et. al. (1996) (Appendix B). Not all of the tree species noted by surveyors were included in the Harmon et. al. (1996) work, and because the regression coefficients are species-specific, trees not in Harmon et al. (1996) were given regression coefficients corresponding to species with similar wood characteristics. The assignment of regression coefficients to vine maple (*Acer circinatum*), hazel (*Corylus cornuta*), dogwood (*Cornus nuttallii*), ash (*Fraxinus latifolia*), bitter cherry (*Prunus emarginata*), crab apple (*Pyrus fusca*), and bearwood (*Rhamnus purshiana*) was based on coefficients provided by Harmon et al. (1996) for big leaf maple (*Acer macrophyllum*). The regression coefficients assigned to willow (*Salix* spp.) were based on those provided for cottonwood (*Populus trichocarpa*) and red alder (*Alnus rubra*).

The total biomass of each tree was found by totaling the values of the total bole, foliage, live branches, dead branches, and roots (Appendix C). Because there were anywhere from one to four trees at any given point, the average biomass per tree was determined for each point.

Mean stem density/ha at each point was then calculated using equations derived from those in Lambert (1994) and explanations of the point-centered quarter method discussed in Cottam and Curtis (1956) and Anderson and Anderson (1975) (Appendix D).

Finally, the average biomass/ha was calculated by multiplying the average biomass/tree at each point with the average number of trees/ha (mean stem density) at each point. All four of the above mentioned steps utilized the Microsoft Access 7.0 program.

The average biomass/ha values were then plotted on a map using the geographical information system (GIS) software, ArcView 3.0 (ESRI 1996). This software provided coordinates of only one point of a section, and these coordinates were in UTM units of meters. Placement of the points along a section boundary was determined by first converting the unit of measure used by the surveyors (chains) to meters by multiplying by 20.11684. Then, formulas were developed in Microsoft Excel 7.0 that helped place the average biomass/ha values at the correct UTM coordinates along each section boundary.

Average biomass/ha and mean stem density/ha data was mapped on ArcView 3.0. The "natural break" statistic was used to divide the data into groups; each point was connected by contour lines depending on which group it was in. The average biomass/ha and the mean stem density/ha data was divided into five "natural groups." The contour lines were drawn based on interpolations made by the "splining" method.

Results:

The raw data showed a wide array of biomass values, ranging from 0.243-18,000 Mg/ha. Areas of high biomass were found along the eastern shore of Bellingham Bay; 2-3 miles both north and east of the bay; and in the southwest corner of Township 40 North, Range 3 East (Figure 2).

Mean stem density also showed a wide range of values, from just over 1 stem/ha to more than 1,700 stems/ha (Figure 3). Areas of high stem density were similar, but not identical to the areas of high biomass. Areas of high stem density are found north of the bay; the southwest corner of Township 40 North, Range 3 East; and in the southeastern corner of Township 38 North, Range 3 East.

The majority of the study area had an average biomass/ha and mean stem density/ha in the low to low-intermediate range of values. The frequency distribution and other statistics are shown below.

Table 1. Biomass frequency distribution

Range (Mg/ha)	Number of Points
0-400	426
401-1,300	66
1,301-3,300	36
3,301-8,000	15
8,001-18,500	3
> 18,500	1
Total	547

Mean = 524.97 Mg
Standard Deviation = 1460.06

Table 2. Mean Stem Density frequency distribution

Range (stems/ha)	Number of points
0-400	508
401-1,200	29
1,201-2,800	7
2,801-6,300	2
6,301-17,400	1
> 17,400	0
Total	547

