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Validating FVS^{Ontario} individual model components using independent datasets based on permanent sample plots located in Quebec

Project number 130-107

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ABSTRACT

The development of models for diameter at breast height (dbh) growth rate, survival rate, stem height and species group density index for the Ontario variant of the Forest Vegetation Simulator ($FVS^{Ontario}$) was completed using data from permanent sample plots located in Ontario. An independent validation exercise was conducted using permanent sample plot data maintained by the ministère des Ressources naturelles et de la Faune du Québec. The species involved included black spruce (*Picea mariana* (Mill.) B.S.P.), jack pine (*Pinus banksiana* Lamb.), balsam fir (*Abies balsamea* (L.) Mill.), trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* Marsh.), white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britt.), basswood (*Tilia americana* L.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), soft maple (*Acer saccharinum* L.), balsam poplar (*Populus balsamifera* L.), red oak (*Quercus rubra* L.), black cherry (*Prunus serotina* Ehrh.), bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch) and white ash (*Fraxinus americana* L.). For each model, predictions and observations were compared and three statistics based on residuals were calculated for all dependent variables: (1) mean percentage of difference, (2) model efficiency and (3) variance ratio. In general, the dbh growth rate and height-dbh models underpredicted dbh growth rate and predicted height from dbh for most species in the Quebec dataset, while survival rate and species group density index were slightly overpredicted. Despite these results, the new models derived for $FVS^{Ontario}$ behaved consistently with the independent dataset.

RÉSUMÉ

Le développement de modèles du taux de croissance du diamètre à hauteur de poitrine (dhp), du taux de survie, de la hauteur de la tige et de l'index de densité de groupe d'essences (IDGE) pour la variante ontarienne du modèle « Forest Vegetation Simulator » ($FVS^{Ontario}$) a été complété à partir de données de parcelles-échantillons permanentes situées en Ontario. Un exercice indépendant de validation a été réalisé avec des données de parcelles-échantillons permanentes du ministère des Ressources naturelles et de la Faune du Québec. Les essences impliquées incluaient l'épinette noire (*Picea mariana* (Mill.) B.S.P.), le pin gris (*Pinus banksiana* Lamb.), le sapin baumier (*Abies balsamea* (L.) Mill.), le peuplier faux-tremble (*Populus tremuloides* Michx.), le bouleau blanc (*Betula papyrifera* Marsh.), l'érable à sucre (*Acer saccharum* Marsh.), le pin blanc (*Pinus strobus* L.), le pin rouge (*Pinus resinosa* Ait.), le hêtre à grandes feuilles (*Fagus grandifolia* Ehrh.), le bouleau jaune (*Betula alleghaniensis* Britt.), le tilleul (*Tilia americana* L.), l'ostryer de Virginie (*Ostrya virginiana* (Mill.) K. Koch), l'érable argenté (*Acer saccharinum* L.), le peuplier baumier (*Populus balsamifera* L.), le chêne rouge (*Quercus rubra* L.), le cerisier tardif (*Prunus serotina* Ehrh.), le caryer cordiforme (*Carya cordiformis* (Wangenh.) K. Koch) et le frêne blanc (*Fraxinus americana* L.). Pour chaque modèle, les prédictions et les observations ont été comparées et trois statistiques basées sur les résidus ont été calculées pour toutes les variables dépendantes : (1) pourcentage moyen de différence, (2) efficacité du modèle et (3) rapport de variance. En général, les modèles de taux de croissance en dhp et de hauteur–dhp ont sous-prédit le taux de croissance en dhp et la hauteur de la tige en fonction du dhp pour la plupart des essences dans l'ensemble de données du Québec, tandis que le taux de survie et l'IDGE étaient légèrement surprédits. En dépit de ces résultats, les nouveaux modèles dérivés pour $FVS^{Ontario}$ se sont comportés de façon cohérente avec la banque de données indépendantes.

INTRODUCTION

New models for dbh growth rate, survival rate, stem height and species group density index (SGDI) were calibrated for the Ontario variant of the Forest Vegetation Simulator ($FVS^{Ontario}$) (Lacerte et al. 2007). Once the development of these models was completed, the need for a validation exercise using an independent dataset was identified to increase confidence in the use of the new models, as suggested by several authors (e.g. Holdaway and Brand 1983, 1986; Vanclay 1994; Farnden 1997). For this reason, enquiries were made to examine the possibility of using inventory datasets containing growth data for similar forest types for which the new models were developed. The inventory dataset developed and maintained by the ministère des Ressources naturelles et de la Faune du Québec was found suitable for a validation exercise using an independent dataset. Many sample plots within this dataset contained remeasured stand data for forest types that were similar to the Ontario forest types.

The datasets used for the validation of the new models of the Ontario variant of FVS included several species from Quebec: black spruce (*Picea mariana* (Mill.) B.S.P.), jack pine (*Pinus banksiana* Lamb.), balsam fir (*Abies balsamea* (L.) Mill.), trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* Marsh.), white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britt.), basswood (*Tilia americana* L.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), soft maple (*Acer saccharinum* L.), balsam poplar (*Populus balsamifera* L.), red oak (*Quercus rubra* L.), black cherry (*Prunus serotina* Ehrh.), bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch) and white ash (*Fraxinus americana* L.). The objective of this study was to present the results of the validation exercise for the new models developed for $FVS^{Ontario}$ using independent data.

MATERIALS AND METHODS

Description of the validation database

The Quebec dataset contained long-term permanent sample plot records for black spruce, jack pine, balsam fir, trembling aspen, white birch, sugar maple, white pine, red pine, American beech, yellow birch, basswood, ironwood, soft maple, balsam poplar, red oak, black cherry, bitternut hickory and white ash (Table 1). The dataset consisted of natural pure and mixed stands for different conditions of age, stand density, quadratic mean diameter (QMD), site index (SI), basal area (BA) and top height. The largest variation in stand attributes was found for black spruce, followed by jack pine, balsam fir, white pine, trembling aspen, sugar maple, American beech, white birch, yellow birch, red oak, red pine, basswood, soft maple, ironwood, balsam poplar, white ash and black cherry.

Table 1. Summary of the Quebec dataset used for a validation exercise of FVS^{Ontario} using independent data

Leading species	Leading species proportions by basal area (%)	Age (year)	Stand density (stems ha^{-1})	QMD (cm)	SI (m)	Basal area (m^2 ha^{-1})	Top height (m)	Number of trees
Black spruce	>70	95 (14,221)*	1382 (200,3950)	14.0 (3.4,26.3)	10 (1,23)	20.0 (1.8,52.5)	13.7 (6.0,24.0)	245373
Black spruce - Other conifers**	>50	78 (18,210)	1408 (275,3275)	14.2 (5.7,25.6)	11 (3,22)	22.0 (1.6,52.1)	14.1 (6.0,22.0)	38664
Black spruce - Other hardwoods£**	>50	60 (24,164)	1380 (275,2925)	15.1 (6.6,23.8)	15 (3,21)	23.8 (2.3,50.4)	15.9 (7.1,23.0)	10778
Jack pine	>70	53 (13,136)	1414 (250,3000)	13.8 (6.7,25.5)	15 (5,23)	20.6 (1.7,47.0)	15.1 (6.2,25.0)	41144
Jack pine - Other conifers	>50	61 (18,126)	1397 (275,3150)	14.3 (8.7,25.7)	14 (8,25)	22.1 (2.3,44.6)	15.1 (9.0,24.0)	9242
Jack pine -other hardwoods	>50	50 (15,84)	1490 (300,2800)	15.7 (9.0,23.9)	18 (12,24)	27.3 (2.9,44.6)	17.9 (8.0,24.9)	2661
Balsam fir	>70	66 (13,195)	1610 (150,4450)	15.3 (4.9,32.4)	13 (2,29)	26.8 (1.8,63.1)	14.3 (6.0,32.0)	118849
Balsam fir - Other conifers	>50	69 (16,197)	1384 (275,2925)	15.1 (6.0.29.9)	13 (5,26)	24.3 (2.0,56.2)	14.3 (7.0,25.0)	39885
Balsam fir - Other hardwoods	>50	52 (21,156)	1263 (275,3675)	15.6 (5.9,29.9)	16 (6,31)	23.1 (2.5,56.1)	15.4 (8.0,24.0)	44161
Trembling aspen	>70	47 (16,155)	1272 (200,2925)	16.2 (5.2,36.2)	20 (5,38)	24.3 (2.0,64.9)	18.5 (8.0,31.0)	26296
Trembling aspen - Other conifers	>50	49 (16,112)	1364 (300,3050)	16.0 (9.5,33.1)	19 (11,30)	25.8 (2.8,55.7)	17.7 (8.0,29.0)	18282
Trembling aspen - Other hardwoods	>50	51 (18,114)	1142 (275,2800)	15.9 (7.0,33.8)	19 (9,28)	22.0 (2.6,47.7)	18.4 (8.0,28.0)	14710
White birch	>70	61 (18,143)	1170 (275,2450)	15.4 (5.0,38.8)	15 (8,23)	20.1 (1.9, 40.3)	15.7 (7.0,23.0)	27503
White birch - Other conifers	>50	59 (20,140)	1173 (275,2750)	15.5 (6.2,31.6)	15 (8,22)	21.3 (2.2,43.9)	15.6 (8.0,23.0)	26974
White birch - Other hardwoods	>50	54 (21,130)	1124 (275,2125)	15.6 (6.5,27.6)	16 (8,27)	20.2 (2.6,36.3)	16.6 (9.0,27.0)	12905
Sugar maple	>70	63 (19,182)	692 (225,1475)	22.1 (8.6,49.6)	18 (9,33)	23.8 (2.8,51.1)	20.2 (10.0,32.0)	30879

Leading species	Leading species proportions by basal area (%)	Age (year)	Stand density (stems ha^{-1})	QMD (cm)	SI (m)	Basal area (m^2 ha^{-1})	Top height (m)	Number of trees
Sugar maple - Other conifers	>50	55 (25,110)	800 (275,1575)	19.5 (11.2,32.0)	17 (11,27)	22.5 (6.7,38.0)	17.5 (12.0,24.0)	3226
Sugar maple - Other hardwoods	>50	60 (21,153)	812 (275,1775)	19.8 (6.8,42.8)	18 (9,34)	23.3 (2.6,48.0)	19.2 (11.0,29.0)	22474
White pine	>70	68 (22,201)	846 (325,1925)	22.7 (8.8,36.1)	17 (7,40)	31.3 (6.6,65.3)	21.2 (9.0,32.0)	2907
White pine - Other conifers	>50	57 (21,138)	951 (325,1650)	19.0 (7.6,30.0)	17 (6,29)	25.7 (2.5,55.1)	18.6 (9.0,27.0)	3591
White pine - Other hardwoods	>50	61 (25,120)	926 (275,2000)	19.8 (13.4,33.5)	17 (7,38)	27.2 (6.6,45.2)	19.5 (10.0,26.0)	2982
Red pine	>70	45 (23,106)	1653 (700,2875)	17.0 (12.2,25.9)	20 (15,23)	35.0 (12.5,57.2)	15.9 (8.0,26.0)	488
Red pine - Other conifers	>50	60 (32,90)	1118 (550,1475)	21.9 (19.3,28.4)	18 (13,27)	41.3 (30.3,58.7)	21.0 (16.0,31.0)	430
Red pine - Other hardwoods	>50	57 (45,69)	988 (300,1325)	18.6 (15.7,20.3)	17 (11,20)	27.2 (6.7,42.3)	19.6 (15.0,22.0)	220
American beech	>70	80 (39,158)	697 (200,1050)	21.8 (12.3,40.7)	-	22.0 (5.6,37.9)	20.0 (11.0,28.0)	1796
American beech - Other conifers	>50	86 (52,120)	704 (500,875)	21.3 (17.5,26.1)	-	25.0 (17.4,37.5)	19.4 (16.0,23.0)	210
American beech - Other hardwoods	>50	70 (21,130)	744 (275,1500)	21.2 (8.7,31.4)	-	24.0 (3.9,45.8)	19.6 (13.0,27.0)	3843
Yellow birch	>70	65 (17,157)	624 (225,1725)	22.9 (7.8,40.0)	16 (9,34)	21.8 (2.4,40.0)	17.6 (11.0,25.0)	6741
Yellow birch - Other conifers	>50	61 (21,118)	777 (275,1575)	20.1 (9.1,33.1)	16 (10,30)	23.9 (3.4,46.4)	17.2 (10.0,23.0)	8614
Yellow birch - Other hardwoods	>50	62 (18,139)	786 (275,1850)	20.2 (7.8,34.9)	17 (8,28)	22.8 (2.5,44.6)	17.8 (8.0,26.0)	8062
Basswood	>70	109 (58,119)	1239 (275,1425)	13.4 (13.0,16.1)	12 (11,16)	16.7 (5.6,18.8)	18.2 (18.0,19.0)	68
Basswood - Other conifers	>50	60 (49,66)	416 (350,475)	17.2 (15.8,18.1)	15 (14,17)	9.7 (9.0,11.0)	18.0 (18.0,18.0)	40

Leading species	Leading species proportions by basal area (%)	Age (year)	Stand density (stems ha^{-1})	QMD (cm)	SI (m)	Basal area (m^2 ha^{-1})	Top height (m)	Number of trees
Basswood - Other hardwoods	>50	49 (23,69)	866 (275,1400)	19.7 (8.6,31.7)	19 (14,31)	25.5 (3.7,37.6)	19.3 (13.0,25.0)	722
Ironwood - Other hardwoods	>50	85 (85,85)	939 (925,950)	15.0 (14.5,15.8)	-	16.7 (15.6,18.2)	17.3 (16.0,19.0)	66
Soft maple	>70	49 (22,102)	732 (300,1075)	22.3 (12.0,38.1)	-	24.2 (9.1,44.7)	21.3 (15.0,33.0)	409
Soft maple - Other hardwoods	>50	49 (45,52)	720 (275,875)	19.6 (16.3,28.5)	-	21.3 (14.4,34.3)	20.5 (16.0,25.0)	209
Balsam poplar	>70	40 (18,71)	1098 (375,1625)	18.2 (10.0,29.2)	-	27.0 (5.3,57.4)	18.8 (10.0,24.0)	914
Balsam poplar - Other conifers	>50	53 (28,65)	1106 (650,1775)	17.8 (14.5,25.5)	-	26.5 (12.1,35.7)	17.1 (12.0,23.0)	565
Balsam poplar - Other hardwoods	>50	40 (33,50)	893 (550,1150)	19.2 (17.5,23.7)	-	24.6 (20.3,27.7)	17.9 (17.0,21.0)	98
Red oak	>70	58 (24,114)	835 (300,1400)	18.3 (10.2,33.3)	16 (9,24)	21.4 (3.7,34.5)	16.9 (9.0,21.0)	1815
Red oak - Other conifers	>50	57 (31,103)	909 (475,1525)	18.1 (13.6,23.8)	16 (12,20)	22.2 (11.2,31.4)	16.2 (11.0,21.0)	821
Red oak - Other hardwoods	>50	62 (20,133)	897 (350,1775)	19.3 (8.5,35.1)	17 (11,29)	25.0 (4.7,37.6)	18.3 (10.0,25.0)	2008
Black cherry	>70	-	1450 (1450,1450)	12.3 (12.3,12.3)	-	17.3 (17.3,17.3)	15.0 (15.0,15.0)	58
Black cherry - Other hardwoods	>50	56 (30,96)	934 (400,1350)	14.8 (10.6, 19.0)	15 (10,22)	15.3 (4.5,22.8)	15.0 (10.0,21.0)	348
White ash	>70	58 (55,62)	575 (300,800)	16.7 (14.1,22.2)	13 (9,16)	11.2 (8.9,12.4)	14.3 (10.0,18.0)	50
White ash - Other hardwoods	>50	51 (31,94)	878 (550,1175)	16.7 (12.1,20.8)	16 (13,19)	18.9 (6.5,28.0)	19.0 (14.0,25.0)	217
Tolerant hardwoods - Other hardwoods[§]	>50	61 (17,132)	827 (350,1475)	19.7 (10.0,32.9)	18 (8,39)	24.4 (6.6,51.1)	19.3 (10.0,26.0)	4352

Leading species	Leading species proportions by basal area (%)	Age (year)	Stand density (stems ha^{-1})	QMD (cm)	SI (m)	Basal area (m^2 ha^{-1})	Top height (m)	Number of trees
Mixed - conifers¤	>50	58 (18,180)	1197 (275,2825)	16.5 (6.7,34.1)	15 (6,37)	24.8 (2.2,63.8)	16.2 (7.0,27.0)	40592
Mixed - hardwoods¥	>50	54 (17,137)	1117 (275,2725)	16.5 (5.5,34.5)	17 (3,35)	22.8 (3.1,57.8)	17.1 (3.0,26.0)	51182

*Values within brackets are the minimum and maximum values obtained.

Legend:
**More than 30% of basal area included other conifers.
£More than 30% of basal area included tolerant or intolerant hardwood species.
§More than 50% of basal area included sugar maple, American beech and soft maple and more than 30% of basal area included trembling aspen, white birch, yellow birch, basswood, ironwood, soft maple, balsam poplar, red oak, black cherry, bitternut hickory and white ash.
¤More than 50% of basal area included black spruce, jack pine, balsam fir, white pine, red pine and tamarack.
¥More than 50% of basal area included trembling aspen, white birch, sugar maple, American beech, yellow birch, basswood, ironwood, soft maple, balsam poplar, red oak, black cherry, bitternut hickory and white ash.

Computation of stand variables for the validation dataset

For each sample plot, different stand variables were computed to ensure their compatibility with the type of input required to run FVS. As the site index for each sample plot of the Quebec dataset had to be computed using Carmean's (1996) site index models, the top height of each plot was computed using the model derived by Bégin and Raulier (1995):

$$H_{ij} = 1.3 + \left[\frac{D_{ij}}{\left(\frac{\overline{D}_i}{\overline{H}_i - 1.3} \right) + \beta_2 \left(D_{ij} - \overline{D}_i \right)} \right] \qquad (1)$$

where: H_{ij} : current total height of sample tree j within plot i (m).

D_{ij} : current dbh of sample tree j within plot i (cm).

$\overline{H}_i$: mean total height of sample trees in plot i (m).

$\overline{D}_i$: mean dbh of sample trees in plot i (cm).

β_2 : estimated regression coefficient.

The SAS procedure 'model' (SAS Institute Inc. 2001) was used to estimate the β_2 coefficient for each species (Appendix 1). For each sample plot, top height was then calculated using model (1) in which D_{ij} was equal to the mean dbh of the four largest trees in a 0.04 ha plot (Pothier and Savard 1998). This procedure ensured that the computation of top height was based on the mean height of the 100 trees with the largest dbh per hectare (Pothier and Savard 1998). Then, site index was estimated for black spruce, jack pine, balsam fir, trembling aspen, white birch, sugar maple, white pine, red pine, yellow birch, basswood, red oak and black cherry using site index equations calibrated for Ontario by Carmean (1996).

For each tree, dbh growth rate, survival rate and basal area of all the trees greater than itself (BAL) were calculated within each sample plot. The derivation of both dbh growth and survival rates required a minimum of two measurements on identified trees within a sample plot. The observed annual dbh growth rate of individual trees was computed as:

$$\Delta dbh = \frac{dbh_2 - dbh_1}{T_2 - T_1} \qquad (2)$$

where Δdbh is the annual dbh growth rate (cm year^{-1}), dbh_2 and dbh_1 the dbh at time T_2 and T_1, respectively.

The observed individual tree survival rate was computed with the equation suggested by Buchman (1983); Buchman et al. (1983) and Buchman (1985):

$$SR = \left[\sum_i X_i \, / \sum_i N_i \right]^{\left[\sum_i N_i / \sum_i i \bullet N_i \right]} \qquad (3)$$

where SR is the survival rate (between 0 and 1), N_i and X_i are the number of trees alive at the beginning and at the end of the status observation interval, respectively, and i is the interval length (year).

For each tree, the basal area of all the trees within a stand that had greater dbh was computed (BAL [m^2 ha^{-1}]). This variable was used as an independent variable in the models derived for survival rate. BAL was identified as a significant independent variable in other studies when survival rate was computed (e.g. Monserud and Sterba 1999; Eid and Tuhus 2001).

Models of the Ontario variant of FVS and quantitative evaluation

A complete description of the new models derived using Ontario data may be found in a companion report (Lacerte et al. 2007). As indicated in Table 2, new models were calibrated for large trees (dbh greater than 7.5 cm) and small trees (dbh smaller than 7.5 cm). For large trees, models were derived for dbh growth rate, survival rate, stem height and species group density index. Stem height and dbh growth rate models were derived for small trees. All the models were statistically significant and demonstrated a biologically consistent pattern.

Table 2. Summary of the new models calibrated for FVS^{Ontario} (adapted from Lacerte et al. 2007)

Species	Origin	Model
Large-tree models *dbh growth rate**		
Black spruce	Natural	(exp(-1.3894dbh$^{-0.0538}$+si$^{0.1535}$/exp(0.1273(dbh/mean_dbh)+0.0219ba)))-1
Black spruce	Plantation	(exp(0.6533dbh$^{-0.7031}$/exp-1.0769(dbh/mean_dbh)+0.00431ba$^{1.6318}$))-1
Jack pine	Natural	(exp((2.2952mean_dbh$^{-1.4313}$+0.000064si^{2})/(exp-0.039dbh)))-1
Balsam fir	Natural	(exp(0.0578ba+0.2131dbh/exp(dbh ba)$^{0.1886}$))-1
White spruce	Plantation	(exp((dbh$^{0.2628}$)/(exp((-0.1522(dbh/mean_dbh))+((ba dbh)$^{0.1490}$)))))-1
Trembling aspen	Natural	(exp((dbh ba)$^{-0.3447}$/exp-0.3333(dbh/mean_dbh)))-1
White birch	Natural	(exp(dbh$^{-1.2617}$+0.000072mean_dbh dbh/exp-0.6411(dbh/mean_dbh)))-1
Sugar maple	Natural	(exp((dbh ba)$^{-0.1885}$/exp-0.0657(dbh/mean_dbh)+0.0137ba))-1
White pine	Natural	(exp((dbh ba)$^{-0.2537}$/exp-0.2010(dbh/mean_dbh)+0.0072ba))-1
White pine	Plantation	(exp(0.00356mean_dbh/exp-1.1527(dbh/mean_dbh)))-1
Red pine	Plantation	(exp(-0.00863dbh+1.9255ba$^{-0.4378}$/exp–0.1322(dbh/mean_dbh)))-1
American beech	Natural	(exp(dbh$^{-0.2821}$/exp-0.1282(dbh/mean_dbh)+0.0284ba))-1
Yellow birch	Natural	(exp(-0.00003dbh^{2}+0.1136mean_dbh$^{0.1915}$/exp-0.3248(dbh/mean_dbh)))-1
Basswood	Natural	(exp((dbh ba)$^{-0.0234}$/exp-0.1686(dbh/mean_dbh)+0.0555ba))-1
Soft maple	Natural	(exp(ba dbh$^{-0.2875}$/exp-0.4235(dbh/mean_dbh)))-1
Balsam poplar	Natural	(exp(-4.3221dbh$^{-0.4410}$+si$^{0.2004}$/exp(dbh/mean_dbh)))-1
Red oak	Natural	(exp(dbh$^{-0.5068}$/exp-0.2577(dbh/mean_dbh)+0.000297ba^{2}))-1
Black cherry	Natural	(exp(0.0109dbh/exp(0.0429mean_dbh ba)))-1
Bitternut hickory	Natural	(exp(0.021dbh mean_dbh/exp(0.2949mean_dbh)))-1

Survival rate

Black spruce	Natural	$(1+(1/(\exp(-0.00051dbh^2+183.0/bal+26.3716dbh\_growth\_rate\ dbh))))^{-1}$
Jack pine	Natural	$(1+(1/(\exp(-0.00069dbh^2+135.3/bal+8.3767dbh\_growth\_rate\ dbh))))^{-1}$
Balsam fir	Natural	$(1+(1/(\exp(0.8038dbh+-0.0315bal+677.8dbh\_growth\_rate))))^{-1}$
White spruce	Plantation	$(1+(1/(\exp(0.2273dbh+-0.2412bal+496.7dbh\_growth\_rate))))^{-1}$
Trembling aspen	Natural	$(1+(1/(\exp(0.00952dbh^2+119.7/bal+285.6dbh\_growth\_rate^2))))^{-1}$
White birch	Natural	$(1+(1/(\exp(0.0142dbh^2+662.9dbh\_growth\_rate))))^{-1}$
Sugar maple	Natural	$(1+(1/(\exp(9.8728dbh+65.5455/bal+26.7809dbh\_growth\_rate))))^{-1}$
White pine	Natural	$(1+(1/(\exp(176.9/bal+1.0844dbh\_growth\_rate\ dbh))))^{-1}$
Red pine	Natural	$(1+(1/(\exp(0.0639dbh^2+605.3/bal+51.2761dbh\_growth\_rate^2))))^{-1}$
Red pine	Plantation	$(1+(1/(\exp(0.0168dbh^2+77.1451/bal+123.0dbh\_growth\_rate^2))))^{-1}$
American beech	Natural	$(1+(1/(\exp(0.00609dbh\ bal+430.2/bal+1.5572dbh\_growth\_rate\ bal))))^{-1}$
Balsam poplar	Natural	$(1+(1/(\exp(4.6209dbh+-0.0841bal+393.7dbh\_growth\_rate^2))))^{-1}$

Height-dbh equation

Black spruce	Natural	$32.3853((1-\exp(-0.0200dbh))^{1.0299})\ si^{0.2006}$
Jack pine	Natural	$6.0237((1-\exp(-0.0601dbh))^{0.6449})\ si^{0.3941}\ ba^{0.0719}$
Balsam fir	Natural	$(1-\exp(-0.1035dbh))\ (dbh\ ba)^{0.4373}$
White spruce	Plantation	$(27.7353ba^{0.0931})\ ((1-\exp(-0.0310dbh))^{1.5241})$
Trembling aspen	Natural	$(1-\exp(-0.1583dbh))\ ba^{0.3929}\ (si\ dbh)^{0.2676}$
White birch	Natural	$10.1815(1-\exp(-0.0677dbh))\ si^{0.2824}$
Sugar maple	Natural	$(0.8924qdbh)\ ((1-\exp(-0.0689dbh))^{1.2318})$
White pine	Natural	$(26.2624ba^{0.1295})\ ((1-\exp(-0.0168dbh))^{0.7809})$
Red pine	Natural	$(10.4580ba^{0.3511})\ ((1-\exp(-0.0395dbh))^{1.1475})$
Red pine	Plantation	$(0.6980ba)\ ((1-\exp(-0.0619dbh))^{1.8594})$
American beech	Natural	$(0.8867ba)\ ((1-\exp(-0.0647dbh))^{1.0707})$
Yellow birch	Natural	$19.8091((1-\exp(-0.00153dbh^2))^{0.3354})$
Basswood	Natural	$(1-\exp(-0.2011dbh))\ (dbh\ ba)^{0.4314}$
Ironwood/Ash/Soft maple	Natural	$(ba^{0.9439})\ ((1-\exp(-0.0401dbh))^{0.7052})$
Red oak	Natural	$24.8731((1-\exp(-0.0533dbh))^{1.1757})$

Species group density index[§]

Species group		
Black spruce		$(0.0693 prop\ ba^2)/(exp\ (0.00337 ba\ mean\_dbh))$
Jack pine		$-0.0074 prop^2\ qdbh+8.5315 ba+13.1703 prop+0.1126 prop^2$
White spruce		$((ba^2\ prop^2)^{0.4785})+(-4.83E\text{-}6 mean\_dbh\ prop^2\ ba^2)$
Aspen		$-0.0119 mean\_dbh\ prop^2+7.0235 ba+0.2940 prop^2$
White birch		$0.1929 prop\ ba+-62.982 qdbh+14.8358 prop$
Red and White pine		$-0.00695 prop^2\ mean\_dbh+0.000046 ba^2\ prop^2+19.511 prop$
Northern hardwoods		$-0.00091 mean\_dbh\ prop^2+0.00114 ba\ prop^2+4.4842 prop$
Red oak		$-0.0103 mean\_dbh\ prop^2+1.3357 ba+0.3092 prop^2$

Small-tree models

height growth rate

Black spruce	Natural	$-0.6337+((\log(bal) ht)^{-0.0617})$
Balsam fir	Natural	$(exp(0.0108 ht\ \log(bal)+\log(bal)^{-2.6830}))-1$
White spruce	Plantation	$0.2351+0.1435 ht+-0.0241 ht^2+-0.0192 bal$
White pine	Natural	$(exp(0.0704 \log(ht)^2+-0.00233 ht\ bal+0.0180 \log(bal)^2))-1$

dbh growth rate

Black spruce	Natural	$0.6944+0.0838 dbh+-0.00942 dbh^2+-0.2548 \log(bal)$
Balsam fir	Natural	$0.1683 \log(dbh)+-0.0001 bal^2$
White spruce	Plantation	$0.7164+0.0165 dbh+-0.2132 \log(bal)$
White pine	Natural	$dbh^{-3.0397}+bal^{-0.8391}$

***Legend**

dbh	Diameter at breast height (cm)
si	Site index (m)
mean_dbh	Average stand dbh (cm)
ba	Stand basal area (m^2 ha^{-1})
bal	Stand basal area of the trees greater than the subject tree (m^2 ha^{-1})
dbh_growth_rate	Annual dbh increment rate (cm yr^{-1})
ht	Stem height-1.3 (m)
qdbh	Quadratic mean diameter (cm)
prop	Species percentage based on number of trees per ha (%)
age	Age (yr)

[§]Species included in the different species group

Species group	**Species**
Black spruce	Black spruce, balsam fir and tamarack
Jack pine	Jack pine
White spruce	White spruce, white cedar and cedar all
Aspen	Trembling aspen, balsam poplar, striped maple
White birch	White birch
Red and White pine	Red pine, white pine
Northern hardwoods	Black ash, soft maple, black cherry, elm species, yellow birch, basswood, sugar maple, American beech, white ash and bitternut hickory
Red oak	Red oak and ironwood

For every tree within each sample plot included in the Quebec dataset (Table 1), dbh growth rate, survival rate, stem height and SGDI were computed using the new models derived for FVS^{Ontario} (Table 2). The predicted dependent variables for each tree were then matched with measured tree data within each sample plot to evaluate the degree to which predictions were consistent with observations. The following statistics based on residuals were computed for the stand variables (Vanclay 1994; Gadow and Hui 1999):

Statistic	Formula	Ideal value
Mean percentage of difference (MPD)	$\sum (100*(y_{obs} - y_{pred})/y_{obs})/n$	0
Model efficiency (MEF)	$\sum(y_{obs} - y_{pred})^2/\sum(y_{obs} - y_{mean(obs)})^2$	0
Variance ratio (VR)	$\sum(y_{pred} - y_{mean(pred)})^2/\sum(y_{obs} - y_{mean(obs)})^2$	1

MPD is a measure of average model bias, MEF provides a relative measure of performance, and VR measures the estimated variance as a proportion of the observed variance. These statistics were computed for each species and different conditions of stand density, site index and projection length. The database contained substantial data for different values of dbh, stand density, site index and projection length. Thus, data classes were defined to facilitate the presentation of the data and for the computation of these statistics (Table 3).

Table 3. Data class values and lower and upper limits that were used to group the observed and predicted values of individual tree data in the Quebec dataset

dbh (cm)		Projection length (yr)		Site index (m)		Stand density (trees/ha)	
Class value	**Class limits**	**Class value**	**Class limits**	**Class value**	**Class limits**	**Class value**	**Class limits**
5	0-10	0	0*	12.5	10-15	250	1-500
15	11-20	2.5	1-5	17.5	16-20	750	501-1000
25	21-30	7.5	6-10	22.5	21-25	1250	1001-1500
35	31-40	12.5	11-15	27.5	25 & greater	1750	1501-2000
45	41 & greater	17.5	16 & up			2250	2001-2500
						2750	2501-3000
						3250	3001-3500
						3750	3501-4000
						4750	4000 & greater

* Projection class 0 represents the statistics computed at the time of first measurement.

RESULTS

Mean percentage of difference (MPD)

The graphs of MPD values are included in Appendix 2. A summary can be found in Table 4 and MPD values for each variable are listed in Appendix 3.

Dbh growth rate

MPD values for dbh growth rate were computed for black spruce, jack pine, balsam fir, trembling aspen, white birch, sugar maple, white pine, American beech, yellow birch, basswood, soft maple, balsam poplar, red oak, black cherry and bitternut hickory. For all species, the majority of MPD values were between -30 and 30% (Table 4 and Appendices 2.1 and 3). Stand density had a noticeable effect on MPD of dbh growth rate for most species. For black spruce, jack pine, sugar maple, American beech and yellow birch, there was a pattern of increase in MPD in absolute value with an increase in stand density class. On the other hand, MPD in absolute value generally decreased with increase in stand density for trembling aspen and white birch. There was no clear pattern for the other species.

A pattern of increase in dbh growth rate with increase in site index was obtained for black spruce, jack pine, balsam fir, trembling aspen, white birch, yellow birch, basswood and balsam poplar stands (Lacerte et al. 2007). For all species, MPD generally increased in absolute value with site index. For instance, average MPD for jack pine stands was 12% for the 12.5 and 17.5 m site index classes and 14% for the 22.5 m site index class. Average MPD for black spruce was 17% for the 12.5 m site index class, -12% for the 17.5 m site index class, and -28% for the 22.5 and 27.5 m site index classes (Appendix 3).

There was no general pattern of change in MPD with projection length (Appendix 2). For nearly all species, MPD values were relatively close for different projection length classes, except for white birch and basswood. For white birch, MPD was relatively close for the first three projection length classes, but decreased sharply for the 17.5 year projection length class. MPD for basswood was positive for the 2.5 and 12.5 year projection length classes, but negative for the 7.5 year projection length class.

