THE UNIVERSITY OF ALBERTA

PHYSICAL COMPONENTS AND BIOMASS REGRESSION EQUATIONS REQUIRED FOR FUEL QUANTIFICATION OF FOREST STANDS IN JASPER NATIONAL PARK, ALBERTA

by

GILLES P. DELISLE

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(SIGNED) ....

PERMANENT ADDRESS:

#304 - 146 François

Ile des Soeurs

Montreal, QUEBEC H3E 1G3

DATED June 26 1986

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled PHYSICAL COMPONENTS AND BIOMASS REGRESSION EQUATIONS REQUIRED FOR FUEL QUANTIFICATION OF FOREST STANDS IN JASPER NATIONAL PARK, ALBERTA submitted by GILLES P. DELISLE in partial fulfilment of the requirements for the degree of Master of Science in Forest Science.

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Supervisor

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ABSTRACT

Representative class diameter (Di) values for diameter classes: 0-0.49, 0.5-0.99, 1.0-2.99, 3.0-4.99 and 5.0-6.99 cm were estimated using different methods: arithmetic class centre (ACC), average diameter ($\bar{D}$), experimental quadratic mean diameter (QMD) and graphical QMD methods for lodgepole pine, Douglas-fir, white spruce and aspen in Jasper National Park, Alberta. Results show the graphical QMD values are a reasonable compromise between the expensive development of experimental QMD values and the low accuracy of values from the other two methods.

Specific gravity (G) values were determined for the above species based on the same size classes and for larger material (7-17 cm) based on wood condition (sound or rotten). A T-test showed significant (95 percent level) differences between sound and rotten G values of larger material.

Biomass regression equations for total weight, foliage weight, wood weight of diameter classes 0-0.49 and 0.5-0.99 and (total) wood weight were developed for tree seedlings (≤3 m in height) of the above four tree species, for five common shrubs (Canadian buffalo-berry, ground juniper, Saskatoon-berry, white meadowsweet and prickly rose), based on basal diameter, and for two dwarf shrubs (common bearberry and twin-flower), based on percent cover. Equations of the allometric model were adopted to model the distribution of data for tree seedlings, shrubs and one

species of dwarf shrub (twin-flower) and a second degree polynomial regression equation was chosen to mimic the distribution of common bearberry data. Regression equations were chosen based on their statistics: r^2 (R^2), SEE, F and t ratios, and distribution of plotted residuals.

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1. INTRODUCTION, OBJECTIVES AND STUDY AREA

Fire is the key environmental factor that initiates new successional sequences, controls the species composition and age structure of several plant communities, and produces vegetation patterns upon which the animal components of the ecosystem depend (Heinselman 1970). Fire has played an important role in the ecology of the northern Rocky Mountain forests where the maintenance and survival of many plant communities depend upon its occurrence (Habeck and Mutch 1973; Tande 1977). These relationships are confirmed by fire history studies performed in the region by a number of authors: Byrne (1968), MacKenzie (1973), Heinselman (1975), Tande (1977, 1979), Hawkes (1979) and White (1985).

The historical importance of fire and relatively old age of forest communities located in Jasper National Park justified and encouraged the initiation of scientific studies leading to a fire management plan for the park. Forest fuel quantification represents one important step in the process of fire management planning, and the accuracy of biomass estimates will greatly influence our understanding of the potential fire behaviour of the stands. This in turn should be reflected in the fire management plan.

From a practical viewpoint, down and dead fuel weights may be effectively estimated through the line intersect method (Van Wagner 1965, 1968, 1982). This technique is best visualised as a strip sample of infinitesimal width along which fuel particles are measured or tallied by size-class

(Van Wagner 1982a). The weight of other forest fuel components, such as tree seedlings, shrubs and dwarf shrubs may be more effectively estimated through statistically-sound, locally-developed, regression equations (Brown 1976, Brown and Marsden 1976).

Two physical properties of the wood particles: specific gravity (G) and representative class diameter (Di) are used in the down and dead fuel weight calculations when using the line intersect method. Thus, more accurate estimates of these physical attributes should undeniably lead to more accurate biomass estimates. The same logic applies to such forest fuels as tree seedlings (≤3 m in height), shrubs and dwarf shrubs, where statistically sound analogs representing local conditions should generate reliable weight estimates.

The objectives of this study were: 1) to develop and compare representative size diameter (Di) values by size class for the four major tree species growing in the study area, 2) to develop specific gravity (G) values by size class and condition for down and dead material for those same species, and 3) to develop site specific regression equations which would predict the weight of the tree seedlings (≤3 m in height), and shrubs based on some easily measurable and reliable independent variables.

The approximately 20,000 ha study area (Figure 1.1) is located in the Montane Forest Zone which surrounds the Jasper townsite (Jasper National Park, Alberta, Canada), located at 52°6' and 53°2' N latitude and 117°5' and 118°4'

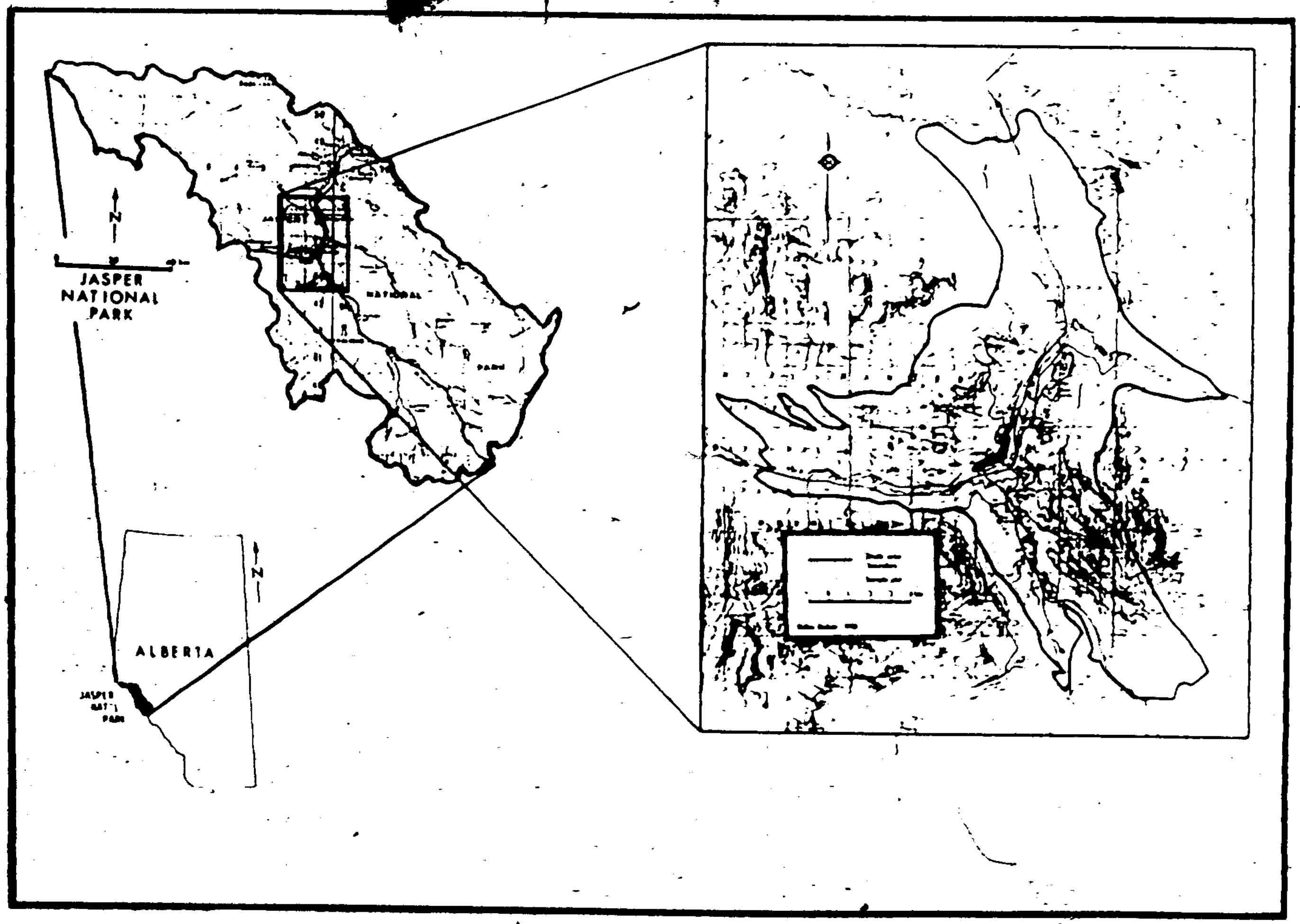

Figure 1.1 Location of the study area, Jasper National Park, Alberta, Canada.

W longitude). Its complex topography and resulting aspect and elevation gradients have a major influence on elements of the local climate such as temperature, precipitation, relative humidity and wind regimes (Holland and Coen 1982). These in turn impact on the fuel elements (Tande 1977). More detailed information on the climate of the study area is available from Stringer and La Roi (1970) and Janz and Storr (1977).

The study area is located in the Douglas-fir (*Pseudotsuga menziesii*[1] (Mirb.) Franco) and lodgepole pine (*Pinus contorta* Loudon var. *latifolia* Engelm.) section (M.5) of the Montane Forest Region as described by Rowe (1972). At this latitude, the Montane Forest Region extends from valley bottom (approximately 1020 m) to about 1530 m (Lee 1976). Within this zone, five forest community types are represented. These are: Douglas-fir, white spruce (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.), black spruce (*Picea mariana* (Mill.) BSP., aspen (*Populus tremuloides* Michx.) and lodgepole pine types (Tande 1979).

This study was performed in the context of a broader project aimed at quantifying forest fuels in the study area. Seventy-four plots established as part of this study were proportionally allocated to various vegetation types. Fuel samples included: (Figure 1.2) duff, down and dead fuels, herbs and grasses, dwarf shrubs, shrubs, tree seedlings (≤3 m in height), live trees and snags. Sampling procedures were

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[1]Moss (1983) was the scientific authority consulted for all common and scientific plant names used in this thesis.

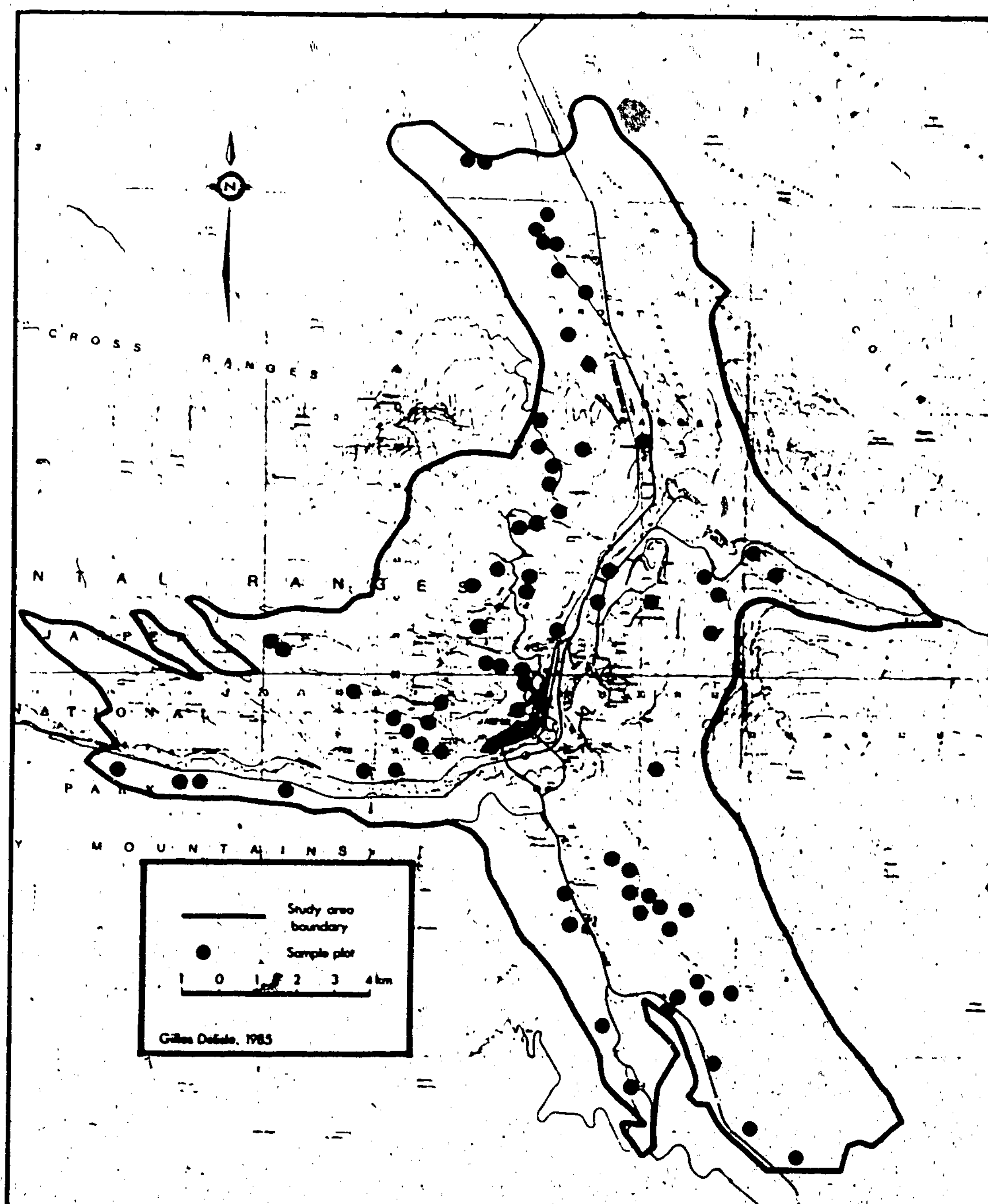

Figure 1.2 Location of the plots established in the study area.

based on a 30 m-side equilateral triangle along which the above fuels were quantified at predetermined locations (Appendix I). Results from this project were used to more accurately quantify such forest fuels as down and dead, tree seedlings, shrubs and dwarf shrubs.

This thesis is presented in a journal paper format and is composed of four chapters. Chapter 1 introduces the scope of the study. Chapters 2 and 3 represent the body of the thesis, each having its own introduction, methods, results and discussion and Chapter 4 is a concluding chapter which summarizes all the material presented and discussed.

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2. QUADRATIC MEAN DIAMETER AND SPECIFIC GRAVITY VALUES FOR TREE SPECIES NATIVE TO JASPER NATIONAL PARK, ALBERTA

2.1 INTRODUCTION

Forest fire intensity (Byram 1959), and more recently termed frontal fire intensity (Alexander 1982), is highly influenced by the weight of the fuelbed. This concept is best demonstrated by the following equation proposed by Byram (1959):

$$I = Hwr \qquad [1]$$

where:

I = fire intensity (kW/m)

H = fuel low heat of combustion (kJ/kg)

w = weight of fuel consumed per unit area (kg/m^2)

r = rate of spread (m/s)

Techniques for estimating down and dead fuel loadings by counting or measuring down and dead roundwood fuel particles along line transects were first proposed by Warren and Olsen (1964) with further refinements by Van Wagner (1965, 1968, 1982a), Brown (1971, 1974) and Roussopoulos and Johnson (1973). Results of their work suggest the weight of down and dead roundwood fuels can be relatively easily determined by measuring or counting fuel particles by size class and solving the following two equations as presented by McRae *et al.* (1979) with some modified symbols adopted from Van Wagner (1982a).

$$W = \frac{0.1234 \times n \times (QMD)^2 \times G \times a \times c}{NL} \qquad [2]$$

for woody fuels less than 7 cm in diameter and

$$W = \frac{0.1234 \times \Sigma d^2 \times G \times a \times c}{NL} \qquad [3]$$

for roundwood fuels equal to or greater than 7 cm in diameter

where:

W =	fuel loading, (kg/m²)
0.1234 =	a constant to convert area to volume
n =	number of intercepts per size class less than 7.0 cm in diameter
$(QMD)^2$ =	squared, quadratic mean diameter, (cm²)
Σd^2 =	sum of squared diameters for intercepts 7.0 cm and greater in diameter, (cm²)
G =	specific gravity of fuel size class, (g/cm³)
a =	correction factor for non-horizontal angle of fuel pieces
c =	slope correction factor, ($c = 1 + (\text{Percent slope}/100)^2$)
N =	number of fuel transects
L =	length of the fuel transect, (m)

Information pertaining to the quadratic mean diameter (QMD) and the specific gravity (G) for each size class, condition and species, of woody fuel is required to solve these equations. QMD and G values for various fuel species and diameter size classes have been presented by a number of authors (Brown 1972, Beaufait and Hardy 1973, Roussopoulos and Johnson 1973, Brown 1974, Brown and Roussopoulos 1974, Brown and Marsden 1976, Bevins 1978, Ryan and Pickford 1978, Roussopoulos 1978, McRae *et al*. 1979, Sackett 1980 and McRae 1982). These values were not appropriate for use in this study because they either do not pertain to tree species native to Jasper National Park, or are not compatible with Canadian diameter size classes, or were developed for tree species which were located on sites geographically distant and physically different from those found in the study area. Therefore, the primary objective of this study was to locally determine the QMD and G values of down and dead roundwood fuel diameter classes (cm): 0-0.49, 0.5-0.99, 1.0-2.99, 3.0-4.99, 5.0-6.99 and G values for rotten and sound down and dead fuels ≥ 7 cm in diameter for Douglas-fir,[3] lodgepole pine, white spruce and aspen.

The fuel diameter size classes used in this study conform to those adopted in Ontario by the Canadian Forestry Service (McRae *et al*. 1979) and are different from diameter size classes used by the USDA Forest Service which are 0-0.24 inch, 0.25-0.99 inch and 1.0-2.99 inches (Brown 1974).

For practical reasons, small down and dead roundwood fuel particles (≤ 6.99 cm) are generally tallied by diameter class rather than directly measured in the field when using the line intersect method (McRae *et al*. 1979). This means a

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[3]Moss (1983) was the scientific authority consulted for all common and scientific plant names used in this thesis.

representative class diameter (Di) value must be chosen for each class.

Theoretically, Di values would be better represented by QMD values, obtained by solving the equation presented by Waugh (1952):

$$QMD = \sqrt{\sum_{i=1}^{n} d^2/n} \qquad [4]$$

where:

d = actual diameters

n = number of samples

rather than using arithmetic class centre (ACC) or average diameters ($\bar{D}$) values:

where:

$$\bar{D} = \sum_{i=1}^{n} d/n \qquad [5]$$

since d^2 is the property being summed (Van Wagner 1982a). The rationale for using quadratic mean instead of average diameter is based on the fact that it better represents the diameter of the cross-section of average area (Husch *et al.* 1972).

There are two different methods of estimating QMD values: (1) experimentally, which involves the collection of actual diameter measurements in the field for each fuel diameter size class and solving equation [4] or (2)graphically, where QMD's are estimated using the diameter frequency distribution which is determined from the data recorded as part of line intersect field sampling procedures (McRae *et al*. 1979) and assuming this frequency is modelled by a simple power function (Van Wagner 1982a, b).

The cost, accuracy and versatility of the value used as the representative class diameter (Di) varies among methods used to determine that value. Theoretically, the experimental method of estimating QMD values is the most accurate, assuming the sample size is sufficiently large (Van Wagner 1982a). However, it is the most expensive, due to increased sampling time required and is less versatile when these results are compared to graphically determined QMD (Van Wagner 1982b) values. The benefits and limitations of graphically determining QMD values are thoroughly discussed by Van Wagner (1982a, b).

The second, third and fourth objectives of this study were to determine the percent difference in fuel volume estimates which would result if experimental QMD values were replaced by: (O_2) graphical QMD values, (O_3) average diameter ($\bar{D}$) values, and (O_4) arithmetic class centre values (ACC).

