WHITE PAPER

USDA Forest Service | Pacific Northwest Region | Umatilla National Forest

WHITE PAPER F14-SO-WP-SILV-20

Height-Diameter Equations for Tree Species of Blue and Wallowa Mountains[1]

David C. Powell; Forest Silviculturist
Supervisor's Office; Pendleton, OR

Initial Version: **SEPTEMBER 2005**
Most Recent Revision: **DECEMBER 2016**

---

[1] White papers are internal reports; they receive only limited review. Viewpoints expressed in this paper are those of the author – they may not represent positions of USDA Forest Service.

INTRODUCTION

Tree diameter and height are essential metrics for characterizing tree condition, and they are often required as input variables for computerized modeling of forest ecosystems. Tree diameter measurements are easily obtained at relatively low cost, but accurate measurements of tree height are considerably more difficult and costly to collect (Moore et al. 1996).

Since forest mensuration datasets often include a diameter value for every tree record but commonly include many records where tree height is missing, height-diameter equations have been developed to 'dub in' missing heights. When tree height measurements are missing, prediction equations can be used to estimate height when diameter is known (Moore et al. 1996).

Blue Mountain national forests (Malheur, Umatilla and Wallowa-Whitman) use a rating system to determine relative probability of tree survival for fire-injured conifers. This rating system uses a variety of external tree-damage indicators (crown scorch, bole scorch, scorch height, duff consumption, etc.) to derive a composite rating reflecting overall probability of tree survival for up to one year after fire (although a longer time period is also considered for mature, large-diameter ponderosa pines) (Scott et al. 2002).

A Scott et al. (2002) tree-mortality protocol was based on computerized modeling of first-order fire effects as implemented by using BehavePlus Fire Modeling System (a current version of this software is described in Andrews et al. 2008). To accomplish tree mortality modeling by characterizing mortality predictors such as scorch height, there is a need to estimate tree height for combinations of species and diameter for which height measurements are lacking.

An objective of this white paper is to describe how regression equations were developed to relate tree height and tree diameter for major conifer species occurring in Blue and Wallowa mountains of northeastern Oregon, southeastern Washington, and west-central Idaho.

DATA AND METHODS

In the 1990s, Blue Mountain national forests installed a grid-based inventory system called Current Vegetation Survey (CVS). Plots were installed on a 1.7-mile grid (each plot was located 1.7 miles away from adjoining plots) except for designated Wilderness areas, where grid spacing was 3.4 miles between plots.

For the Blue Mountains province, initial installation of forested plots occurred in 1993 and 1994; nonforest plots were established across all three national forests in 1995 and 1996. Plot information collected during this 1993-1996 period is referred to as occasion 1 data. Since their initial installation, almost every Blue Mountain plot has been remeasured once, and this subsequent information is referred to as occasion 2 data.

CVS information is generally considered to be the best dataset available for Blue Mountain national forests because:

1) its grid-based approach prevents plot location bias;
2) its quality control/quality assurance emphasis is very high (Max et al. 1996); and
3) it is more consistent, across national forest boundaries, than other dataset alternatives, most of which were developed for an individual national forest.

Occasion 1 CVS tree records for all three Blue Mountain national forests were pooled into a single dataset for a tree diameter-tree height analysis. In accordance with the CVS protocol, some tree records do not provide a tree height because it was not required for measurement (CVS tree measurement requirements – what needed to be measured – varied by tree type; growth sample trees, for example, had more information recorded than other tree-sample types). Therefore, the pooled dataset was filtered to remove all records for which a tree height was not available.

Data filtering utilized a Vegetation Code data item available for every tree record. Trees with a vegetation code of 10 (live tree), 11 (live growth sample tree) and 13 (live site tree) were retained in an analysis dataset because these records provide both tree diameter and tree height measurements. All records pertaining to dead trees were dropped from the analysis file.

After filtering the dataset to remove tree records with missing tree heights, a total of 50,184 records were available for developing regression equations to relate tree diameter and tree height (table 1).

As would be expected, tree records available for height-diameter analysis were distributed among the national forests in approximate proportion to National Forest System land area in each Blue Mountain national forest unit (table 2).

Table 1: Tree record count by vegetation code (sample tree status).

Vegetation Code	Number of Tree Records
10 (Live tree)	1,605
11 (Growth sample tree)	41,711
13 (Site tree)	6,868
Total	50,184

Table 2: Tree record count by national forest.

National Forest Unit	Number of Tree Records
4 (Malheur National Forest)	16,492
14 (Umatilla National Forest)	13,980
16 (Wallowa-Whitman National Forest)	19,712
Total	50,184

Tree records available for height-diameter analysis were distributed among 15 tree species, not all of which were used to develop tree height-diameter equations (table 3).

Table 3: Tree record count by tree species.

Species Code	Tree Species Common Name	Number of Tree Records	Height Equation?
ABGR	Grand fir	11,486	Y
ABLA2	Subalpine fir	2,663	Y
CRATA	Black hawthorne	1	N
JUOC	Western juniper	1,636	N[1]
LAOC	Western larch	3,212	Y
PIAL	Whitebark pine	267	N[1]
PICO	Lodgepole pine	3,710	Y
PIEN	Engelmann spruce	2,676	Y
PIMO	Western white pine	22	Y[2]
PIPO	Ponderosa pine	12,529	Y
POTR	Quaking aspen	22	N
POTR2	Black cottonwood	15	N
PSME	Interior Douglas-fir	11,823	Y
TABR	Pacific yew	60	N
TSME	Mountain hemlock	62	N
Total		50,184	

Sources/Notes: 'Species Code' is an acronym related to scientific plant name (first two letters of genus name plus first 2 letters of species name and then capitalized), with a number added to differentiate between two or more species with the same code. 'Tree Species Common Name' is self-explanatory. 'Number of Tree Records' shows number of data records present in an analysis database used to develop height-diameter equations for the species. 'Height Equation?' shows whether height-diameter equations were developed for a tree species for any of three plant association groups: Y = yes; N = No.

[1] These tree species were not analyzed for height-diameter equations because they are not included in the Scott et al. (2002) post-fire tree mortality rating system.

[2] There were an insufficient number of western white pine records to analyze by plant association group, so they were pooled (and supplemented with records from Umatilla National Forest's big-tree program), and height-diameter equations were then generated for this species as a whole.

Tree height patterns can vary by tree species, tree age, canopy position (crown class), and site quality (site index is commonly used to represent site quality or productivity). To reflect differences in tree growth related to variations in site productivity, potential vegetation (plant association group) was used as a proxy for site index or site productivity. [White Paper F14-SO-WP-SILV-05 examines relationships between site index and potential vegetation in more detail.]

Site productivity reflects potential height growth, whereas canopy position (crown class) reflects how much inherent site potential is realized; dominant trees reach a high proportion of inherent site potential, subordinate trees a low proportion. Most trees used for this analysis are dominant or codominant crown classes (e.g., growth sample trees and site trees in table 1).

Potential vegetation is represented in a CVS database by using ecoclass codes (Hall 1998). Each CVS plot consists of a 5-point cluster spread across a land area of 1 hectare (app. 2.47 acres). Ecoclass codes were recorded for each of five points on a CVS plot. Sampled trees are also coded to the sample point they occur on, so it was possible to use CVS plot and point values, by tree record, to associate an ecoclass code with each record.

Five plant association groups were used as an initial stratification for development of height-diameter equations, ranging from hot dry biophysical environments at low elevations to cold dry environments at high elevations.[2] Five plant association groups, which are similar to those used with a 'UPEST' insect and disease risk calculator (Scott et al. 1998), are as follows:

- Group 1 (G1): ponderosa pine series (representing warmest and driest upland-forest sites);
- Group 2 (G2): Douglas-fir series;
- Group 3 (G3): dry plant communities in a grand fir series;
- Group 4 (G4): moist plant communities in grand fir and lodgepole pine series;
- Group 5 (G5): subalpine fir series (representing coldest upland-forest sites).

A wide variety of ecoclasses (potential vegetation types) are present in the analysis database, and each Ecoclass code was assigned to one, and only one, of the plant association groups described in table 4.

[2] Specifications for how potential vegetation types (plant associations, plant community types, plant communities) are to be assigned to plant association groups were provided by Craig L. Schmitt in an email message addressed to David C. Powell, and dated April 14, 2005.

Table 4: Assignment of potential vegetation types (ecoclasses) to plant association groups, and tree records available for each ecoclass code.

Ecoclass Code	Group	Tree Records	Potential Vegetation Type	Potential Vegetation Type Common Name
CAC4	G5	6	PIAL	whitebark pine
CAC5	G5	9	ABLA2	subalpine fir
CAF0	G5	145	ABLA2-PIAL/POPU	subalpine fir-whitebark pine/skunkleaved polemonium
CAF2	G5	68	ABLA2-PIAL/POPH	subalpine fir-whitebark pine/fleeceflower
CAG111	G5	245	ABLA2/CAGE	subalpine fir/elk sedge
CAG3	G5	7	ABLA2-PIAL/JUDR	subalpine fir-whitebark pine/Drummond's rush
CAG4	G5	200	ABLA2/STOC	subalpine fir/western needlegrass
CAS5	G5	17	Incorrect code (aka CAC5)	
CDG111	G2	2656	PSME/CAGE	Douglas-fir/elk sedge
CDG112	G2	1844	PSME/CARU	Douglas-fir/pinegrass
CDG121	G2	612	PSME/CARU	Douglas-fir/pinegrass
CDG3	G2	20	PSME/grass-forb	Douglas-fir/grass-forb
CDS611	G2	166	PSME/HODI	Douglas-fir/oceanspray
CDS622	G2	370	PSME/SYAL	Douglas-fir/common snowberry
CDS623	G2	145	PSME/SYOR	Douglas-fir/mountain snowberry
CDS624	G2	987	PSME/SYAL	Douglas-fir/common snowberry
CDS625	G2	214	PSME/SYOR	Douglas-fir/mountain snowberry
CDS634	G2	593	PSME/SPBE	Douglas-fir/birchleaf spiraea
CDS711	G2	1297	PSME/PHMA	Douglas-fir/ninebark
CDS722	G2	744	PSME/ACGL-PHMA	Douglas-fir/Rocky Mountain maple-mallow ninebark
CDS812	G2	34	PSME/VAME	Douglas-fir/big huckleberry
CDS821	G2	102	PSME/VAME	Douglas-fir/big huckleberry
CDSD	G2	386	PSME/CELE/CAGE	Douglas-fir/mountain mahogany/elk sedge
CEF221	G5	323	ABLA2/LIBO2	subalpine fir/twinflower
CEF311	G5	102	ABLA2/STAM	subalpine fir/twisted stalk
CEF331	G5	71	ABLA2/TRCA3	subalpine fir/false bugbane
CEF411	G5	655	ABLA2/POPU	subalpine fir/skunkleaved polemonium
CEF9	G5	60	Incorrect code	
CEG312	G5	264	ABLA2/CARU	subalpine fir/pinegrass
CES131	G5	507	ABLA2/CLUN	subalpine fir/queencup beadlily
CES221	G5	15	ABLA2/MEFE	subalpine fir/fool's huckleberry
CES311	G5	343	ABLA2/VAME	subalpine fir/big huckleberry

Ecoclass Code	Group	Tree Records	Potential Vegetation Type	Potential Vegetation Type Common Name
CES314	G5	323	ABLA2/CLUN	subalpine fir/queencup beadlily
CES315	G5	925	ABLA2/VAME	subalpine fir/big huckleberry
CES411	G5	902	ABLA2/VASC	subalpine fir/grouse huckleberry
CES414	G5	767	ABLA2/LIBO2	subalpine fir/twinflower
CES415	G5	481	ABLA2/VASC/POPU	subalpine fir/grouse huckleberry/skunkleaved polemonium
CJG111	OF	444	JUOC/FEID-AGSP	western juniper/Idaho fescue-bluebunch wheatgrass
CJS1	OF	37	JUOC/ARAR	western juniper/low sagebrush
CJS2	OF	41	JUOC/ARTRV	western juniper/mountain big sagebrush
CJS3	OF	3	JUOC/PUTR	western juniper/bitterbrush
CJS321	OF	9	JUOC/PUTR/FEID-AGSP	western juniper/bitterbrush/Idaho fescue-bluebunch wheatgrass
CJS4	OF	160	JUOC/CELE	western juniper/mountain mahogany
CJS8	OF	28	JUOC/ARRI	western juniper/stiff sagebrush
CLF211	G4	118	PICO(ABGR)/LIBO2	lodgepole pine(grand fir)/twinflower
CLG1	G5	81	PICO(ABLA2)/STOC	lodgepole pine(subalpine fir)/western needlegrass
CLG2	G3	964	PICO(ABGR)/CARU	lodgepole pine(grand fir)/pinegrass
CLS4	G4	768	PICO(ABGR)/VASC/CARU	lodgepole pine(grand fir)/grouse huckleberry/pinegrass
CLS415	G5	204	PICO(ABLA2)/VASC/POPU	lodgepole pine(subalpine fir)/grouse huckleberry/skunkleaved polemonium
CLS416	G4	540	PICO/CARU	lodgepole pine/pinegrass
CLS5	G4	595	PICO(ABGR)/VAME/PTAQ	lodgepole pine(grand fir)/big huckleberry/bracken fern
CLS515	G5	127	PICO(ABLA2)/VAME	lodgepole pine(subalpine fir)/big huckleberry
CLS6	G4	66	PICO(ABGR)/ALSI	lodgepole pine(grand fir)/Sitka alder
CMS131	G5	109	TSME/VASC	mountain hemlock/grouse huckleberry
CMS231	G5	79	TSME/VAME	mountain hemlock/big huckleberry
CPG1	G1	4	PIPO/bunchgrass	ponderosa pine/bunchgrass
CPG111	G1	1797	PIPO/AGSP	ponderosa pine/bluebunch wheatgrass
CPG112	G1	387	PIPO/FEID	ponderosa pine/Idaho fescue
CPG131	G1	199	PIPO/FEID	ponderosa pine/Idaho fescue
CPG132	G1	106	PIPO/AGSP	ponderosa pine/bluebunch wheatgrass
CPG221	G1	748	PIPO/CARU	ponderosa pine/pinegrass
CPG222	G1	1311	PIPO/CAGE	ponderosa pine/elk sedge
CPS1	G1	36	PIPO/ARTR	ponderosa pine/big sagebrush
CPS131	G1	106	PIPO/ARTRV/FEID-AGSP	ponderosa pine/mountain big sagebrush/Idaho fescue-bluebunch wheatgrass
CPS221	G1	26	PIPO/PUTR/CARO	ponderosa pine/bitterbrush/Ross sedge
CPS222	G1	29	PIPO/PUTR/CAGE	ponderosa pine/bitterbrush/elk sedge
CPS226	G1	46	PIPO/PUTR/FEID-AGSP	ponderosa pine/bitterbrush/Idaho fescue-bluebunch wheatgrass

Ecoclass Code	Group	Tree Records	Potential Vegetation Type	Potential Vegetation Type Common Name
CPS231	G1	10	PIPO/PUTR/AGSP	ponderosa pine/bitterbrush/bluebunch wheatgrass
CPS232	G1	218	PIPO/CELE/CAGE	ponderosa pine/mountain mahogany/elk sedge
CPS233	G1	42	PIPO/CELE/PONE	ponderosa pine/mountain mahogany/Wheeler's bluegrass
CPS234	G1	174	PIPO/CELE/FEID-AGSP	ponderosa pine/mountain mahogany/Idaho fescue-bluebunch wheatgrass
CPS5	G1	3	PIPO/SYAL	ponderosa pine/common snowberry
CPS522	G1	130	PIPO/SYAL	ponderosa pine/common snowberry
CPS523	G1	144	PIPO/SPBE	ponderosa pine/birchleaf spiraea
CPS524	G1	639	PIPO/SYAL	ponderosa pine/common snowberry
CPS525	G1	141	PIPO/SYOR	ponderosa pine/mountain snowberry
CPS7	G1	1	PIPO/PHMA	ponderosa pine/mallow ninebark
CWC3	G4	4	ABGR-PICO	grand fir-lodgepole pine
CWC811	G4	90	ABGR/TABR/CLUN	grand fir/Pacific yew/queencup beadlily
CWC812	G4	191	ABGR/TABR/LIBO2	grand fir/Pacific yew/twinflower
CWF311	G4	756	ABGR/LIBO2	grand fir/twinflower
CWF312	G4	2059	ABGR/LIBO2	grand fir/twinflower
CWF421	G4	1769	ABGR/CLUN	grand fir/queencup beadlily
CWF422	G4	435	ABGR/TABR/CLUN	grand fir/Pacific yew/queencup beadlily
CWF512	G4	151	ABGR/TRCA3	grand fir/false bugbane
CWF611	G4	27	ABGR/GYDR	grand fir/oakfern
CWF612	G4	36	ABGR/POMU-ASCA3	grand fir/sword fern-ginger
CWG1	G3	432	ABGR/ARCO	grand fir/heartleaf arnica
CWG111	G3	3729	ABGR/CAGE	grand fir/elk sedge
CWG112	G3	1480	ABGR/CARU	grand fir/pinegrass
CWG113	G3	3975	ABGR/CARU	grand fir/pinegrass
CWG211	G4	131	ABGR/BRVU	grand fir/Columbia brome
CWS211	G4	1260	ABGR/VAME	grand fir/big huckleberry
CWS212	G4	1001	ABGR/VAME	grand fir/big huckleberry
CWS321	G3	457	ABGR/SPBE	grand fir/birchleaf spiraea
CWS322	G3	505	ABGR/SPBE	grand fir/birchleaf spiraea
CWS412	G4	810	ABGR/ACGL-PHMA	grand fir/Rocky Mountain maple-ninebark
CWS541	G4	456	ABGR/ACGL	grand fir/Rocky Mountain maple
CWS811	G4	1417	ABGR/VASC	grand fir/grouse huckleberry
CWS812	G4	915	ABGR/VASC-LIBO2	grand fir/grouse huckleberry-twinflower
CWS912	G4	303	ABGR/ACGL	grand fir/Rocky Mountain maple
FW	NF	3	Wet forblands	wet forblands

Ecoclass Code	Group	Tree Records	Potential Vegetation Type	Potential Vegetation Type Common Name
GB41	NF	33	AGSP	bluebunch wheatgrass
GB4111	NF	10	AGSP-ERHE	bluebunch wheatgrass-Wyeth's buckwheat
GB4112	NF	1	AGSP-POSA3-SCAN	bluebunch wheatgrass-Sandberg's bluegrass-narrowleaf skullcap
GB4113	NF	6	AGSP-POSA3 (BASALT)	bluebunch wheatgrass-Sandberg's bluegrass (basalt)
GB4114	NF	3	AGSP-POSA3-ASCU4	bluebunch wheatgrass-Sandberg's bluegrass-Cusick's milkvetch
GB4118	NF	2	AGSP-POSA3-OPPO	bluebunch wheatgrass-Sandberg's bluegrass-pricklypear
GB42	NF	3	AGIN	Whitmar wheatgrass
GB4911	NF	18	AGSP-POSA3-DAUN	bluebunch wheatgrass-Sandberg's bluegrass-onespike oatgrass
GB50	NF	1	FEID	Idaho fescue
GB59	NF	22	FEID-AGSP	Idaho fescue-bluebunch wheatgrass
GB5911	NF	6	FEID-KOCR (RIDGE)	Idaho fescue-prairie junegrass (ridge)
GB5915	NF	13	FEID-AGSP (RIDGE)	Idaho fescue-bluebunch wheatgrass (ridge)
GB5917	NF	8	FEID-AGSP-BASA	Idaho fescue-bluebunch wheatgrass-balsamroot
GB5918	NF	1	FEID-AGSP-PHCO2	Idaho fescue-bluebunch wheatgrass-Snake River phlox
GB5921	NF	2	FEID-CAHO	Idaho fescue-Hood's sedge
GB70	NF	1	ELGL	blue wildrye
GB90	NF	8	POSA3-DAUN	Sandberg's bluegrass-onespike oatgrass
GB9111	NF	24	POSA3-DAUN	Sandberg's bluegrass-onespike oatgrass
GS10	NF	13	STOC	western needlegrass
GS11	NF	1	FEVI	green fescue
GS1112	NF	1	FEVI-LULA2	green fescue-spurred lupine
GS12	NF	2	FEID (ALPINE)	Idaho fescue (alpine)
GS50	NF	11	STIPA-SIHY-TRSP	needlegrass-bottlebrush squirreltail-spike trisetum
HQG1	OF	2	POTR/CARU	quaking aspen/pinegrass
MD3111	NF	2	POPR (MEADOW)	quaking aspen (Kentucky bluegrass meadow)
MNXX	NF	2	Mine tailings/dredge piles	tailings/dredge piles
MS20	NF	1	CALU	woodrush sedge
MW19	NF	3	Wet meadow-tall sedge	tall sedge meadow
NACO	NF	2	Avalanche path	avalanche path dominated by conifers
NR	NF	2	Rock	rock
SD1911	NF	12	ARAR/FEID-AGSP	low sagebrush/Idaho fescue-bluebunch wheatgrass
SD21	NF	5	ARTR	big sagebrush
SD2911	NF	53	ARTRV/FEID-AGSP	mountain big sagebrush/Idaho fescue-bluebunch wheatgrass
SD2917	NF	7	ARTRV-SYOR/BRCA	mountain big sagebrush-mountain snowberry/mountain brome
SD3111	NF	9	PUTR/FEID-AGSP	bitterbrush/Idaho fescue-bluebunch wheatgrass

Ecoclass Code	Group	Tree Records	Potential Vegetation Type	Potential Vegetation Type Common Name
SD3112	NF	4	PUTR/AGSP	bitterbrush/bluebunch wheatgrass
SD40	NF	3	CELE/CAGE	mountain mahogany/elk sedge
SD4111	NF	24	CELE/FEID-AGSP	mountain mahogany/Idaho fescue-bluebunch wheatgrass
SD49	NF	2	CELE	mountain mahogany
SD65	NF	1	GLNE/AGSP	spiny greenbush/bluebunch wheatgrass
SD70	NF	1	CHNA	rabbitbrush
SD91	NF	1	ARRI	rigid sage
SD9111	NF	24	ARRI/POSA3	stiff sagebrush/Sandberg's bluegrass
SD9221	NF	3	ARAR/POSA3	low sagebrush/Sandberg's bluegrass
SD93	NF	2	ERIOGONUM	buckwheat
SM1111	NF	18	PHMA-SYAL	ninebark-common snowberry
SM19	NF	45	PHMA	mallow ninebark
SM30	NF	9	PREM-HODI	bitter cherry-oceanspray
SM31	NF	15	SYAL-ROSA	common snowberry-rose
SM3111	NF	24	SYAL-ROSA	common snowberry-rose
SM32	NF	29	SYOR	mountain snowberry
SS40	NF	1	Alpine sagebrush	alpine sagebrush
SS49	NF	3	ARTRV	mountain big sagebrush
SS4911	NF	15	ARTRV/CAGE	mountain big sagebrush/elk sedge
SW20	NF	3	Alder wetlands	alder

Sources/Notes: ‘Ecoclass Code’ and ‘Potential Vegetation Type Common Name’ are from Crowe and Clausnitzer (1997), Hall (1998), Johnson and Clausnitzer (1992), and Johnson and Simon (1987). ‘Potential Vegetation Type’ is an acronym derived from scientific plant name (first two letters of genus name plus first 2 letters of species name and then capitalized), with a number added to differentiate between two or more species with same code. ‘Group’ refers to plant association group as described in the text, with two additions: nonforest (NF) refers to nonforest ecoclass codes where tree records are available in the database (perhaps indicating a data inconsistency), and other forest (OF) refers primarily to western juniper woodland types. ‘Tree Records’ column provides number of tree records present in a height-diameter analysis database for each combination of Ecoclass Code and Group.

Tree records available for height-diameter analysis were distributed among five plant association groups in expected proportions, with groups occurring at lowest and highest elevations (groups 1 and 5, respectively) having fewer records than mid-elevation groups (groups 2, 3, and 4) (table 5).

Table 5: Tree record count by plant association group.

Plant Association Group Code	Number of Tree Records
G1: Plant Association Group 1	6,297
G2: Plant Association Group 2	10,170
G3: Plant Association Group 3	11,542
G4: Plant Association Group 4	13,898
G5: Plant Association Group 5	7,035
NF: nonforest ecoclass codes	518
OF: other forest ecoclass codes	724
Total	50,184

Sources/Notes: Table 4 describes how potential vegetation types for Blue and Wallowa mountains were assigned to plant association groups.

Note that height-diameter analyses were completed by using two levels of stratification: an initial stratification was by plant association group (but ignoring 'nonforest' and 'other forest' groups in table 5), and a second stratification was by tree species (note that some groups included a dozen or more of the fifteen tree species included in table 3).

Tree records available for height-diameter analysis were loaded into a Corel Paradox database application, and filtering steps described above were completed at this stage.

After filtering was completed, remaining records were exported to Microsoft Excel spreadsheet software for regression (trend line) analyses. Note that a separate Excel workbook exists for each of five plant association groups, and all tree records for a group (all species combined) are on a worksheet named in this way: G1 Trees, G2 Trees, etc.

Correlation (regression) analysis was initiated by plotting a graph of the relationship between two variables – tree diameter and tree height. The independent (x-axis) variable is tree diameter; the dependent (y-axis) variable is tree height. Data points consisting of tree height and tree diameter measurements, as stratified by plant association group and then by tree species, were graphed as a scatter (XY) plot. Both linear and nonlinear regressions were used to fit curves to broad height growth patterns contained in the scatter plots.

Excel provides six trend line (regression) alternatives: linear, logarithmic, polynomial, power, exponential, and moving average. Since tree height-diameter relationships are typically nonlinear (Huang et al. 1992, Moore et al. 1996, Yuancai and Parresol 2001), five of these trend line options (all except moving average) were used in order to examine which trend line alternative provided the 'best' fit (as evaluated by using regression results).

A fire-caused tree mortality rating system developed by Scott et al. (2002) includes eight tree species: ponderosa pine, interior Douglas-fir, Engelmann spruce, lodgepole pine, western larch, grand fir/white fir, subalpine fir, and western white pine.

Of these species, there were an insufficient number of tree records to stratify western white pine by plant association group. So, for this species only, all CVS tree records for white pine were pooled (they came from plant association groups 4 and 5), and then combined with records from Umatilla National Forest's big-tree program, to generate a single dataset pertaining exclusively to western white pine.

Tree diameter-height trend lines for western white pine were generated from a pooled dataset (table 11; fig. 26).

Note that height-diameter trend lines were not produced for tree species not included in the Scott et al. (2002) tree mortality rating system, although a sufficient number of tree records are available to do so for several species (western juniper in group 1 and 2, and whitebark pine in group 5, for example).

Trend lines were generated by using a multi-step process:

1. Data was first stratified by plant association group (PAG), and an Excel workbook exists for each of five primary PAGs. Workbooks are named by using this protocol: G1 Trees, G2 Trees, G3 Trees, G4 Trees, and G5 Trees.
2. Within a PAG, tree records were stratified by tree species, and this sorting was accomplished by using Excel's sort function (from its Data menu).
3. After sorting by species and within a PAG, all diameter and height records were selected for an individual species (note that not all species were analyzed because some species had an insufficient number of records, or a species was not included in the Scott et al. 2002 protocol).
4. Selected tree records, by tree species, were graphed as an XY (scatter) plot by using Excel's chart wizard function. With this chart type, each combination of diameter and height represents one observation and is plotted on the chart with a marker (dot).
5. After generating an XY scatter chart for a tree species, alternative trend lines were evaluated by selecting the 'Add Trendline' option from Excel's Chart menu. Trend line options were then selected to display equation and regression (R^2) values on the resulting chart.
6. Since five trend lines were being generated for each XY scatter chart for a given tree species, results of each trend line were copied into Microsoft's PowerPoint presentation software application. This process was necessary because underlying data on which a trend line was being displayed (e.g., a field of XY scatter points) remained the same for each trend line, which required that one trend line be deleted before adding the next one.

Note: It is possible to display all five trend lines, and their associated equations and R^2 values, simultaneously on a single chart, but this approach produces a cluttered result that is hard to interpret. For each species, another option would have been to generate an XY (scatter) chart five times, and then add each individual trend line to them, one at a time, but this approach requires much more effort than the 'add and delete' process described here.

7. After copying each chart to PowerPoint, it was possible to generate graphics output files (Windows metafiles) for inclusion in this document as appendix 1 (see figures 1-26).

RESULTS AND DISCUSSION

As described above, this tree height-diameter analysis process was based on double stratification: an initial stratification by plant association group (PAG), followed by a second stratification by using tree species. Overall results of this phase of the process are summarized in five tables (tables 6-10), with one table for each plant association group.

Each PAG table (tables 6-10) shows a tree species occurring in a PAG, number of tree records associated with a species, and coefficient of determination (R^2) values for each of five regression or trend types examined.

An appendix provides a series of figures showing charts generated for each unique combination of PAG and tree species. Each chart includes XY (scatter) points for a species, with tree diameter as an x-axis variable and tree height as a y-axis variable. A regression trend line is superimposed over scatter-plot data, and regression information (type, equation, R^2 value, and number of data points/tree records) is provided in one corner of each chart.

As explained in a methods section, there were insufficient tree records to stratify western white pine by plant association group, so it was analyzed by using a pooled dataset consisting of CVS records and information from Umatilla National Forest's big-tree program. Results from a western white pine analysis are provided in table 11 and figure 26.

A coefficient of explanation or coefficient of determination (this is an R^2 value shown on each chart) is always positive regardless of which trend line is examined, indicating that there is a positive association between the independent (tree diameter) and dependent (tree height) variables in these analyses.

This association is probably not a causal relationship, but perhaps indicates a mutual interaction between these two variables. Rather than tree diameter 'causing' variation in tree height, it is more realistic to think of these variables as varying together, rather than a one-way causal relationship (Kent and Coker 2002).

Results shown in tables 6-11 corroborate observations that tree height-diameter relationships are typically nonlinear (Huang et al. 1992, Moore et al. 1996, Yuancai and Parresol 2001), as evidenced by the fact that linear regression values were almost always lower than those obtained from logarithmic, polynomial, or power trend lines. Regression values associated with exponential trend lines were consistently the lowest of five trend line alternatives examined.

After discounting two trend line alternatives with low regression values (linear and exponential), three remaining alternatives were not always consistent from one species to another, or from one group to another (for the same species).

Although it is not perfectly consistent, note that a power trend line generally provided the highest regression value (for 77% of analyses, power had the highest coefficient of determination). This result indicates that a higher proportion of variation in a y-axis variable (tree height) was explained by the x-axis variable (tree diameter) when the two variables were analyzed by using a power function. For 23% of analyses, polynomial had the highest coefficient of determination.

Table 6: Tree record count and regression values for group 1.

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE				
		Linear	Logarithmic	Polynomial	Power	Exponential
ABGR	89	.8704	.819	.8845	.8823	.772
JUOC	568					
LAOC	50					
PICO	63					
PIEN	3					
PIPO	3,851	.7541	.7108	.775	.8007	.6494
POTR	4					
POTR2	7					
PSME	369	.7946	.7661	.8229	.8939	.6885
Total	5,004					

Sources/Notes: Table 3 describes tree species codes. Gray shading indicates highest R^2 value. This table does not include statistics for Prognosis form (next section describes a Prognosis form analysis).

Table 7: Tree record count and regression values for group 2.

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE				
		Linear	Logarithmic	Polynomial	Power	Exponential
ABGR	276	.7596	.7622	.8228	.8612	.6569
ABLA2	14					
JUOC	240					
LAOC	227	.7872	.7831	.8215	.8345	.6354
PIAL	4					
PICO	141					
PIEN	16					
PIPO	3,257	.7643	.7495	.7963	.8189	.6453
POTR	1					
POTR2	3					
PSME	4,160	.6853	.7154	.7418	.7946	.6031

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE				
		Linear	Logarithmic	Polynomial	Power	Exponential
TABR	1					
Total	8,340					

Sources/Notes: Table 3 describes tree species codes. Gray shading indicates highest R^2 value. This table does not include statistics for a Prognosis form (next section describes a Prognosis form analysis).

