Validation Summary of GYPSY Sub-Models

("Internal" Validation)

Prepared for:

Forest Resources Improvement Association of Alberta

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EXECUTIVE SUMMARY

Alberta Sustainable Resource Development (SRD) has completed the latest revision of the GYPSY model on May 21, 2009. Some of the GYPSY sub-models were re-formulated and re-fitted after FRIAA-GYPSY internal validation project was completed in March 2009.

This latest GYPSY was re-validated against the same internal validation data using the same method as in the previous validation.

This report describes the project objectives and validation methods, and presents results from the various assessments.

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1. Objectives

The objective of the project is to validate four GPYSP sub-models - Top Height Models, Density Models, Basal Area Increment Models, and Gross Total Volume Models using the internal data set provided by Alberta Sustainable Resource Development (SRD).

2. Validation Methods

2.1 Trajectory Plots

1. Observed vs predicted values -age trajectories in side-by-side graphs
2. Error trajectories (e.g., error vs total age)

2.2 Statistics

1. Root mean square error (of prediction)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

2. Goodness-of-fit index

$$GoFI = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

3. Bias ($\bar{e}$)

$$Bias = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}$$

A positive $\bar{e}$ suggests that the model gives predictions that are on average too low (under-estimated by $\bar{e}$ %); and a negative $\bar{e}$, too high (over-estimated by $\bar{e}$ %).

4. Percent bias

$$Bias\% = \frac{Bias}{\bar{y}} \times 100$$

5. Absolute value of mean error

$$Error\_ABS = \frac{\sum_{i=1}^{n} |(y_i - \hat{y}_i)|}{n}$$

6. Percent of absolute value of mean error

$$Error\_ABS\% = \frac{Error\_ABS}{\bar{y}} \times 100$$

Where:

y_i - the i^{th} observed value,

$\hat{y}_i$ - the i^{th} predicted value,

$\bar{y}$ - the mean of the observed values,

n - the total number of observations.

3. Sub-Model Descriptions

The final sub-models and a brief description of each are presented below.

3.1 Top Height Models

Due to the variation in height growth patterns, different forms are used for the top height models for the four GYPSY species:

[1] $$H_{top} = SI_t \times \left(\frac{1 + \exp(b_1 + b_2\sqrt{\ln(1+50)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})}{1 + \exp(b_1 + b_2\sqrt{\ln(1+totage)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})} \right)$$ (AW)

[2] $$H_{top} = SI_t \times \left(\frac{1 + \exp(b_1 + b_2\sqrt{\ln(1+50)} + b_3\ln(SI_t) + b_4\sqrt{50})}{1 + \exp(b_1 + b_2\sqrt{\ln(1+totage)} + b_3\ln(SI_t) + b_4\sqrt{50})} \right)$$ (PL and SB)

[3] $$H_{top} = SI_t \times \left(\frac{1 + \exp(b_1 + b_2\sqrt{\ln(1+50^2)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})}{1 + \exp(b_1 + b_2\sqrt{\ln(1+totage^2)} + b_3[\ln(SI_t)]^2 + b_4\sqrt{50})} \right)$$ (SW)

where:

H_{top} = top height (m), i.e., average height of the 100 largest DBH trees per ha
SI_t = totage-based site index, i.e., top height at 50 years total age
totage = total age from the point of germination

Estimated coefficients for the top height models are listed in Table 1 below.

Table 1. Estimated coefficients for the top height models.

	Model 1	Model 2		Model 3
Parameter	**AW**	**PL**	**SB**	**SW**
b_1	9.90889	12.84571	14.56236	12.14943
b_2	-3.92451	-5.73936	-6.04705	-3.77051
b_3	-0.32778	-0.91312	-1.53715	-0.28534
b_4	0.13438	0.150668	0.240174	0.165483

3.2 Density Models (non-spatial)

The density models describe stand density changes over time. They are functions of age, current or initial density, site quality and species mixtures. All models are species-specific. In GYPSY, stand density is defined differently for different stand types and species (coniferous versus deciduous).

- *Fire-origin stand:* stand density always refers to stems/ha of the subject species > 1.3 m tall
- *Post-harvest stand:* for AW, stand density refers to stems/ha for aspen trees > 1.3 m tall; for SB, SW and PL, stand density refers to stems/ha of the subject species > 0.3 m tall

Aspen

[4] $$N = SDF_{aw} \times \left(\frac{1+\exp[b_1 + b_2 SI_{bh} + b_3 \ln(1+50)]}{1+\exp[b_1 + b_2 SI_{bh} + b_3 \ln(1+bhage)]} \right)$$

$$b_1 = -\left(\frac{1}{\sqrt{SDF_{aw}/1000}} + \sqrt{1+\sqrt{\frac{50}{\sqrt{SDF_{aw}}\cdot \ln(1+50)}}} \right) \times \ln(1+50)$$

$$b_2 = \frac{c_0}{4}\left(\sqrt{SDF_{aw}}\right)^{1/SDF_{aw}}$$

$$b_3 = (1+c_0) SDF_{aw}^{\left[\frac{c_1+\ln(SDF_{aw})}{SDF_{aw}}\right]}$$

$c_0 = 0.717966$, and $c_1 = 6.67468$.

Black spruce

[5] $$N = SDF_{sb} \times \left(\frac{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+50)]}{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+totage)]} \right)$$

$$b_1 = \frac{c_1}{\left(\sqrt{SDF_{sb}/1000} + \ln(1+50)\right)^{c_2}}$$

$$b_2 = c_3$$

$$b_3 = c_3 SDF_{sb}^{\,1/SDF_{sb}}$$

c_1 = -26.3836, c_2 = 0.166483, and c_3 = 2.738569.

White spruce

[6] $$N = SDF_{sw} \times \left(\frac{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+50)]}{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+totage)]} \right)$$

$$b_1 = \frac{c_1}{\left(\ln(SDF_{sw}) + \ln(1+50)\right)^{c_2}} + z_1 \sqrt{1 + SDF_{aw}/1000}$$

$$b_2 = c_3$$

$$b_3 = c_3 SDF_{sw}^{\,1/SDF_{sw}}$$

c_1 = -231.617, c_2 = 1.176995, and c_3 = 1.733601.

if SDF_aw = 0 then z1 = 0; if SDF_aw > 0 then z1 = 1.

Lodgepole pine

[7] $$N = SDF_{pl} \times \left(\frac{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+50)]}{1 + \exp[b_1 + b_2 \ln(SI_{bh}) + b_3 \ln(1+totage)]} \right)$$

$$b_1 = \left(c_1 + \frac{z_1 (SDF_{aw}/1000)}{2} + \frac{z_2 (SDF_{sw}/1000)}{3} + \frac{z_3 (SDF_{sb}/1000)}{4} \right) + \frac{c_2}{\left(\sqrt{SDF_{pl}}\right)^{c_3}}$$

$$b_2 = \frac{c_4}{\left(\sqrt{SDF_{pl}}\right)^{c_5}}$$

$$b_3 = c_4 SDF_{pl}^{k}, \quad k = \frac{1 + c_6 \sqrt{SDF_{pl}}}{SDF_{pl}}$$

c_1 = -5.25144, c_2 = -483.195, c_3 = 1.138167, c_4 = 1.017479, c_5 = -0.05471, and c_6 = 4.11215.

if SDF_aw = 0 then z1 = 0; if SDF_sw = 0 then z2 = 0; if SDF_sb = 0 then z3 = 0.
if SDF_aw > 0 then z1 = 1; if SDF_sw > 0 then z2 = 1; if SDF_sb > 0 then z3 = 1.

Where in [4]-[7]:

N = density (stems/ha) of the subject species
SDF_{aw} = stand density factor for AW, which is N at 50 years bhage
SDF_{sb} = stand density factor for SB, which is N at 50 years totage
SDF_{sw} = stand density factor for SW, which is N at 50 years totage
SDF_{pl} = stand density factor for PL, which is N at 50 years totage
SI_{bh} = site index (m) of the subject species at 50 years bhage

3.3 Basal Area Increment Models (non-spatial)

The basal area increment models provide annual basal area increment predictions. They are functions of breast height age, site index, density, basal area, and species composition (SC), where SC refers to the ratio of stand densities between the subject species and all species combined ($SC = N_{species}/N_{all}$). All models are species-specific. They can be used to make basal area predictions whether the current stand basal area is available or not.

Aspen
[8]

$$BAINC = \frac{10^{-4} a_1 Bhage_1^2 \exp\left(-a_2 Bhage_1^{(1/2+a_1)}\right)\cdot[\ln(1+N_0\sqrt{1+Bhage_1})]^2 SI_{aw} SC_1^{a_5}}{(1+BA_1)^{a_3}\left[1+\exp\left(1-\frac{\ln(1+SC_1^2)}{2}\right)\right]} + k$$

$$k = a_4 \ln(0.01 + Bhage_1/10)$$

a_1 = 0.751313, a_2 = 0.018847, a_3 = 1.143762, a_4 = -0.03475, and a_5 = 0.835189.

Black spruce

[9] $$BAINC = 10^{-4} a_1 \exp(-a_2 Bhage_1) Bhage_1^{(\sqrt{a_1}+a_2)} SC_1^{a_3}\cdot k$$

$$k = \frac{(1+\sqrt{N_0}\cdot\sqrt{1+Bhage_1})\ln(1+SI_{sb})\exp\left(-\frac{N_0/4}{10000}\right)}{(1+BA_1)^{a_2}}$$

a_1 = 0.966285, a_2 = 0.056315, and a_3 = 0.17191.

White spruce

[10] $$BAINC = \frac{10^{-4} a_1 (a_2 + Bhage_1)^2 (1 + Bhage_1)^{(\sqrt{a_1}+a_2-a_3)} \exp(-a_2 Bhage_1) SC_1^{a_6} \cdot m}{\left[1 + \exp\left(1 + k + \frac{\ln\left(1 + \sqrt{N_0}/10000\right)}{2} + a_3 \ln(1 + BA_1)\right)\right]}$$

$$m = [\ln(1 + N_0 \sqrt{1 + Bhage_1})]^2 \sqrt{SI_{sw}} \exp\left(-\frac{N_0/10}{10000}\right)$$

$$k = a_4 z_1 \ln\left(1 + \frac{SDF_{aw}}{10000}\right) + a_5 z_2 \ln\left(1 + \frac{SDF_{pl}}{10000}\right) + z_3 \ln\left(1 + \frac{SDF_{sb}}{10000}\right)$$

a_1 = 0.089153, a_2 = 0.072171, a_3 = -0.11483, a_4 = 5.839408,
a_5 = 1.753002, a_6 = 0.239521.

if SDF_{aw} = 0 then z_1 = 0; if SDF_{pl} = 0 then z_2 = 0; if SDF_{sb} = 0 then z_3 = 0;
if SDF_{aw} > 0 then z_1 = 1; if SDF_{pl} > 0 then z_2 = 1; if SDF_{sb} > 0 then z_3 = 1.

Lodgepole pine

[11] $$BAINC = \frac{10^{-4} a_1 Bhage_1 \exp(-a_2 Bhage_1)\left(1 + \frac{\ln(1 + Bhage_1)}{2}\right) \cdot m_1}{\left[1 + \exp\left(\frac{k}{2} + \ln\left(1 + \frac{1}{3} \cdot \frac{N_0}{10000}\right) - a_3 \sqrt{SC_1} + a_4 \ln(1 + BA_1)\right)\right]} + m_2$$

$$m_1 = (1 + a_3 + SI_{pl}{}^{a_6}) \sqrt{N_0} \exp\left(-\frac{1}{3} \cdot \frac{N_0}{10000}\right)$$

$$m_2 = a_5 \ln(0.01 + Bhage_1/10)$$

$$k = z_1 \ln\left(1 + \frac{SDF_{aw}}{1000}\right) + \frac{z_2}{2} \ln\left(1 + \frac{SDF_{sw}}{1000}\right) + \frac{z_3}{2} \ln\left(1 + \frac{SDF_{sb}}{1000}\right)$$

a_1 = 3.923984, a_2 = 0.05752, a_3 = 0.560402, a_4 = 0.672506,
a_5 = -0.00358, and a_6 = 0.775765.

if SDF_{aw} = 0 then z_1 = 0; if SDF_{sw} = 0 then z_2 = 0; if SDF_{sb} = 0 then z_3 = 0;
if SDF_{aw} > 0 then z_1 = 1; if SDF_{sw} > 0 then z_2 = 1; if SDF_{sb} > 0 then z_3 = 1.

Where in [8]-[11]:

BAINC = annual basal area increment for the subject species (m^2/ha/year)
$Bhage_1$ = current breast height age (years)
N_0 = initial density at bhage zero (for AW)
N_0 = initial density at totage zero (for SB, SW and PL)
$SI_{species}$ = site index (SI_{bh}, m) at 50 years bhage
SC_1 = current species composition ($N_{species}/N_{all}$)
BA_1 = current basal area (m^2/ha) for the subject species

In practice, GYPSY users can assume that for aspen, the initial density at bhage zero is equivalent to the initial density at totage zero.

3.4 Gross Total Volume Models

The gross total volume models predict the species-specific gross total volume of a stand at a 0/0 utilization standard based on the top height and basal area of the subject species.

White spruce and black spruce:

[12] $$Tvol = \beta_1 BA^{\beta_2} H_{top}^{\beta_3}$$

Aspen and lodgepole pine:

[13] $$Tvol = \beta_1 BA^{\beta_2} H_{top}^{\beta_3} \exp\left(1 + \frac{\beta_4}{H_{top}^2 + 1}\right)$$

Where in [24]-[25]:

Tvol = gross total volume (m^3/ha) of the subject species at the 0/0 utilization standard
BA = total basal area (m^2/ha) of the subject species
H_{top} = top height (m) of the subject species

Estimated coefficients for the gross total volume models are listed in Table 3.

Table 2. Estimated coefficients for the gross total volume models.

	Model [12]		Model [13]	
Parameter	**SB**	**SW**	**AW**	**PL**
b_1	0.48628	0.41104	0.24872	0.24872
b_2	0.98296	0.98311	0.98568	0.98568
b_3	0.9106	0.97106	0.85728	0.85728
b_4			-24.9961	-24.9961

4. Results

The validation results are presented by sub-models respectively, in the following sections.

4.1 Top Height Models

4.1.1 Simulating Projections – totage>=10

Site index was calculated by limiting totage>=10 years in this round.

Site index trajectories

The stability of site index over age can be examined from the site index trajectories on two different scales (Figure 3). On the left side of the figure are the site index trajectories on the smaller scales, while on the right side are the trajectories on the larger scales.

Top height forward and backward projections

The forward projections were generated based on the information of the first observation, while the backward projections were generated based on the information of the last observation (of the same plot).

The graphs of observed top height vs. totage trajectories, projections and errors are presented in Figures 2 - 5. In the figures, left graphs are from forward projection, while right graphs are from backward projection.

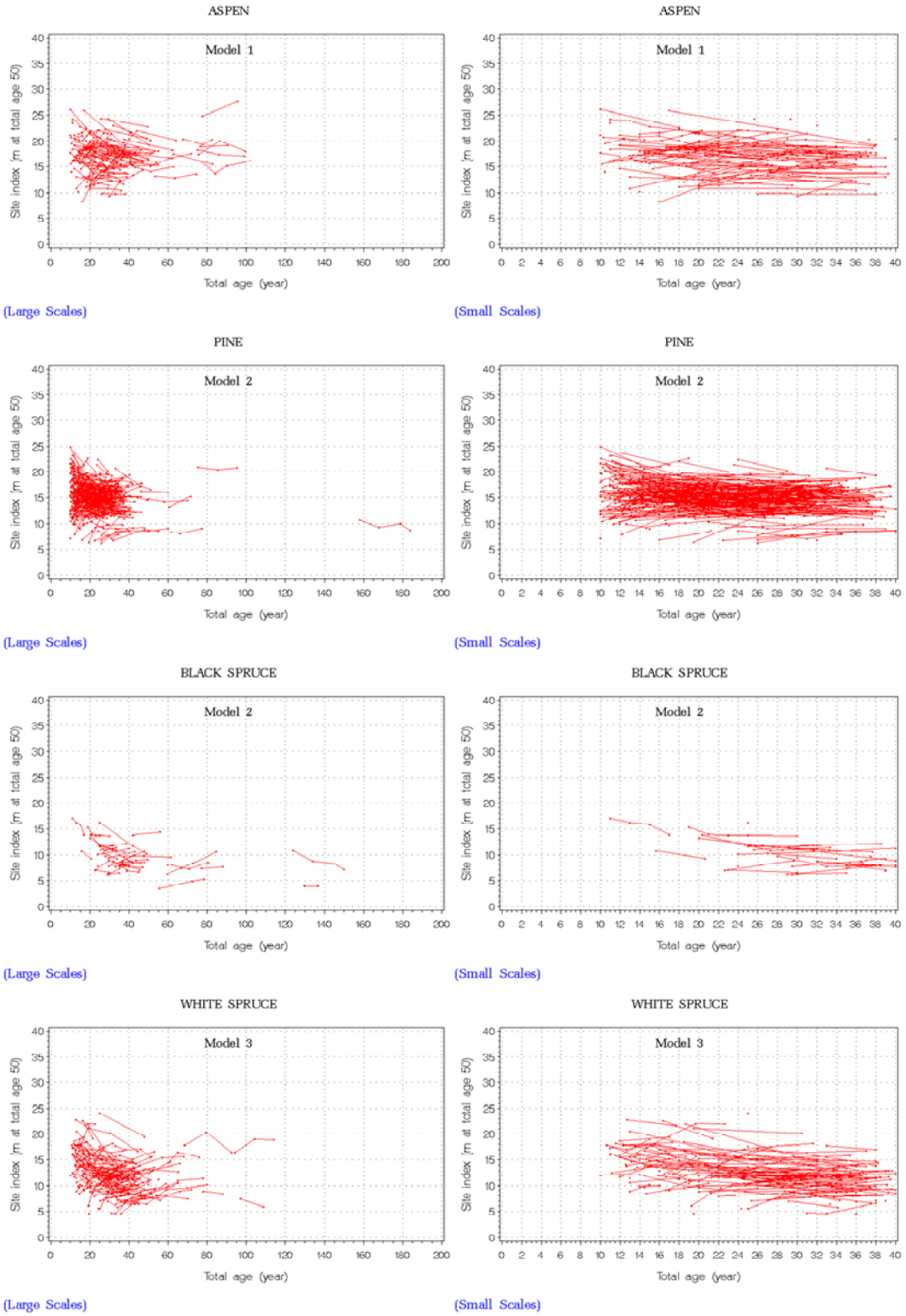


Figure 1. Site index trajectories (totage>=10).

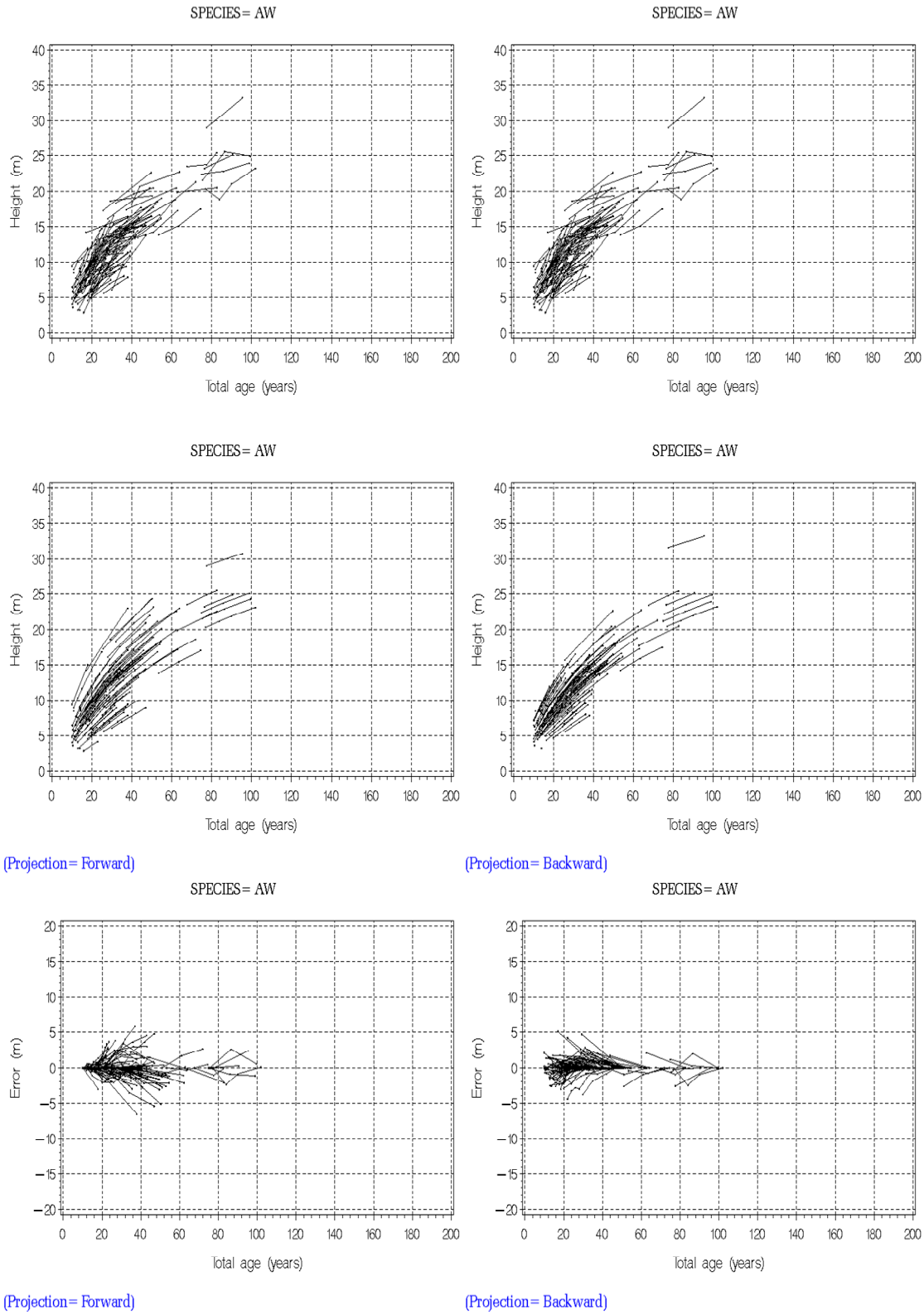


Figure 2.Top height vs. age with projections for AW (totage>=10).