2.2 METHODS

All sample stands of the representative species were selected with the aid of: (1) aerial photographs (A23238-44 to 46, 52 and 53, 102 and 103, A232401 to 4, 16 to 23, 1973, available from Energy, Mines and Resources (EMR), Ottawa, Ontario), (2) a composite of four 1:50,000 scale topographic maps (83E/1, 83F/4, 83D/16 and 83C/13 from EMR, Edition 2), (3) biophysical information from Holland and Coen (1982), and (4) to a lesser extent the stand origin map of the Athabasca river valley around Jasper townsite, Jasper National Park, Alberta (Tande 1977, 1979).

Randomly located and oriented line transects were established in five different pure stands of Douglas-fir, lodgepole pine, white spruce, and aspen. For each of these four tree species the first 20 down and dead roundwood fuel particles encountered along the transect line for each of the five diameter classes (Table 2.1) per stand were measured to the nearest mm using calipers. A total of approximately 100 samples per diameter class per species were recorded. Experimental QMD and average ($\hat{D}$) values for each diameter class by species were determined from these field data, using equations (4) and (5), respectively.

Graphical QMD values were determined using the diameter frequency distribution data which were collected as part of line transect sampling procedure (Delisle 1983)[3] in 64 plots of lodgepole pine, four plots of Douglas-fir and three plots of aspen. The procedures described in Van Wagner (1982a, b) were followed. Sampling line lengths varied by fuel diameter size class (Table 2.1) and conformed to guidelines described by McRae *et al.* (1979). Line transects were not established

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[3]Delisle, G. 1983. Forest fuels quantification in the Montane forest surrounding Jasper townsite, Jasper National Park, Canada. Study proposal. Unpublished document.

Table 2.1 Line lengths used for sampling down and dead roundwood diameter size class fuels.

Size class	Diameter class (cm)	Line lengths (m)
1	0.0 - 0.49	15
2	0.5 - 0.99	30
3	1.0 - 2.99	45
4	3.0 - 4.99	60
5	5.0 - 6.99	75

in pure white spruce stands located in the study area because these stands are usually found on flood plains which are frequently contaminated with roundwood material from other species. Therefore, the QMD values for white spruce in Jasper National Park were not determined using the graphical method.

Both the experimental QMD data collection and G sample collection were done simultaneously along the same line transects. A portion of wood was collected from every third roundwood particle sampled as part of the experimental QMD sampling design. These subsamples of wood were used to determine the specific gravity (G) of wood species by size class. A total of 30 G samples per diameter class (1-5) were collected for each species. Material equal to or larger than 7 cm up to 17 cm diameter was stratified by wood quality status (sound or rotten) and an approximately three cm thick disk sample was collected. Approximately five wood samples were collected for every two cm class, per species, by wood quality status; for a total of about 25 samples for both sound and rotten material within the diameter class 7-17 cm.

Specific gravity for small (0-6.99 cm) and large (7-17 cm) diameter material was estimated based on oven dry volume obtained by water immersion using the American Society For Testing and Materials method D2395-65T, Mode II (Anon. 1968).

Assuming a randomly oriented population consisting of horizontal pieces of circular cross-section, wood volumes

(m^3/ha) have been calculated using a basic equation presented by Van Wagner (1968):

$$V = (\pi^2/8L)\Sigma d^2 \qquad [6]$$

where:

V = volume per unit area (m^3/ha)

d = piece diameter at intersection (cm)

L = length of sample line (m)

This equation has been modified to accomodate the class diameter tally system proposed by Van Wagner (1968):

$$V = (\pi^2/8L)\ (niDi^2) \qquad [7]$$

where:

ni = is the number of intersections in diameter class

Di = representative class diameter (Van Wagner 1982a, b)

Comparison of Di values obtained from different methods would be meaningless since representative class (Di) values are developed only to provide better fuel quantification estimates, where Di values have to be squared (equation [7]). Results from comparisons on the basis of wood weight would have been identical, since G is common to one size class regardless of the Di values used to calculate W, using the equation:

$$W = (G\pi^2/8L)\Sigma(niDi^2) \qquad [8]$$

where:

W = weight per unit ground area

G = density in units of weight per unit volume (Van Wagner 1982a)

Therefore percent difference based on wood volume (m^3/ha) was calculated for the graphical versus the experimental QMD method as well as for arithmetic class centre (ACC) values and average diameter ($\bar{D}$) versus the experimental QMD method. T-tests were performed to determine the statistical difference between sound and rotten specific gravity values for combined material 7-17 cm in diameter.

2.3 RESULTS

2.3.1 Representative class diameter (Di)

The arithmetic class centre (ACC), average diameter ($\bar{D}$), experimental and graphical QMD (with associated adjusted frequency and slope (Van Wagner 1982b) values have been developed for the four most common tree species native to the study area, based on dive diameter classes ranging from 0 to 6.99 cm (Table 2.2). Average diameter ($\bar{D}$) values are consistently smaller than the experimental QMD values for all four tree species and all fuel diameter size classes. No such bias is apparent from the comparison of arithmetic class centre (ACC) with experimental QMD (values) as positive as well as negative differences do occur (Table 2.2).

Table 2.2 Arithmetic class centre (ACC), average diameter (D) and experimental and graphical QMD values by size class for lodgepole pine (PICO), Douglas-fir (PSME), aspen (POTR), and white spruce (PIGL).

Species	Size class	Diameter class (cm)	Arithm. class centre (ACC)	Experimental					Graphical		
				n	D	Sx	QMD	Sx	adj n* freq.	slope b	QMD
PICO	1	0.0-0.49	0.25	100	0.3251	.0085	.3360	.0054	39,600.00		0.3234
	2	0.5-0.99	0.75	100	0.6841	.0130	.6964	.0188	9,168.00		0.7163
	3	1.0-2.99	2.00	101	1.8294	.0583	1.9208	.2287	1,047.00	-1.6741	1.7884
	4	3.0-4.99	4.00	100	3.8474	.0535	3.8844	.4227	440.25		3.9005
	5	5.0-6.99	6.00	100	5.8948	.0600	5.9253	.7124	220.80		5.9375
PSME	1	0.0-0.49	0.25	100	0.2651	.0074	0.2753	.0044	11,736.00		0.3076
	2	0.5-0.99	0.75	100	0.6705	.0124	0.6820	.0176	732.00		0.6960
	3	1.0-2.99	2.00	100	1.6171	.0496	1.6916	.1821	91.00	-2.3999	1.6653
	4	3.0-4.99	4.00	100	3.8551	.0549	3.8940	.4369	14.25		3.8405
	5	5.0-6.99	6.00	100	5.8335	.0579	5.8621	.6949	5.40		5.8914
POTR	1	0.0-0.49	0.25	100	0.3287	.0090	0.3408	.0061	1,212.00		0.3170
	2	0.5-0.99	0.75	100	0.6534	.0136	0.6674	.0195	414.00		0.7080
	3	1.0-2.99	2.00	100	1.7255	.0559	1.8137	.2148	52.00	-1.9661	1.7378
	4	3.0-4.99	4.00	100	3.8664	.0578	3.9093	.4564	9.00		3.8753
	5	5.0-6.99	6.00	100	5.8459	.0551	5.8718	.6510	2.40		5.9190
PIGL	1	0.0-0.49	0.25	100	0.2995	.0091	0.3131	.0058			
	2	0.5-0.99	0.75	100	0.6960	.0147	0.7114	.0218			
	3	1.0-2.99	2.00	99	1.7048	.0566	1.7954	.2146			
	4	3.0-4.99	4.00	100	3.7630	.0496	3.7956	.3847			
	5	5.0-6.99	6.00	100	5.8681	.0564	5.8951	.6626			

The increase in standard error of the mean ($S\hat{x}$) values associated with $\bar{D}$ and experimental QMD's reflects the wider diameter ranges from size class 1 to 5. The $S\hat{x}$ associated with experimental QMD has been calculated from squared diameters as opposed to original diameter data in the case of $\bar{D}$ resulting in appreciable differences. Statistical comparisons between $\bar{D}$ and experimental QMD's would however be meaningless since they, as well as their associated statistics, originated from the same data set.

Percent difference in wood volume estimates using ACC, $\bar{D}$ and graphical QMD's as compared to experimental QMD's as representative class diameter (Di) values were estimated (Table 2.3). Based on cost and accuracy, the general conclusion is for the graphical QMD (Table 2.3, column 15) to be the best compromise, followed by $\bar{D}$ which shows a consistent bias when compared to experimental QMD, which is assumed to be the best estimator of Di (Van Wagner 1982a). There is no biological reason why ACC should precisely represent Di values and this is confirmed by the relatively high differences observed when ACC and experimental QMD method results are compared (Table 2.3, column 13).

2.3.2 Specific gravity (G)

Specific gravity (G) values per size class of small down and dead roundwood fuels ranging from 0 to 6.99 cm in diameter for lodgepole pine, Douglas-fir, aspen and white spruce were developed (Table 2.4). Combined $\bar{G}$ values (7-17

Table 2.3 Wood volumes per size class per species based on different values of (Di)^2.

Species	Size class	(ACC)^2	Experimental (D)^2	Experimental (QMD)^2	Graphical (QMD)^2	Length of sample line	Tallied freq. ni	Wood Volume (m^3/ha) (ACC)^2	From experimental (D)^2	From experimental (QMD)^2	From graphical (QMD)^2	Percent difference in wood vol. estimates based on exp. (QMD)^2 (ACC)^2	(D)^2	(QMD)^2 graph
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lodgepole pine	1	.0625	.1057	.1129	.1046	15	3,300	16.9634	28.6885	30.6426	28.3899	-44.64	-6.38	-7.35
	2	.5625	.4680	.4850	.5131	30	1,528	35.3455	29.4075	30.4757	32.2414	15.98	-3.50	5.79
	3	4.000	3.3467	3.6895	3.1984	45	1,047	114.8164	96.0640	105.9038	91.8072	8.42	-9.29	-13.31
	4	16.000	14.8025	15.0886	15.2139	60	587	193.1152	178.6618	182.1149	183.6273	6.04	-1.90	0.83
	5	36.000	34.7487	35.1092	35.2539	75	368	217.9209	210.3463	212.5285	213.4044	2.54	-1.03	0.41
	Total	-	-	-	-	-	-	578.1614	543.1681	561.6655	549.4702	2.94	-3.29	-2.17
Douglas-fir	1	.0625	.0703	.0758	.0946	15	978	5.0273	5.6547	6.0971	7.6094	-17.55	-7.26	24.80
	2	.5625	.4496	.4651	.4844	30	122	2.8221	2.2557	2.3334	2.4302	20.94	-3.33	4.15
	3	4.0000	2.6150	2.8615	2.7732	45	91	9.9793	6.5239	7.1389	6.9186	39.79	-8.61	-3.08
	4	16.0000	14.8618	15.1632	14.7494	60	19	6.2507	5.8061	5.9238	5.7622	5.52	-1.99	-2.73
	5	36.0000	34.0297	34.3642	34.7086	75	9	5.3296	5.0379	5.0874	5.1384	4.76	-0.97	1.00
	Total	-	-	-	-	-	-	29.4090	25.2783	26.5806	27.8588	10.64	-4.90	4.81
Aspen	1	.0625	.1080	.1161	.1005	15	101	0.5192	0.8971	0.9644	0.8384	-46.16	-6.98	-13.44
	2	.5625	.4269	.4454	.5013	30	69	1.5961	1.2113	1.2638	1.4224	26.29	-4.15	12.55
	3	4,0000	2.9774	3.2895	3.0199	45	52	5.7024	4.2446	4.6895	4.3052	21.60	-9.49	-8.19
	4	16.0000	14.9490	15.2826	15.0180	60	12	3.9478	3.6885	3.7708	3.7055	4.69	-2.18	-1.73
	5	36.0000	34.1745	34.4780	35.0346	75	4	2.3687	2.2486	2.2686	2.3052	4.41	-0.88	1.61
	Total	-	-	-	-	-	-	14.1342	12.2901	12.9571	12.5731	9.08	-5.15	-2.96
White spruce	1	.0625	.0897	.0980	-	15	385	1.9791	2.8403	3.1032	-	-36.22	-8.47	-
	2	.5625	.4844	.5061	-	30	85	1.9662	1.6932	1.7691	-	11.14	-4.29	-
	3	4.0000	2.9063	3.2235	-	45	65	7.1280	5.1791	5.7443	-	24.09	-9.84	-
	4	16.0000	14.1602	14.4066	-	60	10	3.2899	2.9115	2.9622	-	11.06	-1.71	-
	5	36.0000	34.4346	34.7522	-	75	13	7.6983	7.3635	7.4315	-	3.59	-0.92	-
	Total	-	-	-	-	-	-	22.0615	19.9877	21.0103	-	5.00	-4.87	-

Table 2.4 Specific gravity (g/cm³) per size class and condition for Douglas-fir, lodgepole pine, aspen and white spruce.

Condition	Size class Range (cm)	Lodgepole pine n	Lodgepole pine G	Lodgepole pine Sx	Douglas-fir n	Douglas-fir G	Douglas-fir Sx	Aspen n	Aspen G	Aspen Sx	White spruce n	White spruce G	White spruce Sx
Sound and rotten	0.0-0.49	30	.4413	.0181	29	.4800	.0177	31	.5084	.0180	30	.4753	.0191
	0.5-0.99	31	.4823	.0131	30	.5763	.0105	31	.4781	.0207	30	.5523	.0160
	1.0-2.99	30	.4793	.0202	29	.5472	.0126	31	.3958	.0137	29	.5841	.0131
	3.0-4.99	30	.4763	.0109	30	.5000	.0166	31	.4045	.0081	29	.5338	.0220
	5.0-6.99	30	.4330	.0139	31	.4955	.0102	31	.4316	.0136	30	.4683	.0155
Sound	7-8.9	5	.5160	.0291	6	.5100	.0244	4	.4350	.0202	5	.4340	.0172
Rotten		5	.4480	.0203	5	.4240	.0140	6	.3800	.0248	5	.3580	.0289
Sound	9-10.9	9	.4511	.0092	5	.5660	.0040	5	.3860	.0194	5	.4460	.0153
Rotten		5	.4080	.0280	5	.4900	.0279	4	.2950	.0272	5	.4040	.0150
Sound	11-12.9	5	.4560	.0150	3	.4800	.0264	4	.4375	.0175	5	.4340	.0308
Rotten		5	.3720	.0386	6	.4950	.0203	7	.3943	.0342	5	.4220	.0086
Sound	13-14.9	5	.4740	.0258	5	.5520	.0389	6	.4117	.0162	5	.4180	.0165
Rotten		5	.3960	.0206	6	.3883	.0442	3	.2933	.0696	4	.3725	.0342
Sound	15-16.9	6	.4467	.0150	5	.4840	.0223	5	.4340	.0181	5	.4360	.0169
Rotten		6	.4267	.0123	3	.4533	.0333	4	.3925	.0320	5	.4140	.0216
Sound	7-16.9	30	.4657	.0086	24	.5212	.0131	24	.4192	.0085	25	.4336	.0084
Rotten		26	.4108	.0114	25	.4492	.0155	24	.3613	.0172	24	.3950	.0105

cm in diameter) for sound and for rotten large down and dead roundwood fuels have been obtained from weighed specific gravity averages distributed between five size classes, specifically 7-8.9, 9-10.9, 11-12.9, 13-14.9 and 15-16.9 (Table 2.4).

The overall tendency is for the smaller size classes to display higher G values as compared to the larger size classes in the range of 7 to 17 cm. Specific gravity (G) values for rotten wood are consistently lower when compared to sound wood values for all four tree species. The standard error of the mean ($S\bar{x}$) associated with the rotten wood G values are generally higher than the $S\bar{x}$ associated with sound wood samples for lodgepole pine, Douglas-fir, aspen and white spruce.

A T-test performed on the combined large diameter (7-17 cm) values for sound versus rotten materials reveals highly significant differences at t .01 for all four species.

2.4 DISCUSSION

2.4.1 Representative class diameter (Di)

Fuel volumes calculated from graphical QMD (Table 2.3, column 15) differ from .41 to 24.80 percent (in absolute value), based on size class and species. The range of percent difference in wood volume observed between species for combined size classes 1-5 calculated using graphical versus experimental QMD values, varied from 2.17 to 4.81.

Comparable results were shown by Van Wagner (1982b) where the difference between wood volumes ranged from 0.1 to 21.7 percent and the total percent difference per species for combined size class varied by 4.8 percent. Table 2.5 shows a comparison of results.

Potential fire intensity (kW/m) was determined for each size class representative of the average of all lodgepole pine stands sampled by solving equation [1]. The low heat of combustion (H) value of 18,460 kJ/kg, was selected based on 10 percent fuel moisture content as suggested by Van Wagner (1972 and 1973), and Albini (1976). The rate of spread was arbitrarily set to 0.5 m per second (Table 2.6). The average weights for these plots was calculated using equation [8] and data from Tables 2.3 and 2.4.

The 13.31 percent difference in fuel weight estimation of size class 3 due to QMD methods used resulted in a difference in fire intensity of 96.92 kW/m or .64 m in flame length (Table 2.6).[4] But these theoretical differences in fire intensity taken at the level of one size class may be misleading, however, since they may not accurately represent natural forest fuel situations, in which fuel size classes are intermingled. The fact that wood particles are intermingled affects volume to area ratio and moisture of the fuel bed composed of all size classes, thus reflecting on the overall potential fire behavior.

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[4]Flame length estimated from equation: $I=259.833\ (L)^{2.174}$ (Alexander 1982).

Table 2.5 Wood volumes in five diameter classes from a line intersect sample in conifer slash (Van Wagner 1982b).[3]

Size class	Wood volume, m³/ha: From Experimental QMD	Wood volume, m³/ha: From graphical QMD	Difference: Percent
1	1.45	1.59	+9.7
2	1.08	1.28	+18.5
3	3.78	4.60	+21.7
4	7.98	7.99	+0.1
5	6.49	6.32	-2.6
Total	20.78	21.78	+4.8

[3]Table 2.5 is a correction of Table 2 in Van Wagner 1982b (personal communication with the author 14/1/85).

Table 2.6 Average weights and potential fire intensities calculated from experimental and graphical QMD's for an average lodgepole pine plot.

Size class	Average weight (kg/m^2) per lodgepole pine plot based on		Fire intensity (kW/m) obtained from I = Hwr (Byram 1959) based on	
	Experimental QMD	Graphical QMD	Experimental QMD	Graphical QMD
1	.0211	.0196	194.75	180.91
2	.0230	.0243	212.29	224.29
3	.0793	.0688	731.94	635.02
4	.1355	.1366	1250.66	1260.82
5	.1438	.1444	1327.27	1333.81

For that reason, wood volumes developed from different QMD values are more effectively compared based on mean value per species instead of size-class value. Differences smaller than five percent would occur if graphically instead of experimental QMD values were used to calculate total wood volumes based on combined size classes 1 to 5 (Table 2.3).

As in the case of the previous comparison, the percent error obtained when wood volumes obtained from average diameter ($\bar{D}$) estimates as opposed to experimental QMD values has a tendency to diminish from size class one to size class five for the same species. This in turn leads to errors in fire potential estimates. In this case, the sign affecting the percent error is always the same, suggesting a negative bias. This is due to the fact that in the quadratic mean method the diameters are squared, thus giving more weight to the larger values.

Results suggest using experimental QMD values instead of $\bar{D}$ would reduce wood volume biases by 3.29 to 5.15 percent for combined small size classes and by as much as 9.84 percent for a single size class (Table 2.3). Brown and Roussopoulos (1974) have observed differences as high as 16 percent. But there is no apparent advantage in using $\bar{D}$ over locally developed experimental QMD estimates since both are generated from the same expensively derived field data. Further, experimental QMD's better represent the natural situation over $\bar{D}$. This was recognized and adopted by several authors (Van Wagner 1968, Husch *et al* 1972, Brown 1974, Brown and Roussopoulos 1974, Bevins 1978, Ryan and Pickford 1978, Sackett 1980).