Table 4. Summary of MPD (%) values obtained for each species in the Quebec dataset

Species	Dbh growth rate (cm yr^{-1})	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Black spruce	8 (-163,180)*	0 (-7,0)	-30 (-172,54)	20 (-579,93)
Jack pine	1 (-717,81)	0 (-7,0)	-37 (-261,20)	-83 (-1189,31)
Balsam fir	-24 (-400,85)	0 (-8,0)	-1 (-190,83)	-2 (-3576,93)
Trembling aspen	1 (-1957,94)	0 (-7,0)	5 (-410,56)	-42 (-8977,58)
White birch	33 (-2521,93)	0 (-15,0)	-21 (-178,31)	27 (-3330,100)
Sugar maple	-30 (-430,83)	0 (-6,0)	13 (-83,73)	6 (-682,82)
White pine	17 (-370,83)	0 (0,0)	-14 (-122,27)	-169 (-3131,15)
Red pine	.	0 (0,0)	-17 (-62,20)	-128 (-2050,12)
American beech	-20 (-437,80)	0 (0,0)	5 (-96,67)	-5 (-1358,73)
Yellow birch	-35 (-3344,93)	.	-10 (-153,32)	5 (-2830,81)
Basswood	-58 (-796,87)	.	12 (-45,54)	14 (-315,63)
Ironwood	.	.	19 (-64,73)	-12 (-452,69)

Species	Dbh growth rate (cm yr^{-1})	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Soft maple	-41 (-339,55)	.	28 (-20,65)	-6 (-2095,41)
Balsam poplar	50 (-50,92)	0 (0,0)	.	-43 (-1102,49)
Red oak	-35 (-292,83)	.	-13 (-156,35)	-28 (-762,69)
Black cherry	100 (100,100)	.	.	24 (-360,74)
Bitternut hickory	64 (45,75)	.	.	24 (-38,44)
White ash	.	.	30 (-23,75)	0 (-928,77)

*Values within brackets are the minimum and maximum values obtained.

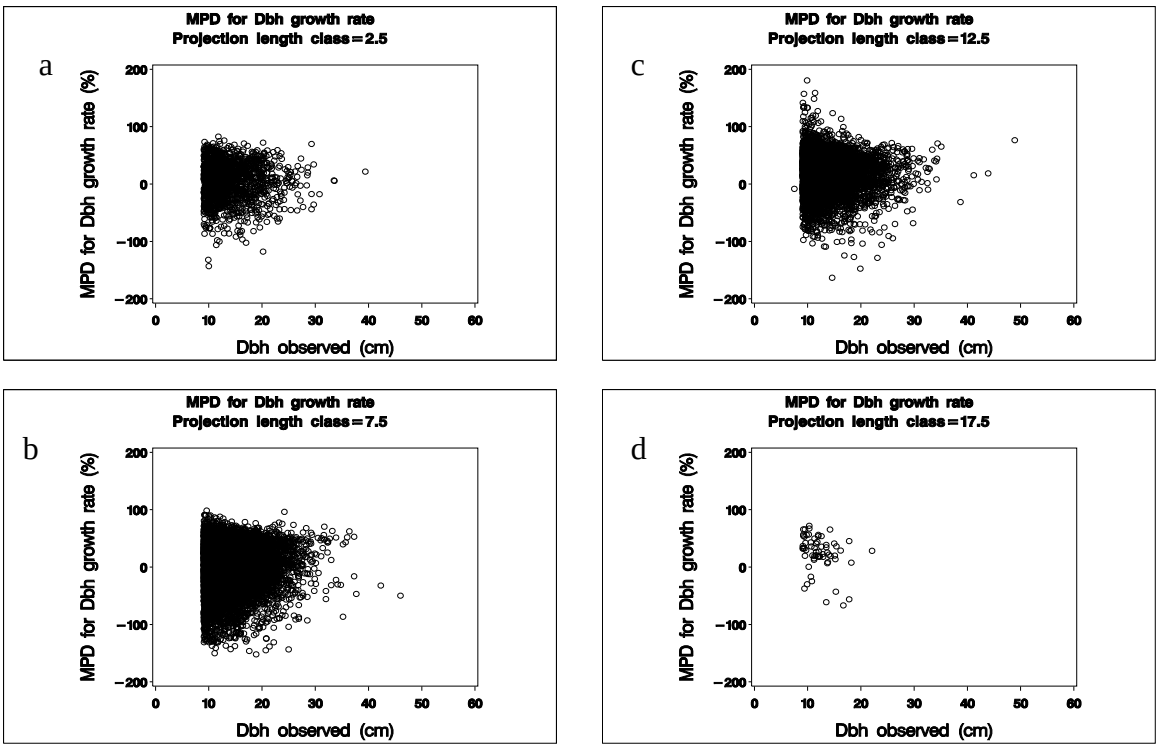

Figure 1. MPD for dbh growth rate (%) as a function of observed dbh for black spruce at different projection length classes.

The comparison of MPD for predicted vs observed dbh growth rate provided an overview of the capacity of the new model to predict dbh growth rate of small and large black spruce trees (Figure 1). MPD generally decreased with increase in dbh for the 2.5, 7.5 and 12.5 year projection length classes (Figure 1). For instance, MPD for the 7.5 year projection length class varied between -143 and 73% for the 7.5 cm dbh class, while it varied between -106 and 83% and between -18 and 22% for the 15 and 35 cm dbh classes (Figure 1b). There was no general pattern of variation in MOD for the 17.5 year projection length class (Figure 1c). However, the range of variation in dbh was relatively small compared with the other projection length classes.

Survival rate

MPD for survival rate was computed for black spruce, jack pine, balsam fir, trembling aspen, white birch, sugar maple, white pine, red pine, American beech and balsam poplar (Table 4, Appendices 2.2 and 3). For all species, the majority of MPD values varied between 0 and -10% (Table 4 and Appendices 2.2 and 3). As the majority of MPD values were close to 0%, no clear pattern was evident with stand density, site index (Appendix 3) or projection length (Appendix 2.2).

Height-dbh equation

Even though relatively large negative and positive values were obtained, the majority of MPD values for the height-dbh equation varied between -50 and 30% for all species (Table 4, Appendices 2.3 and 3). There was a pattern of decrease in MPD values in absolute value with increase in stand density for most species (Appendix 3). For instance, average MPD for black spruce in the 12.5 m site index class changed from -40% for the 250 stems ha^{-1} stand density class to -10% for the 3250 stems ha^{-1} stand density class for black spruce (Appendix 3). Comparable changes were obtained for jack

pine and white birch. The MPD values for most species changed noticeably with site index. There was a pattern of increase in MPD in absolute value with increase in site index for black spruce, jack pine and balsam fir. For trembling aspen, white birch and yellow birch, MPD in absolute value generally decreased with increase in site index. No noticeable pattern was observed for change in MPD with projection length (Appendix 2.3).

Species group density index (SGDI)

For all species, the majority of MPD values for SGDI varied between -200 and 35% and 61% of them were positive (Table 4, Appendices 2.4 and 3).

Stand density had a noticeable effect on MPD values for all the species groups, except for black spruce, balsam fir, ironwood, soft maple, balsam poplar, red oak, black cherry, bitternut hickory and white ash (Appendix 3). For instance, MPD in absolute value generally decreased with increase in stand density for jack pine, trembling aspen, white pine and red pine. For white birch, sugar maple, American beech, yellow birch and basswood, there was a general pattern of increase in MPD in absolute value with increase in stand density. Site index also had a noticeable effect on MPD for some species. For black spruce, jack pine, trembling aspen, white birch, red pine and sugar maple, MPD generally decreased in absolute value with increase in site index. For balsam fir, white pine and yellow birch, site index had the opposite effect. Variation in MPD with projection length class was minimal for all the species, except for the red and white pine species groups.

Model efficiency (MEF)

A summary of MEF values for each species in the Quebec dataset is given in Table 5 and MEF values for each variable are listed in Appendix 4. Many MEF values were around the ideal value (0) (Table 5 and Appendix 4).

Dbh growth rate

MEF for dbh growth rate was computed for all species, except for red pine, ironwood, soft maple and white ash. Despite the fact that there was a large variation in MEF for all the species, the majority of MEF values were between 0 and 3 (Table 5 and Appendix 4). Some MEF values were extremely high for white birch compared with the other species. For most species, there was no clear effect of stand density and site index on MEF for dbh growth rate (Appendix 4).

Table 5. Summary of MEF values obtained for each species in the Quebec dataset

Species	Dbh growth rate (cm yr-1)	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Black spruce	5 (1,217)*	1 (1,1)	16 (0,848)	20 (0,2291)
Jack pine	17 (0,937)	1 (1,1)	30 (0,1476)	51 (0,1475)
Balsam fir	10 (1,589)	1 (1,2)	16 (0,2638)	152 (0,30324)
Trembling aspen	21 (0,1612)	1 (1,1)	14 (0,760)	6 (0,88)
White birch	3.14E+27 (1,3.93E+29)	1 (1,2)	9 (0,308)	29 (0,1561)
Sugar maple	2 (0,17)	1 (1,1)	382 (0,22926)	5 (0,93)
White pine	7 (0,166)	.	10 (0,208)	42 (0,348)
Red pine	.	.	13 (0,48)	9 (0,38)
American beech	21 (1,1087)	.	52 (0,2960)	5 (0,82)
Yellow birch	6 (1,169)	.	24 (0,2100)	10 (0,517)
Basswood	13 (1,96)	.	18 (0,356)	10 (0,113)
Ironwood	.	.	416 (0,7405)	3 (0,46)
Soft maple	.	.	.	.
Balsam poplar	3 (1,5)	2 (1,3)	.	22 (0,237)

Species	Dbh growth rate (cm yr-1)	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Red oak	21 (1,552)	.	110 (0,3779)	51 (0,969)
Black cherry	23 (4,161)	.	.	4 (0,51)
Bitternut hickory	1986 (1986,1986)	.	.	1 (0,1)
White ash	.	.	602 (2,9221)	2 (0,12)

*Values within brackets are the minimum and maximum values obtained.

Survival rate

MEF for survival rate was calculated for black spruce, jack pine, balsam fir, trembling aspen, white birch, sugar maple and balsam poplar stands (Table 5 and Appendix 4). For most species, the majority of MEF values varied between 1 and 3 (Table 5 and Appendix 4). There was no noticeable pattern of change in MEF with change in stand density or site index (Appendix 4).

Height-dbh equation

MEF values were computed for all species, except for soft maple, balsam poplar, black cherry and bitternut hickory (Table 5 and Appendix 4). Even though there was substantial variability, the majority of MEF values were between 0 and 12 (Table 5 and Appendix 4). For all species, there was no clear pattern of change in MEF for any variable (Appendix 4). The greatest MEF values were obtained in stand density classes lower than or equal to 1250 stems ha^{-1} for jack pine, trembling aspen, sugar maple, white pine and ironwood stands. For black spruce, balsam fir, red pine, American beech, yellow birch, basswood, red oak and white ash, the highest values were in site index classes lower than 17.5 m in general.

Species group density index (SGDI)

All species had MEF values computed for SGDI, except for soft maple (Table 5, Appendix 4). For black spruce, balsam fir, trembling aspen, white birch, sugar maple, yellow birch, ironwood, balsam poplar, black cherry, bitternut hickory and white ash, no clear pattern of change in MEF with increase in stand density or site index was observed. For white pine, red pine and American beech, there was a pattern of decrease in MEF with increase in stand density. For instance, when stand density class increased from 250 to 1750 stems ha^{-1}, MEF changed from 134 to 4, in average, for white pine. There was a pattern of increase in MEF with increase in site index for jack pine and basswood, while there was a pattern of decrease for red oak. For jack pine, trembling aspen, sugar maple, white pine, red pine, American beech, yellow birch, basswood, ironwood, balsam poplar, red oak, black cherry and white ash, the majority of the highest MEF values were in the 750 stems ha^{-1} stand density class.

Variance ratio (VR)

A summary of VR can be found in Table 6 and detailed values for each variable are listed in Appendix 5. The majority of VR values were localized around the ideal value (1) (Table 6 and Appendix 5).

Dbh growth rate

VR was computed for all species, except for ironwood, soft maple, and white ash. Despite the large variation observed, the majority of VR values varied between 0 and 1. All the values computed for balsam fir, balsam poplar and black cherry were equal to 0 (Table 6 and Appendix 5). There was no noticeable effect of stand density or site index on VR for all the species.

Survival rate

All VR values for survival rate across all species of interest were equal to 0 (Table 6 and Appendix 5).

Height-dbh equations

VR for the height-dbh equations was computed for all species, except for soft maple, balsam poplar, black cherry and bitternut hickory. The majority of VR values were between 0 and 3 (Table 6 and Appendix 5). No clear effect of stand density or site index was noticeable for all species (Appendix 5).

Species group density index (SGDI)

VR for SGDI was computed for all species, except for soft maple (Table 6 and Appendix 5). The majority of VR values were between 0 and 3. There was no noticeable effect of stand density or site index on VR for most species. For jack pine, VR decreased, on average, from 10 to 0 when the stand density class increased from 250 to 2750 stems ha^{-1} (Appendix 5). A similar pattern was observed with trembling aspen: when the stand density class increased from 250 to 2750 stems ha^{-1}, VR decreased on average from 9 to 0 (Appendix 5). VR for white pine changed on average from 14 to 2 when the stand density class changed from 250 to 1750 stems ha^{-1}. There was a noticeable effect of site index on VR only for balsam fir: VR decreased from 9 to 2 on average when the site index class increased from 12.5 to 27.5 m. For all species, the majority of VR values greater than 3 were found in the stand density classes lower than 1250 stems ha^{-1}.

Table 6. Summary of VR values obtained for each species in the Quebec dataset

Species	Dbh growth rate (cm yr^{-1})	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Black spruce	0 (0,22)*	0 (0,0)	3 (0,174)	2 (0,177)
Jack pine	2 (0,68)	0 (0,0)	1 (0,11)	4 (0,24)
Balsam fir	0 (0,5)	0 (0,0)	2 (0,168)	6 (0,693)
Trembling aspen	1 (0,121)	0 (0,0)	8 (0,678)	3 (0,46)
White birch	1.16E+24 (0,1.45E+26)	0 (0,0)	2 (0,83)	4 (0,35)
Sugar maple	0 (0,1)	0 (0,0)	48 (0,5810)	1 (0,5)
White pine	1 (0,10)	.	2 (0,18)	8 (0,70)
Red pine	6 (0,59)	.	5 (0,31)	3 (0,10)
American beech	0 (0,4)	0 (0,0)	2 (0,14)	1 (0,12)
Yellow birch	2 (0,57)	.	1 (0,12)	2 (0,85)
Basswood	5 (0,73)	.	1 (0,8)	2 (0,27)
Ironwood	.	.	124 (0,2208)	2 (0,14)
Soft maple	.	.	.	.
Balsam poplar	0 (0,0)	0 (0,0)	.	2 (0,11)

Species	Dbh growth rate (cm yr^{-1})	Survival rate (proportion)	Height-dbh equation (m)	Species group density index (trees per ha)
Red oak	0 (0,2)	.	1 (0,9)	11 (0,228)
Black cherry	0 (0,0)	.	.	0 (0,1)
Bitternut hickory	2 (2,2)	.	.	1 (0,1)
White ash	.	.	59 (0,962)	1 (0,5)

*Values within brackets are the minimum and maximum values obtained.

Single-tree results for predicted and observed dbh growth

For the new calibrated dbh growth models, predictions and observations for all species were compared for different projection lengths and site indexes (Appendices 6.1 and 6.2). Differences between predicted and observed dbh growth rate varied between 0 and 1 cm in absolute value. However, differences greater than 0.3 cm in absolute value were exceptional. In fact, 75% of the differences between predictions and observations were between 0 and 0.15 cm $year^{-1}$. The greatest differences were obtained for basswood. For black spruce and jack pine, around 80% of the differences between predictions and observations were lower than 0.1 cm $year^{-1}$ in absolute value. The same proportion was about 50% for balsam fir, trembling aspen, white birch, sugar maple, American beech, yellow birch and red oak, and 37% for white pine, basswood, soft maple and balsam poplar. Only 0.01% of the differences between predictions and observations were lower than 0.1 cm yr^{-1} in absolute value for black cherry. For all species, there was an obvious pattern of overprediction for the smallest dbh classes and a pattern of underprediction for the largest dbh classes. However, these patterns were less obvious for jack pine, American beech and basswood than for the other species (Appendices 6.1 and 6.2).

There was no noticeable pattern of change in the differences between predictions and observations with projection length, except for a reduction in the amplitude of the differences between predictions and observations. For all species, about 80% of the differences between predictions and observations were less than 0.15 cm $year^{-1}$ in absolute value for the 2.5-year projection length. The same proportion remained fairly close for the 7.5 and 12.5-year projection length classes (73 and 80%). For the 17.5-year projection length class, all the differences between predictions and observations were less than 0.15 cm $year^{-1}$. However, very few data existed in the 17.5-year projection length (Appendix 6.1).

Regarding site index, there was no noticeable pattern of change in the differences between predictions and observations with increase in site index, except for a reduction in the amplitude of the differences between observations and predictions (Appendix 6.2). About 80% of the differences were less than 0.15 cm $year^{-1}$ in absolute value for the 12.5 m site index class. For the 17.5 and 22.5 m site index classes, the percentages of differences lower than 0.15 cm $year^{-1}$ were 74 and 61%, respectively (Appendix 6.2).

DISCUSSION

The validation of models using independent datasets is an essential element of model development. This study presented different statistics on the predictions of dbh growth rate, survival rate, height-dbh equation and SGDI for the new calibrated models for $FVS^{Ontario}$. The validation exercise was conducted using an independent dataset that included species from the Quebec forest inventory databank.

In general, the new calibrated models of $FVS^{Ontario}$ performed well in predicting dbh growth rate, survival rate, height-dbh equation and SGDI using Quebec's forest data. However, for most species, the MPD values indicated that dbh growth rate was underpredicted for several stand conditions, except for sugar maple, American beech, yellow birch, basswood and red oak (Table 4 and Appendices 2 and 3). Similar results were obtained in other studies that dealt with the use of FVS for different forest types (Guertin and Ramm 1996; Canavan and Ramm 2000; Lessard et al. 2001). In this study, few extreme MPD values were computed for dbh growth rate. Extreme values were obtained essentially for jack pine, trembling aspen, white birch, yellow birch and basswood. These extreme values were associated with low basal area (<10 m^2 ha^{-1}) and dbh (<15 cm). Figure 1 provides a good example of the predictive capacity of the new calibrated model for black spruce. In general, the amplitude of variation in MPD indicated a problem of prediction for small dbhs, even

though average MPD was around 0% (Table 4). Differences in stand density conditions may explain the relatively large proportion of underpredicted dbh growth rate. The Ontario data that were used to calibrate the new dbh growth models covered different ranges of stand density conditions compared with the Quebec data, which included stands with lower densities. Also, errors in the estimation of site index may be considered. As previously mentioned, the site index of the stands in the Quebec dataset was estimated using the Ontario site index equations. As the evaluation of site index requires stand age, errors in the age estimation of the stands in the Quebec dataset could result in a lack of precision in the estimated site index, resulting in errors in the prediction of dbh growth rate.

Except for a few overpredictions, MPD values for survival rate were near or equal to 0% for most species (Table 4 and Appendices 2 and 3). The results obtained in the present study compared favourably well with those by Buchman et al. (1983). The authors found a slight overestimation of the tree survival rate model. Another study by Eid and Tuhus (2001) showed both over- and under-prediction trends in mortality rates. Compared with these two studies, the species in the Quebec dataset responded very well to the new calibrated model of survival rate.

MPD for height-dbh equation suggested that the new models were well adapted for Quebec's conditions. For the majority of species, the height-dbh model as a function of dbh underpredicted stem height (Table 6 and Appendices 2 and 3). A similar pattern was observed by McClellan and Biles (2003), who evaluated the performance of FVS-SEAPROG by comparing model predictions with observed height values for the largest 40 trees per acre. Their residuals were between -7.6 and 7.9 m with an average of 0.55 m that underestimated tree height. A few extreme MPD values for the height-dbh equation were obtained only for jack pine, balsam fir and trembling aspen and were associated with lower basal area (<10 m^2 ha^{-1}) and dbh (<15 cm).

The SGDI model overpredicted SGDI for the majority of Quebec's forest types. The patterns observed in the present study were not inconsistent with the results of other studies that dealt with similar variables related to stand density. In the study on the performance of SEAPROG-FVS, McClellan and Biles (2003) found that the number of trees per acre (TPA) was generally overestimated, except for dense stands. In contrast, Canavan and Ramm (2000), testing TPA for the Lake States variant of FVS (LS-FVS) on a 10-year projection length under three levels of simulation runs, found that the TPA model underpredicted for all combined species and all levels of simulation. Several extreme MPD values were computed in this study and were associated with lower basal area (<15 m^2 ha^{-1}) and site index (<15 m).

Except for a few extreme values, MEF generally indicated that the new model of $FVS^{Ontario}$ performed well for predicting stand variables for many sample plots in the Quebec dataset. The VR values, which consist of a measure of the estimated variance relative to the observed variance, indicated that $FVS^{Ontario}$ was relatively precise. For both MEF and VR, the best results were obtained with survival rate. For dbh growth rate, height-dbh equation and SGDI, the extreme values were associated with particular conditions, such as lower stand density (<1250 stems ha^{-1}) and site index (<15 m). This may be due to the small amount of data used in the validation exercise.

CONCLUSION

The validation of newly developed models for $FVS^{Ontario}$ using independent data from Quebec produced consistent results. However, the proportion of underpredicted dbh growth rates was fairly high for all the species. Differences in the characteristics between the calibration dataset, which consisted of stand data located in Ontario, and the validation dataset could explain this pattern, along with errors in the estimation of site index. Even though the new models behaved consistently using an independent dataset, the results nevertheless pointed out that the use of models derived empirically

with statistical methods must be used with caution for forest stands with characteristics that may differ from those of the calibration dataset.

ACKNOWLEDGEMENTS

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REFERENCES

Bégin, J.; Raulier, F. 1995. Comparaison de différentes approches, modèles et tailles d'échantillons pour l'établissement de relations hauteur-diamètre locales. Can. J. For. Res. 25:1303-1312.

Buchman, R.G. 1983. Survival predictions for major Lake States tree species. USDA For. Serv., North Central For. Exp. Stn., Res. Pap. NC-233.

Buchman, R.G.; Pederson, S.P.; Walters, N.R. 1983. A tree survival model with application to species of the Great Lakes region. Can. J. For. Res. 13:601-608.

Buchman, R.G. 1985. Performance of a tree survival model on national forests. North. J. Appl. For. 2:114-116.

Canavan, S.J.; Ramm, C.W. 2000. Accuracy and precision of 10 year predictions for Forest Vegetation Simulator - Lake States. North. J. Appl. For. 17(2):62-70.

Carmean, W.H. 1996. Site-quality evaluation, site-quality maintenance, and site-specific management for forest land in northwest Ontario. Ont. Minist. Nat. Resour., NWST, Thunder Bay, Ontario, Tech. Rep. TR-105.

Eid, T.; Tuhus, E. 2001. Models for individual tree mortality in Norway. For. Ecol. Manag. 154:69-84.

Farnden, C. 1997. Calibration and use of FVS for simulating stand dynamics of multi-storied wet-belt white spruce/subalpine fir stands near Prince George, BC. McGregor Model Forest Association, Prince George, BC, Canada.

Gadow, K.V.; Hui, G. 1999. Modelling forest development. Kluwer Academic Publishers, Boston.

Guertin, P.J.; Ramm, C.W. 1996. Testing Lake States TWIGS: five-year growth projections for upland hardwoods in northern Lower Michigan. North. J. Appl. For. 13:182-188.

Holdaway, M.R.; Brand, G.J. 1983. An evaluation of the STEMS tree growth projection system. USDA For. Serv., North Central For. Exp. Stn., Res. Pap. NC-234.

Holdaway, M.R.; Brand, G.J. 1986. An evaluation of Lake States STEMS85. USDA For. Serv., North Central For. Exp. Stn., Res. Pap. NC-269.

Lacerte, V.; Larocque, G.R.; Woods, M; Parton, W.J. 2007. Forest Vegetation Simulator model calibration for Ontario ($FVS^{Ontario}$). Project number 130-107. Nat. Resour. Can., Can. For. Serv., Laurentian For. Cent., Information Report LAU-X-

Lessard, V.C.; McRoberts, R.E.; Holdaway, M.R. 2001. Diameter growth models using Minnesota Forest Inventory and Analysis data. For. Sci. 47:301-310.

McClellan, M.H.; Biles, F.E. 2003. Performance of the SEAPROG prognosis variant of the forest vegetation simulator. USDA For. Serv., Pacific Northwest Res. Stn., Res. Pap. PNW-RP-555.

Monserud, R. A.; Sterba, H. 1999. Modeling individual tree mortality for Austrian forest species. For. Ecol. Manag. 113:109-123.

Pothier, D.; Savard, F. 1998. Actualisation des tables de production pour les principales espèces forestières du Quebec. Gouvernement du Québec, ministère des Ressources naturelles du Québec, Direction des inventaires forestiers.

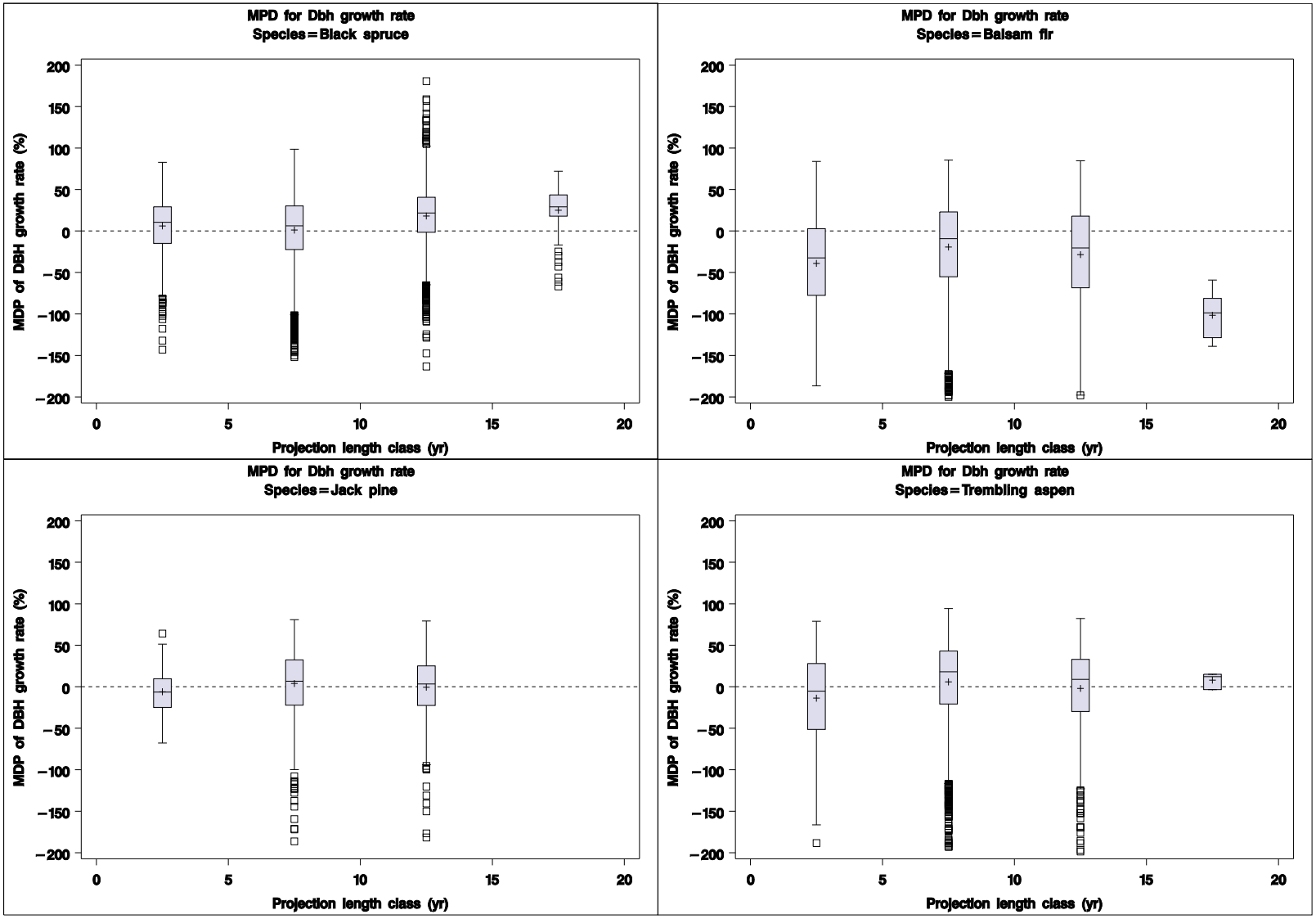
SAS Institute Inc. 2001. Commercial Computer Software (release 8.02). Cary, NC, USA.

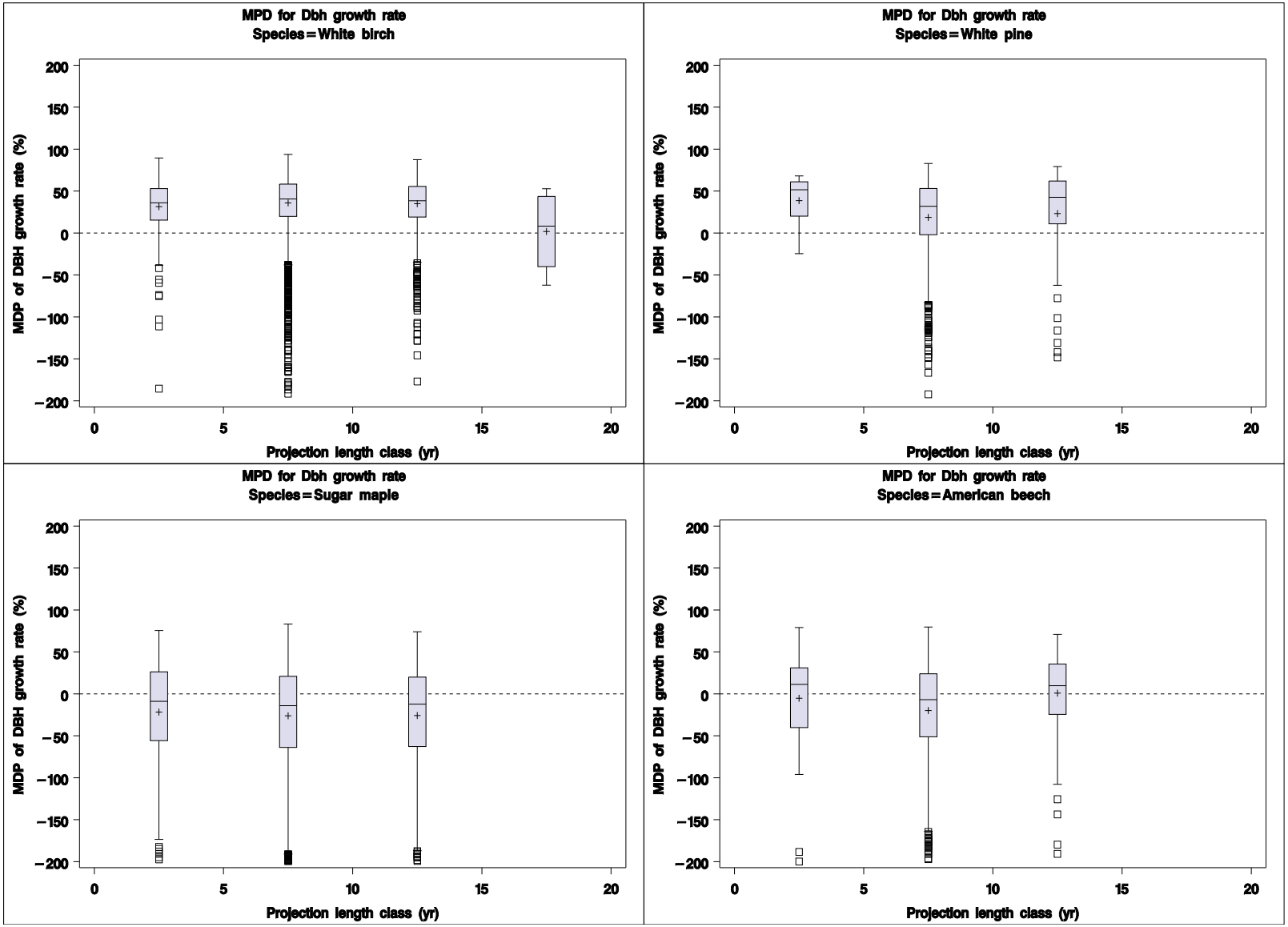
Vanclay, J.K. 1994. Modelling forest growth and yield: applications to mixed tropical forests. CAB International, Wallingford, UK.