Table 8: Tree record count and regression values for group 3.

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE				
		Linear	Logarithmic	Polynomial	Power	Exponential
ABGR	3,340	.7682	.7738	.8203	.8306	.6368
ABLA2	85					
JUOC	39					
LAOC	663	.7577	.8103	.8303	.7367	.5404
PIAL	16					
PICO	679	.6432	.663	.6837	.7261	.5699
PIEN	105					
PIPO	2,227	.8386	.8063	.8712	.8692	.7072
POTR	11					
PSME	2,332	.7817	.7902	.827	.818	.6285
Total	9,497					

Sources/Notes: Table 3 describes tree species codes. Gray shading indicates highest R^2 value. This table does not include statistics for a Prognosis form (next section describes a Prognosis form analysis).

Table 9: Tree record count and regression values for group 4.

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE				
		Linear	Logarithmic	Polynomial	Power	Exponential
ABGR	4,042	.7613	.7811	.8202	.8343	.628
ABLA2	275	.7808	.7947	.8309	.8285	.6757
CRATA	1					
JUOC	2					
LAOC	1,498	.7396	.8049	.8201	.8392	.5828
PICO	1,301	.6264	.6856	.695	.7352	.5513
PIEN	979	.8192	.825	.8702	.8858	.6727
PIMO	15					
PIPO	735	.8125	.801	.8611	.8792	.7046
POTR	1					
POTR2	3					
PSME	2,330	.773	.8069	.8402	.8329	.6187
TABR	57					
TSME	1					
Total	11,240					

Sources/Notes: Table 3 describes tree species codes. Gray shading indicates highest R^2 value. This table does not include statistics for a Prognosis form (next section describes a Prognosis form analysis).

Table 10: Tree record count and regression values for group 5.

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE Linear	Logarithmic	Polynomial	Power	Exponential
ABGR	836	.7775	.8175	.8493	.8817	.6586
ABLA2	1,734	.6656	.7317	.7573	.7732	.5769
LAOC	584	.6449	.7603	.7609	.8317	.5494
PIAL	235					
PICO	941	.5839	.6628	.6721	.7022	.51
PIEN	1,333	.7375	.8017	.8275	.8481	.6175
PIMO	7					
PIPO	12					
POTR	1					
PSME	463	.5617	.6738	.7001	.7738	.5083
TSME	60					
Total	6,206					

Sources/Notes: Table 3 describes tree species codes. Gray shading indicates highest R^2 value. This table does not include statistics for a Prognosis form (next section describes a Prognosis form analysis).

Table 11: Tree record count and regression values for western white pine (pooled records).

Tree Species	Number of Tree Records	REGRESSION (R^2) VALUES BY EQUATION TYPE Linear	Logarithmic	Polynomial	Power	Exponential
PIMO	31	.8444	.84	.8757	.9122	.7381

Sources/Notes: Table 3 describes tree species code. Gray shading indicates highest R^2 value. Note that western white pine was not stratified by plant association group due to an insufficient number of records. This table pertains to 22 western white pine records from CVS plots (see tables 9-10 for groups 4-5) and 9 tree records from Umatilla National Forest's big-tree program. Also, note that a Prognosis form analysis was not completed for western white pine due to its small sample size.

UPDATE USING PROGNOSIS PROCEDURE

After generating diameter-height regressions described in this paper, the Scott et al. (2002) group reviewed results to evaluate whether their tree mortality prediction needs would be met by the resulting equations (Introduction section provides information about their needs). They had concerns about whether regression results adequately incorporate variations in tree height growth, in relation to diameter, that typically occur during tree and stand development.

For example, a graphic representation of tree height growth shows a characteristic S-shaped (sigmoidal) curve that can be divided into three main phases: juvenile or early-age growth (which may be slow for shade-tolerant, late-seral species or relatively rapid for shade-intolerant, early-seral species); sapling-size to maturity; and old-age growth (mature to overmature phase).

As described earlier in this white paper, length of time that a tree spends in each phase can vary by species, inherent site productivity, and existing stand conditions such as canopy position or crown class (Cochran 1979a, b; Harrington and Murray 1982; Larson 1986).

Height growth may be relatively consistent within each of three phases, often approaching a linear relationship for a sapling-to-mature phase where tree growth tends to be optimal, but when all three phases are graphed simultaneously, the resulting growth pattern may be complex and result in an S-shaped or sigmoidal trend described earlier. Excel's range of regression functions may not be wide enough to evaluate datasets containing complex relationships with multiple inflection points (such as sigmoidal patterns).

To examine this pattern complexity issue in more detail, the entire dataset was provided to an analyst at Forest Management Service Center (Fort Collins, Colorado), and he was asked to examine more sophisticated statistical functions than were possible from Excel. The analyst loaded data into a stand-alone statistical package (SAS Analytics, Statistical Analysis System) and checked it for data errors.

He fit two additional model forms to the data: Prognosis form, and a Log-Linear Exponential model. A Log-Linear Exponential model showed no advantage over models available in Excel, so it was not considered further. The Prognosis form [Height=EXP(C0+C1*(1/(DBH+1)))+4.5] did show promise because it tended to produce a typical sigmoidal pattern.

The Prognosis form will not predict negative heights (a good attribute☺). It also tends to level off for high values of DBH, rather than turning down and predicting lower heights. Since it is non-linear, calculation of an R-Squared statistic is not included with the output, and it must be calculated separately. Plots of data, predicted heights, and 95% confidence limits for predictions, are presented as a set of tables. A table of R-Squares for this Prognosis model, along with models that Powell fit, are presented in table 12.

Note: Prognosis refers to a long-tenured growth-and-yield model developed originally for interior Pacific Northwest (first Prognosis variant was a North Idaho variant). Any reference to a 'Prognosis form' in this narrative refers to height-diameter relationships incorporated in the Prognosis model. Prognosis variants were developed for many areas of the country, including Blue Mountains beginning in 1986 (Keyser and Dixon 2015). Prognosis is now called the Forest Vegetation Simulator (Dixon 2015).

Table 12: R-squared statistics for all models evaluated for a tree height-diameter relationship.

Group	Species	Records	Linear	Logarithmic	Polynomial	Power	Exponential	Prognosis
1	ABGR	89	.8704	.819	.8845	.8823	.772	.878
	PIPO	3851	.7541	.7108	.775	.8007	.6494	.7605
	PSME	369	.7946	.7661	.8229	.8939	.6885	.8017
2	ABGR	276	.7596	.7622	.8228	.8612	.6569	.8101
	LAOC	227	.7872	.7831	.8215	.8345	.6354	.8089
	PIPO	3257	.7643	.7495	.7963	.8189	.6453	.7872
	PSME	4160	.6853	.7154	.7418	.7946	.6031	.7366
3	ABGR	3340	.7682	.7738	.8203	.8306	.6368	.8125
	LAOC	663	.7577	.8103	.8303	.7367	.5404	.8322

Group	Species	Records	Linear	Logarithmic	Polynomial	Power	Exponential	Prognosis
	PICO	679	.6432	.663	.6837	.7361	.5699	.6847
	PIPO	2227	.8386	.8063	.8712	.8692	.7072	.8625
	PSME	2332	.7817	.7902	.827	.818	.6285	.8196
4	ABGR	4042	.7613	.7811	.8202	.8343	.628	.8163
	ABLA2	275	.7808	.7947	.8309	.8285	.6757	.8331
	LAOC	1498	.7396	.8049	.8201	.8392	.5828	.8232
	PICO	1301	.6264	.6856	.695	.7352	.5513	.7017
	PIEN	979	.8192	.825	.8702	.8858	.6727	.8713
	PIPO	735	.8125	.801	.8611	.8792	.7046	.8576
	PSME	2330	.773	.8069	.8402	.8329	.6187	.8370
5	ABGR	836	.7775	.8175	.8493	.8817	.6586	.8522
	ABLA2	1734	.6656	.7317	.7573	.7732	.5769	.7580
	LAOC	584	.6449	.7603	.7609	.8317	.5494	.7744
	PICO	941	.5839	.6628	.6721	.7022	.51	.6762
	PIEN	1333	.7375	.8017	.8275	.8481	.6175	.8298
	PSME	463	.5617	.6738	.7001	.7738	.5083	.6946
Not fit:								
	PIMO	31	.8444	.84	.8757	.9122	.7381	n too small

If model selection is based only on an R-Squared value, then a Power model would appear to be superior. However, if we consider graphs along with model predictions, we see that a Power model over-predicts tree height for large diameters. A Polynomial model also looks good when considering just the R-Squared statistics, but for large diameters it often under-predicts tree height. An Exponential model is also undependable for predicting tree height for large-diameter trees. A Linear model, for the most part, over-predicts tree height for large-diameter trees.

This leaves a Logarithmic model as one with the best pattern of predictions. It predicts tree height relatively well for large-diameter trees (with perhaps a slight under-estimation). However, results suggest that when fit to this dataset, a Prognosis model should also be considered. The Prognosis fits are also included in the charts presented in appendix 1.

It appears that a Prognosis model under-predicts tree heights at small diameters. In a Prognosis system, small-diameter trees are fit by using a separate model. If tree height under-estimates for small tree diameters is a significant concern for how these models will be used, then other alternatives should perhaps be considered.

Appendix 1 presents a series of charts (figs. 1-26) that are stratified first by potential vegetation (e.g., groups 1 to 5), and secondly by tree species. For each species within a group, 6 charts are provided: linear, logarithmic, polynomial, power, exponential, and Prognosis form. Each chart shows pertinent regression information – equation, r-squared value, and number of tree records.

LITERATURE CITED

Andrews, P.L.; Bevins, C.D.; Seli, R.C. 2008. BehavePlus fire modeling system, version 4.0: User's guide. Gen. Tech. Rep. RMRS-GTR-106WWW Revised. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 116 p. https://www.treesearch.fs.fed.us/pubs/5488

Cochran, P.H. 1979a. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-251. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p. https://www.treesearch.fs.fed.us/pubs/37177

Cochran, P.H. 1979b. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-252. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p. https://www.treesearch.fs.fed.us/pubs/37178

Dixon, G.E. 2015. Essential FVS: a user's guide to the Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: USDA Forest Service, Forest Management Service Center. 226 p. https://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/EssentialFVS.pdf

Hall, F.C. 1998. Pacific Northwest ecoclass codes for seral and potential natural communities. Gen. Tech. Rep. PNW-GTR-418. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 290 p. http://www.treesearch.fs.fed.us/pubs/5567

Harrington, C.A.; Murray, M.D. 1982. Patterns of height growth in western true firs. In: Oliver, C.D.; Kenady, R.M., eds. Proceedings of the biology and management of true fir in the Pacific Northwest symposium. Contribution No. 45. Seattle, WA: University of Washington, College of Forest Resources, Institute of Forest Resources: 209-214.

Huang, S.; Titus, S.J.; Wiens, D.P. 1992. Comparison of nonlinear height-diameter functions for major Alberta tree species. Canadian Journal of Forest Research. 22(9): 1297-1304. doi:10.1139/x92-172

Johnson, C.G., Jr.; Simon, S.A. 1987. Plant associations of the Wallowa-Snake province, Wallowa-Whitman National Forest. Tech. Pub. R6-ECOL-TP-255A-86. Portland, OR: USDA Forest Service, Pacific Northwest Region. 550 p. http://ecoshare.info/2011/11/03/plant-associations-of-the-wallowa-snake-province/

Johnson, C.G., Jr.; Clausnitzer, R.R. 1992. Plant associations of the Blue and Ochoco Mountains. Tech. Pub. R6-ERW-TP-036-92. Baker City, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 200 p. http://ecoshare.info/wp-content/uploads/2011/02/Plant-Associations-of-the-blue-and-Ochoco-Mountains.pdf

Kent, M.; Coker, P. 2002. Vegetation description and analysis: a practical approach. Chichester, UK: John Wiley & Sons. 363 p. isbn:0-471-94810-1

Keyser, C.E.; Dixon, G.E., comps. 2015. Blue Mountains (BM) variant overview – Forest Vegetation Simulator. Internal Rep. Fort Collins, CO: USDA Forest Service, Forest Management Service Center. 58 p. https://www.fs.fed.us/fmsc/ftp/fvs/docs/overviews/FVSbm_Overview.pdf

Larson, B.C. 1986. Development and growth of even-aged stands of Douglas-fir and grand fir. Canadian Journal of Forest Research. 16(2): 367-372. doi:10.1139/x86-063

Max, T.A.; Schreuder, H.T.; Hazard, J.W.; Oswald, D.D.; Teply, J.; Alegria, J. 1996. The Pacific Northwest Region vegetation and inventory monitoring system. Res. Pap. PNW-RP-

493. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 22 p. https://www.treesearch.fs.fed.us/pubs/2875

Moore, J.A.; Zhang, L.; Stuck, D. 1996. Height-diameter equations for ten tree species in the inland Northwest. Western Journal of Applied Forestry. 11(4): 132-137. doi:10.1093/wjaf/11.4.132

Scott, D.W.; Schmitt, C.L.; Ager, A. 1998. Analyzing insect and disease risks for watershed analysis with the UPEST risk calculator program. BMZ-98-1. La Grande, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest, Blue Mountains Pest Management Zone. 25 p.

Scott, D.W.; Schmitt, C.L.; Spiegel, L.H. 2002. Factors affecting survival of fire injured trees: a rating system for determining relative probability of survival of conifers in the Blue and Wallowa Mountains. BMPMSC-03-01. La Grande, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest, Blue Mountains Pest Management Service Center. 86 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_025713.pdf

Yuancai, L.; Parresol, B.R. 2001. Remarks on height-diameter modeling. Res. Note SRS-10. Asheville, NC: USDA Forest Service, Southern Research Station. 5 p. https://www.treesearch.fs.fed.us/pubs/2817

Appendix 1: Height-diameter trend lines by plant association group and tree species

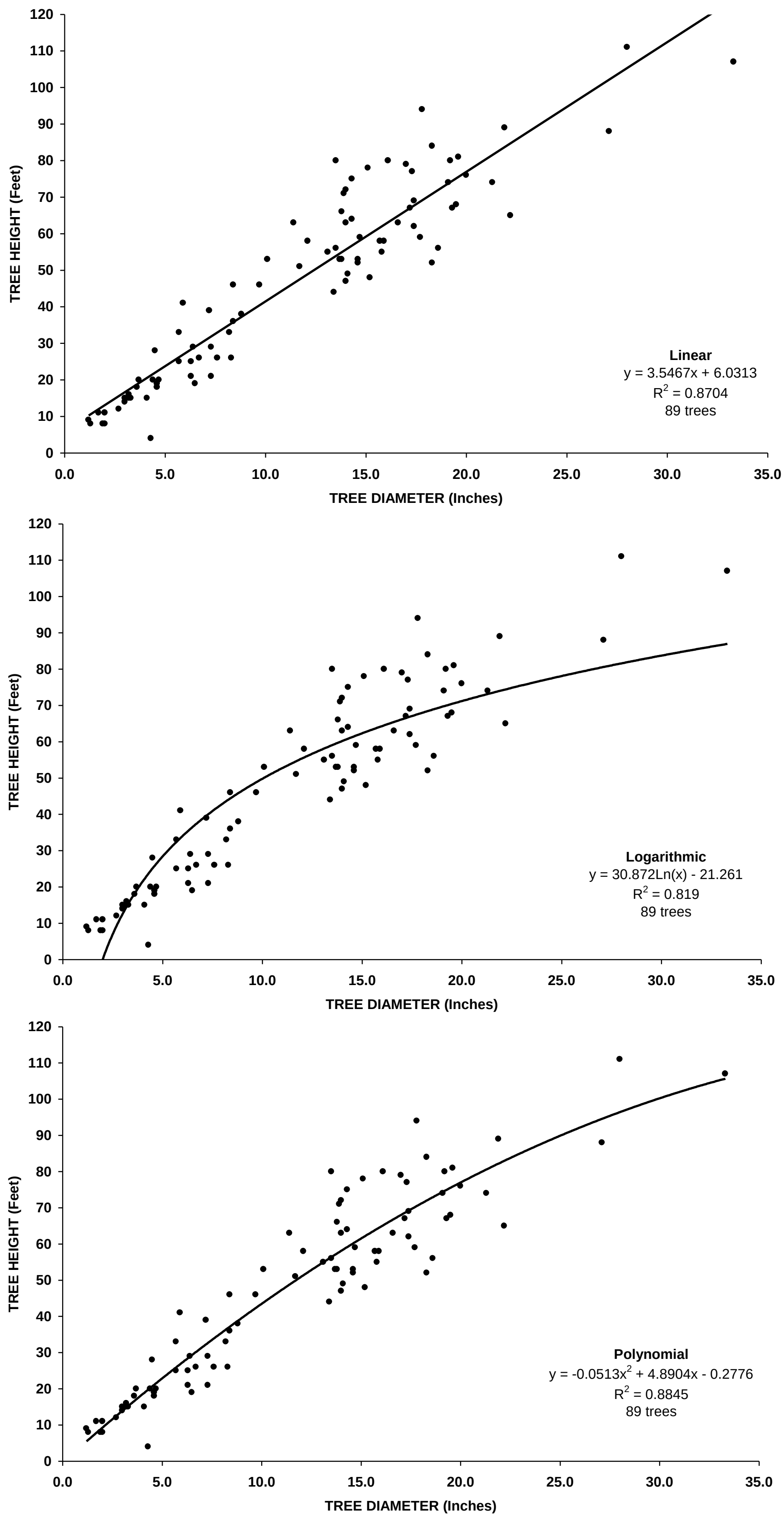


Figure 1(a): Linear, logarithmic, and polynomial trend lines for grand fir on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

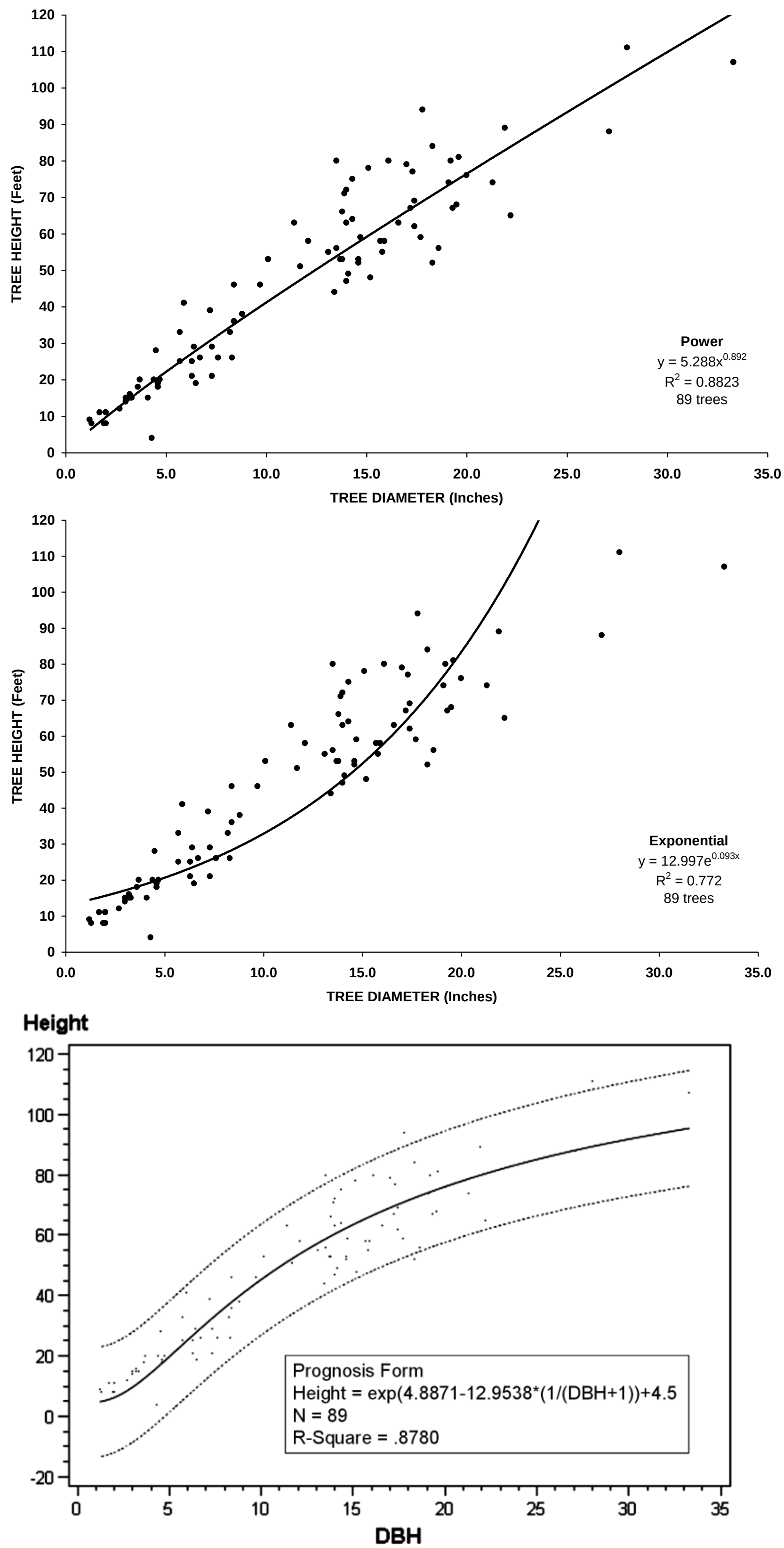


Figure 1(b): Power, exponential, and Prognosis trend lines for grand fir on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

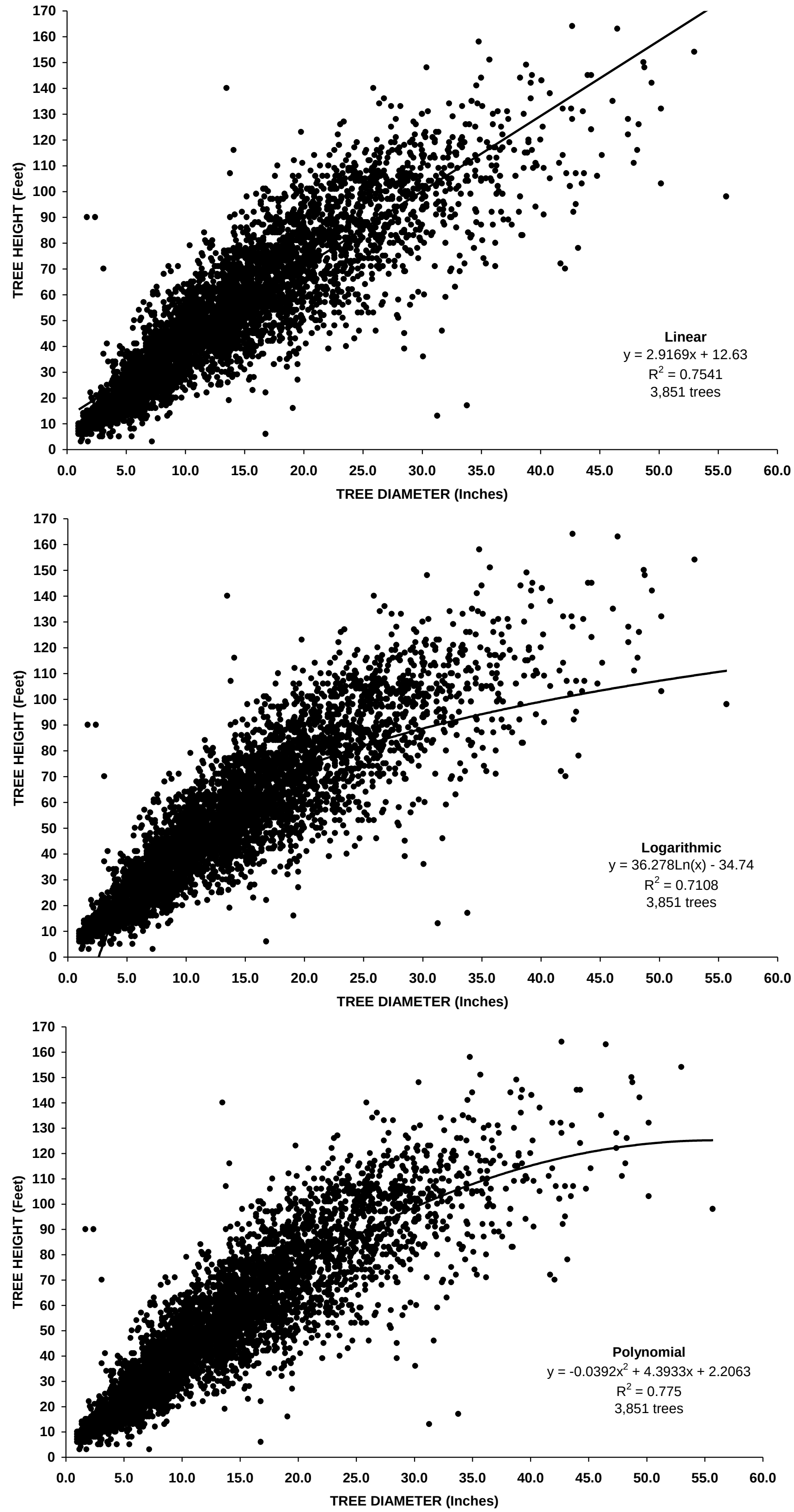


Figure 2(a): Linear, logarithmic, and polynomial trend lines for ponderosa pine on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

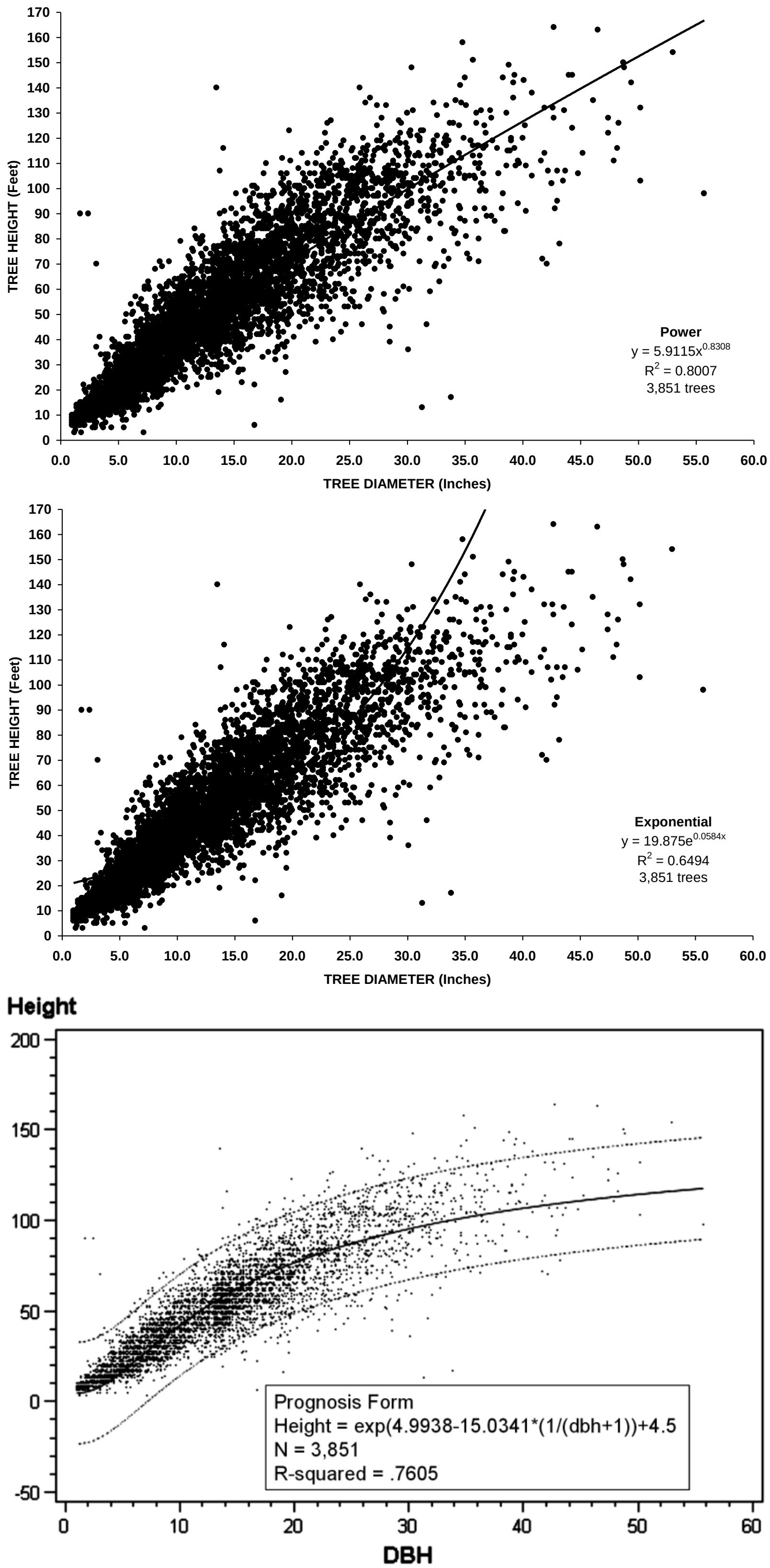


Figure 2(b): Power, exponential, and Prognosis trend lines for ponderosa pine on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

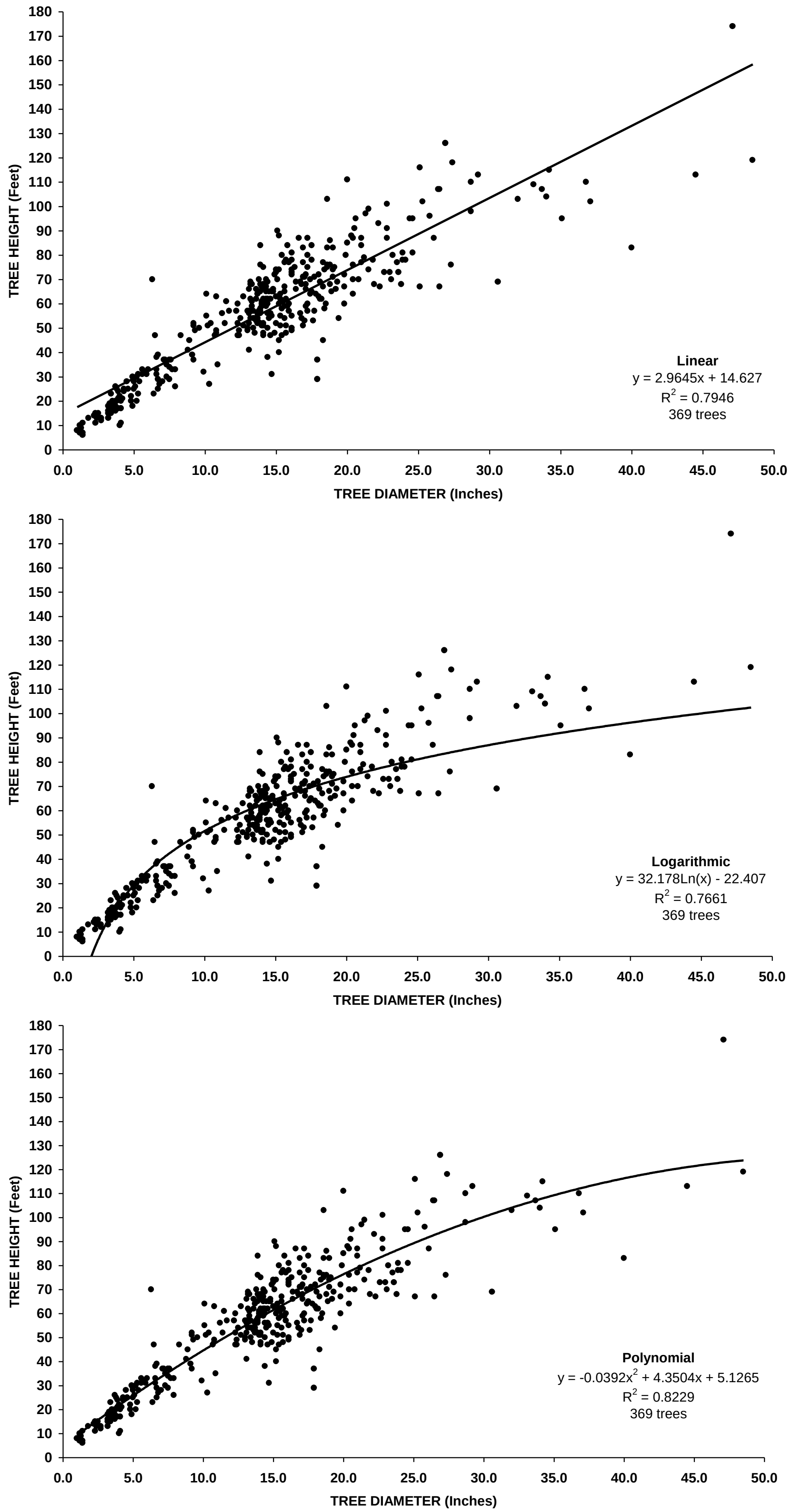


Figure 3(a): Linear, logarithmic, and polynomial trend lines for interior Douglas-fir on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