Percent difference in wood volume estimates resulting when arithmetic class centre (ACC) values were used as class diameter when compared to experimental QMD are quite substantial. Some values are as high as 46.16 percent (aspen) for one size class (0-0.49 cm) and 10.64 percent (Douglas-fir) for combined small size classes (Table 2.3). Fahnestock (1977) noted the same problem when diameter-class mid-points were used and suggested that arbitrary values might be more appropriate as class diameter. Modified mid-point diameters of 0.125, 0.5, and 1.5 inches for the 0-0.25, 0.25-1.0, and 1.0-3.0 inch size classes were used by Pickford *et al.* (1977) and were found to be the best approximators of class diameter based on a large sample size.

Composite QMD values are available for the Canadian (McRae *et al.* 1979) as well as for the American (Brown 1974, Anderson 1978) size classes. There are, however, a number of reasons restricting their usage. First, combined values of QMD only approximate the representative class diameter of a size class for a species. Second, composite QMD values published in Brown (1974) are averages of non-slash and slash fuels. Composite QMD values in McRae *et al.* (1979) are strictly related to slash fuels whereas the Jasper study pertains to a natural fuel situation. Third, the composite values from these two studies were developed from several species not native to Jasper. Fourth, only the McRae *et al*. 1979 size classes are common to those of the Jasper study. And finally, because the geographic location from which composite QMD's were developed is so distant from Jasper, genetic variation in plants of the same species could cause difference in QMD estimates. This last point is particularly important and is emphasized in a study by Ryan and Pickford (1978), where locally developed QMD's are known to have reduced the bias in predicted fuel loadings by 4 to 57 percent.

QMD or specific gravity values generated from slash versus natural fuel situation should, for the same species sampled in stands of the same region, be different, as recognized by Brown (1974). This is due to the fact that fresh slash material is generally covered with bark which contrasts with the generally bark-less naturally fallen small (<7 cm in diameter) down and dead material. These differences should gradually disappear as bark detaches from slash material with time.

2.4.2 Specific gravity

Several of the factors limiting the use and comparison of representative class diameters between different studies, also apply to specific gravity (G) data. Specific gravity data are expensive to produce and are only published in a few papers. Most specific gravity values are only compatible with the American diameter-class system (Brown 1972, Beaufait and Hardy 1973, Ryan and Pickford 1978, Sackett 1980). Composite G values are available (Brown 1974, McRae *et al.* 1979), but, as in the case of composite QMD values there are a number of reasons for not using them in the context of Jasper fuel study. The best and only serious alternative to accurate G values per size class per species and condition is to locally develop the values. In fact, it might be necessary in order to obtain realistic fuel loading estimates since differences in predicted loading caused by use of local determination of specific gravity ranged from 2 to 44 percent in a study performed in the Blue Mountains of Oregon (Ryan and Pickford 1978).

Specific gravity values developed for size classes 1 to 5 of the four tree species selected for this project were obtained from a minimum sample size of about 30. Results suggesting larger specific gravity values for smaller size classes as compared to higher size classes (Table 2.4) may be attributed to the larger proportion of dense heartwood contained in smaller woody material.

Because of the relatively small sample size of about 25 for the combined (7-17 cm) larger material, a T-test was used to establish if differences between sound and rotten values were significant for all species sampled. Significant differences at 95 percent confidence level have been found between sound and rotten material of all four species. A larger variation would probably have resulted if the specific gravity of all punky samples collected could have been successfully estimated through laboratory procedures. The very punky material has low specific gravity values but was difficult to process using the laboratory procedures described earlier.

The larger sx values associated with rotten versus sound material (Table 2.4) are probably due to the wider range of specific gravity values which could qualify as rotten as compared to sound. Both determinations were based on subjective judgements.

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3. BIOMASS REGRESSION EQUATIONS FOR COMMON SHRUBS AND TREE SEEDLINGS NATIVE TO JASPER NATIONAL PARK, ALBERTA

3.1 INTRODUCTION

Live plant biomass is "potential fuel" (Brown and Davis 1973) which may contribute to the total heat output, spread rate, and resistance to control of a wildland fire. Shrub and tree seedling biomass is important because of the amount of organic material by weight and volume it contributes to the total fuel loading of a stand. In addition, these plants contribute to the vertical layering of the fuelbed. This third dimension directly affects the crowning potential of the stand because these shorter plants act as "ladder fuels" (Brown and Davis 1973, Pyne 1984). Also, the natural disposition of dead foliage, twigs and bark flakes are intercepted or collect on these standing plants, thus reducing the decaying process and creating a more continuous and well aerated fuelbed. This phenomenon is particularly important at the forest floor level where thick stands of common bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) or twin-flower (*Linnaea borealis* L. var. *americana* (Forbes) Rehd.) are present (Muraro 1964, Lawson 1972, Fahnestock 1976, and Alexander 1978).

Several authors have published regression equations or tables which predict the oven-dry weight of standing live and dead biomass from easily obtained independent variables such as basal diameter, height, canopy or ground cover (percent) or diameter at breast height (dbh) (Telfer 1969 and 1972, Bentley, Seegrist and Blakeman 1970, Brown 1976, Brown and Marsden 1976, Edwards 1976, Ohmann, Grigal and Brander 1976, Grigal and Ohmann 1977, Roussopoulos and Loomis 1979, Martin, Frewing and McClanahan 1981, Ohmann, Grigal and Rogers 1981, Olson and Martin 1981, Agee 1983). But most of these relationships are for plant species not native to the study area or the data were obtained from species growing on sites geographically distant from the study area. Additionally, most analogs were not developed to predict the weight of fuel components for use with fuel size classes recognized by most forestry agencies in Canada.

Therefore, as part of the forest fuel quantification study (Delisle 1983),[5] relationships between various independent variables and oven-dry weight were developed for four species of tree seedlings (≤3 m in height): lodgepole pine (*Pinus contorta* Loudon var. *latifolia* Engelm.),[6] Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white spruce (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.) and aspen (*Populus tremuloides* Michx.); five species of shrubs: Canadian buffalo-berry (*Shepherdia canadensis* (L.) Nutt.), ground juniper (*Juniperus communis* L.), Saskatoon-berry (*Amelanchier alnifolia* Nutt.), white meadowsweet (*Spiraea lucida* Dougl.) and prickly rose (*Rosa*

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[5]Delisle, G. 1983. Forest fuels quantification in the Montane forest surrounding Jasper townsite, Jasper National Park, Canada. Study proposal. Unpublished report.
[6]Moss (1983) is the scientific authority consulted for all common and scientific plant names used in this thesis.

acicularis Lindl.); and two species of dwarf shrubs: common bearberry and twin-flower.

3.2 METHODS

3.2.1 Shrubs and tree seedlings (≤3 m in height)

Randomly located and oriented two-meter wide transect lines of different lengths were established in five different stands for each species. Information pertaining to selected shrubs and tree seedling stems: basal diameter (cm), height (cm), and dbh (cm) (when applicable) was collected. Once measured all aerial portions of shrub and tree seedling stems were collected. An attempt was made to collect data from the smallest to the largest individual of each species, with two samples per 0.10 cm basal diameter increment. This resulted in different sample sizes by species.

Laboratory work consisted of separating foliage from wood and further stratifying woody material into appropriate size classes: (size class 1 (0-0.49 cm), size class 2 (0.50-0.99 cm), size class 3 (1-1.49 cm), size class 4 (1.50-1.99 cm), size class 5 (2.00-2.99 cm), size class 6 (3.00-4.99, and size class 7 (5.00-7.00 cm)). Woody material and foliage were subsequently oven-dried for a period of 24 hours at 100°C (Ponto 1972) and then weighed to nearest 0.1 g.

3.2.2 Dwarf shrubs

Randomly located plots (30 x 60 cm) used to sample common bearberry and twin-flavor were established in the study area as part of the Jasper forest fuels quantification study (Delisle 1983).[7] The percent cover (± 1%) and height (± 0.5 cm) of the dwarf shrub species was visually estimated for each plot. Live and dead shrub material (leaves and stems) located above the forest floor and contained in a vertical projection of the sampling frame was collected, oven-dried for 24 hours at 100°C and weighed to ±0.1 g.

Oven-dried weights of the different size classes, of total wood (total of all size classes), foliage and of total stem (wood and foliage) were used to develop basal diameter (d), dbh (when available) and height (h) regression equations for medium shrubs and tree seedlings. Oven-dried biomass of dwarf shrub material were used to develop regression equations based on percent cover and height.

3.3 RESULTS

3.3.1 Shrubs and tree seedlings (≤3 m in height)

Regression equations describing the relationships between the log of the basal stem diameter (d) and the dependent variables (total weight, foliage weight, wood weight and wood weights of size classes one and two (when

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[7]Delisle, G. 1983. Forest fuels quantification in the Montane forest surrounding Jasper townsite, Jasper National Park, Canada. Study proposal. Unpublished report.

applicable), were developed for tree seedlings and shrubs based on oven-dried collected samples (Table 3.1 and 3.2). Curves for the regression equations presented in Table 3.2 representing the data distribution for the fuels components by species, and plotted on the same scale are shown in Figures 3.1 to 3.9. Regression curves with data points for every fuel component of the tree seedlings and shrubs have also been produced (See Appendix II).

Among the variables: basal diameter (d), dbh and height (h), log (d) had the highest correlation with log (w) for all weight components for all species of tree seedlings and shrubs. Diameter at breast height (dbh) was not considered as an independent variable since it only applied to larger stems. Height (h) was also disregarded as a variable because it is not a truly independent variable when used in conjunction with basal diameter. Covariance analysis confirmed that only a small increase in precision was gained by using log (h) as a second independent variable.

T-tests conducted on intercept (d) and slope (b) were found significant to the 99 percent level for all equations presented in Table 3.2. These equations all exhibited a highly significant F ratio, thus, verifying of the sound relationship between dependent and independent variables.

Although T and F tests related to the regression equation developed for size class 2 of lodgepole pine turned out to be highly significant, it was rejected on the basis of a surprisingly low r^2 and high SEE values.

Table 3.1 Sampling intensity, percent frequency occurrence per stem for size classes 1 to 7, and basal stem diameter range sampled for shrubs and tree seedlings (≤3 m in height).

Species	n	SC1	SC2	SC3	SC4	SC5	SC6	SC7	Basal stem diameter (cm)
Shrubs									
Canadian buffalo-berry	59	100	81	61	32	20	-	-	0.19-3.19
Ground juniper	44	100	73	45	23	5	-	-	0.08-3.00
Saskatoon-berry	22	100	55	-	-	-	-	-	0.18-1.15
White meadowsweet	12	100	-	-	-	-	-	-	0.19-0.31
Prickly rose	20	100	-	-	-	-	-	-	0.15-0.58
Tree seedlings (≤3 m in height)									
Lodgepole pine	85	100	89	73	56	46	11	-	0.27-5.64
Douglas-fir	89	100	89	71	58	47	18	3	0.14-7.85
Aspen	19	100	47	16	-	-	-	-	0.17-1.00
White spruce	86	100	91	74	59	47	16	-	0.19-5.64

SC1 = Size class 1 (0.00-0.49 cm)
SC2 = Size class 2 (0.50-0.99 cm)
SC3 = Size class 3 (1.00-1.49 cm)
SC4 = Size class 4 (1.50-1.99 cm)
SC5 = Size class 5 (2.00-2.99 cm)
SC6 = Size class 6 (3.00-4.99 cm)
SC7 = Size class 7 (5.00-6.99 cm)

Table 3.2 Regression components for estimating weight of various tree seedling and shrub species using the linear regression model: log (weight, g) = a + b log (basal diameter, cm) + log e

Species	Weight	n	a	b	r^2	SEE	F
Lodgepole pine	Total	85	1.36	2.53	0.984	0.1027	4950.82
	Foliage	85	1.05	2.19	0.948	0.1641	1515.30
	Wood	85	1.03	2.84	0.978	0.1371	3614.89
	Size class 1	85	0.65	2.18	0.966	0.1307	2383.70
Douglas-fir	Total	89	1.39	2.43	0.982	0.1222	4830.53
	Foliage	89	1.12	2.24	0.981	0.1157	4747.38
	Wood	89	1.05	2.62	0.981	0.1357	4680.28
	Size class 1	89	0.83	2.17	0.977	0.1245	3624.62
	Size class 2	79	0.43	2.19	0.846	0.2340	428.34
White spruce	Total	86	1.54	2.49	0.984	0.1092	5212.00
	Foliage	86	1.27	2.38	0.972	0.1385	2998.00
	Wood	86	1.19	2.63	0.986	0.1099	5804.83
	Size class 1	86	0.96	2.26	0.974	0.1275	3217.31
	Size class 2	78	0.61	1.83	0.757	0.2577	237.80
Aspen	Total	19	1.17	2.29	0.944	0.1447	283.75
	Foliage	19	0.31	1.65	0.649	0.3138	31[illegible]
	Wood	19	1.13	2.60	0.828	0.2157	479.[illegible]8
	Size class 1	19	0.72	1.83	0.828	0.2157	81.62
	Size class 2	9	0.88	4.58	0.743	0.1975	20.21
Canadian buffalo-berry	Total	59	1.58	2.77	0.971	0.1597	1843.96
	Foliage	59	0.86	2.05	0.886	0.2425	442.05
	Wood	59	1.46	2.96	0.970	0.1719	1821.23
	Size class 1	59	1.20	2.33	0.934	0.2049	803.52
	Size class 2	48	1.02	2.61	0.888	0.1745	369.10

Table 3.2 continued

Ground Juniper	Total	44	1.79	2.43	0.975	0.1516	1657.04
	Foliage	44	1.52	2.26	0.967	0.1637	1221.74
	Wood	44	1.45	2.57	0.970	0.1786	1332.50
	Size class 1	44	1.17	2.16	0.953	0.1893	840.69
	Size class 2	32	0.96	2.13	0.644	0.2790	54.34
Saskatoon-berry	Total	22	1.56	3.01	0.977	0.1239	881.47
	Foliage	22	0.71	2.21	0.901	0.1976	181.69
	Wood	22	1.50	3.35	0.981	0.1245	1093.60
	Size class 1	22	1.05	2.53	0.961	0.1381	488.41
	Size class 2	12	1.36	4.63	0.770	0.2576	33.55
Whyte meadowsweet	Total	12	1.76	2.89	0.931	0.1134	134.85
	Foliage	12	0.98	2.40	0.805	0.1707	41.30
	Wood	12	1.76	3.19	0.955	0.1002	212.07
Prickly rose	Total	20	1.55	2.40	0.869	0.1863	119.52
	Foliage	20	0.93	1.89	0.570	0.3283	23.82
	Wood	20	1.44	2.72	0.868	0.2115	118.72

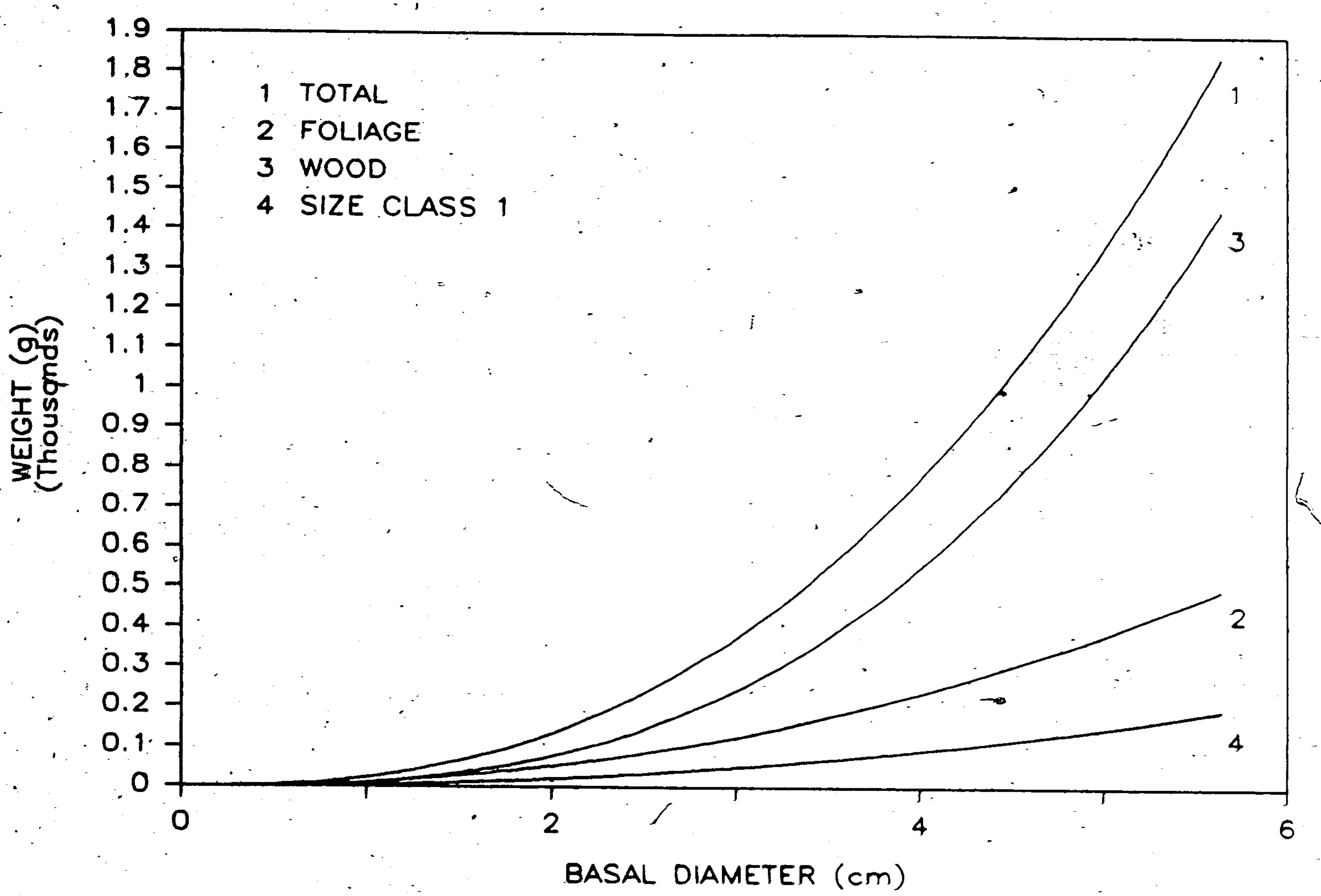

Figure 3.1 Regression equation curves representing different fuel components of lodgepole pine (*Pinus contorta*) seedlings (≤3 m in height).