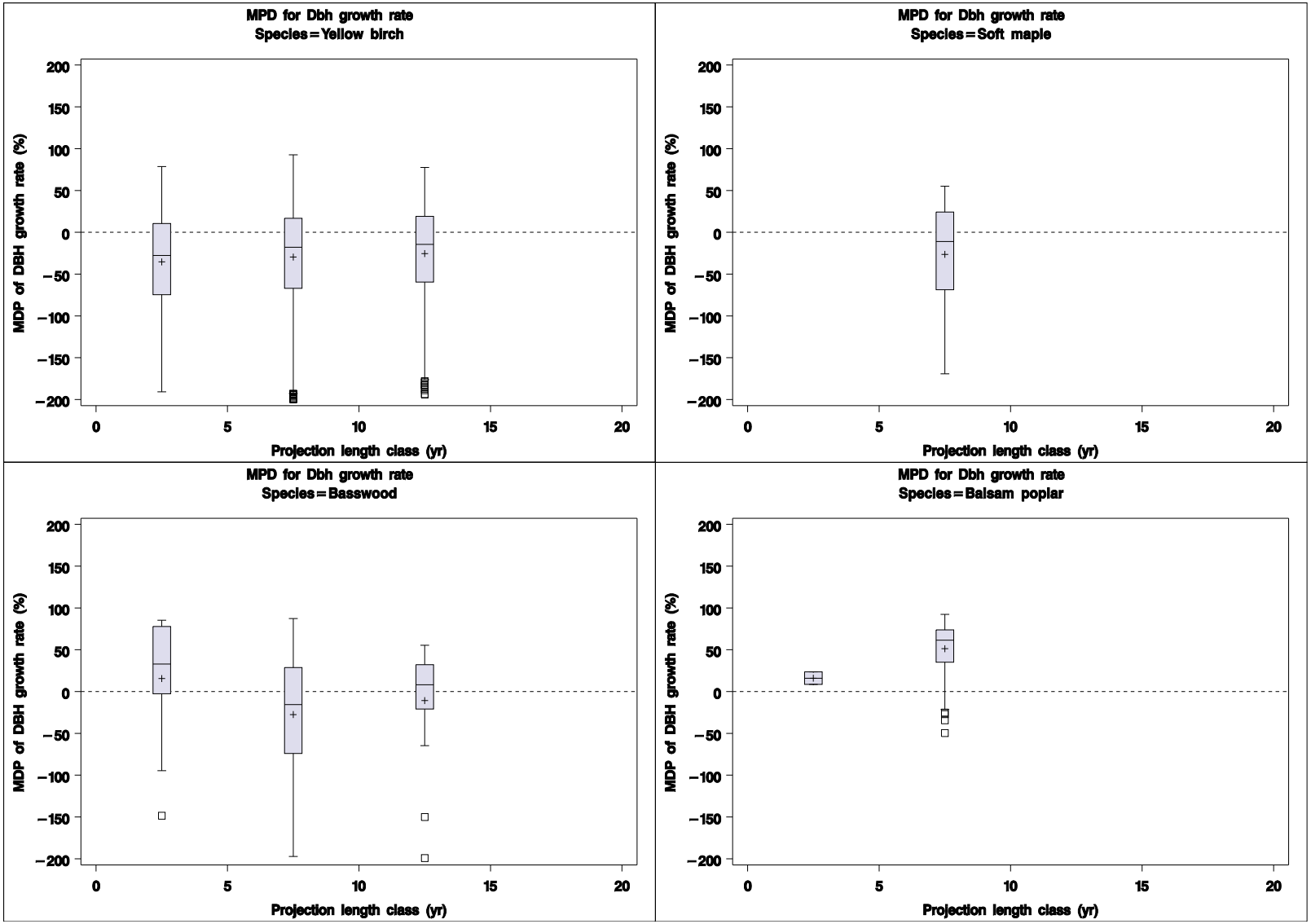
Appendix 1: SAS procedure used to estimate top height of sample plots in the Quebec dataset. The equation developed by Bégin and Raulier (1996) was used.

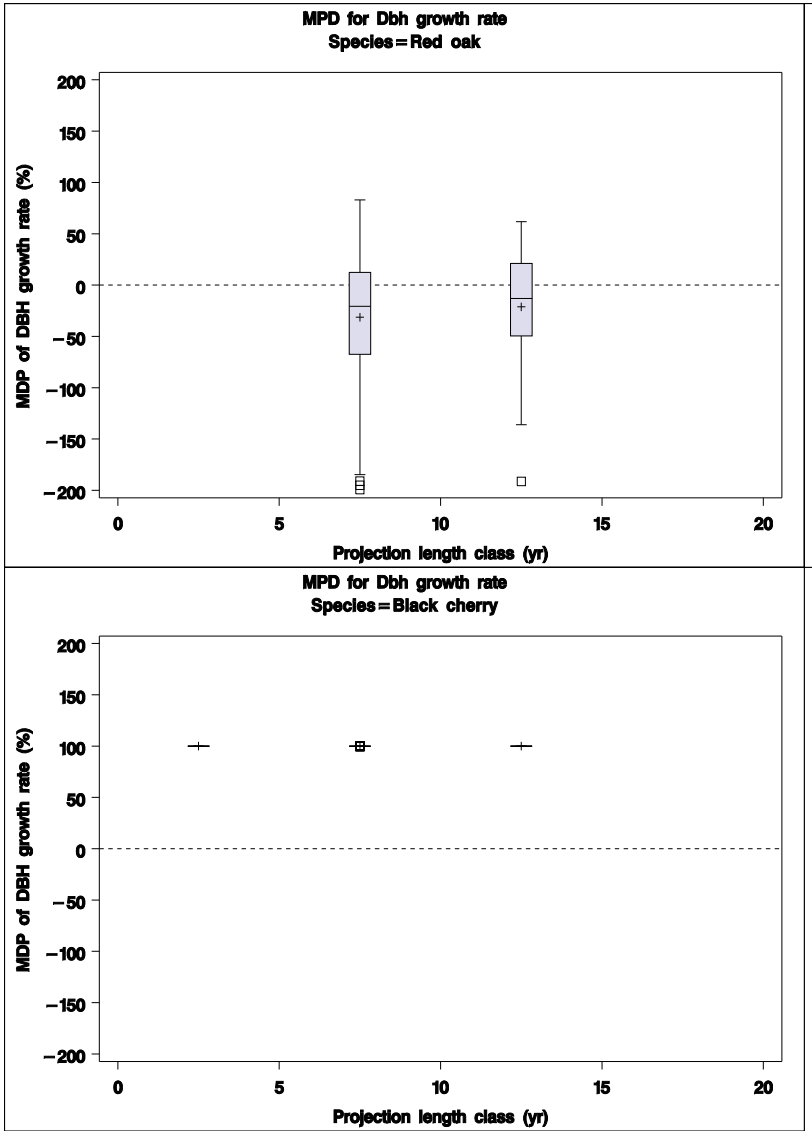
```
proc model data=HAUTEUR2;
BY ESSENCE;
  TITLE1 "HAUTEUR";
  ID IDPEP NOARBRE MEAN_DBH DHPCM MEAN_DBH ESSENCE MEAN_H;
     parms  B2=0 TO 20 BY 0.1;
           HT=1.3+(DHPCM/((MEAN_DBH/(MEAN_H-1.3))+(B2*(DHPCM-MEAN_DBH)) ) );
     fit HT START=(B2 0)/ CORRS OUT=RESULTS_HAUT
 CONVERGE=0.000001 MAXITER=1000 PRL=WALD OUTEST=TEST.HAUT OUTALL;
          ODS OUTPUT ParameterEstimates=TEST.ParameterEstimatesHT;
          ODS OUTPUT ResidSummary=TEST.ResidSummaryHT;
   run;
quit;
```

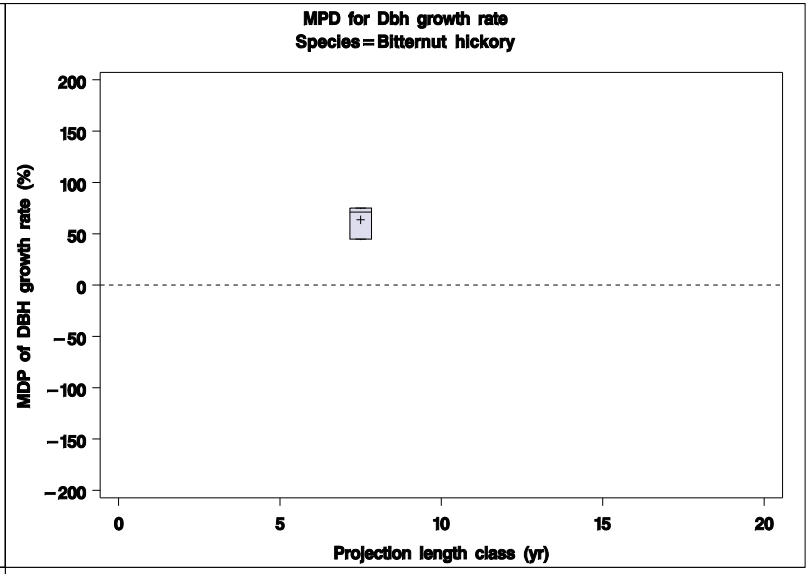
Appendix 2.1: Boxplots of MPD values of the dbh growth rate models for different species at different projection length classes.




MPD for Dbh growth rate
Species=White birch
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=White pine
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=Sugar maple
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=American beech
MDP of DBH growth rate (%)
Projection length class (yr)

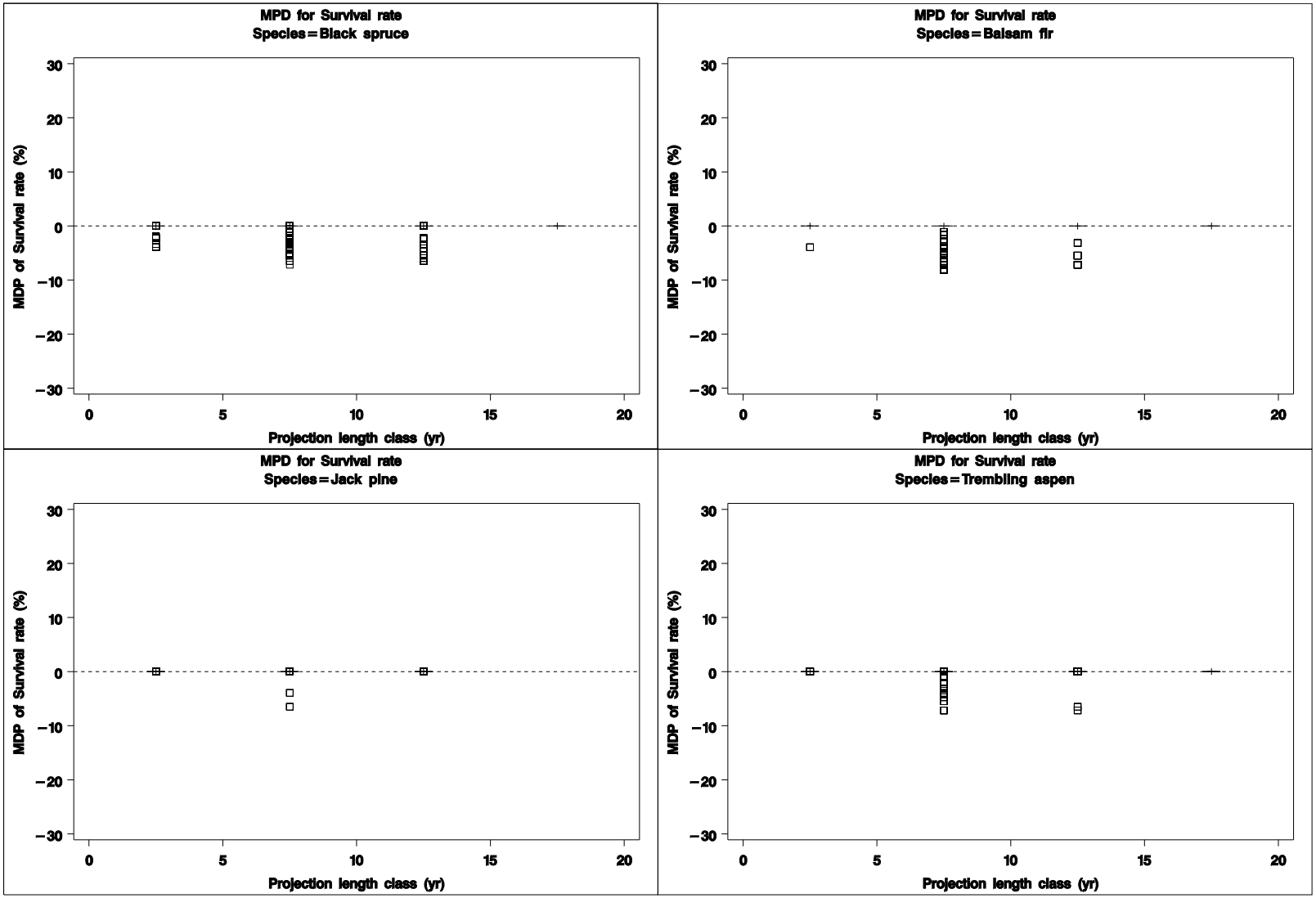

MPD for Dbh growth rate
Species=Yellow birch
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=Soft maple
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=Basswood
MDP of DBH growth rate (%)
Projection length class (yr)
MPD for Dbh growth rate
Species=Balsam poplar
MDP of DBH growth rate (%)
Projection length class (yr)

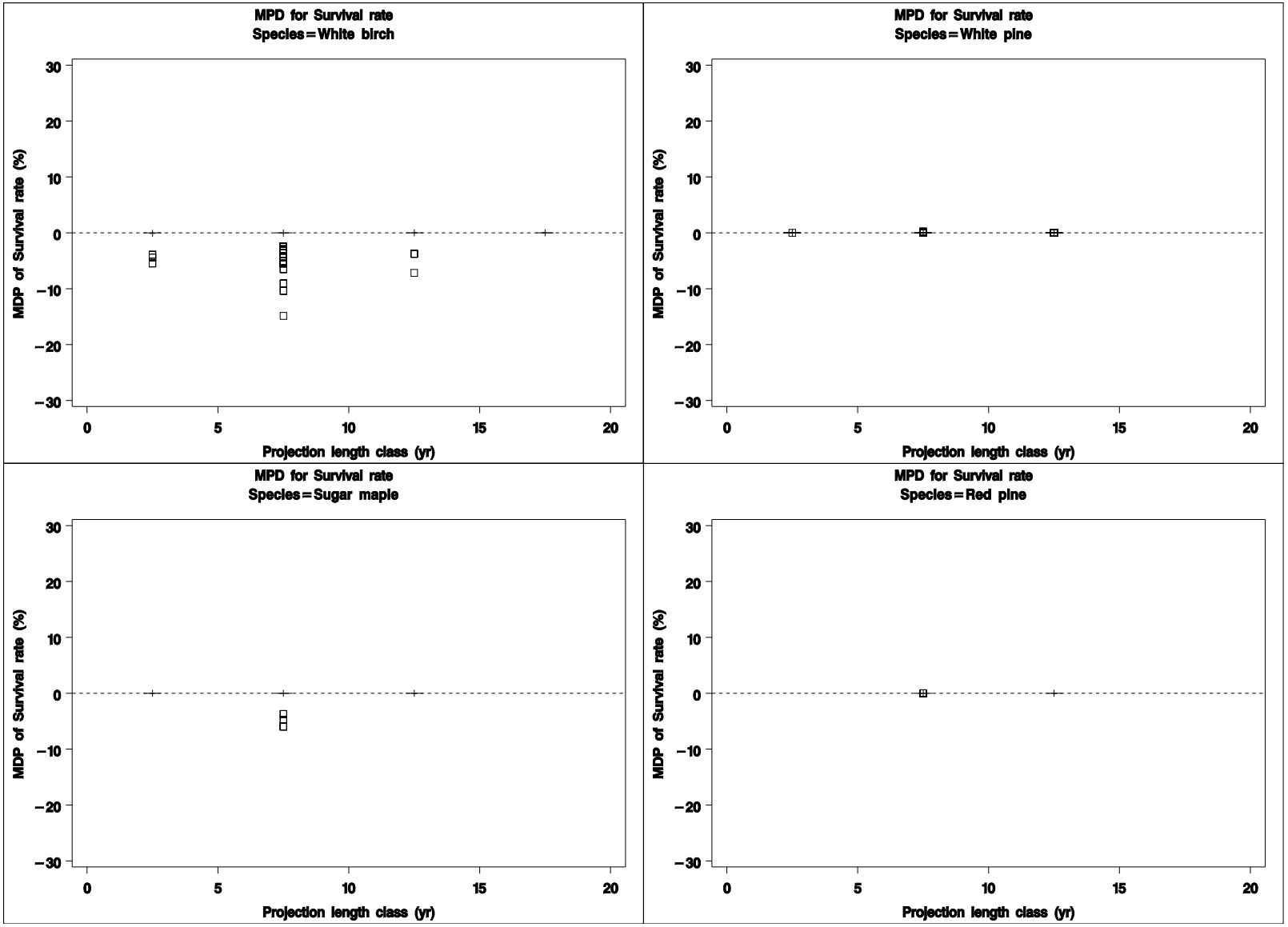

MPD for Dbh growth rate
Species = Red oak
MDP of DBH growth rate (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

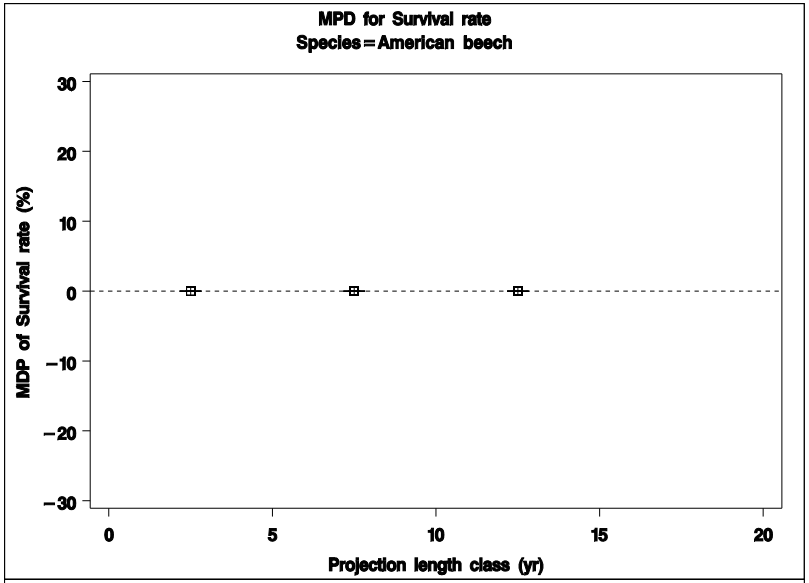

MPD for Dbh growth rate
Species = Bitternut hickory
MDP of DBH growth rate (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

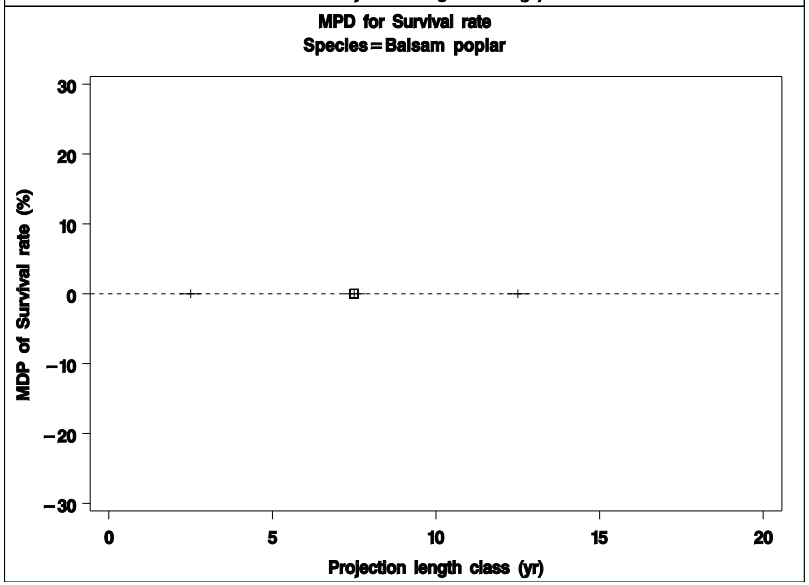
MPD for Dbh growth rate
Species = Black cherry
MDP of DBH growth rate (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

Appendix 2.2: Average MPD values of the survival rate models for different species at different projection length classes

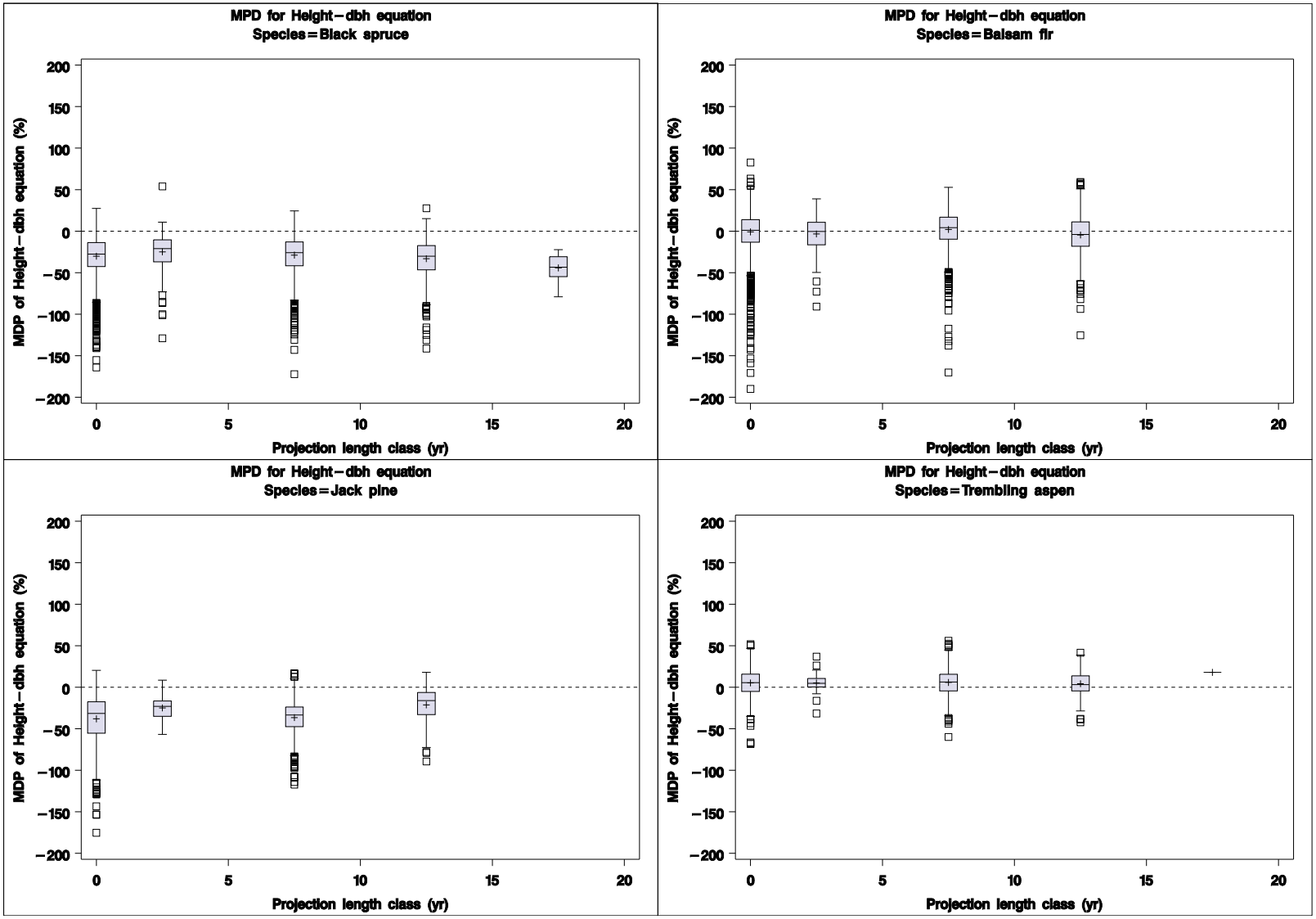


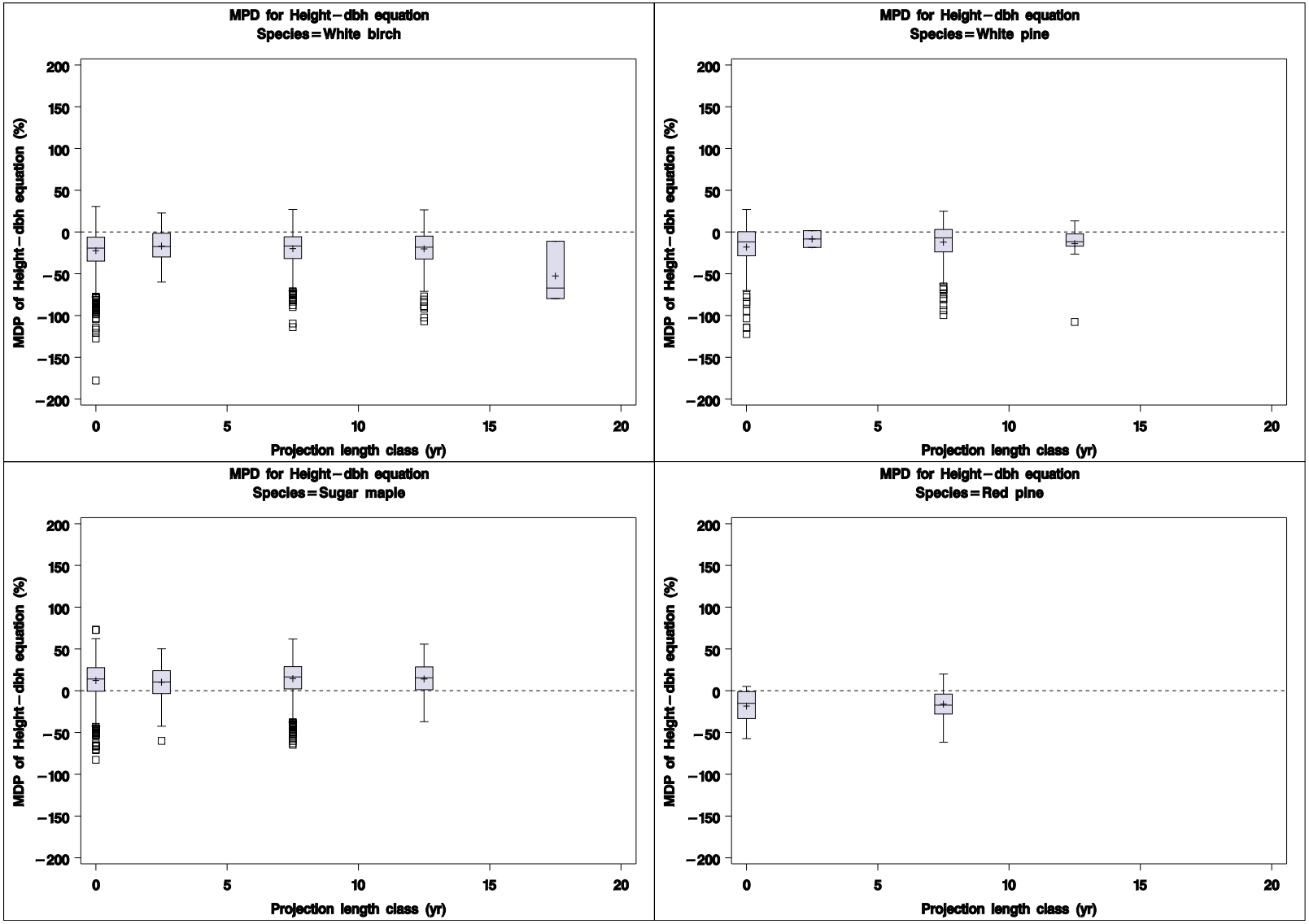

MPD for Survival rate
Species=White birch
MDP of Survival rate (%)
Projection length class (yr)
MPD for Survival rate
Species=White pine
MDP of Survival rate (%)
Projection length class (yr)
MPD for Survival rate
Species=Sugar maple
MDP of Survival rate (%)
Projection length class (yr)
MPD for Survival rate
Species=Red pine
MDP of Survival rate (%)
Projection length class (yr)

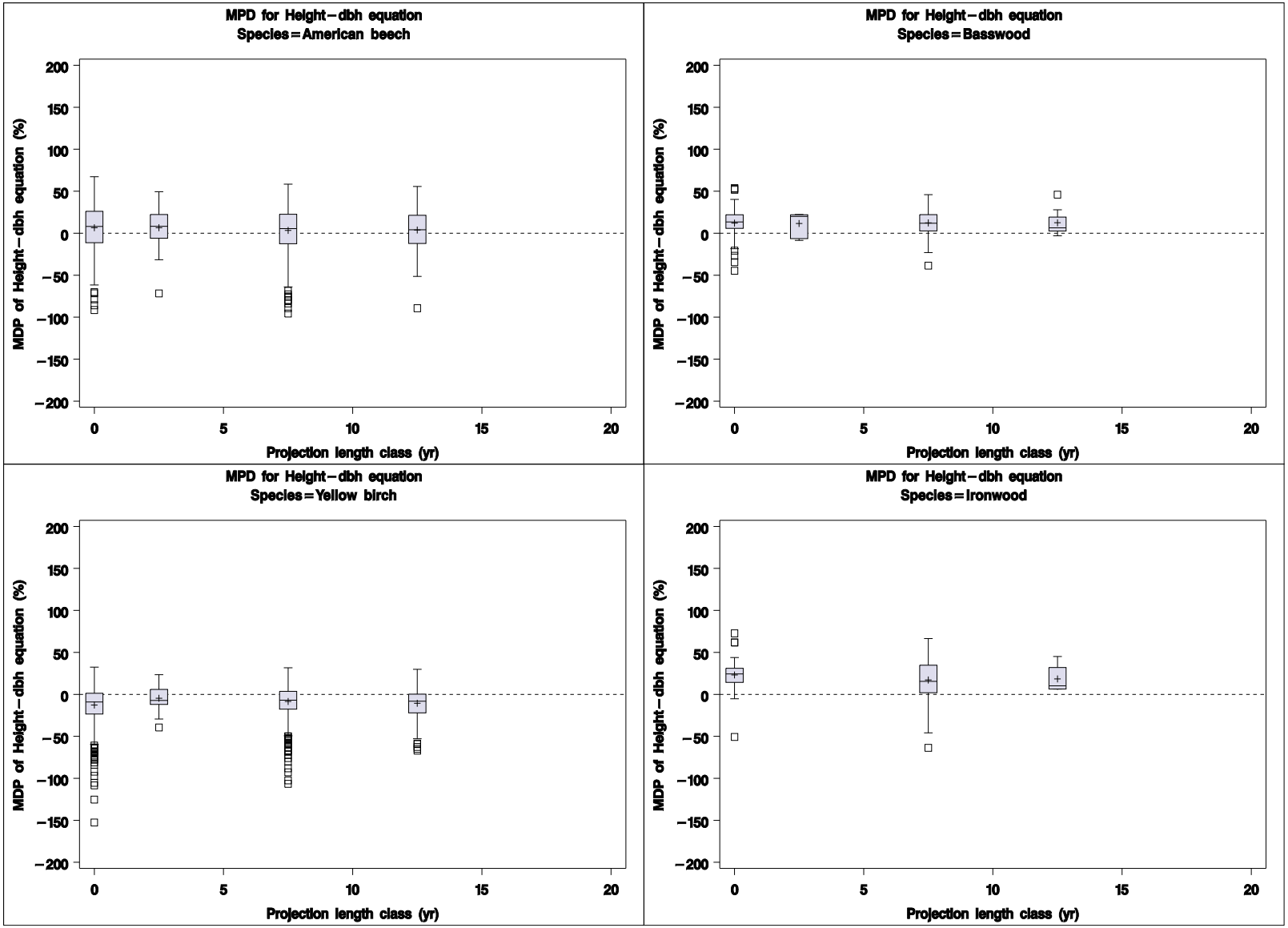

MPD for Survival rate
Species=American beech
MDP of Survival rate (%)
30
20
10
0
−10
−20
−30
0
5
10
15
20
Projection length class (yr)

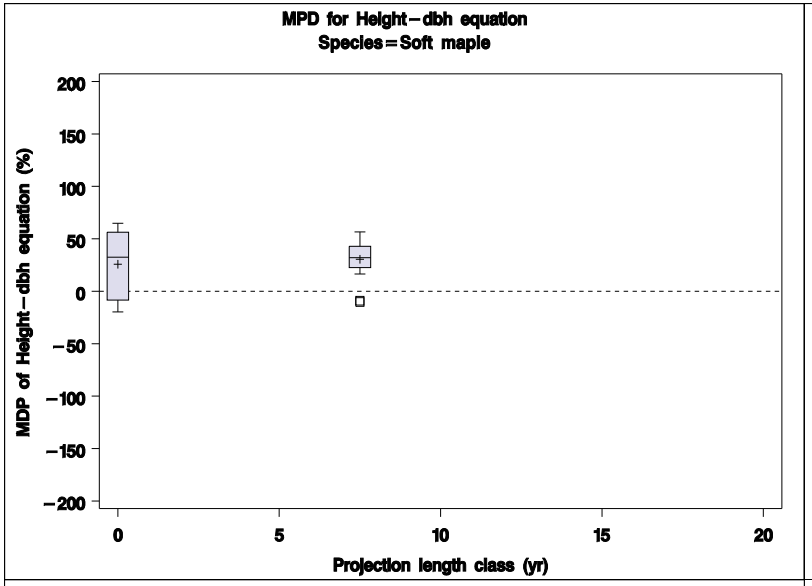

MPD for Survival rate
Species=Balsam poplar
MDP of Survival rate (%)
30
20
10
0
−10
−20
−30
0
5
10
15
20
Projection length class (yr)

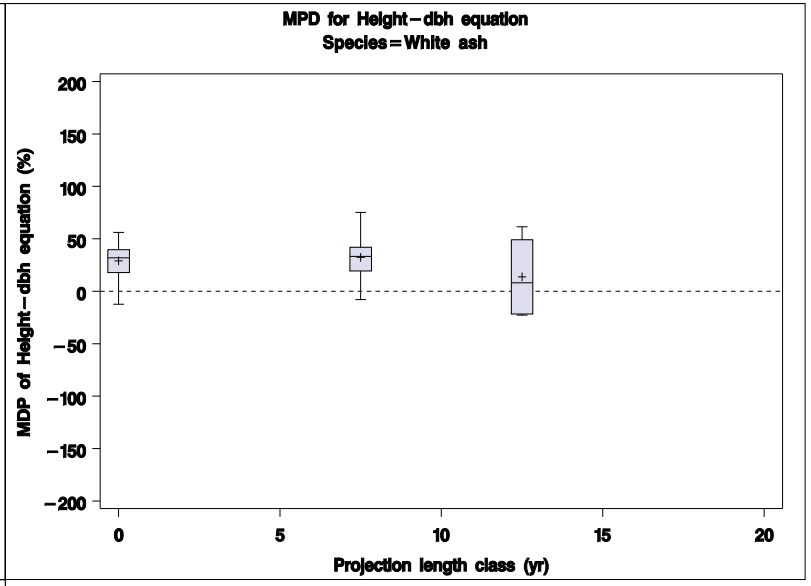
Appendix 2.3: Boxplots of MPD values of the height-dbh models for different species at different projection length classes