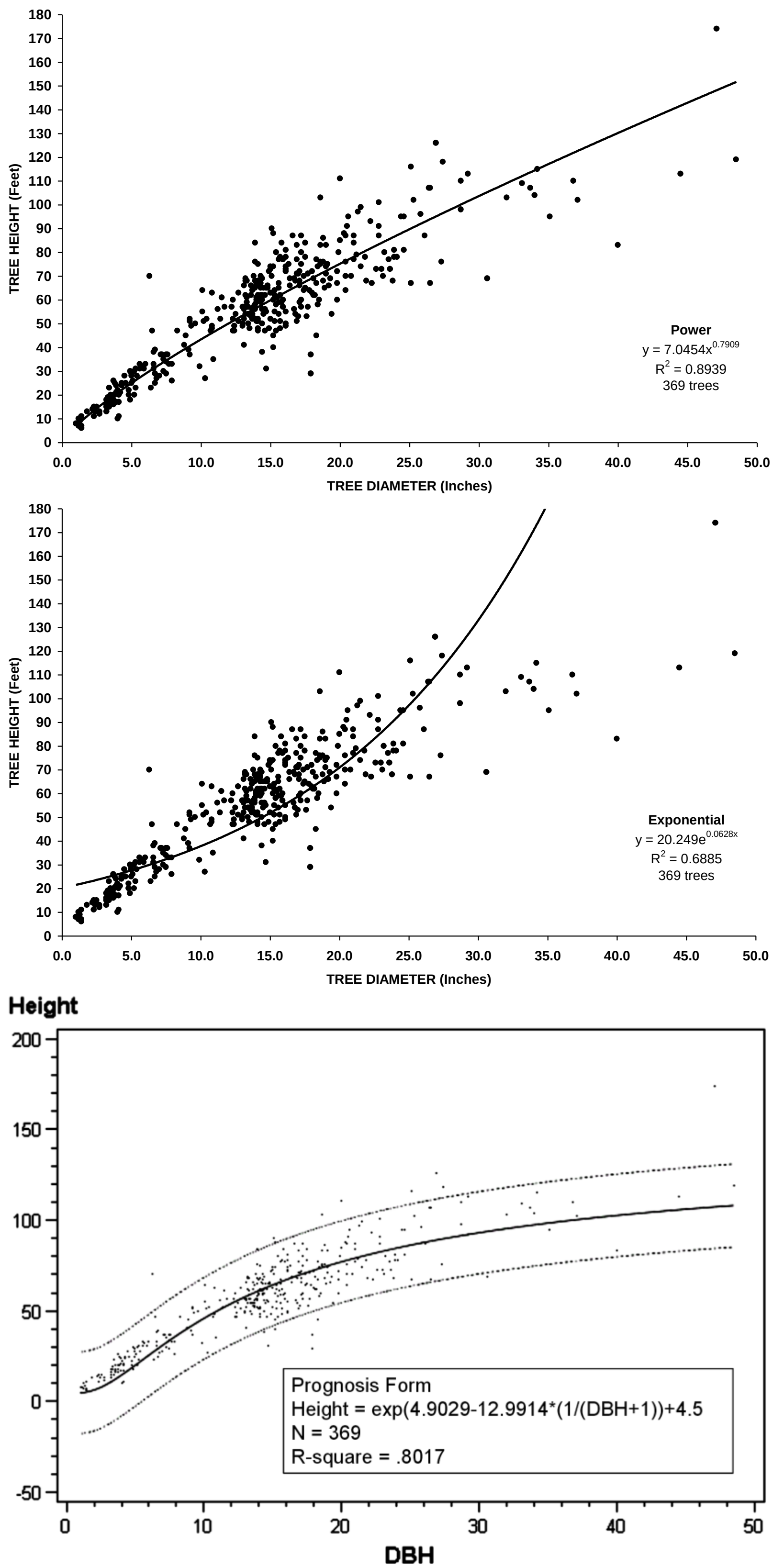


Figure 3(b): Power, exponential, and Prognosis trend lines for interior Douglas-fir on group 1 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

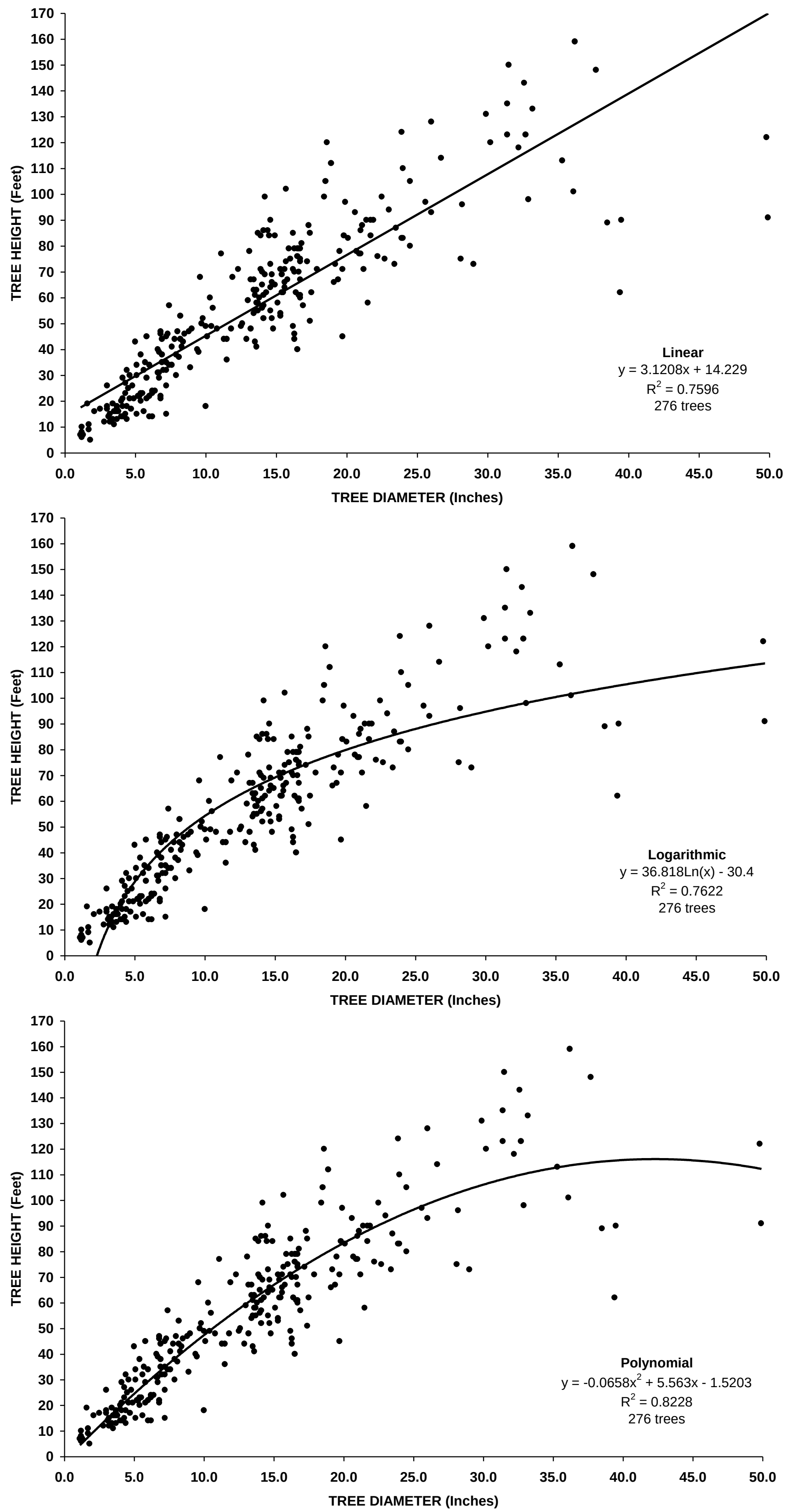


Figure 4(a): Linear, logarithmic, and polynomial trend lines for grand fir on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

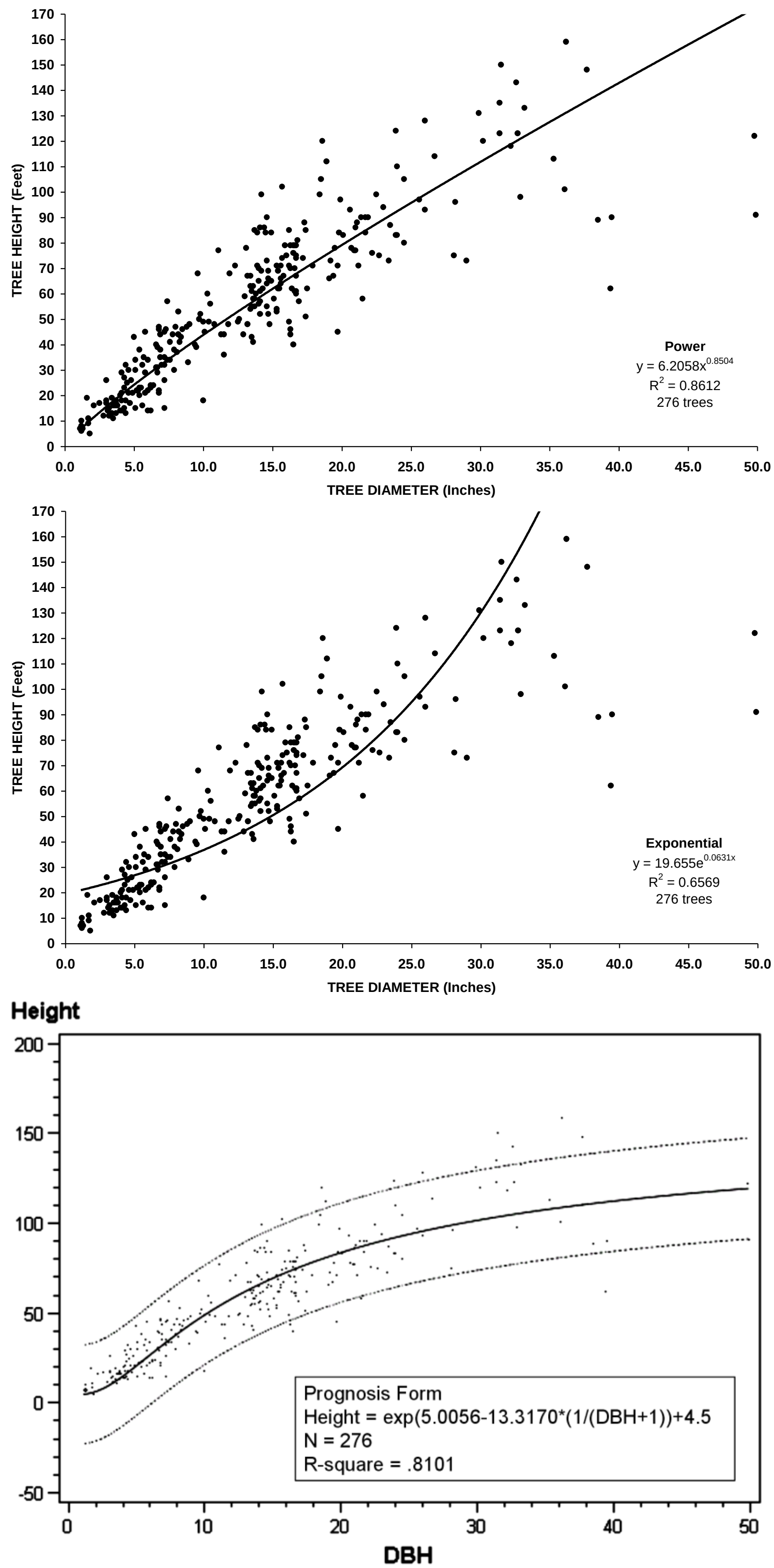


Figure 4(b): Power, exponential, and Prognosis trend lines for grand fir on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

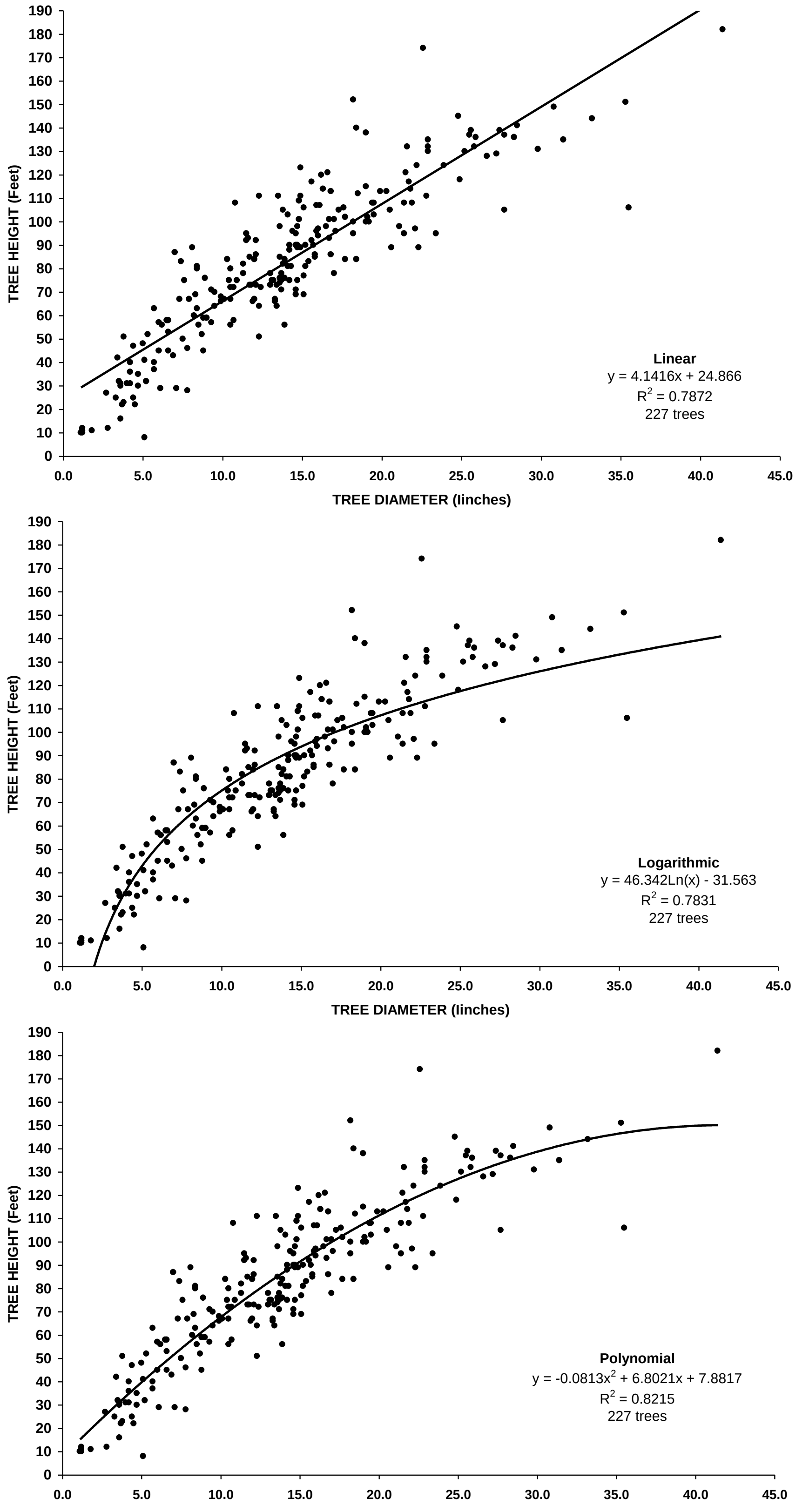


Figure 5(a): Linear, logarithmic, and polynomial trend lines for western larch on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

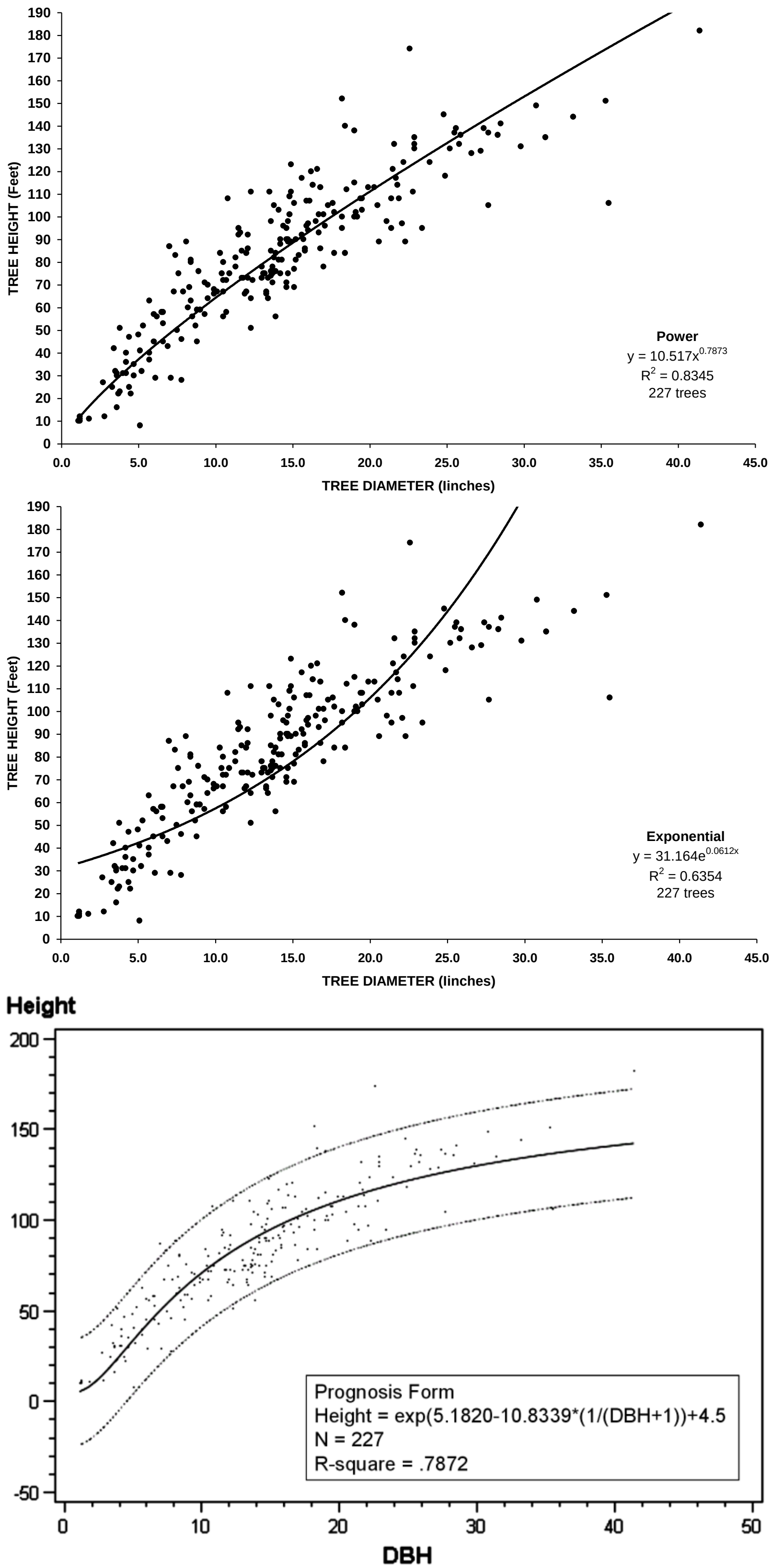


Figure 5(b): Power, exponential, and Prognosis trend lines for western larch on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

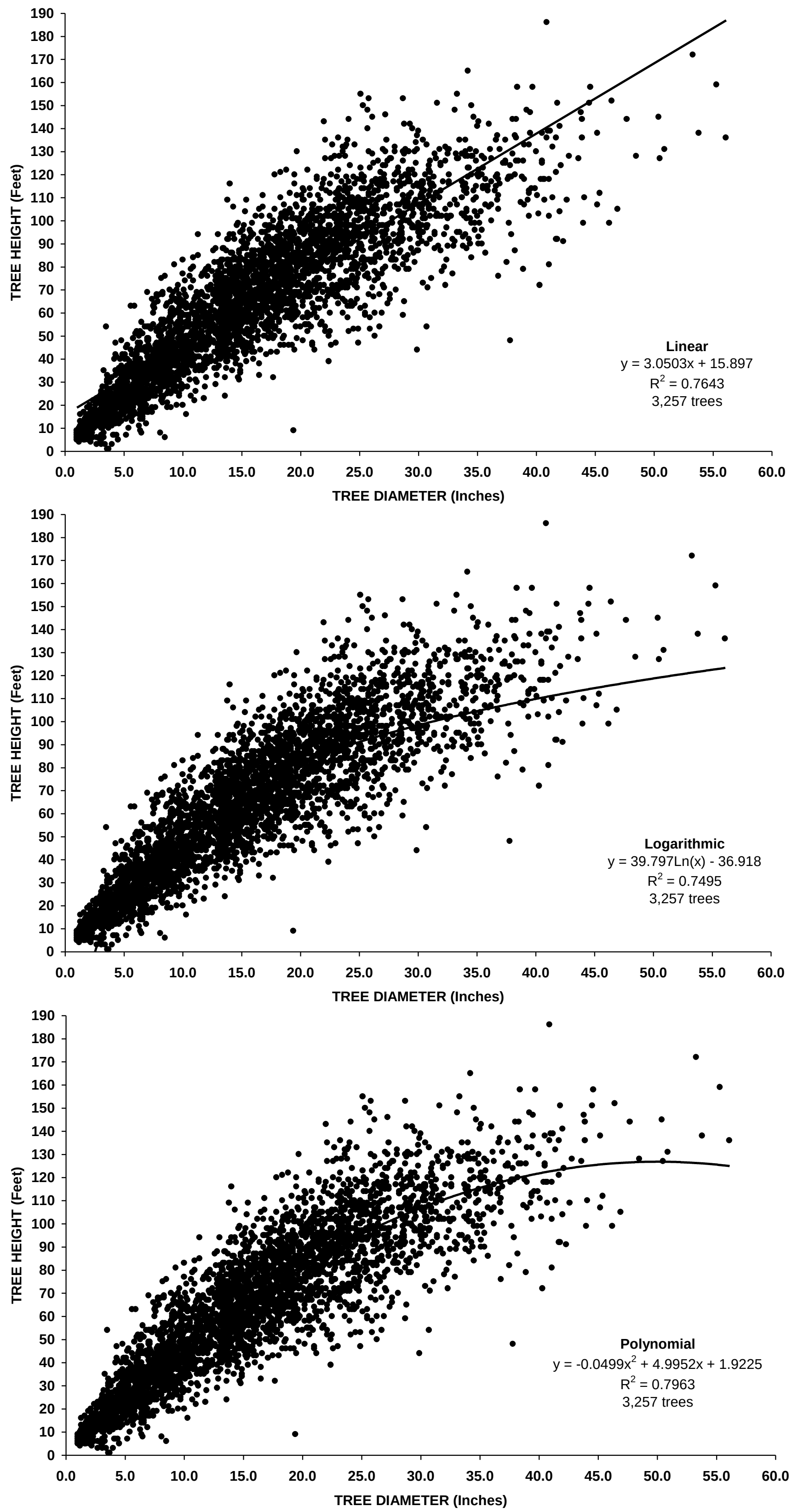


Figure 6(a): Linear, logarithmic, and polynomial trend lines for ponderosa pine on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

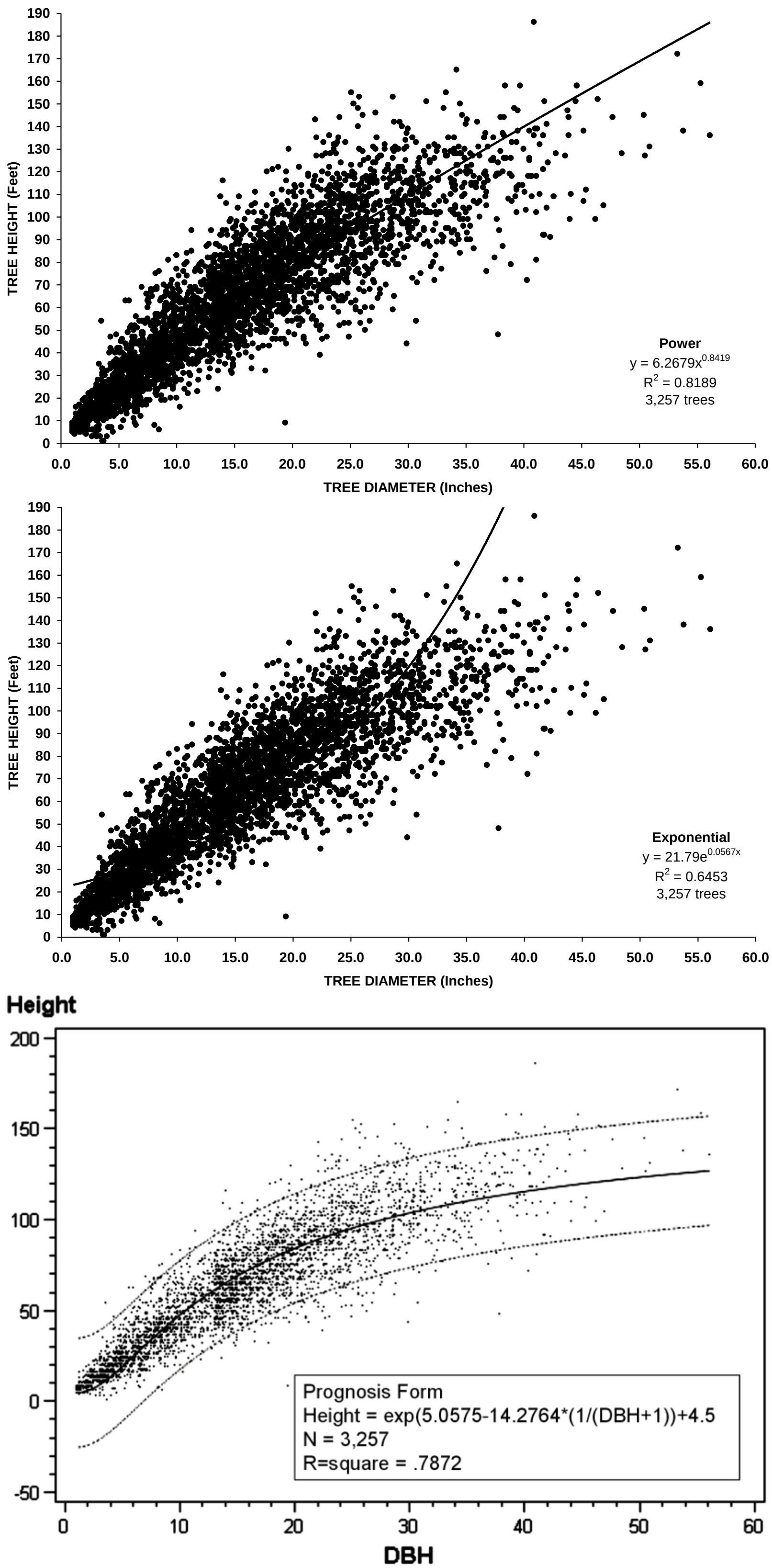


Figure 6(b): Power, exponential, and Prognosis trend lines for ponderosa pine on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

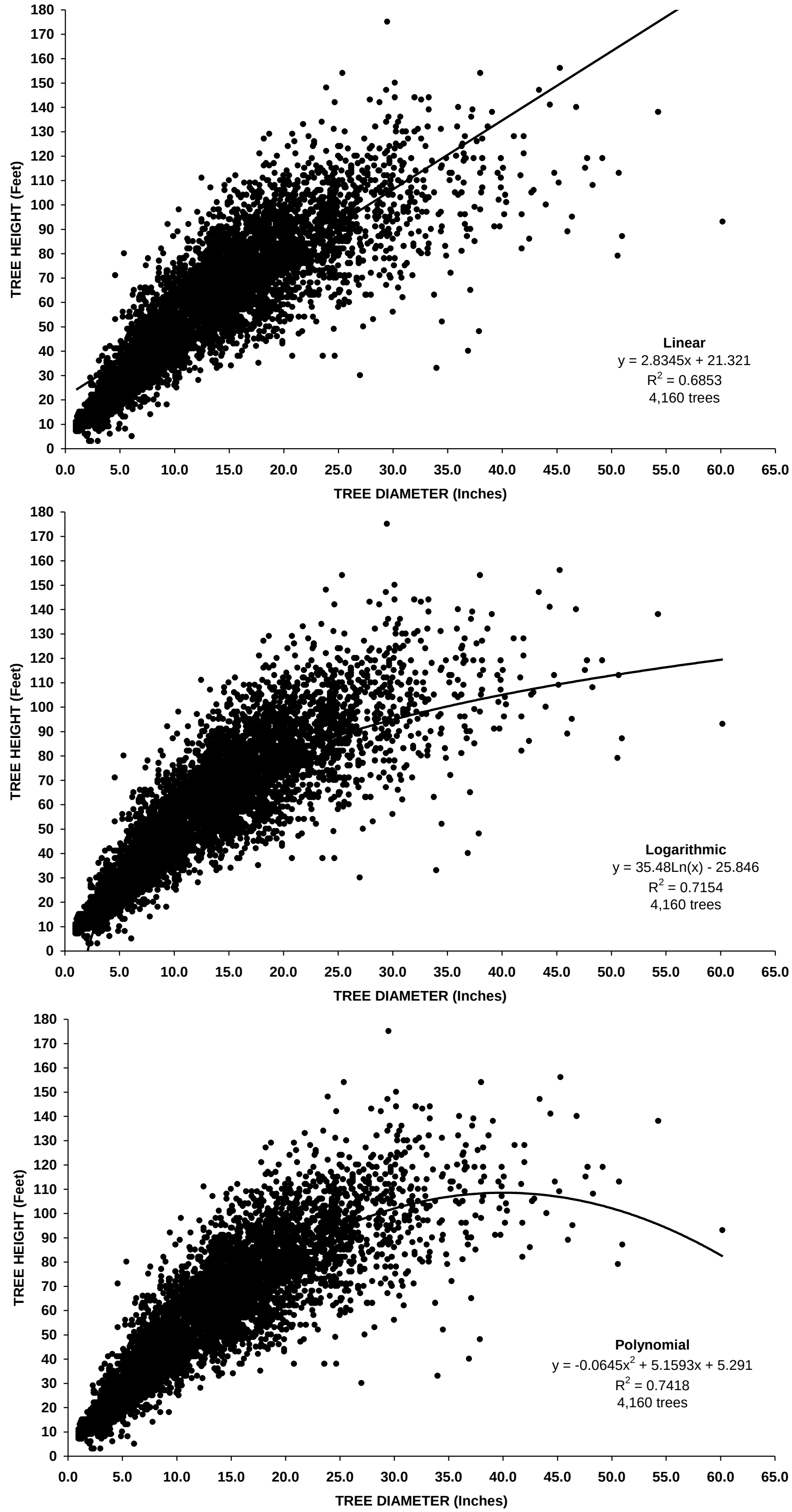


Figure 7(a): Linear, logarithmic, and polynomial trend lines for interior Douglas-fir on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