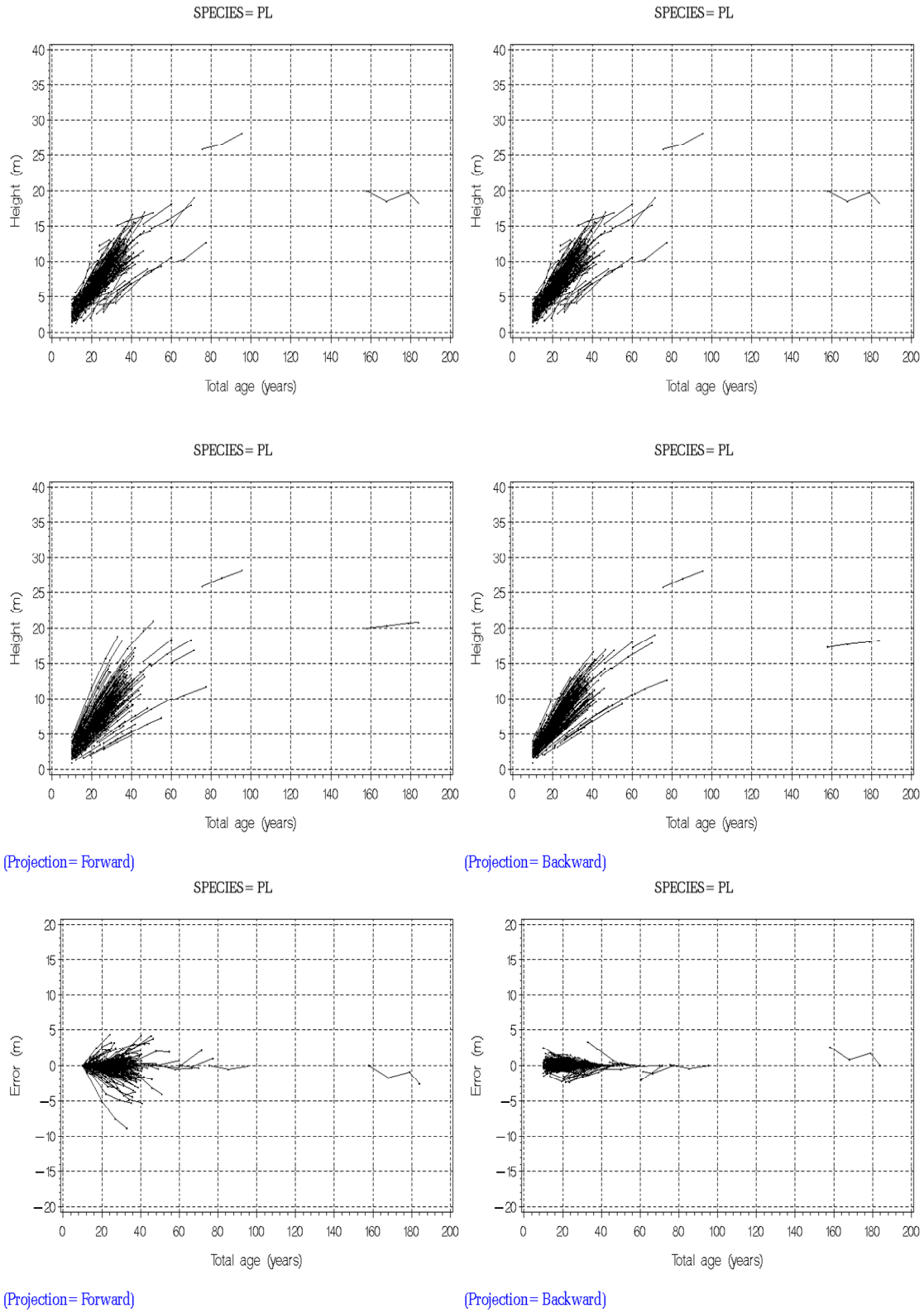


Figure 3. Top height vs. age with projections for PL (totage>=10).

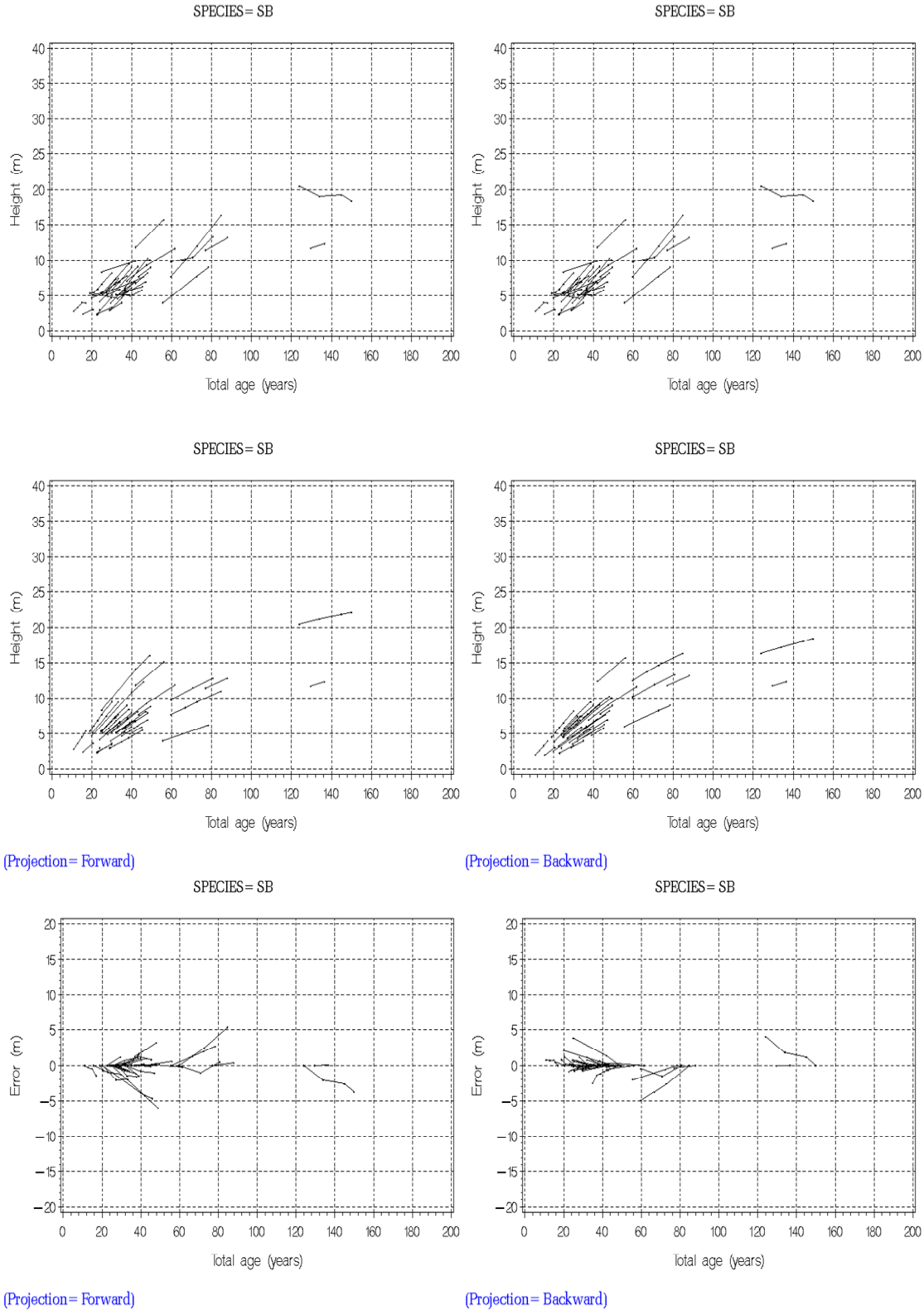


Figure 4. Top height vs. age with projections for SB (totage>=10).

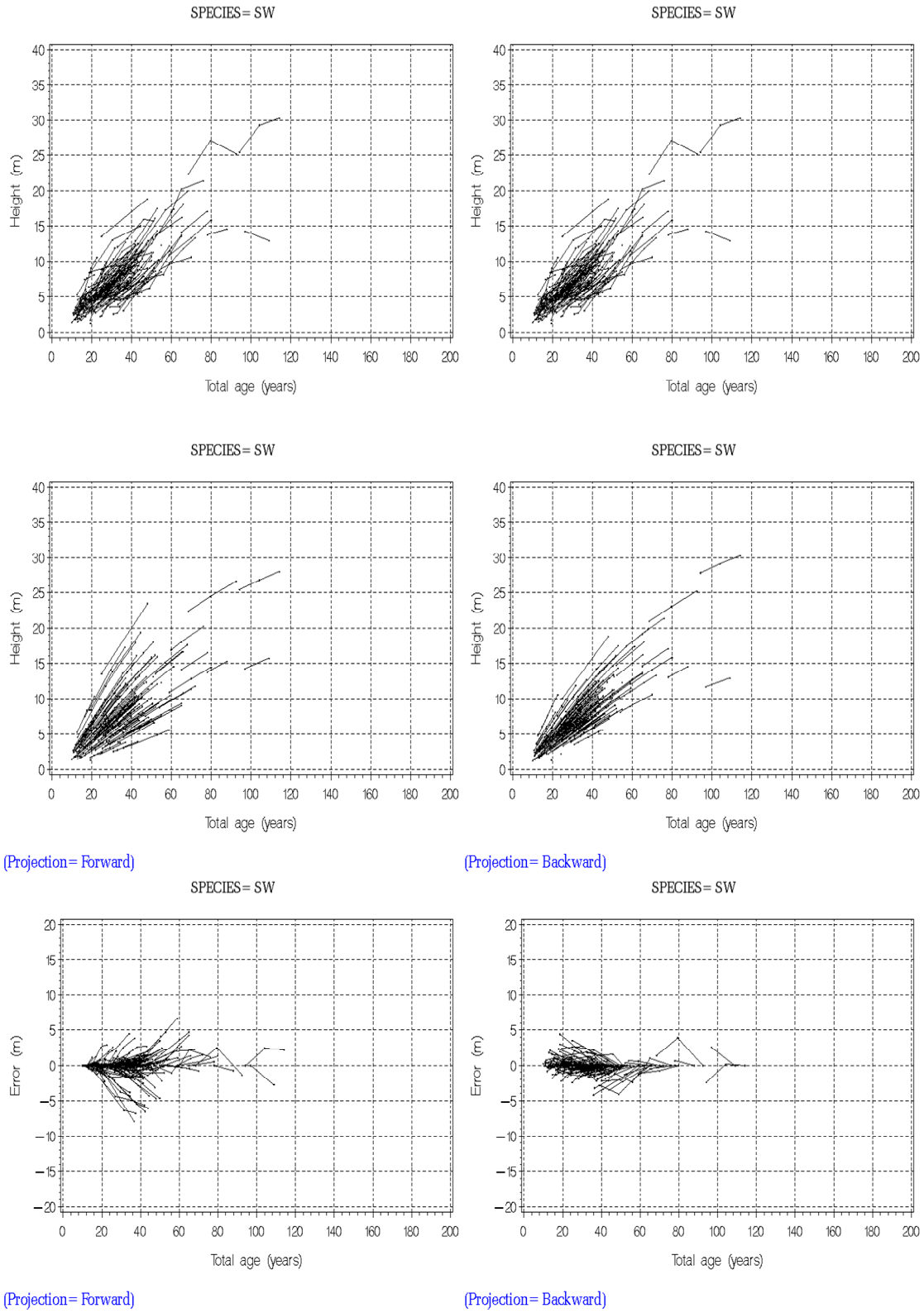


Figure 5. Top height vs. age with projections for SW (totage>=10).

When plots have only one observation, the predicted height should equal the measured height. This is true for the first observation in forward projections (or last in backward projections) in repeatedly measured plots. Therefore, two types of statistics summaries were generated.

1. using all data (Forward-1 and Backward-1), and

2. not using the plots with only one observation, and not using the first observation in forward projections (or last in backward projections) (Forward-2 and Backward-2).

Summary statistics are presented in Table 3.

Table 3. Top height model performance statistics (totage>=10).

				Mean TopHT							
Company	**Projection**	**Species**	**N**	**Observed**	**Predicted**	**RMSE**	**GoFI**	**Error_ABS**	**Error_ABS%**	**Bias**	**Bias%**
All	Forward-1	AW	336	11.703	11.649	1.438	0.913	0.873	7.456	0.054	0.457
		PL	898	6.957	7.064	1.109	0.900	0.591	8.497	-0.107	-1.540
		SB	100	7.371	7.513	1.508	0.836	0.853	11.570	-0.142	-1.927
		SW	473	7.332	7.323	1.493	0.872	0.809	11.037	0.009	0.129
	Backward-1	AW	336	11.703	11.735	1.149	0.944	0.700	5.983	-0.032	-0.272
		PL	898	6.957	6.949	0.542	0.976	0.316	4.540	0.008	0.114
		SB	100	7.371	7.400	1.094	0.914	0.567	7.687	-0.029	-0.393
		SW	473	7.332	7.449	0.928	0.951	0.535	7.291	-0.116	-1.588
	Forward-2	AW	222	12.654	12.573	1.769	0.847	1.321	10.436	0.081	0.640
		PL	550	8.211	8.386	1.417	0.814	0.965	11.755	-0.175	-2.130
		SB	61	8.246	8.479	1.931	0.727	1.398	16.955	-0.233	-2.824
		SW	301	8.328	8.313	1.872	0.796	1.272	15.271	0.015	0.179
	Backward-2	AW	222	10.671	10.719	1.413	0.901	1.060	9.931	-0.048	-0.452
		PL	550	6.257	6.244	0.692	0.951	0.516	8.242	0.013	0.207
		SB	61	6.892	6.939	1.401	0.859	0.929	13.478	-0.047	-0.689
		SW	301	6.579	6.762	1.163	0.906	0.840	12.768	-0.183	-2.780

4.1.2 Simulating Projections – totage>5

Site index was calculated by limiting totage>5 years in this round. The following steps were completed (limiting totage>5) by just repeating the procedures in section 4.1.1. The purpose is to see if models performance well for younger stands.

Figure 6 presents the site index trajectories on two different scales for examining the stability of site index over age.

The graphs of observed top height vs. totage trajectories, projections and errors are presented in Figures 7 - 10. In the figures, left graphs are from forward projection, while right graphs are from backward projection.

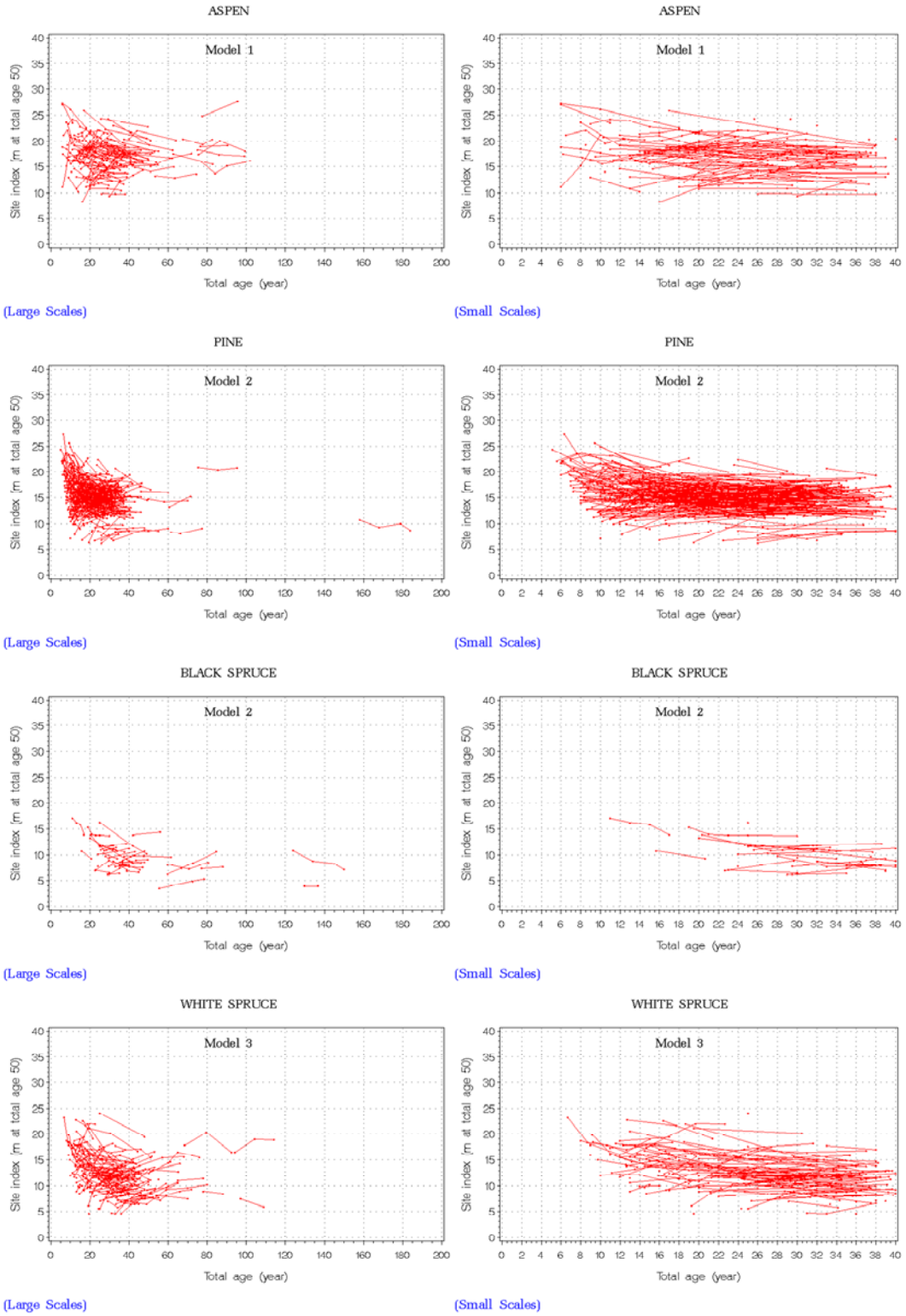


Figure 6. Site index trajectories (totage>5).

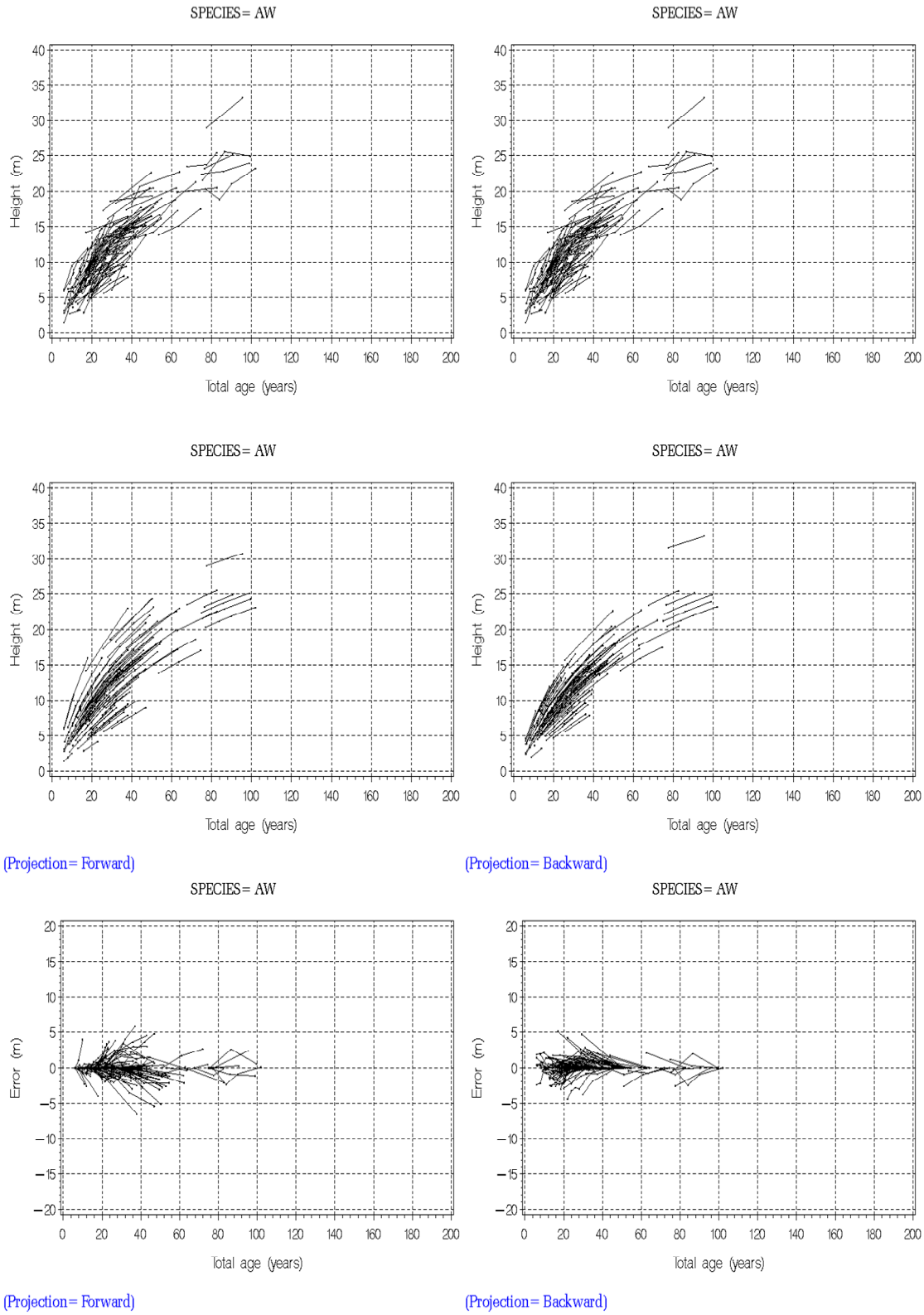


Figure 7. Top height vs. age with projections for AW (totage>5).