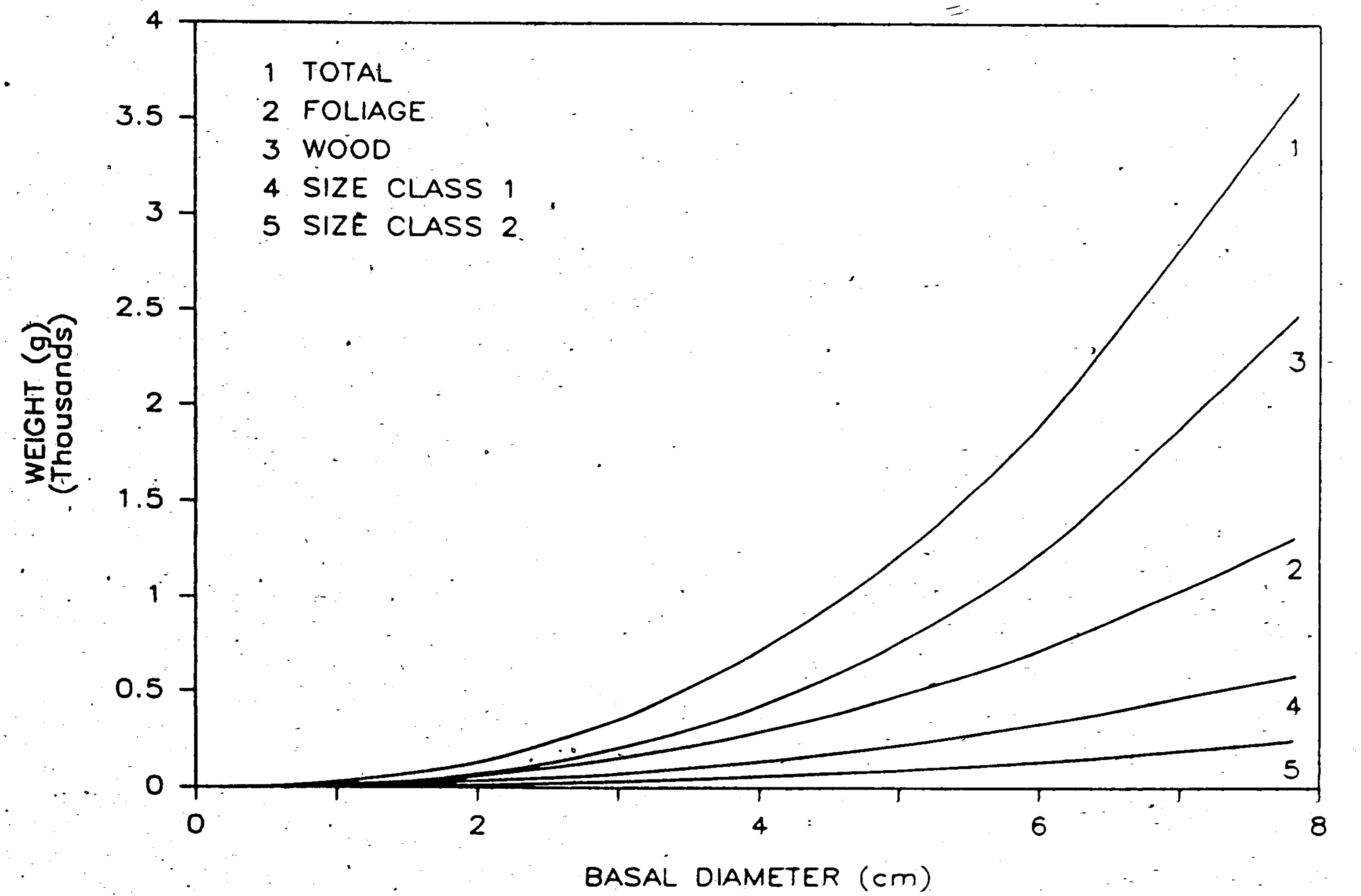

Figure 3.2 Regression equation curves representing different fuel components of Douglas-fir (*Pseudotsuga menziesii*) seedlings (≤3 m in height).

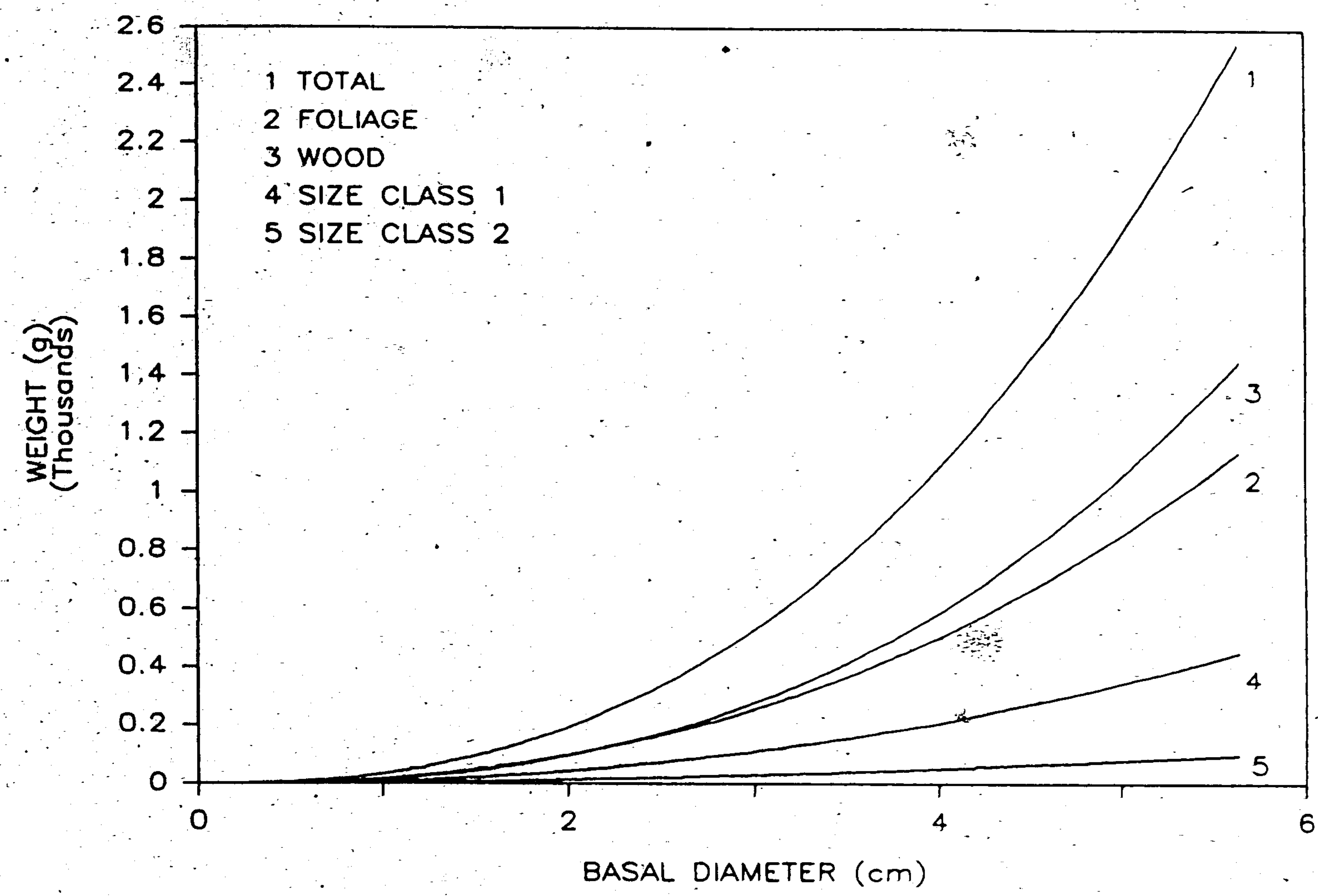

Figure 3.3 Regression equation curves representing different fuel components of white spruce (*Picea glauca*) seedlings (≤3 m in height).

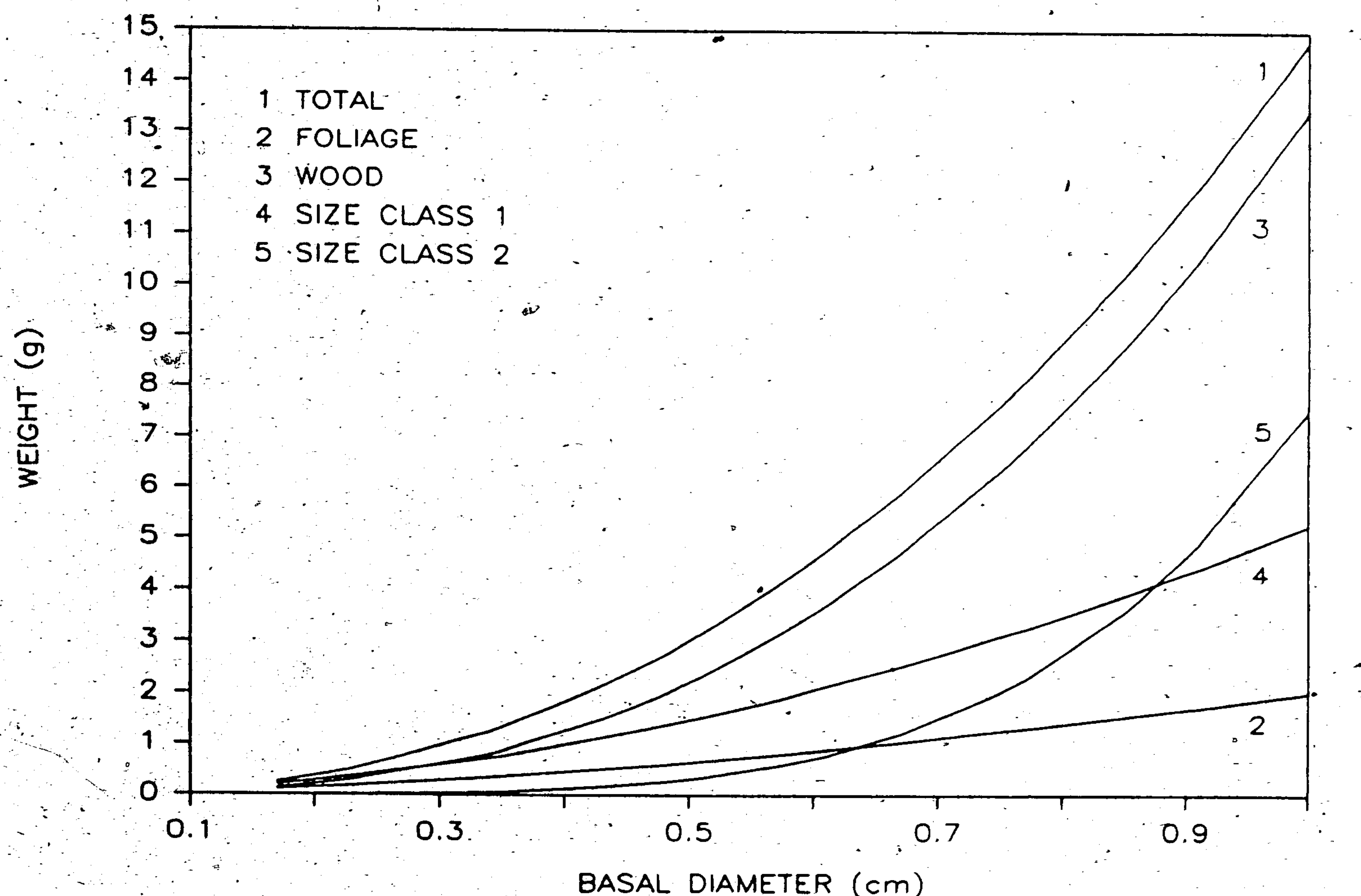

Figure 3.4 Regression equation curves representing different fuel components of aspen (*Populus tremuloides*) seedlings (≤3 m in height).

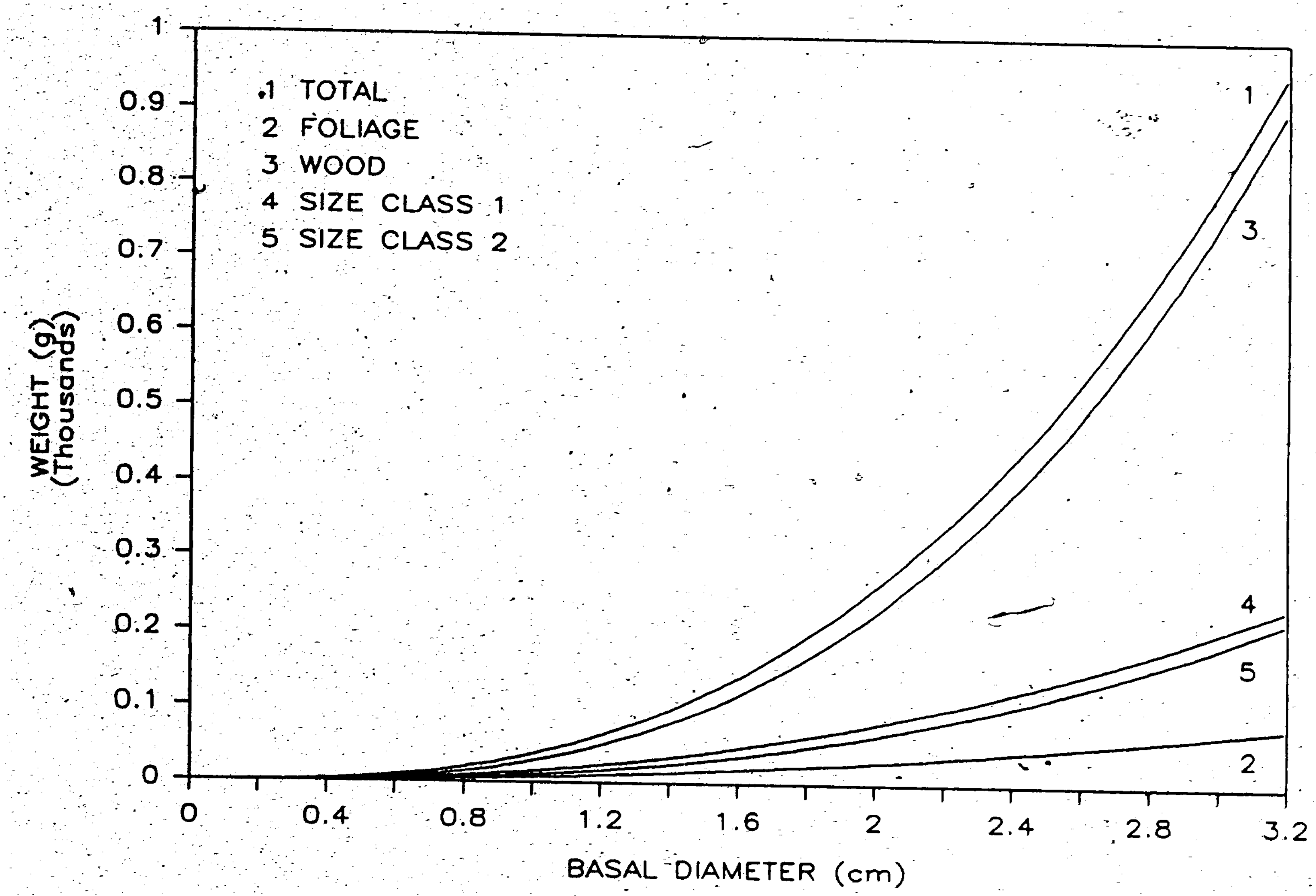

Figure 3.5 Regression equation curves representing different fuel components of Canadian buffalo-berry (*Shepherdia canadensis*) shrub.

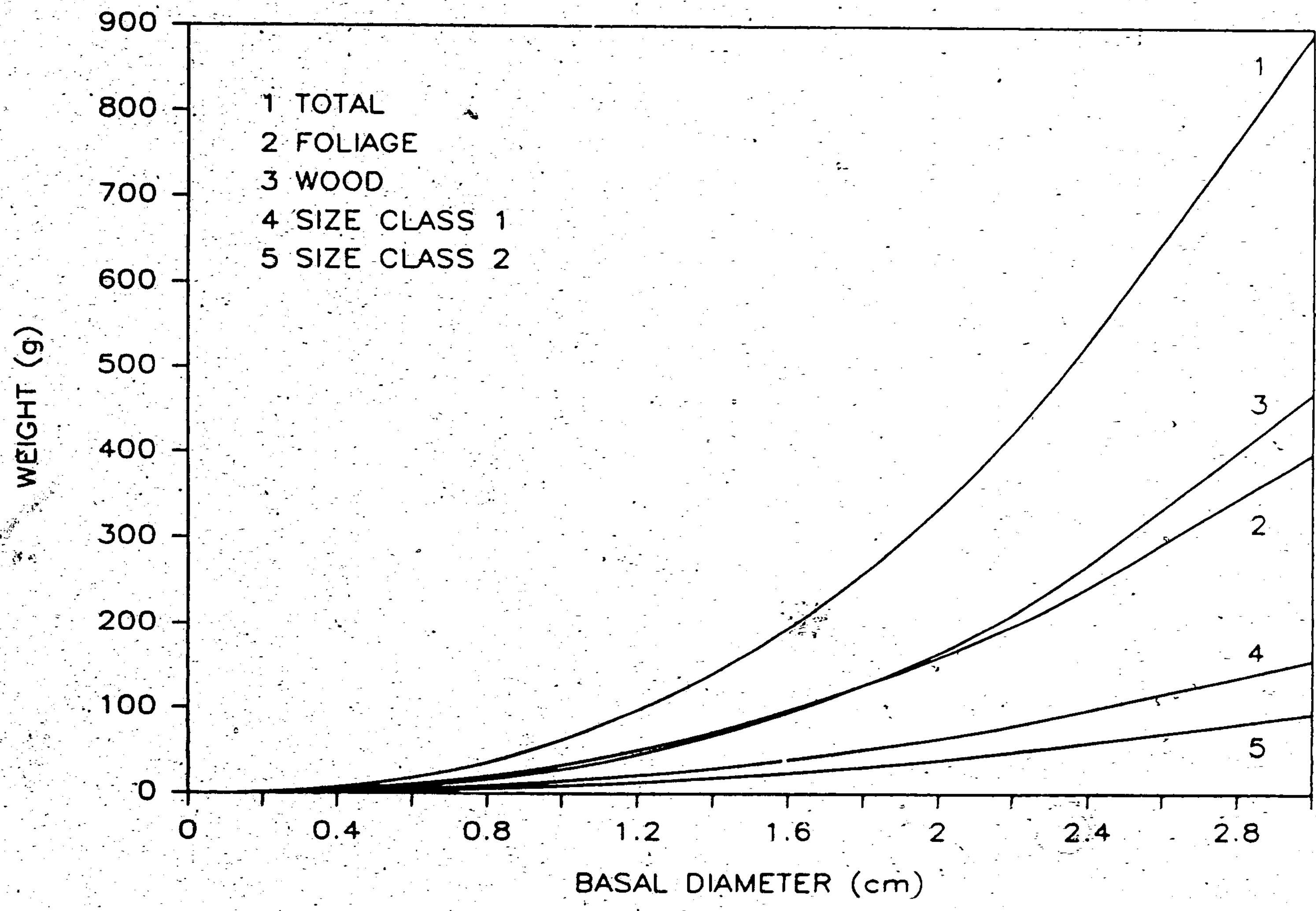

Figure 3.6 Regression equation curves representing different fuel components of ground juniper (*Juniperus communis*) shrub

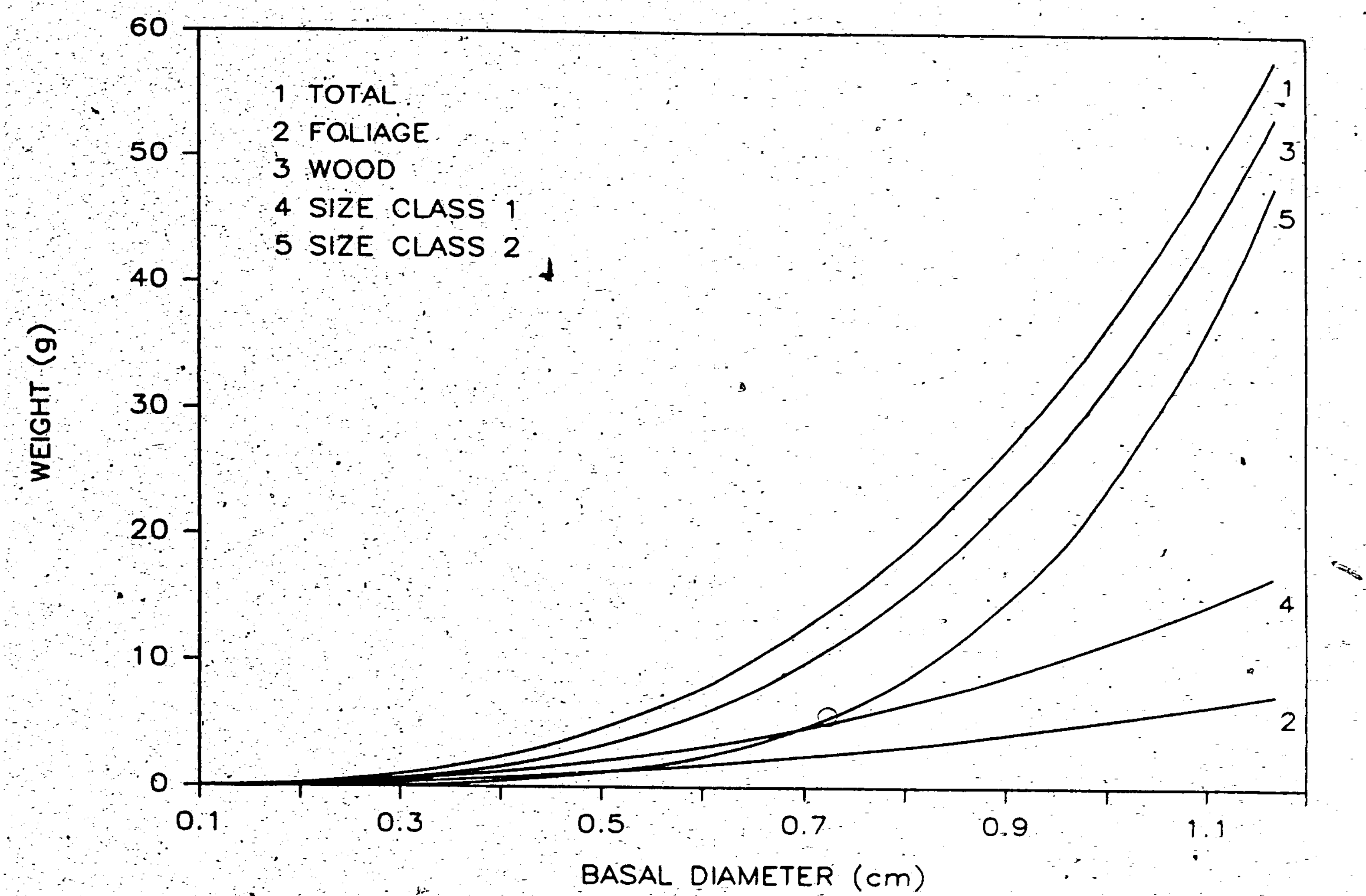

Figure 3.7 Regression equation curves representing different fuel components of Saskatoon-berry (*Amelanchier alnifolia*) shrub.