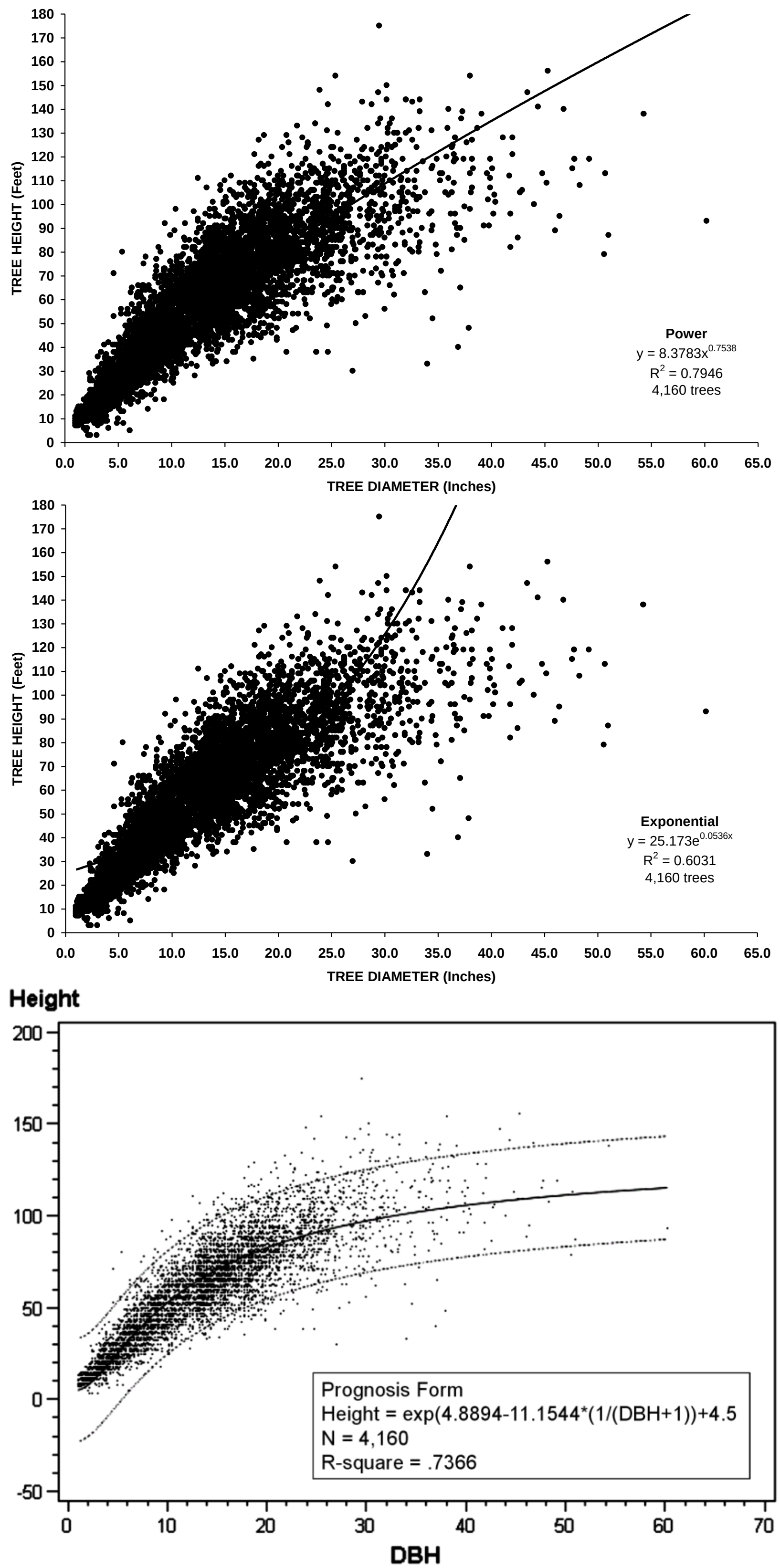


Figure 7(b): Power, exponential, and Prognosis trend lines for interior Douglas-fir on group 2 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

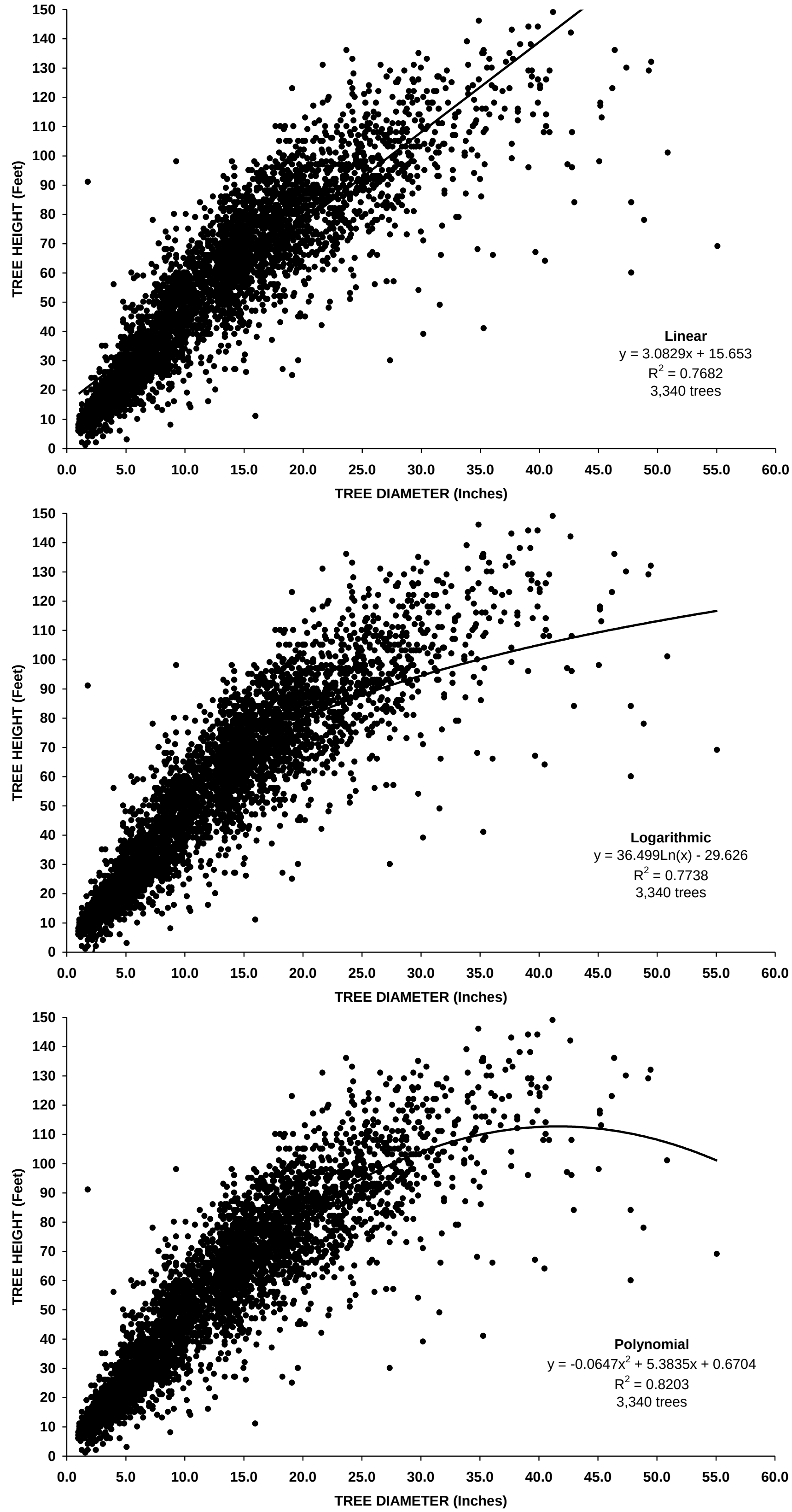


Figure 8(a): Linear, logarithmic, and polynomial trend lines for grand fir on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

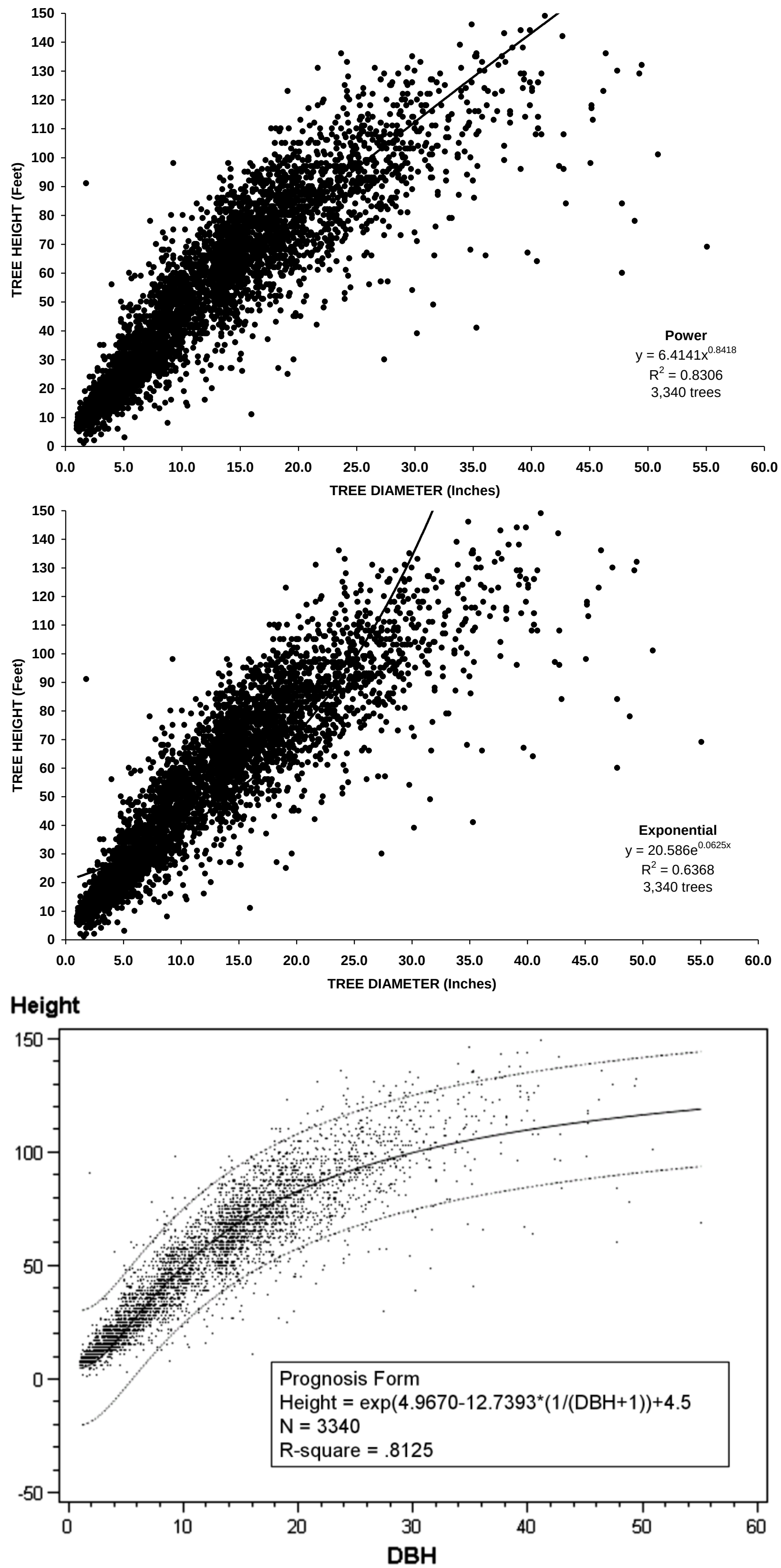


Figure 8(b): Power, exponential, and Prognosis trend lines for grand fir on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

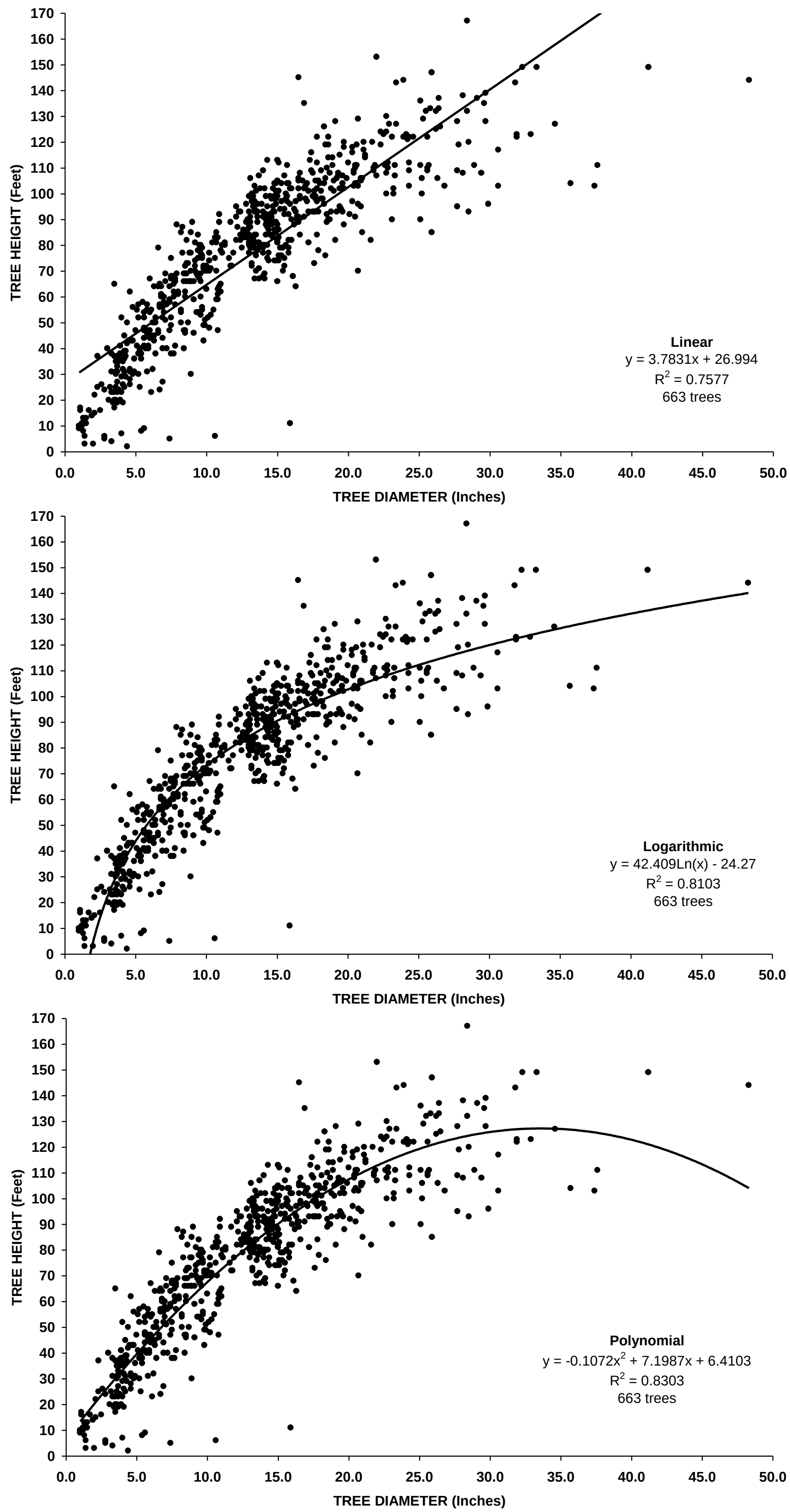


Figure 9(a): Linear, logarithmic, and polynomial trend lines for western larch on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

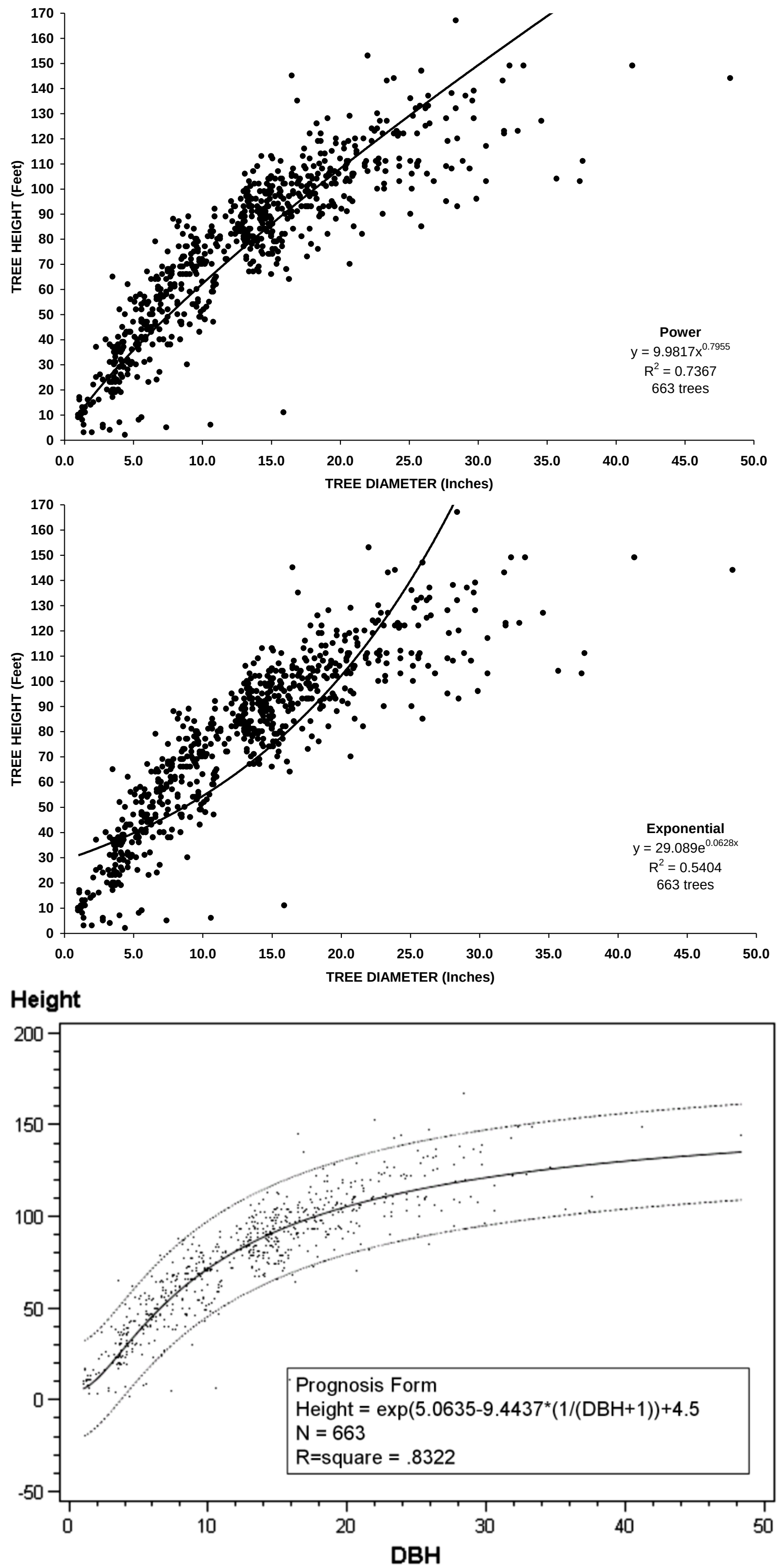


Figure 9(b): Power, exponential, and Prognosis trend lines for western larch on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

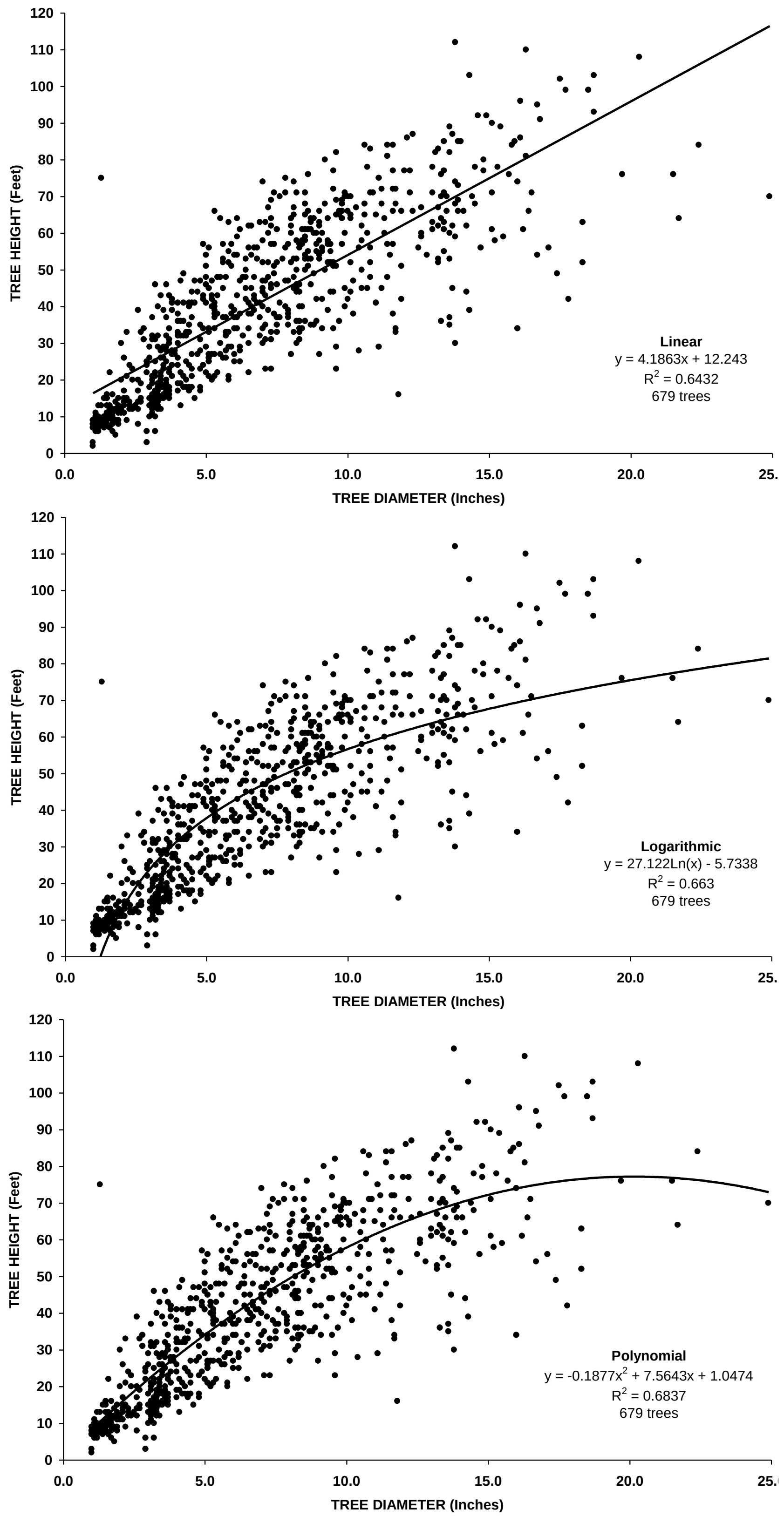


Figure 10(a): Linear, logarithmic, and polynomial trend lines for lodgepole pine on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

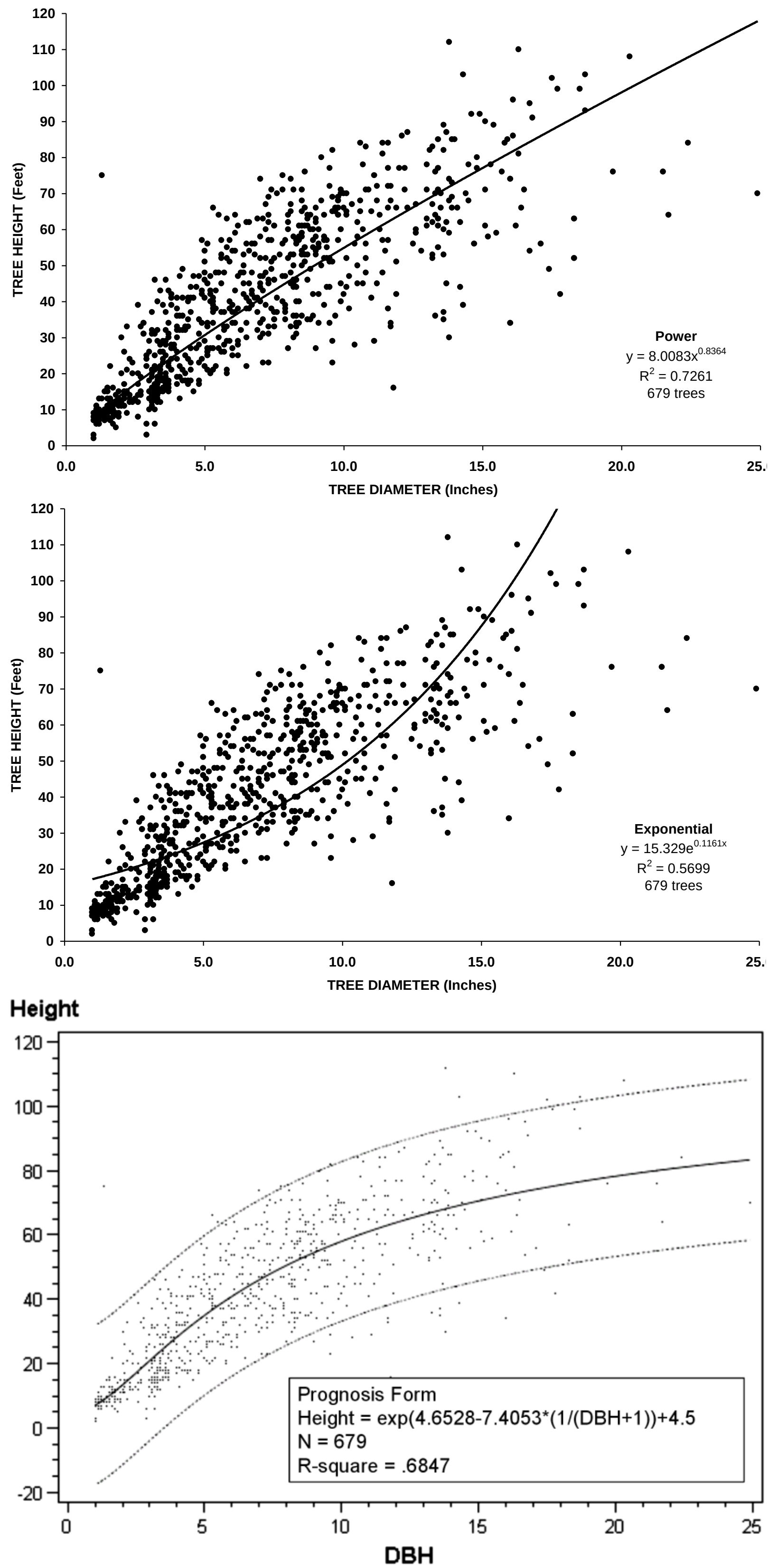


Figure 10(b): Power, exponential, and Prognosis trend lines for lodgepole pine on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

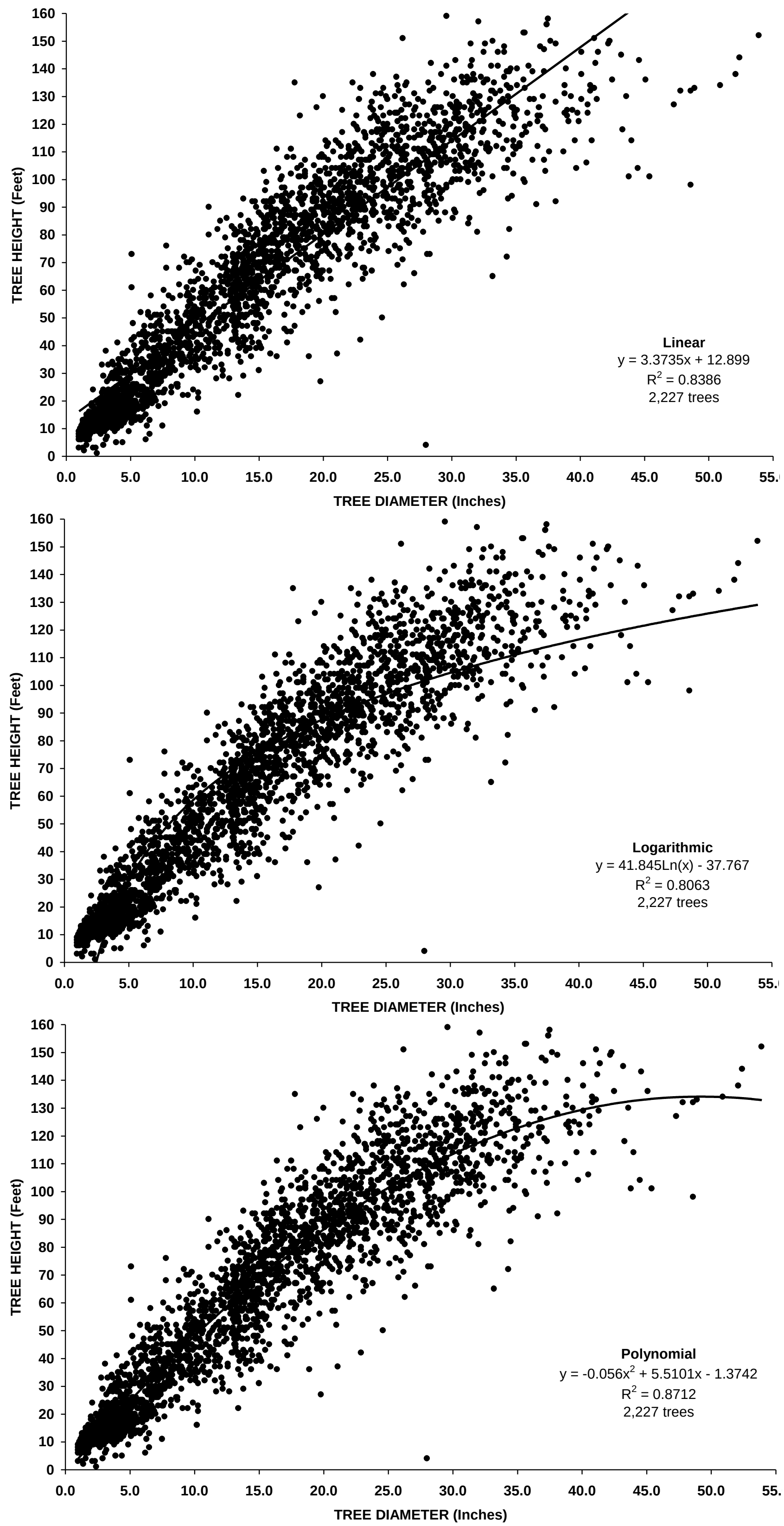


Figure 11(a): Linear, logarithmic, and polynomial trend lines for ponderosa pine on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