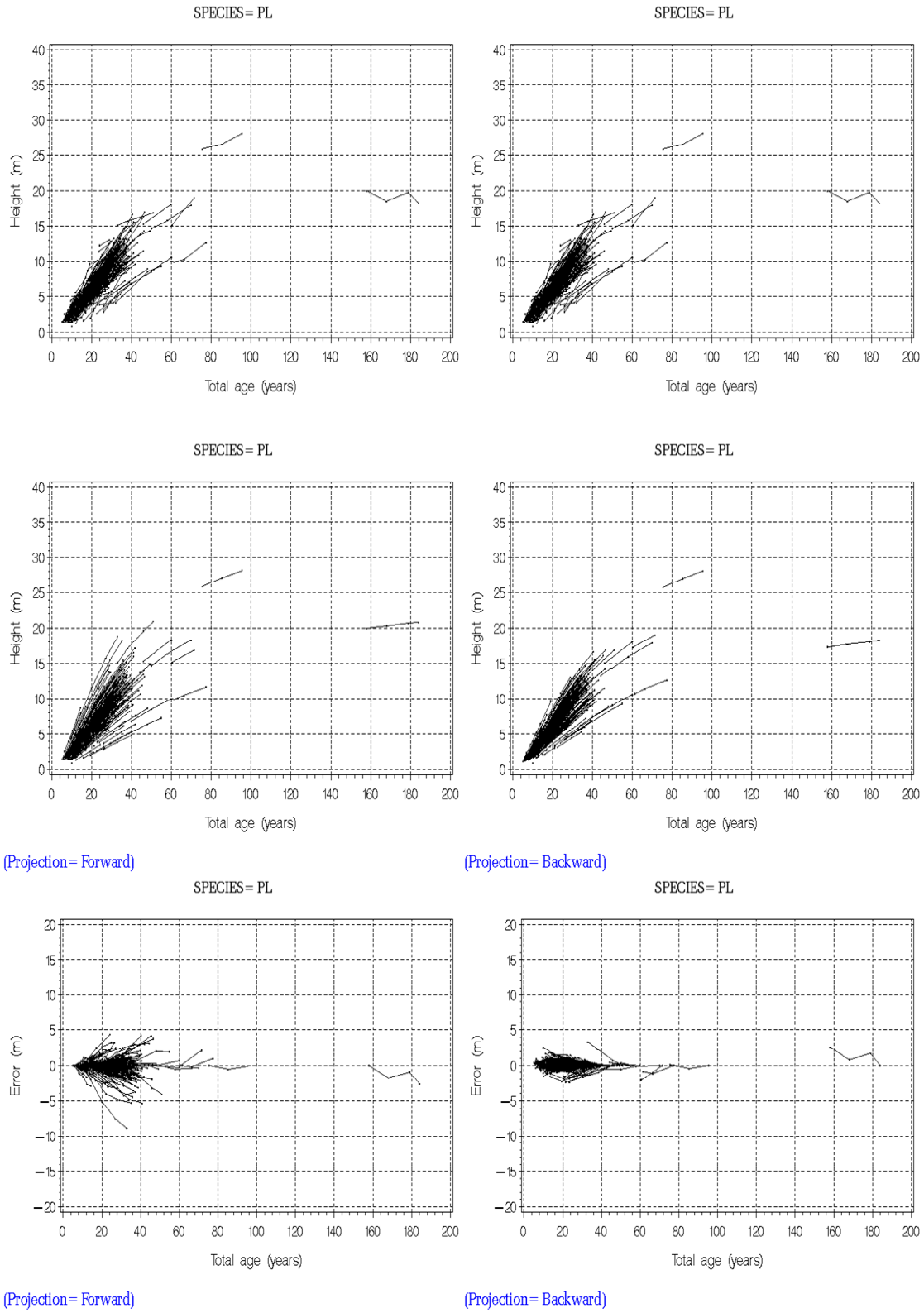


Figure 8. Top height vs. age with projections for PL (totage>5).

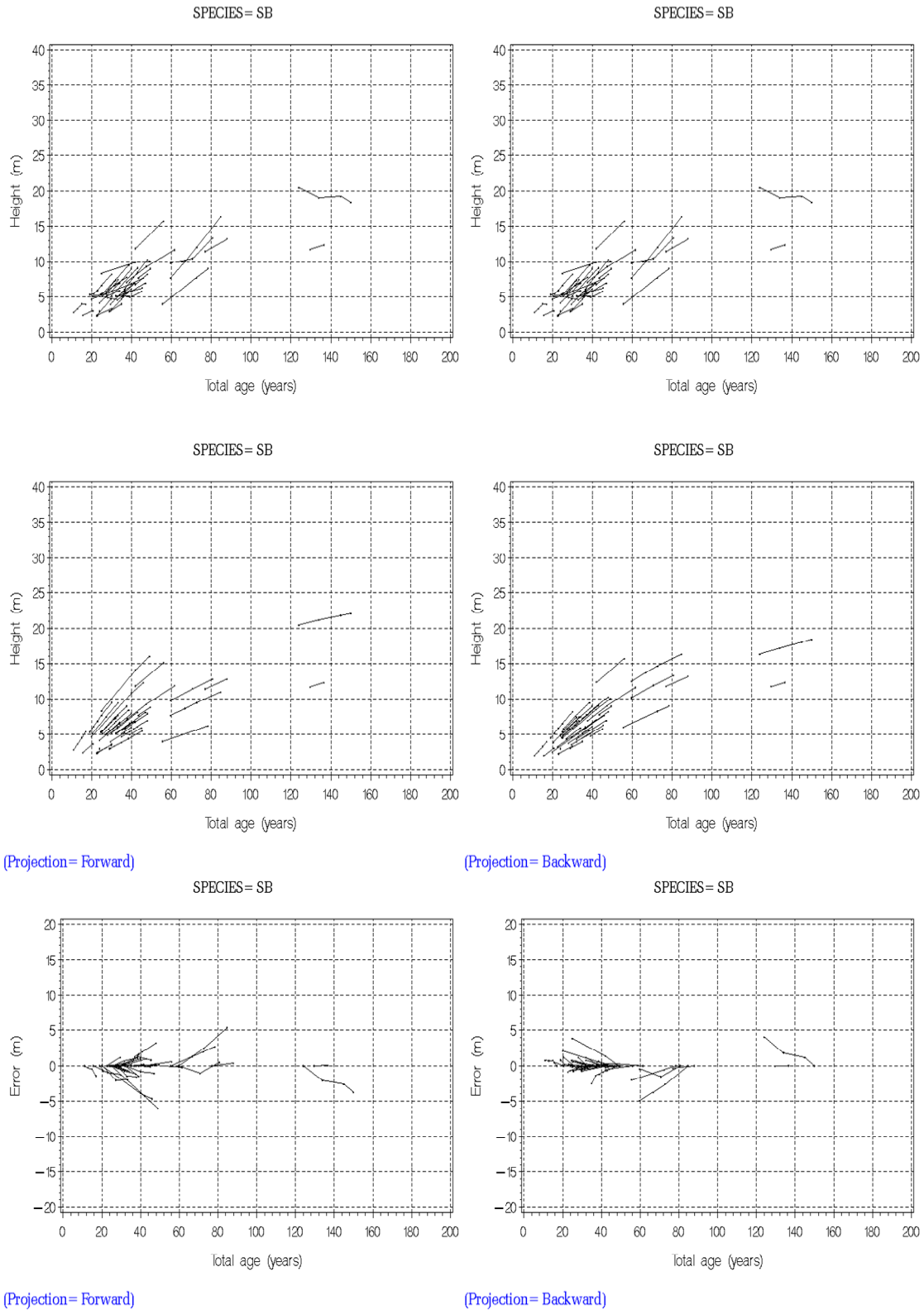


Figure 9. Top height vs. age with projections for SB (totage>5).

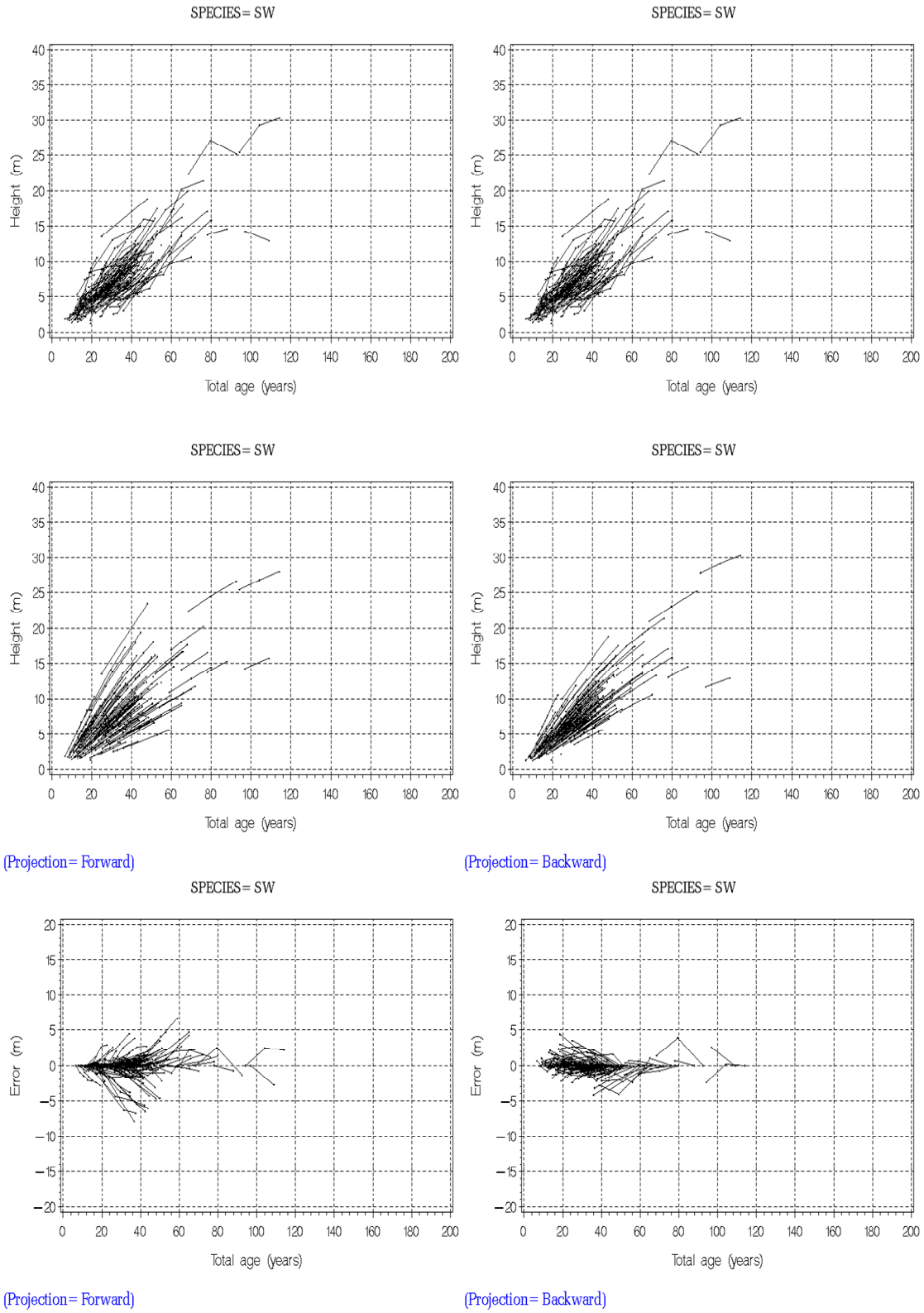


Figure 10. Top height vs. age with projections for SW (totage>5).

Summary statistics are presented in Table 4.

Table 4. Top height model performance statistics (totage>5).

Company	Projection	Species	N	Mean TopHT Observed	Mean TopHT Predicted	RMSE	GoFI	Error_ABS	Error_ABS%	Bias	Bias%
All	Forward-1	AW	352	11.3673	11.3272	1.4407	0.9173	0.8775	7.7193	0.0401	0.3528
		PL	968	6.6073	6.7138	1.0988	0.9070	0.5911	8.9465	-0.1066	-1.6127
		SB	100	7.3710	7.5131	1.5078	0.8359	0.8528	11.5700	-0.1420	-1.9268
		SW	481	7.2435	7.2728	1.5063	0.8715	0.8295	11.4514	-0.0293	-0.4048
	Backward-1	AW	352	11.3673	11.3860	1.1511	0.9472	0.7106	6.2513	-0.0187	-0.1642
		PL	968	6.6073	6.5893	0.5318	0.9782	0.3134	4.7432	0.0180	0.2717
		SB	100	7.3710	7.4000	1.0940	0.9136	0.5666	7.6868	-0.0290	-0.3928
		SW	481	7.2435	7.3528	0.9222	0.9518	0.5310	7.3302	-0.1093	-1.5092
	Forward-2	AW	237	12.2287	12.1691	1.7557	0.8610	1.3033	10.6574	0.0596	0.4871
		PL	616	7.7020	7.8694	1.3774	0.8402	0.9289	12.0607	-0.1674	-2.1740
		SB	61	8.2459	8.4788	1.9306	0.7269	1.3981	16.9548	-0.2328	-2.8236
		SW	307	8.2153	8.2613	1.8854	0.7963	1.2996	15.8193	-0.0459	-0.5592
	Backward-2	AW	237	10.2676	10.2953	1.4028	0.9081	1.0554	10.2790	-0.0277	-0.2700
		PL	616	5.8119	5.7837	0.6667	0.9573	0.4925	8.4736	0.0282	0.4853
		SB	61	6.8917	6.9392	1.4007	0.8591	0.9288	13.4777	-0.0475	-0.6888
		SW	307	6.4902	6.6615	1.1544	0.9086	0.8319	12.8178	-0.1713	-2.6391

4.2 Density Models (non-spatial)

4.2.1 Simulating Projections - totage>=10

Both site index and stand density factor were calculated by limiting totage>=10 years in this round.

Two types of projections were completed.

1. Iteration #1 (Iteration-1): show the “worst possible” model projections from “one-shot” early observations

-Use the first observations at or (first) beyond 10 years total age and they must have site index and SDF available to make projections, i.e.,

-Site index predicted from the first ht-age pair at or beyond 10 years total age

-Stand density factor (always 0.3) predicted from the first density-age pair at or beyond 10 years total age

- Use the first (earliest) observation which has both predicted site index and stand density factor available.

2. Iteration #2 (Iteration-2): use the averages to make projections, i.e.,

-Site indices averaged per plot, this average is assigned as the plot site index

-Stand density factors averaged per plot, this average SDF is assigned as the plot SDF

For PL, SB and SW, density models were tested by using stand density from trees with height > 0.3 m tall. For AW, density model was tested by using stand density from trees with height > 0.3 m tall (density0.3), as well as using stand density from trees with height > 1.3 m tall (density1.3).

The graphs of observed density vs. totage trajectories, projections and errors are presented in Figures 11 - 15. In the figures, left graphs are from Iteration #1 projection, while right graphs are from Iteration #2 projection.

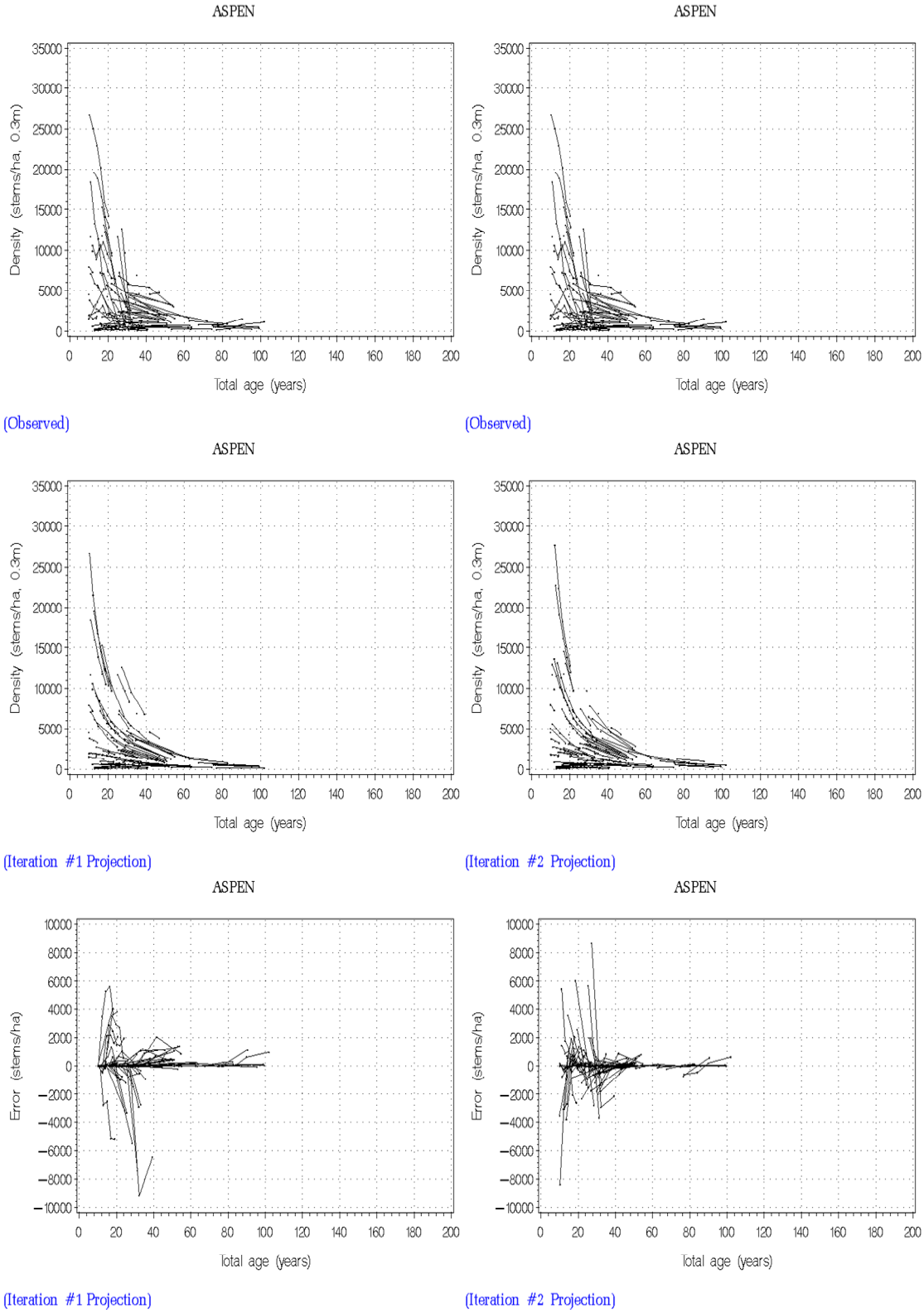


Figure 11. Density vs. age with projections for AW (totage>=10, density0.3).

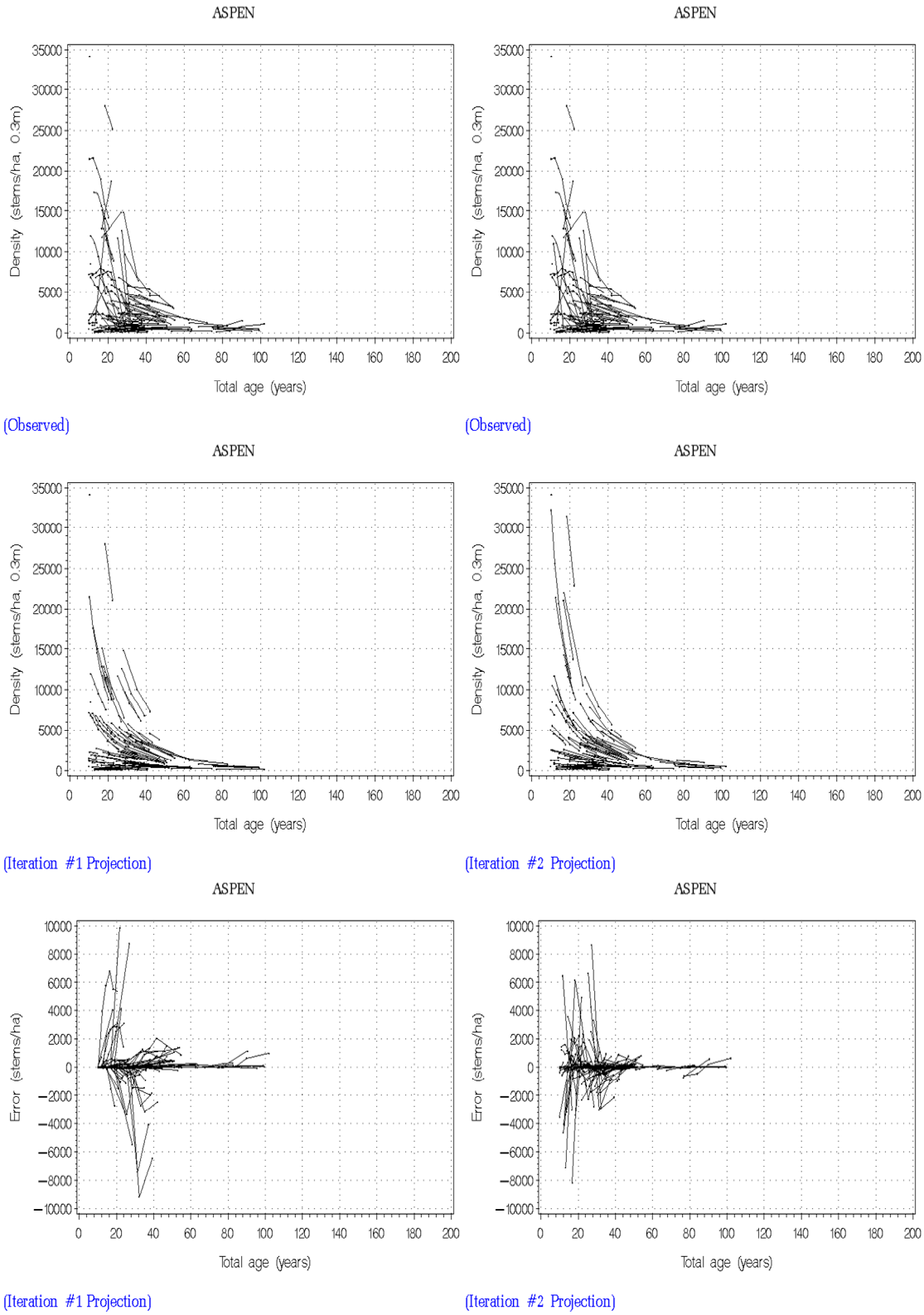


Figure 12. Density vs. age with projections for AW (totage>=10, density1.3).

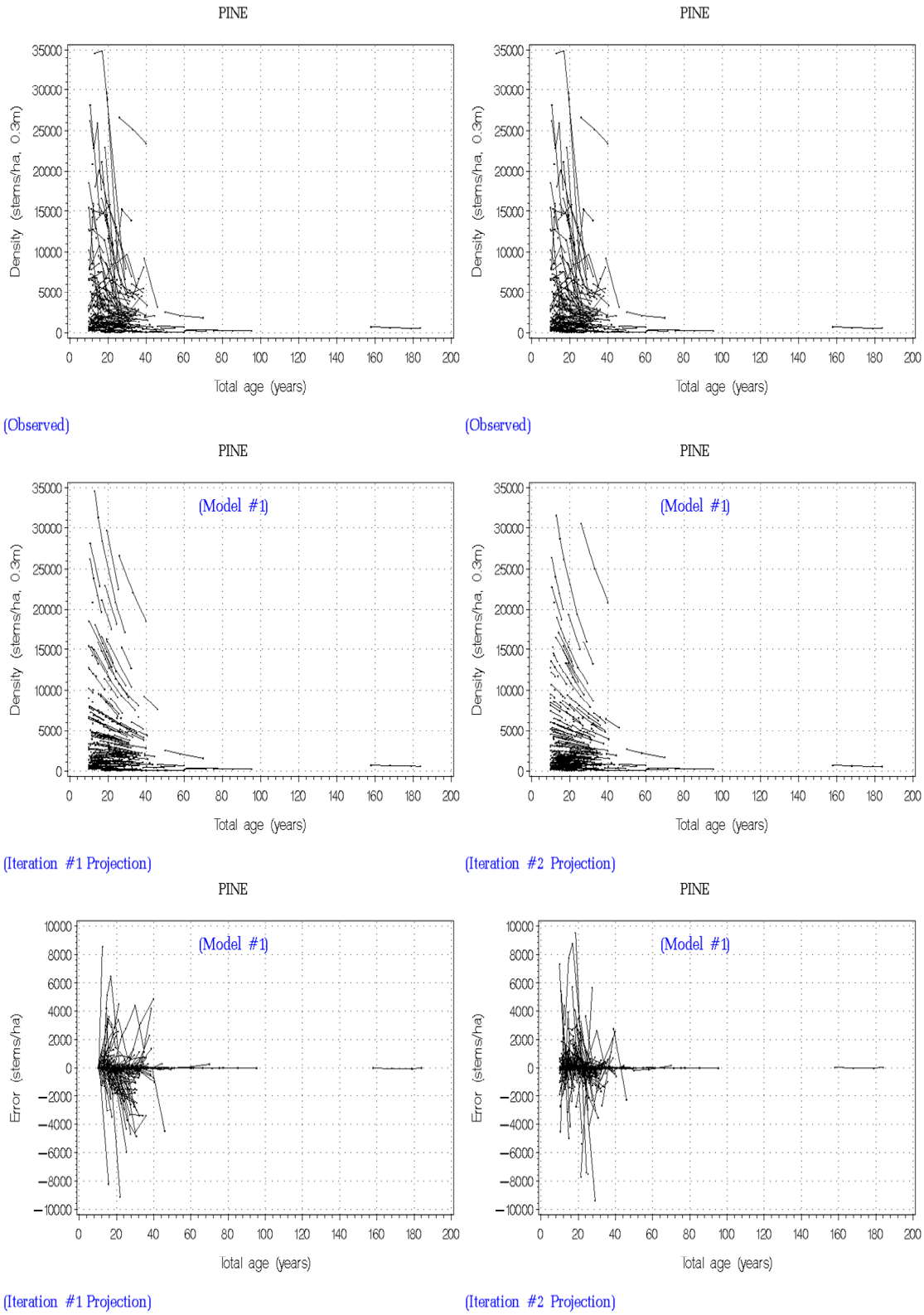


Figure 13. Density vs. age with projections for PL (totage>=10).