Mean = 113.53 stems/ha
Standard Deviation = 492.30

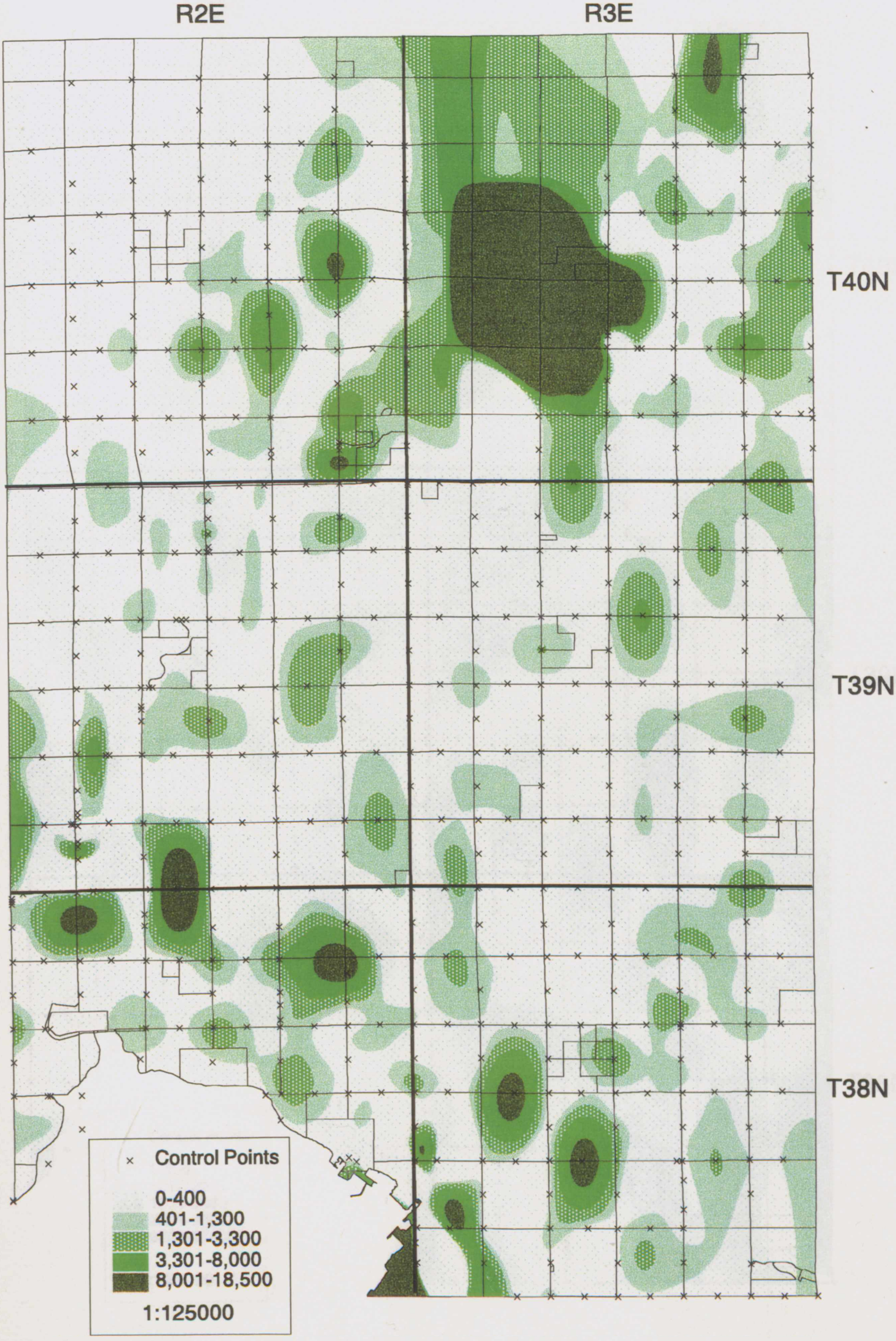

Figure 2. Average Biomass (Mg/ha)