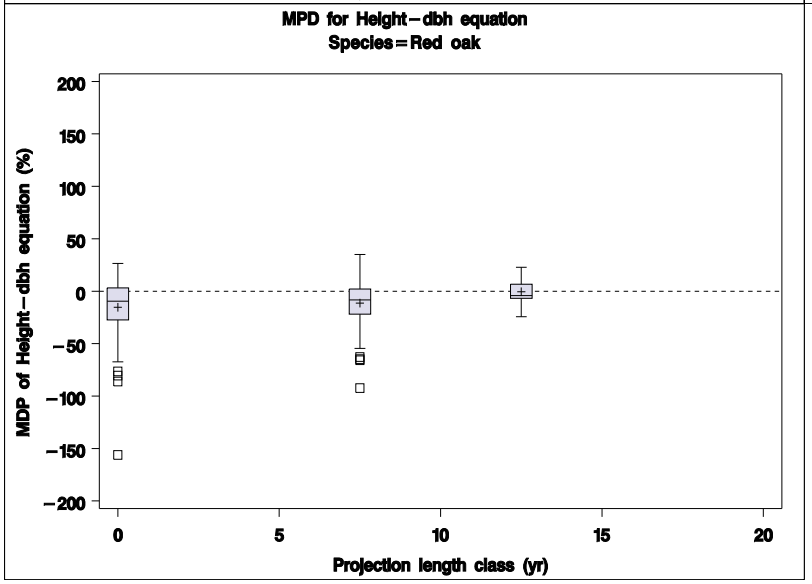



MPD for Height−dbh equation
Species=White birch
MDP of Height−dbh equation (%)
Projection length class (yr)
MPD for Height−dbh equation
Species=White pine
MDP of Height−dbh equation (%)
Projection length class (yr)
MPD for Height−dbh equation
Species=Sugar maple
MDP of Height−dbh equation (%)
Projection length class (yr)
MPD for Height−dbh equation
Species=Red pine
MDP of Height−dbh equation (%)
Projection length class (yr)

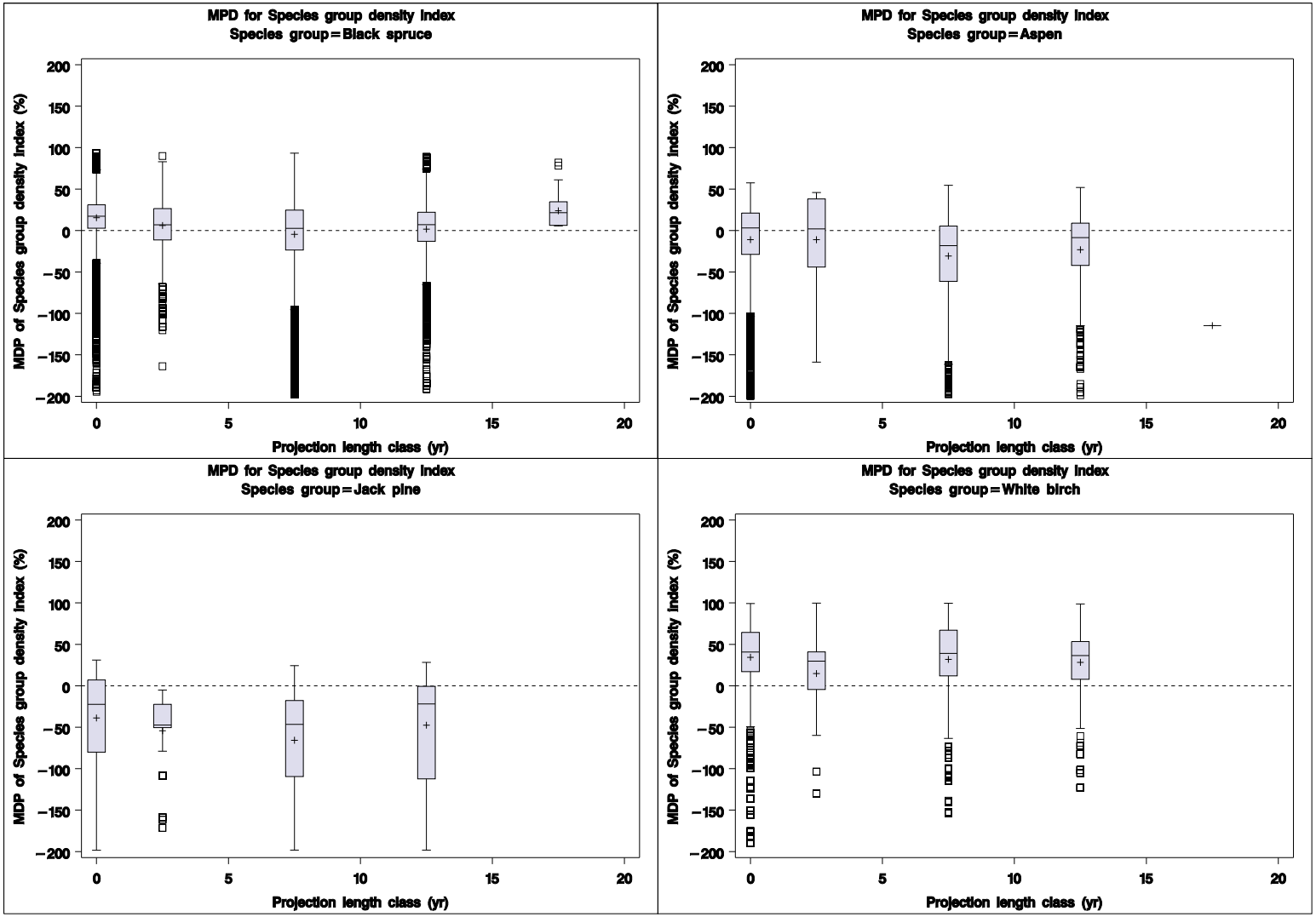

MPD for Height−dbh equation
Species=American beech
MPD for Height−dbh equation
Species=Basswood
MPD for Height−dbh equation
Species=Yellow birch
MPD for Height−dbh equation
Species=Ironwood
MDP of Height−dbh equation (%)
Projection length class (yr)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20

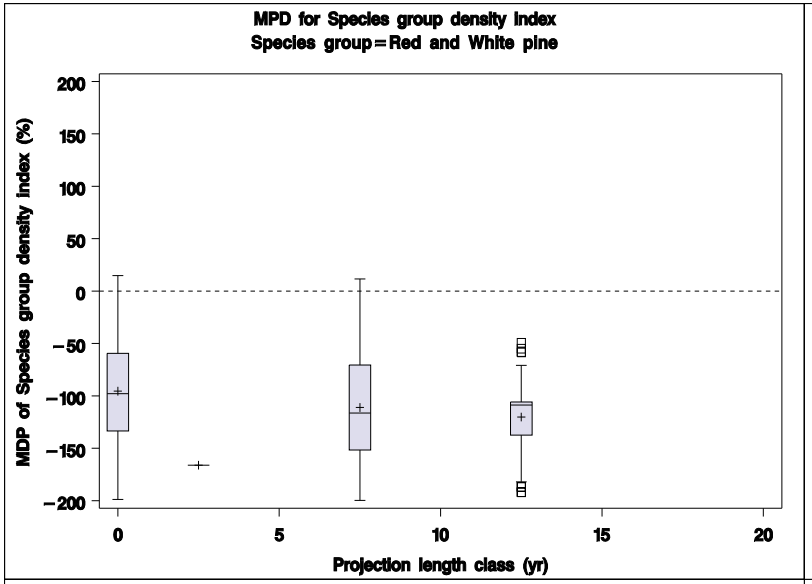

MPD for Height−dbh equation
Species=Soft maple
MDP of Height−dbh equation (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

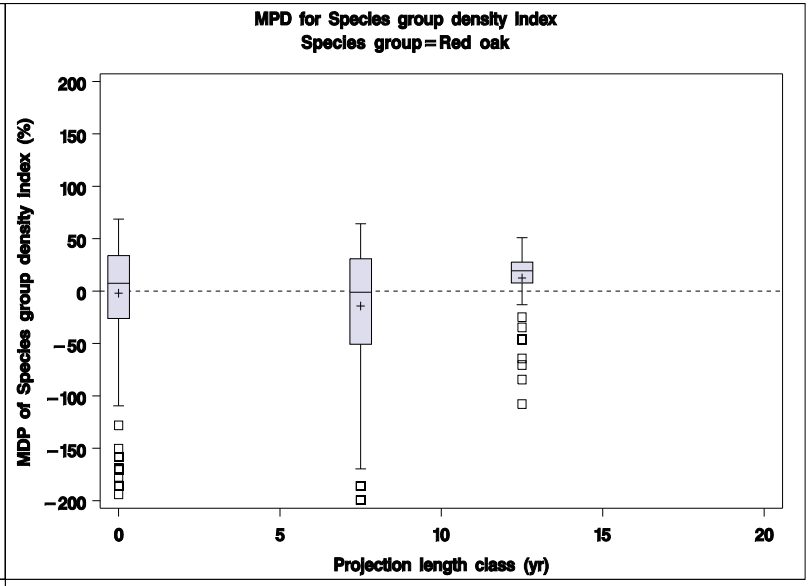

MPD for Height−dbh equation
Species=White ash
MDP of Height−dbh equation (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

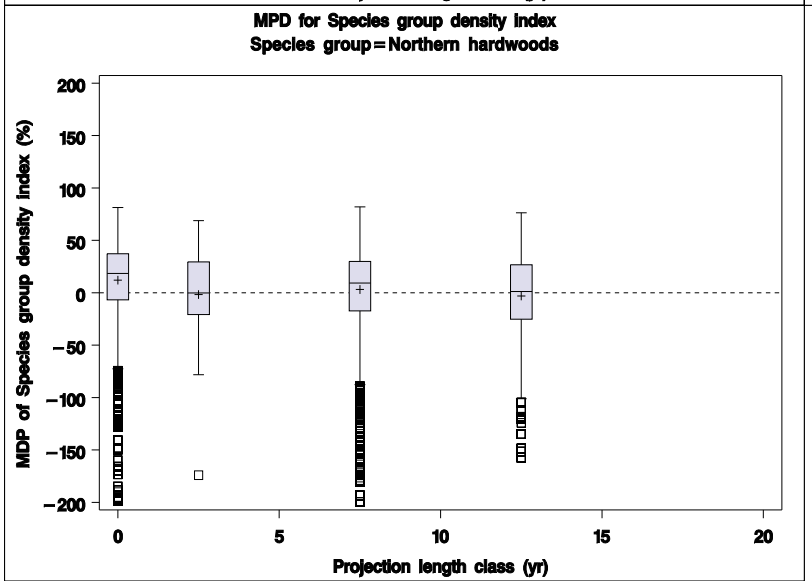

MPD for Height−dbh equation
Species=Red oak
MDP of Height−dbh equation (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

Appendix 2.4: Boxplots of MPD values of the species group density index models for different species at different projection length classes




MPD for Species group density index
Species group=Red and White pine
MDP of Species group density index (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)


MPD for Species group density index
Species group=Red oak
MDP of Species group density index (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)


MPD for Species group density index
Species group=Northern hardwoods
MDP of Species group density index (%)
200
150
100
50
0
−50
−100
−150
−200
0
5
10
15
20
Projection length class (yr)

Appendix 3: Average MPD values obtained for the dbh growth rate, survival rate, height-dbh and species group density index models for different species under different combinations of stand density and site index classes

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Black spruce	**250**	5	-22	19	.	0	0	0	.	-40	-47	-48	-57	53	23	8	-45
	750	10	-10	-24	-26	0	0	0	0	-33	-35	-45	-46	25	7	-15	-55
	1250	13	-9	-36	.	0	0	0	.	-26	-30	-31	.	17	9	-7	.
	1750	15	-6	-15	.	0	0	0	.	-21	-25	-15	.	20	12	3	10
	2250	18	-3	5	.	0	0	0	.	-21	-18	.	.	25	22	11	.
	2750	19	10	.	.	0	0	.	.	-15	-22	.	.	28	25	.	.
	3250	25	47	.	.	0	0	.	.	-10	-47	.	.	32	-39	.	.
	4750	.	.	.	.	.	.	.	.	.	.	.	.	54	.	.	.
Jack pine	**250**	20	38	31	.	0	0	0	.	-47	-62	-51	.	-306	-308	-291	.
	750	14	10	7	.	0	0	0	.	-36	-40	-45	.	-142	-137	-105	-160
	1250	-20	-2	3	.	0	0	0	.	-26	-28	-33	.	-61	-49	-43	.
	1750	-7	-8	-20	.	0	0	0	.	-15	-18	-26	.	-10	-7	-23	.
	2250	-2	-16	-22	.	0	0	0	.	-15	-19	-16	.	-4	13	7	.
	2750	-20	-18	.	.	0	0	.	.	.	-13	.	.	-16	5	.	.
	3250	-25	.	.	.	0	.	.	.	-10	.	.	.	1	.	.	.
Balsam fir	**250**	-37	-6	17	-21	0	0	0	0	14	17	19	6	12	-6	-32	-55
	750	-31	-7	-10	-9	0	0	0	0	-2	7	12	16	1	-18	-26	-37
	1250	-36	-11	-16	-9	0	0	0	0	-10	2	5	-3	8	-6	-10	-14
	1750	-39	-16	-27	-15	0	0	0	0	-11	-2	3	1	16	5	9	8
	2250	-40	-24	-26	.	0	0	0	.	-14	-7	-5	.	22	21	23	.
	2750	-39	-28	.	.	0	0	.	.	-20	-4	.	.	33	31	.	.
	3250	-39	-20	.	.	0	-1	.	.	-8	-5	.	.	34	23	.	.
	3750	-19	.	.	.	0	.	.	.	.	.	.	.	32	.	.	.

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
	4750	.	.	.	.	.	.	.	.	-28	.	.	.	54	.	.	.
Trembling aspen	**250**	-57	-11	-11	16	0	0	0	0	25	22	16	20	-158	-136	-118	-105
	750	-13	3	15	14	0	0	0	0	7	7	8	8	-68	-52	-61	-54
	1250	6	-8	10	19	0	0	0	0	-9	1	1	4	-45	-28	-14	-14
	1750	15	-14	10	29	0	0	0	0	-3	-4	-3	-9	-52	-8	12	0
	2250	-5	8	9	.	0	0	0	.	-33	-12	-5	-5	-31	29	21	38
	2750	.	-4	.	.	.	0	.	.	-20	-18	.	.	34	33	.	.
	3250	-27	.	.	.	0	.	.	.	.	.	.	.	7	.	.	.
White birch	**250**	43	45	20	-67	0	0	0	0	-34	-26	-30	-49	-59	26	-17	.
	750	36	37	44	43	0	0	0	0	-27	-21	-18	-45	12	33	37	.
	1250	31	30	34	43	0	0	0	0	-23	-14	-12	-20	28	39	50	.
	1750	29	32	31	17	0	0	0	.	-21	-12	-14	-9	48	47	49	94
	2250	29	33	28	.	0	0	0	.	-14	-12	-7	.	81	75	70	.
	2750	34	16	.	.	0	0	.	.	-16	-17	.	.	.	.	.	.
	3250	.	-68	.	.	.	0	.	.	.	-37	.	.	.	75	.	.
	3750	.	.	.	.	.	.	.	.	-14	.	.	.	.	.	.	.
Sugar maple	**250**	-24	-17	-14	6	0	0	0	0	-5	0	6	6	-35	-29	-24	-19
	750	-46	-28	-21	-27	0	0	0	0	11	16	22	26	10	12	13	8
	1250	-78	-42	-27	-54	0	0	0	0	25	32	38	38	46	41	40	40
	1750	-87	-39	-32	.	0	0	0	.	29	36	34	.	59	57	55	.
	2250	.	-30	.	.	.	0	.	.	.	.	.	.	.	71	.	.
	2750	.	-67	.	.	.	0	.	.	.	.	.	.	.	82	.	.
White pine	**250**	-5	0	37	23	0	0	0	0	-15	-16	-19	-16	-356	-276	-295	-453
	750	11	22	29	20	0	0	0	0	-24	-15	-5	-3	-155	-162	-184	-214
	1250	11	22	31	.	0	0	0	.	-24	-22	2	.	-100	-88	-102	-115
	1750	.	6	-5	.	.	0	0	.	-11	-4	4	-13	-37	-46	-12	7

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
	2250	.	.	76	.	.	.	0	.	.	.	.	.	.	.	4	.
Red pine	**250**	.	.	-150	.	.	.	0	.	.	-6	-19	.	-343	-246	-264	.
	750	-35	-28	8	79	0	0	0	0	-17	-12	-3	-24	-266	-148	-112	-123
	1250	-159	-3	-111	.	0	0	0	.	-17	-35	20	.	-55	-56	-96	.
	1750	.	27	.	.	.	0	.	.	-31	-30	.	.	2	-17	.	.
	2250	.	55	.	.	.	0	.	.	.	.	.	.	.	12	.	.
American beech	**250**	-3	-9	-54	.	0	0	0	.	3	12	20	4	-63	-34	-21	-8
	750	-25	-16	-10	-26	0	0	0	0	-5	1	-3	3	-8	6	6	10
	1250	-17	-31	-66	.	0	0	0	.	-26	11	20	.	33	42	39	44
	1750	.	-4	-80	.	.	0	0	.	.	.	.	.	51	59	68	.
Yellow birch	**250**	-17	-15	-33	39	.	.	.	.	-18	-10	-7	-11	-36	-31	-20	-34
	750	-33	-38	-21	-4	.	.	.	.	-15	-7	0	-10	7	14	17	12
	1250	-92	-47	-18	-4	.	.	.	.	-24	-8	1	-1	30	39	43	42
	1750	-13	-60	-36	.	.	.	.	.	-18	-11	-5	.	60	57	66	.
	2250	-51	-60	.	.	.	.	.	.	-31	-15	.	.	72	76	.	.
Basswood	**250**	-245	-15	-139	.	.	.	.	.	31	22	18	-6	-45	-27	-17	-14
	750	-66	-56	-39	-6	.	.	.	.	0	9	16	19	15	20	15	6
	1250	-18	-53	-6	.	.	.	.	.	-3	4	2	23	48	51	46	50
	1750	.	31	-16	.	.	.	.	.	.	.	4	.	.	52	61	.
Ironwood	**250**	.	.	.	.	.	.	.	.	40	33	44	.	-40	19	-19	-30
	750	.	.	.	.	.	.	.	.	24	18	20	.	9	-8	2	-4
	1250	.	.	.	.	.	.	.	.	.	9	15	.	47	30	33	.
	1750	.	.	.	.	.	.	.	.	.	-16	.	.	.	13	.	.
Soft maple	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	-334	-1	.
	750	.	.	.	.	.	.	.	.	.	47	.	.	.	9	.	.

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Balsam poplar	**250**	.	27	.	.	.	0	.	.	.	.	.	.	.	-45	-62	.
	750	91	64	57	.	0	0	0	.	.	.	.	.	-227	-45	-33	.
	1250	.	46	47	.	.	0	0	.	.	.	.	.	10	-28	-77	-9
	1750	.	63	-50	49	.	0	0	0	.	.	.	.	-104	34	6	10
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	48	.	.
	2750	.	1	.	.	.	0	.	.	.	.	.	.	.	48	.	.
Red oak	**250**	-9	-27	.	.	.	.	.	.	-29	-8	.	-4	-164	-207	8	-54
	750	-64	-23	-4	-91	.	.	.	.	-25	-8	3	-9	-46	-11	-25	-20
	1250	-41	-54	-30	24	.	.	.	.	-17	-7	13	21	29	18	2	38
	1750	-23	1	-51	.	.	.	.	.	-41	4	.	.	47	59	-28	.
Black cherry	**250**	100	100	.	.	.	.	.	.	.	.	.	.	-15	-40	-7	.
	750	100	100	100	.	.	.	.	.	.	.	.	.	-8	22	32	25
	1250	.	100	100	.	.	.	.	.	.	.	.	.	58	48	36	.
	1750	.	100	100	.	.	.	.	.	.	.	.	.	.	54	71	.
Bitternut hickory	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-11	.
	750	.	45	73	.	.	.	.	.	.	.	.	.	.	29	38	.
White ash	**250**	.	.	.	.	.	.	.	.	45	39	33	.	-38	-24	-12	.
	750	.	.	.	.	.	.	.	.	35	31	35	.	4	15	10	33
	1250	.	.	.	.	.	.	.	.	.	7	35	.	59	45	41	44
	1750	.	.	.	.	.	.	.	.	.	.	.	.	.	33	69	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	77	.	.

Appendix 4: Average MEF values obtained for the dbh growth rate, survival rate, height-dbh and species group density index models for different species under different combinations of stand density and site index classes.

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Black spruce	**250**	2	3	109	.	1	.	.	.	7	6	3	59	11	3	1	3
	750	10	2	2	1	1	1	.	.	28	9	4	15	3	1	3	11
	1250	6	1	1	.	1	1	1	.	5	3	14	.	4	2	5	.
	1750	3	1	1	.	1	1	.	.	7	5	283	.	4	0	2	.
	2250	4	1	14	.	1	1	.	.	5	56	.	.	8	0	0	.
	2750	3	2	.	.	.	1	.	.	9	13	.	.	344	2	.	.
	3250	3	.	.	.	.	.	.	.	87	.	.	.	56	.	.	.
	4750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jack pine	**250**	2	7	2	.	.	.	.	.	36	21	10	.	62	126	55	.
	750	2	97	36	.	.	.	1	.	11	8	6	.	30	143	107	.
	1250	6	3	2	.	.	.	1	.	10	152	10	.	3	4	1	.
	1750	1	96	2	.	.	.	.	.	10	3	13	.	0	0	194	.
	2250	36	4	3	.	.	.	.	.	.	3	24	.	0	0	6	.
	2750	1	3	.	.	.	.	.	.	.	36	.	.	3	1	.	.
	3250	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Balsam fir	**250**	3	5	15	1	1	1	.	.	4	4	5	1	4	3	15	2
	750	21	1	1	4	.	1	1	.	1	1	1	1	13	1	2	1
	1250	13	1	1	2	1	1	1	.	2	3	1	69	5	1	1	1
	1750	10	1	1	3	1	1	1	.	1	2	1	.	3	1	0	0
	2250	4	1	5	.	1	2	1	.	4	379	7	.	1906	11	3	.
	2750	4	1	.	.	1	.	.	.	3	2	.	.	63	6	.	.
	3250	295	1	.	.	.	1	.	.	2	.	.	.	864	.	.	.
	3750	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
	4750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trembling aspen	**250**	6	259	3	2	.	.	.	.	4	9	48	3	18	22	25	11
	750	1	1	2	2	1	1	.	.	18	3	15	2	8	7	5	5
	1250	3	3	2	2	.	1	1	.	87	12	2	3	1	1	1	0
	1750	2	24	1	1	.	1	1	.	4	2	2	8	2	1	2	1

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
	2250	3	1	1	.	.	.	1	.	.	12	1	1	1	2	3	.
	2750	.	2	.	.	.	.	.	.	.	5	.	.	1	4	.	.
	3250	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
White birch	**250**	5	2	12	.	.	.	.	.	9	4	1	1	17	13	0	.
	750	3	3	3	3	1	1	1	.	3	3	9	8	3	5	5	.
	1250	3	23	3	1.31E+29	1	1	.	.	16	4	48	3	5	2	23	.
	1750	2	4	2	.	1	1	.	.	3	6	9	1	4	6	8	.
	2250	2	4	3	.	1	1	.	.	2	12	38	.	525	25	.	.
	2750	3	2	.	.	.	.	.	.	.	9	.	.	.	.	.	.
	3250	.	300	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	3750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sugar maple	**250**	2	1	1	1	.	.	.	.	793	1	2	1	6	8	6	1
	750	1	1	1	1	.	1	.	.	3	3	3	8	1	2	1	14
	1250	6	2	2	2	.	.	.	.	1761	18	2882	28	1	11	4	6
	1750	5	6	6	.	.	.	.	.	.	62	16	.	.	3	2	.
	2250	.	0	.	.	.	.	.	.	.	.	.	.	.	12	.	.
	2750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
White pine	**250**	2	1	2	7	.	.	.	.	2	5	55	2	135	106	224	88
	750	2	7	3	2	.	.	.	.	31	11	1	0	34	29	16	60
	1250	29	2	2	.	.	.	.	.	1	9	1	.	4	4	11	.
	1750	.	9	1	.	.	.	.	.	0	0	0	10	1	8	0	0
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Red pine	**250**	.	.	75	.	.	.	.	.	.	1	.	.	.	35	.	.
	750	13	2	1	.	.	.	.	.	10	13	12	.	10	17	7	.
	1250	8	64	0	.	.	.	.	.	48	9	.	.	2	3	5	.
	1750	.	9	.	.	.	.	.	.	.	8	.	.	.	.	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
American beech	**250**	2	2	8	.	.	.	.	.	497	5	6	7	8	11	2	3
	750	2	2	2	1	.	.	.	.	2	2	2	2	1	3	2	17
	1250	1	1	363	.	.	.	.	.	.	5	4	.	2	1	1	.
	1750	.	1	21	.	.	.	.	.	.	.	.	.	.	.	.	.

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Yellow birch	**250**	3	2	1	25	.	.	.	.	2	4	8	2	3	57	1	12
	750	1	3	2	2	.	.	.	.	1	2	268	1	0	0	1	11
	1250	12	1	2	1	.	.	.	.	2	2	4	8	1	1	1	0
	1750	2	19	8	.	.	.	.	.	7	2	.	.	2	3	7	.
	2250	2	58	.	.	.	.	.	.	24	.	.	.	4	37	.	.
Basswood	**250**	48	8	34	.	.	.	.	.	2	4	1	.	9	23	66	.
	750	3	9	6	4	.	.	.	.	0	55	2	.	1	1	1	19
	1250	56	26	2	.	.	.	.	.	.	1	1	7	1	10	1	13
	1750	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Ironwood	**250**	.	.	.	.	.	.	.	.	6	.	5	.	14	1	.	.
	750	.	.	.	.	.	.	.	.	3	1063	1	.	5	1	0	.
	1250	.	.	.	.	.	.	.	.	.	.	8	.	.	2	4	.
	1750	.	.	.	.	.	.	.	.	.	14	.	.	.	1	.	.
Soft maple	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Balsam poplar	**250**	.	3	.	.	.	.	.	.	.	.	.	.	.	30	.	.
	750	3	3	3	.	.	.	.	.	.	.	.	.	14	1	3	.
	1250	.	4	.	.	.	3	.	.	.	.	.	.	.	1	0	.
	1750	.	2	.	.	.	1	.	.	.	.	.	.	.	10	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	2750	.	1	.	.	.	3	.	.	.	.	.	.	.	237	.	.
Red oak	**250**	4	10	.	.	.	.	.	.	631	4	.	.	291	51	.	.
	750	12	2	2	5	.	.	.	.	2	3	2	.	2	1	6	0
	1250	5	5	1	552	.	.	.	.	7	1	2	.	2	1	3	1
	1750	2	1	.	.	.	.	.	.	.	8	.	.	.	16	.	.
Black cherry	**250**	7	.	.	.	.	.	.	.	.	.	.	.	51	0	4	.
	750	12	62	8	.	.	.	.	.	.	.	.	.	1	0	2	2
	1250	.	8	5	.	.	.	.	.	.	.	.	.	.	3	1	.
	1750	.	10	.	.	.	.	.	.	.	.	.	.	.	2	2	.
Bitternut hickory	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
	750	.	.	1986	.	.	.	.	.	.	.	.	.	.	1	.	.

		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
White ash	**250**	.	.	.	.	.	.	.	.	2	26	41	.	7	2	12	.
	750	.	.	.	.	.	.	.	.	3090	6	5	.	2	1	1	.
	1250	.	.	.	.	.	.	.	.	.	12	795	.	.	2	4	.
	1750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix 5: Average VR values obtained for the dbh growth rate, survival rate, height-dbh and species group density index models for different species under different combinations of stand density and site index classes.

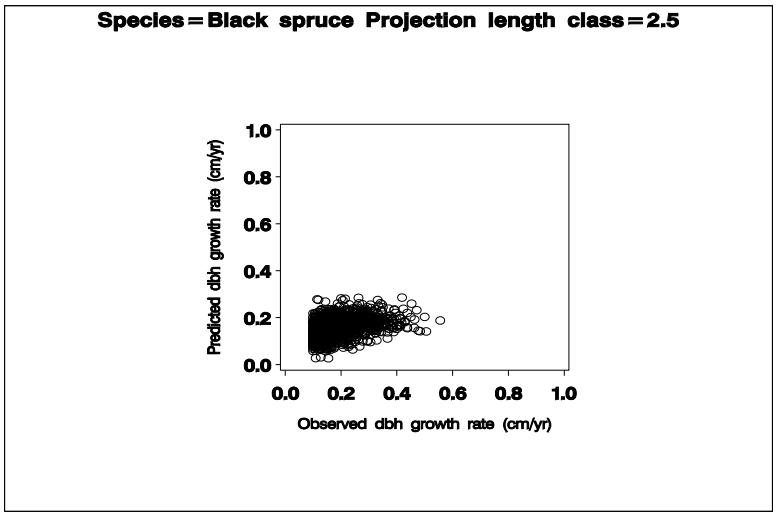
		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Black spruce	**250**	1	0	0	.	0	.	.	.	2	2	2	1	2	1	1	2
	750	1	0	0	0	0	0	.	.	2	2	1	3	1	2	3	2
	1250	0	0	0	.	0	0	0	.	1	2	1	.	2	1	1	.
	1750	0	0	0	.	0	0	.	.	2	2	59	.	1	1	1	.
	2250	0	0	0	.	0	0	.	.	1	4	.	.	1	1	1	.
	2750	0	0	.	.	.	0	.	.	3	1	.	.	20	0	.	.
	3250	0	.	.	.	.	.	.	.	2	.	.	.	0	.	.	.
	4750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jack pine	**250**	0	1	0	.	.	.	.	.	1	1	0	.	13	12	6	.
	750	1	8	12	.	.	.	0	.	1	1	0	.	5	5	1	.
	1250	2	1	1	.	.	.	0	.	1	2	2	.	2	1	1	.
	1750	0	1	0	.	.	.	.	.	1	1	0	.	1	1	1	.
	2250	5	1	0	.	.	.	.	.	.	1	2	.	1	0	1	.
	2750	0	1	.	.	.	.	.	.	.	2	.	.	0	0	.	.
	3250	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Balsam fir	**250**	0	0	0	0	0	0	.	.	1	3	1	1	3	3	5	1
	750	0	0	0	0	.	0	0	.	1	1	1	1	8	2	2	2
	1250	0	0	0	0	0	0	0	.	1	1	2	1	1	2	2	2
	1750	0	0	0	0	0	0	0	.	1	2	1	.	1	1	1	1
	2250	0	0	0	.	0	0	0	.	2	26	6	.	44	12	1	.
	2750	0	0	.	.	0	.	.	.	3	3	.	.	2	1	.	.
	3250	0	0	.	.	.	0	.	.	2	.	.	.	1	.	.	.
	3750	0	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.
	4750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

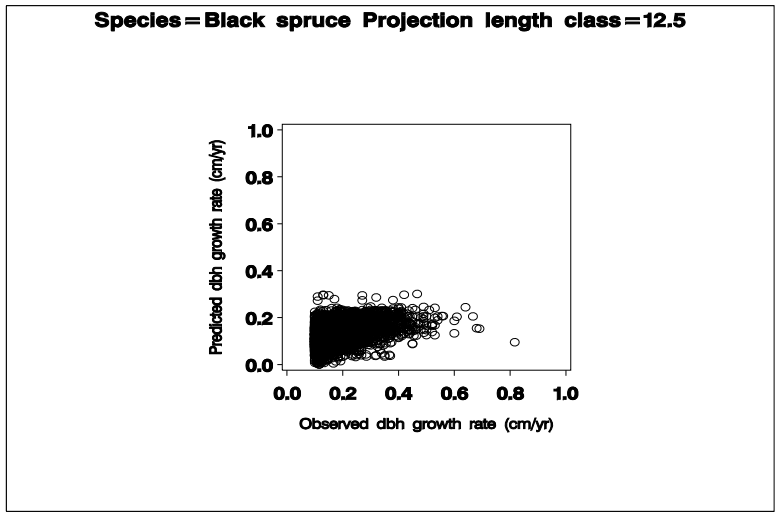
		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Trembling aspen	**250**	0	0	0	0	.	.	.	.	2	1	2	1	10	11	14	1
	750	0	0	0	0	0	0	.	.	15	1	3	0	3	2	3	4
	1250	0	0	0	0	.	0	0	.	76	3	1	2	1	2	1	1
	1750	0	24	0	0	.	0	0	.	10	2	2	1	0	1	1	1
	2250	0	0	0	.	.	.	0	.	.	2	1	0	0	0	0	.
	2750	.	0	.	.	.	.	.	.	.	1	.	.	0	0	.	.
	3250	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
White birch	**250**	0	0	1	.	.	.	.	.	1	2	1	1	13	14	1	.
	750	0	1	0	0	0	0	0	.	1	1	2	1	2	3	4	.
	1250	1	22	0	4.82E +25	0	0	.	.	1	1	4	0	3	1	3	.
	1750	0	0	0	.	0	0	.	.	1	1	1	2	1	3	1	.
	2250	0	0	0	.	0	0	.	.	1	2	42	.	3	1	.	.
	2750	0	0	.	.	.	.	.	.	.	1	.	.	.	.	.	.
	3250	.	176	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	3750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sugar maple	**250**	0	0	0	0	.	.	.	.	325	2	1	1	1	1	2	1
	750	0	0	0	0	.	0	.	.	1	2	1	1	1	1	1	1
	1250	0	0	0	0	.	.	.	.	34	1	11	1	0	0	0	0
	1750	0	0	0	.	.	.	.	.	.	2	0	.	.	0	0	.
	2250	.	1	.	.	.	.	.	.	.	.	.	.	.	0	.	.
	2750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
White pine	**250**	0	0	0	1	.	.	.	.	2	1	10	1	22	9	10	14
	750	1	0	0	0	.	.	.	.	2	2	1	1	12	6	8	2
	1250	0	0	0	.	.	.	.	.	1	4	0	.	3	3	6	.
	1750	.	4	0	.	.	.	.	.	0	1	1	3	1	4	1	1
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

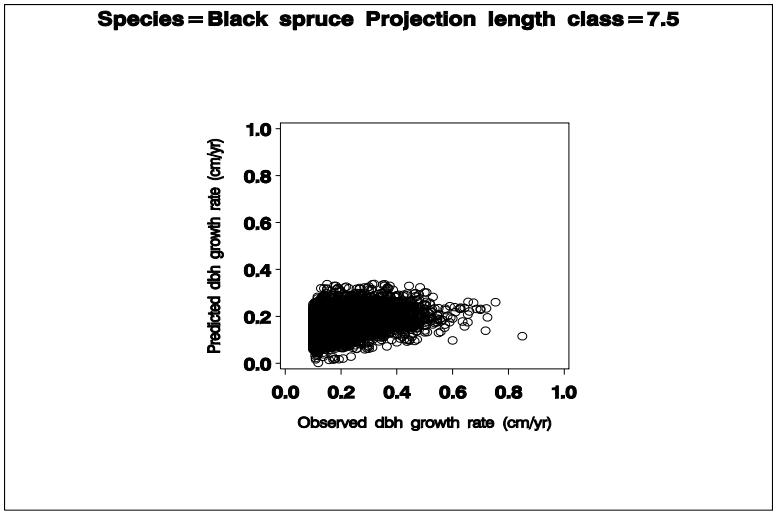
		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
Red pine	**250**	.	.	0	.	.	.	.	.	.	0	.	.	.	10	.	.
	750	6	1	2	.	.	.	.	.	2	4	16	.	2	4	3	.
	1250	2	21	1	.	.	.	.	.	3	5	.	.	3	2	1	.
	1750	.	2	.	.	.	.	.	.	.	1	.	.	.	.	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
American beech	**250**	0	0	0	.	.	.	.	.	3	2	1	1	2	2	1	4
	750	0	0	1	0	.	.	.	.	1	2	3	2	1	1	1	0
	1250	0	0	1	.	.	.	.	.	.	2	0	.	0	0	0	.
	1750	.	0	0	.	.	.	.	.	.	.	.	.	.	.	.	.
Yellow birch	**250**	1	0	0	0	.	.	.	.	1	1	1	2	2	8	1	8
	750	0	0	0	0	.	.	.	.	1	1	1	1	1	1	1	1
	1250	7	0	0	0	.	.	.	.	1	1	2	3	1	1	0	0
	1750	0	12	1	.	.	.	.	.	12	1	.	.	0	0	0	.
	2250	0	3	.	.	.	.	.	.	3	.	.	.	0	0	.	.
Basswood	**250**	1	3	0	.	.	.	.	.	0	1	0	.	3	1	18	.
	750	1	1	1	0	.	.	.	.	1	2	3	.	1	1	1	1
	1250	43	19	0	.	.	.	.	.	.	1	0	1	0	0	0	0
	1750	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	.
Ironwood	**250**	.	.	.	.	.	.	.	.	0	.	0	.	4	0	.	.
	750	.	.	.	.	.	.	.	.	1	317	0	.	5	2	2	.
	1250	.	.	.	.	.	.	.	.	.	.	6	.	.	0	3	.
	1750	.	.	.	.	.	.	.	.	.	5	.	.	.	2	.	.
Soft maple	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Balsam poplar	**250**	.	0	.	.	.	.	.	.	.	.	.	.	.	0	.	.
	750	0	0	0	.	.	.	.	.	.	.	.	.	11	2	3	.