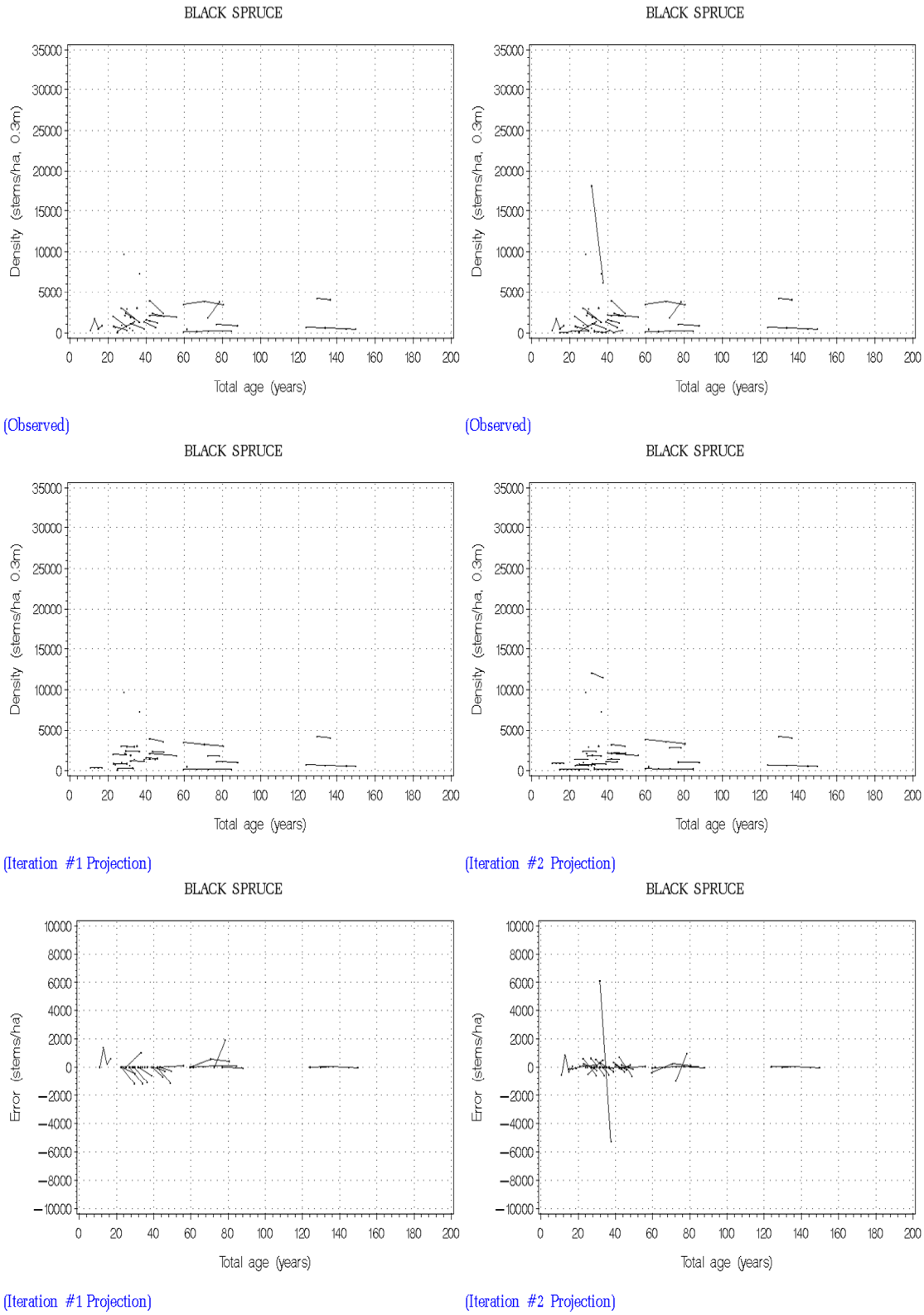


Figure 14. Density vs. age with projections for SB (totage>=10).

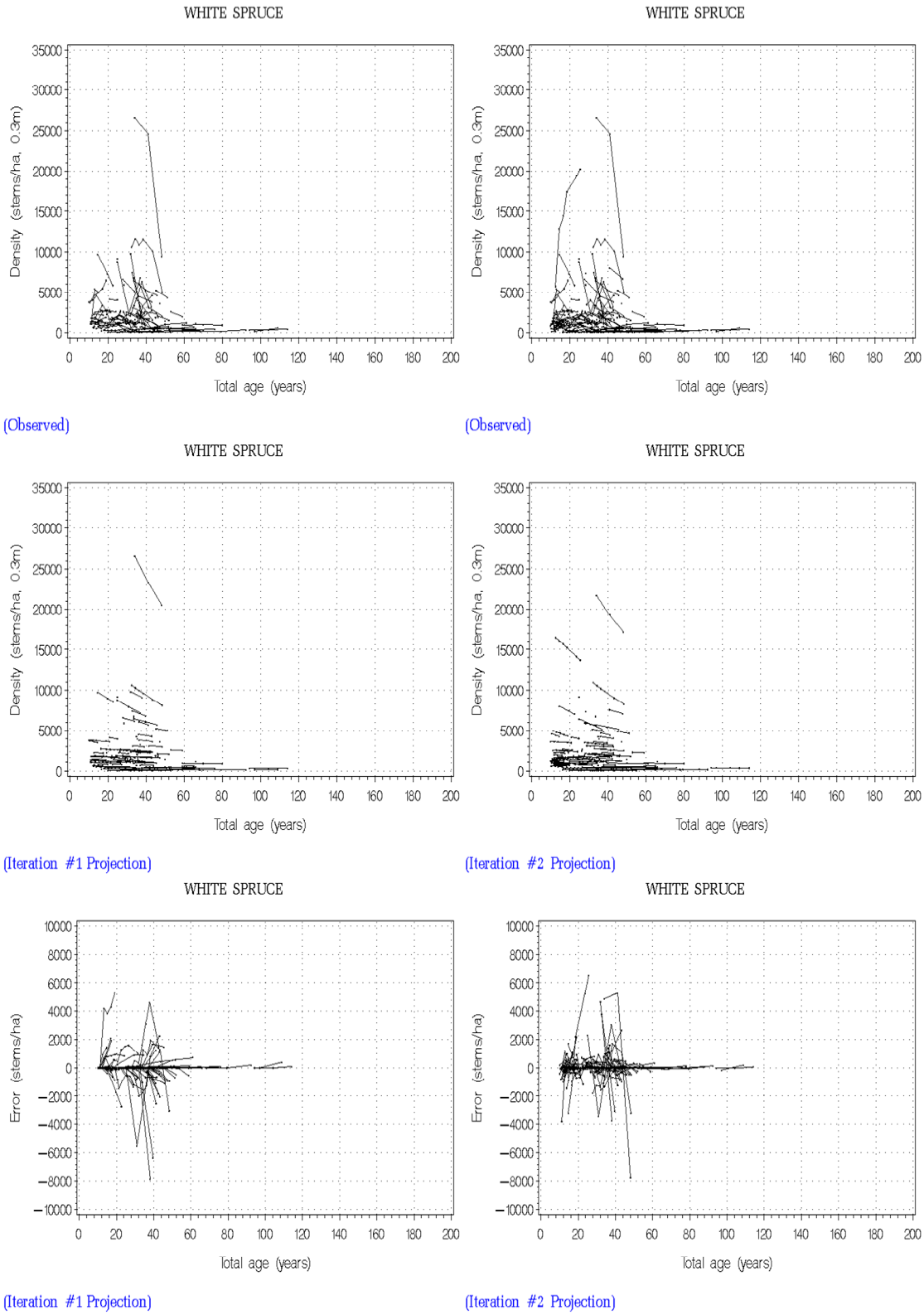


Figure 15. Density vs. age with projections for SW (totage>=10).

When plots have only one observation, the predicted density should equal the measured density. This is true for the first observation in Iteration #1 projections in repeatedly measured plots. Therefore, four types of statistics summaries were generated.

3. Using all data (Iteration-1-1and Iteration-2-1)

    a. Iteration-1-1: using the information of the first obs with available site index, SDF, and Y2BH to simulate projections, and including this first obs and the plots with only one observation for statistics summary.

    b. Iteration-2-1: using averages of site index, SDF, and Y2BH to simulate projections, and including the first obs and the plots with only one observation for statistics summary.

4. Not using the plots with only one observation, and/or not using the first observation (Iteration 1-2 and Iteration 2-2)

    a. Iteration-1-2: using the information of the first obs with available site index, SDF, and Y2BH to simulate projections, but not including this first obs and the plots with only one observation for statistics summary.

    b. Iteration-2-2: using averages of site index, SDF, and Y2BH to simulate projections, but not including the plots with only one measurement for statistics summary because their predictions are equal to themselves. The first obs in repeatedly measured plots were still included because their predictions are not equal to themselves.

Summary statistics based on the tested models are presented in Table 5.

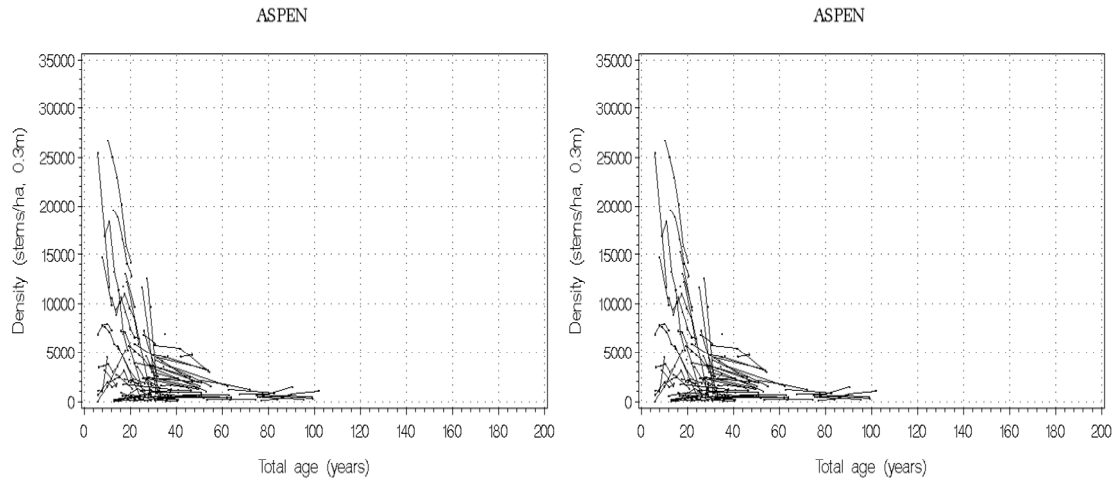
Table 5. Density model performance statistics (totage>=10).

Company	Density	Projection	Species	N	Mean Density Observed	Mean Density Predicted	RMSE	GoFI	Error_ABS	Error_ABS%	Bias	Bias%
All	0.3 m	Iteration-1-1	AW	252	3546.20	3465.17	1461.34	0.90	621.45	17.52	81.04	2.29
			PL	636	3763.11	3933.08	1717.65	0.89	602.26	16.00	-169.97	-4.52
			SB	57	1760.83	1773.55	499.16	0.92	238.67	13.55	-12.72	-0.72
			SW	291	2172.55	2208.80	1295.50	0.80	510.99	23.52	-36.24	-1.67
		Iteration-1-2	AW	147	3435.63	3296.71	1913.34	0.84	1065.35	31.01	138.92	4.04
			PL	316	3707.56	4049.65	2436.80	0.77	1212.14	32.69	-342.09	-9.23
			SB	25	1408.04	1437.04	753.71	0.60	544.18	38.65	-29.00	-2.06
			SW	153	2209.20	2278.14	1786.64	0.62	971.88	43.99	-68.93	-3.12
		Iteration-2-1	AW	254	3534.62	3554.60	1337.08	0.92	630.57	17.84	-19.98	-0.57
			PL	670	3609.39	3545.03	1453.71	0.92	600.19	16.63	64.35	1.78
			SB	75	1745.27	1733.51	985.85	0.85	344.74	19.75	11.76	0.67
			SW	377	2169.09	2148.61	1165.69	0.87	485.72	22.39	20.48	0.94
		Iteration-2-2	AW	231	3534.52	3556.49	1402.07	0.91	693.36	19.62	-21.97	-0.62
			PL	534	3787.97	3707.23	1628.34	0.91	753.04	19.88	80.74	2.13
			SB	61	1608.64	1594.18	1093.14	0.81	423.86	26.35	14.46	0.90
			SW	323	2222.56	2198.66	1259.37	0.86	566.92	25.51	23.90	1.08
	1.3 m	Iteration-1-1	AW	299	3499.92	3272.80	1750.14	0.88	715.41	20.44	227.12	6.49
		Iteration-1-2		188	3335.99	2974.78	2207.14	0.78	1137.81	34.11	361.22	10.83
		Iteration-2-1		303	3504.94	3570.38	1719.80	0.88	786.68	22.44	-65.44	-1.87
		Iteration-2-2		297	3419.90	3486.67	1737.08	0.86	802.57	23.47	-66.77	-1.95

4.2.2 Simulating Projections - totage>5

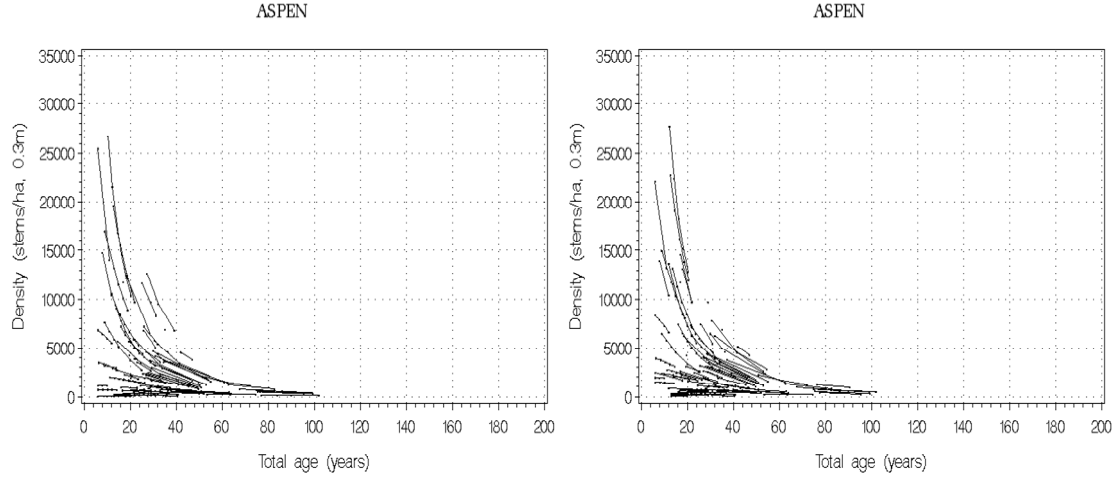
Both site index and stand density factor were calculated by limiting totage>5 years in this round. The following steps were completed (limiting totage>5) by just repeating the procedures in section 4.2.1. The purpose is to see if models performance well for younger stands.

The graphs of observed density vs. totage trajectories, projections and errors are presented in Figures 16 - 20. In the figures, left graphs are from Iteration #1 projection, while right graphs are from Iteration #2 projection.



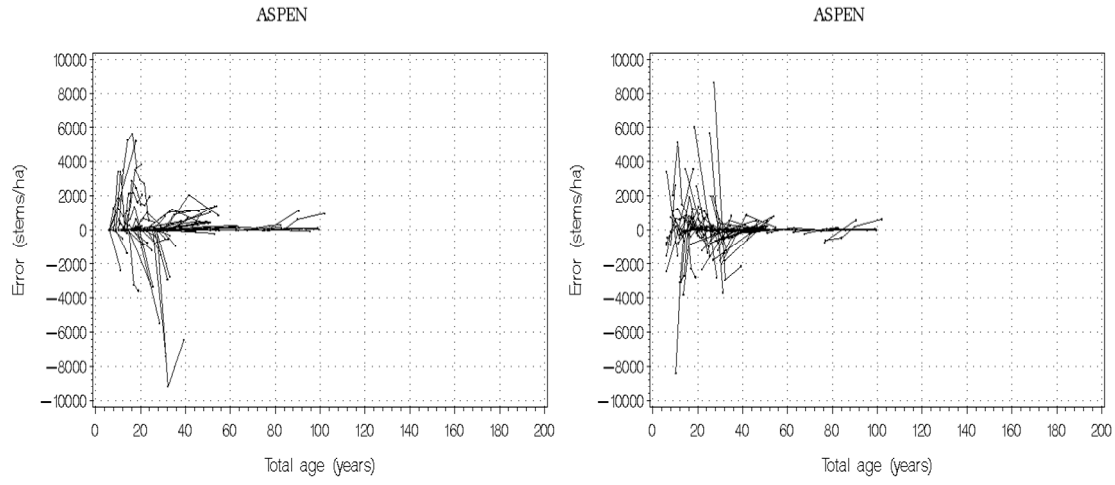
(Observed)

(Observed)



(Iteration #1 Projection)

(Iteration #2 Projection)



(Iteration #1 Projection)

(Iteration #2 Projection)

Figure 16. Density vs. age with projections for AW (totage>5, density0.3).

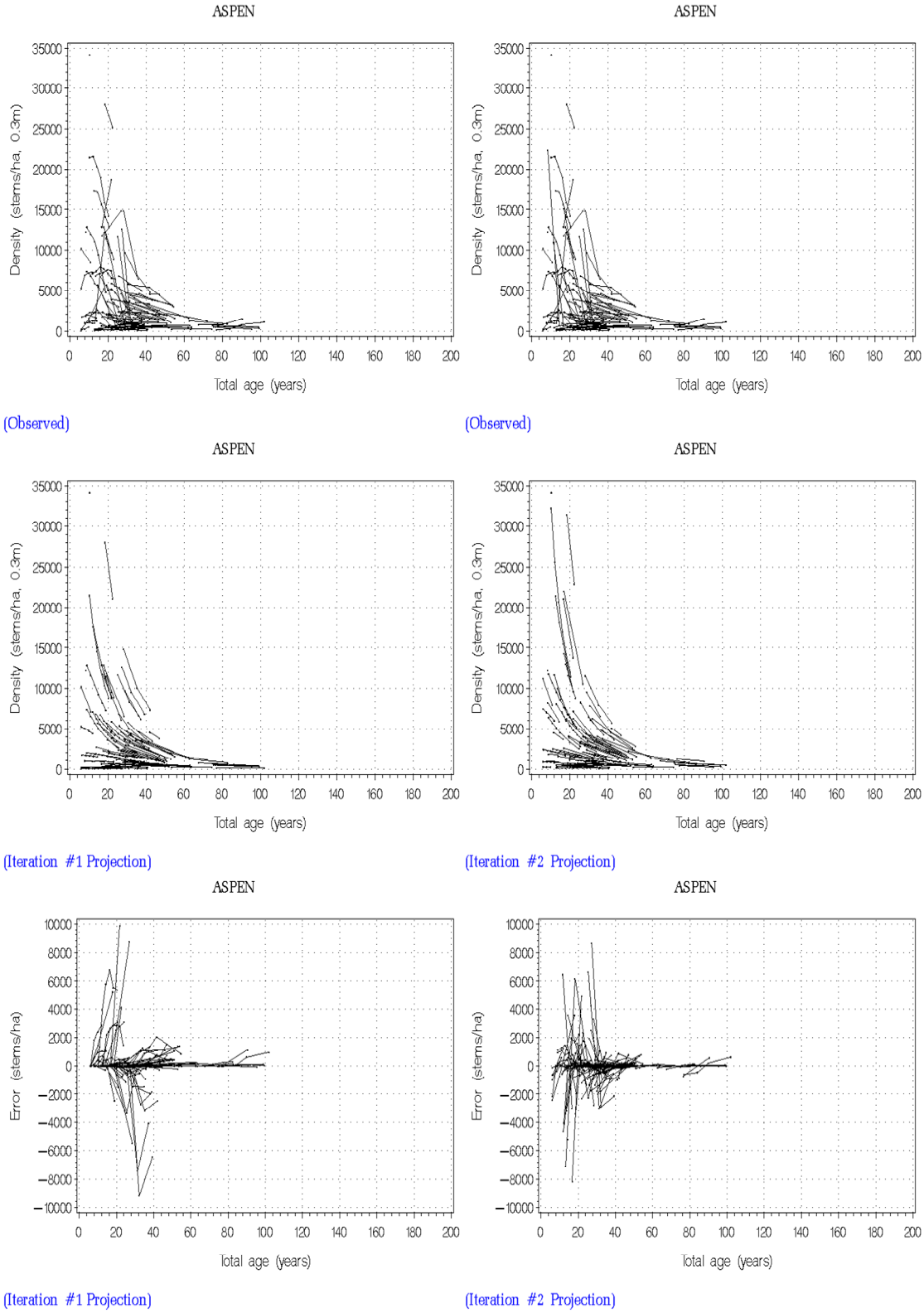


Figure 17. Density vs. age with projections for AW (totage>5, density1.3).