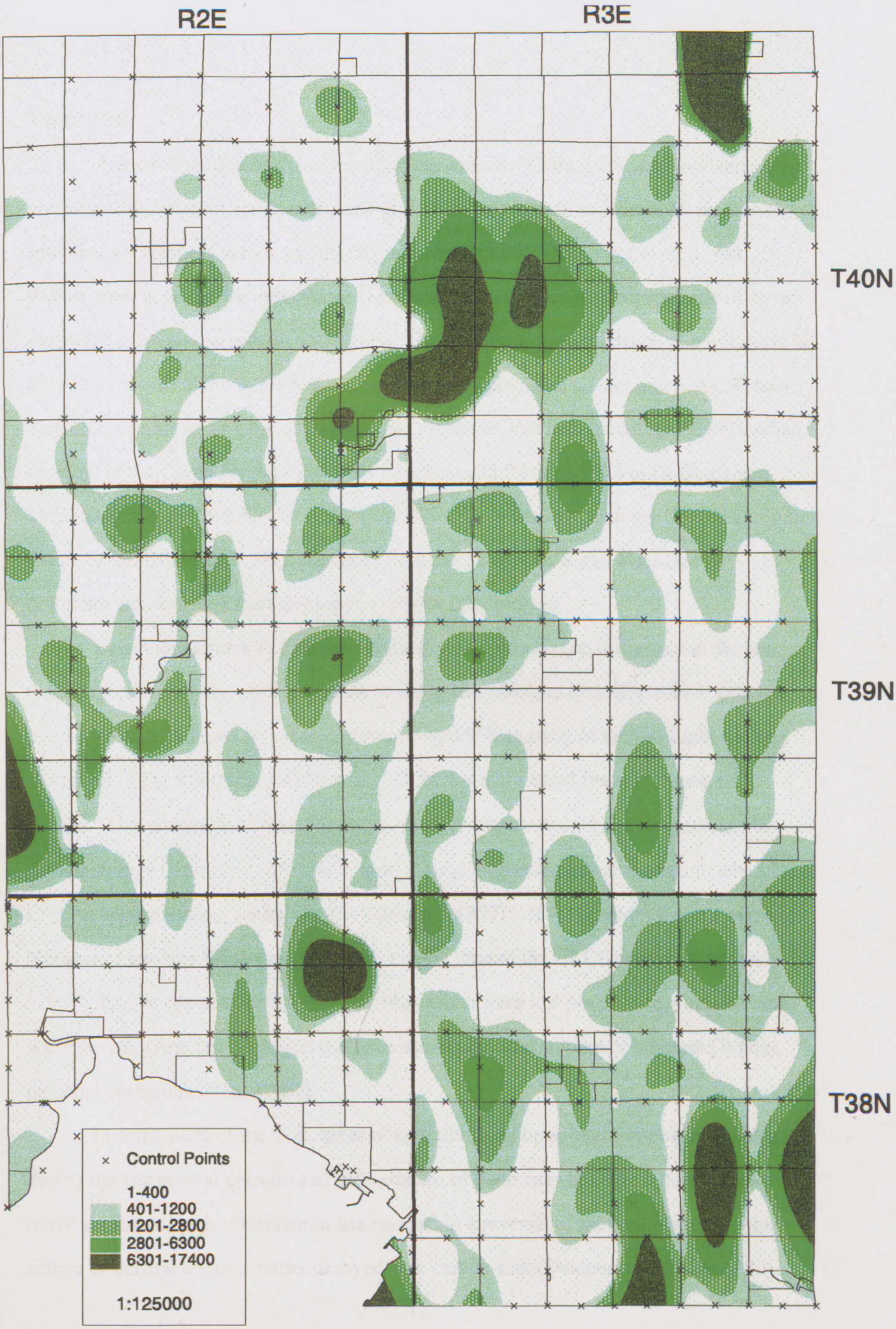

Figure 3. Mean Stem Density (Stems/ha)

Discussion:

Results from this study indicate that the western Whatcom County lowlands were not primarily dense and/or decadent old-growth forest. This is supported by the low to intermediate biomass values and the fair amount of alder, maple, cottonwood, and willow trees noted by the surveyors. These hardwood species are characteristic of open mesic sites, not an old-growth understory. The reason for the abundance of hardwoods is probably a result of the moist Nooksack River flood plain that covers much of the study area and possible anthropogenic influences. However, this area is ecologically classified as being in the *Tsuga heterophylla* zone (Franklin and Dyrness 1973 in Di Domenico 1982) and/or being climatically and topographically continuous with the Coastal Douglas Fir Zone (Di Domenico 1982). In either case, the study area is still classified by dominant conifers as is seen throughout western Washington.

Even though not all of the study area was old-growth conifer forests at the time of the first settlers, we can draw conclusions about how changes in land use have affected overall average biomass and carbon storage. By the beginning of the twentieth century, almost all of the study area had been logged for timber, cleared for agriculture, or burned. This change from forest cover to cultivated land resulted in a net decrease in carbon storage (Harmon et. al. 1990), from a mean plant biomass of approximately 8 kg C/m^2 to approximately 1.4 kg C/m^2 (Schlesinger 1997) . If we consider that the average biomass of western Whatcom County during the time of the GLOS surveys was nearly 525 Mg/ha, we can reason that over 260 Mg carbon were lost per hectare when the area was cleared. (Amount of carbon is approximately half the amount of biomass (Wallin, personal communication, 1997)).

In some parts of the U.S., areas of agricultural or open land have been abandoned during the last several decades and reforestation of these sites has been allowed to occur. In the southeast, such reforestation has resulted in a reversal of the area from a carbon source as detrital organic matter decayed, to a carbon sink (Delcourt and Harris 1980).

The change from carbon source to sink has occurred on this time scale because young, rapidly growing trees "pull" more CO_2 out of the atmosphere than mature stands (Harmon et. al. 1990). These conditions of reforestation are now occuring in western Whatcom County where agricultural fields are being left to grow over with natural vegetation (e.g. the Huxley forest near Ferndale).