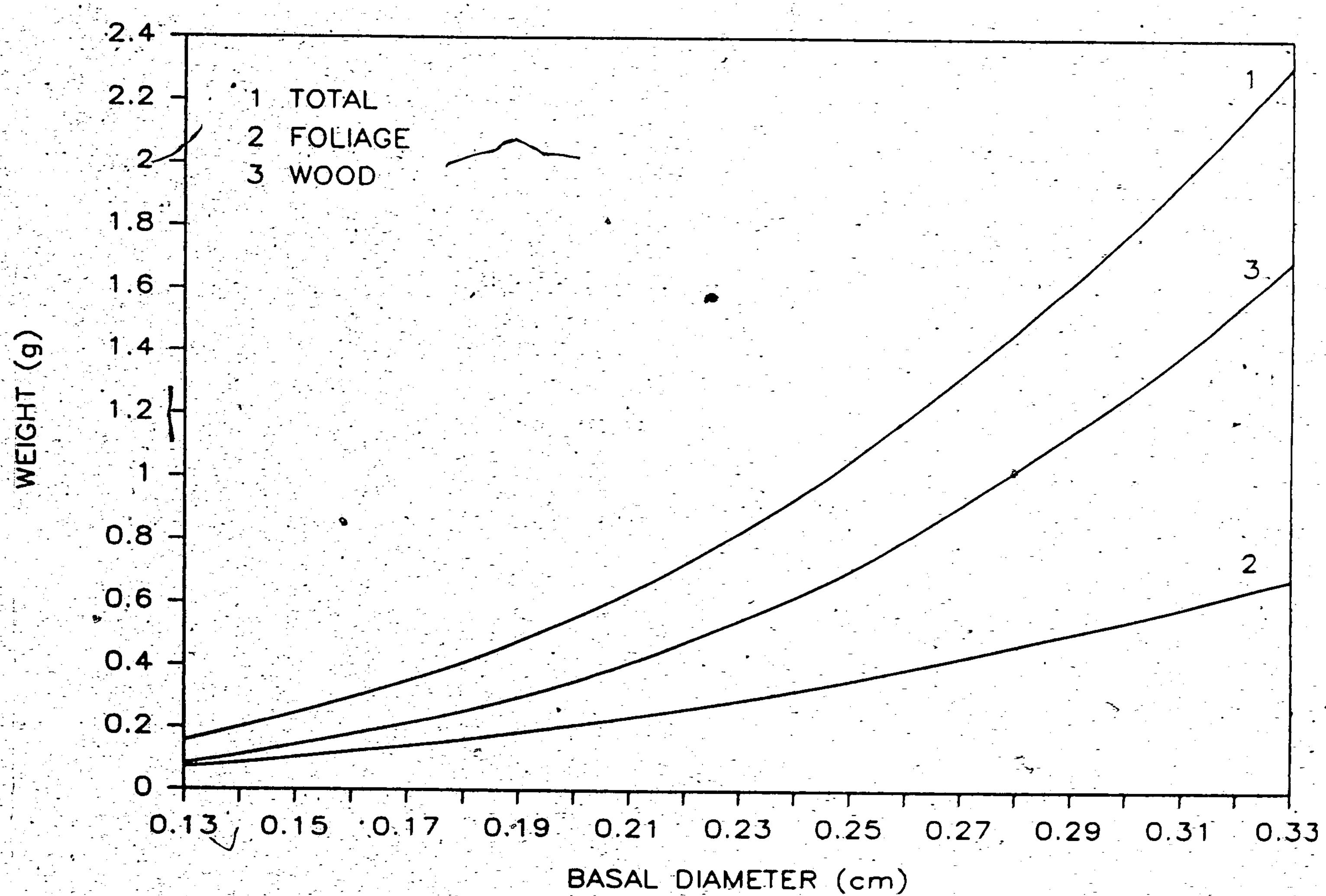

Figure 3.8 Regression equation curves representing different fuel components of white meadowsweet (*Spiraea lucida*) shrub.

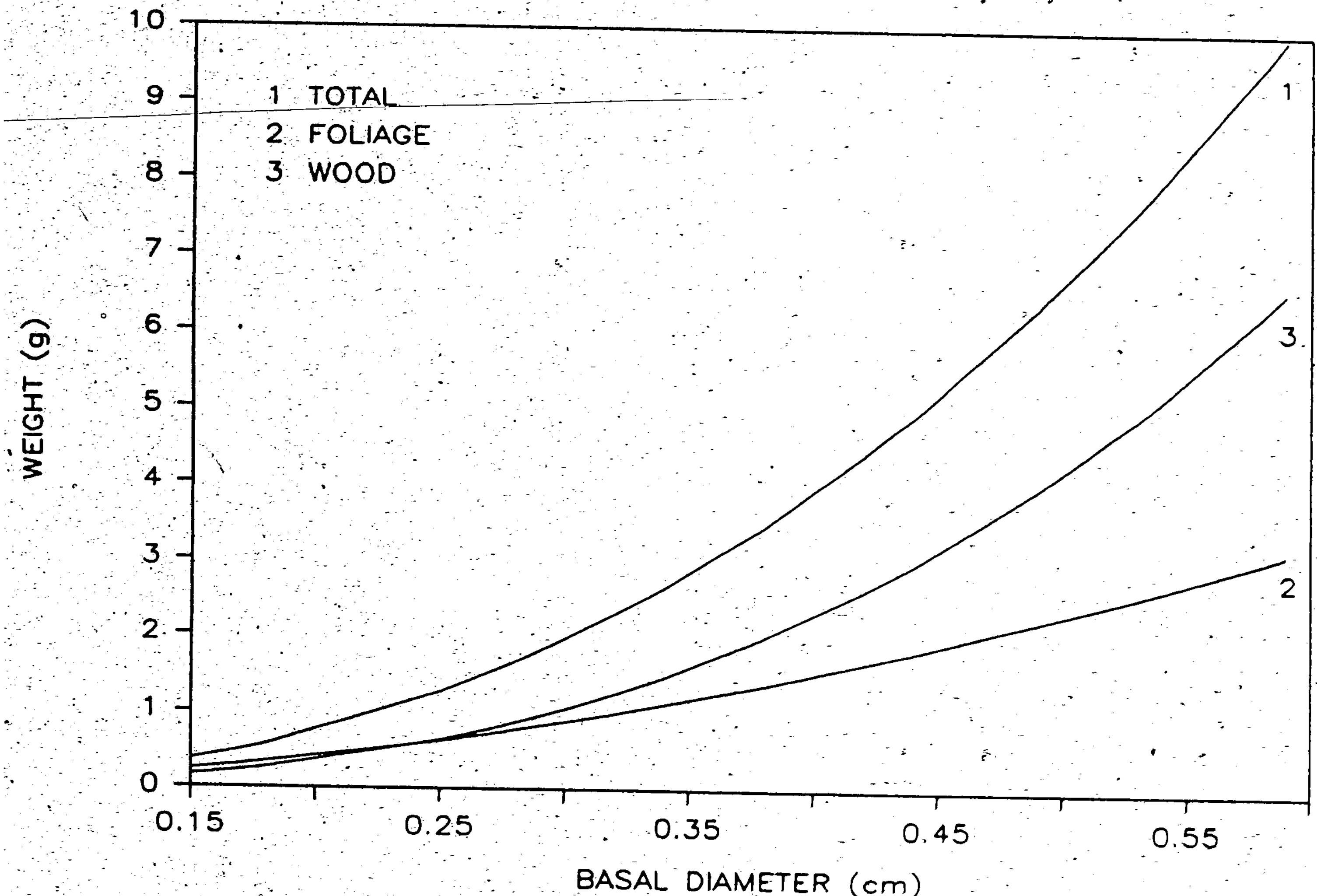

Figure 3.9 Regression equation curves representing different fuel components of prickly rose (*Rosa acicularis*) shrub.

Since no size class 2 white meadowsweet and prickly rose material was sampled, weight of size class 1 is equivalent to wood weight (Table 3.2).

3.3.2 Dwarf shrubs

Height was rejected as an independent variable for both twin-flower and common bearberry species. This was done for two reasons: first, height measurement is very subjective, depending on how the plant lays on the forest floor and second, because the height variations among dwarf shrub plots are rather small. This observation agrees with that reported by Alexander (1978).

Relationships between cover (percent) and weight (t/ha) for dwarf shrub species were established through regression analysis, based on 230 twin-flower and 210 common bearberry randomly located plots (30 x 60 cm). A power function (arithmetic model) was used to model the distribution of twin-flower data (Figure 3.10) and a second degree polynomial equation was used to model the distribution of common bearberry data (Figure 3.11). As for shrub and tree seedling regression equations, the twin-flower regression equation intercept was corrected for logarithmetic bias according to Baskerville (1972). An F ratio significant at the 99 percent level for both equations presented in Table 3.3 emphasizes the validity of the relationship between dependent and independent variables. A T-test conducted on slopes (b) of dwarf shrubs' regression equations was highly

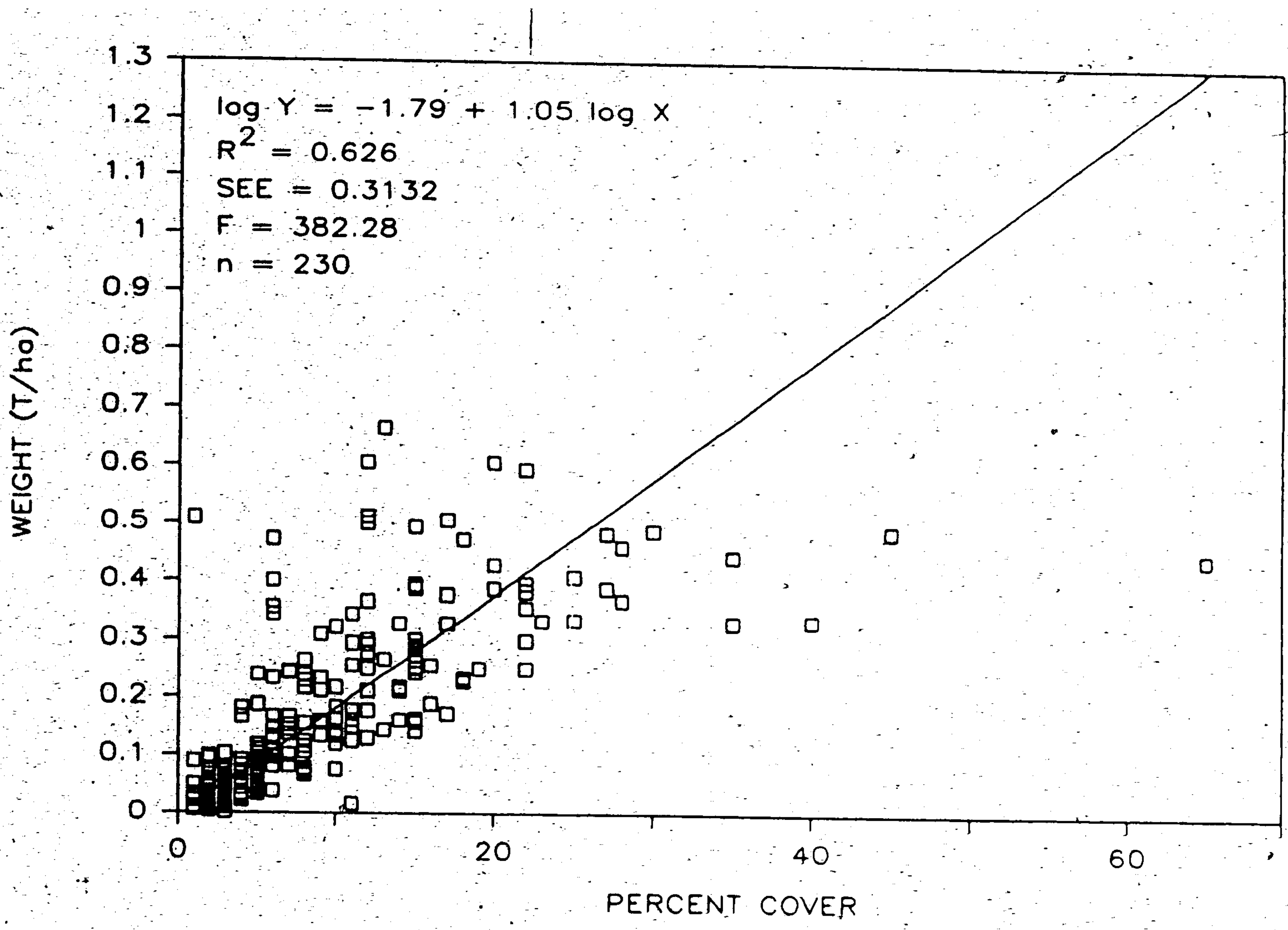

Figure 3.10 Data points and regression equation curve modeling the relationships between percent cover and weight (t/ha) for twin-flower (*Linnaea borealis*).

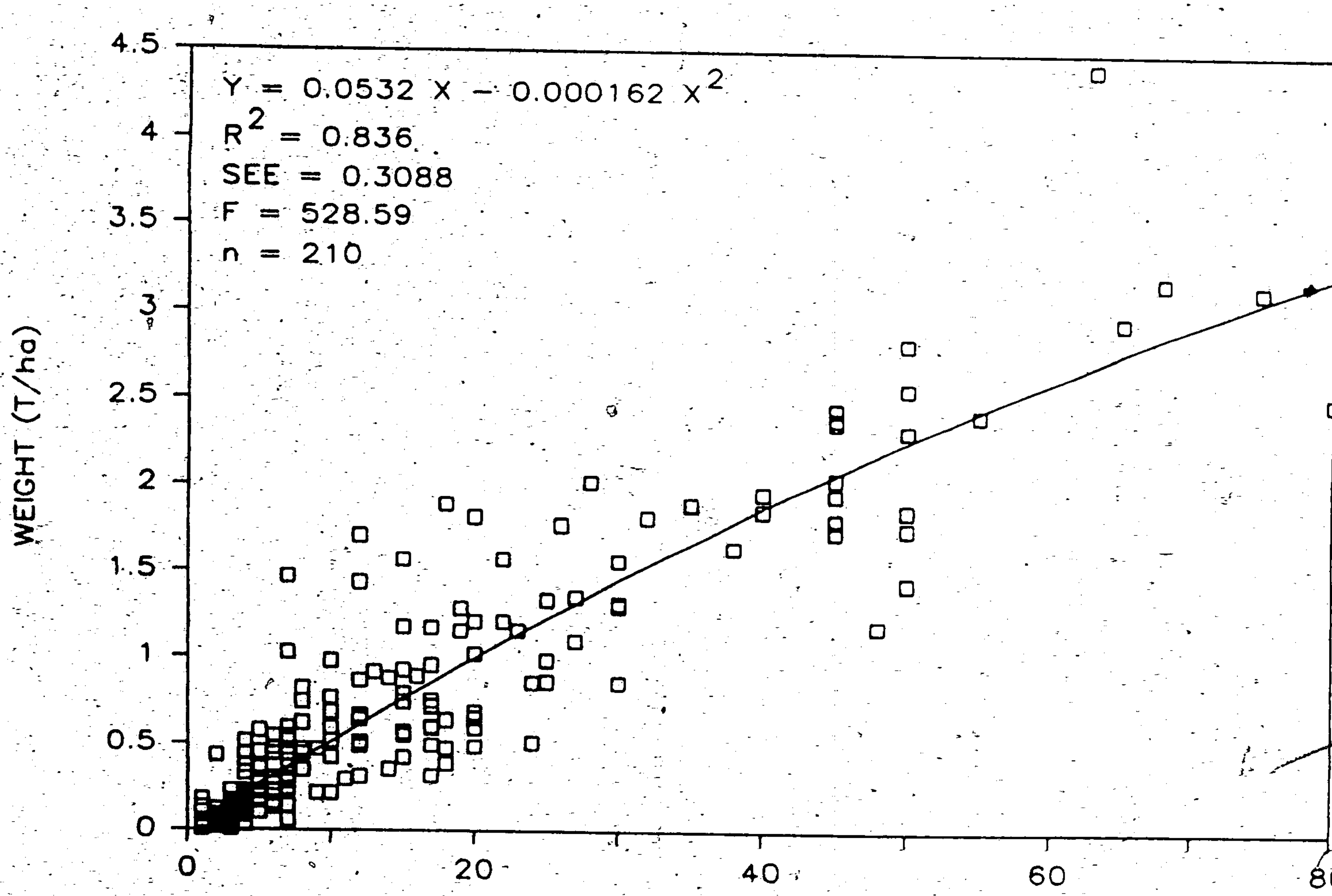

Figure 3.11 Data points and regression equation curve modeling the relationships between percent cover and weight (t/ha) for common bearberry (*Arctostaphylos uva-ursi*).

Table 3.30 Regression equations for estimating weight of dwarf shrub species based on cover.