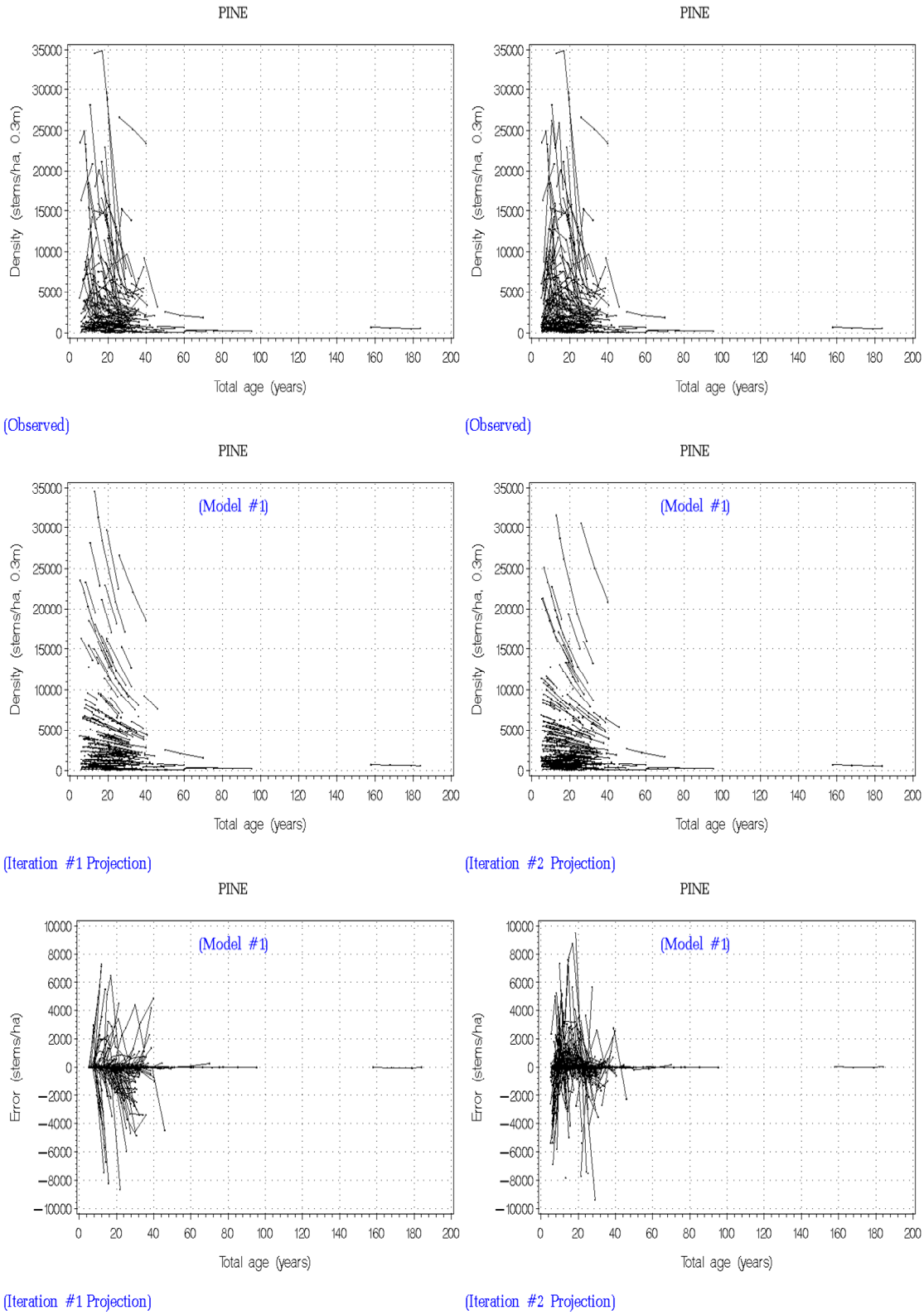


Figure 18. Density vs. age with projections for PL (totage>5).

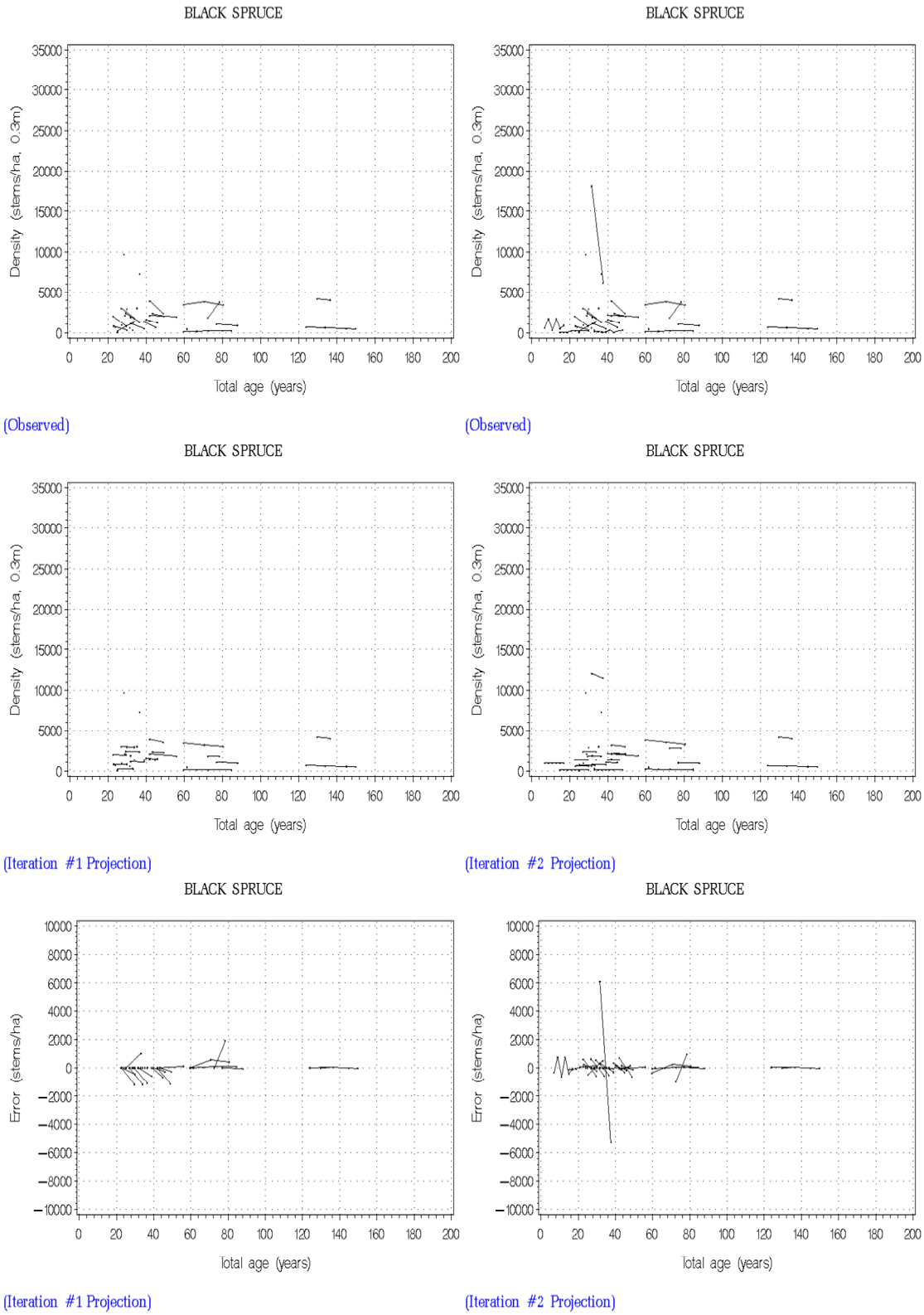
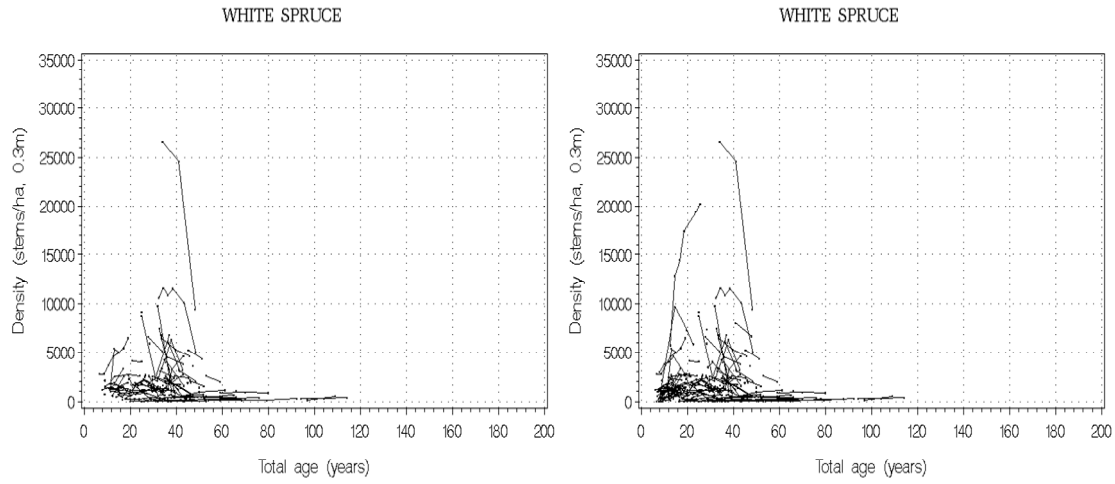
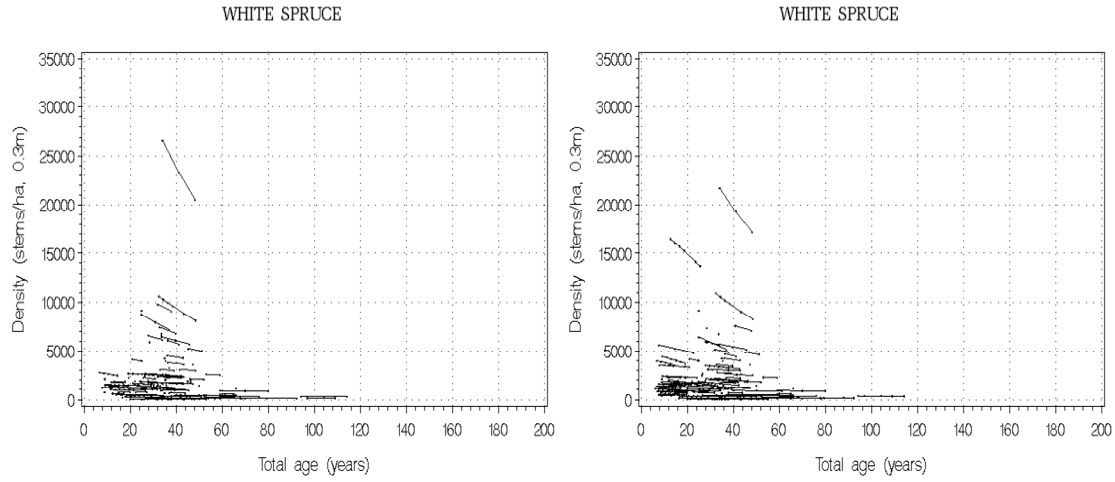


Figure 19. Density vs. age with projections for SB (totage>5).



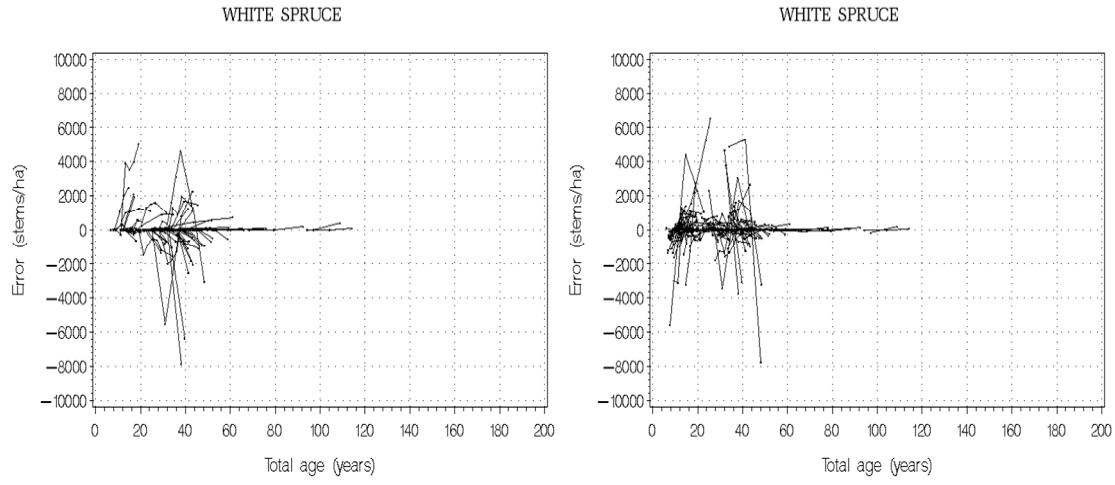
(Observed)

(Observed)



(Iteration #1 Projection)

(Iteration #2 Projection)



(Iteration #1 Projection)

(Iteration #2 Projection)

Figure 20. Density vs. age with projections for SW (totage>5).

Summary statistics based on the tested models are presented in Table 6.

Table 6. Density model performance statistics (totage>5).

Company	Density	Projection	Species	N	Mean Density Observed	Mean Density Predicted	RMSE	GoFI	Error_ABS	Error_ABS%	Bias	Bias%
All	0.3 m	Iteration-1-1	AW	261	3680.84	3501.57	1450.56	0.91	649.40	17.64	179.28	4.87
			PL	603	3653.50	3879.64	1997.87	0.85	732.67	20.05	-226.15	-6.19
			SB	53	1829.57	1884.84	472.78	0.93	215.10	11.76	-55.27	-3.02
			SW	279	2101.48	2105.63	1306.89	0.80	521.02	24.79	-4.15	-0.20
		Iteration-1-2	AW	159	3667.17	3372.88	1858.48	0.85	1066.00	29.07	294.28	8.02
			PL	314	3514.17	3948.46	2768.61	0.70	1407.02	40.04	-434.29	-12.36
			SB	22	1459.14	1592.29	733.82	0.65	518.19	35.51	-133.15	-9.13
			SW	150	2113.30	2121.01	1782.36	0.62	969.11	45.86	-7.71	-0.36
		Iteration-2-1	AW	268	3700.48	3696.41	1347.07	0.93	673.86	18.21	4.06	0.11
			PL	781	3630.89	3560.35	1852.42	0.87	847.02	23.33	70.53	1.94
			SB	77	1729.81	1717.99	977.77	0.85	351.27	20.31	11.82	0.68
			SW	406	2083.56	2056.42	1211.15	0.85	542.13	26.02	27.14	1.30
		Iteration-2-2	AW	249	3767.56	3763.19	1397.52	0.92	725.28	19.25	4.37	0.12
			PL	678	3807.57	3726.32	1988.15	0.86	975.70	25.63	81.25	2.13
			SB	63	1594.08	1579.63	1080.97	0.81	429.33	26.93	14.45	0.91
			SW	357	2103.85	2072.99	1291.60	0.84	616.54	29.31	30.86	1.47
	1.3 m	Iteration-1-1	AW	308	3514.65	3235.37	1756.01	0.87	744.04	21.17	279.28	7.95
		Iteration-1-2		201	3413.35	2985.40	2173.72	0.78	1140.12	33.40	427.95	12.54
		Iteration-2-1		319	3596.42	3623.02	1888.33	0.86	843.48	23.45	-26.59	-0.74
		Iteration-2-2		317	3472.58	3499.34	1894.28	0.84	848.80	24.44	-26.76	-0.77

4.3 Basal Area Increment Models (non-spatial)

4.3.1 Projections with observed BA

The projections were completed by using the information from the first observations (obs) at or beyond 10 years total age where site index, SDF, and BA are available to make projections. That is:

-Site index predicted from the first ht-age pair at or beyond 10 years total age

-Stand density factor (always >=0.3 m in tree height) predicted from the first density-age pair at or beyond 10 years total age

- Observed BA available for the first obs

There are two options for data inclusion in the projections.

In option 1, the projections were completed by setting following limits on the data.

1. totage>=10
2. site index >0

3. density ($N_{0.3}$- based on the trees with height >=0.3 m) >0, and

4. BA >0

For some of plots, the $N_{0.3}$ is available at some measurements, while it is not available at other measurements (due to survey protocol change). By limiting $N_{0.3}$ >0, some measurements of plots, that don't have $N_{0.3}$, but have BA, were excluded in the validation.

In option 2, the limit of $N_{0.3}$ >0 in option 1 was removed in the projections. By doing so,

1. More observations were obtained and used in the validation.

2. Stability of BAINC models could be tested when the available data were changed.

For the projections, the graphs of observed basal area vs. totage trajectories, projections and errors are presented in Figures 21 – 24. In the figures, left graphs are from Option 1 projection, while right graphs are from Option 2 projection.

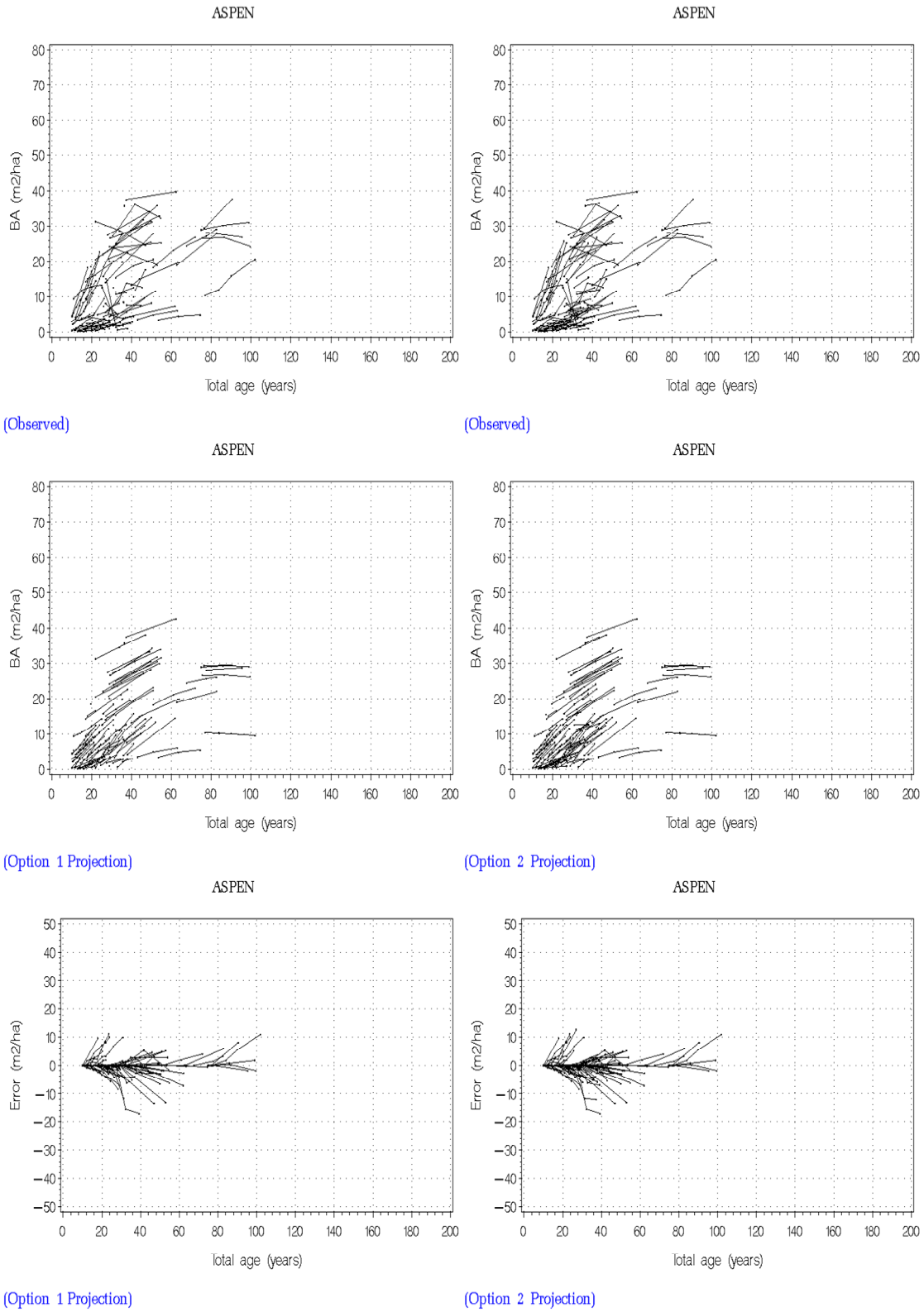
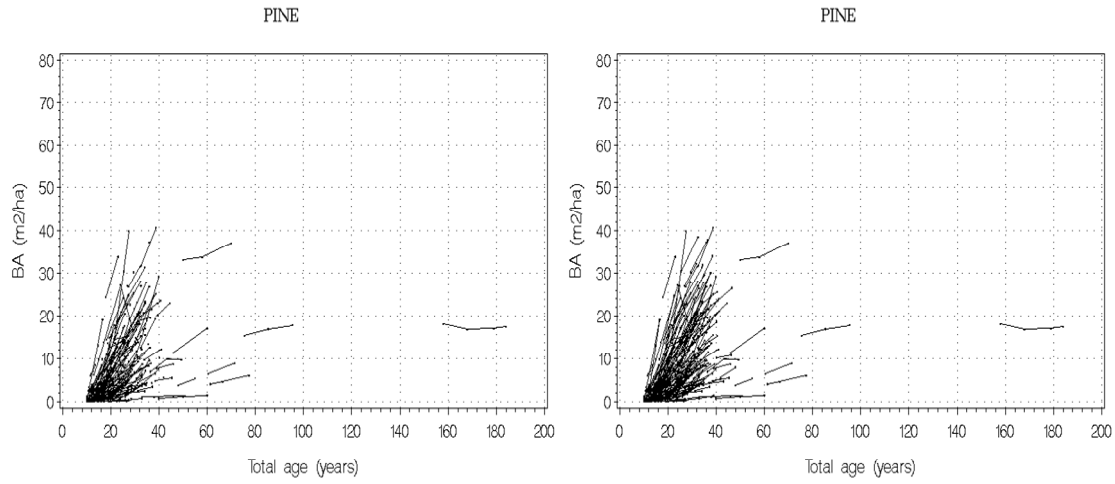
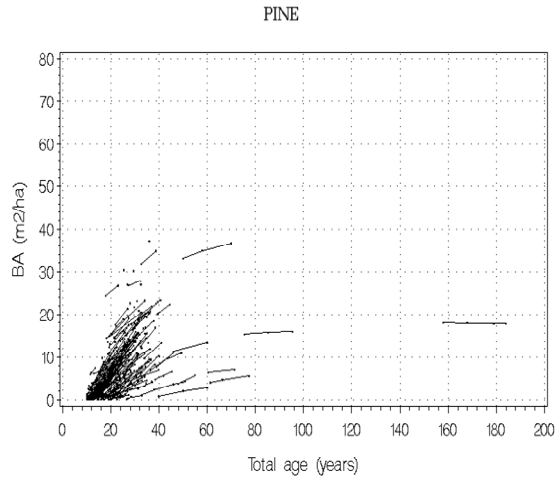


Figure 21. Basal area vs. age with projections for AW (with observed BA).