The above scenario explains changes that have occurred only over the past few decades. When looking at a longer time scale, i.e. comparing average biomass and carbon storage between the mid-nineteenth century and the present, we see that there has been an overall loss of carbon stored in biomass and the study area is still a carbon source. Harmon et. al. (1980) show that even though young stands annually take up more carbon because of their higher growth rates, the slower growing old-growth stands have more carbon stored in the system overall. Harmon et al. (1990) show that even with reforestation, the change in vegetation from an old-growth to a young forest (approximately 60 years old) results in a net loss of about 175 Mg C/ha (350 Mg biomass/ha).

Also, even though Whatcom County is still largely rural, the city of Bellingham and other nearby towns have grown substantially over the last 140 years. Houses, roads, and shopping centers also factor into the overall reduction of carbon stored in the area.

Possible Sources of Error:

With a study of this type, it is important to consider how and why data and/or results may be erroneous.

One thing I had no control over was the original surveyors' data. Although they were instructed to mark the nearest 2-4 trees as witness trees, surveyors sometimes preferred some trees over others based on size, hardness, or bark character (Bourdo 1956; Hushen et. al. 1966 in Di Domenico 1982). Furthermore, the trees used to mark township and section corners were to be inscribed with information regarding township, range and section numbers. A tree with a stem of at least three inches in diameter would be required to fulfill such instructions (Delcourt and Delcourt 1996). Such selectivity on the part of the surveyors would tend to underestimate stem density by seeking larger diameter trees even though they might be further away from the corner point, and overestimate biomass if larger trees were preferred over smaller ones.

Secondly, not all of the data transcribed from the original surveyor notes was usable. Instances of tree diameter or no distance from a point to the nearest tree failing to be recorded by the surveyors resulted in those data being deleted. Areas that were already cleared or were in places with no vegetation were not transcribed.

There was also the problem of tree species names recorded by the surveyors. The surveyors recorded the common name of the trees but common names change across time and regions. "Balsam," as indicated in the notes, was interpreted to mean cottonwood. Surveyors also used what appeared to be the abbreviation "Do." Based on knowledge of stem diameter, this notation was believed to indicate dogwood. Educated guesses of *Psuedotsuga menziesii* and *Pinus contorta* were made for the species noted by surveyors as "fir" and "pine," respectively. Finally, there were two entries of "skunkwood" which were omitted when no information about this common name could be found.

The result of omitting some of the data was that each point could have anywhere from zero to the maximum of four trees. Because points where only one (or none) tree existed could not be used in the stem density equations, approximately 10% of the original data set was omitted.

Lastly, the "spline" method that interpolated the data to draw the contour lines may also have been a source of inaccuracy. Most notably, this can be seen in the southwest corner of T40N R3E where high values of mean stem density and average biomass are plotted. We do not know for sure what the values should be in this area because no data was collected by surveyors due to the fact that this area was burned over when they arrived. Since no vegetative data was transcribed for these sections, the corresponding areas on Figures 1 and 2, where the computer interpolated high values, should be considered carefully. Because this area was noted as being burned, the amount of living biomass was probably small; however, the dead biomass is another example of large releases of carbon from the system, with minimal amounts of carbon uptake by "new" vegetation.

Conclusions:

Reconstructions of historical vegetation maps are growing in importance in ecological studies. Comparisons between land cover now and at a given time in the past can give insight into how ecological processes may change under certain conditions. Historical vegetation patterns as well as stand structure and age can help scientists to determine things such as the global carbon cycle which is of interest today.

Original General Land Office Survey data provides a systematic and fairly uniform collection of information regarding an area's historical vegetative ecology. Although discrepancies and unknowns in surveyor data should be expected, this information provides a valuable tool for the growing interest in the field of historical ecology.

Appendix A: Plant species recorded by surveyors

Common Name	Species Name
Alder	*Alnus rubra*
Ash	*Fraxinus latifolia*
Bearwood	*Rhamnus purshiana*
Birch	*Betula papyrifera*
Cedar	*Thuja plicata*
Cherry (bitter)	*Prunus emarginata*
Cottonwood	*Populus trichocarpa*
Crabapple	*Pyrus fusca*
Dogwood	*Cornus nuttallii*
Douglas fir	*Pseudotsuga menzeisii*
Hazel	*Corylus cornuta*
Hemlock	*Tsuga heterophylla*
Maple	*Acer macrophyllum*
Pine (lodgepole)	*Pinus contorta*
Spruce	*Picea sitchensis*
Vine Maple	*Acer circinatum*
White fir	*Abies grandis*
Willow	*Salix* spp.