Common Bearberry
$\text{Weight (t/ha)} = 0.0532\ (\%\ \text{cover}) - 0.000162\ (\%\ \text{cover})^2$
$R^2 = 0.836$
$SEE = 0.3088$
$F = 528.59$
Twin-flower
$\text{Log (weight) (t/ha)} = -1.79 + 1.05\ \log\ (\%\ \text{cover})$
$r^2 = 0.626$
$SEE = 0.3132$
$F = 382.28$

significant, thus allowing the rejection of the hypothesis of b=0. A T-test conducted on the intercept (a) of the common bearberry regression equation was found to be non-significant. For that reason, the intercept value was discarded, thus forcing the intercept through the origin (Figure 3.11). Since the T-test conducted on the intercept (a) of the twin-flower regression equation was found highly to be significant, it was retained in the equation (Table 3.3).

3.4 DISCUSSION

3.4.1 Shrubs and tree seedlings (≤3 m in height)

Plotted tree seedling and shrub data by weight over basal stem diameter of various components (Appendix I), revealed that the power function was well suited to model the distribution (Zar 1968). The linear form of the allometric model ($\log y_i = \log a + b \log x_i + \log \epsilon_i$) was used to predict component oven-dried weight (y) in g from basal stem diameter values (x) cm, with an error of ϵ, in order to generate statistics related to the regression equations.

Transformation of estimates from a logarithmic equation back to arithmetic units may not be done directly without introducing a bias resulting in a systematic under-estimation of weight (Zar 1968). A direct transformation based on antilog transformation fails to account for the skewness of the distribution in arithmetic units, thus yielding the median rather than the mean value of y for a given x (Baskerville 1972). This was rectified by adjusting the intercept using the following equation:

$$\hat{Y} = 10^{(a + MSR/2)} \qquad [1]$$

where:

a = intercept

MSR = mean square residual

$\hat{Y}$ = adjusted intercept (Baskerville 1972)

Although oven-dried weights for tree seedling and shrub stems were determined for every component by size-class, only regression equations representing the first size classes were considered, and this for both statistical and practical reasons. Statistical justification is based on the facts that the general trend in regression equations from size class 1 to 7 is: diminishing sample size (n) (Table 3.1), poorer distribution of residuals, increasing standard error of the estimate (SEE) diminishing coefficient of determination values (r^2) and decreasing F statistic and T values related to intercept and slope to the point where they become non-significant (Table 3.4 and Appendix III). Since live tree seedling and shrub material larger than one cm in diameter would rarely be consumed during even high intensity fires (personal communication from Z. Chrosciewicz 20/3/86), there was no practical reason for developing

Table 3.4 Statistics related to tree seedling and shrubs regression equations which have been rejected.

Species	Size class	n	r^2	SEE	F
Lodgepole pine	2	76	0.463	0.3750	63.7169
	3	62	0.057	0.2538	3.6181
	4	48	0.004	0.2978	0.1621
	5	39	0.327	0.2895	17.9475
	6	9	0.646	0.1726	12.7898
Douglas-fir	3	63	0.557	0.1913	76.8033
	4	52	0.453	0.2272	41.4651
	5	42	0.639	0.2517	70.7946
	6	16	0.724	0.3735	36.7240
	7	3	0.600	0.5715	1.5006
White spruce	3	64	0.131	0.2519	9.3643
	4	51	0.228	0.2678	14.4393
	5	40	0.637	0.2541	66.8080
	6	14	0.816	0.2862	53.3248
Trembling aspen	3	0.258	0.1041	0.3475	
Canadian buffalo-berry	3	36	0.414	0.3073	23.9894
	4	19	0.071	0.2752	1.3062
	5	12	0.037	0.2593	0.3827
Ground juniper	3	20	0.109	0.3275	2.2022
	4	10	0.101	0.2314	0.8950
	5	2	–	–	–

statistically sound regression equations of the general form: $\log y_i = \log a + b \log x_i + \log \epsilon_i$ for size class 3 and larger.

Trends in Figures 3.1 to 3.9 suggest the distribution of biomass in a stem is related more to the fact that the species has needle-like leaves instead of broad leaves than if the species belonged to the tree seedling as opposed to the shrub category. Foliage weight of white spruce (Figure 3.3) and common ground juniper (Figure 3.6) have almost as high as wood weight, which should be taken into consideration when dealing with fire behavior potential.

The high biomass value of size class 2 as compared to size class 1 and foliage displayed by aspen (Figure 3.4) and Saskatoon-berry (Figure 3.7) suggest that animal predation may occur, thus reducing the importance of biomass from size class 1 as compared to size class 2. In fact, small branches and twigs of both of these species are known to be quite nutritious, supplying ungulates with nitrogen not found in cured grass, during the winter months.* Aspen regression equations presented in Table 3.2 should be used with care however, since the relatively small data set ($n = 19$) only represents a small range of basal diameters, namely 0.17 to 1.0 cm (Table 3.1). The restricted sampling range of live stems (considered for sampling) reflects the low occurrence of aspen seedlings ≥ 1 cm in diameter which is probably caused by animal utilization.

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*Personal communication with Gary Trottier from the Canadian Wildlife Service.

Without predation, curves pertaining to aspen (Figure 3.4) and Saskatoon (Figure 3.7) would probably follow the trends observed in the biomass curves for Canadian buffalo-berry (Figure 3.5), which like white meadowsweet (Figure 3.8) and prickly rose (Figure 3.9) are rarely used by ungulates in this study area.

3.4.2 Dwarf shrubs

Differences in growth forms in one species of dwarf shrub, common bearberry growing in geographically distant areas have been noted and are reflected in the difference of the components of the second degree polynomial equation used in both Brown and Marsden (1976), and Alexander (1978). This provided additional justification for local development of two common dwarf shrub species in the study area (Table 3.3).

The allometric curve which models the distribution of twin-flower data should be used with caution, since only two percent of the sample points exceed cover values of 30 percent. The confidence limit of the curve over 30 percent cover becomes too wide to encourage the use of this curve for cover values exceeding this point. This opinion is shared by Ohmann *et al.* 1981. The relatively low r^2 value due to the rather large variations around $\hat{Y}$ reflects the difficulty associated with twin-flower cover sampling.

Because of its growing habit which tends to form thick stands, common bearberry was an easier shrub to sample than twin-flower. This is reflected in the smaller variation above and below Ŷ (Figure 3.11) as well as in the statistical parameters associated with the regression equation (Table 3.3). In this case, data support the regression line up to a percent cover of 80 percent.

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4. CONCLUSION AND RECOMMENDATIONS

Accurate fuel loading estimates will lead to better prediction of potential forest fire intensity. These estimates are highly infuenced by specific gravity and representative class diameter (Di) values which are required to solve existing equations when using the line intersect method. Results of this study show the quadratic mean diameter (QMD) best estimates the representative class diameter for roundwood diameter size classes: 0.0-0.49 cm, 0.50-99 cm, 1.0-2.99 cm, 3.0-4.99 cm, and 5.0-6.99 cm. Further, QMD's calculated from the graphical method is an acceptable alternative to the more common standard of determining the QMD using actual diameter measurement. Also, it is far cheaper to calculate QMD's using the graphical method when compared to the experimental approach. Differences between the most commonly reported methods of determining Di's are analyzed and discussed for lodgepole pine, Douglas-fir, white spruce, and aspen.

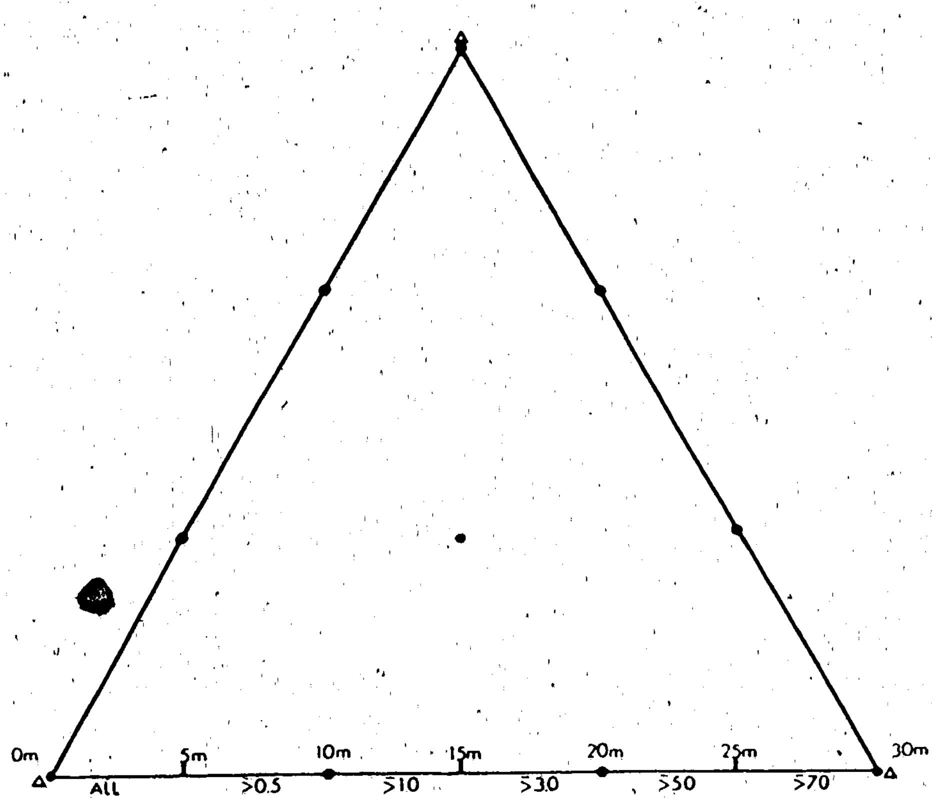
Specific gravity values were determined for the five roundwood diameter size classes, plus roundwood >7cm in diameter by soundness (Rotten and Sound) for the four tree species mentioned above. These values agree with previously published data but are specific to trees sampled in Jasper National Park.

Biomass regression equations were developed for lodgepole pine, Douglas-fir, white spruce, aspen tree seedlings (<3 m in ht); Canadian buffalo-berry, ground juniper, saskatoon berry, white meadowsweet, prickly rose, and two dwarf shrubs (common bearberry and twin-flower). These species are common in Jasper National Park, the study area. Equations were developed that would predict foliage weight, total stem weight and roundwood fuel weights by the five size classes mentioned above for the four tree species and taller shrubs also listed. The logarithmic transformation of the model $Y = aX$ consistently provided the best estimate of biomass weights for all tree seedlings and shrubs, except common bearberry, when basal diameter or in the case of twin-flower percent cover are used as the independent variables (b). The R^2 for these relationships ranged from .570 to .986 and all were highly significant. The accuracy of this model diminished with an increase in roundwood size classes due to: (1) an apparent change in seedling form and in some cases a shortage of samples. For common bearberry, the second degree bionomial model with percent cover as the independent variable produced a good estimate of biomass (R^2=.836).

APPENDIX I - SAMPLING DESIGN FOR THE JASPER FUEL QUANTIFICATION STUDY

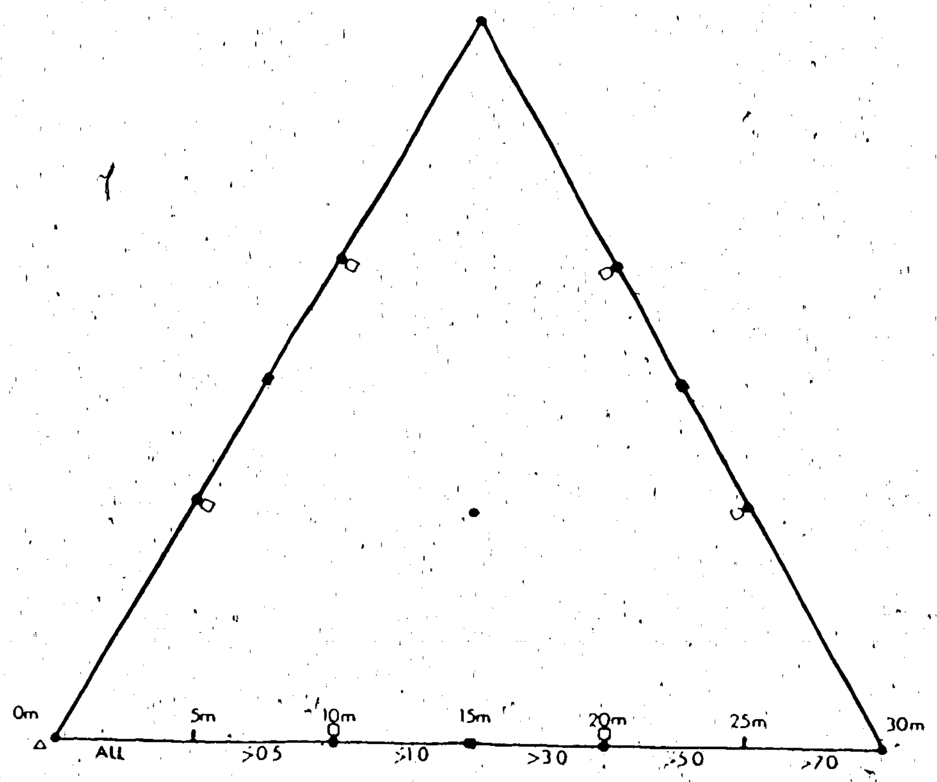
A) First field season

B) Second field season



1. Crown fuels
   - ● A. Standing live trees (>3 m in height) — Tree count inside triangle and 10 plots using the PCQ methods.
   - ● B. Standing dead trees (>3 m in height) — Tree count inside triangle.
2. Surface fuels
   - ● A. Standing live seedlings (>3 m in height) — 4 x 1.8 m radius plot
   - ● B. Shrubs — 4 x 1.0 m radius plot
   - ● C. Herbs, grasses and dwarf shrubs — 6 x 4 (30 x 60 cm) relative estimate
   - D. Downed and dead fuels — Line intersect method
3. Ground fuels
   - ● Duff depth — 10 x 4 duff depth sub-plots
4. △ Photo-point — 3 black and white and 3 color stereopairs

A) Sampling design: 1983 field season - Plot #1 - #37



1.	Crown fuels	
●	A. Standing live trees (>3 m in height)	Tree count inside triangle and 10 plots using the PCQ methods.
●	B. Standing dead trees (>3 m in height)	Tree count inside triangle.
2.	Surface fuels	
□	A. Standing live seedlings (>3 m in height)	10 x 1.8 m radius plot
⊔	B. Shrubs	10 x 1.0 m radius plot
□	C. Herbs, grasses and dwarf shrubs	10 x 4 (30 x 60 cm) relative estimate plots
	D. Downed and dead fuels	Line intersect method
3.	Ground fuels	
●	Duff depth	10 x 4 duff depth sub-plots
4.△	Photo-point	1 black and white stereopair