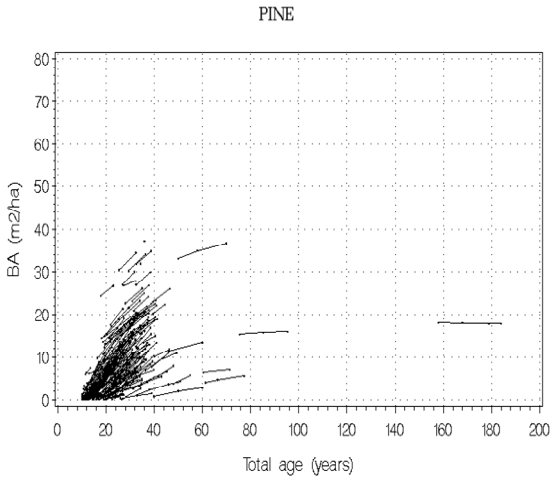


(Observed)

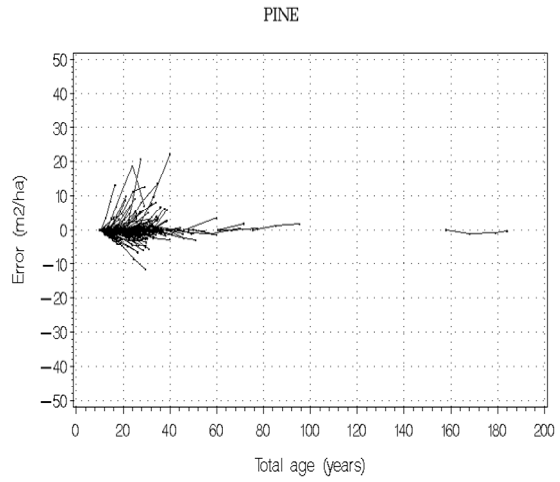
(Observed)



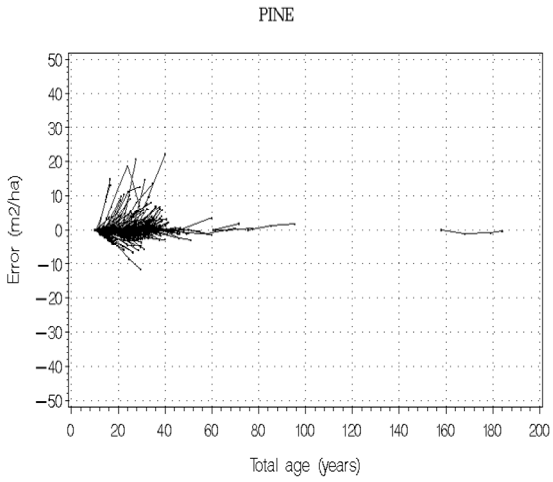
(Option 1 Projection)



(Option 2 Projection)



(Option 1 Projection)



(Option 2 Projection)

Figure 22. Basal area vs. age with projections for PL (with observed BA).

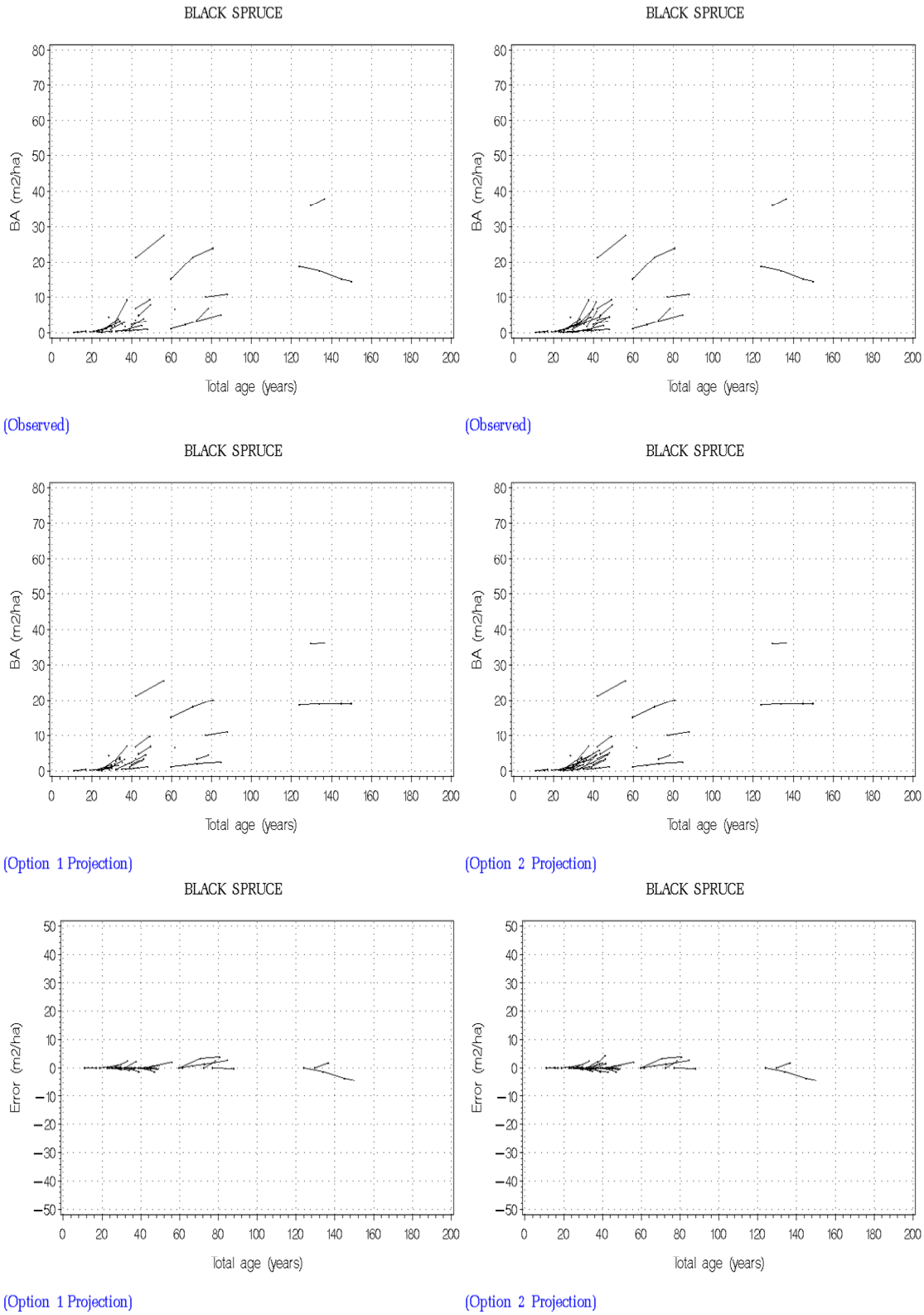


Figure 23. Basal area vs. age with projections for SB (with observed BA).

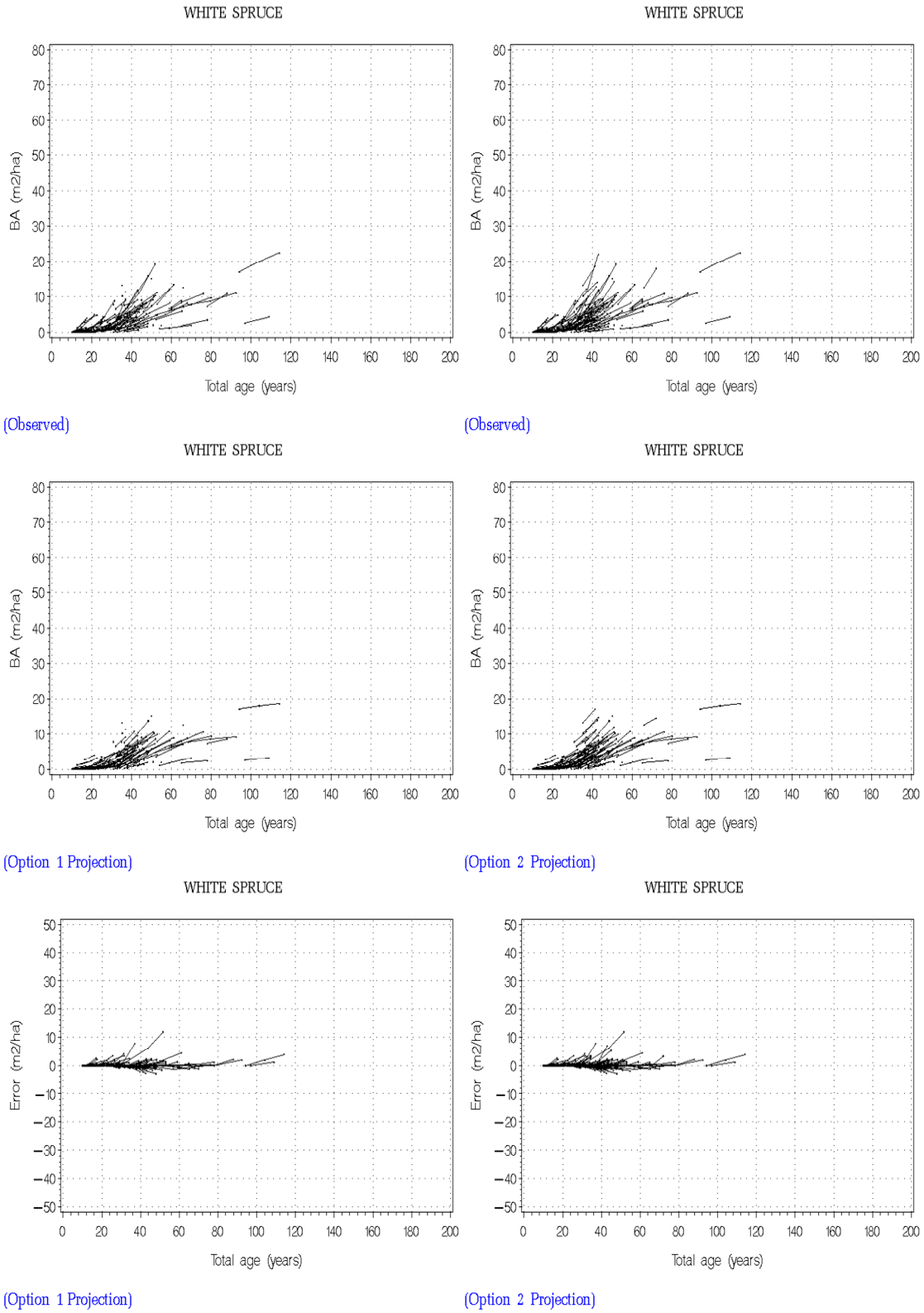


Figure 24. Basal area vs. age with projections for SW (with observed BA).

Because the first observation BA (or current BA at time one) was used as a starting point, plots that have only one observation, and the first observation in projections in repeatedly measured plots have the predicted BA equal to the observed BA. Therefore, two types of statistics summaries were generated.

1. Using all data (Summary 1)

Summary 1: using the information of the first obs with available site index, SDF, and N_0 to simulate projections, and including this first obs and the plots with only one observation for statistics summary.

2. Not using the plots with only one observation and not using the first observation (Summary 2)

Summary 2: using the information of the first obs with available site index, SDF, and N_0 to simulate projections, but not including this first obs and the plots with only one observation for statistics summary.

Summary statistics based on the tested models are presented in Table 7.

Table 7. BAINC Model performance statistics (with observed BA).

					Mean BA							
Company	**Option**	**Summary**	**Species**	**N**	**Observed**	**Predicted**	**RMSE**	**GoFI**	**Error_ABS**	**Error_ABS%**	**Bias**	**Bias%**
All	1	1	AW	254	10.988	11.152	3.468	0.881	1.841	16.759	-0.163	-1.488
			PL	656	6.614	6.524	2.572	0.883	1.100	16.629	0.091	1.374
			SB	72	5.585	5.447	1.185	0.979	0.585	10.471	0.137	2.457
			SW	347	3.150	2.921	1.182	0.897	0.486	15.445	0.229	7.275
		2	AW	148	11.848	12.129	4.543	0.808	3.160	26.674	-0.281	-2.368
			PL	328	7.812	7.631	3.638	0.787	2.200	28.159	0.182	2.326
			SB	36	6.727	6.453	1.676	0.964	1.170	17.386	0.274	4.080
			SW	182	3.744	3.308	1.632	0.837	0.928	24.770	0.437	11.668
	2	1	AW	293	10.882	11.097	3.532	0.874	1.927	17.706	-0.215	-1.979
			PL	773	7.544	7.267	2.706	0.891	1.239	16.421	0.277	3.669
			SB	85	5.200	5.023	1.238	0.974	0.641	12.329	0.177	3.413
			SW	394	3.514	3.233	1.282	0.898	0.569	16.188	0.281	7.987
		2	AW	179	11.771	12.123	4.519	0.805	3.154	26.792	-0.352	-2.994
			PL	426	9.290	8.788	3.645	0.823	2.248	24.195	0.502	5.407
			SB	46	6.112	5.784	1.683	0.956	1.185	19.382	0.328	5.365
			SW	222	4.326	3.828	1.707	0.852	1.010	23.336	0.498	11.514

4.3.2 Projections without observed BA

The projections simulated in Section 4.3.1 used the first obs (which age is greater than 10) as a starting point and had the observed BA of the first obs in the BAINC models.

In some cases, projections need to be simulated by starting from age 0 and when the observed BA is not available. The following projections were made where the observed BA was not included in the BAINC models.

For the projections, the graphs of observed basal area vs. totage trajectories, projections and errors are presented in Figures 25 – 28. In the figures, left graphs are from Option 1 projection, while right graphs are from Option 2 projection.

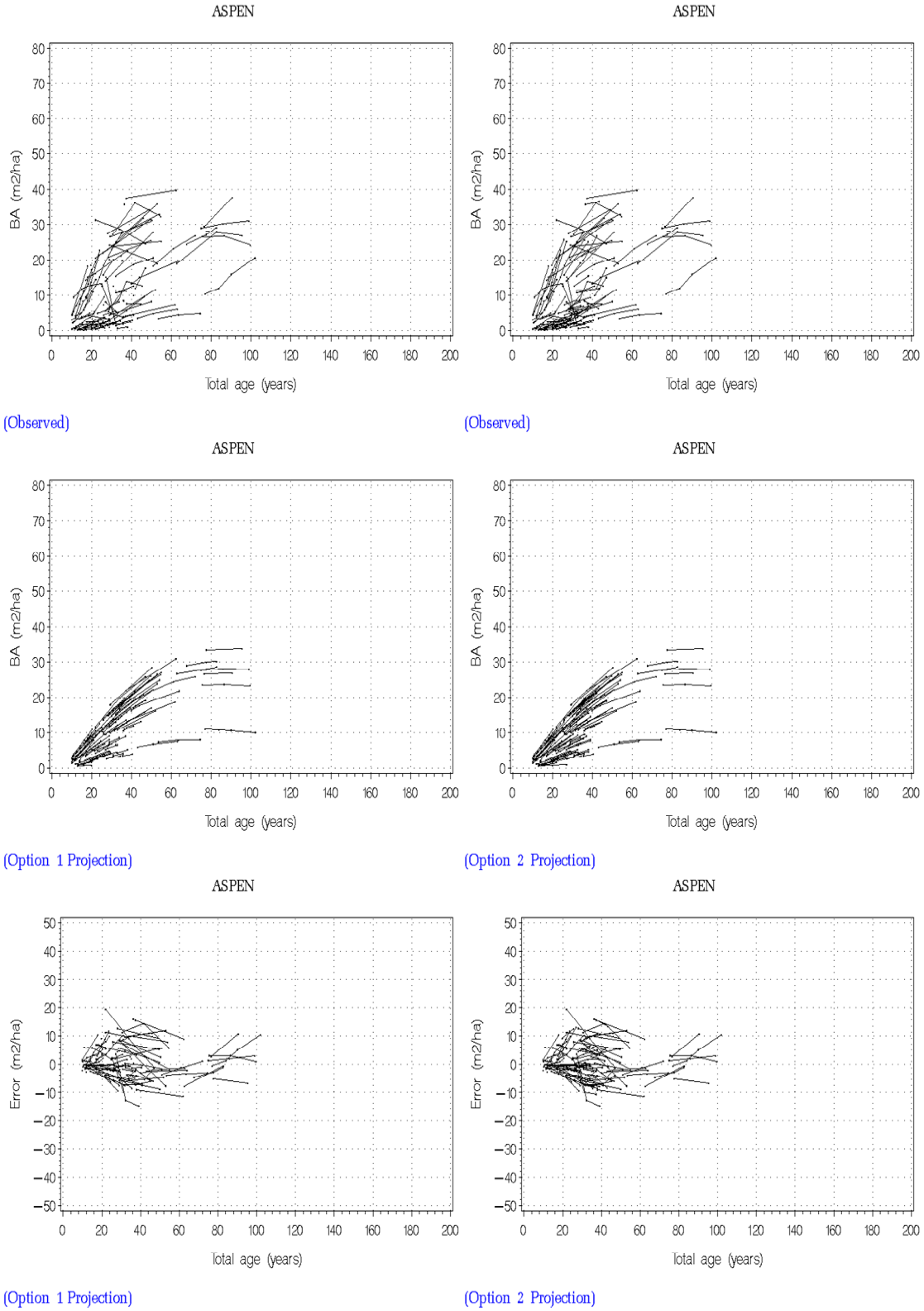


Figure 25. Basal area vs. age with projections for AW (without observed BA).

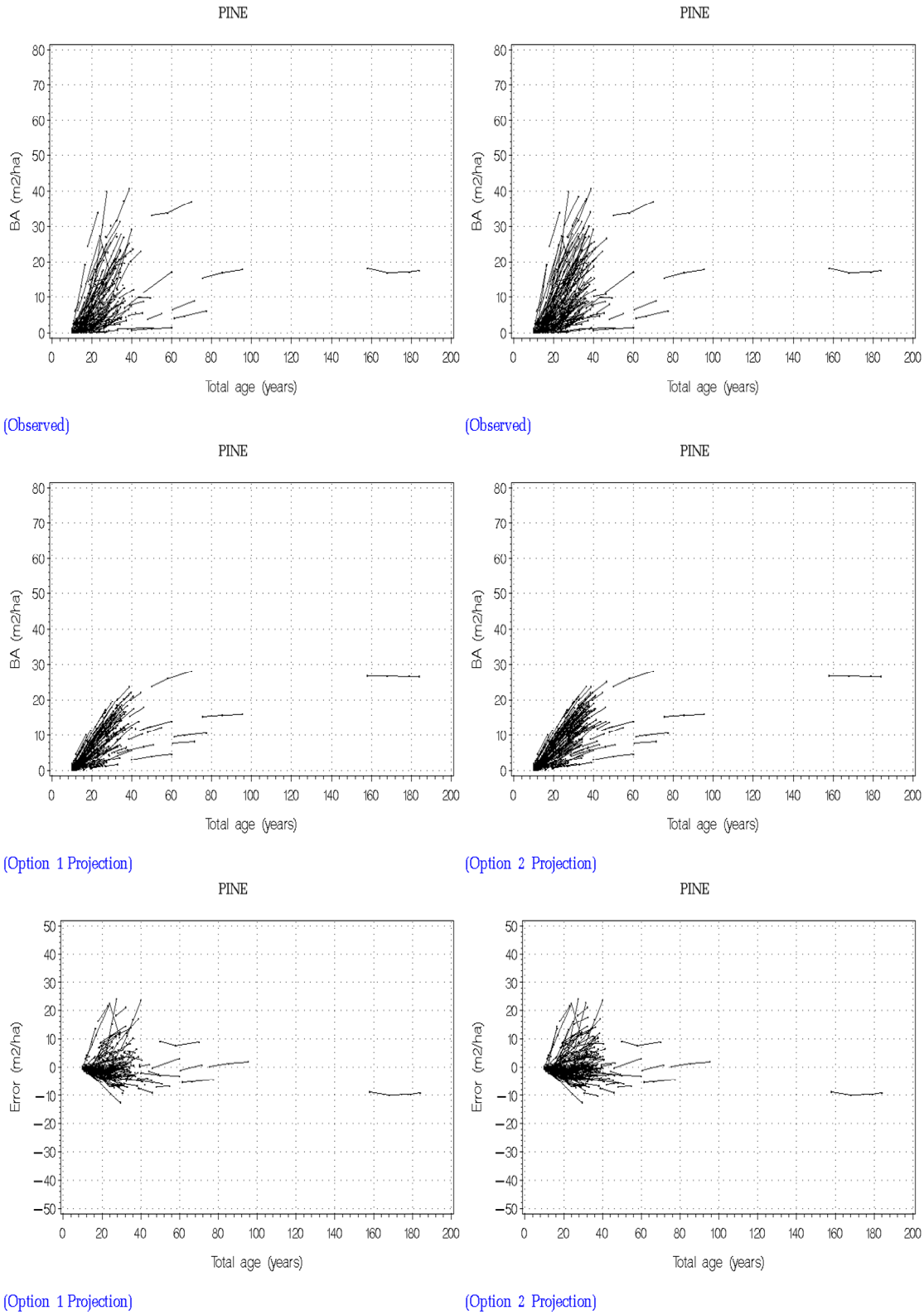


Figure 26. Basal area vs. age with projections for PL (without observed BA).

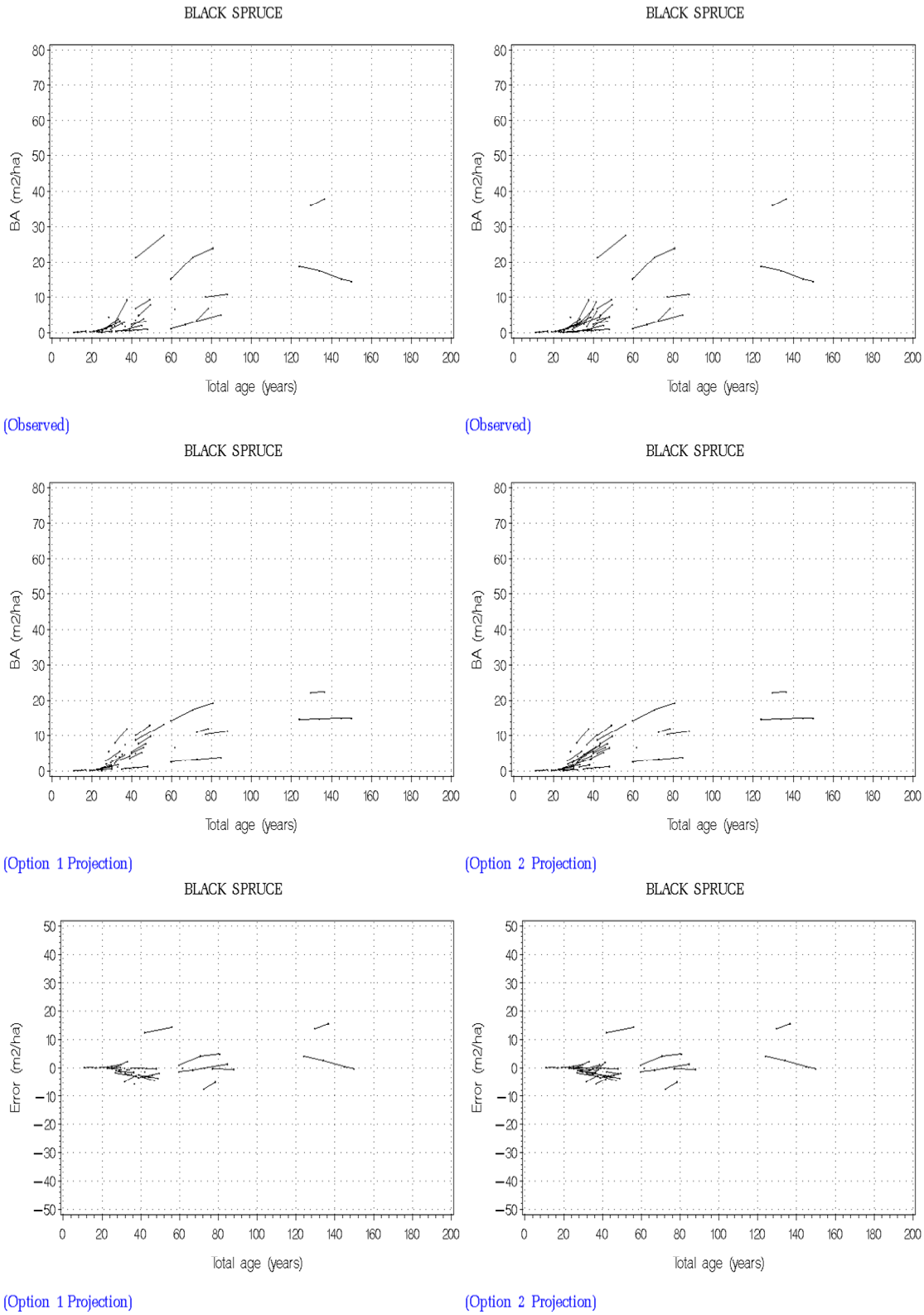


Figure 27. Basal area vs. age with projections for SB (without observed BA).