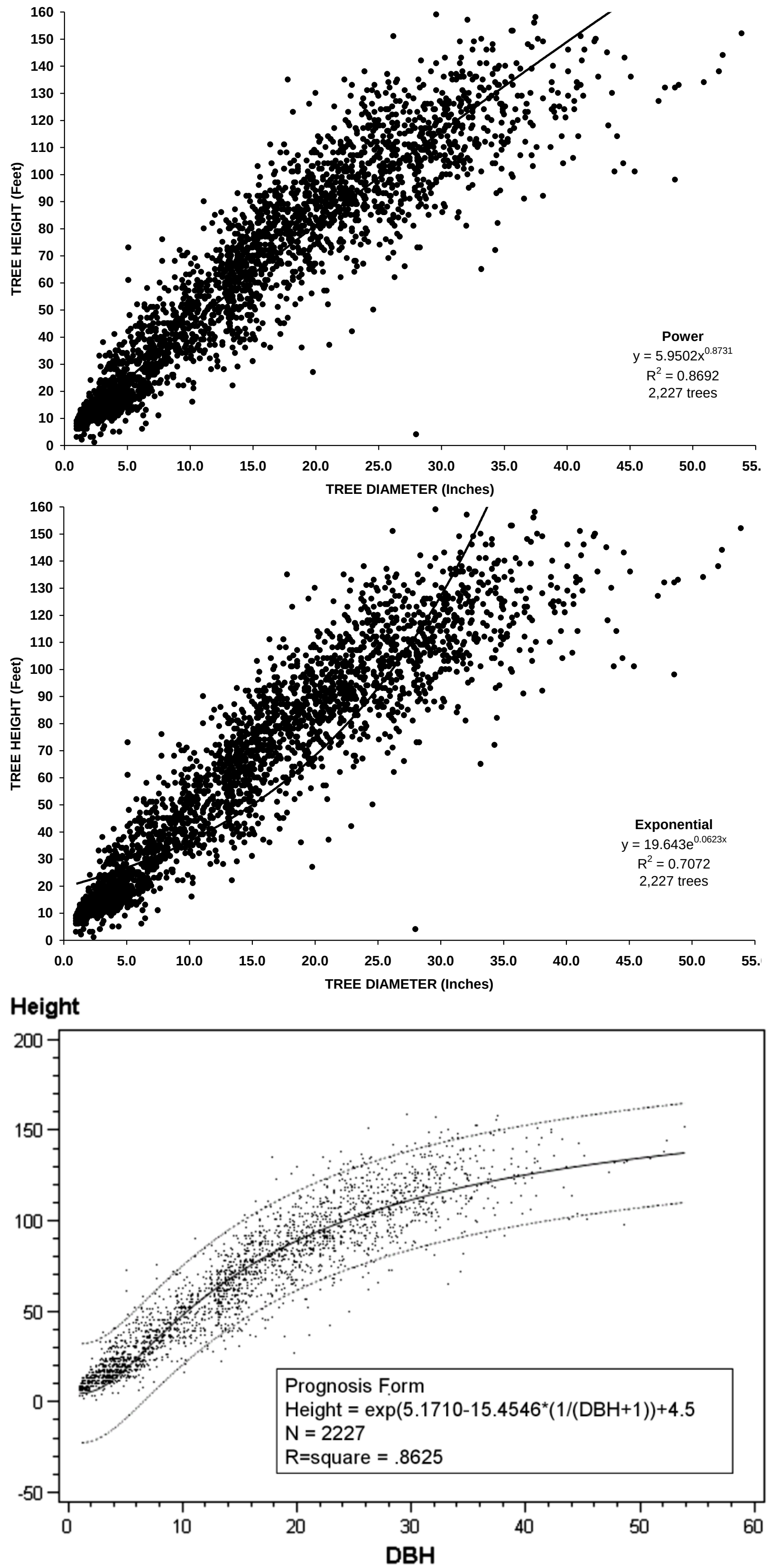


Figure 11(b): Power, exponential, and Prognosis trend lines for ponderosa pine on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

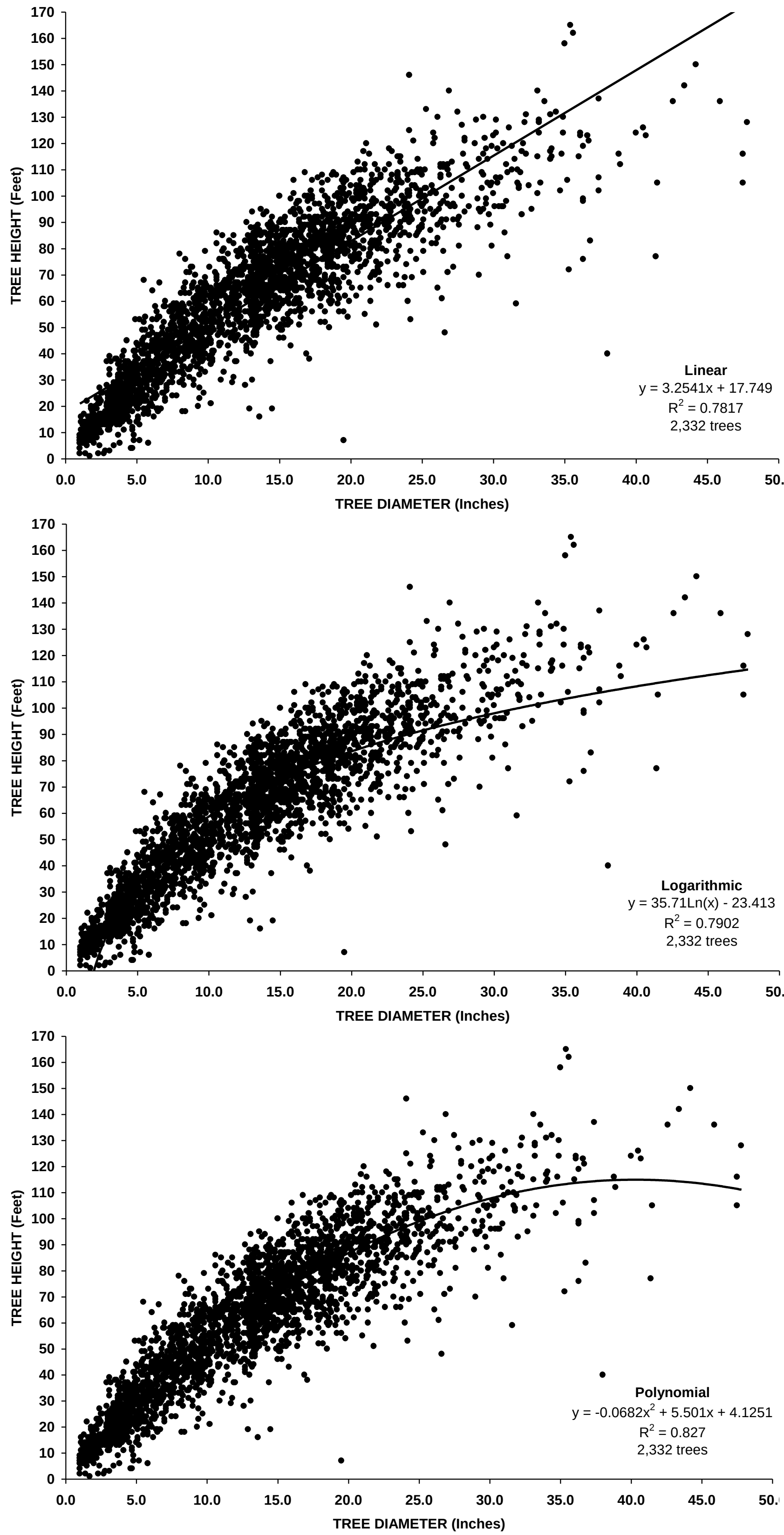
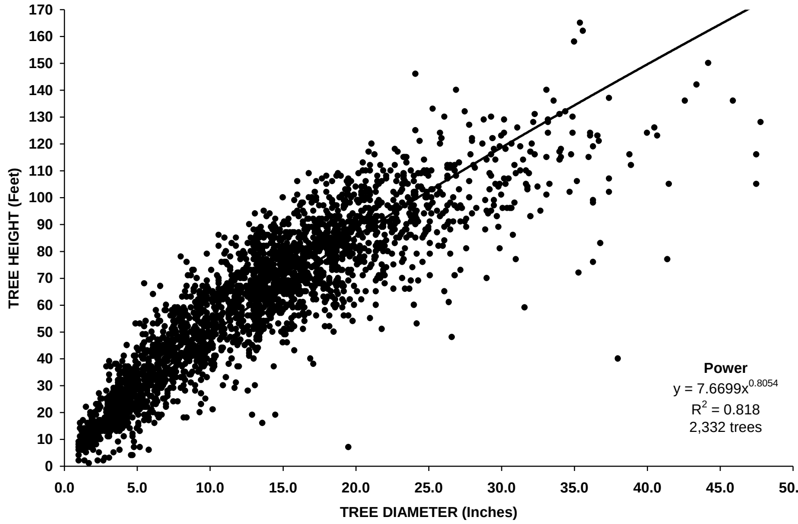
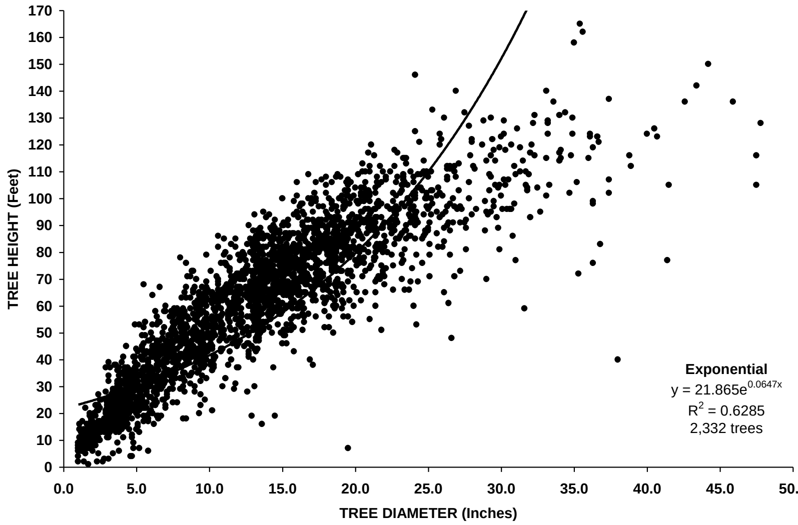


Figure 12(a): Linear, logarithmic, and polynomial trend lines for interior Douglas-fir on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).





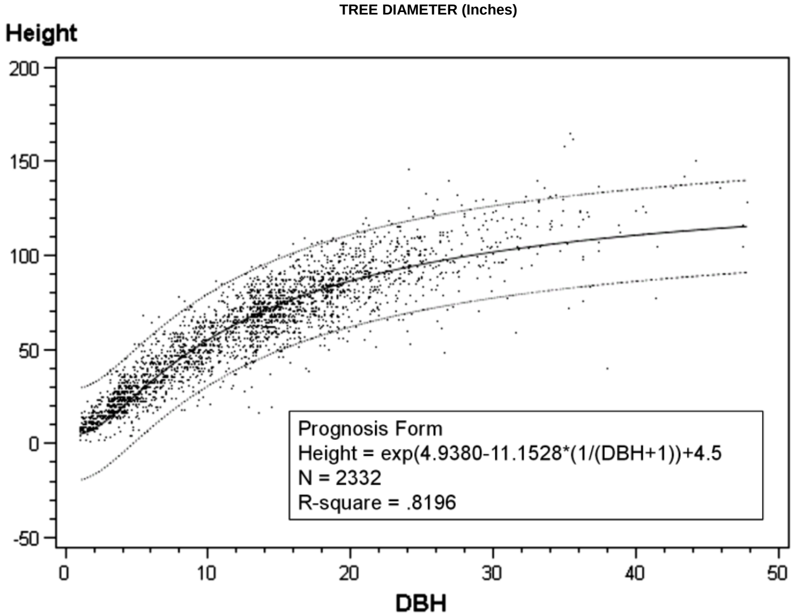


Figure 12(b): Power, exponential, and Prognosis trend lines for interior Douglas-fir on group 3 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

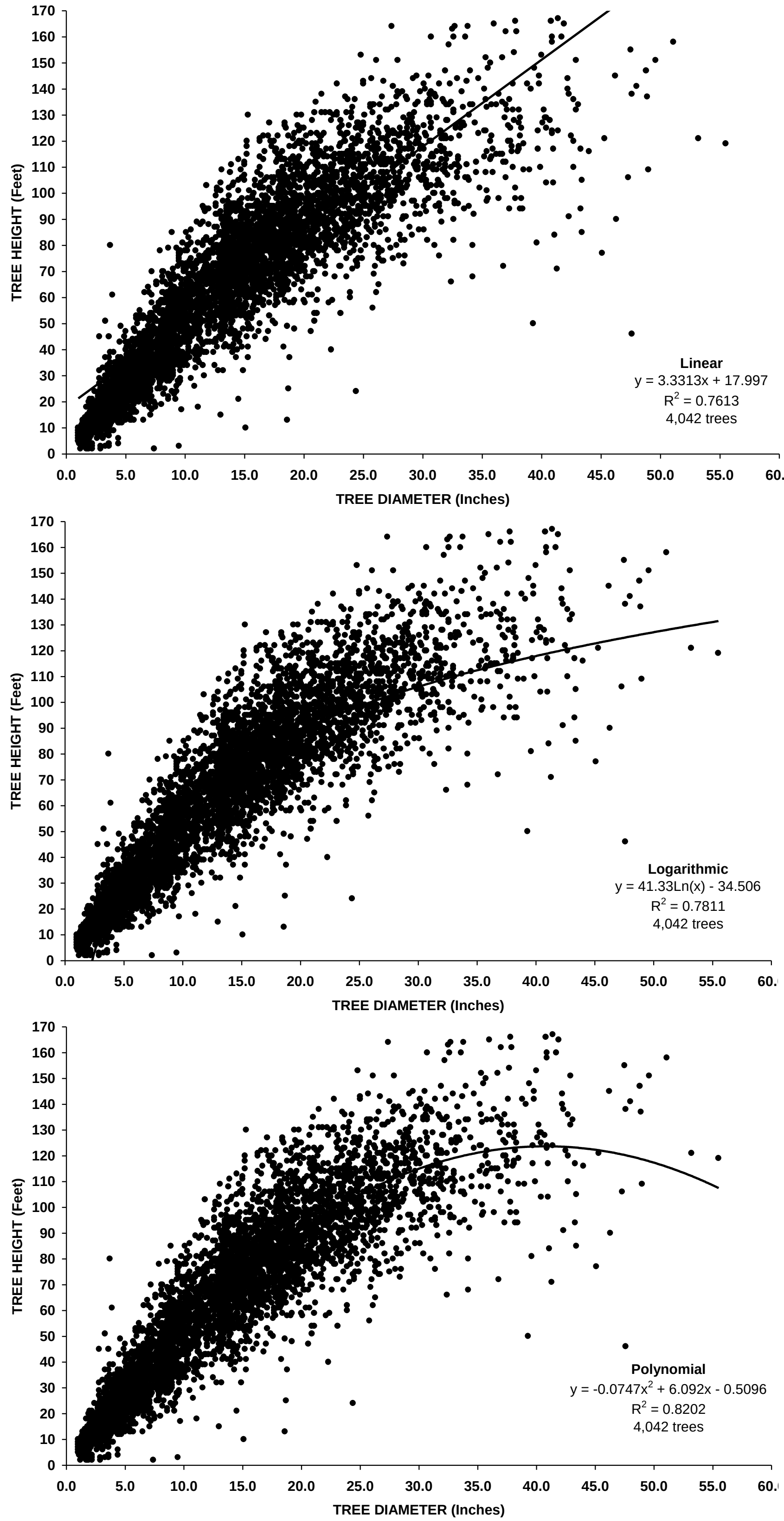


Figure 13(a): Linear, logarithmic, and polynomial trend lines for grand fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

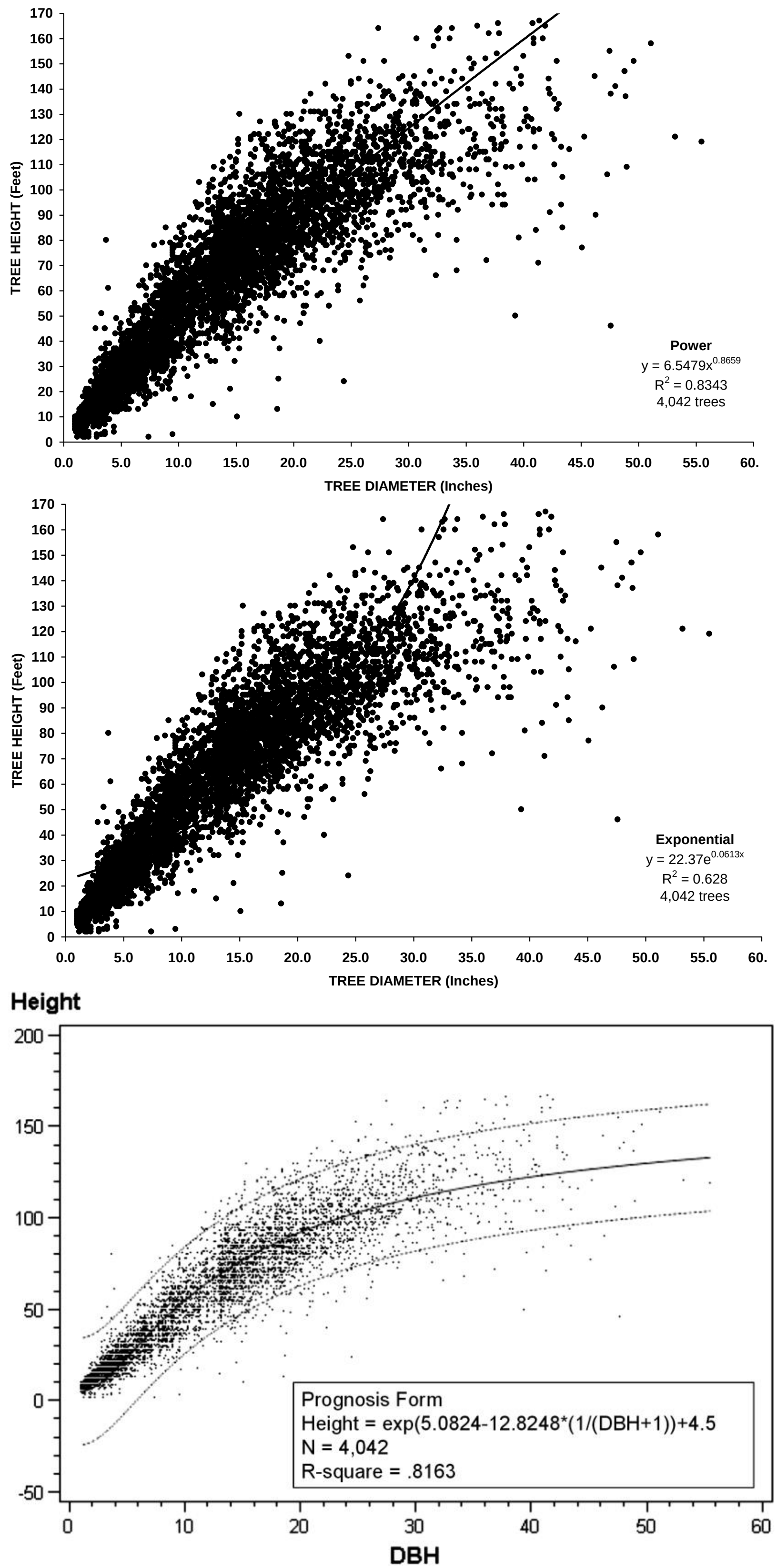


Figure 13(b): Power, exponential, and Prognosis trend lines for grand fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

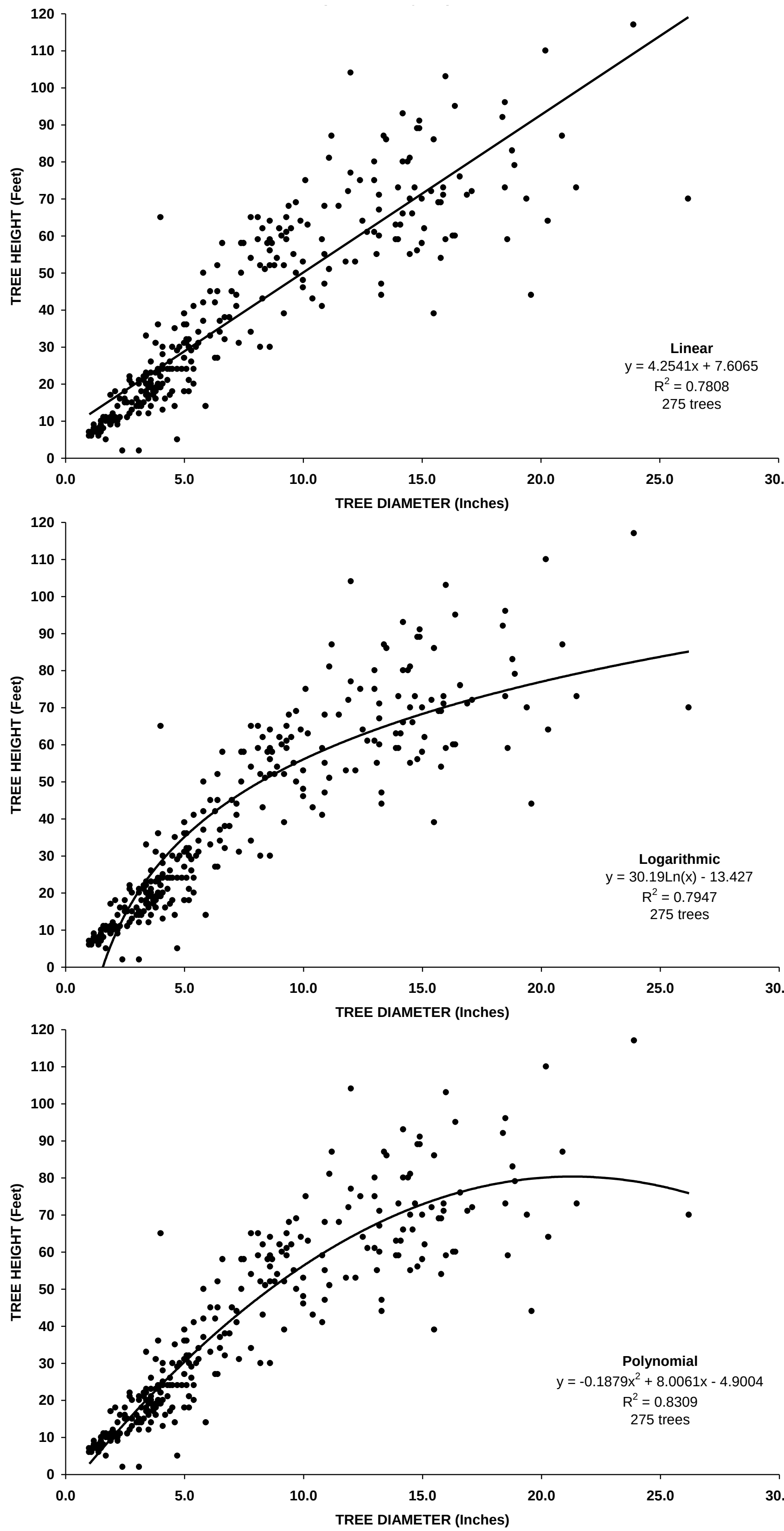


Figure 14(a): Linear, logarithmic, and polynomial trend lines for subalpine fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

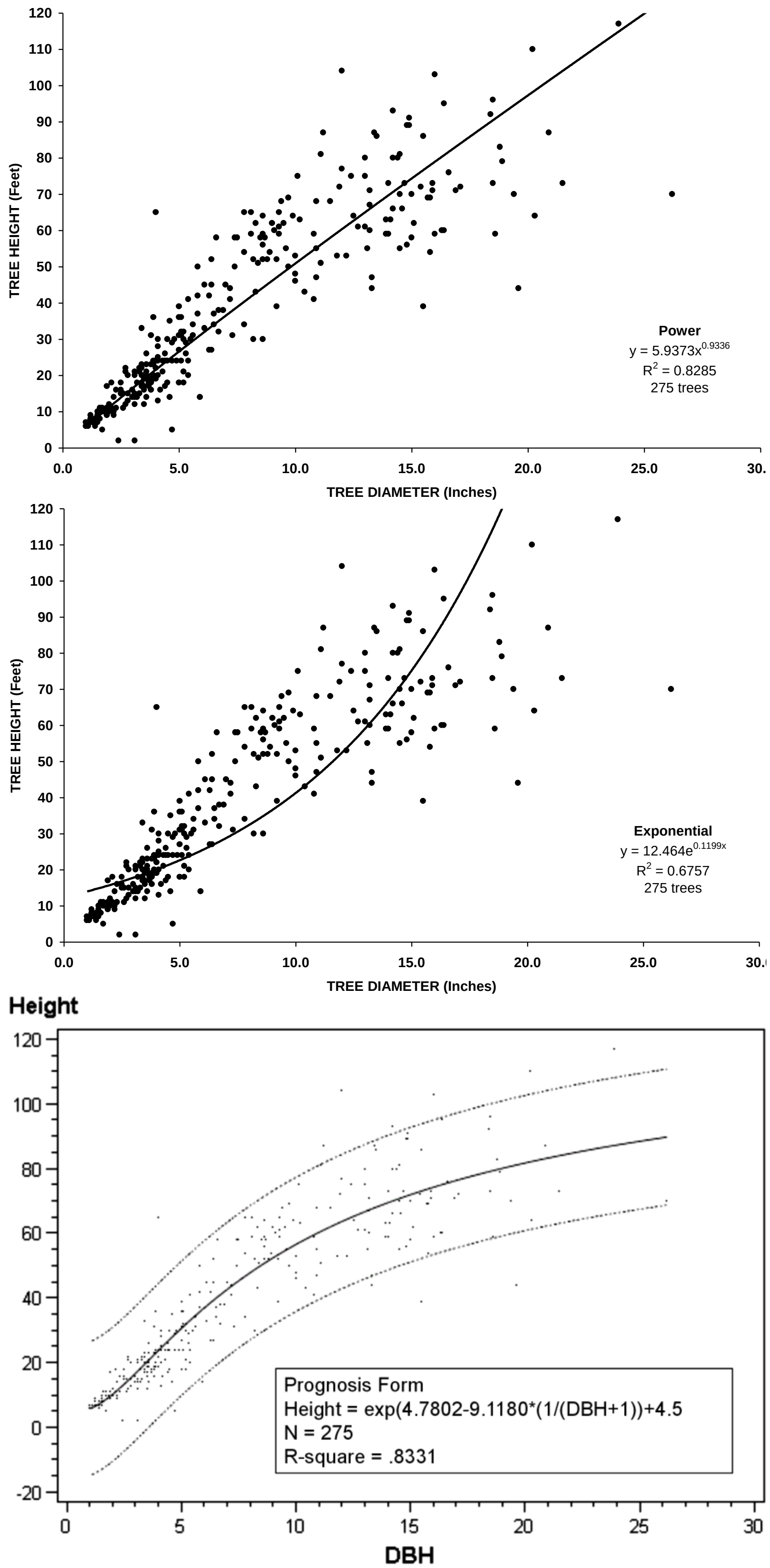


Figure 14(b): Power, exponential, and Prognosis trend lines for subalpine fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

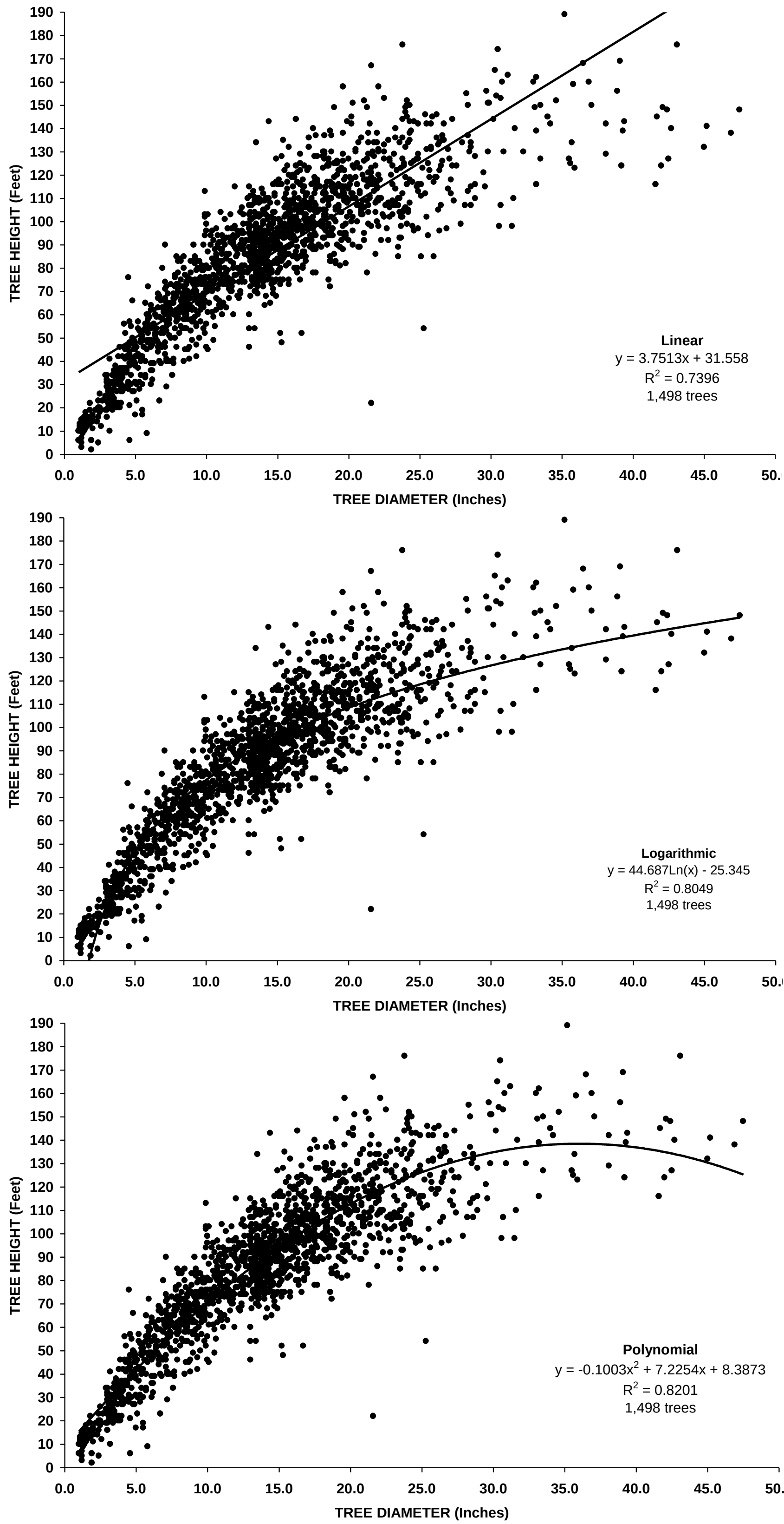


Figure 15(a): Linear, logarithmic, and polynomial trend lines for western larch on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