B) Sampling design: 1984 field season - Plot #38 - #74

APPENDIX II - REGRESSION EQUATION CURVES AND ASSOCIATED STATISTICS FOR TREE SEEDLINGS AND SHRUBS

A. Pinus contorta

B. Pseudotsuga menziesii

C. Picea glauca

D. Populus tremuloides

E. Shepherdia canadensis

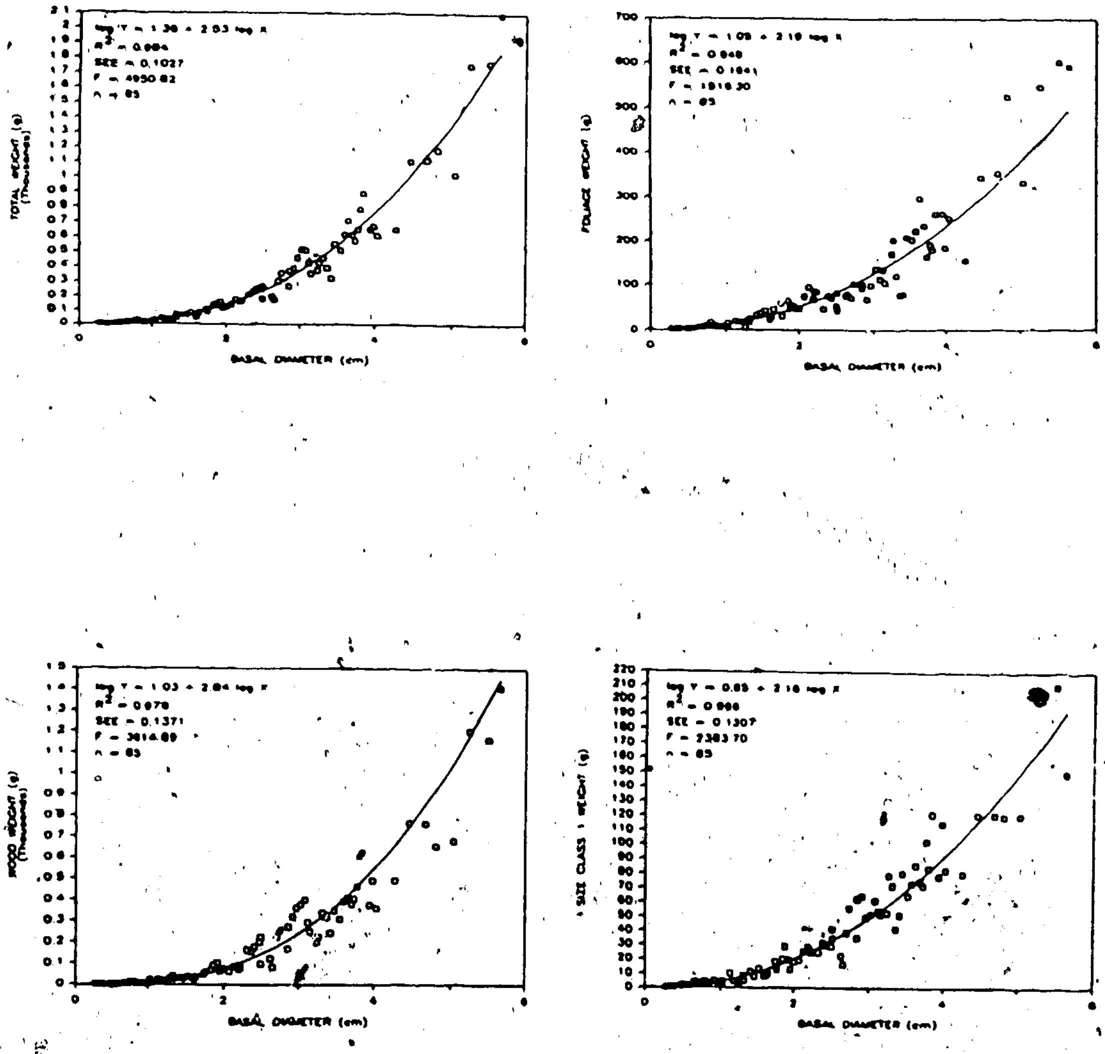
F. Juniperus communis

G. Amelanchier alnifolia

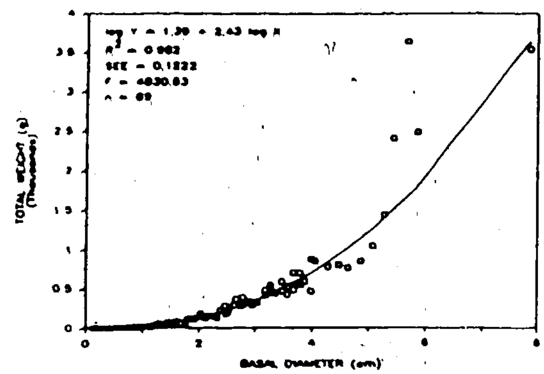
H. Spireae lucida

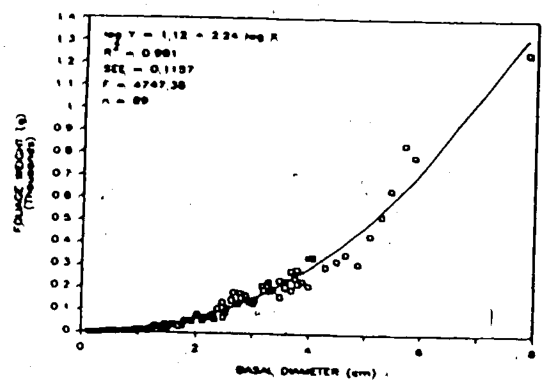
I. Rosa acicularis

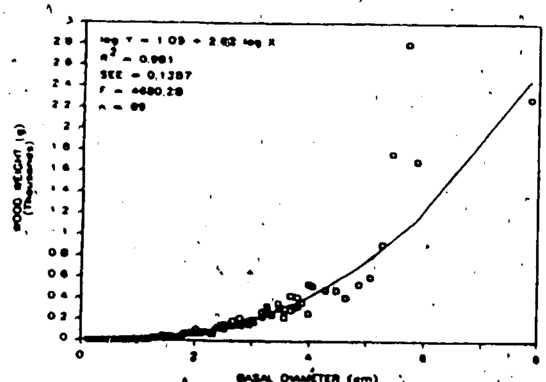
A. Pinus contorta

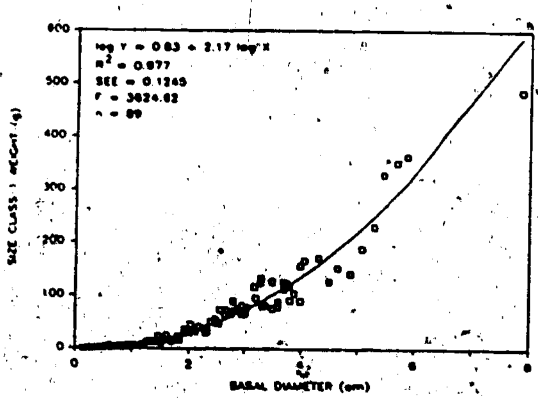


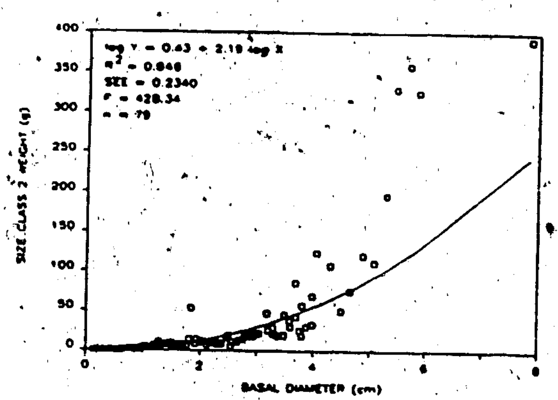
B. Pseudotsuga menziesii



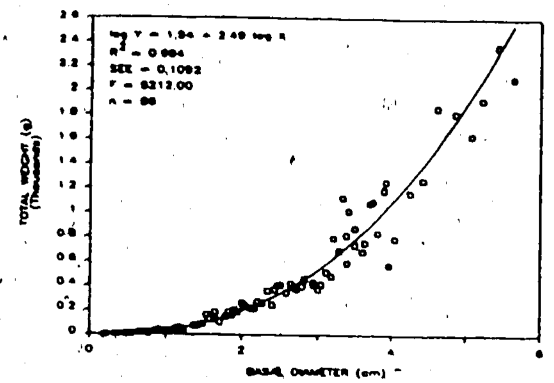


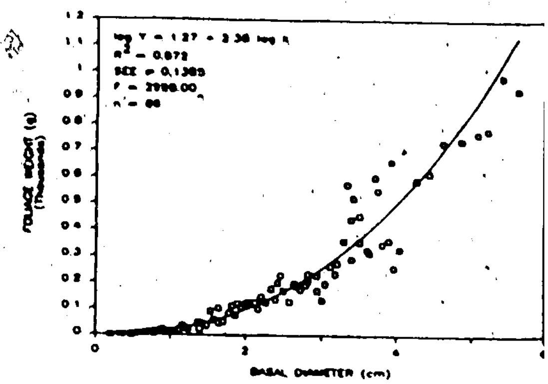


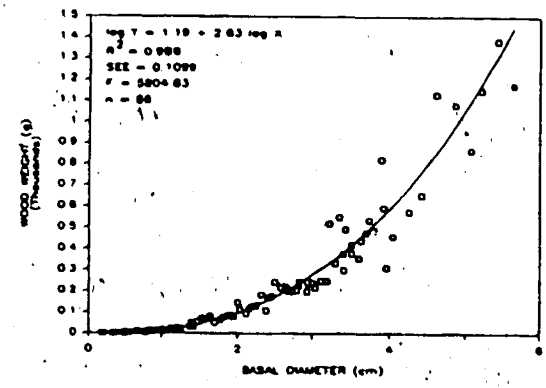


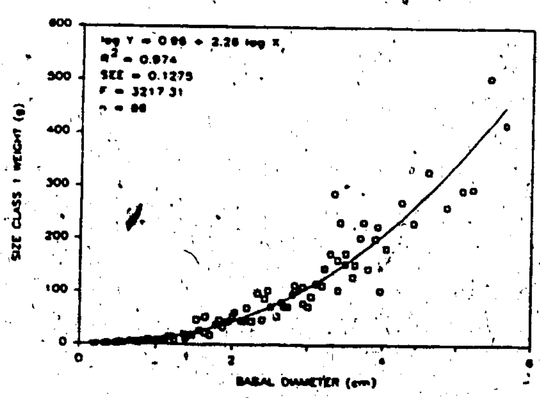


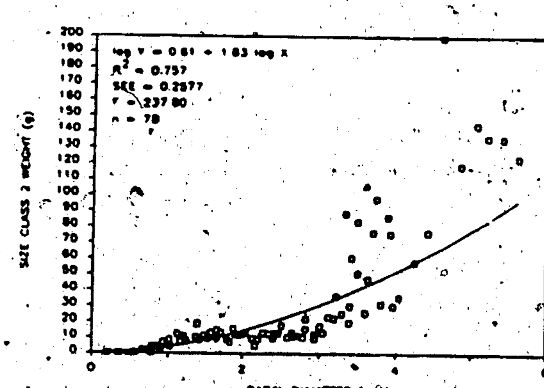
C. Picea glauca



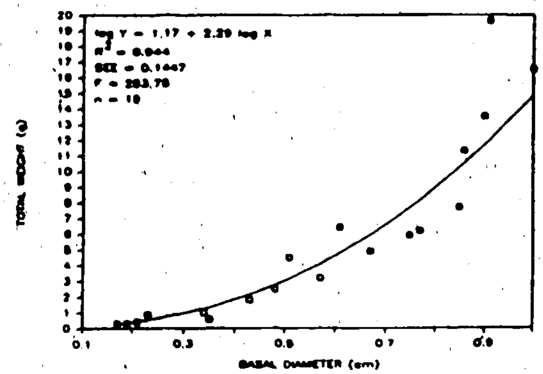


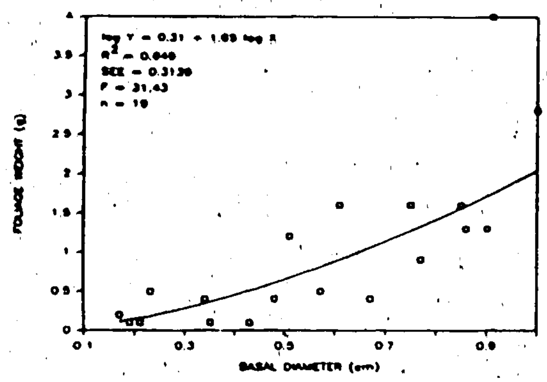


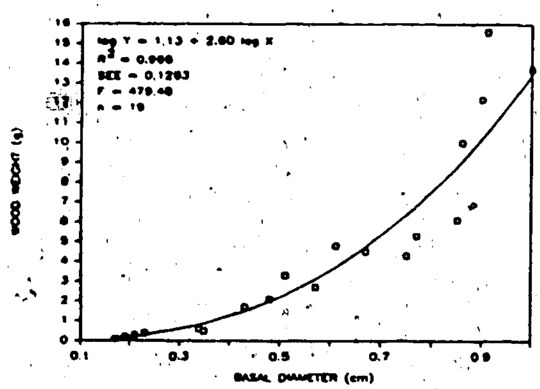


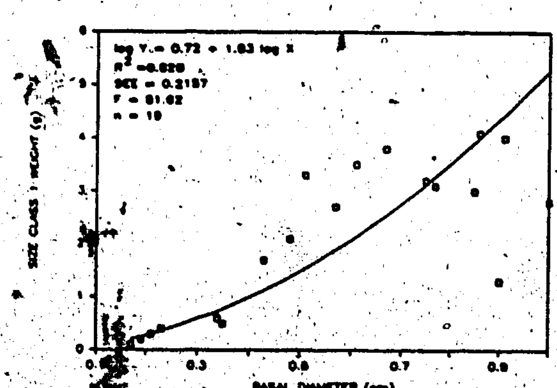


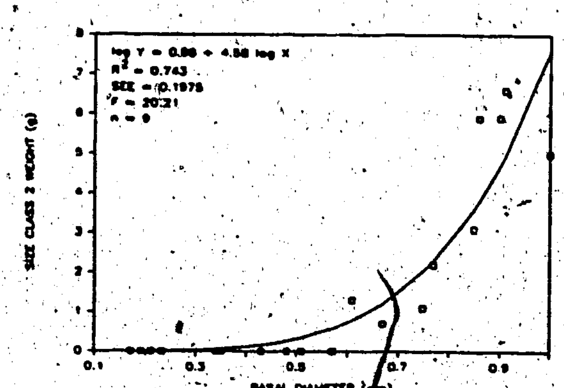
D. Populus tremuloides



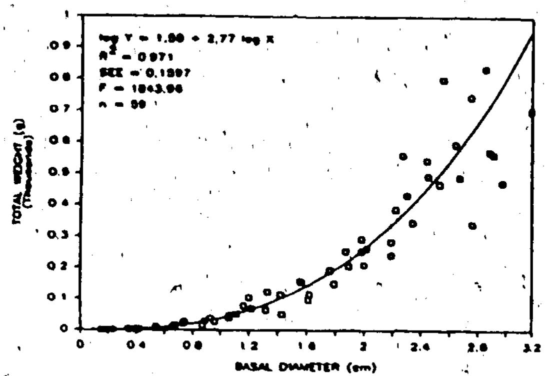


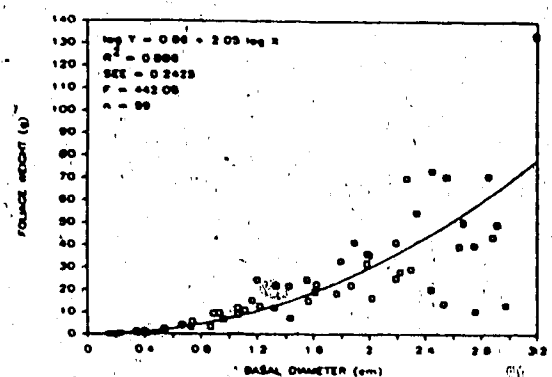


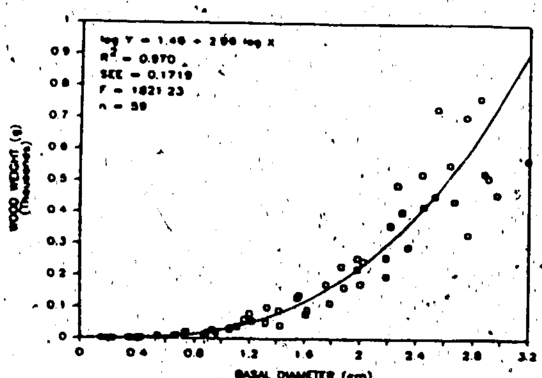


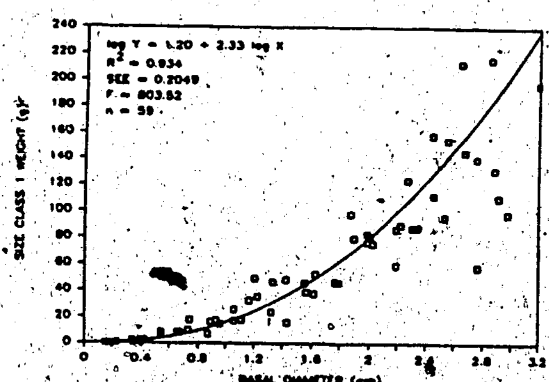


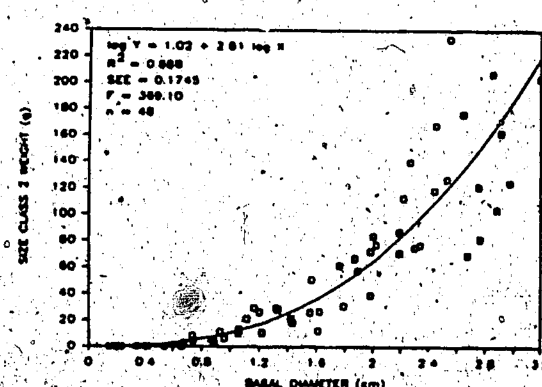
E. Shepherdia canadensis



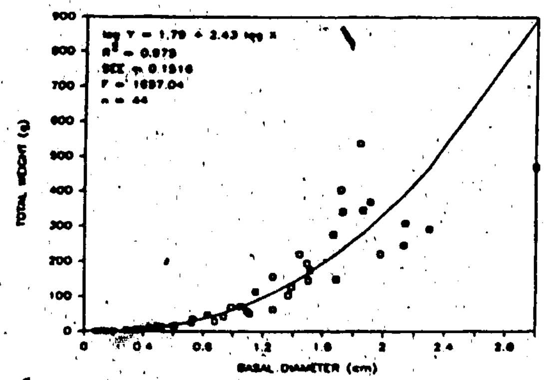


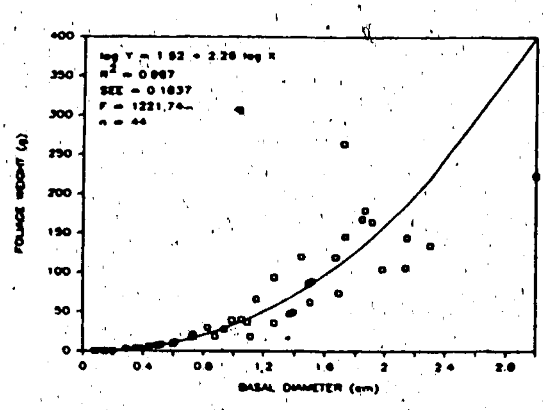


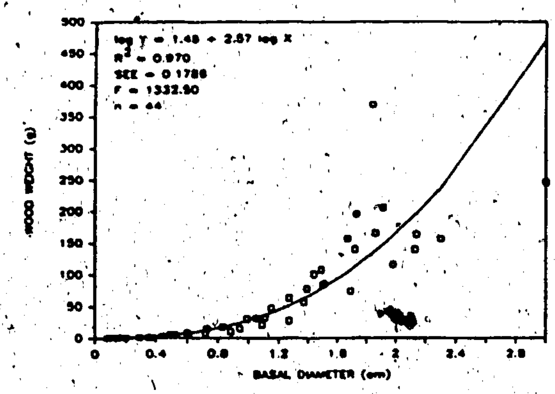


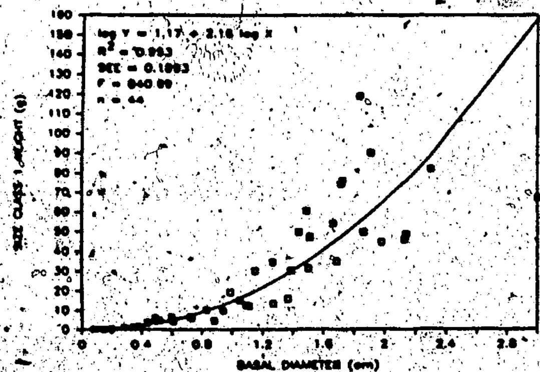


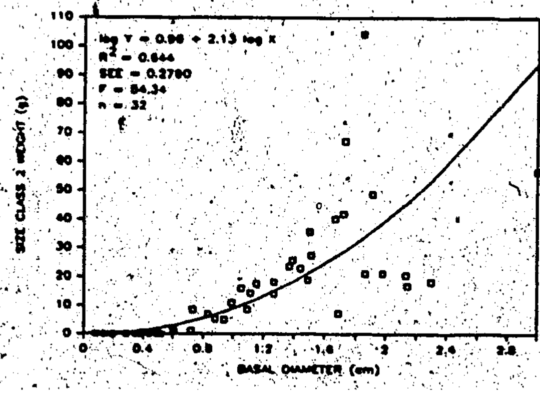
F. Juniperus communis



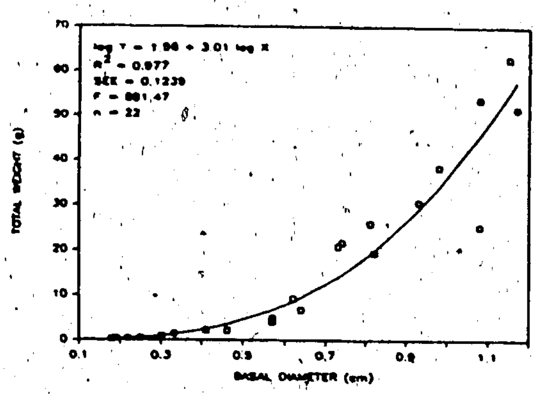


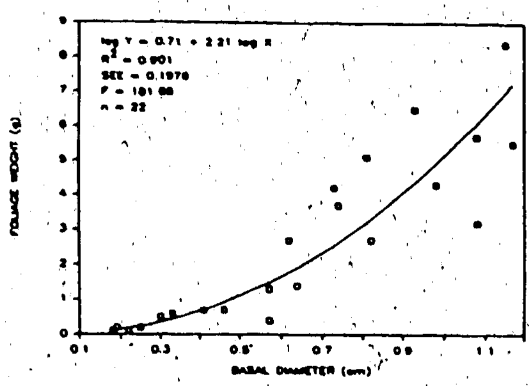


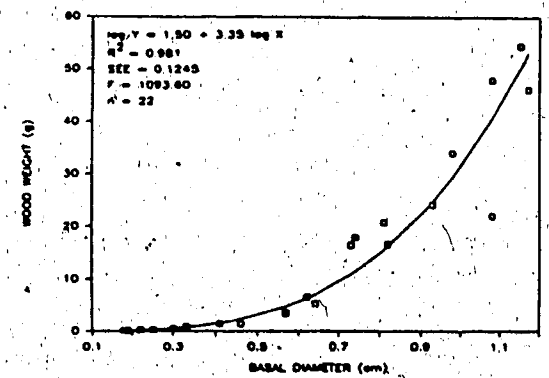


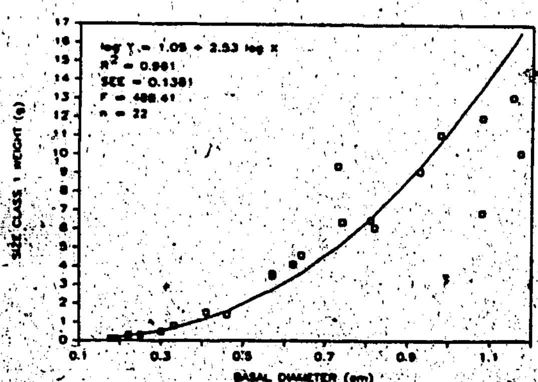


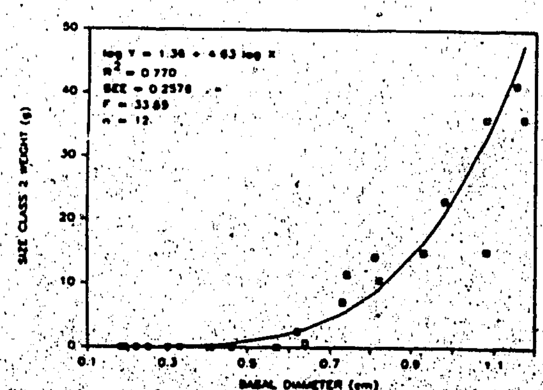
G. Amelanchier alnifolia



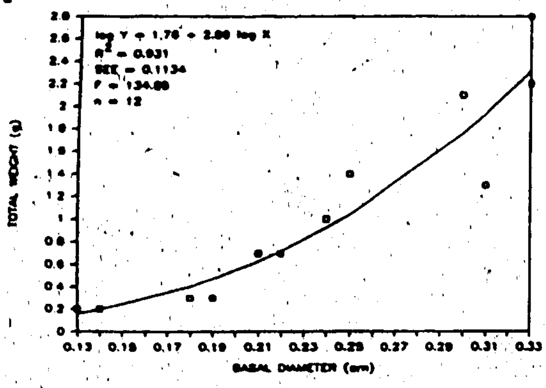


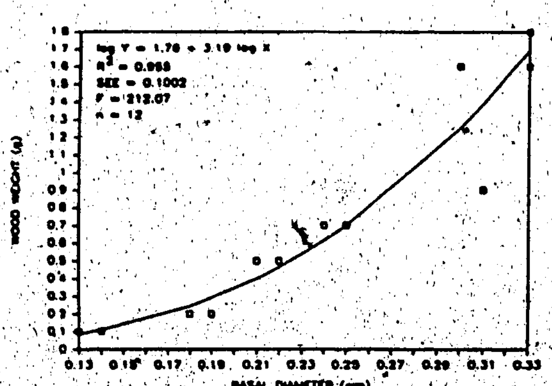


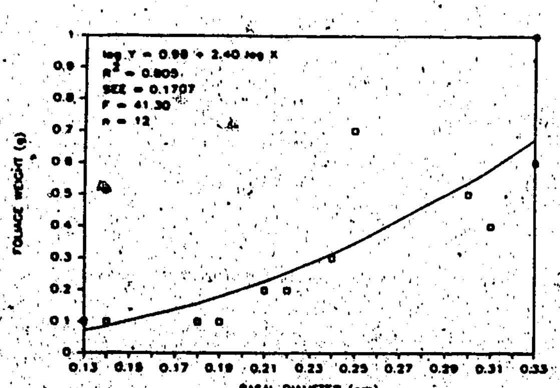




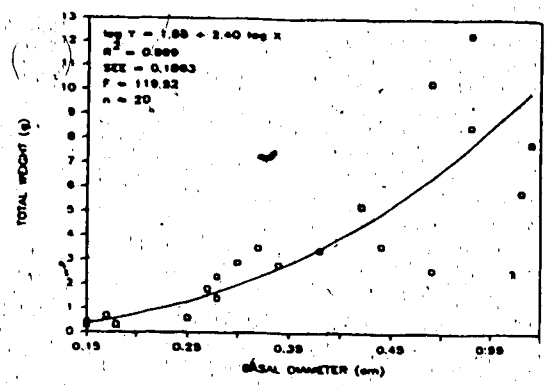
H. Spireae lucida

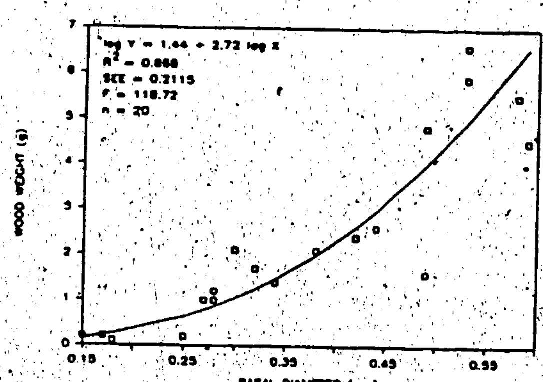


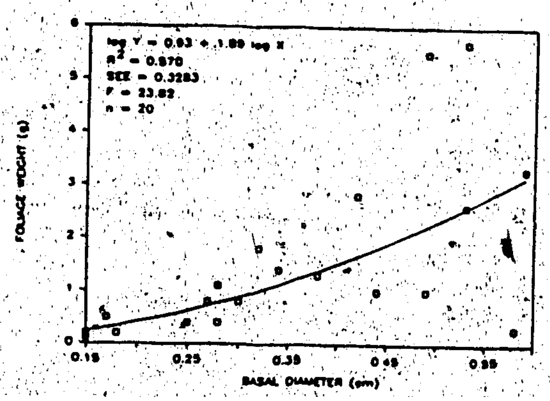




I. Rosa acicularis







APPENDIX III - STATISTICS ASSOCIATED TO TREE SEEDLINGS AND SHRUBS' REGRESSION EQUATIONS

PICO = lodgepole pine

PSME = Douglas-fir

PIGL = white spruce

POTR = aspen

SHCA = Canadian buffalo-berry

JUCO = ground juniper

AMAL = Saskatoon-berry

SPLU = white meadowsweet

ROAC = prickly rose

ARUV = common bearberry

LIBO = twin-flower

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
				PICO Total				
	1.36154	0.01497	90.98	Regression	1	54.459	54.459	4950.82
log(x)	2.52715	0.03516	71.87	Residual	83	0.875	0.011	
				Total	84	55.334		
				Foliage				
	1.04085	0.02392	43.51	Regression	1	40.940	40.940	1516.30
log(x)	2.19114	0.05620	38.99	Residual	83	2.236	0.027	
				Total	84	43.176		
				Wood				
	1.02227	0.01999	51.14	Regression	1	68.683	68.683	3614.89
log(x)	2.83805	0.04696	60.43	Residual	83	1.561	0.019	
				Total	84	70.244		
				Size Class 1				
	0.63990	0.01905	33.58	Regression	1	40.523	40.523	2383.71
log(x)	2.17994	0.04477	48.69	Residual	83	1.419	0.017	
				Total	84	41.941		
				Size Class 2				
	0.67070	0.07958	8.43	Regression	1	8.9586	8.9586	63.72
log(x)	1.4782	0.1852	7.98	Residual	74	10.4055	0.1406	
				Total	75	19.3642		
				Size Class 3				
	1.17593	0.09095	12.93	Regression	1	0.23304	0.23304	3.62
log(x)	0.3689	0.1939	1.90	Residual	60	3.86466	0.06441	
				Total	61	4.09770		
				Size Class 4				
	1.6591	0.1950	8.51	Regression	1	0.01437	0.01437	0.16
log(x)	-0.1501	0.3728	-0.40	Residual	46	4.07895	0.08867	
				Total	47	4.09332		

VARIABLE	COEFFICIENT	ST. DEV. OF COEFF.	T-RATIO COEF./SD.	DUE TO	Analysis of variance DF	SS	SS/DF	MS= F
				PICO SIZE CLASS 5				
log(x)	0.8908	0.2608		Regression	1	1.5040	1.5040	17.95
	2.0187	0.4765	3.76	Residual	37	3.1007	0.0838	
			4.24	Total	38	4.6047		
				SIZE CLASS 6				
log(x)	0.1223	0.6678		Regression	1	0.38088	0.38088	12.79
	3.5235	0.9852	0.18	Residual	7	0.20845	0.02978	
			3.58	Total	8	0.58933		
				PSME TOTAL				
log(x)	1.38317	0.01598		Regression	1	72.458	72.458	4830.53
	2.43039	0.03489	86.55	Residual	87	1.299	0.015	
			69.67	Total	88	73.757		
				FOLIAGE				
log(x)	1.10856	0.01513		Regression	1	61.716	61.716	4747.38
	2.24300	0.03304	73.25	Residual	87	1.165	0.013	
			67.90	Total	88	62.881		
				WOOD				
log(x)	1.03887	0.01775		Regression	1	84.245	84.245	4680.28
	2.62062	0.03875	58.52	Residual	87	1.603	0.018	
			67.62	Total	88	85.847		
				SIZE CLASS 1				
log(x)	0.81842	0.01629		Regression	1	57.994	57.994	3624.62
	2.17433	0.03555	50.25	Residual	87	1.349	0.016	
			64.16	Total	88	59.343		

VARIABLE	COEFFICIENT	ST.DEV. OF COEFF.	T-RATIO COEF./SD.	DUE TO	Analysis of variance DF	SS	MS= SS[illegible]	F
				PSME SIZE CLASS 2				
log(x)	0.39928	0.04685	8.52	Regression	1	23.559	23.559	428.35
	2.1888	0.1055	20.74	Residual	77	4.217	0.055	
				Total	78	27.776		
				SIZE CLASS 3				
log(x)	0.77618	0.06793	11.43	Regression	1	2.8110	2.8110	76.80
	1.2293	0.1403	8.76	Residual	61	2.2320	0.0366	
				Total	62	5.0429		
				SIZE CLASS 4				
log(x)	0.6757	0.1264	5.34	Regression	1	2.1396	2.1396	41.47
	1.5231	0.2366	6.44	Residual	50	2.5807	0.0516	
				Total	51	4.7202		
				SIZE CLASS 5				
log(x)	0.2313	0.1940	1.21	Regression	1	4.4813	4.4813	70.79
	2.8256	0.3359	8.41	Residual	40	2.5333	0.0633	
				Total	41	7.0146		
				SIZE CLASS 6				
log(x)	-2.2781	0.6964	-3.27	Regression	1	5.1230	5.1230	36.72
	6.263	1.033	6.06	Residual	14	1.9526	0.1395	
				Total	15	7.0756		
				SIZE CLASS 7				
log(x)	-3.033	4.228	-0.72	Regression	1	0.4901	0.4901	1.50
	6.407	5.230	1.22	Residual	1	0.3266	0.3266	
				Total	2	0.8167		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	Analysis of variance DF	SS	MS= SS/DF	F
				PIGL TOTAL				
				Regression	1	62.544	62.544	5212.00
	1.53017	0.01496	102.28	Residual	84	1.001	0.012	
log(x)	2.49267	0.03441	72.45	Total	85	63.545		
				FOLIAGE				
				Regression	1	56.962	56.962	2998.00
	1.25945	0.01898	66.36	Residual	84	1.611	0.019	
log(x)	2.37883	0.04365	54.50	Total	85	58.573		
				WOOD				
				Regression	1	69.658	69.658	5804.83
	1.17909	0.01507	78.26	Residual	84	1.015	0.012	
log(x)	2.63061	0.03465	75.93	Total	85	70.673		
				SIZE CLASS 1				
				Regression	1	51.477	51.477	3217.31
	0.94978	0.01748	54.34	Residual	84	1.366	0.016	
log(x)	2.26140	0.04020	56.26	Total	85	52.843		
				SIZE CLASS 2				
				Regression	1	15.695	15.695	237.80