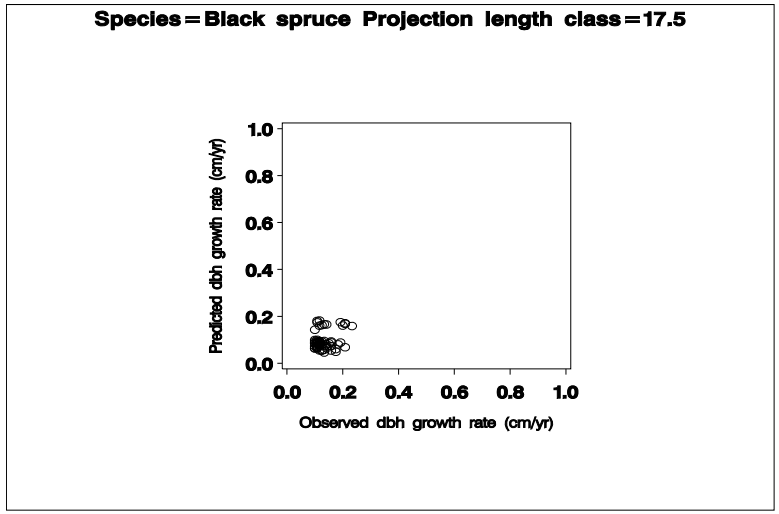
		Dbh growth rate (cm yr^{-1})				Survival rate (proportion)				Height-dbh (m)				Species group density index (trees per ha)			
		Site index class (m)															
		12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5	12.5	17.5	22.5	27.5
Species	**Stand density**																
	1250	.	0	.	.	.	0	.	.	.	.	.	.	.	0	0	.
	1750	.	0	.	.	.	0	.	.	.	.	.	.	.	0	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	2750	.	0	.	.	.	0	.	.	.	.	.	.	.	0	.	.
Red oak	**250**	0	0	.	.	.	.	.	.	2	1	.	.	58	7	.	.
	750	0	0	0	0	.	.	.	.	1	1	1	.	3	2	3	1
	1250	1	0	0	0	.	.	.	.	2	0	1	.	2	2	1	0
	1750	0	0	.	.	.	.	.	.	.	8	.	.	.	0	.	.
Black cherry	**250**	0	.	.	.	.	.	.	.	.	.	.	.	0	1	1	.
	750	0	0	0	.	.	.	.	.	.	.	.	.	0	1	1	0
	1250	.	0	0	.	.	.	.	.	.	.	.	.	.	0	0	.
	1750	.	0	.	.	.	.	.	.	.	.	.	.	.	0	0	.
Bitternut hickory	**250**	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
	750	.	.	2	.	.	.	.	.	.	.	.	.	.	0	.	.
White ash	**250**	.	.	.	.	.	.	.	.	0	3	1	.	0	1	0	.
	750	.	.	.	.	.	.	.	.	323	1	1	.	2	1	1	.
	1250	.	.	.	.	.	.	.	.	.	2	24	.	.	0	0	.
	1750	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	2250	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

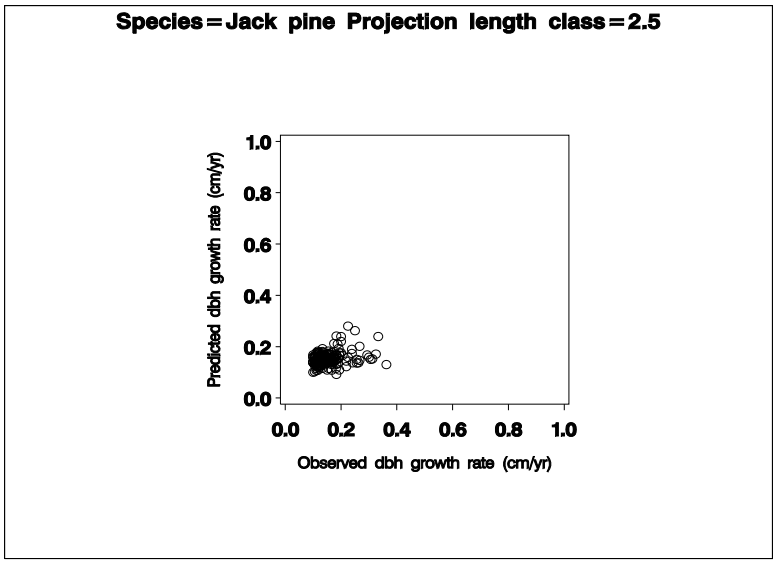
Appendix 6.1: Scatter plots of predicted dbh growth rate (cm/yr) against observed dbh growth rate (cm/yr) for different projection length classes for species in the Quebec dataset

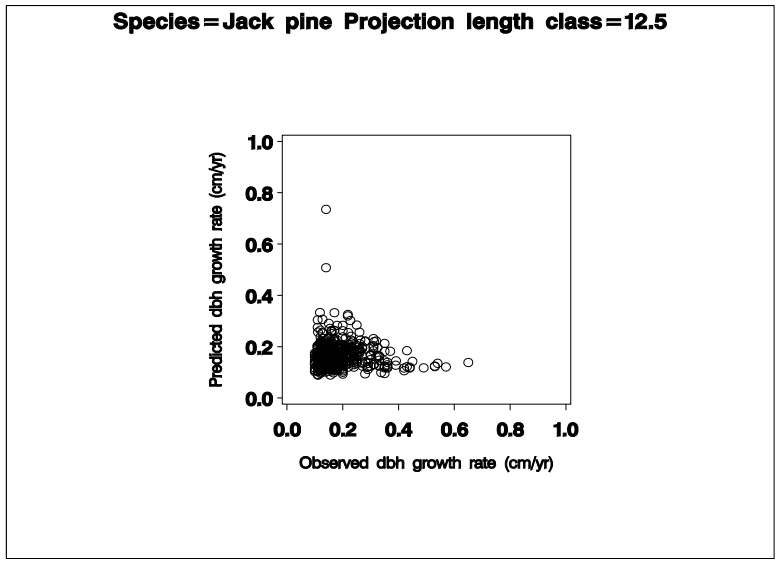


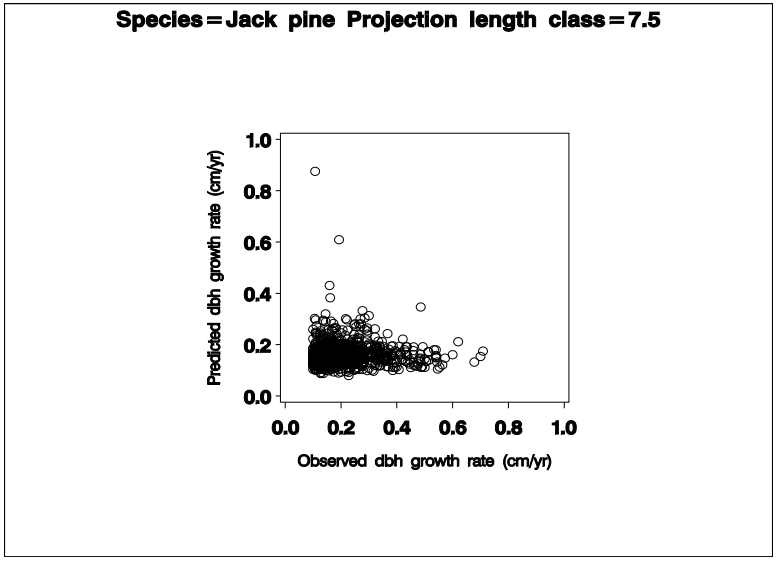


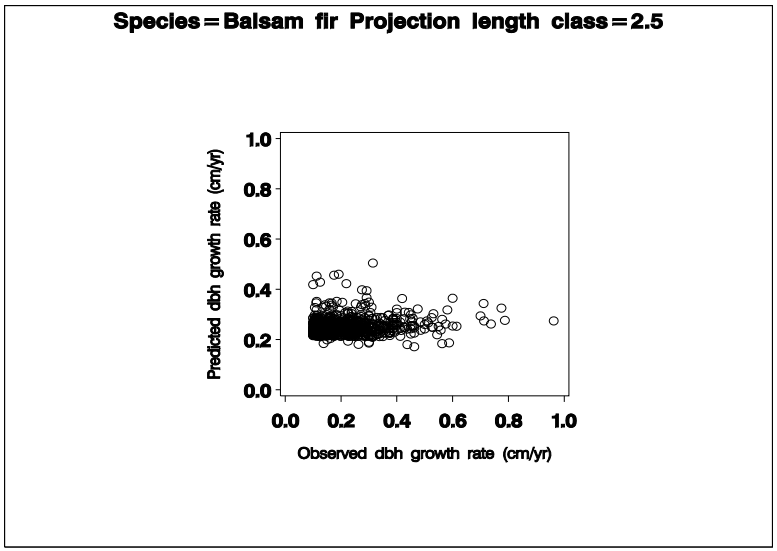


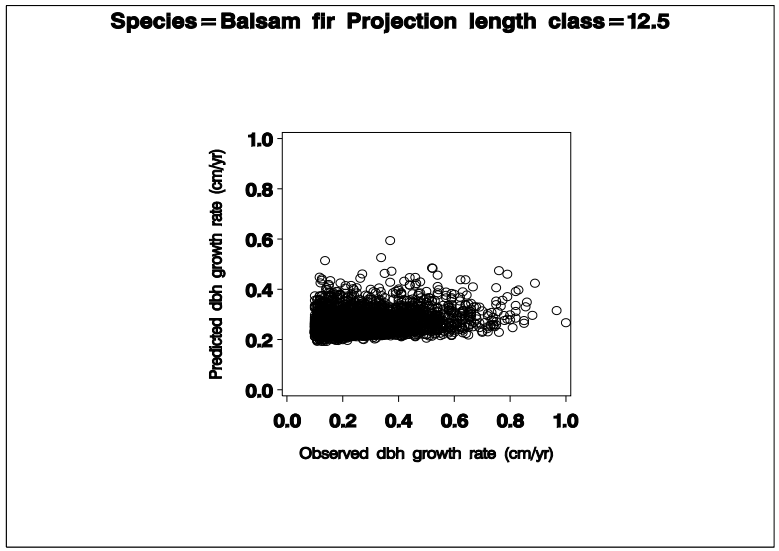


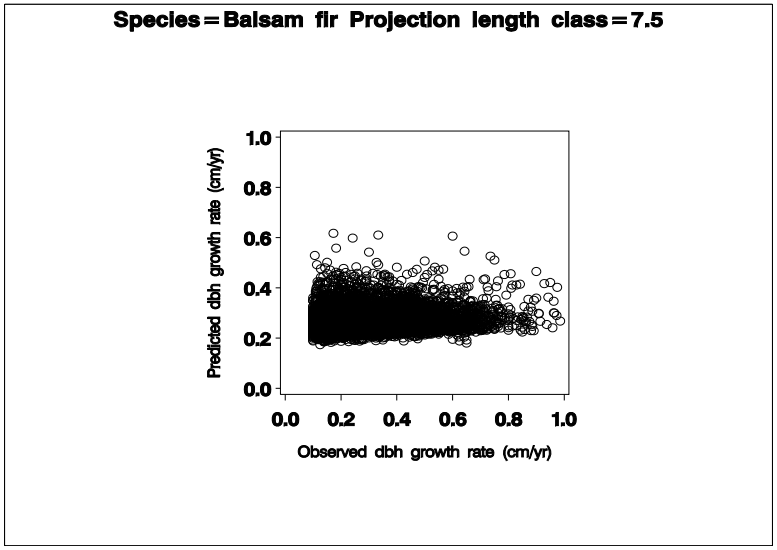

Species=Jack pine Projection length class=2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

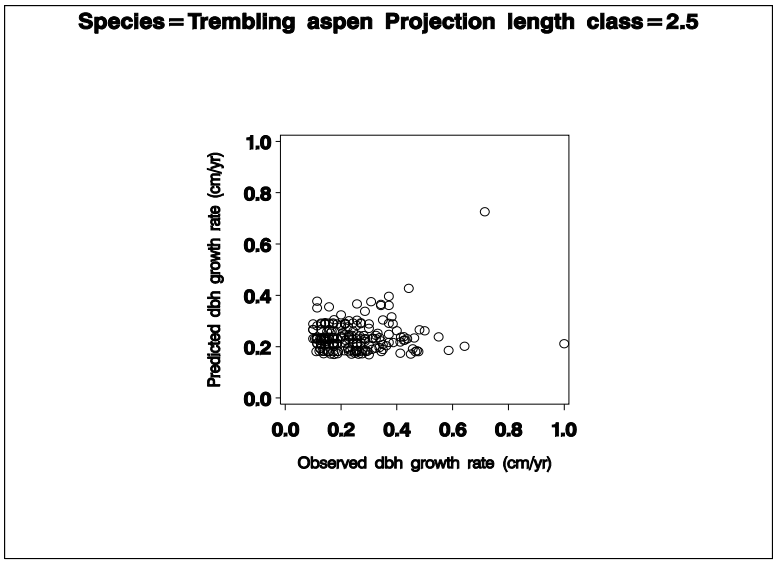

Species=Jack pine Projection length class=12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

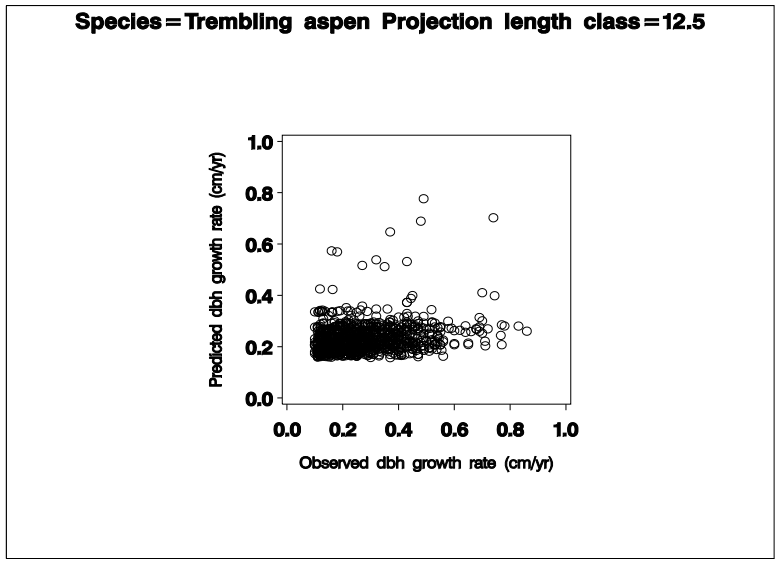

Species=Jack pine Projection length class=7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

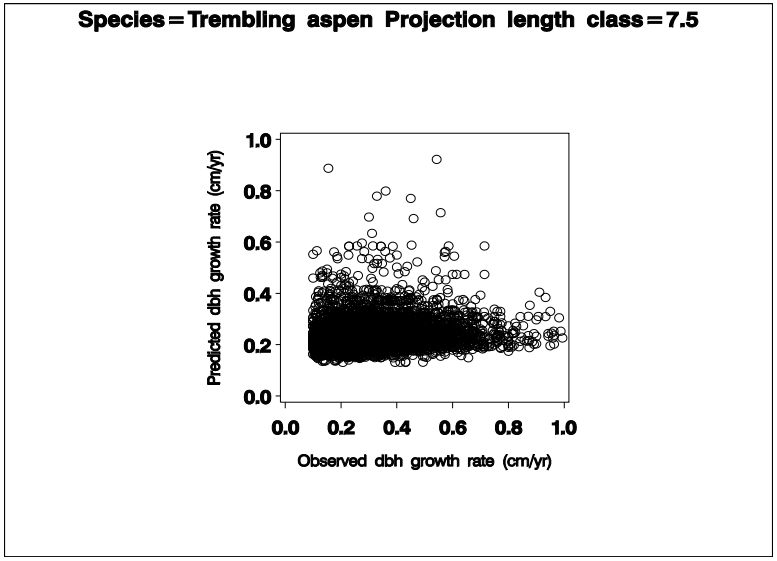

Species = Balsam fir Projection length class = 2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

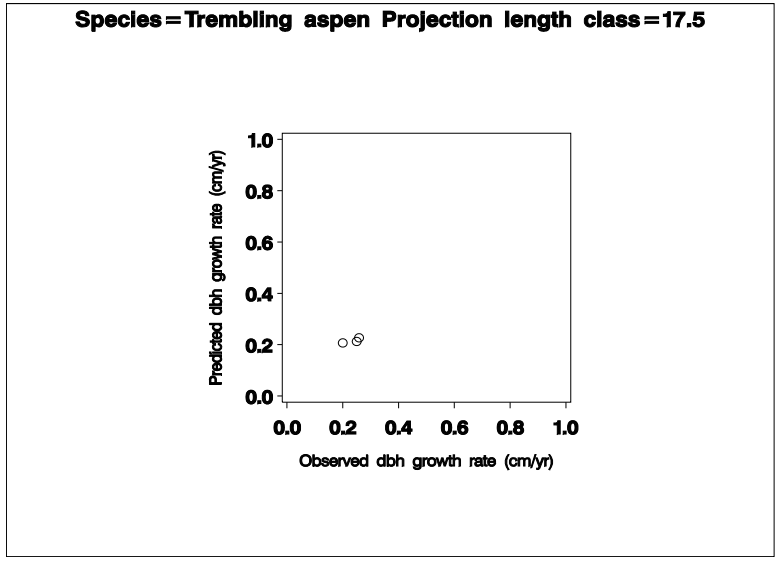

Species = Balsam fir Projection length class = 12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

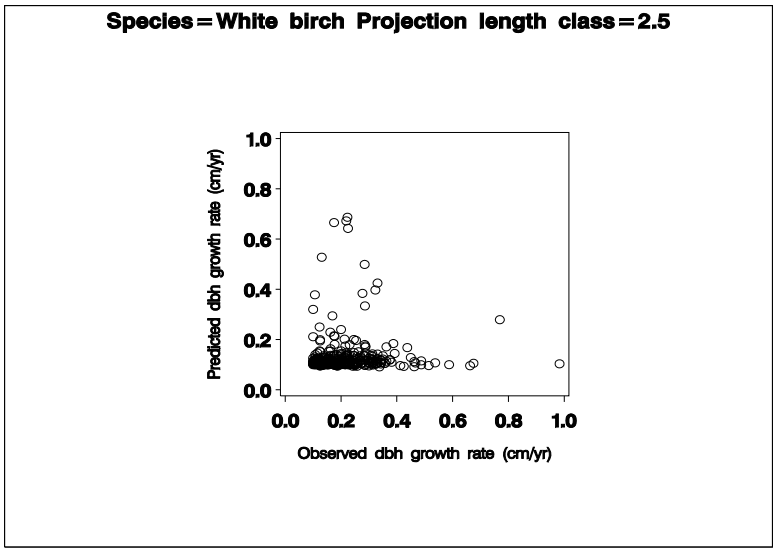

Species = Balsam fir Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

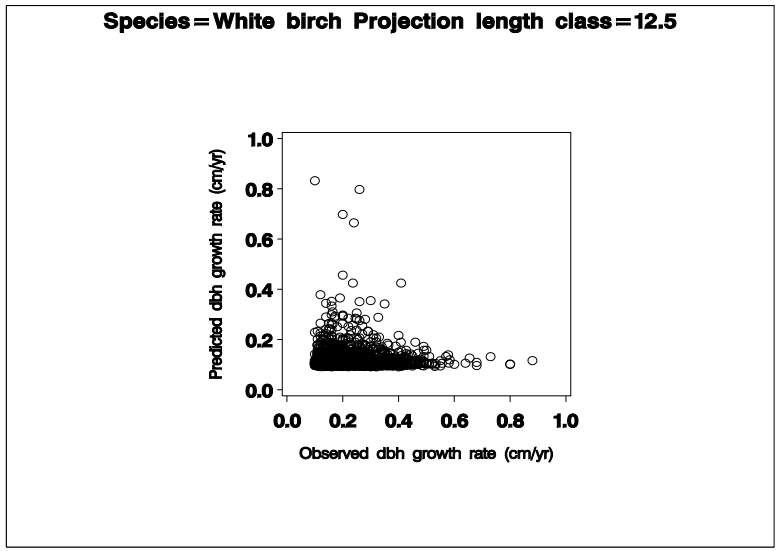

Species = Trembling aspen Projection length class = 2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

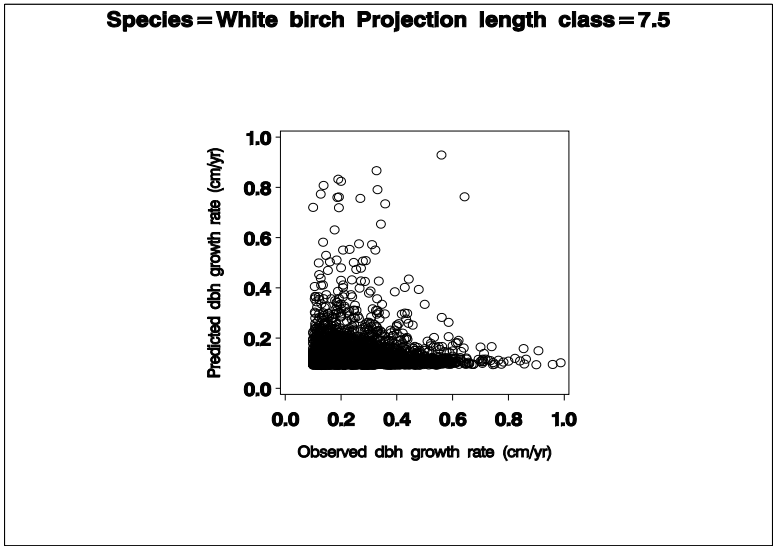

Species = Trembling aspen Projection length class = 12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

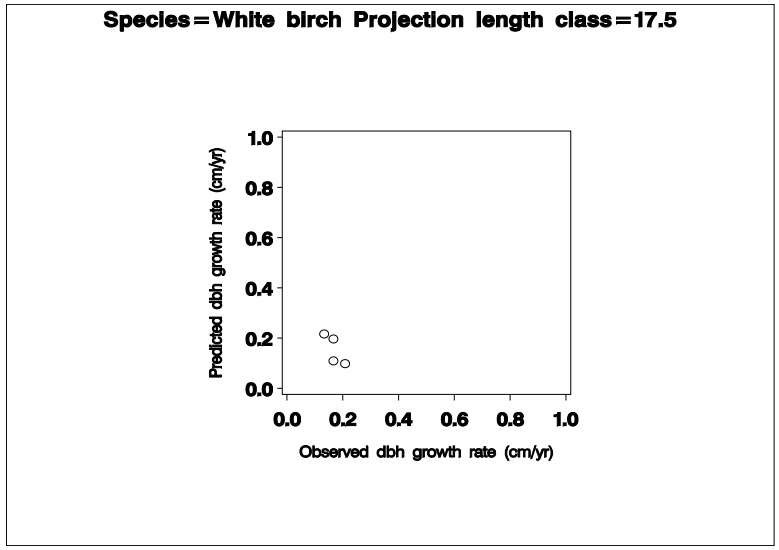

Species = Trembling aspen Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

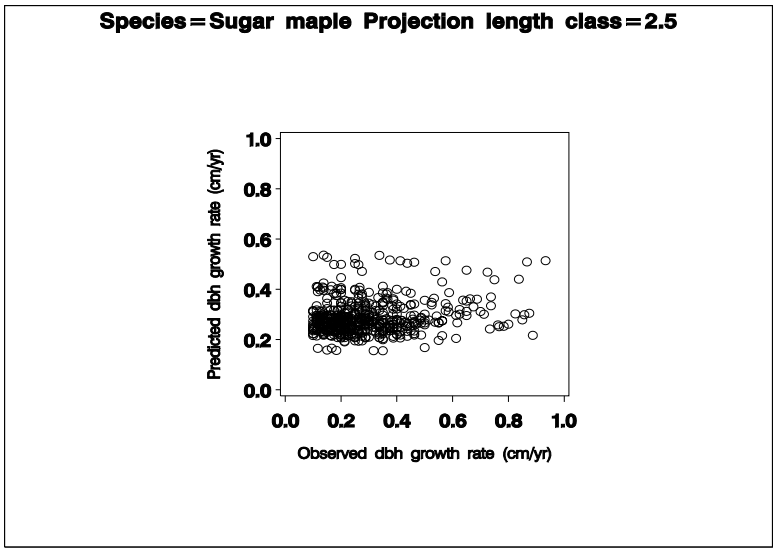

Species = Trembling aspen Projection length class = 17.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

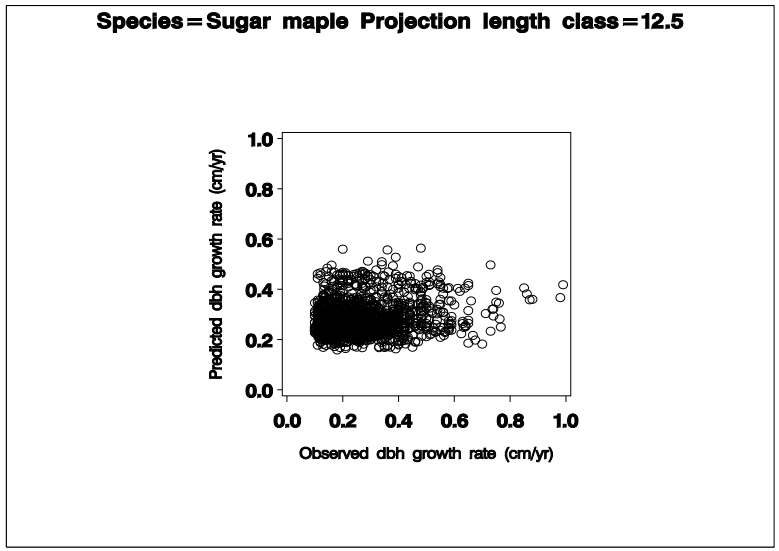

Species=White birch Projection length class=2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

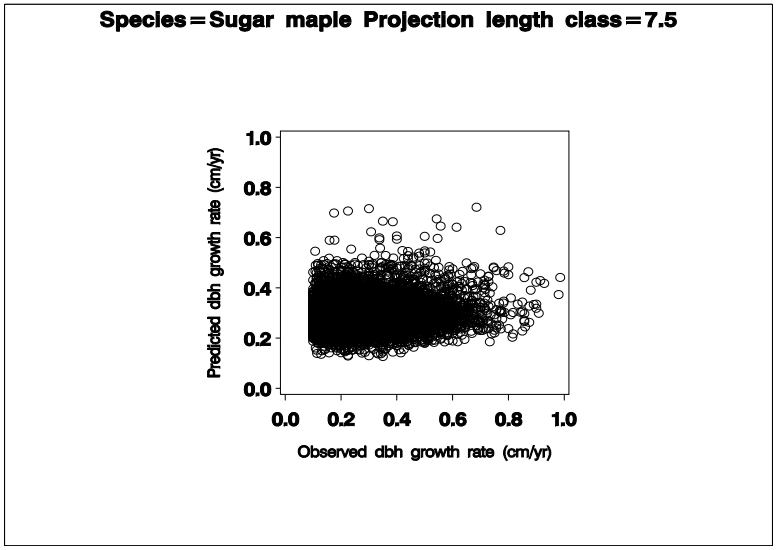

Species=White birch Projection length class=12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

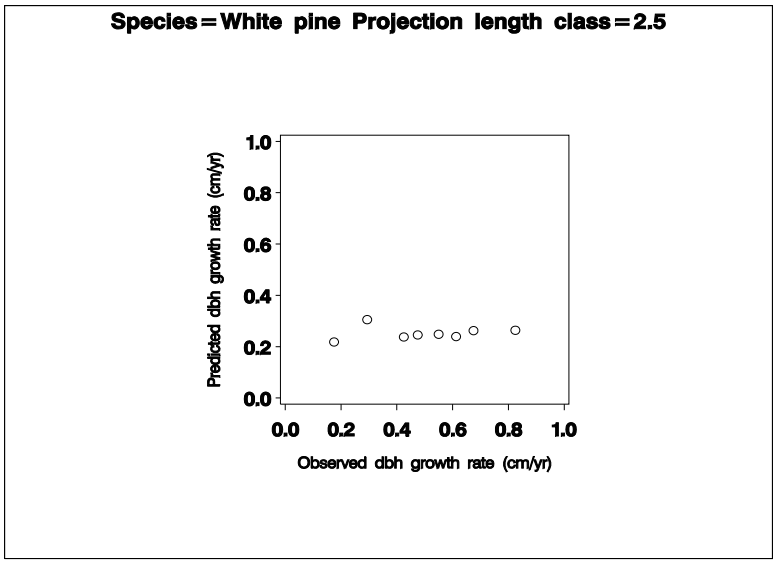

Species=White birch Projection length class=7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

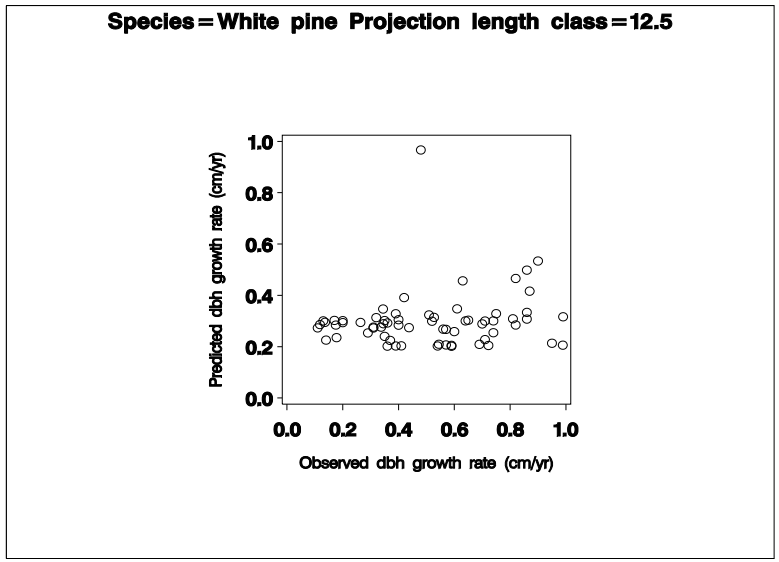

Species=White birch Projection length class=17.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