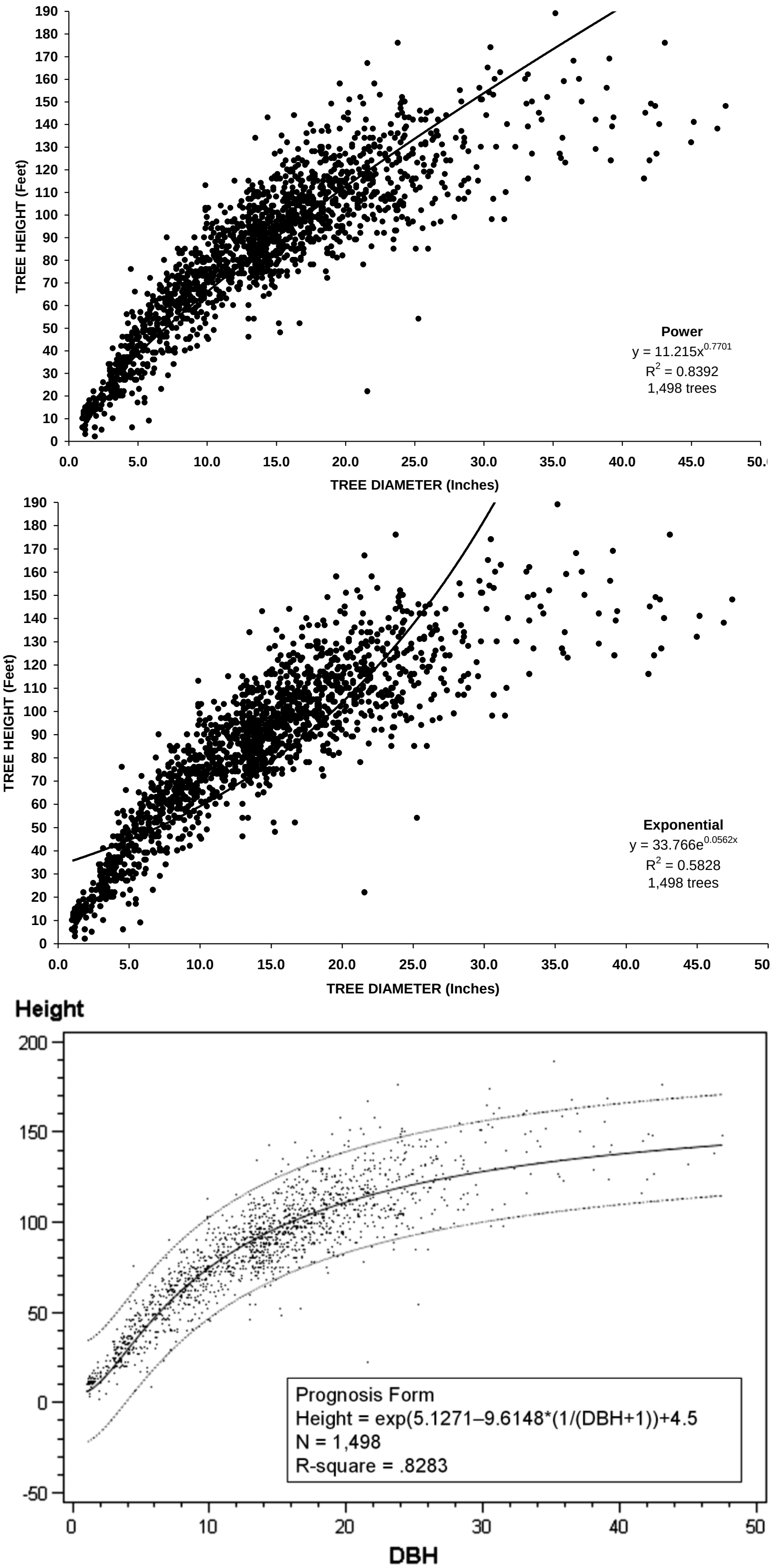


Figure 15(b): Power, exponential, and Prognosis trend lines for western larch on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

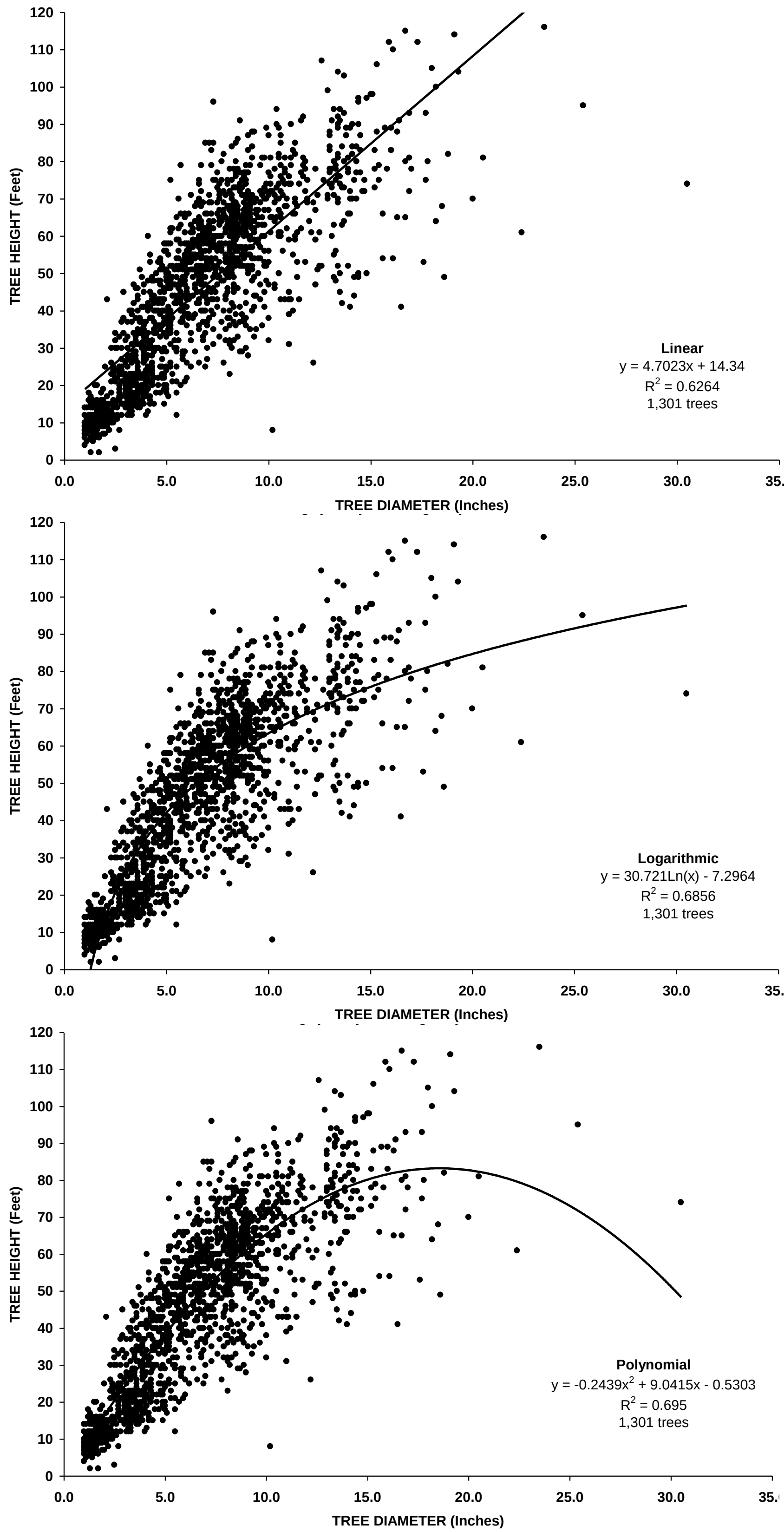


Figure 16(a): Linear, logarithmic, and polynomial trend lines for lodgepole pine on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

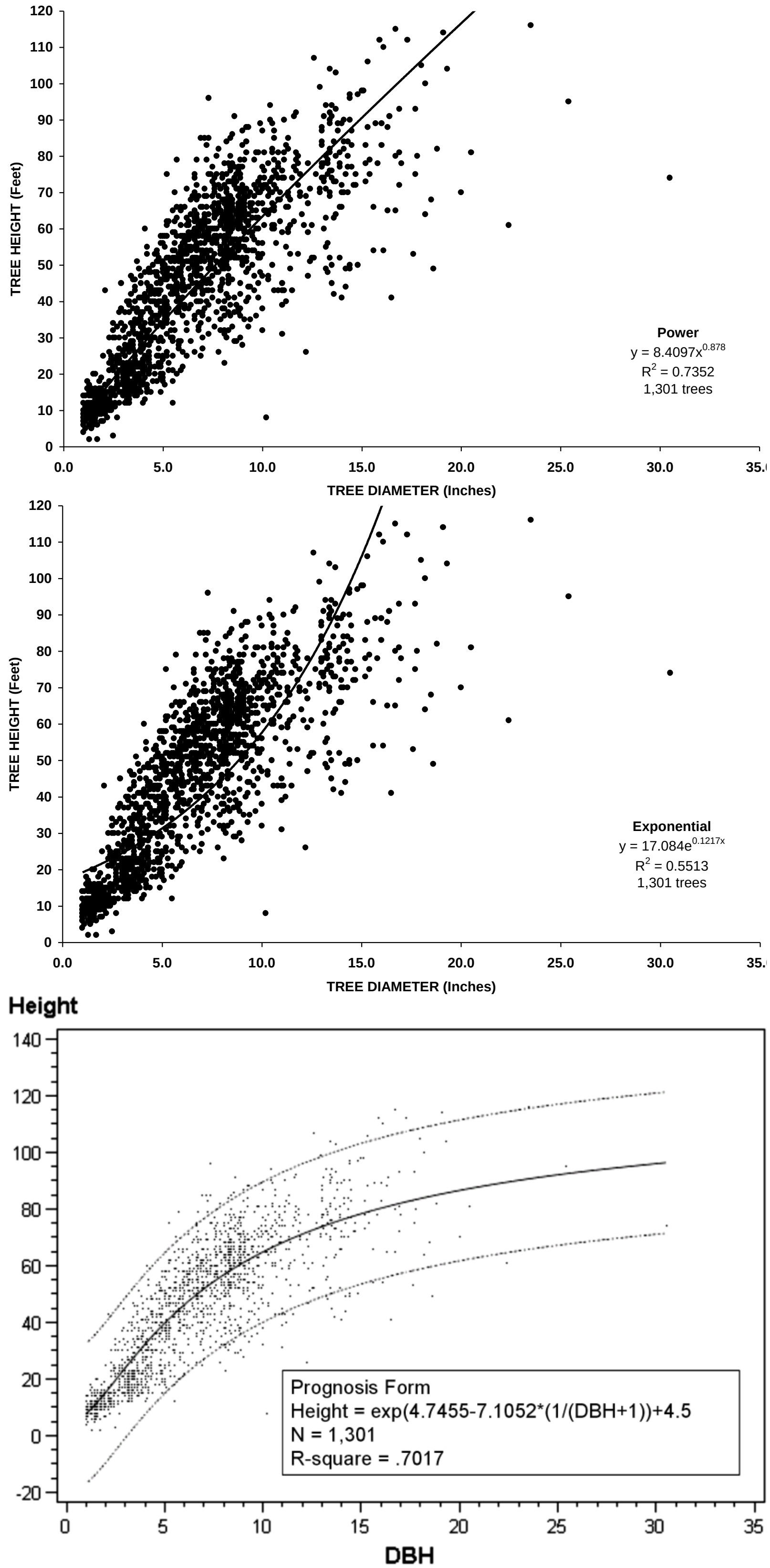


Figure 16(b): Power, exponential, and Prognosis trend lines for lodgepole pine on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

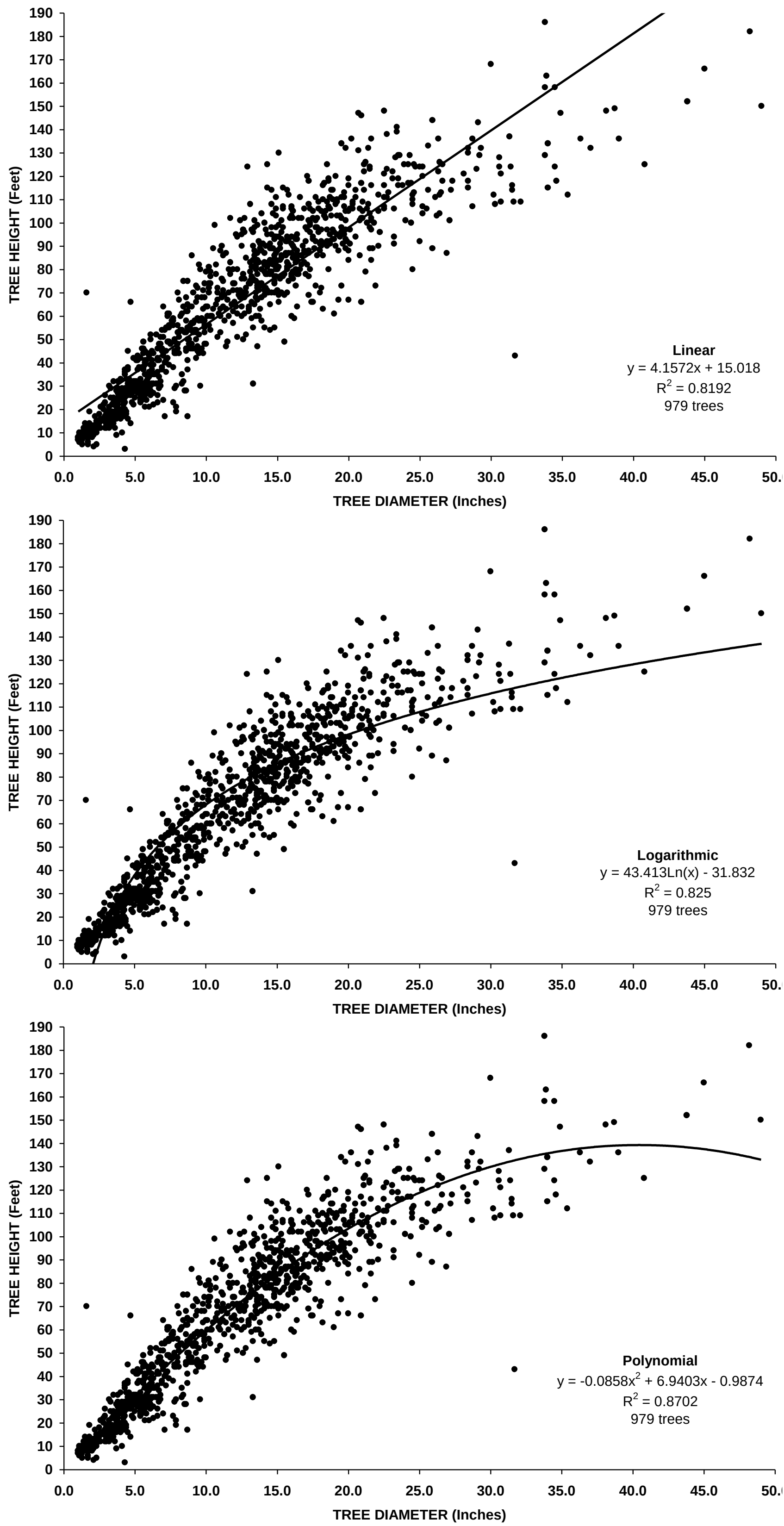


Figure 17(a): Linear, logarithmic, and polynomial trend lines for Engelmann spruce on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

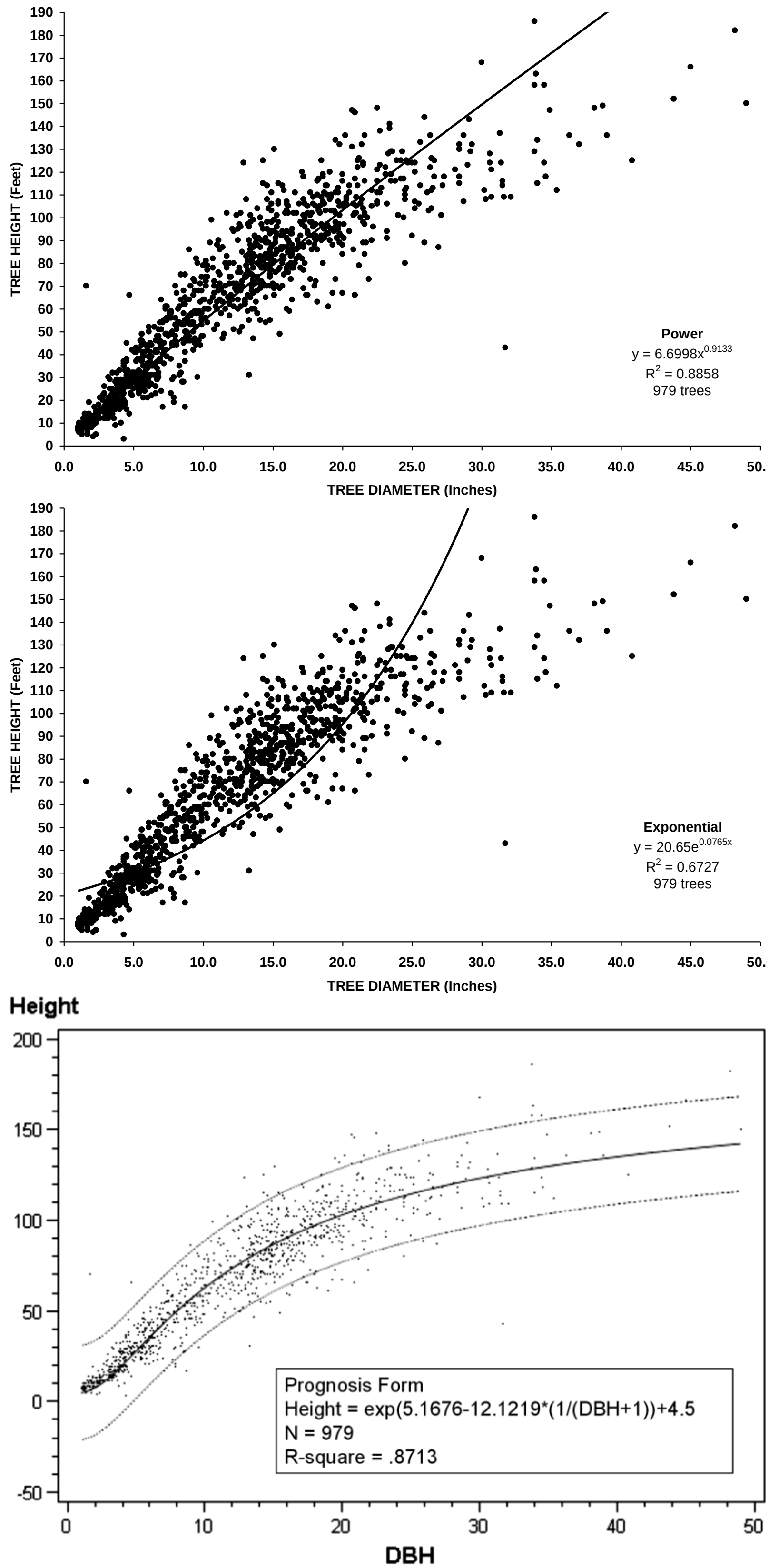


Figure 17(b): Power, exponential, and Prognosis trend lines for Engelmann spruce on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

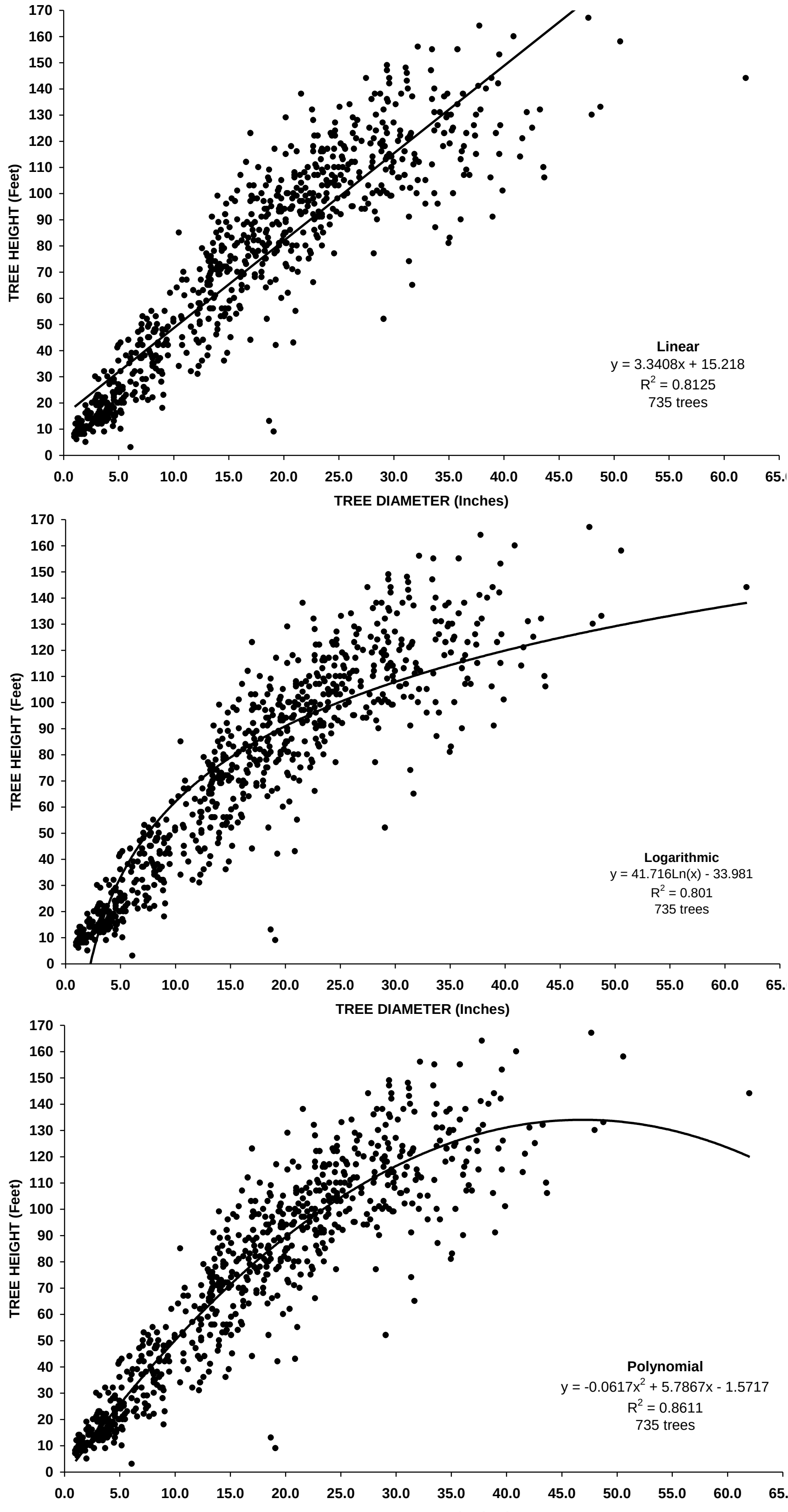


Figure 18(a): Linear, logarithmic, and polynomial trend lines for ponderosa pine on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

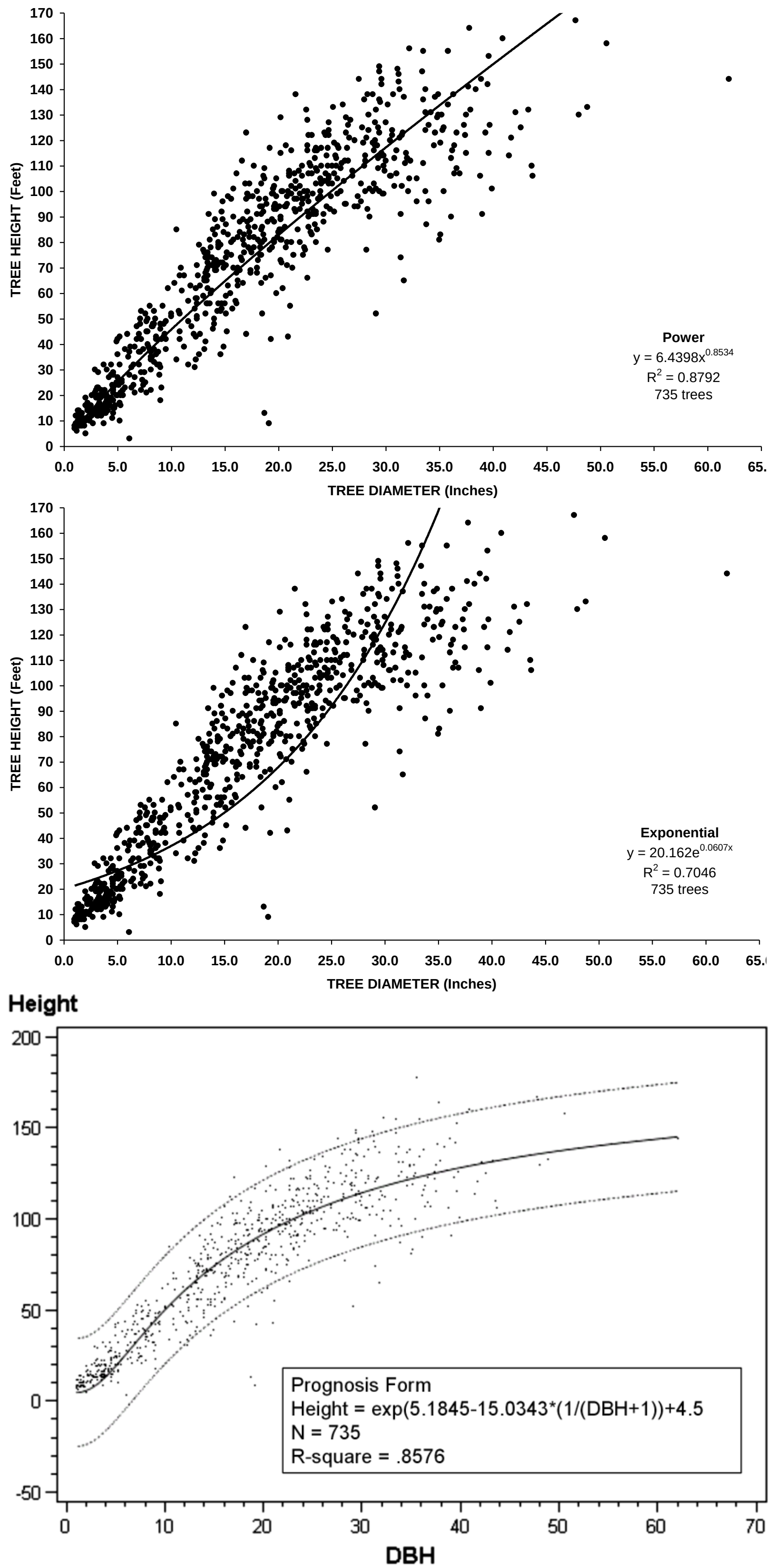


Figure 18(b): Power, exponential, and Prognosis trend lines for ponderosa pine on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

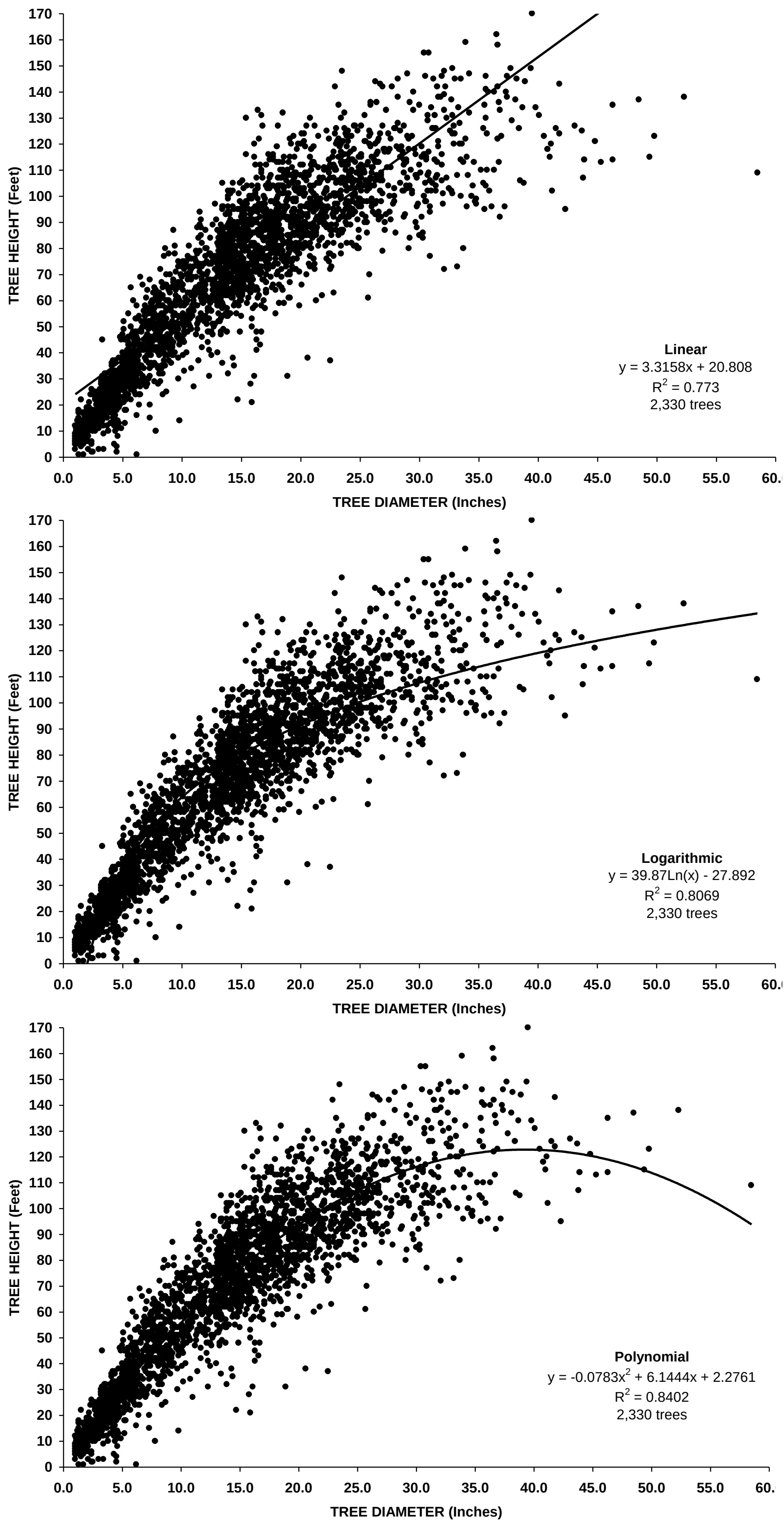


Figure 19(a): Linear, logarithmic, and polynomial trend lines for interior Douglas-fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