	0.57910	0.05051	11.46	Residual	76	5.045	0.066	
log(x)	1.8288	0.1189	15.38	Total	77	20.740		
				SIZE CLASS 3				
				Regression	1	0.59407	0.59407	9.36
	1.11840	0.08894	12.57	Residual	62	3.93344	0.06344	
log(x)	0.5841	0.1909	3.06	Total	63	4.52751		
				SIZE CLASS 4				
				Regression	1	1.0353	1.0353	14.44
	0.9942	0.1574	6.32	Residual	49	3.5150	0.0717	
log(x)	1.1682	0.3075	3.80	Total	50	4.5503		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
				PIGL SIZE CLASS 5				
				Regression	1	4.3158	4.3158	66.81
	-0.0044	0.2329	-0.02	Residual	38	2.4543	0.0646	
log(x)	3.4575	0.4230	8.17	Total	39	6.7701		
				SIZE CLASS 6				
				Regression	1	4.3673	4.3673	53.32
	-3.2539	0.7194	-4.52	Residual	12	0.9826	0.0819	
log(x)	8.167	1.118	7.30	Total	13	5.3499		
				POTR TOTAL				
				Regression	1	5.9588	5.9588	283.75
	1.16035	0.05317	21.82	Residual	17	0.3562	0.0210	
log(x)	2.2932	0.1360	16.86	Total	18	6.3150		
				FOLIAGE				
				Regression	1	3.0930	3.0930	31.43
	0.2640	0.1153	2.29	Residual	17	1.6735	0.0984	
log(x)	1.6521	0.2947	5.61	Total	[illegible]	4.7665		
				WOOD				
				Regression	1	7.6716	7.6716	479.48
	1.12383	0.04641	24.22	Residual	17	0.2713	0.0160	
log(x)	2.6020	0.1187	21.92	Total	18	7.9430		
				SIZE CLASS 1				
				Regression	1	3.7951	3.7951	81.62
	0.70280	0.07924	8.87	Residual	17	0.7910	0.0465	
log(x)	1.8301	0.2026	9.03	Total	18	4.5861		
				SIZE CLASS 2				
				Regression	1	0.78787	0.78787	20.21
	0.8648	0.1165	7.42	Residual	7	0.27296	0.03899	
log(x)	4.576	1.018	4.49	Total	8	1.06084		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
					Analysis of variance			
				POTR SIZE CLASS 3				
				Regression	1	0.00377	0.00377	0.35
	0.9476	0.1038	9.13	Residual	1	0.01085	0.01085	
log(x)	1.727	2.928	0.59	Total	2	0.01462		
				SHCA TOTAL				
				Regression	1	47.943	47.943	1843.96
	1.56818	0.02182	71.87	Residual	57	1.454	0.026	
log(x)	2.77304	0.06396	43.36	Total	58	49.396		
				FOLIAGE				
				Regression	1	26.081	-26.081	442.05
	0.82861	0.03314	25.00	Residual	57	3.353	0.059	
log(x)	2.04530	0.09714	21.06	Total	58	29.434		
				WOOD				
				Regression	1	54.637	54.637	1821.23
	1.45323	0.02348	61.88	Residual	57	1.684	0.030	
log(x)	2.96031	0.06883	43.01	Total	58	56.321		
				SIZE CLASS 1				
				Regression	1	33.748	33.748	803.52
	1.17544	0.02800	41.98	Residual	57	2.393	0.042	
log(x)	2.32657	0.08207	28.35	Total	58	36.141		
				SIZE CLASS 2				
				Regression	1	11.073	11.073	369.10
	1.00595	0.04044	24.87	Residual	46	1.401	0.030	
log(x)	2.6068	0.1367	19.06	Total	47	12.474		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
				SHCA SIZE CLASS 3				
	0.9359	0.1503	6.23	Regression	1	2.2646	2.2646	23.99
log(x)	2.1798	0.4451	4.90	Residual	34	3.2105	0.0944	
				Total	35	5.4751		
				SIZE CLASS 4				
	1.2622	0.4143	3.05	Regression	1	0.09892	0.09892	1.31
log(x)	1.203	1.052	1.14	Residual	17	1.28737	0.07573	
				Total	18	1.38629		
				SIZE CLASS 5				
	2.4805	0.7121	3.48	Regression	1	0.02574	0.02574	0.38
log(x)	-1.031	1.667	-0.62	Residual	10	0.67256	0.06726	
				Total	11	0.69830		
				JUCO TOTAL				
	1.77695	0.02327	76.37	Regression	1	38.112	38.112	1657.04
log(x)	2.42911	0.05966	40.71	Residual	42	0.966	0.023	
				Total	43	39.078		
				FOLIAGE				
	1.50543	0.02512	59.92	Regression	1	32.987	32.987	1221.74
log(x)	2.25988	0.06442	35.08	Residual	42	1.126	0.027	
				Total	43	34.113		
				WOOD				
	1.42678	0.02740	52.07	Regression	1	42.640	42.640	1332.50
log(x)	2.56934	0.07027	36.57	Residual	42	1.339	0.032	
				Total	43	43.979		
				SIZE CLASS 1				
	1.15460	0.02905	39.75	Regression	1	30.265	30.265	840.69
log(x)	2.16464	0.07449	29.06	Residual	42	1.505	0.0367	
				Total	43	31.770		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
						Analysis of variance		
				JUCO SIZE CLASS 2				
	0.91831	0.06107	15.04	Regression	1	4.2277	4.2277	54.34
log(x)	2.1289	0.2889	7.37	Residual	30	2.3353	0.0778	
				Total	31	6.5630		
				SIZE CLASS 3				
	1.0307	0.1902	5.42	Regression	1	0.2363	0.2363	2.20
log(x)	1.1204	0.7550	1.48	Residual	18	1.9312	0.1073	
				Total	19	2.1675		
				SIZE CLASS 4				
	1.3160	0.3380	3.89	Regression	1	0.04792	0.04792	0.90
log(x)	1.012	1.070	0.95	Residual	8	0.42835	0.05354	
				Total	9	0.47626		
				SIZE CLASS 5				
	2.63708	0.0	-	Regression	1	0.08529	0.08529	-
log(x)	-3.57909	0.0	-	Residual	0	-	-	
				Total	1	0.08529		
				SPLU TOTAL				
	1.7537	0.1640	10.70	Regression	1	1.7396	1.7396	134.85
log(x)	2.8909	0.2485	11.63	Residual	10	0.1286	0.0129	
				Total	11	1.8632		
				FOLIAGE				
	0.9704	0.2468	3.93	Regression	1	1.2020	1.2020	41.31
log(x)	2.4030	0.3742	6.42	Residual	10	0.2914	0.0291	
				Total	11	1.4934		
				WOOD				
	1.7557	0.1448	12.12	Regression	1	2.1207	2.1207	212.07
log(x)	3.1918	0.2195	14.54	Residual	10	0.1003	0.0100	
				Total	11	2.2210		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
				AMAL TOTAL				
				Regression	1	13.222	13.222	881.47
	1.54522	0.03725	41.48	Residual	20	0.307	0.015	
log(x)	3.0104	0.1026	29.35	Total	21	13.529		
				FOLIAGE				
				Regression	1	7.1042	7.1042	181.69
	0.69078	0.05942	11.63	Residual	20	0.7810	0.0391	
log(x)	2.2067	0.1636	13.49	Total	21	7.8852		
				WOOD				
				Regression	1	16.404	16.404	1093.60
	1.48937	0.03742	39.80	Residual	20	0.310	0.015	
log(x)	3.3531	0.1030	32.54	Total	21	16.713		
				SIZE CLASS 1				
				Regression	1	9.3286	9.3286	488.41
	1.04190	0.04153	25.09	Residual	20	0.3816	0.0191	
log(x)	2.5286	0.1144	22.11	Total	21	9.7101		
				SIZE CLASS 2				
				Regression	1	2.2276	2.2276	33.55
	1.33196	0.08744	15.23	Residual	10	0.6636	0.0664	
log(x)	4.6263	0.7985	5.79	Total	11	2.8913		
				ROAC TOTAL				
				Regression	1	4.1474	4.1474	119.52
	1.5323	0.1146	13.37	Residual	18	0.6246	0.0347	
log(x)	2.4027	0.2198	10.93	Total	19	4.7720		

Variable	Coefficient	St. Dev. of coef.	T-ratio coef./SD	Due to	DF	SS	MS= SS/DF	F
				ROAC FOLIAGE				
				Regression	1	2.5675	2.5675	23.82
	0.8794	0.2020	4.35	Residual	18	1.9405	0.1078	
log(x)	1.8905	0.3874	4.88	Total	19	4.5081		
				WOOD				
				Regression	1	5.3070	5.3070	118.72
	1.4187	0.1301	10.90	Residual	18	0.8050	0.0447	
log(x)	2.7179	0.2495	10.89	Total	19	6.1120		
				ARUV TOTAL				
Constant	0.00643	0.03650	0.18	Regression	2	100.431	50.216	528.59
% cover	0.05323	0.00395	13.47	Residual	207	19.739	0.095	
(% cover)²	-0.00016	0.00006	-2.48	Total	209	120.170		
				LIBO TOTAL				
				Regression	1	37.464	37.464	382.28
Constant	-1.84232	0.04721	-39.02	Residual	228	22.372	0.098	
log (% cover)	1.05290	0.05389	19.54	Total	229	59.836		