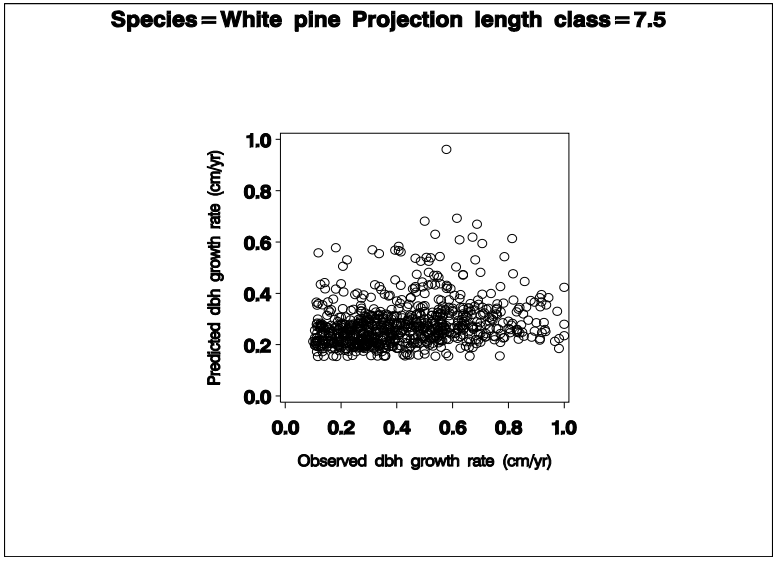

Species=Sugar maple Projection length class=2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

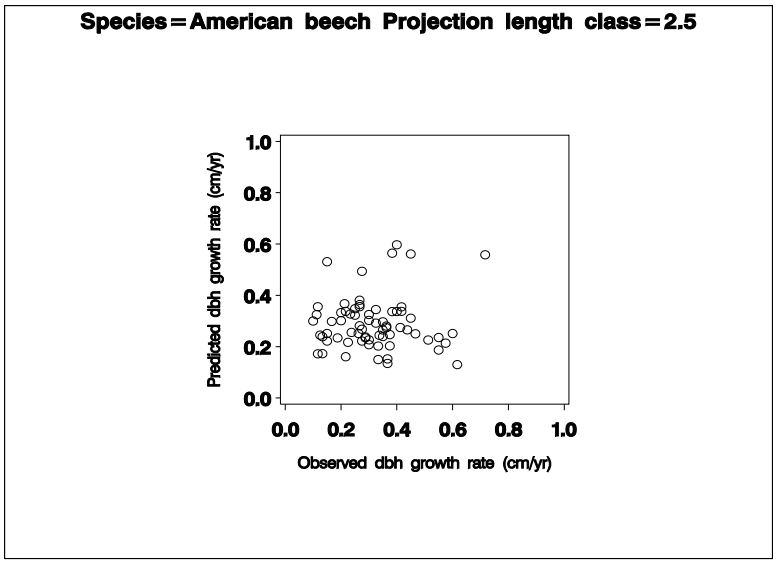

Species=Sugar maple Projection length class=12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

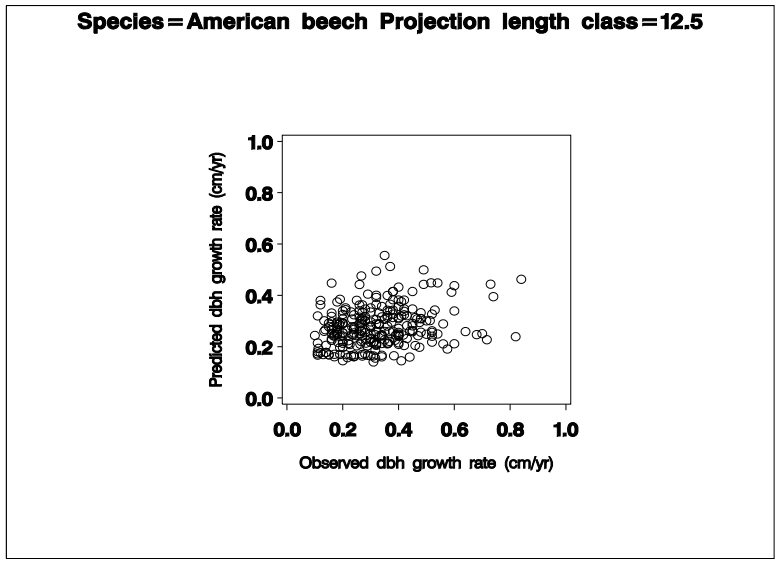

Species=Sugar maple Projection length class=7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

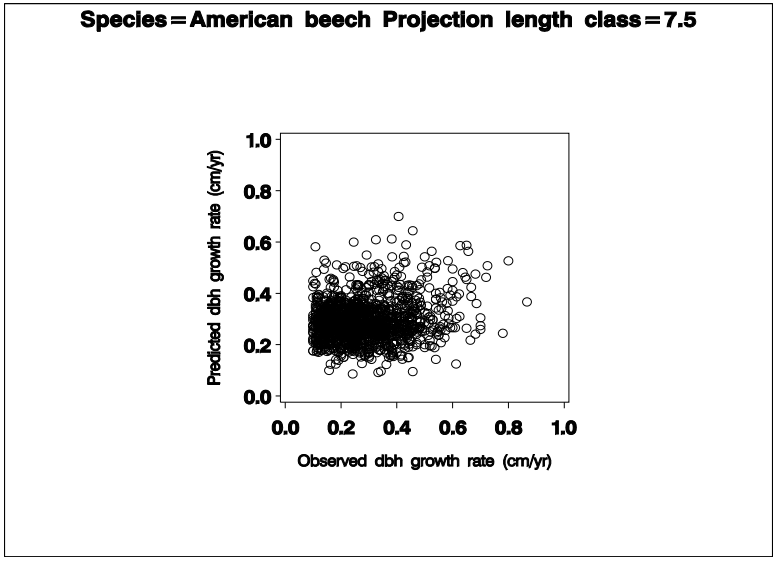

Species=White pine Projection length class=2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

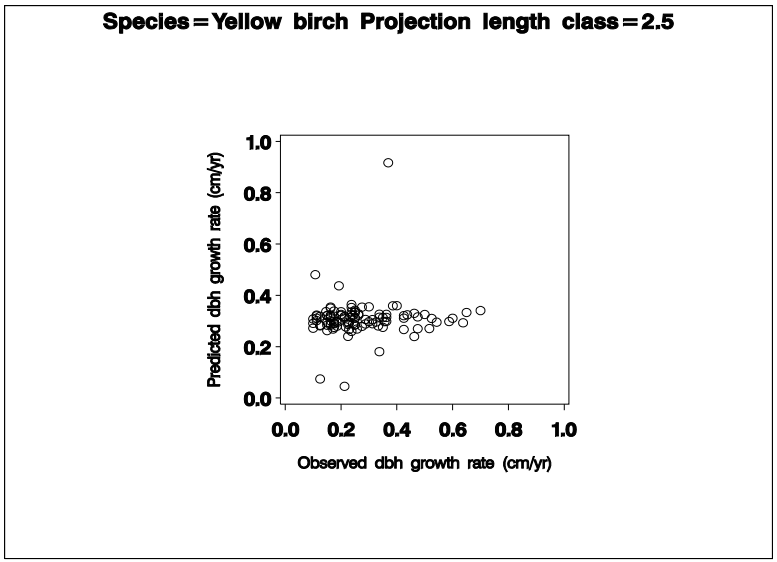

Species=White pine Projection length class=12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

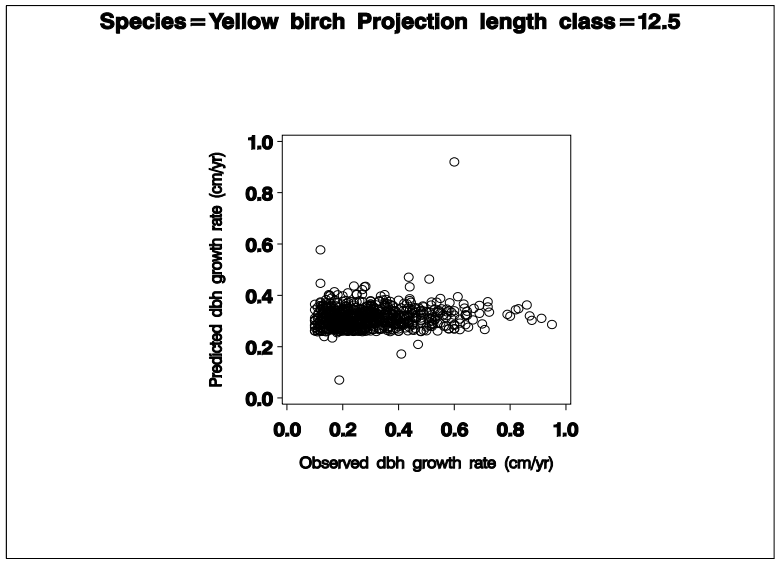

Species=White pine Projection length class=7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

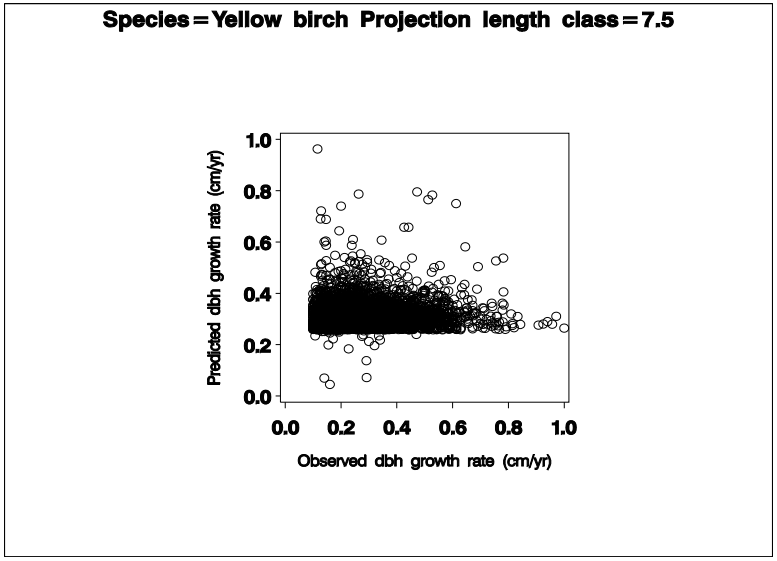

Species=American beech Projection length class=2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

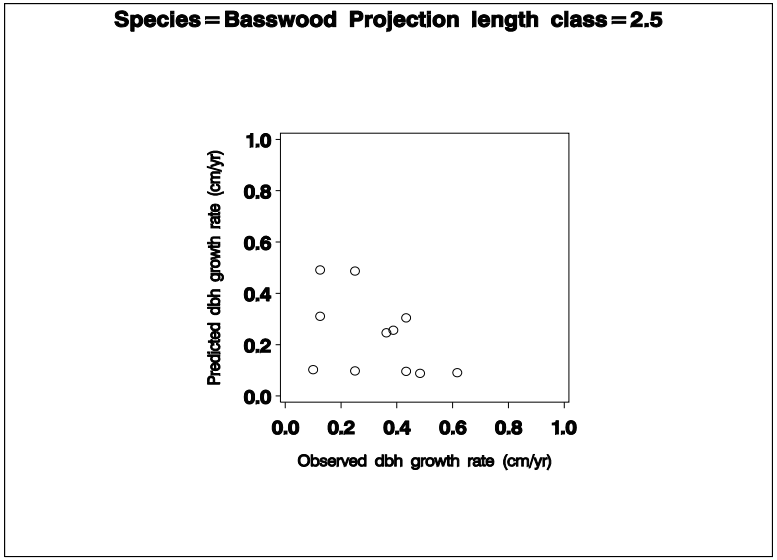

Species=American beech Projection length class=12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

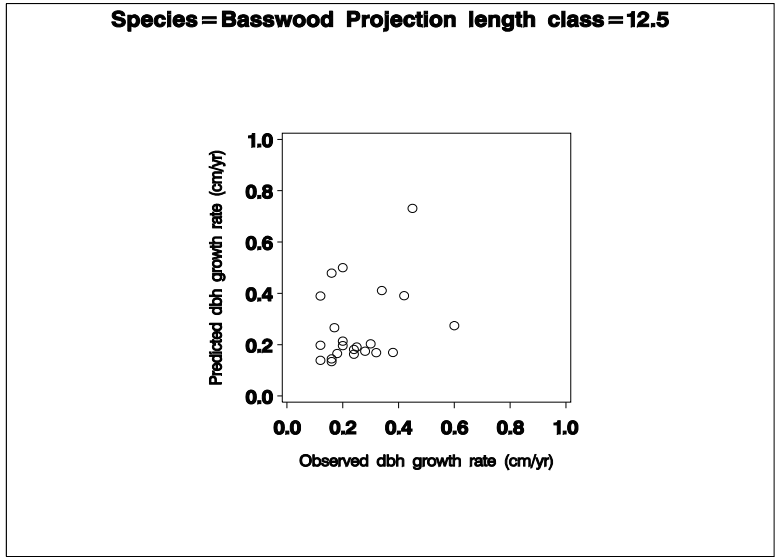

Species=American beech Projection length class=7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

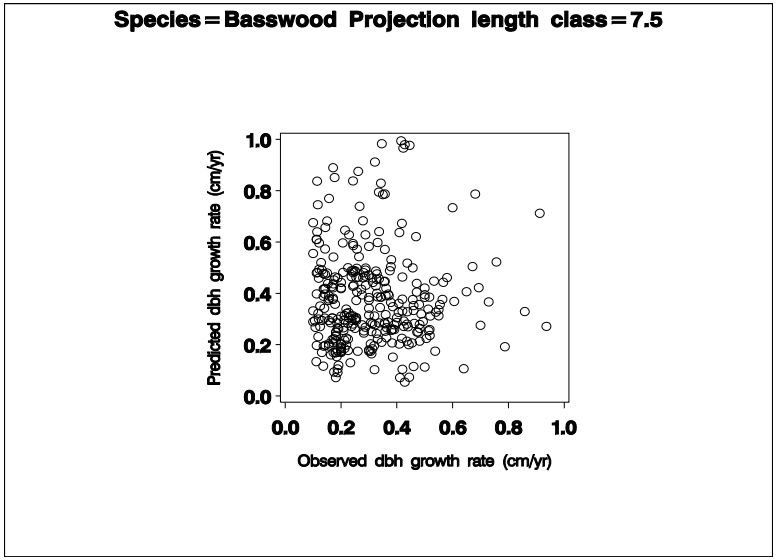

Species = Yellow birch Projection length class = 2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

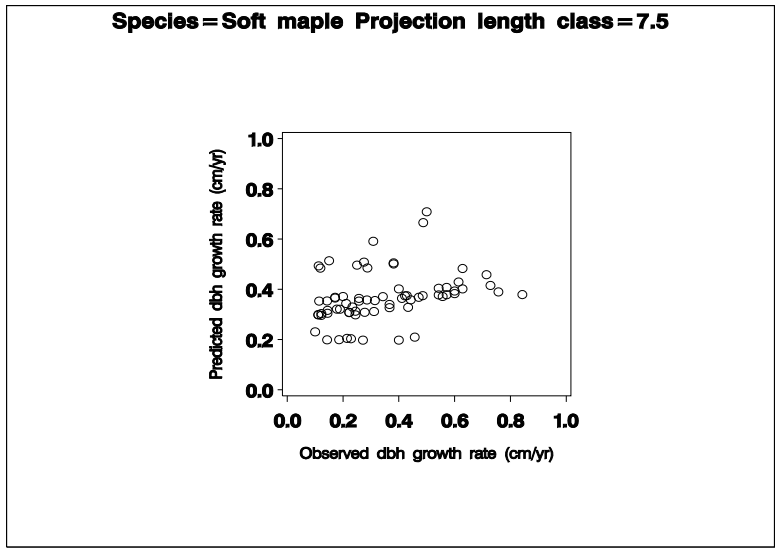

Species = Yellow birch Projection length class = 12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

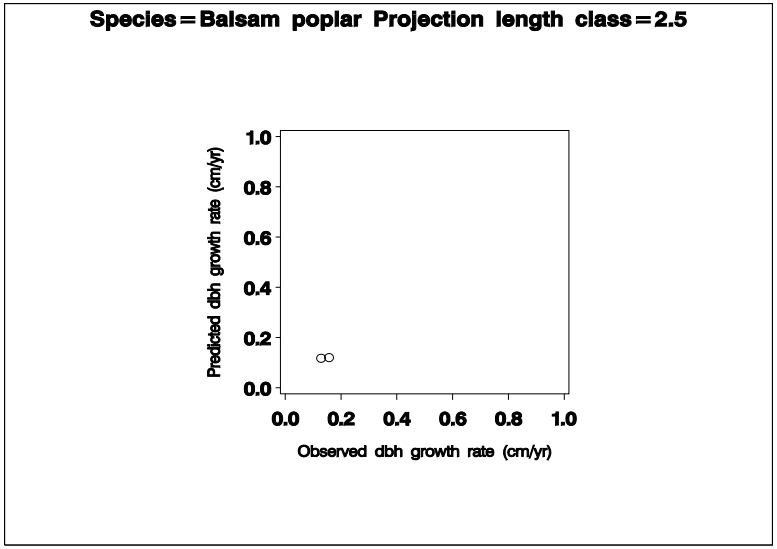

Species = Yellow birch Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

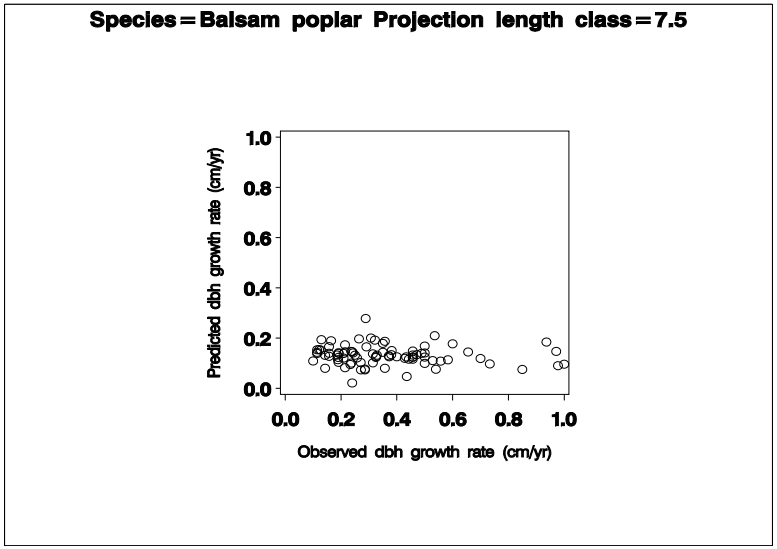

Species = Basswood Projection length class = 2.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

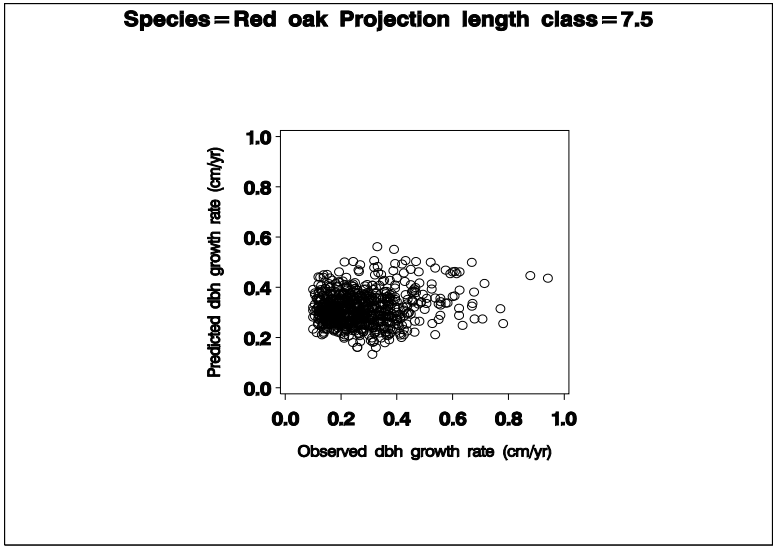

Species = Basswood Projection length class = 12.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

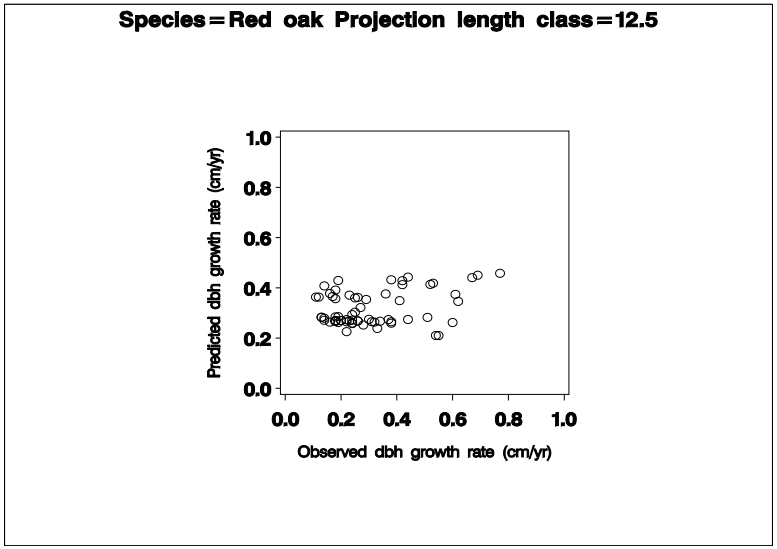

Species = Basswood Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

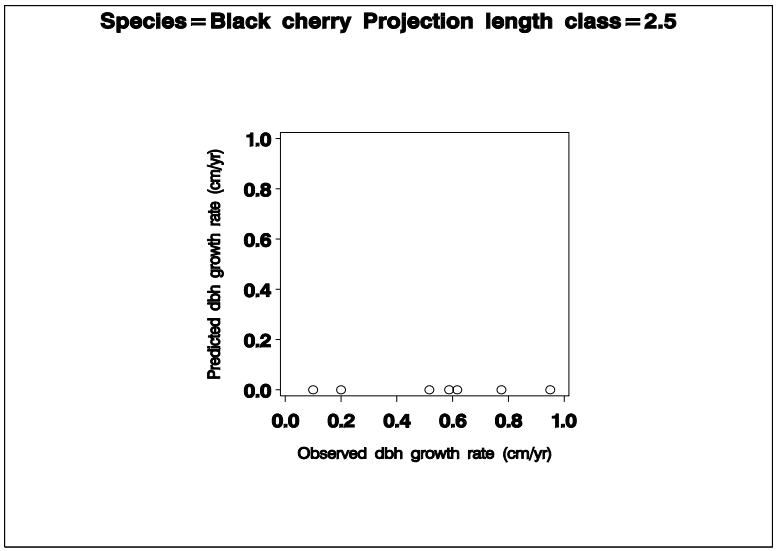

Species=Soft maple Projection length class=7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed dbh growth rate (cm/yr)

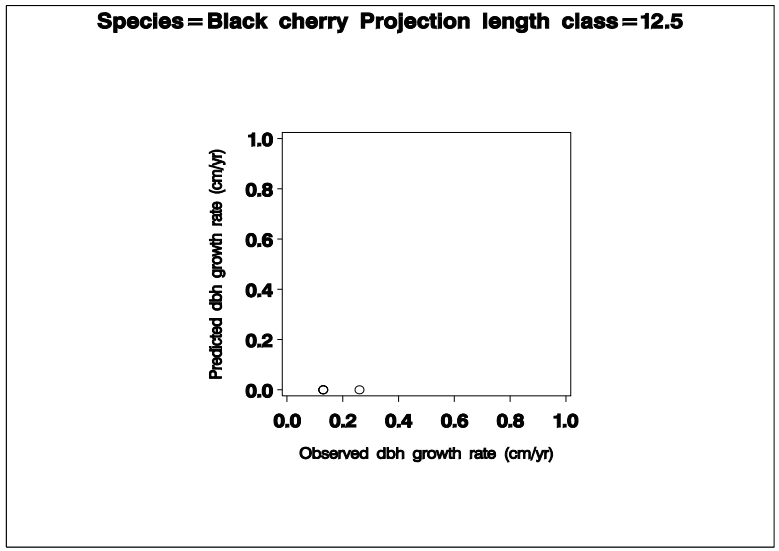

Species = Balsam poplar Projection length class = 2.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

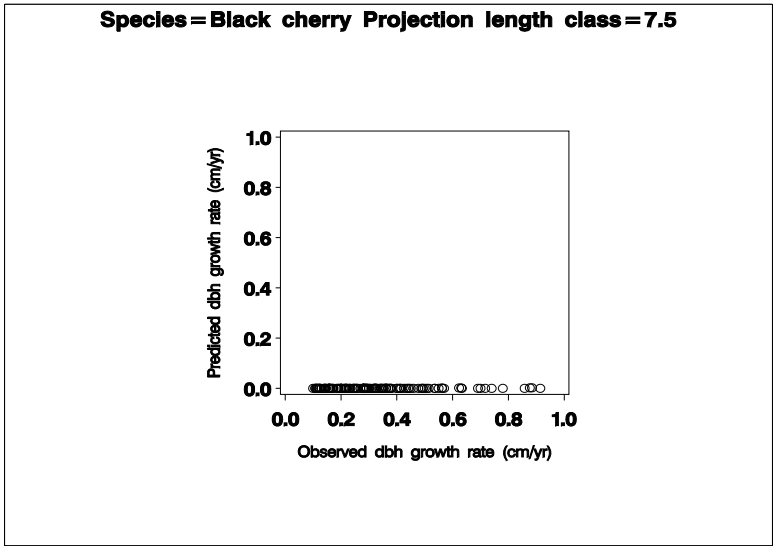

Species = Balsam poplar Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

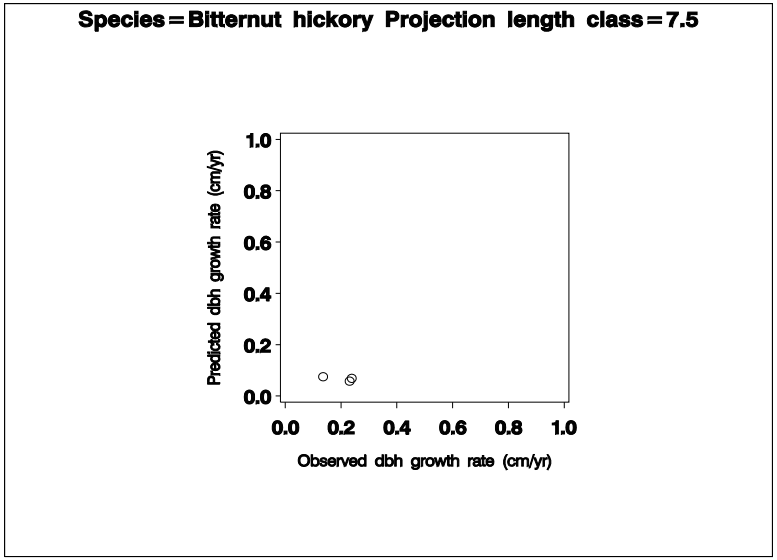

Species=Red oak Projection length class=7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)


Species=Red oak Projection length class=12.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

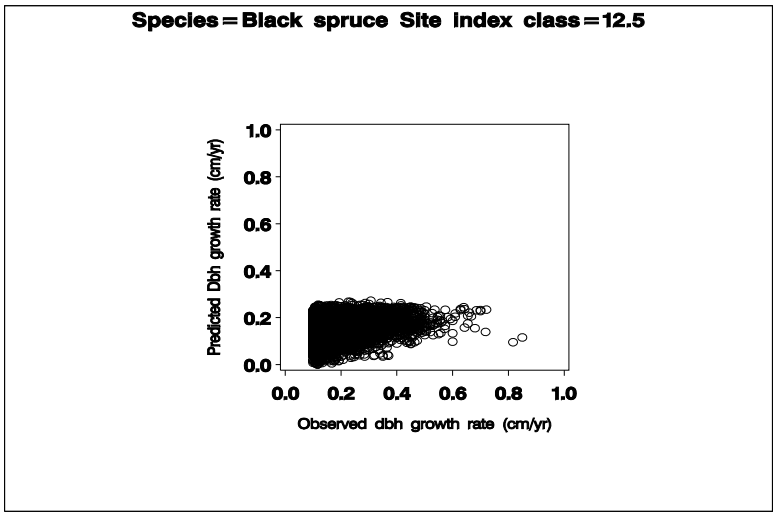

Species=Black cherry Projection length class=2.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

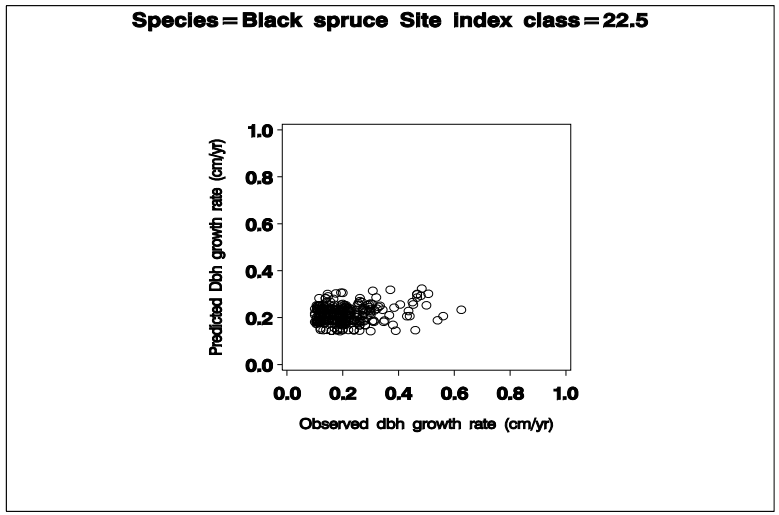

Species=Black cherry Projection length class=12.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

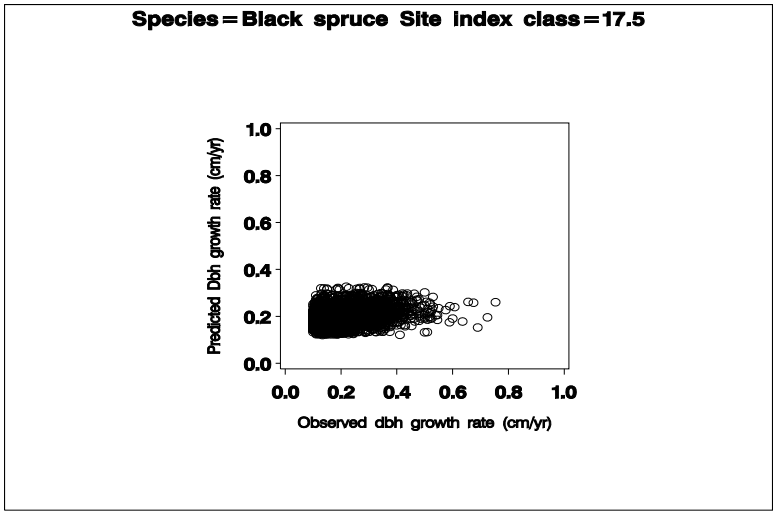

Species=Black cherry Projection length class=7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)

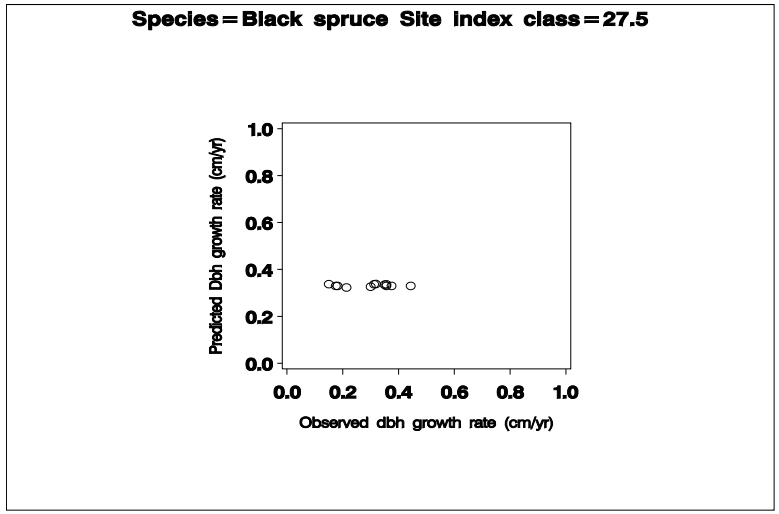

Species = Bitternut hickory Projection length class = 7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed dbh growth rate (cm/yr)

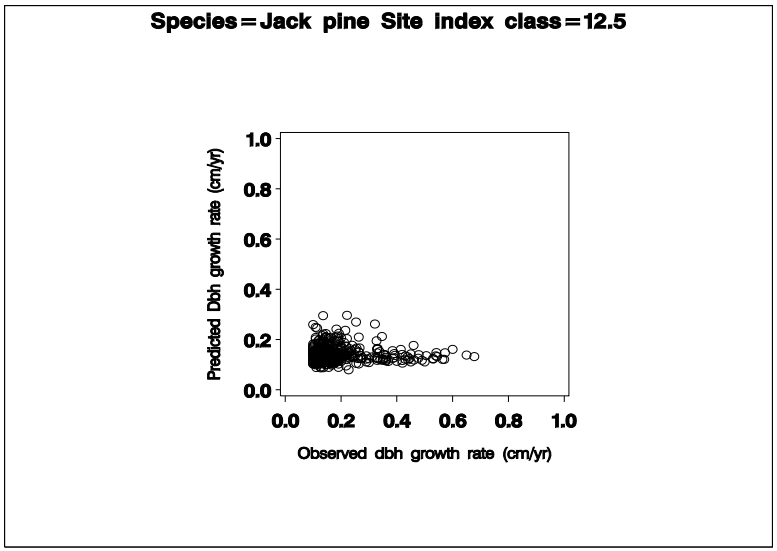
Appendix 6.2: Scatter plots of predicted dbh growth rate (cm/yr) against observed dbh growth rate (cm/yr) for different site index classes for species in the Quebec dataset