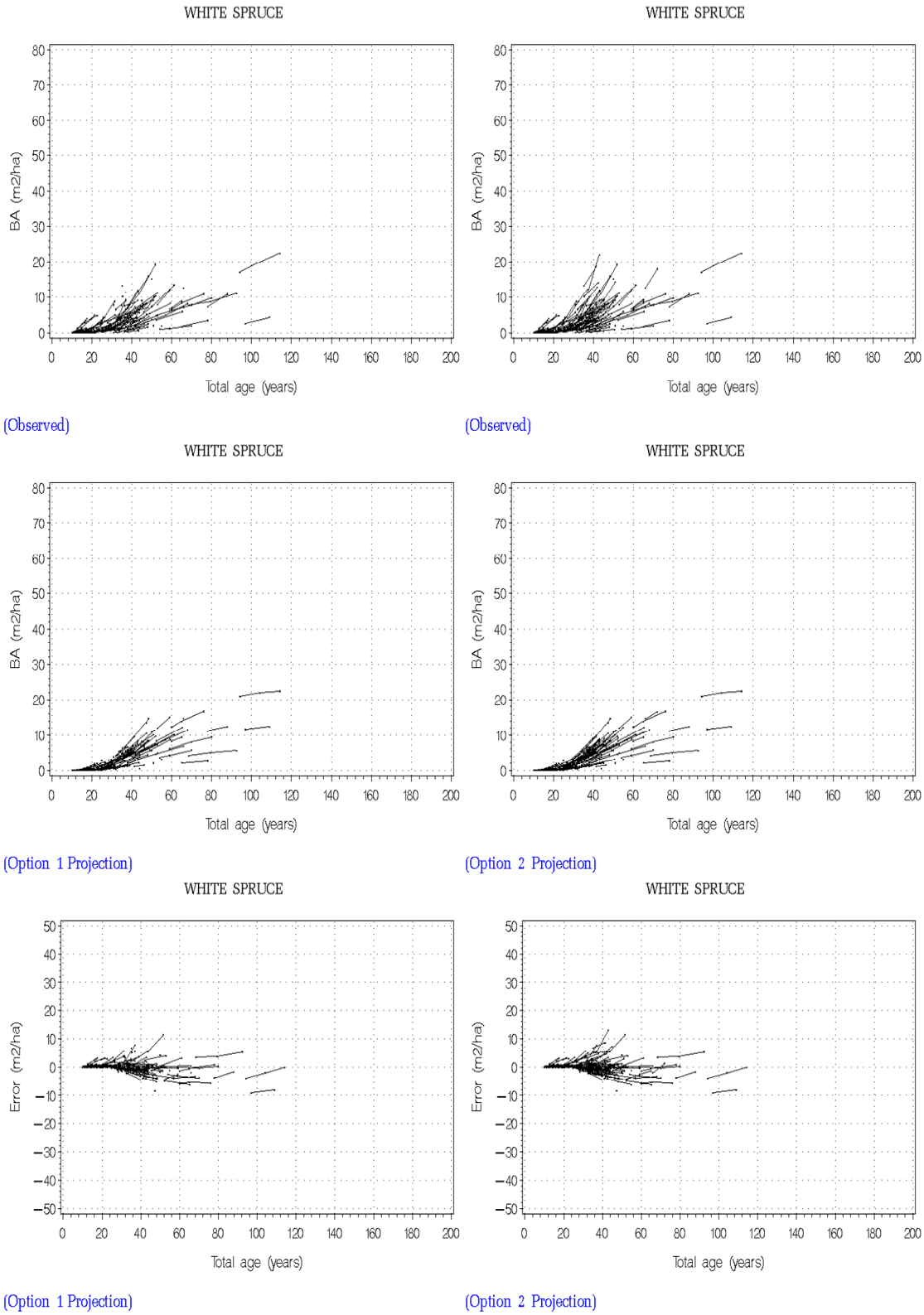


Figure 28. Basal area vs. age with projections for SW (without observed BA).

Since the BA projection does not necessarily pass through the first obs (unlike the previous BA projections where the observed BA of the first obs is included in the BAINC models), all observations, including the first obs and the plots with only one observation, were used for statistics summary. Summaries are presented in Table 8.

Table 8. BAINC Model performance statistics (without observed BA).

Company	Option	Species	N	Mean BA Observed	Mean BA Predicted	RMSE	GoFI	Error_ABS	Error_ABS%	Bias	Bias%
All	1	AW	254	10.988	10.768	5.399	0.712	4.093	37.246	0.220	2.004
		PL	656	6.614	6.749	4.394	0.658	2.824	42.694	-0.135	-2.036
		SB	72	5.585	5.709	4.014	0.761	2.310	41.370	-0.125	-2.233
		SW	347	3.150	3.233	2.105	0.674	1.286	40.815	-0.084	-2.653
	2	AW	285	11.033	10.818	5.524	0.695	4.191	37.987	0.215	1.947
		PL	754	7.605	7.438	4.690	0.671	3.044	40.024	0.167	2.192
		SB	82	5.379	5.596	3.828	0.758	2.235	41.550	-0.217	-4.029
		SW	387	3.545	3.520	2.348	0.661	1.445	40.773	0.025	0.693

4.4 Gross Total Volume Models

4.4.1 Projections with observed BA

The projections were completed by using the information from the first observations (obs) at or beyond 10 years total age where site index, SDF, and BA are available to make projections. That is:

-Site index predicted from the first ht-age pair at or beyond 10 years total age

-Stand density factor (always >=0.3 m in tree height) predicted from the first density-age pair at or beyond 10 years total age

- Observed BA available for the first obs

There are two options for data inclusion in the projections.

In option 1, the projections were completed by setting following limits on the data.

1. totage>=10
2. site index >0
3. density ($N_{0.3}$- based on the trees with height >=0.3 m) >0, and
4. BA >0

For some of plots, the $N_{0.3}$ is available at some measurements, while it is not available at other measurements (due to survey protocol change). By limiting $N_{0.3}$ >0, some measurements of plots, that don't have $N_{0.3}$, but have BA, were excluded in the validation.

In option 2, the limit of $N_{0.3}$ >0 in option 1 was removed in the projections. By doing so,

1. More observations were obtained and used in the validation.

2. Stability of volume models could be tested when the available data were changed.

For the projections, the graphs of observed gross total volume vs. totage trajectories, projections and errors are presented in Figures 29 – 32. In the figures, left graphs are from Option 1 projection, while right graphs are from Option 2 projection.

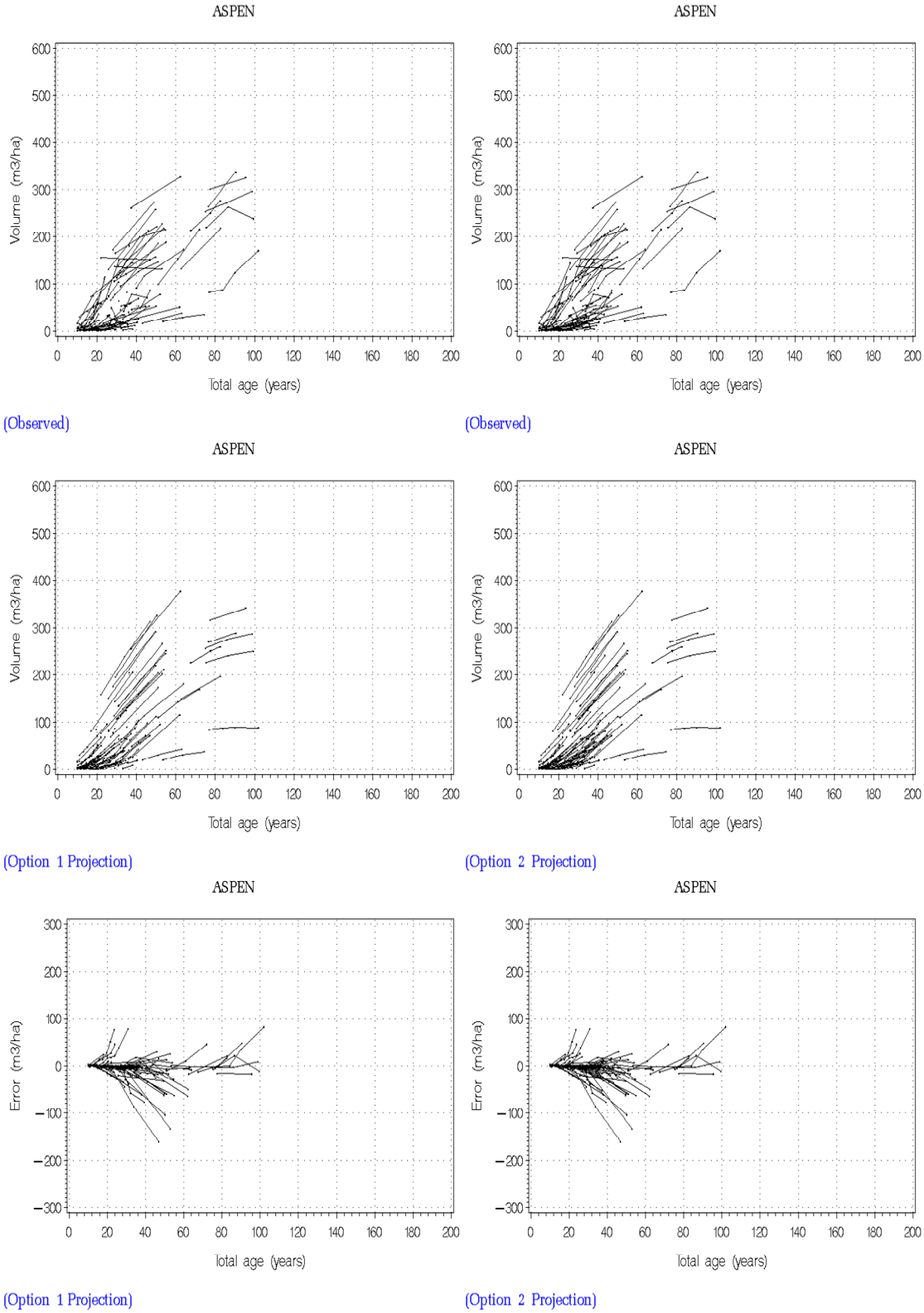


Figure 29. Gross total volume vs. age with projections for AW (with observed BA).

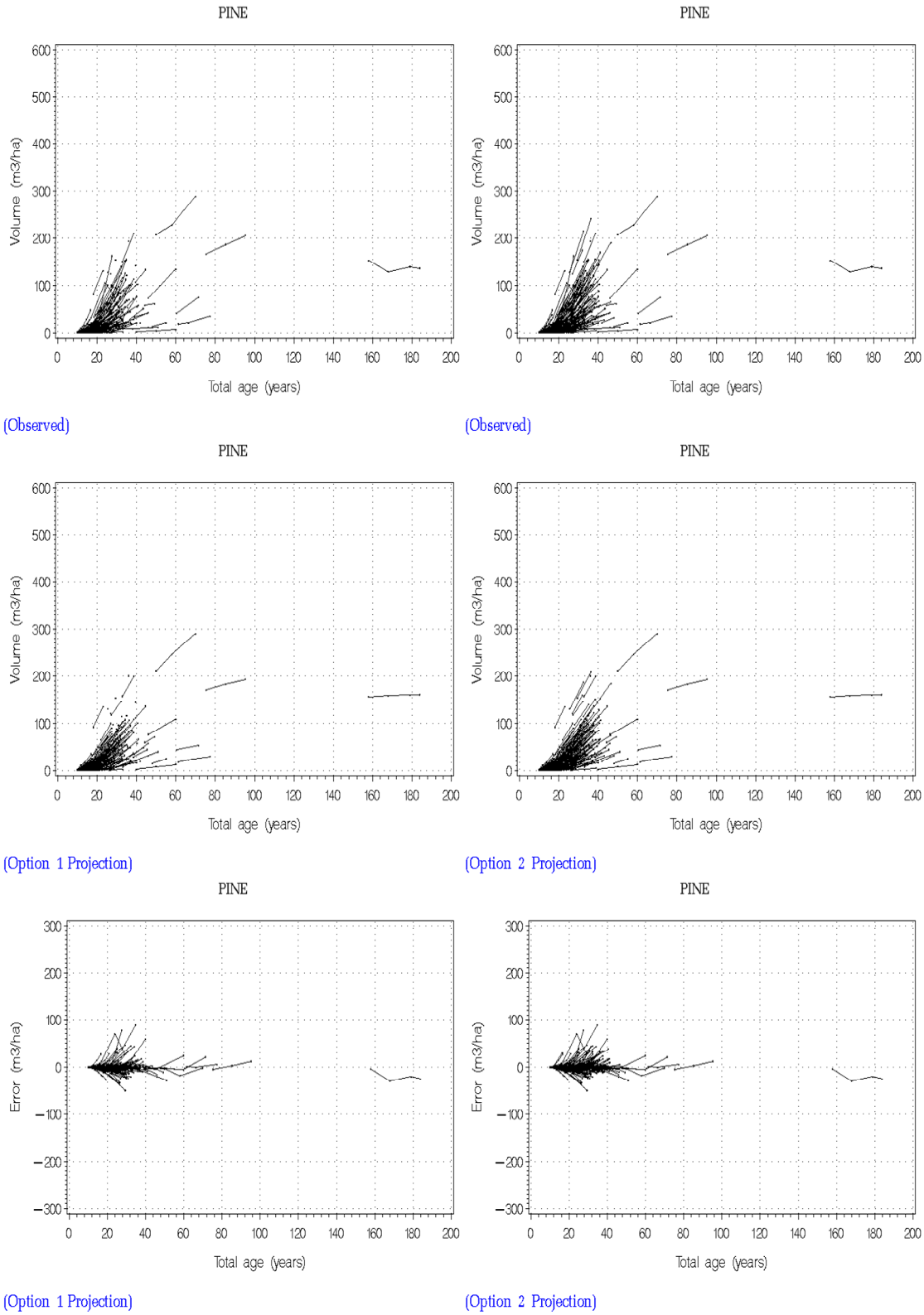


Figure 30. Gross total volume vs. age with projections for PL (with observed BA).

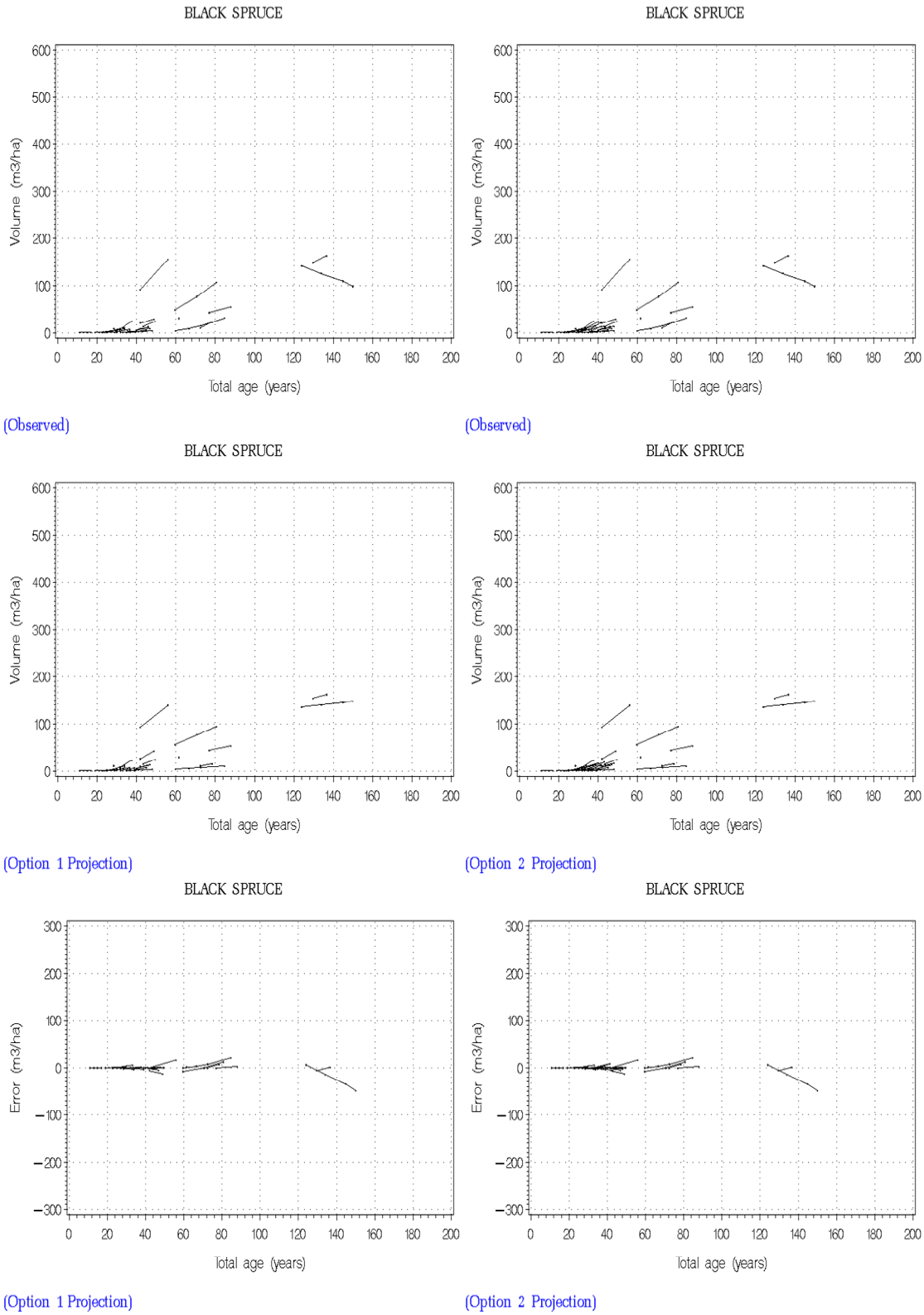


Figure 31. Gross total volume vs. age with projections for SB (with observed BA).

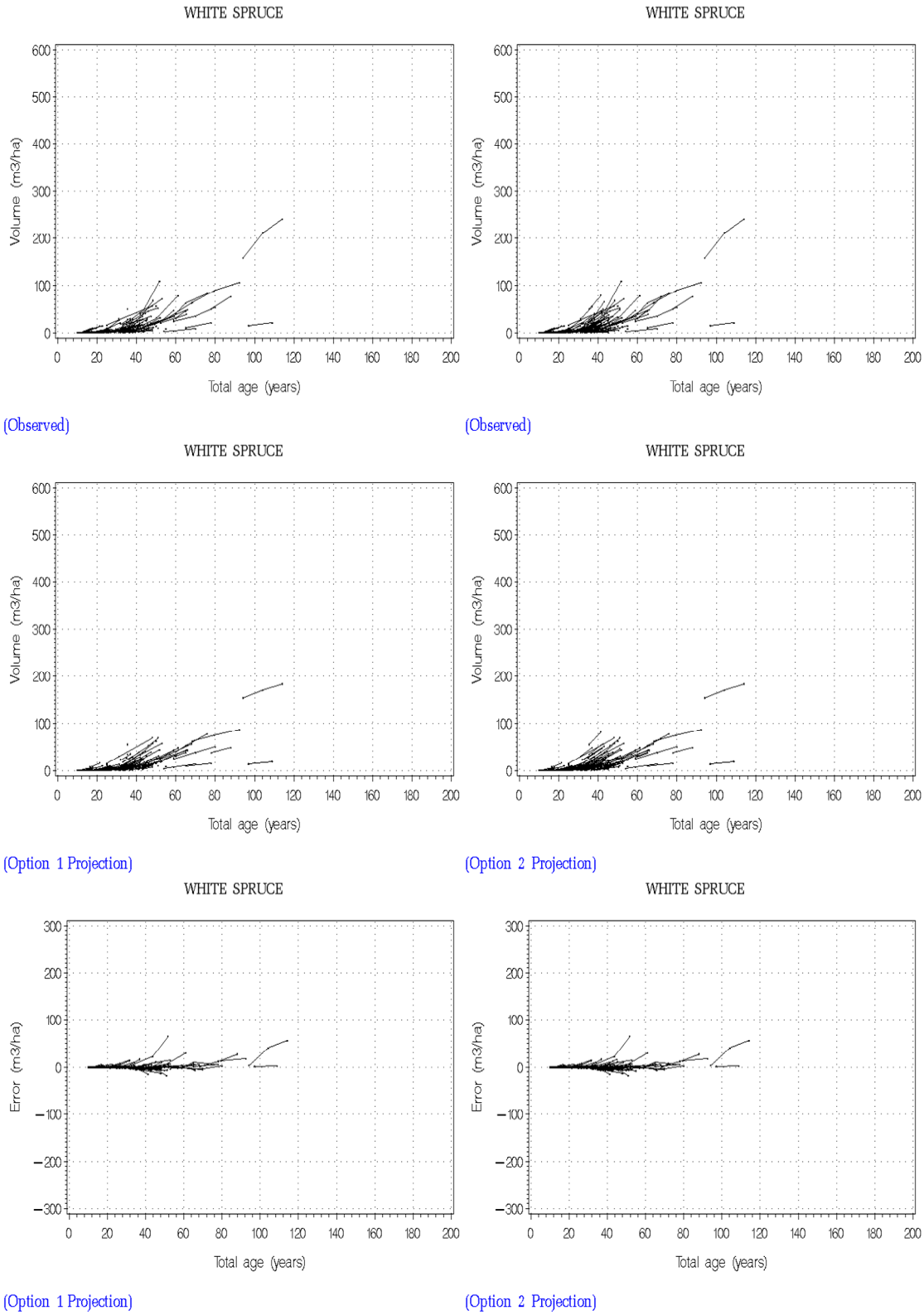


Figure 32. Gross total volume vs. age with projections for SW (with observed BA).