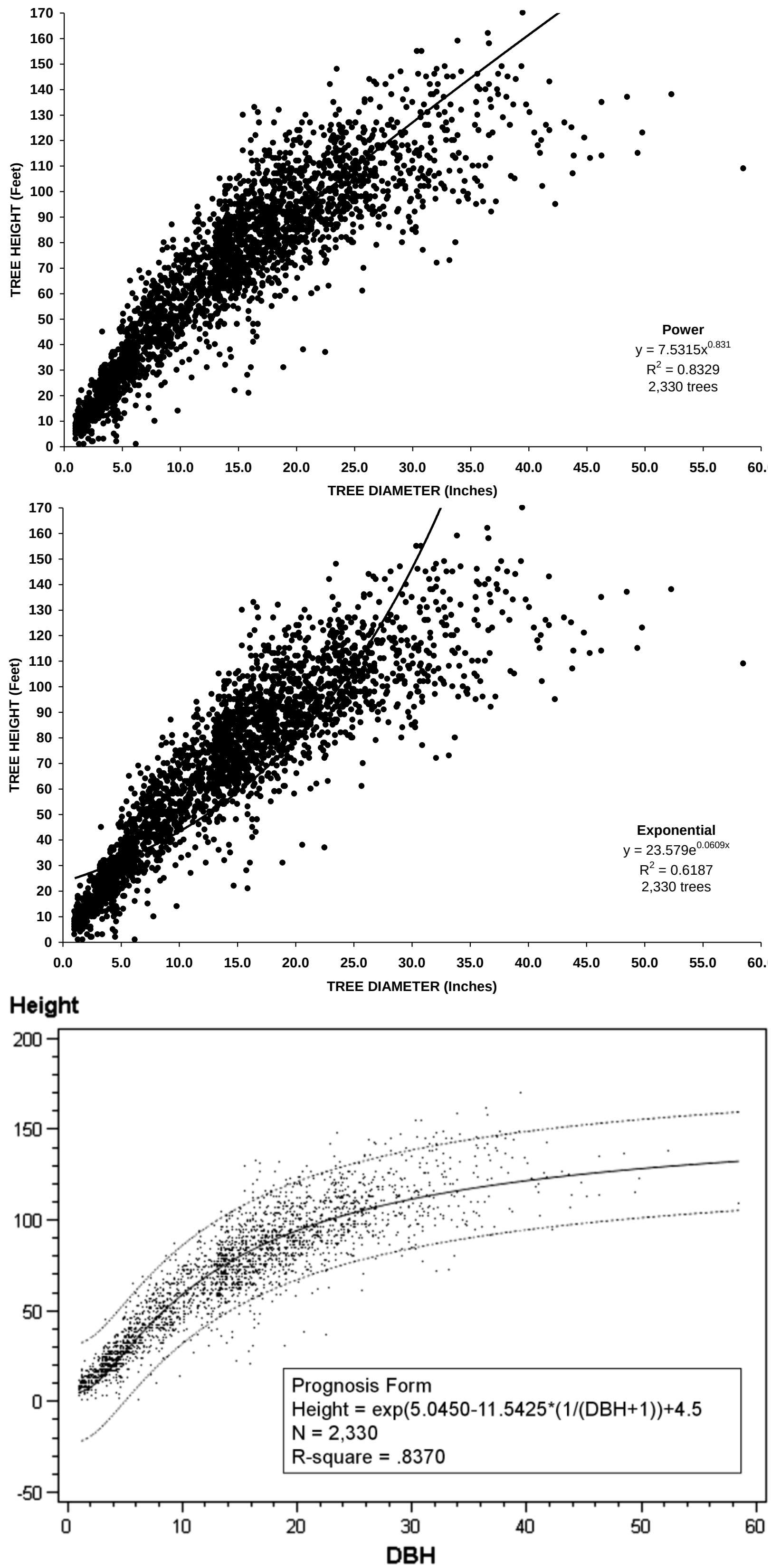


Figure 19(b): Power, exponential, and Prognosis trend lines for interior Douglas-fir on group 4 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

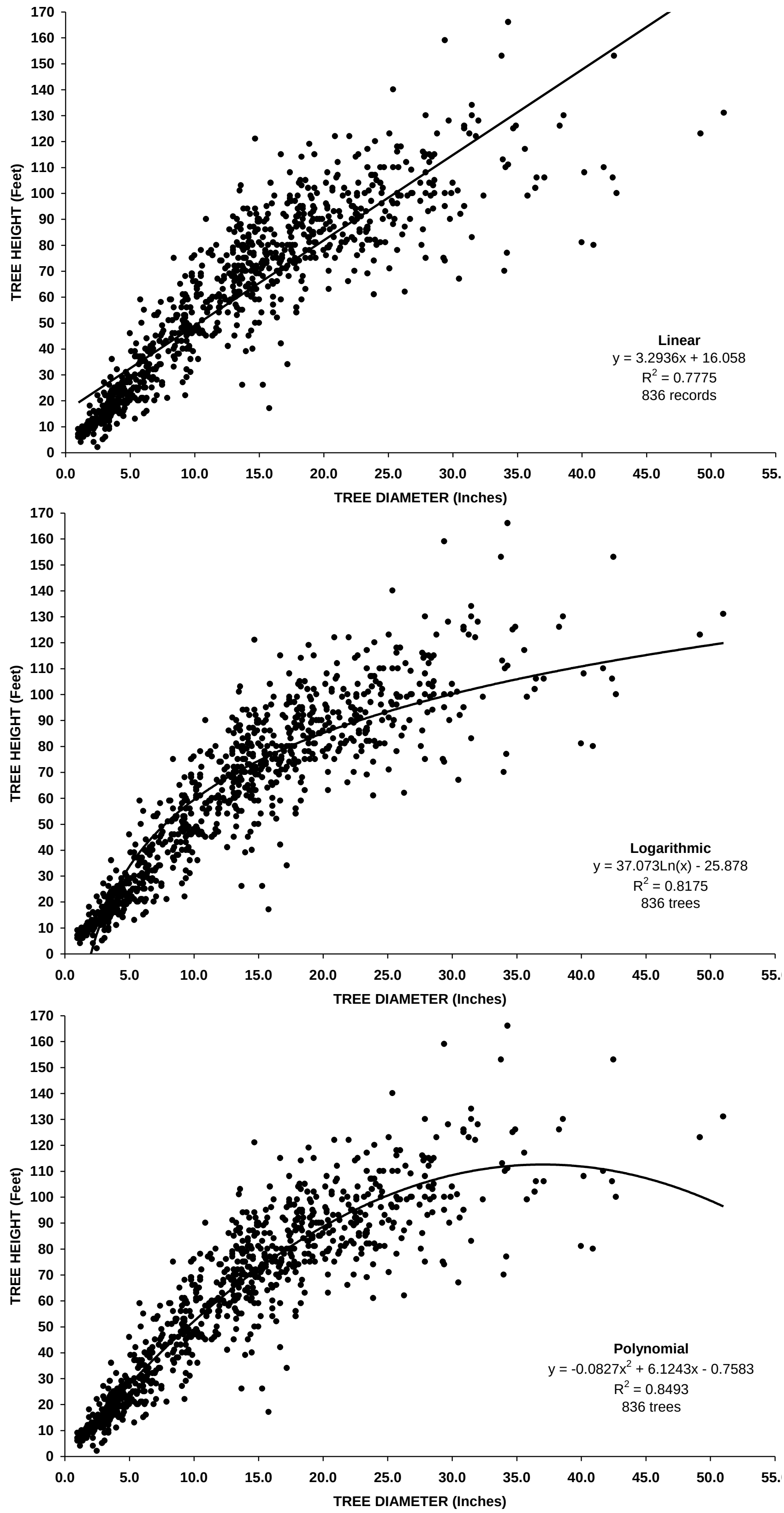


Figure 20(a): Linear, logarithmic, and polynomial trend lines for grand fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

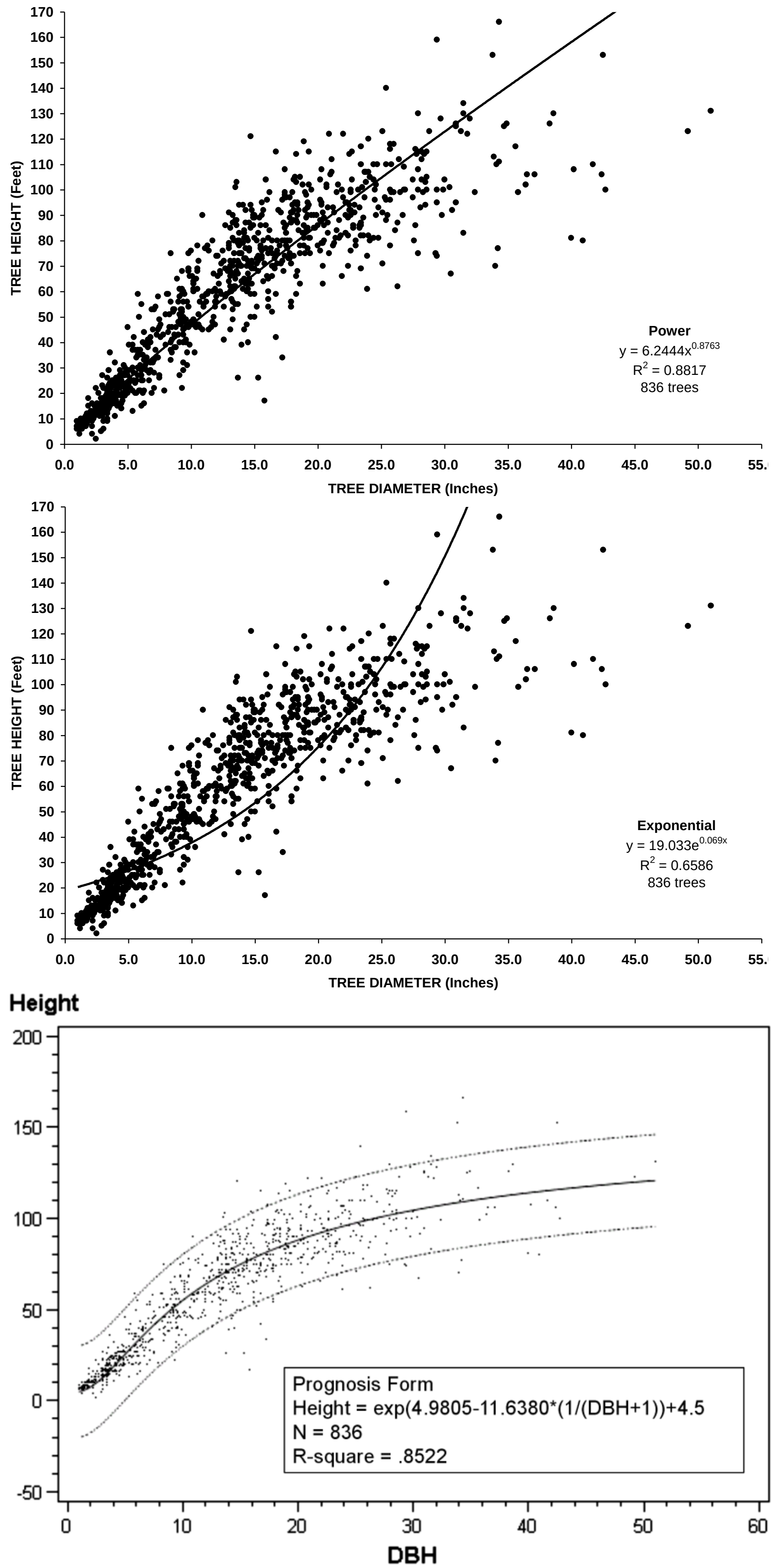


Figure 20(b): Power, exponential, and Prognosis trend lines for grand fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

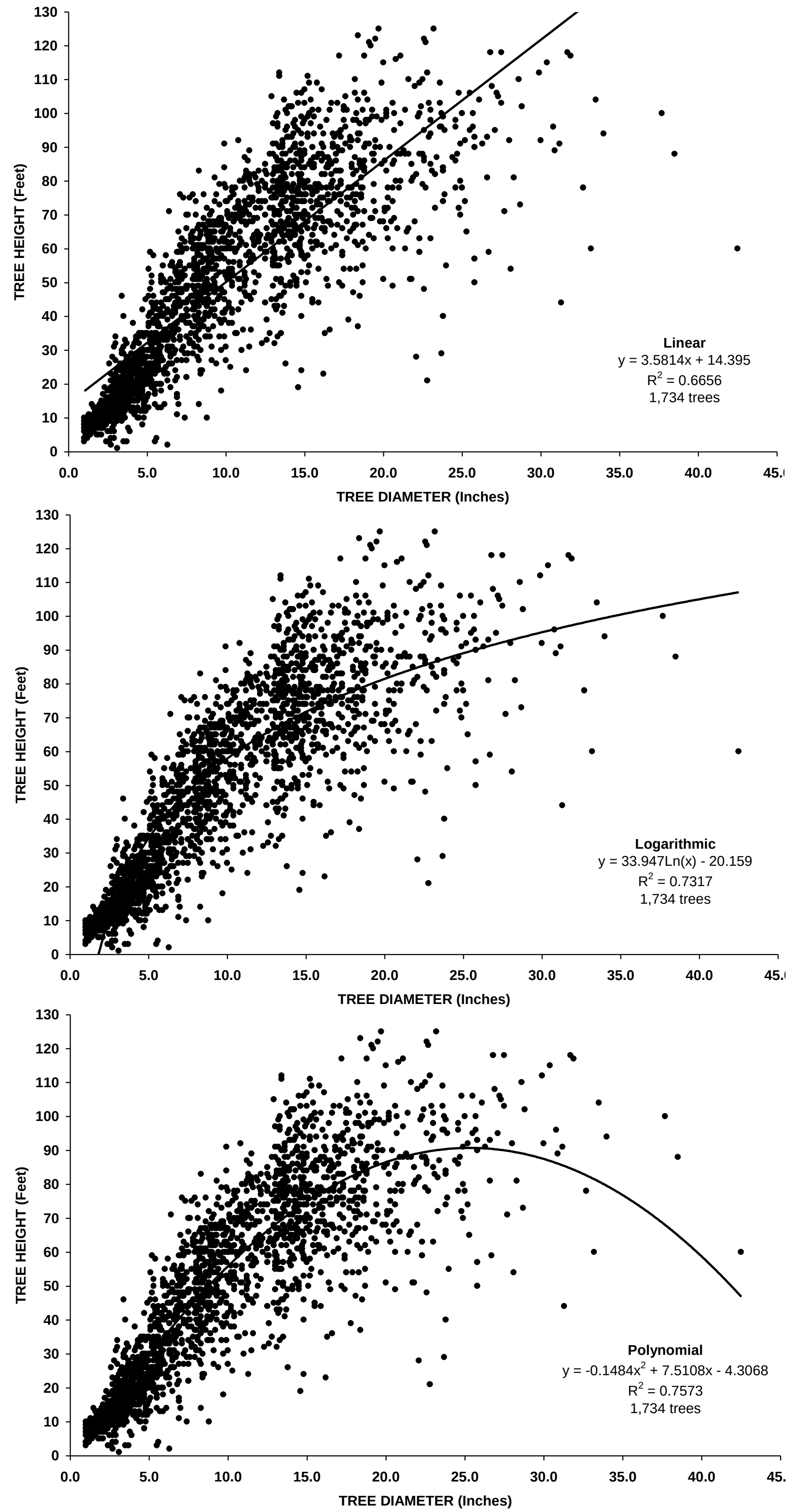


Figure 21(a): Linear, logarithmic, and polynomial trend lines for subalpine fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

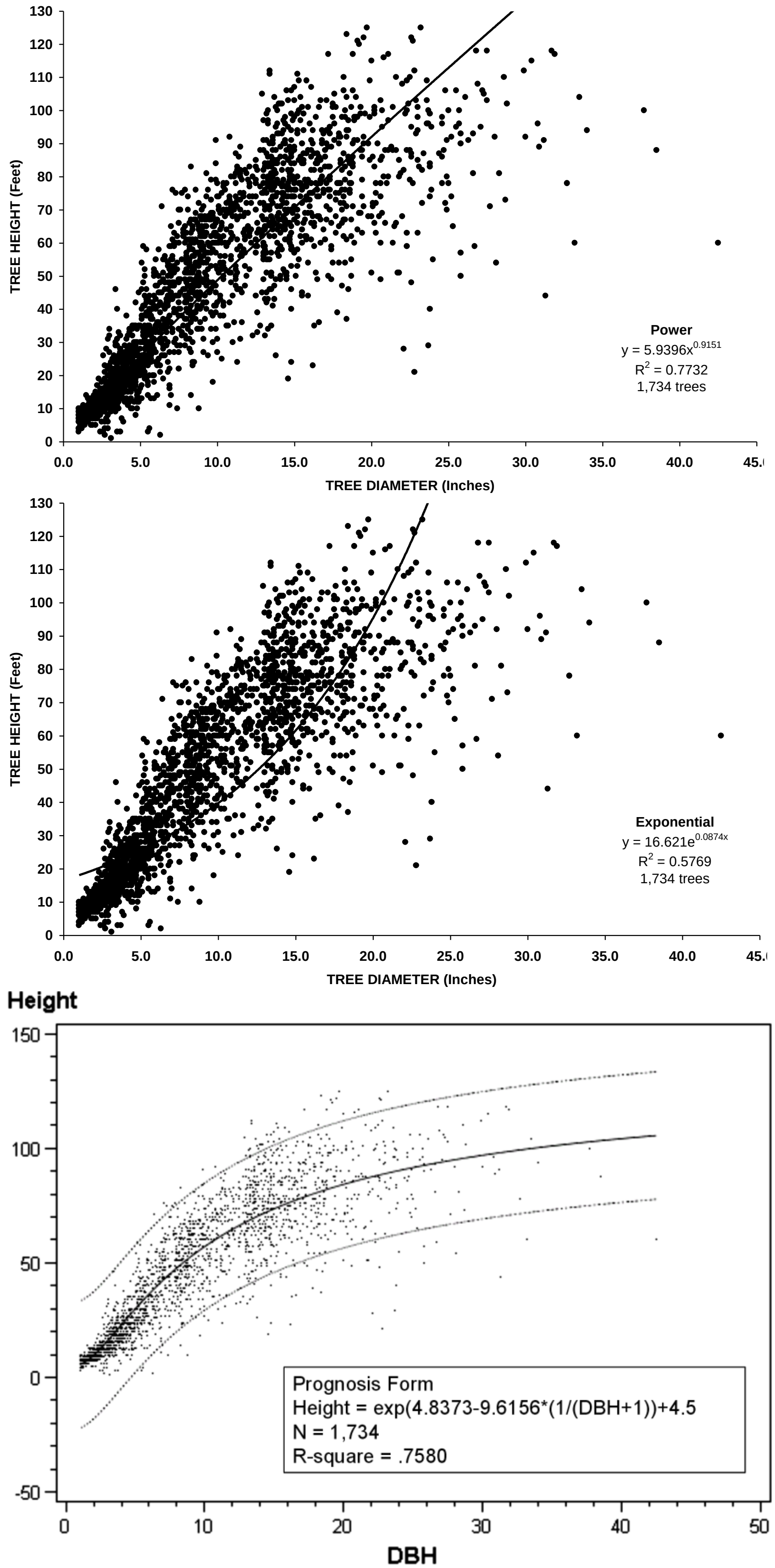


Figure 21(b): Power, exponential, and Prognosis trend lines for subalpine fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

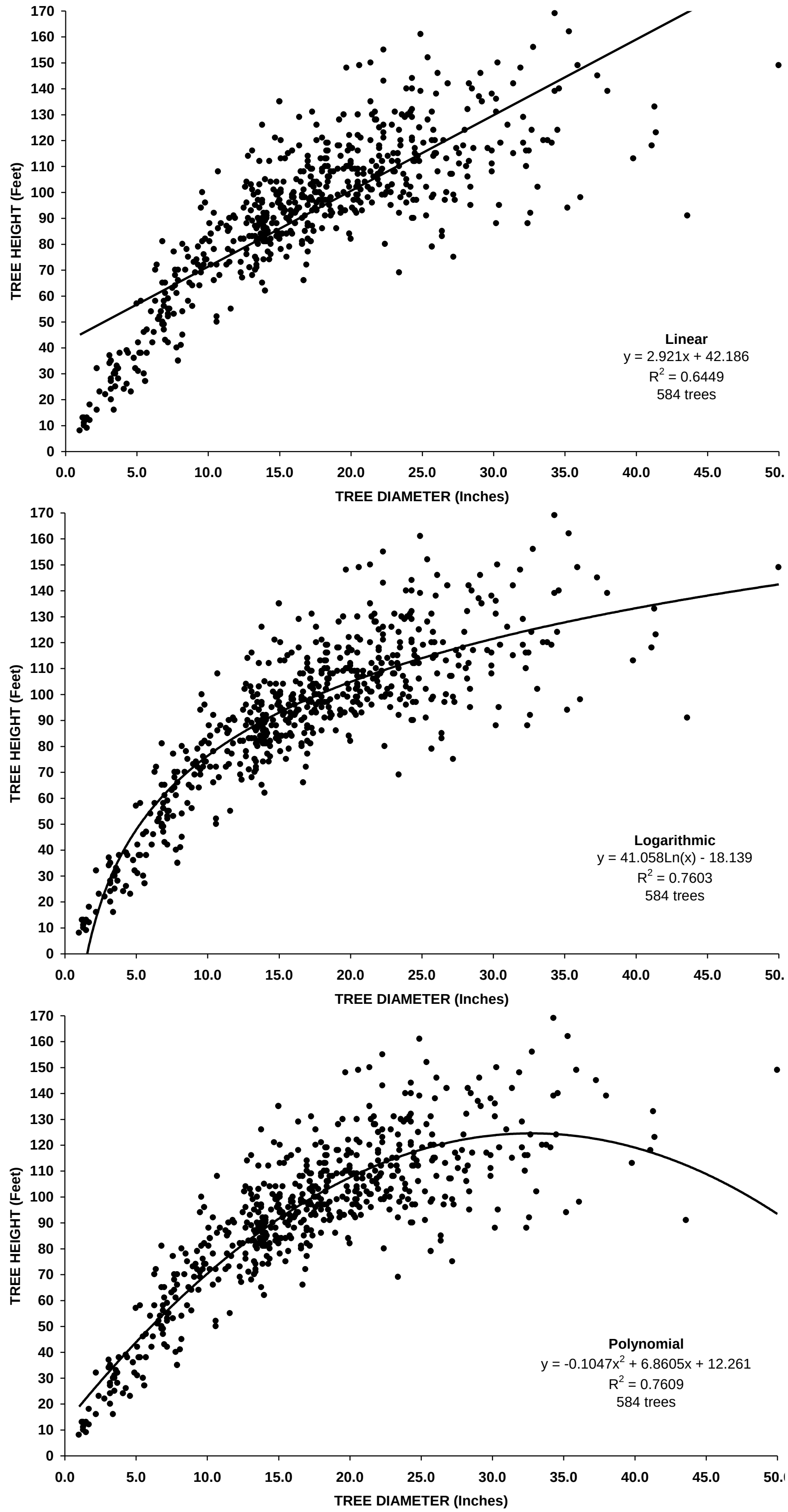


Figure 22(a): Linear, logarithmic, and polynomial trend lines for western larch on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

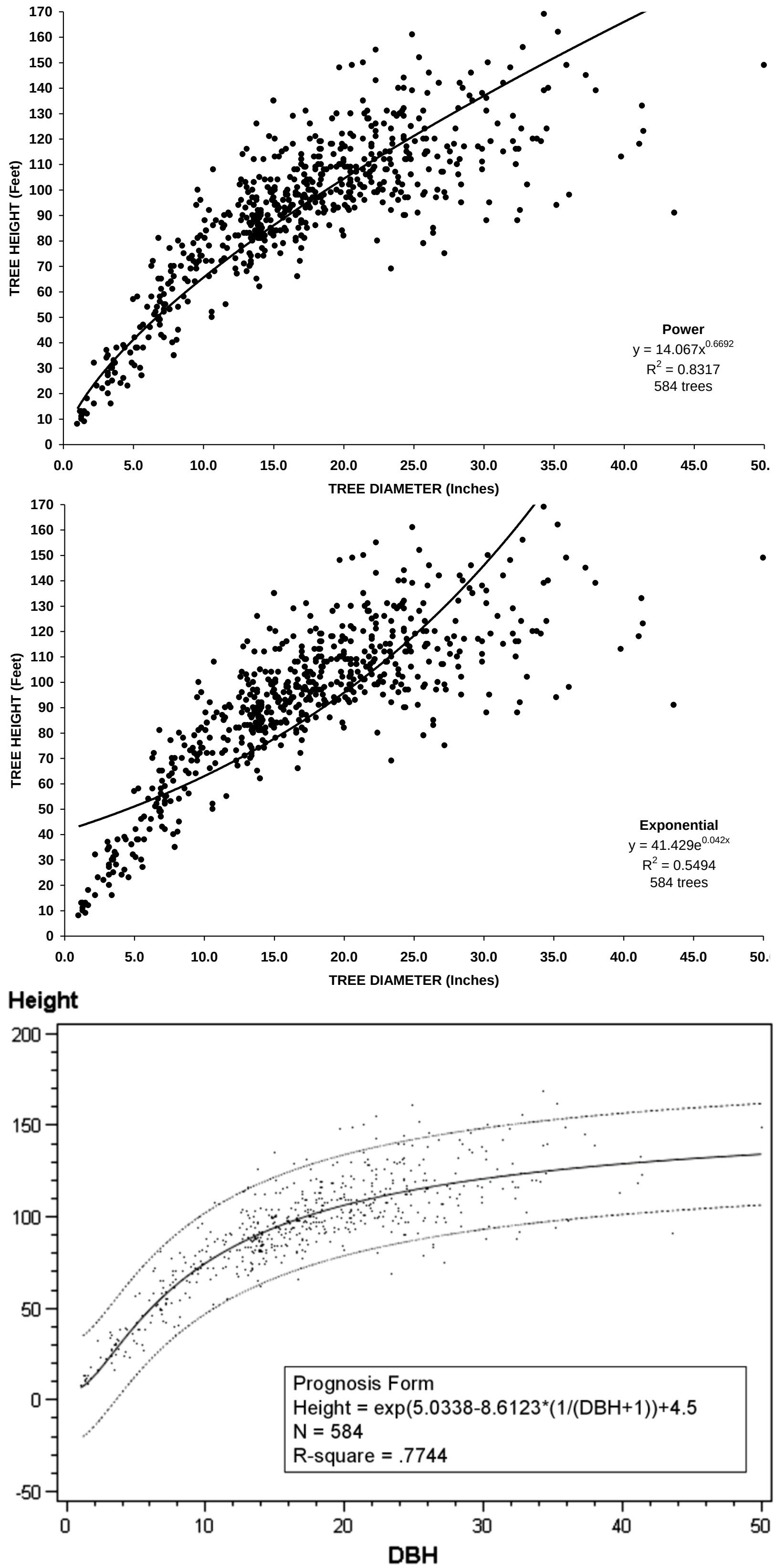


Figure 22(b): Power, exponential, and Prognosis trend lines for western larch on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

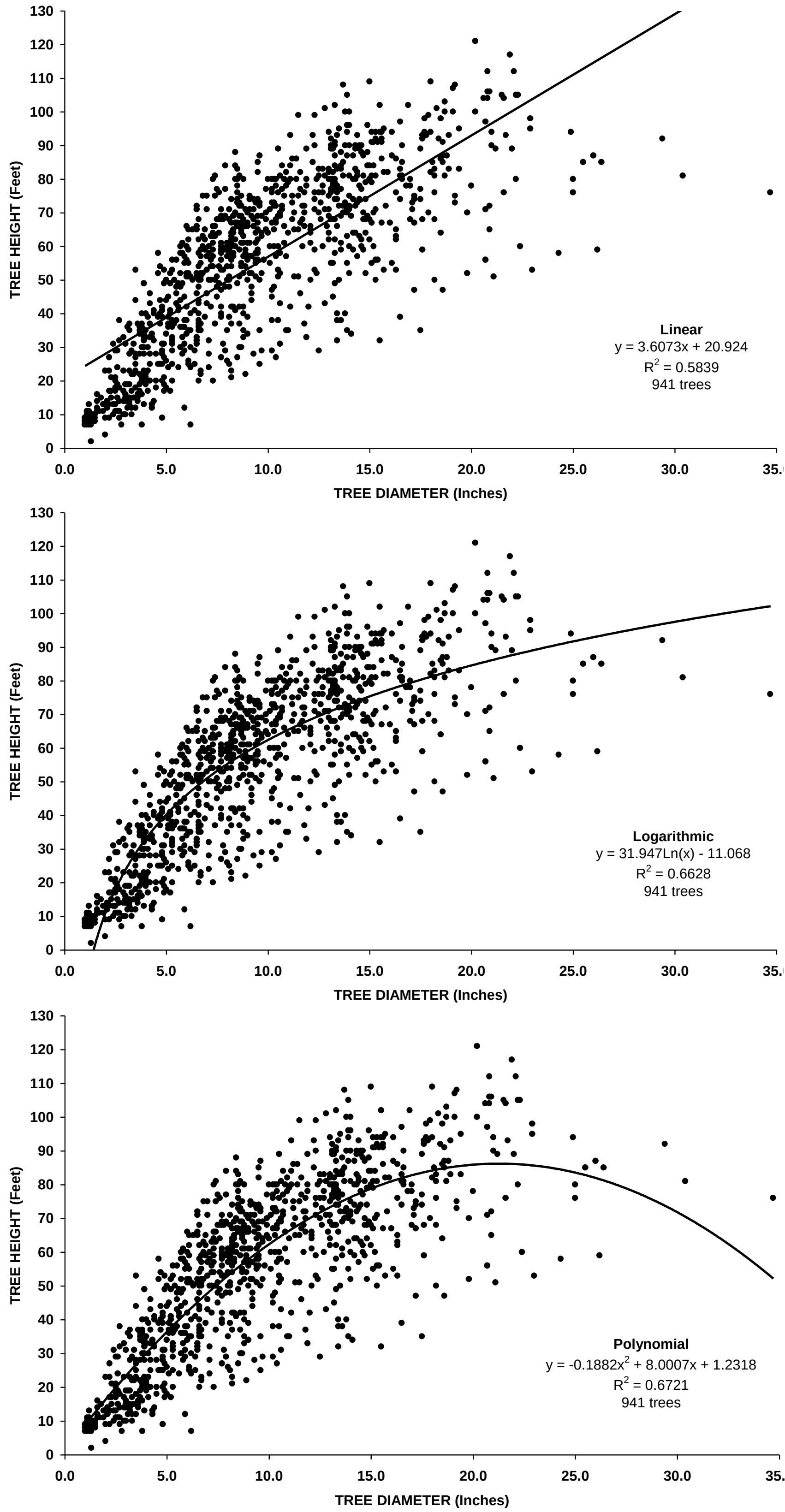


Figure 23(a): Linear, logarithmic, and polynomial trend lines for lodgepole pine on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

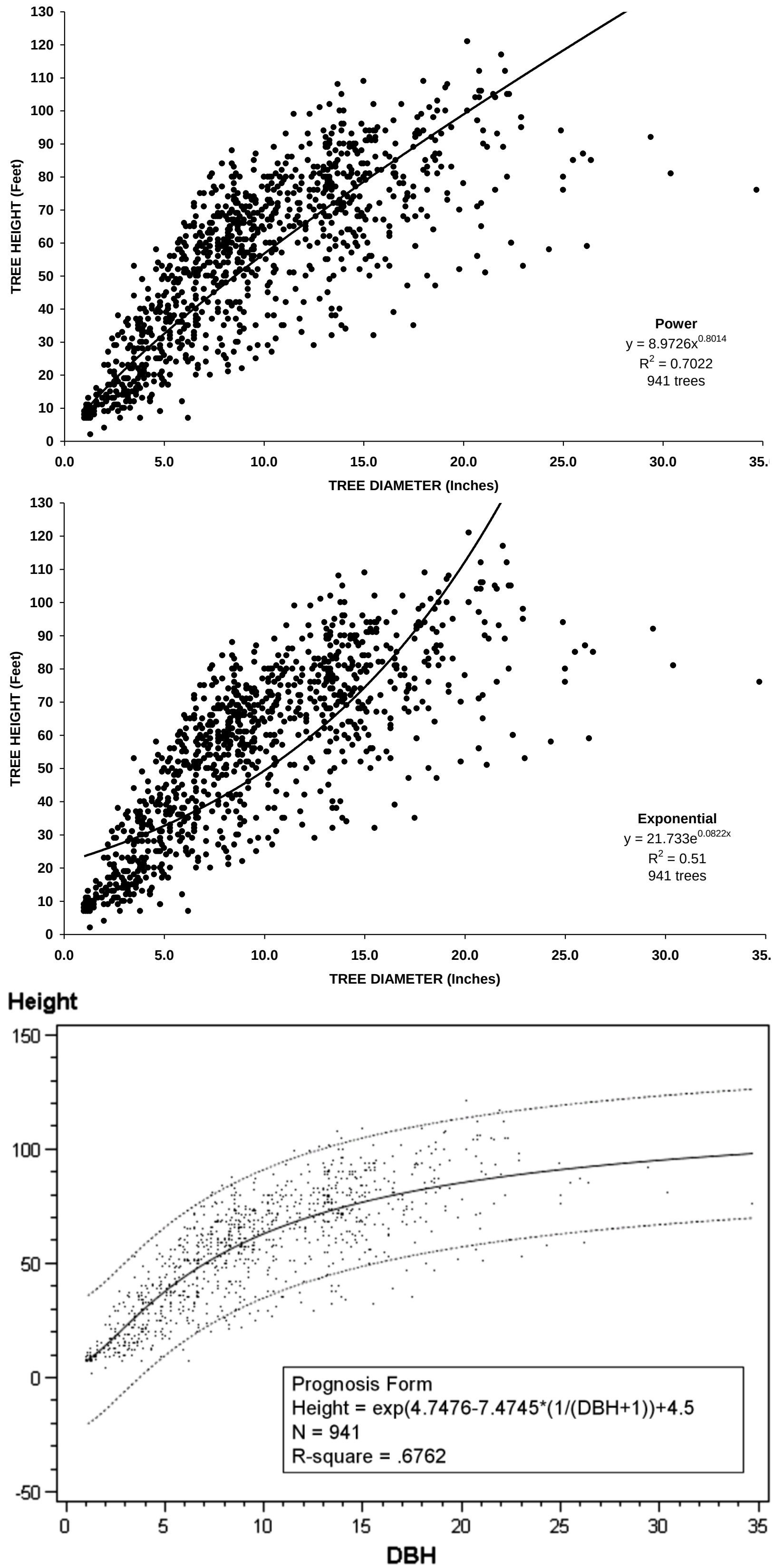


Figure 23(b): Power, exponential, and Prognosis trend lines for lodgepole pine on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