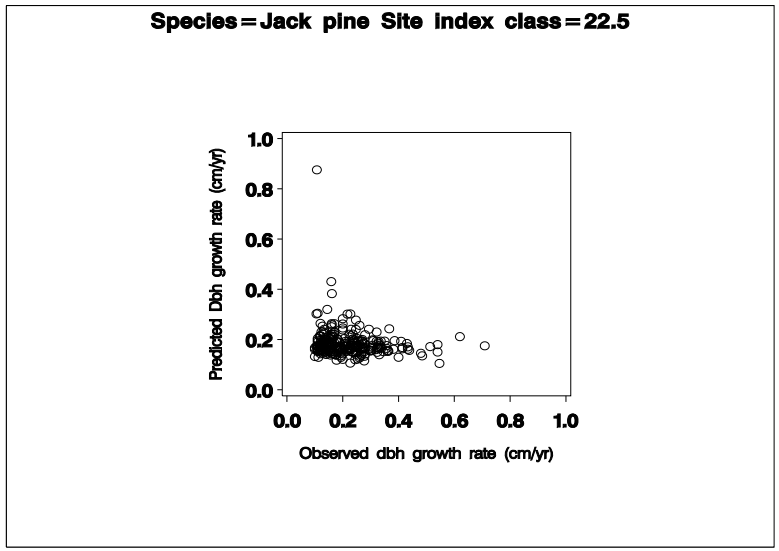


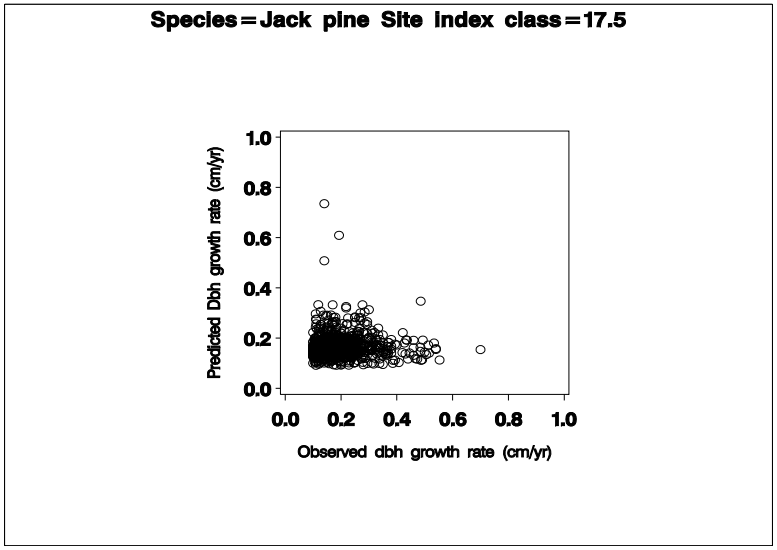


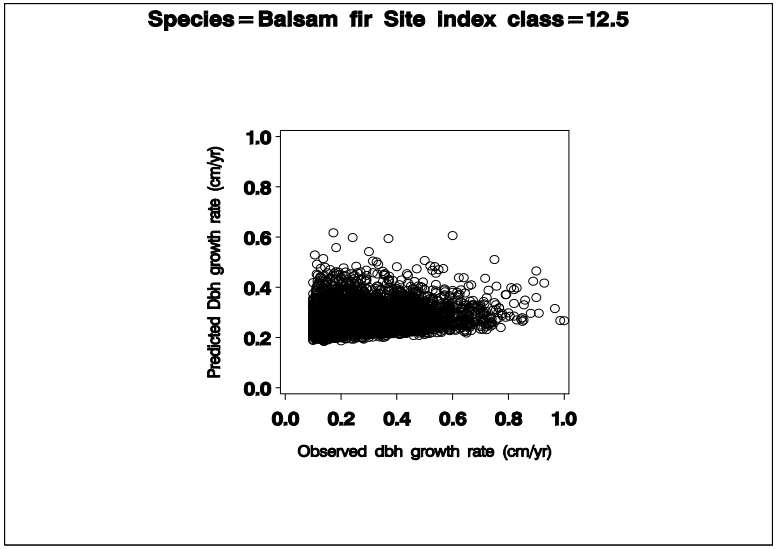


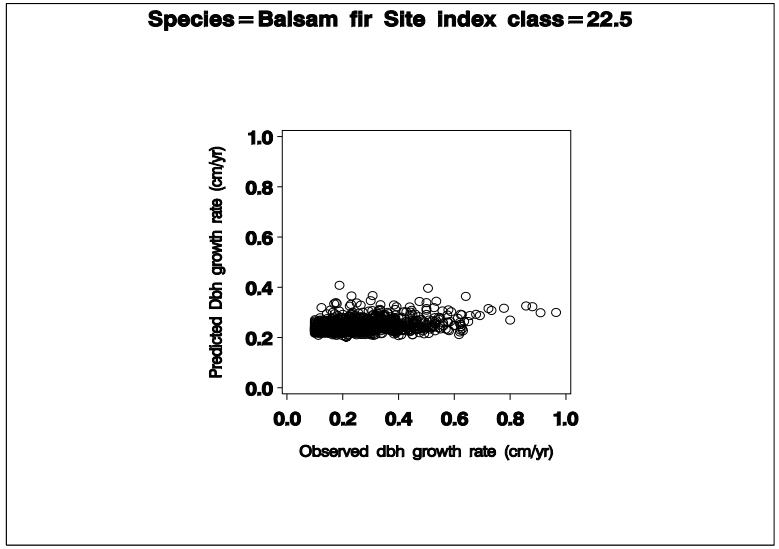


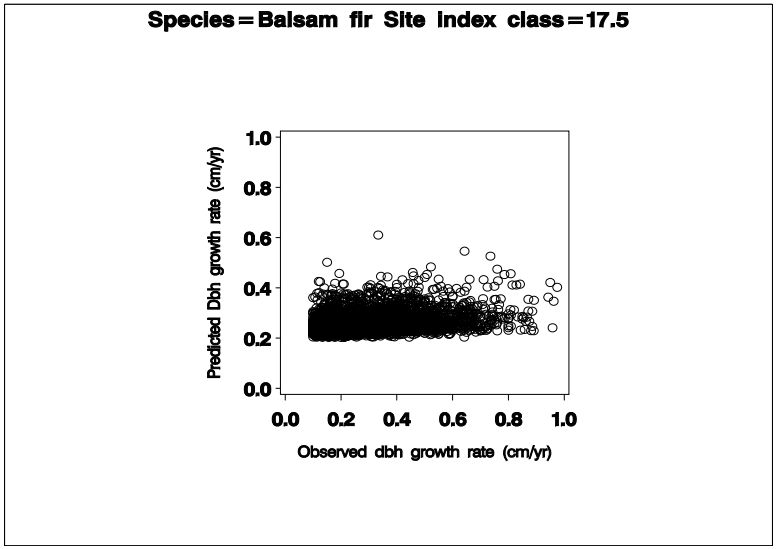

Species=Jack pine Site index class=12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

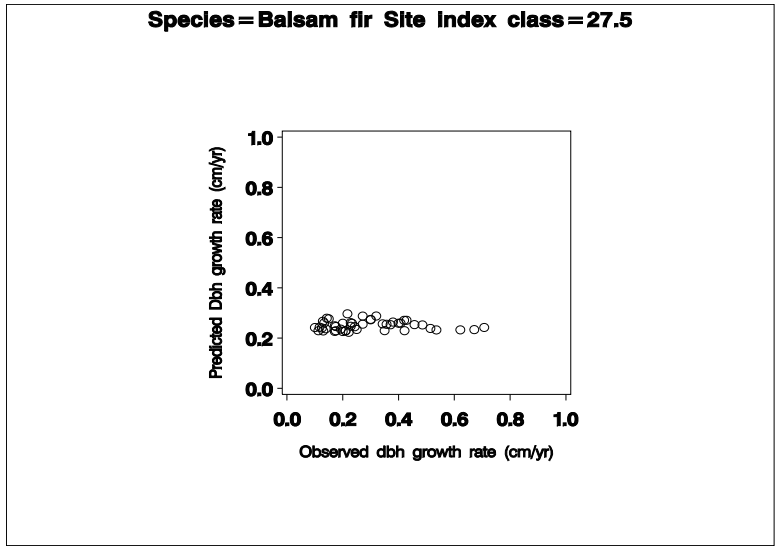

Species=Jack pine Site index class=22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

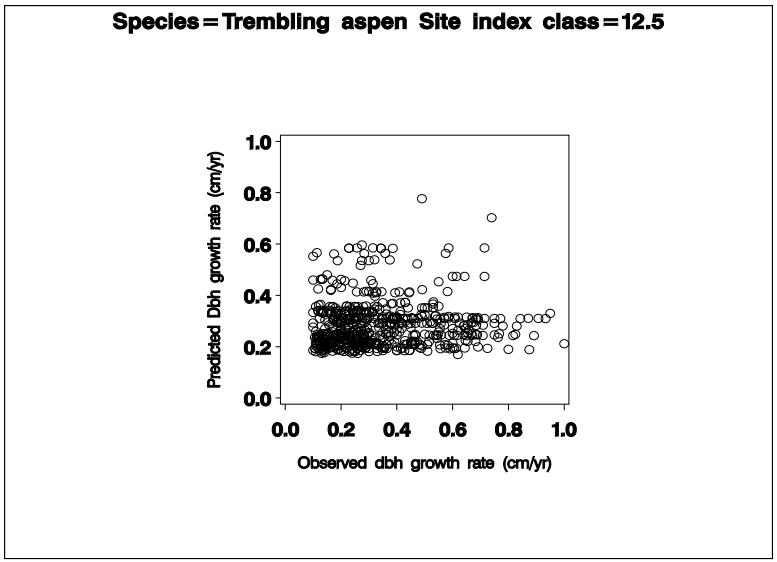

Species=Jack pine Site index class=17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

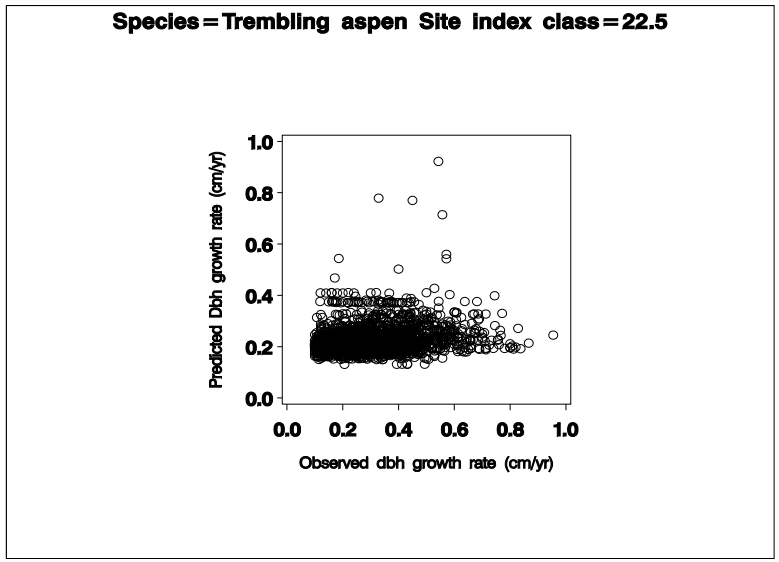

Species = Balsam fir Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

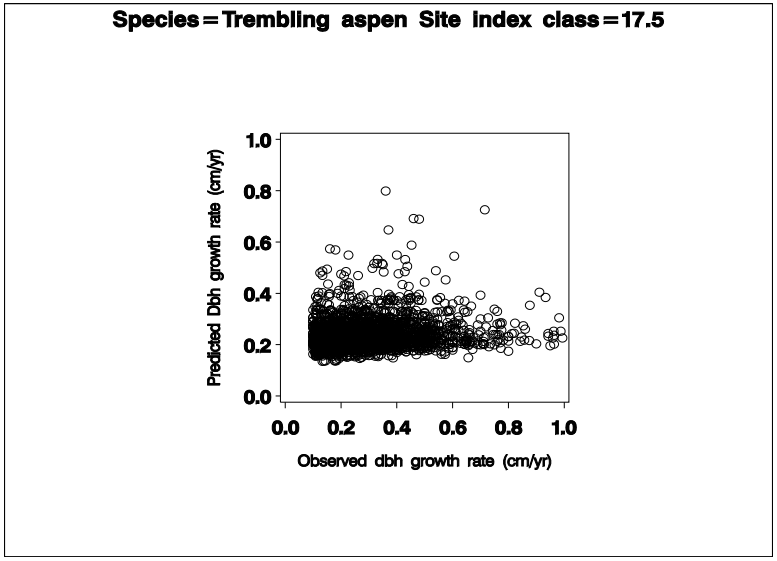

Species = Balsam fir Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

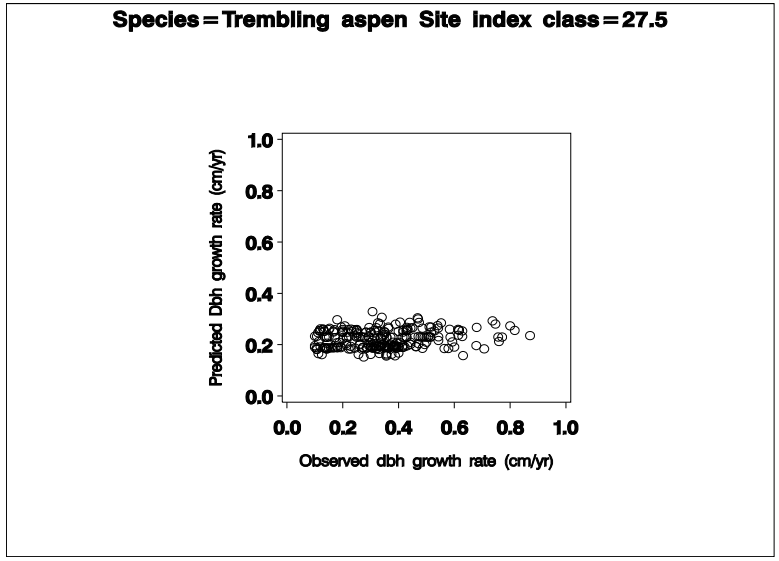

Species = Balsam fir Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

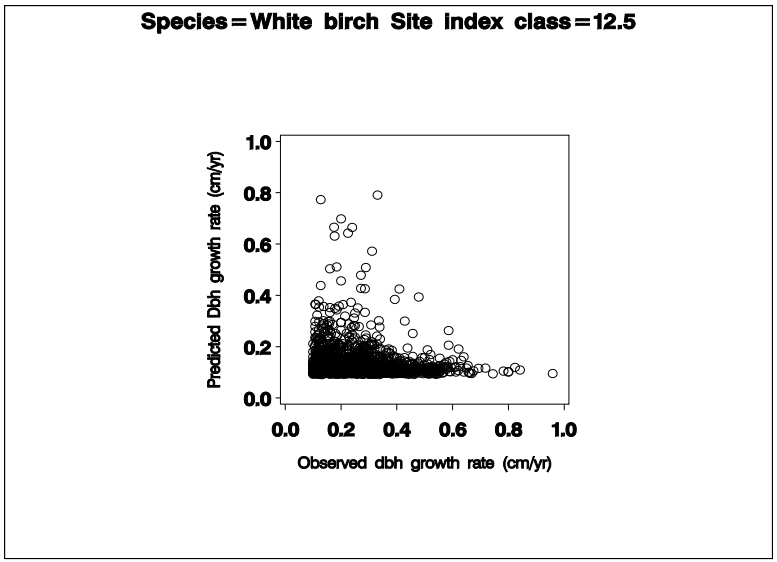

Species = Balsam fir Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

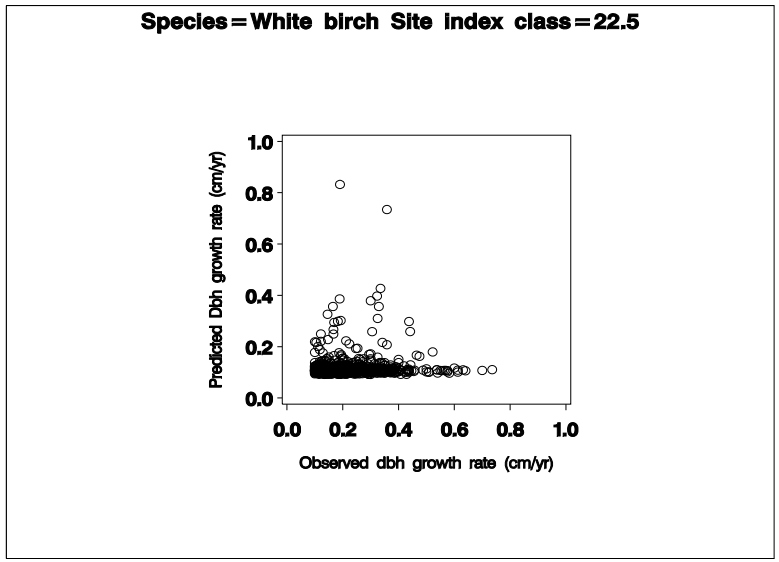

Species = Trembling aspen Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

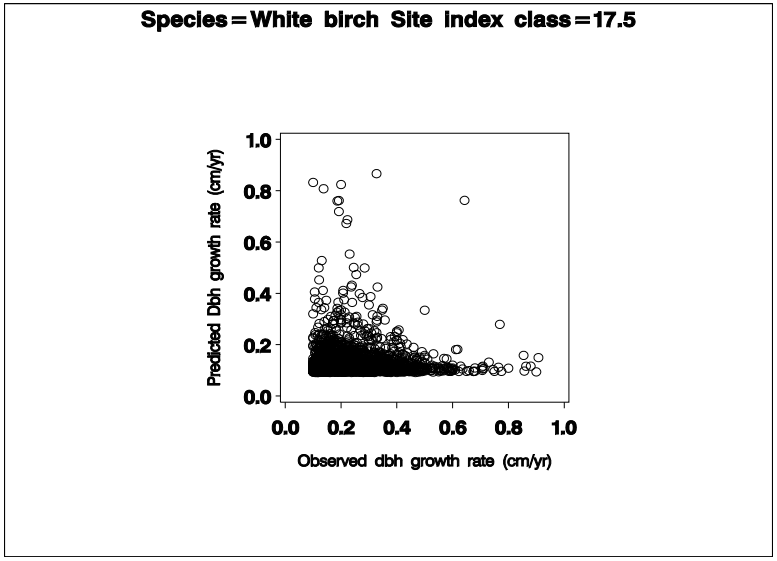

Species = Trembling aspen Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

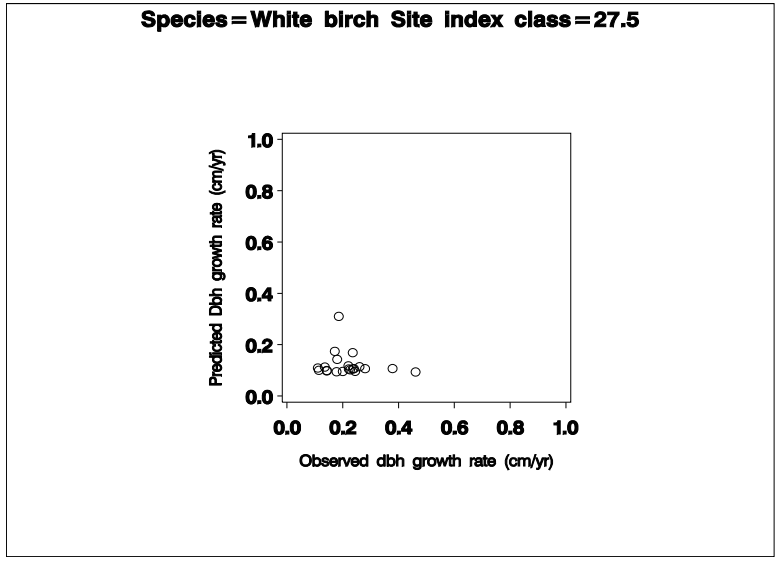

Species = Trembling aspen Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

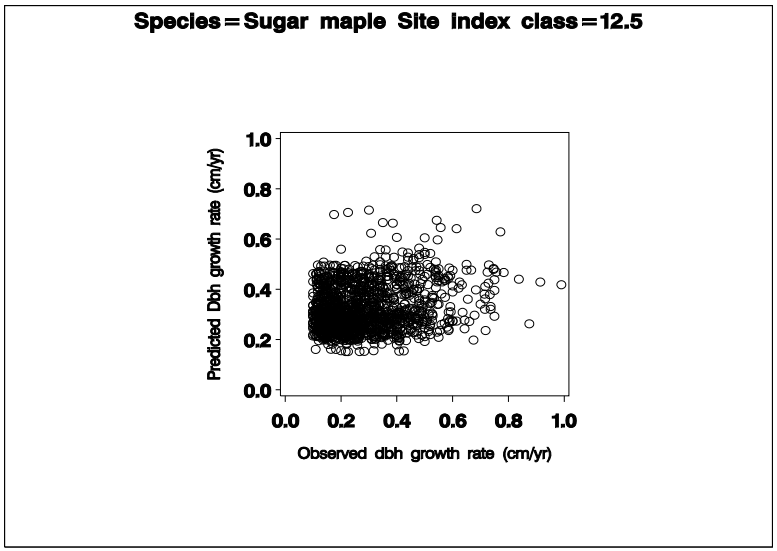

Species = Trembling aspen Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

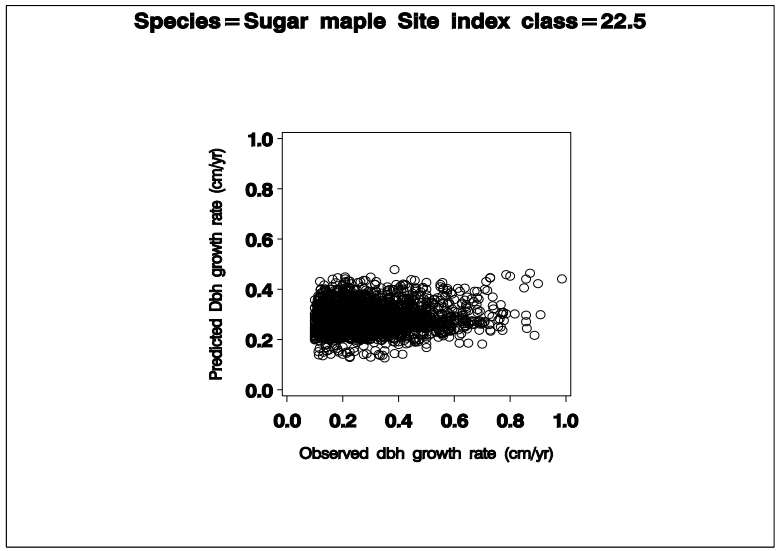

Species=White birch Site index class=12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

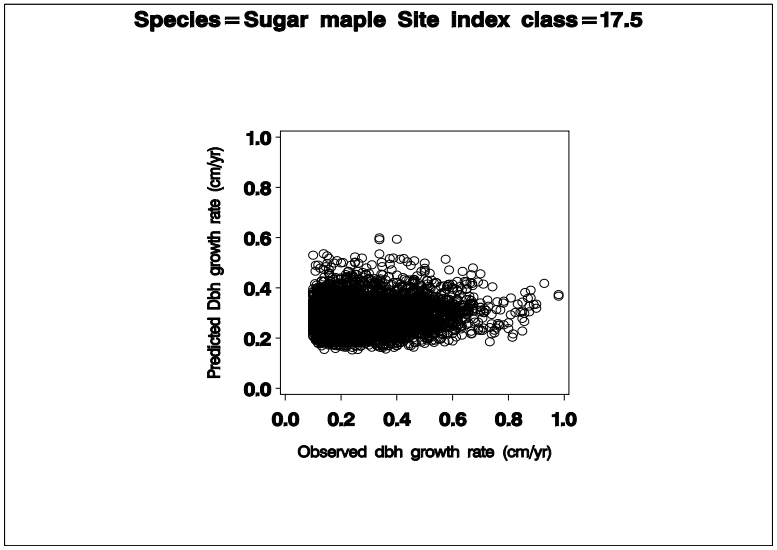

Species=White birch Site index class=22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

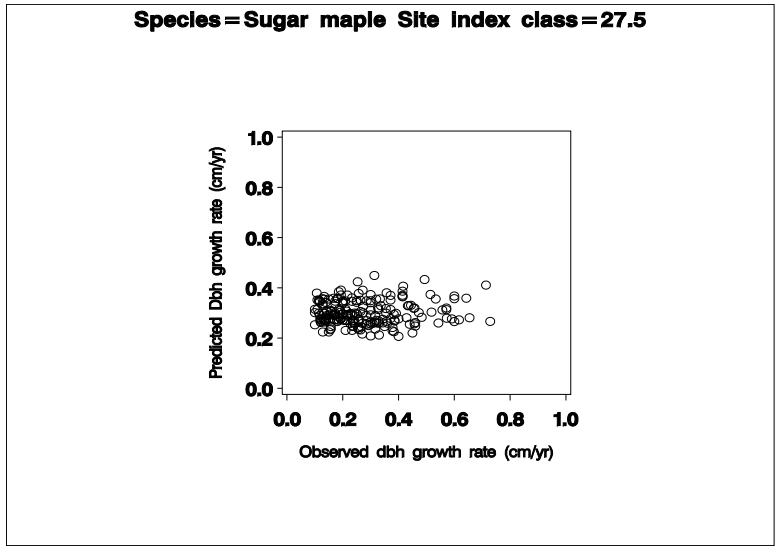

Species=White birch Site index class=17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

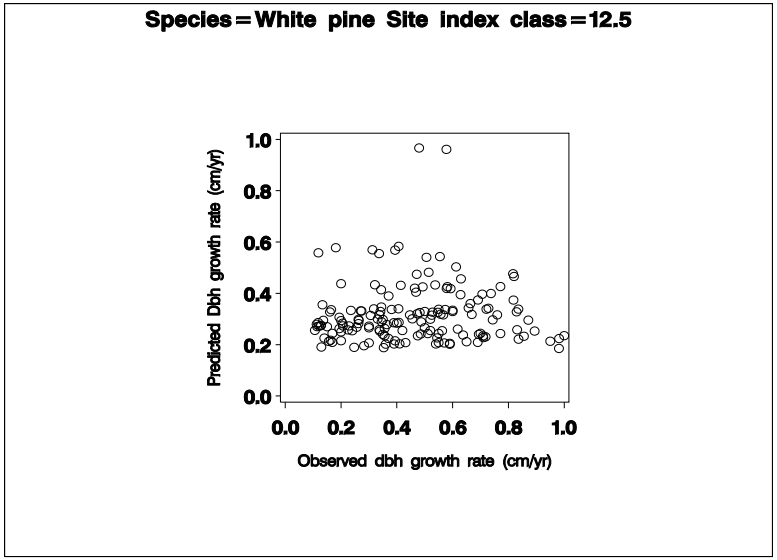

Species=White birch Site index class=27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

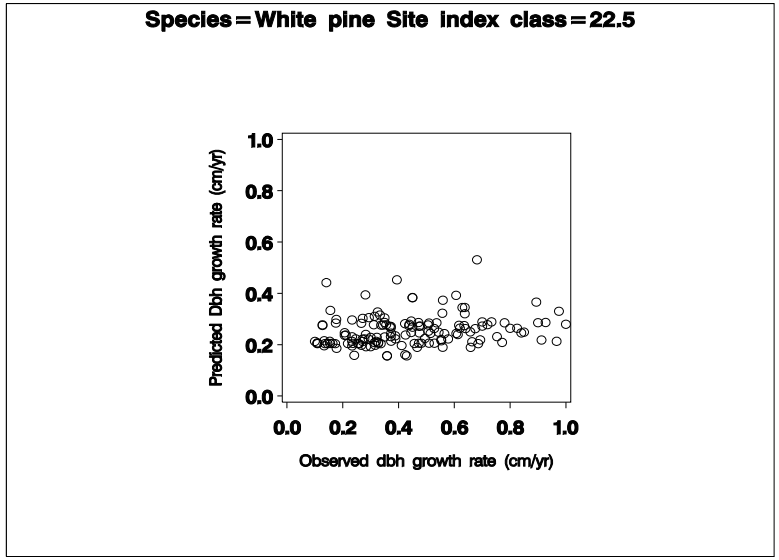

Species=Sugar maple Site index class=12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

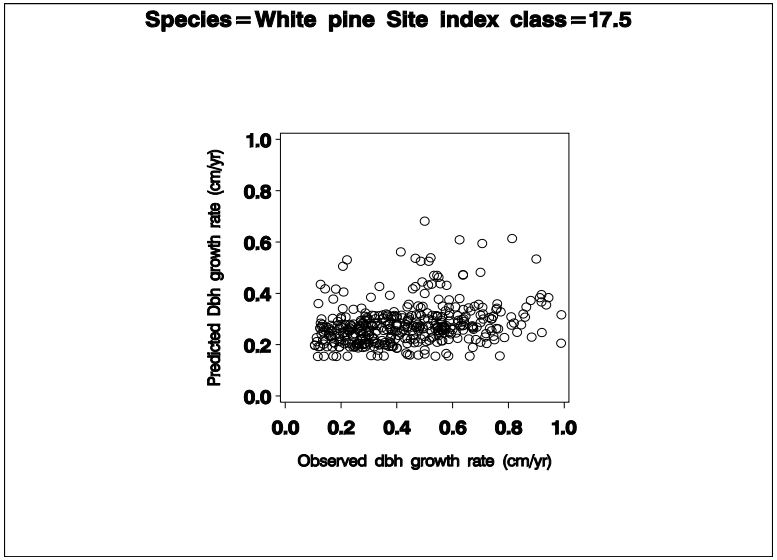

Species=Sugar maple Site index class=22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

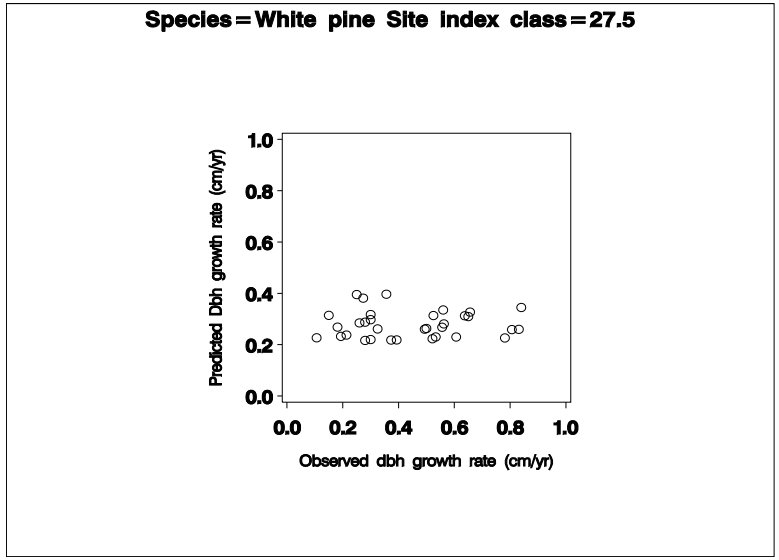

Species=Sugar maple Site index class=17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

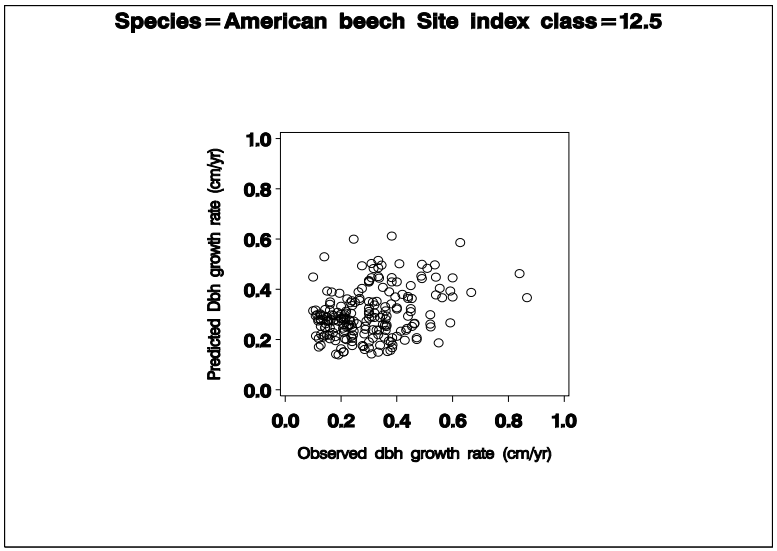

Species=Sugar maple Site index class=27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