Appendix B: Regression coefficients used to calculate tree biomass

Species	Bark B0	Bark B1	Wood B0	Wood B1	Leaf B0	Leaf B1	Live Branch B0	Live Branch B1	Dead Branch B0	Dead Branch B1
Abies grandis	2.106921	2.727100	2.551192	2.785600	2.359100	2.192600	1.670800	2.626100	-0.177240	2.805000
Acer circinatum	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Acer macrophyllum	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Alunus rubra	2.265355	2.461700	4.238755	2.461800	-2.447300	3.243400	-0.911945	3.488600	-0.707845	2.624300
Betula papyrifera	2.265355	2.461700	4.238755	2.461800	-2.447300	3.243400	-0.911945	3.488600	-0.707845	2.624300
Cornus nuttallii	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Corylus cornuta	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Fraxinus latifolia	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Picea sitchenisis	4.731108	1.705900	4.366473	2.363300	1.085755	2.780000	1.718655	2.518000	3.378800	1.750300
Pinus contorta	1.012802	2.067600	4.572091	2.343800	3.289100	1.836200	2.307360	2.353300	3.378800	0.750300
Populus trichocarpa	2.265355	2.461700	4.238755	2.461800	-2.447300	3.243400	-0.911945	3.488600	-0.707845	2.624300
Prunus emarginata	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Psuedotsuga menzeisii	2.902625	2.481800	4.841987	2.332300	4.061600	1.700900	3.213700	2.138200	3.378800	1.750300
Pyrus fusca	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Rhamnus purshiana	2.333800	2.574000	3.414800	2.723000	0.415955	2.503300	2.671760	2.430000	4.791800	1.092000
Salix spp.	2.265355	2.461700	4.238755	2.461800	-2.447300	3.243400	-0.911945	3.488600	-0.707845	2.624300
Thuja plicata	2.385440	2.198700	3.862652	2.445400	4.290800	1.782400	3.641700	2.087700	3.378800	1.750300
Tsuga heterophylla	2.766209	2.347400	4.176308	2.535300	2.777800	2.128000	1.758800	2.778000	-0.177240	2.805000

Biomass equations, from Harmon et al. (1996):

Appendix C: Equations used to calculate tree biomass

Equation 1. Bole bark biomass:

$Ln(M_{bole})$ = Bark B_0 + Bark B_1 ln(dbh * 2.54)

M_{bole} is the bole bark mass (g)

dbh is the diameter in breast height (in.)

Equation 2. Bole wood biomass:

$Ln(M_{bole})$ = Wood B_0 + Wood B_1 ln(dbh * 2.54)

M_{bole} is the bole wood mass (g)

dbh is the diameter in breast height (in.)

Equation 3. Leaf biomass

$Ln(M_{leaf})$ = Leaf B_0 + Leaf B_1 ln(dbh * 2.54)

M_{leaf} is the leaf mass (g)

dbh is the diameter in breast height (in.)

Equation 4. Live branch biomass

$Ln(M_{lb})$ = Live branch B_0 + Live branch B_1 ln(dbh * 2.54)

M_{lb} is the live branch mass (g)

dbh is the diameter in breast height (in.)

Equation 5. Dead branch biomass

$Ln(M_{db})$ = Dead branch B_0 + Dead branch B_1 ln(dbh * 2.54)

Mdb is the dead branch mass (g)

dbh is the diameter in breast height (in.)

Equation 6. Root biomass

$Ln(M_{root}) = 2.2117 + 2.6929 \ln(dbh * 2.54)$

M_{root} is the root mass (g)

dbh is the diameter in breast height (in.)

Avg. biomass/tree/point = (Eq. 1+Eq. 2+Eq. 3+Eq. 4+Eq. 5+Eq. 6) / # of trees at point

Appendix D: Equations used to calculate mean stem density

Mean stem density/ha equations, adapted from Lambert (1994), Cottam and Curtis (1956) and Anderson and Anderson (1975).

Two trees: $10{,}000 / [(Q_1 + Q_2)/2]^2 * 0.65$

Three trees: $10{,}000 / [(Q_1 + Q_2 + Q_3)/3]^2 * 0.81$

Four trees: $10{,}000 / [(Q_1 + Q_2 + Q_3 + Q_4)/4]^2$

10,000 is the number of m^2/ha
Q_n refers to the distance (m) from the corner point to the tree.
Stem density was not calculated for points that had less than two trees recorded.

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