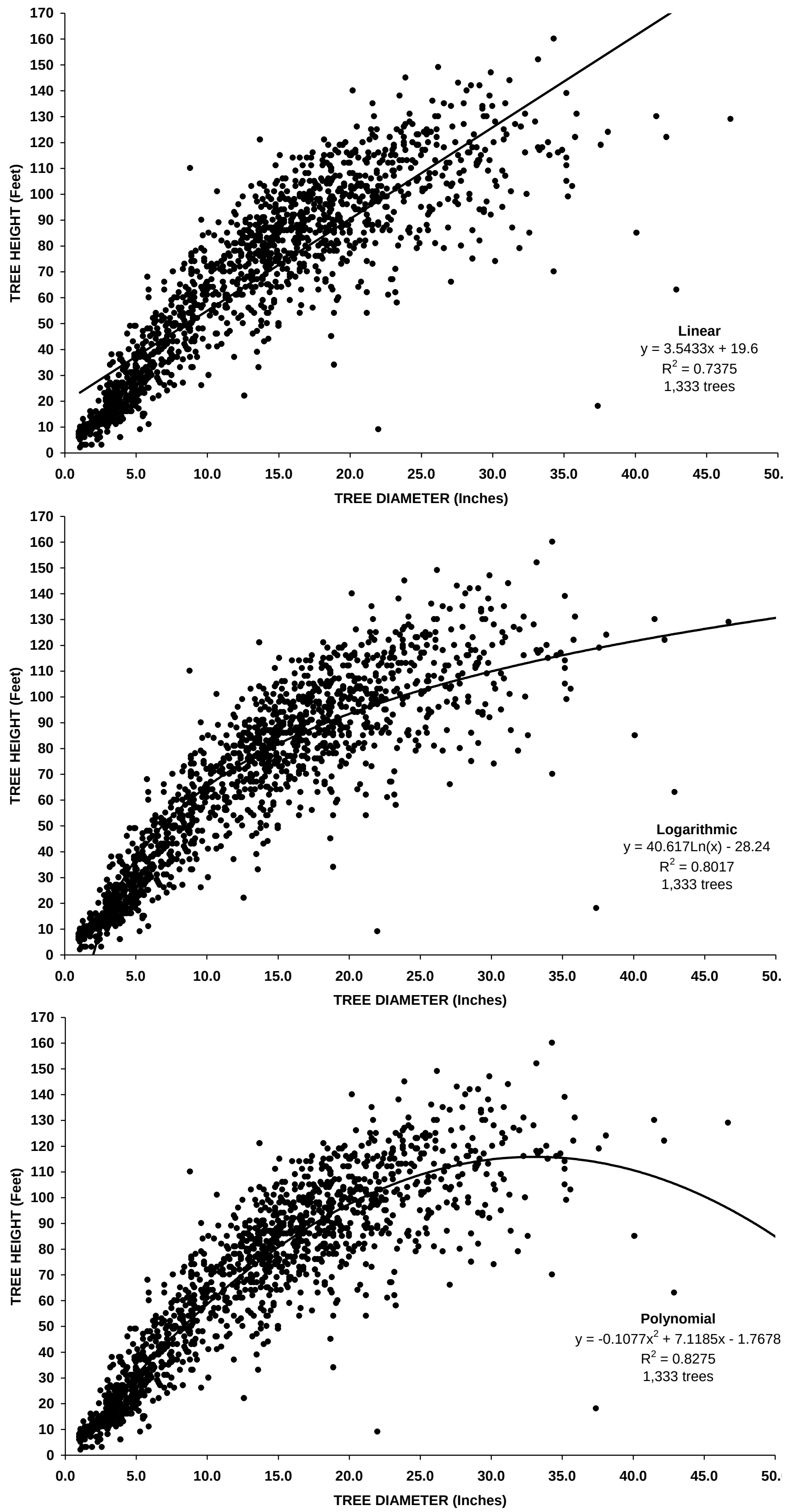


Figure 24(a): Linear, logarithmic, and polynomial trend lines for Engelmann spruce on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

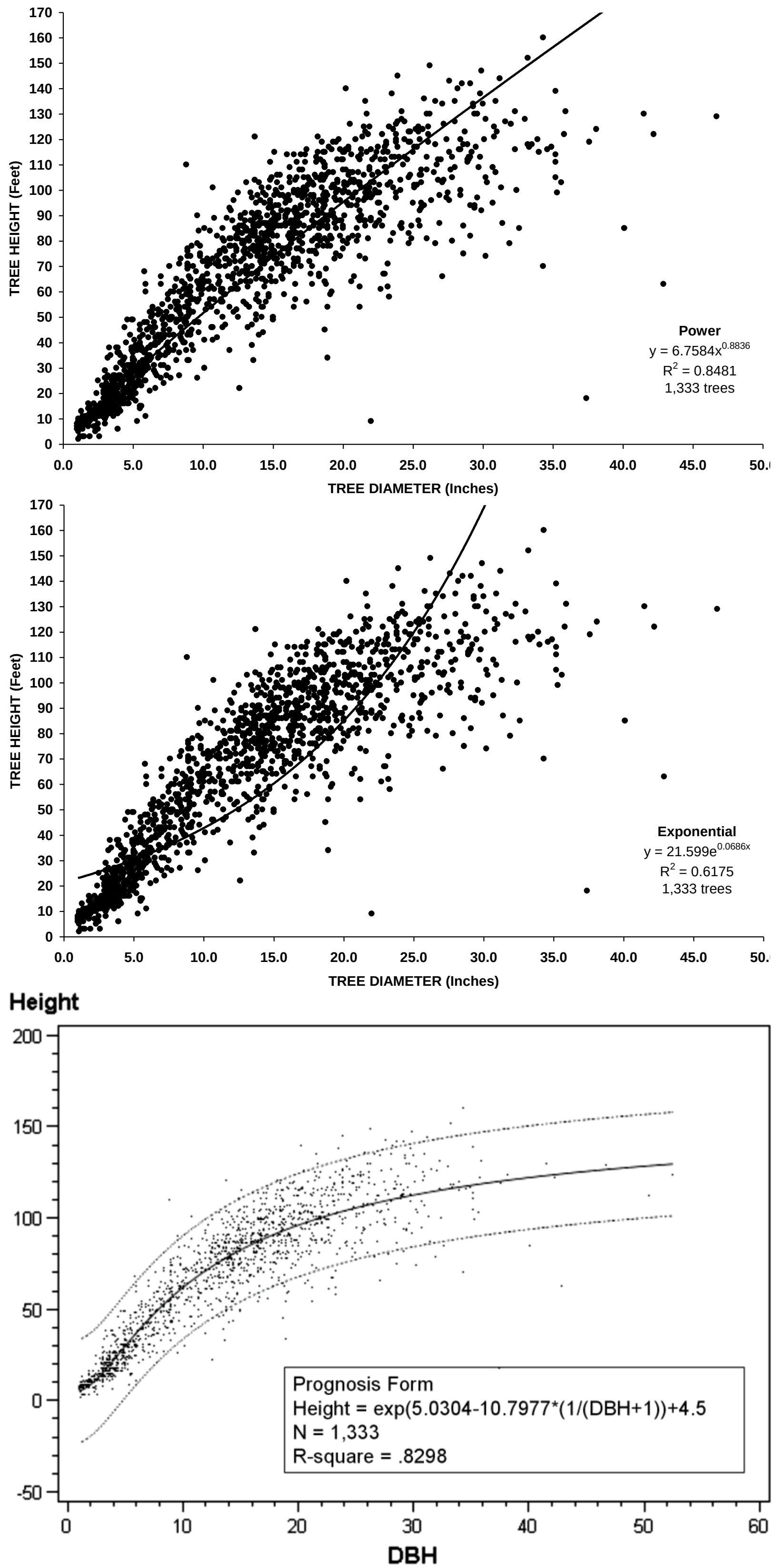


Figure 24(b): Power, exponential, and Prognosis trend lines for Engelmann spruce on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

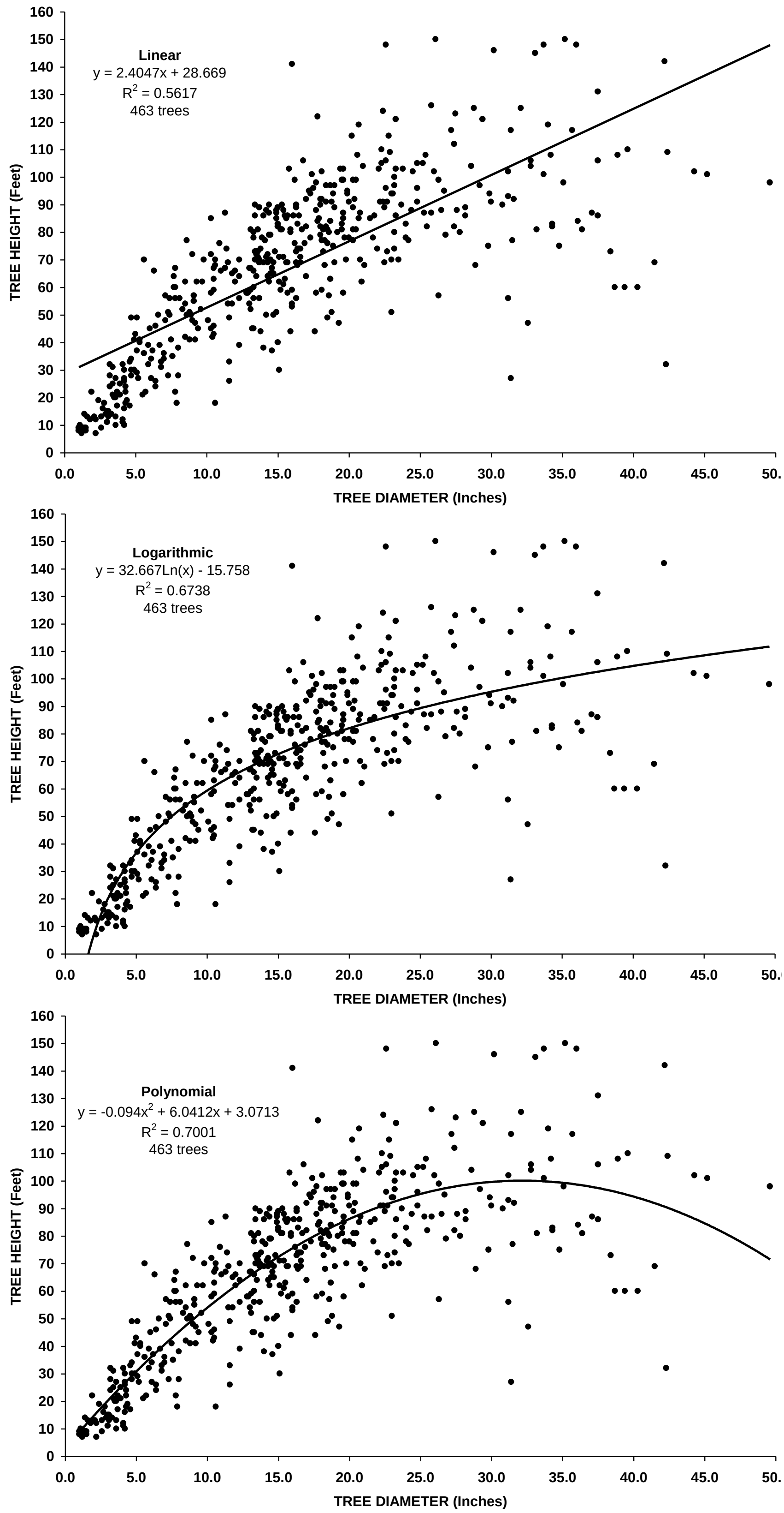


Figure 25(a): Linear, logarithmic, and polynomial trend lines for interior Douglas-fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

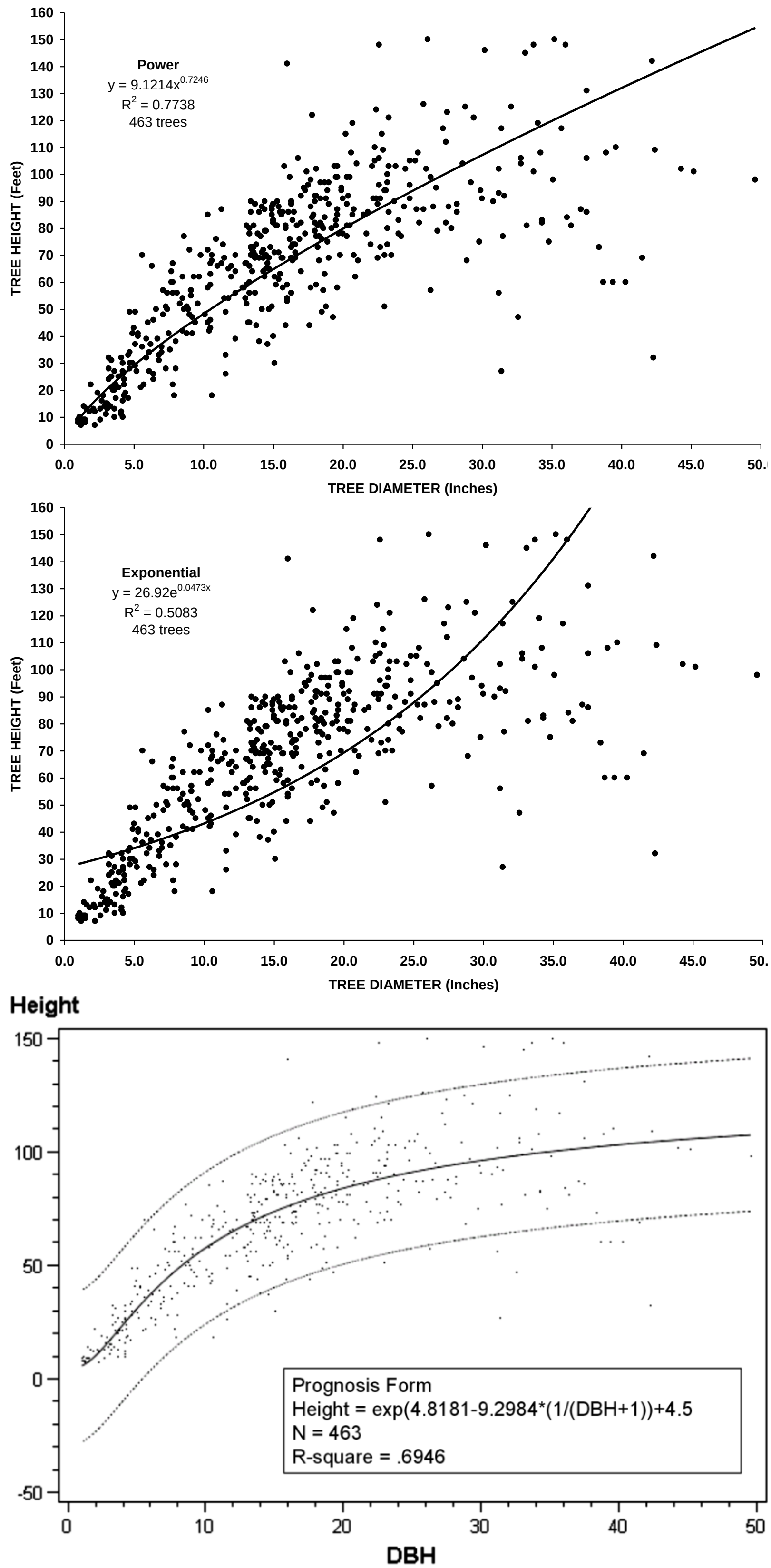


Figure 25(b): Power, exponential, and Prognosis trend lines for interior Douglas-fir on group 5 sites. Regression data is provided on each chart (equation; r^2 value; number of tree records).

Appendix 1: Height-diameter trend lines by plant association group and tree species

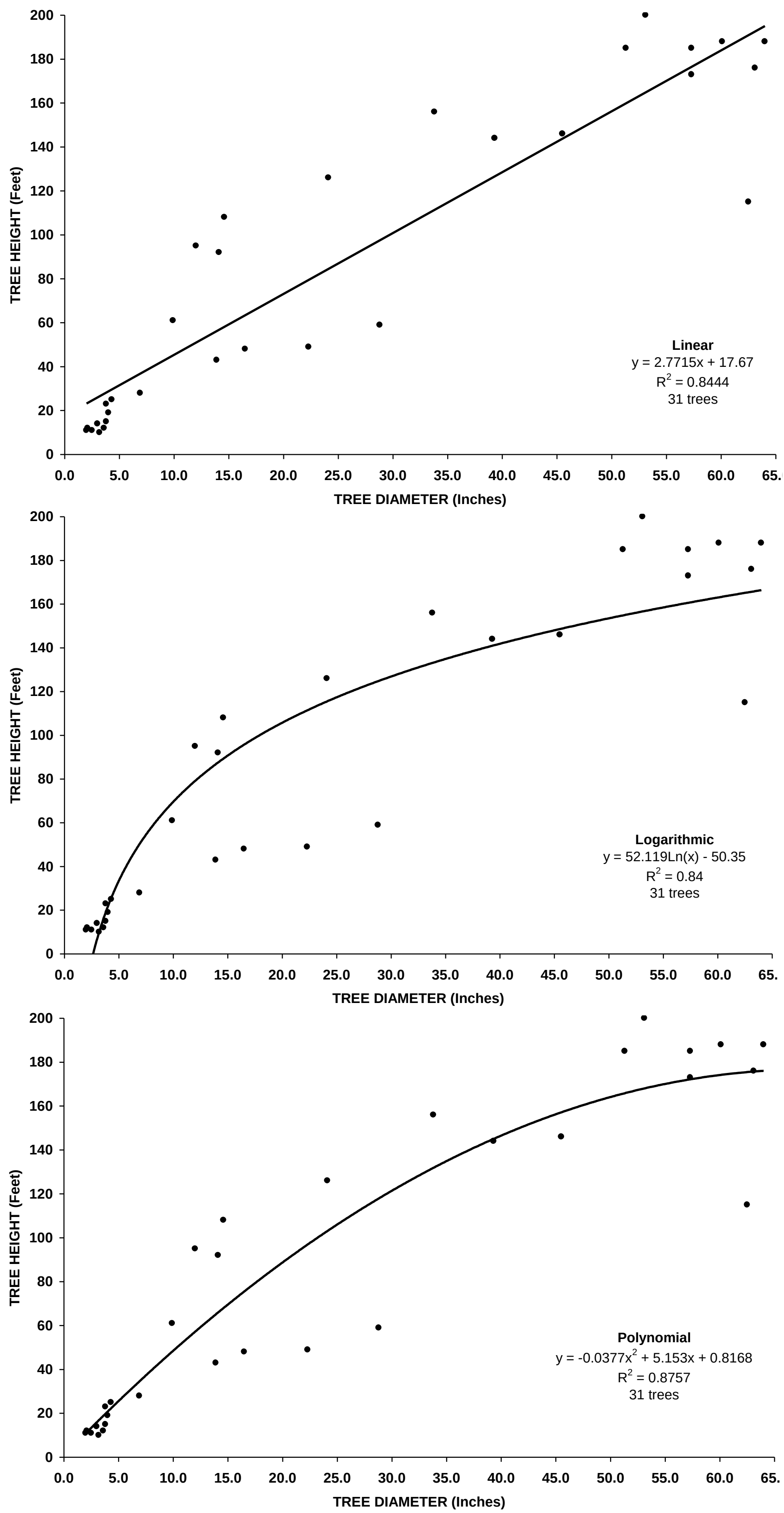


Figure 26(a): Linear, logarithmic, and polynomial trend lines for western white pine of Blue Mountains. Regression data is provided on each chart (equation; r^2 value; no. of tree records).

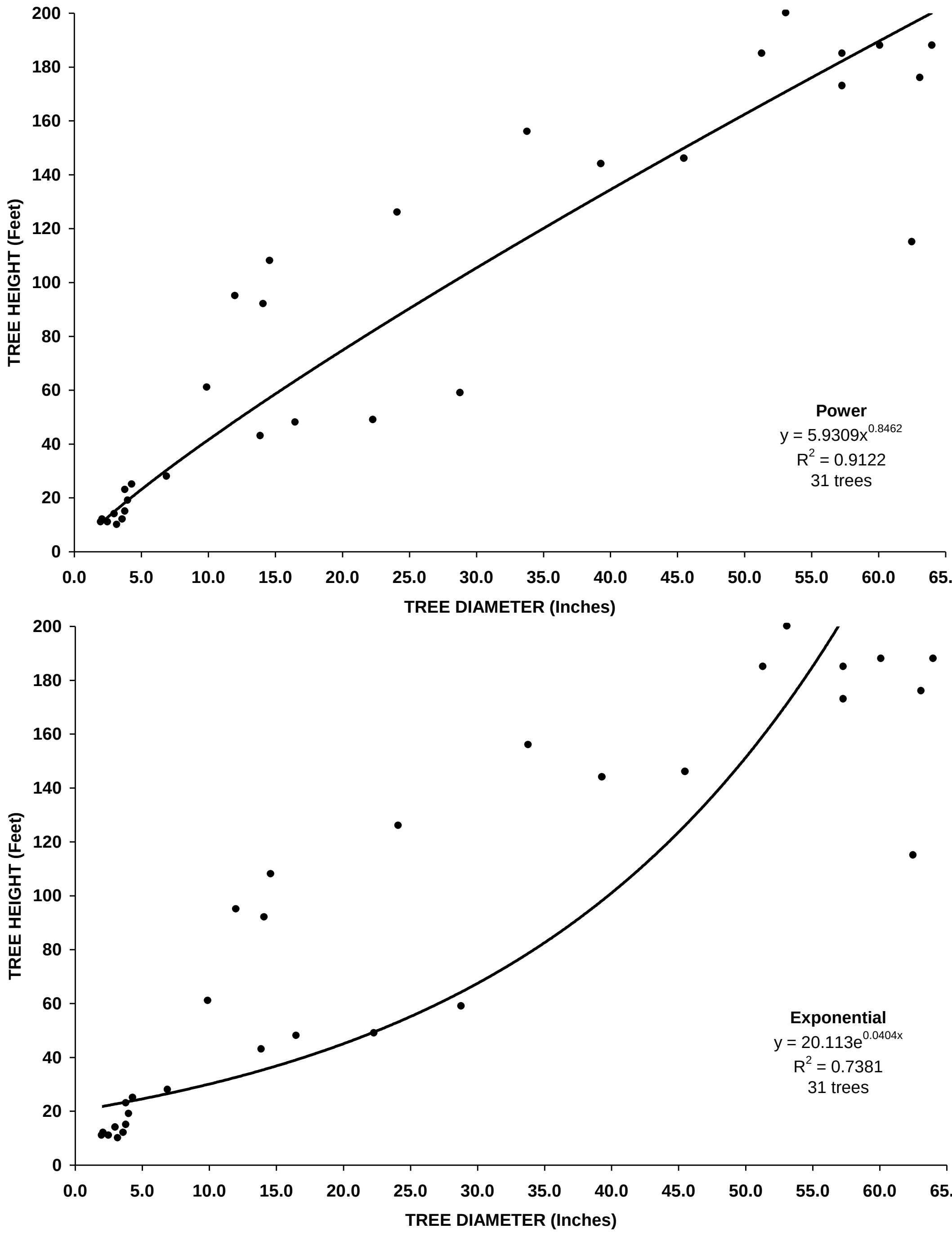


Figure 26(b): Power and exponential trend lines for western white pine of Blue Mountains. Regression data is provided on each chart (equation; r^2 value; number of tree records). No Prognosis form trend line is given because white pine sample size was too small to evaluate.

APPENDIX 2: SILVICULTURE WHITE PAPERS

White papers are internal reports, and they are produced with a consistent formatting and numbering scheme – all papers dealing with Silviculture, for example, are placed in a silviculture series (Silv) and numbered sequentially. Generally, white papers receive only limited review and, in some instances pertaining to highly technical or narrowly focused topics, the papers may receive no technical peer review at all. For papers that receive no review, the viewpoints and perspectives expressed in the paper are those of the author only, and do not necessarily represent agency positions of the Umatilla National Forest or the USDA Forest Service.

Large or important papers, such as two papers discussing active management considerations for dry and moist forests (white papers Silv-4 and Silv-7, respectively), receive extensive review comparable to what would occur for a research station general technical report (but they don't receive blind peer review, a process often used for journal articles).

White papers are designed to address a variety of objectives:

(1) They guide how a methodology, model, or procedure is used by practitioners on the Umatilla National Forest (to ensure consistency from one unit, or project, to another).

(2) Papers are often prepared to address ongoing and recurring needs; some papers have existed for more than 20 years and still receive high use, indicating that the need (or issue) has long standing – an example is white paper #1 describing the Forest's big-tree program, which has operated continuously for 25 years.

(3) Papers are sometimes prepared to address emerging or controversial issues, such as management of moist forests, elk thermal cover, or aspen forest in the Blue Mountains. These papers help establish a foundation of relevant literature, concepts, and principles that continuously evolve as an issue matures, and hence they may experience many iterations through time. [But also note that some papers have not changed since their initial development, in which case they reflect historical concepts or procedures.]

(4) Papers synthesize science viewed as particularly relevant to geographical and management contexts for the Umatilla National Forest. This is considered to be the Forest's self-selected 'best available science' (BAS), realizing that non-agency commenters would generally have a different conception of what constitutes BAS – like beauty, BAS is in the eye of the beholder.

(5) The objective of some papers is to locate and summarize the science germane to a particular topic or issue, including obscure sources such as master's theses or Ph.D. dissertations. In other instances, a paper may be designed to wade through an overwhelming amount of published science (dry-forest management), and then synthesize sources viewed as being most relevant to a local context.

(6) White papers function as a citable literature source for methodologies, models, and procedures used during environmental analysis – by citing a white paper, specialist reports can include less verbiage describing analytical databases, techniques, and so forth, some of which change little (if at all) from one planning effort to another.

(7) White papers are often used to describe how a map, database, or other product was developed. In this situation, the white paper functions as a 'user's guide' for the new product. Examples include papers dealing with historical products: (a) historical fire extents for the Tucannon watershed (WP Silv-21); (b) an 1880s map developed from General Land Office survey notes (WP Silv-41); and (c) a

description of historical mapping sources (24 separate items) available from the Forest's history website (WP Silv-23).

The following papers are available from the Forest's website: Silviculture White Papers

Paper #	Title
1	Big tree program
2	Description of composite vegetation database
3	Range of variation recommendations for dry, moist, and cold forests
4	Active management of Blue Mountains dry forests: Silvicultural considerations
5	Site productivity estimates for upland forest plant associations of Blue and Ochoco Mountains
6	Blue Mountains fire regimes
7	Active management of Blue Mountains moist forests: Silvicultural considerations
8	Keys for identifying forest series and plant associations of Blue and Ochoco Mountains
9	Is elk thermal cover ecologically sustainable?
10	A stage is a stage is a stage…or is it? Successional stages, structural stages, seral stages
11	Blue Mountains vegetation chronology
12	Calculated values of basal area and board-foot timber volume for existing (known) values of canopy cover
13	Created opening, minimum stocking, and reforestation standards from Umatilla National Forest Land and Resource Management Plan
14	Description of EVG-PI database
15	Determining green-tree replacements for snags: A process paper
16	Douglas-fir tussock moth: A briefing paper
17	Fact sheet: Forest Service trust funds
18	Fire regime condition class queries
19	Forest health notes for an Interior Columbia Basin Ecosystem Management Project field trip on July 30, 1998 (handout)
20	Height-diameter equations for tree species of Blue and Wallowa Mountains
21	Historical fires in headwaters portion of Tucannon River watershed
22	Range of variation recommendations for insect and disease susceptibility
23	Historical vegetation mapping
24	How to measure a big tree
25	Important Blue Mountains insects and diseases
26	Is this stand overstocked? An environmental education activity
27	Mechanized timber harvest: Some ecosystem management considerations
28	Common plants of south-central Blue Mountains (Malheur National Forest)
29	Potential natural vegetation of Umatilla National Forest
30	Potential vegetation mapping chronology
31	Probability of tree mortality as related to fire-caused crown scorch
32	Review of "Integrated scientific assessment for ecosystem management in the interior Columbia basin, and portions of the Klamath and Great basins" – Forest vegetation
33	Silviculture facts
34	Silvicultural activities: Description and terminology

Paper #	Title
35	Site potential tree height estimates for Pomeroy and Walla Walla Ranger Districts
36	Stand density protocol for mid-scale assessments
37	Stand density thresholds as related to crown-fire susceptibility
38	Umatilla National Forest Land and Resource Management Plan: Forestry direction
39	Updates of maximum stand density index and site index for Blue Mountains variant of Forest Vegetation Simulator
40	Competing vegetation analysis for southern portion of Tower Fire area
41	Using General Land Office survey notes to characterize historical vegetation conditions for Umatilla National Forest
42	Life history traits for common Blue Mountains conifer trees
43	Timber volume reductions associated with green-tree snag replacements
44	Density management field exercise
45	Climate change and carbon sequestration: Vegetation management considerations
46	Knutson-Vandenberg (K-V) program
47	Active management of quaking aspen plant communities in northern Blue Mountains: Regeneration ecology and silvicultural considerations
48	Tower Fire…then and now. Using camera points to monitor postfire recovery
49	How to prepare a silvicultural prescription for uneven-aged management
50	Stand density conditions for Umatilla National Forest: A range of variation analysis
51	Restoration opportunities for upland forest environments of Umatilla National Forest
52	New perspectives in riparian management: Why might we want to consider active management for certain portions of riparian habitat conservation areas?
53	Eastside Screens chronology
54	Using mathematics in forestry: An environmental education activity
55	Silviculture certification: Tips, tools, and trip-ups
56	Vegetation polygon mapping and classification standards: Malheur, Umatilla, and Wallowa-Whitman National Forests
57	State of vegetation databases for Malheur, Umatilla, and Wallowa-Whitman National Forests
58	Seral status for tree species of Blue and Ochoco Mountains

REVISION HISTORY

December 2016: The first version of this white paper was prepared in September 2005 in response to a request from Blue Mountains Service Center (La Grande, OR). For this revision, minor formatting and editing changes were made, including adding a white-paper header and assigning a white-paper number. An appendix was added describing the white paper system, including a list of available white papers.