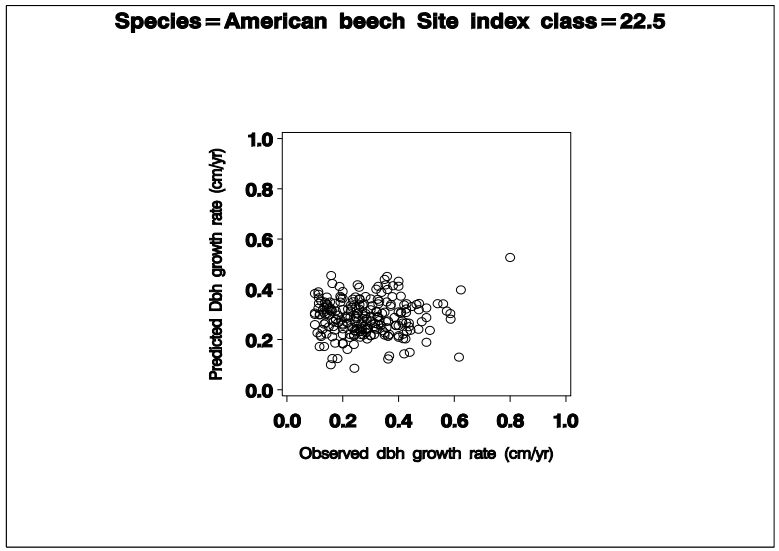

Species = White pine Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

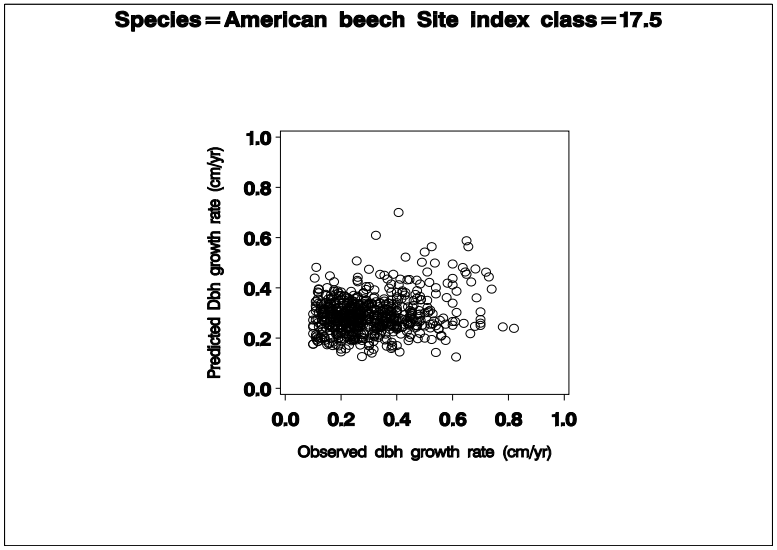

Species = White pine Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

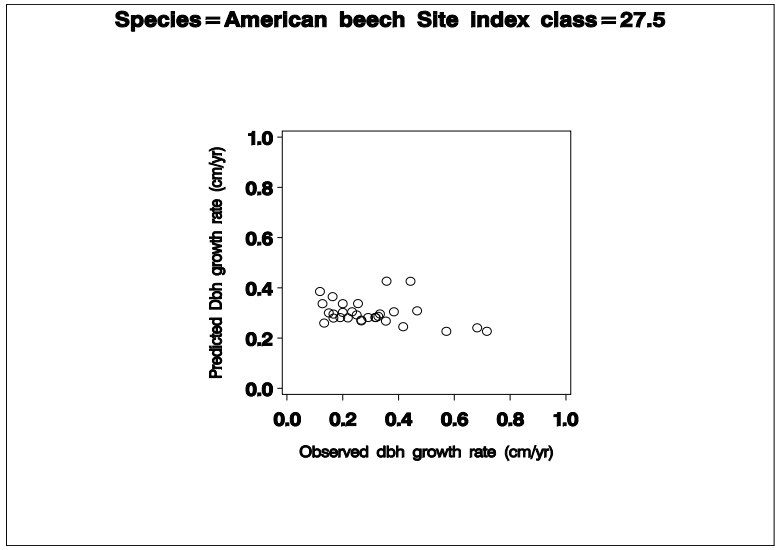

Species = White pine Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

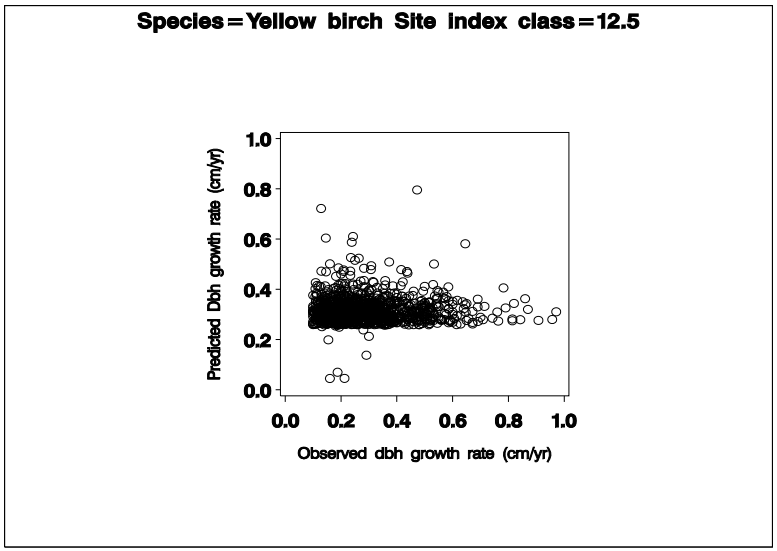

Species = White pine Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

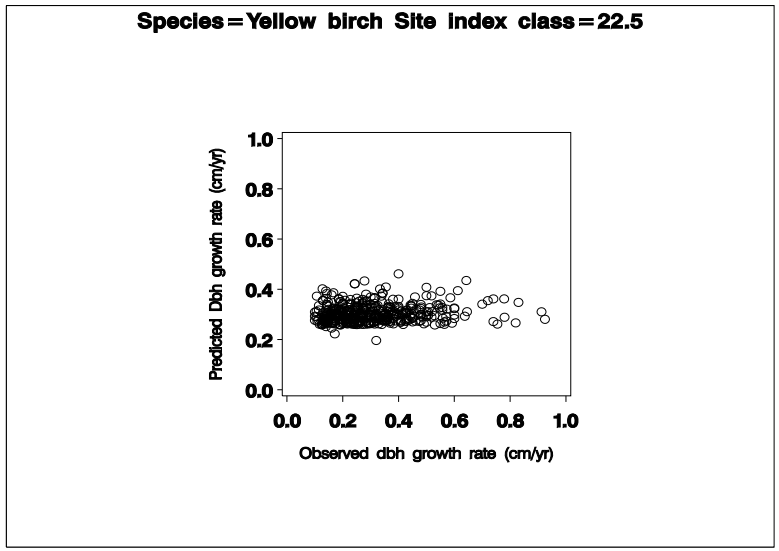

Species=American beech Site index class=12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

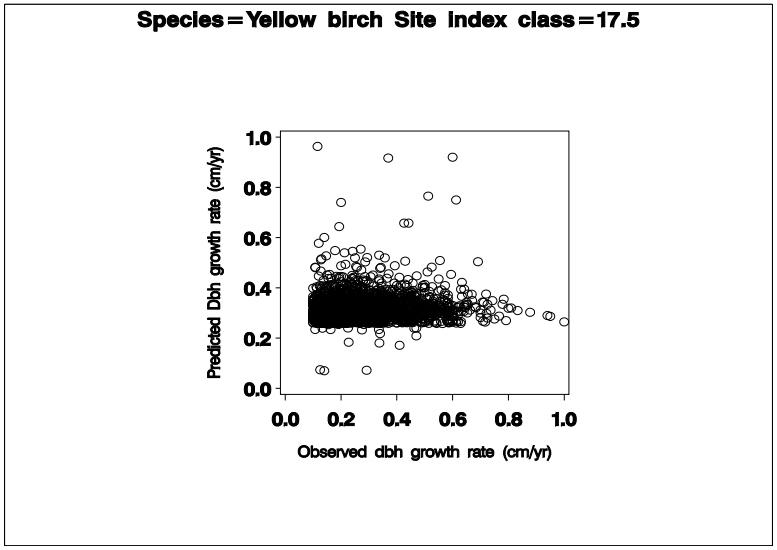

Species=American beech Site index class=22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

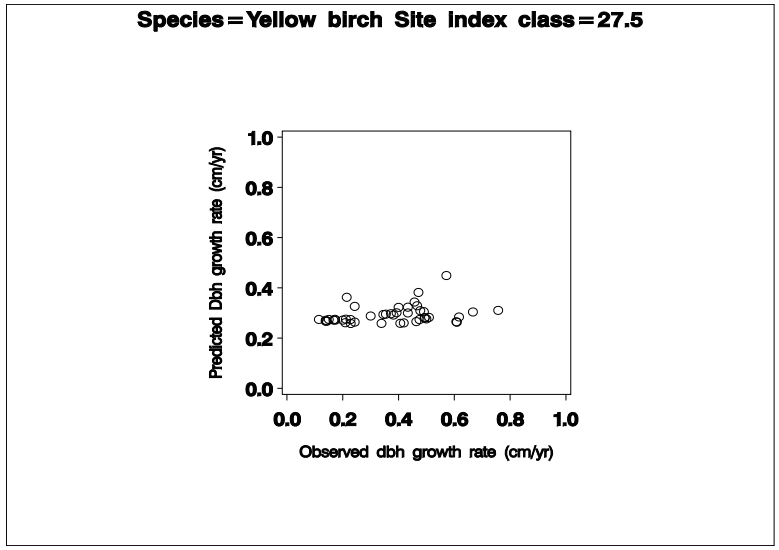

Species=American beech Site index class=17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

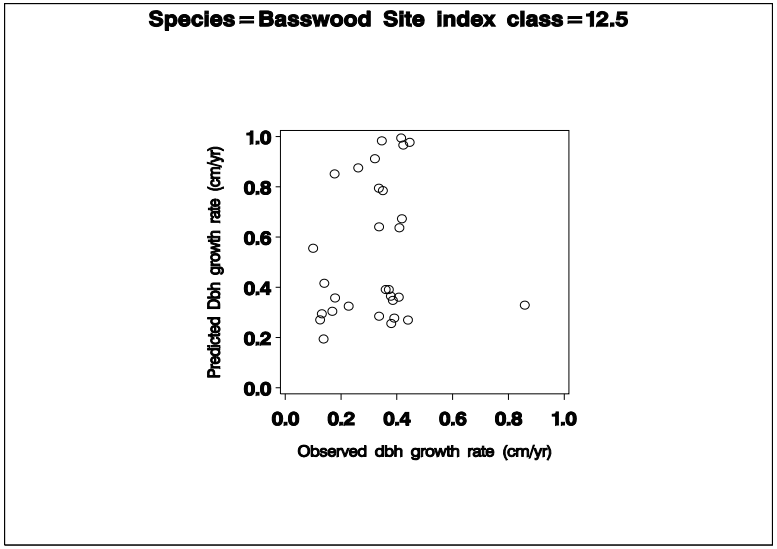

Species=American beech Site index class=27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

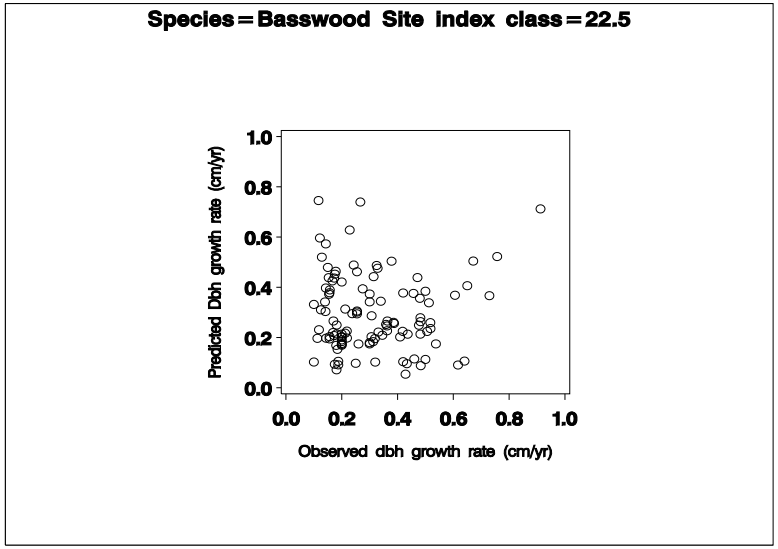

Species = Yellow birch Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

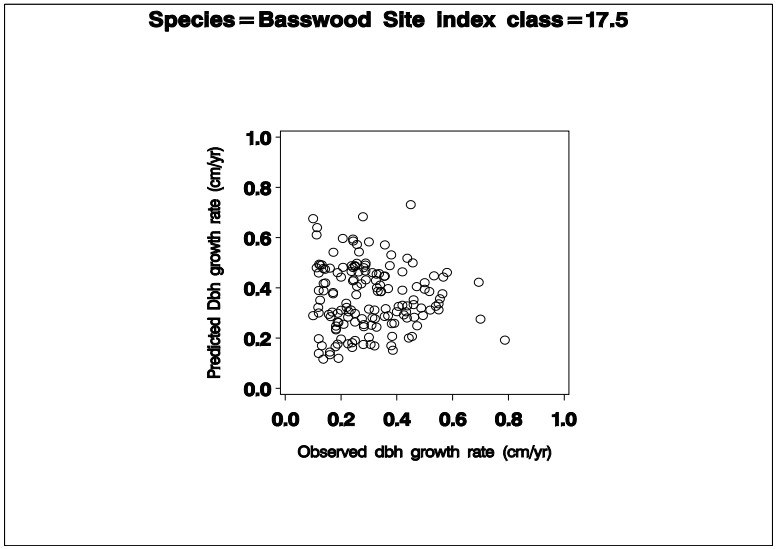

Species = Yellow birch Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

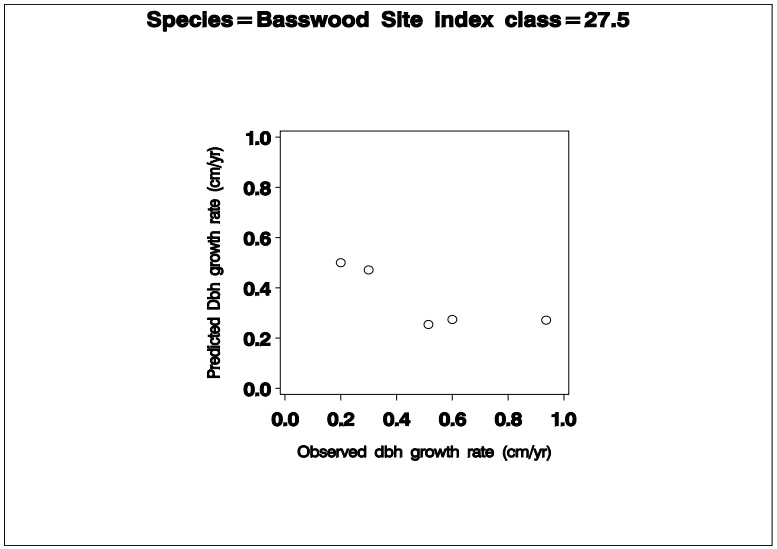

Species = Yellow birch Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

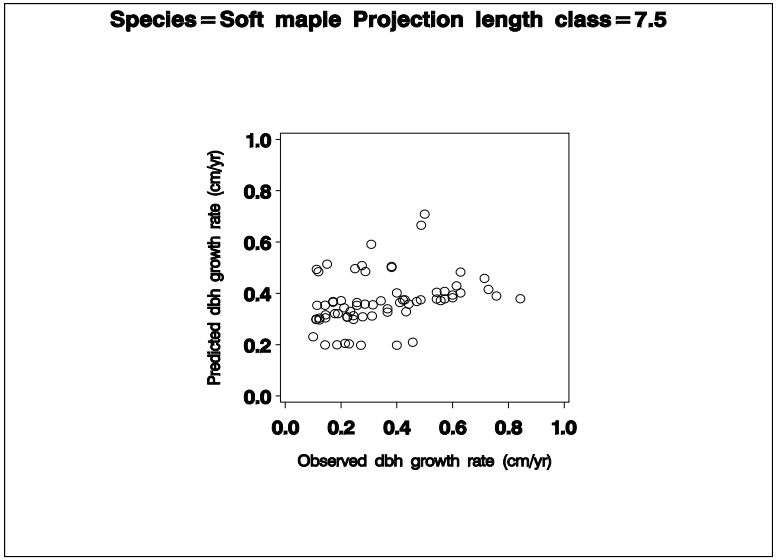

Species = Yellow birch Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

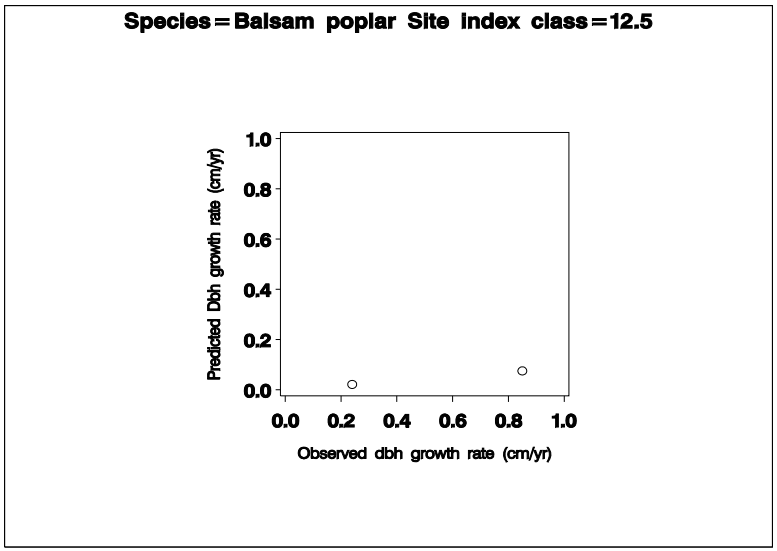

Species = Basswood Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

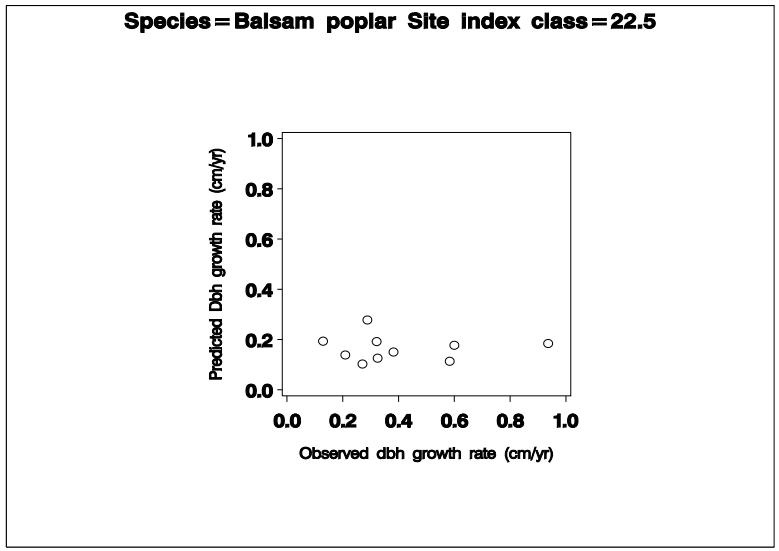

Species = Basswood Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

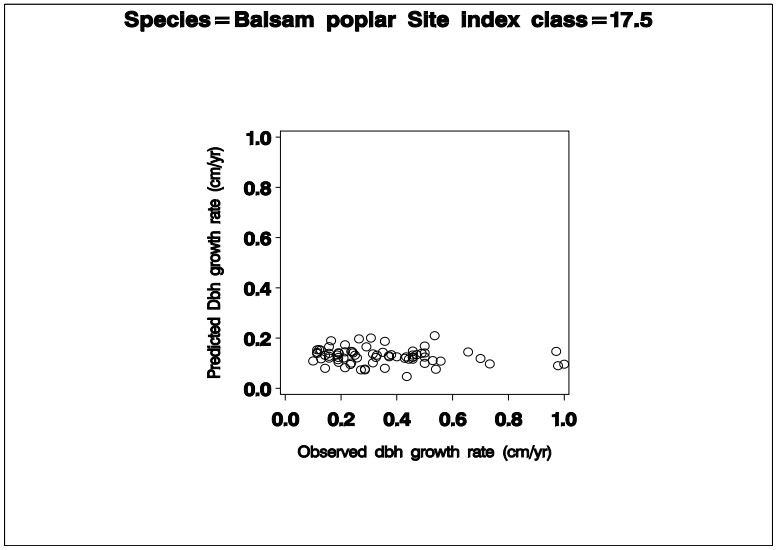

Species = Basswood Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

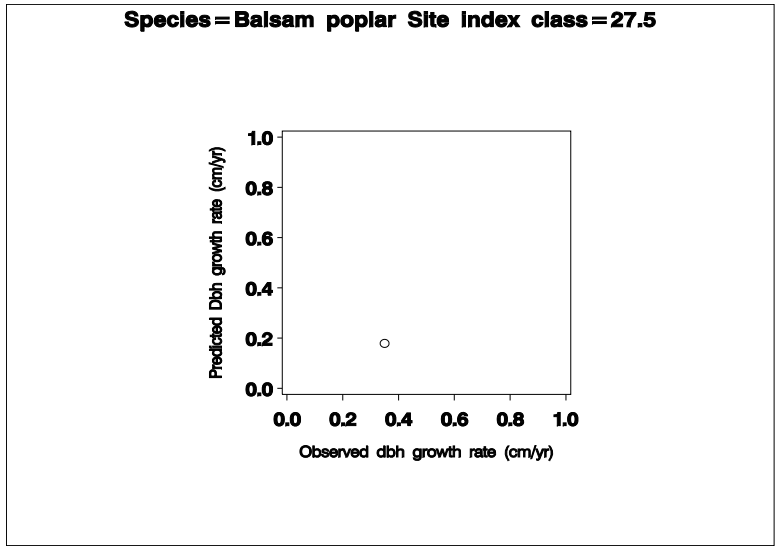

Species = Basswood Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

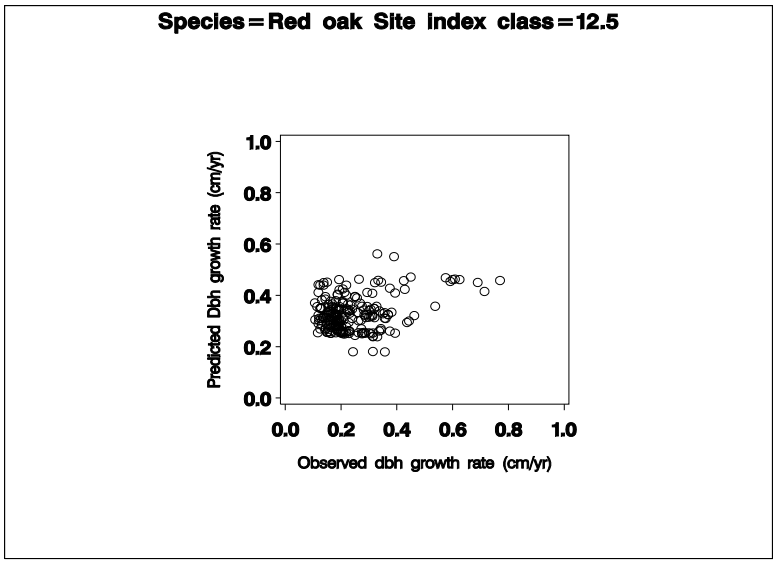

Species=Soft maple Projection length class=7.5
Predicted dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed dbh growth rate (cm/yr)

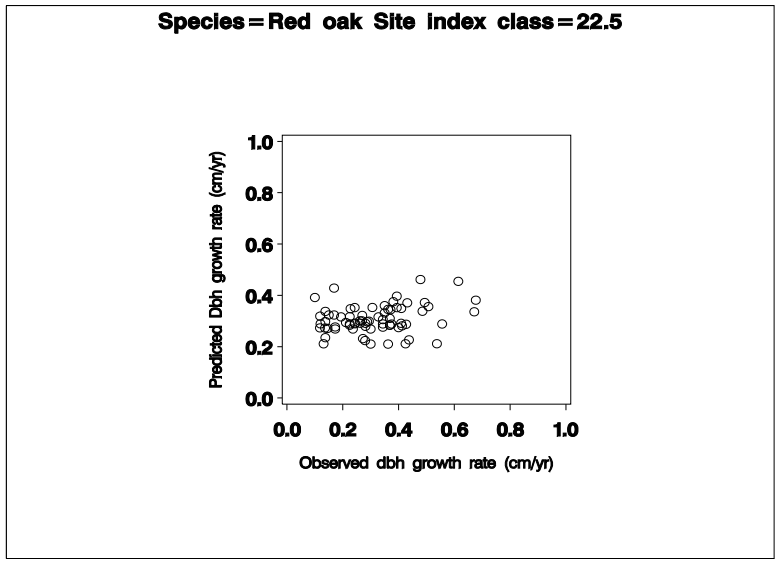

Species=Balsam poplar Site index class=12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

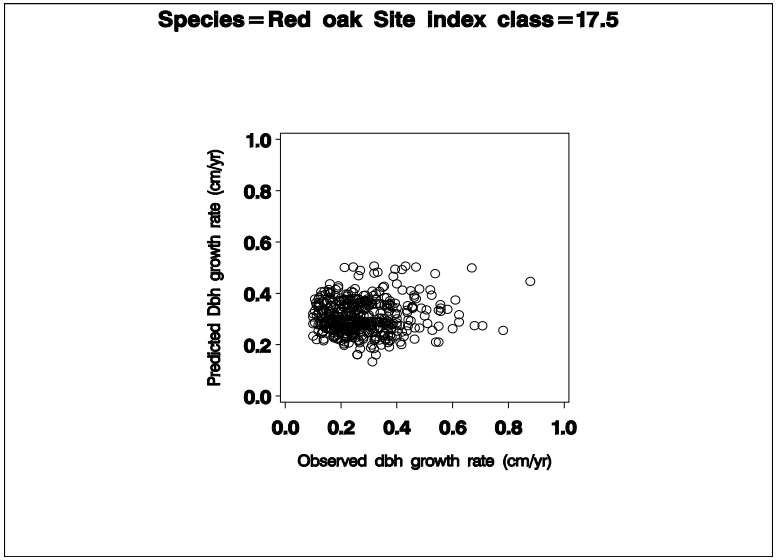

Species=Balsam poplar Site index class=22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

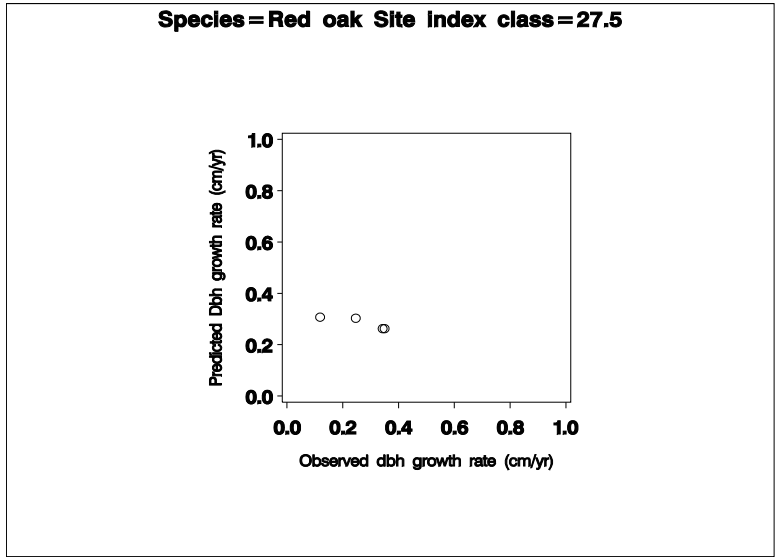

Species=Balsam poplar Site index class=17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

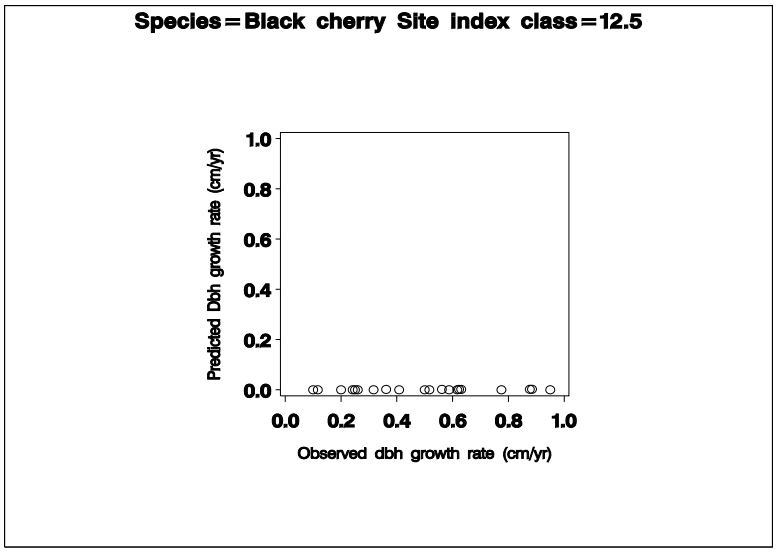

Species=Balsam poplar Site index class=27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

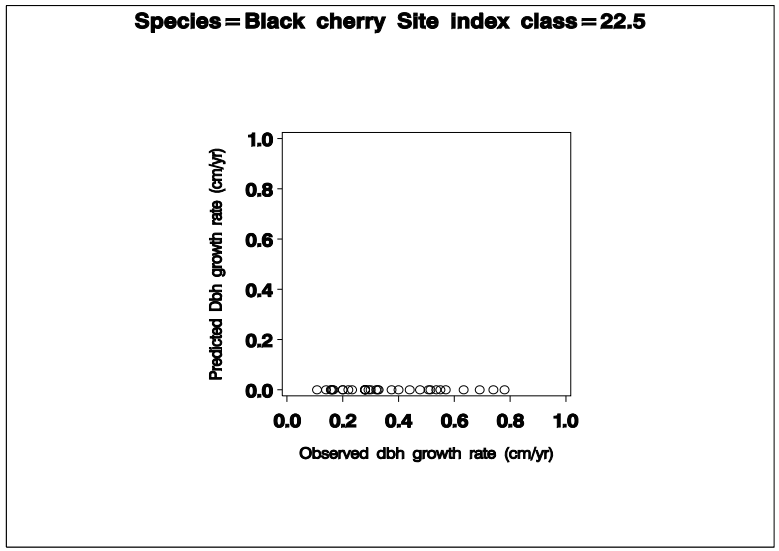

Species = Red oak Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

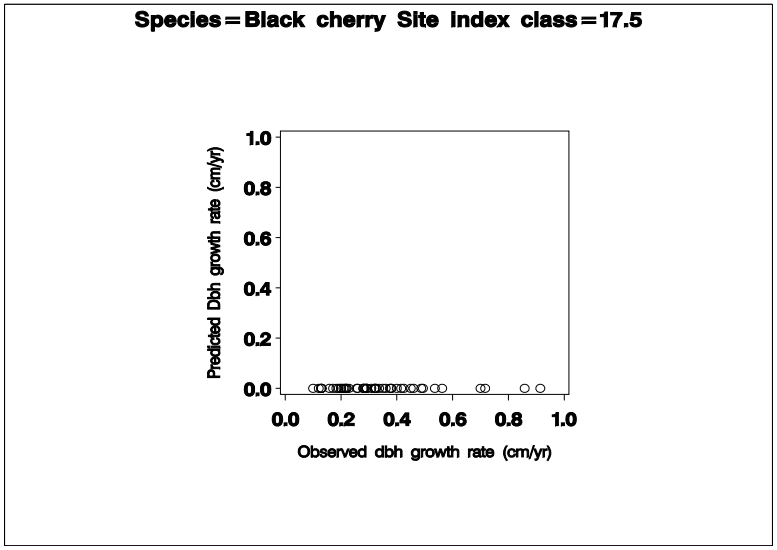

Species = Red oak Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

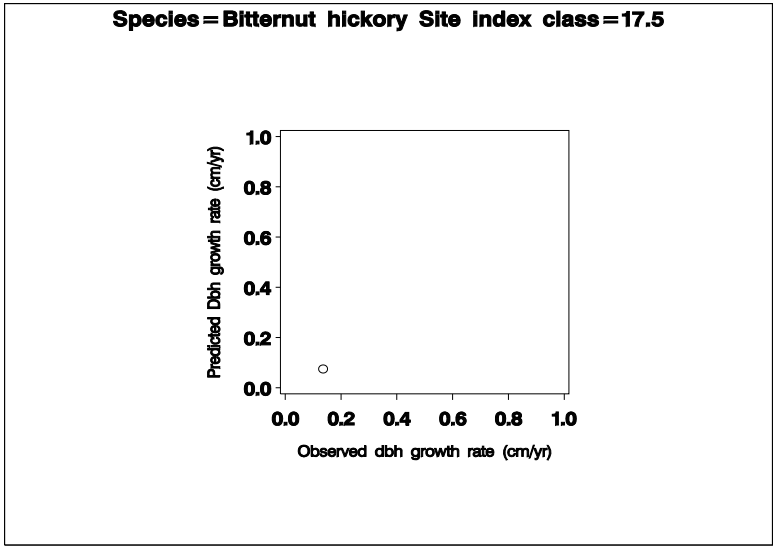

Species = Red oak Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0

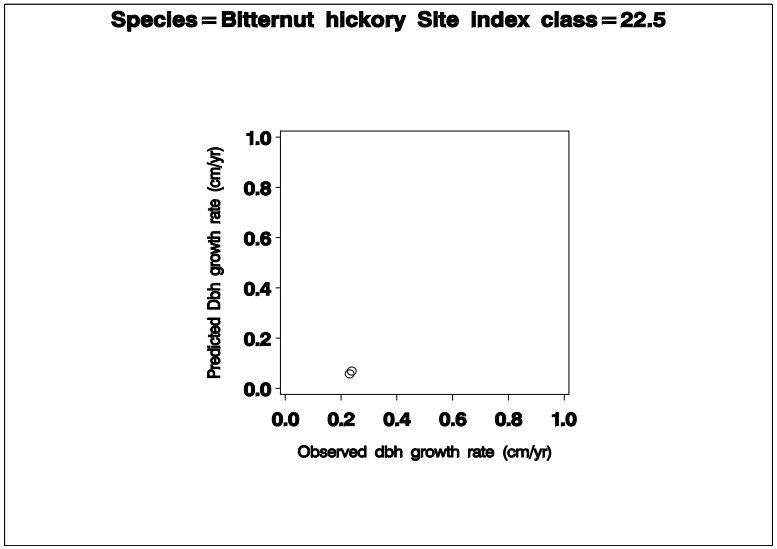

Species = Red oak Site index class = 27.5
Predicted Dbh growth rate (cm/yr)
Observed dbh growth rate (cm/yr)
0.0
0.2
0.4
0.6
0.8
1.0


Species = Black cherry Site index class = 12.5
Predicted Dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)


Species = Black cherry Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)


Species = Black cherry Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)


Species = Bitternut hickory Site index class = 17.5
Predicted Dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)


Species = Bitternut hickory Site index class = 22.5
Predicted Dbh growth rate (cm/yr)
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0
Observed dbh growth rate (cm/yr)