Since the gross total volume projection does not necessarily pass through the first obs (unlike projections for top height, density and basal area), all observations, including the first obs and the plots with only one observation, were used for statistics summary. Summaries are presented in Table 9.

Table 9. Gross total volume model performance statistics (with observed BA).

				Mean Volume							
Company	**Option**	**Species**	**N**	**Observed**	**Predicted**	**RMSE**	**GoFI**	**Error_ABS**	**Error_ABS%**	**Bias**	**Bias%**
All	1	AW	254	64.193	68.665	25.025	0.898	12.923	20.131	-4.473	-6.968
		PL	656	25.302	25.888	10.311	0.927	4.758	18.805	-0.587	-2.319
		SB	72	24.382	25.249	8.571	0.958	3.550	14.561	-0.867	-3.557
		SW	347	13.090	12.231	6.779	0.927	2.627	20.068	0.859	6.563
	2	AW	285	63.432	68.336	24.411	0.897	13.019	20.524	-4.904	-7.730
		PL	754	30.467	30.285	10.897	0.934	5.423	17.801	0.182	0.597
		SB	82	22.731	23.388	8.160	0.958	3.491	15.358	-0.658	-2.895
		SW	387	14.233	13.373	6.649	0.928	2.774	19.490	0.860	6.044

4.4.2 Projections without observed BA

The projections simulated in Section 4.4.1 used the first obs (which age is greater than 10) as a starting point and had the observed BA of the first obs in the BAINC models.

In some cases, projections need to be simulated by starting from age 0 and when the observed BA is not available. The following projections were made where the observed BA was not included in the BAINC models.

For the projections, the graphs of observed gross total volume vs. totage trajectories, projections and errors are presented in Figures 33 – 36. In the figures, left graphs are from Option 1 projection, while right graphs are from Option 2 projection.

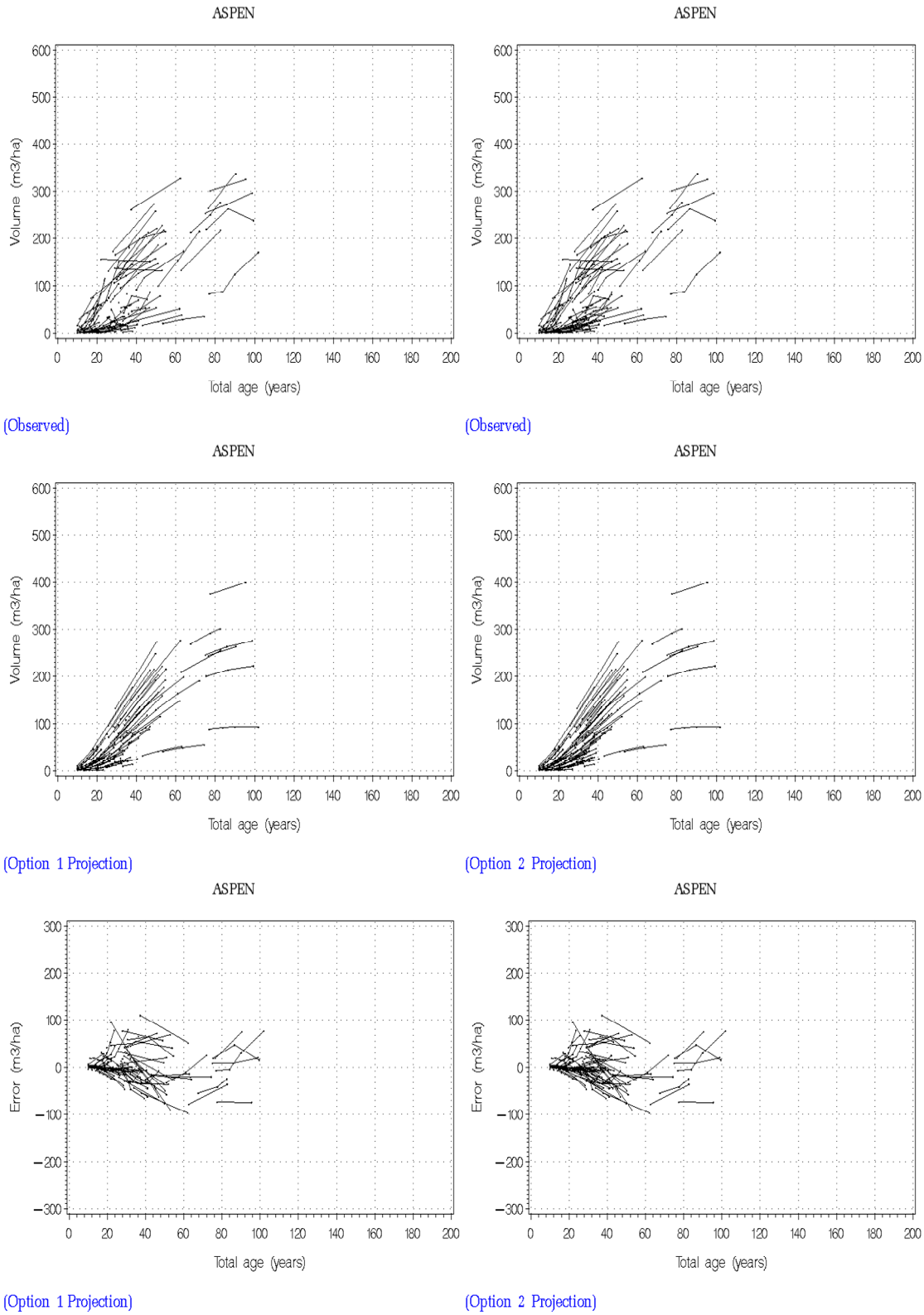


Figure 33. Gross total volume vs. age with projections for AW (without observed BA).

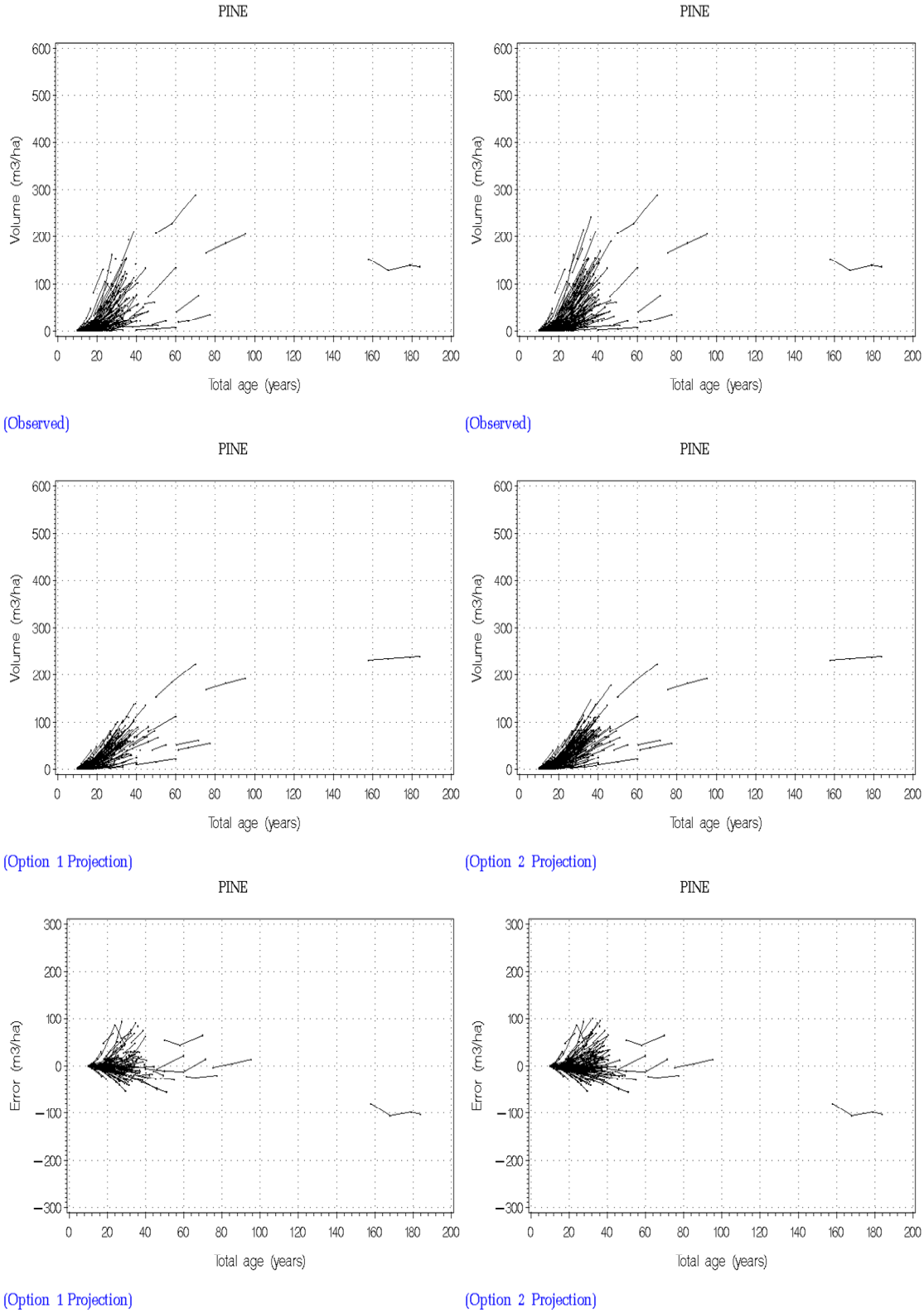
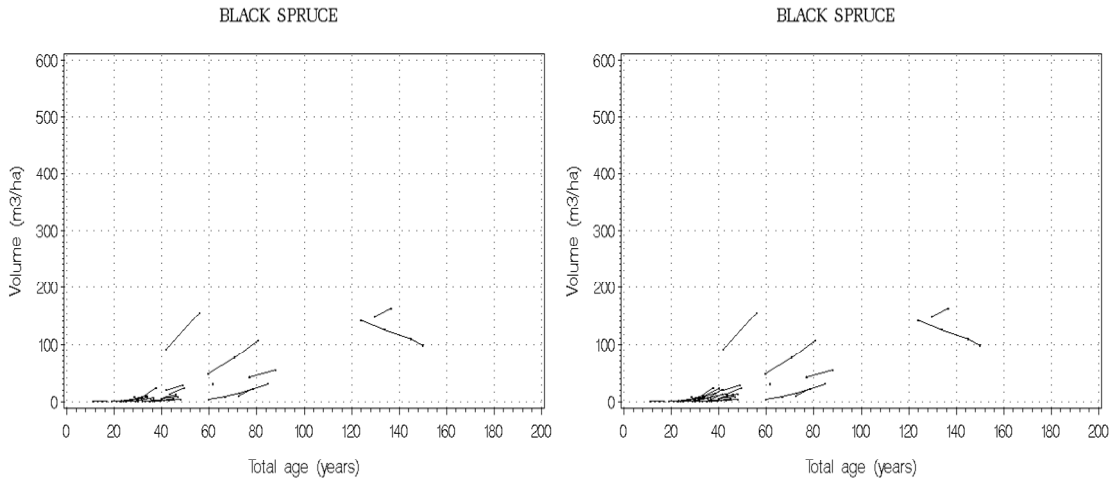
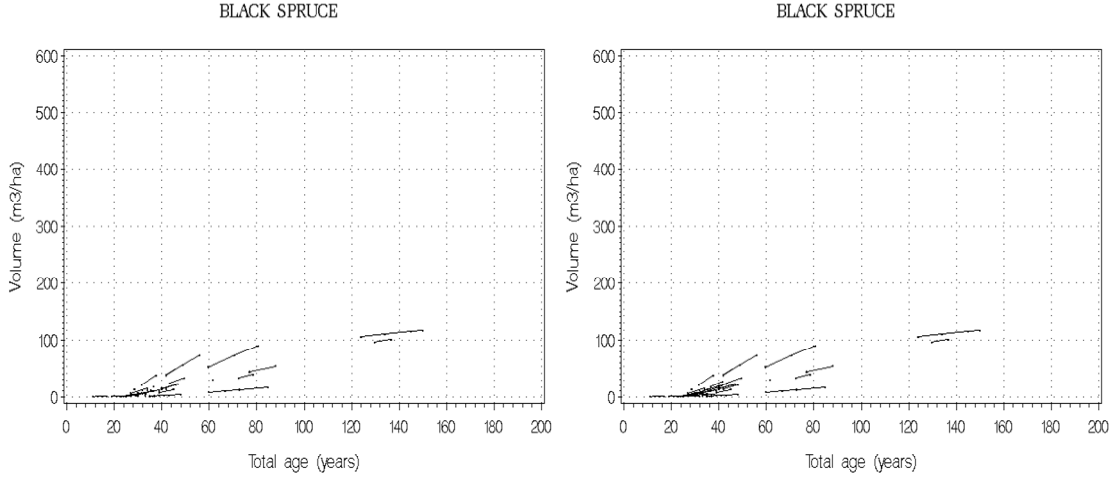


Figure 34. Gross total volume vs. age with projections for PL (without observed BA).



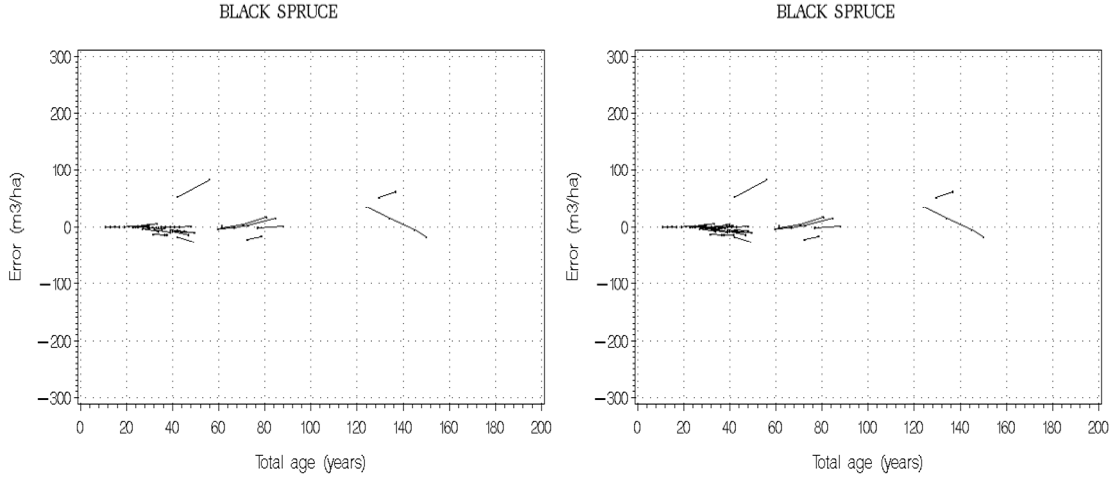
(Observed)

(Observed)



(Option 1 Projection)

(Option 2 Projection)



(Option 1 Projection)

(Option 2 Projection)

Figure 35. Gross total volume vs. age with projections for SB (without observed BA).

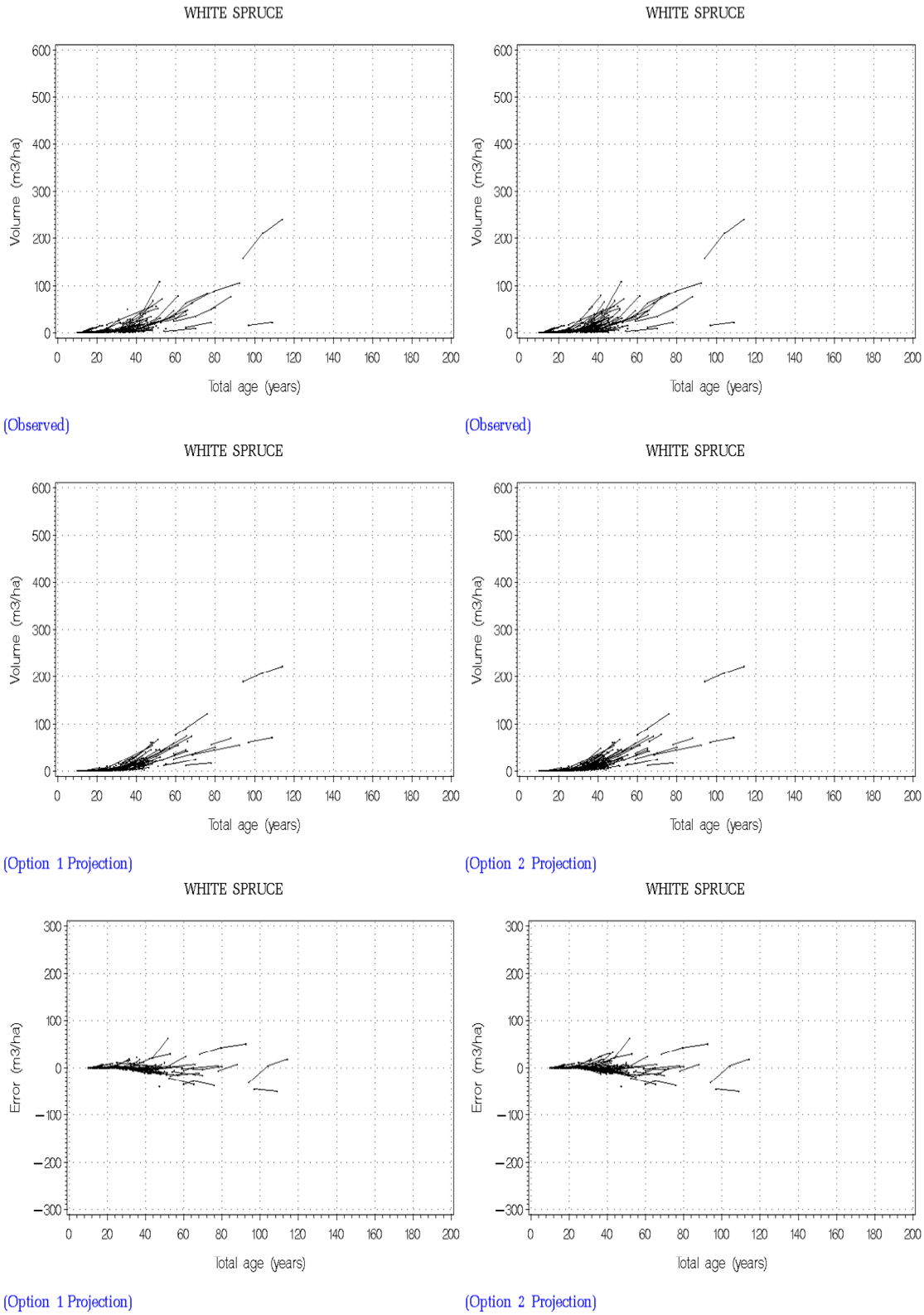


Figure 36. Gross total volume vs. age with projections for SW (without observed BA).

Summaries are presented in Table 10.

Table 10. Gross total volume model performance statistics (without observed BA).

Company	Option	Species	N	Mean Volume Observed	Mean Volume Predicted	RMSE	GoFI	Error_ABS	Error_ABS%	Bias	Bias%
All	1	AW	254	64.193	65.561	30.892	0.845	21.368	33.287	-1.368	-2.132
		PL	656	25.302	26.306	18.697	0.760	10.365	40.964	-1.004	-3.969
		SB	72	24.382	23.595	17.483	0.827	9.018	36.986	0.787	3.228
		SW	347	13.090	13.649	9.711	0.850	4.696	35.876	-0.559	-4.268
	2	AW	285	63.432	64.953	30.682	0.837	21.458	33.828	-1.521	-2.398
		PL	754	30.467	30.215	20.127	0.774	11.593	38.053	0.251	0.825
		SB	82	22.731	22.394	16.527	0.827	8.503	37.407	0.336	1.480
		SW	387	14.233	14.518	9.959	0.839	5.099	35.821	-0.285	-2.002

5. Discussions and Conclusions

5.1 Top Height Models

1. For all species, statistics indicate that the models perform better in backward projections than in forward projections.

2. For all species, models perform very well considering the statistics - high GoFI and small Bias%.

3. For all species, statistics indicate models perform relatively more poorly when not using the plots with only one observation, and/or not using the first observation (Forward-2 and Backward-2) compared to using all data (Forward-1 and Backward-1).

4. For all species, models don't perform differently when reducing totage>=10 to totage>5.

   However, readers should exercise caution to draw any conclusions due to sample size issue, especially for species SB and SW. For example, none of obs for SB and eight obs for SW have totage in the range 5<totage<10 in the validation. Therefore, models should be used with a caution for stands younger than 10 years old before a firm conclusion can be achieved based on more data for SB and SW.

   For PL we may be confident to draw this conclusion - when reducing totage>=10 to totage>5 model still performs very well, because there were enough data between ages 5 to 10 (i.e., 70 obs) used in the test. But for Aw, we should be cautious to make the same conclusion because there were only 16 obs between ages 5 to 10 available in the test.

5. For all species, models don't perform differently when reducing totage>=10 to totage>5. However, readers should exercise caution to draw any conclusions due to sample size issue. For example, none of obs for SB and eight obs for SW have totage in the range 5<totage<10 in the validation. Therefore, models should be used with a caution for stands younger than 10 years old before a firm conclusion can be achieved based on more data.

6. Models show relatively strong stability of site index over time, especially for PL.

7. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenarios (Forward 1 and Backward 1), the Bias% values are all within ±2% when totage>=10 years.

   The best performer is AW, then PL, which have the relatively smaller Bias% and the higher GoFI. SB has relatively larger Bias% and the lower GoFI.

5.2 Density Models (non-spatial)

1. For all species, performances of all models are improved significantly when using averages (Iteration #2) of site index, SDF, and Y2BH to simulate projections compared to using the information of the first obs (Iteration #1).

2. For all species, statistics indicate models perform relatively more poorly when not using the plots with only one observation, and/or not using the first observation (Iteration 1-2 and Iteration 2-2) compared to using all data (Iteration-1-1and Iteration-2-1).

3. For all species, models don't perform differently when reducing totage>=10 to totage>5. However, readers should exercise caution to draw any conclusions due to sample size issue. For example, only four obs for SB, nine obs for AW, and twelve obs for SW have totage in the range 5<totage<10 in the validation. Therefore, models should be used with a caution for stands younger than 10 years old before a firm conclusion can be achieved based on more data.

4. For AW, model performs well when using density1.3. For the most likely projection scenario Iterations 1-1, the GoFI is 0.88 and the Bias% is 6.49%.

   When compared to using density0.3, the model performs a little bit poorer (GoFI: 0.88 vs. 0.90. Bias%: 6.49% vs. 2.29%).

5. SB has the relatively smaller Bias%, but also has the relatively lower GoFI in average. Its model is not influenced by SDFs of other species. However, big variations of GoFI (from 0.60 to 0.92) were found. This may indicate that its sample sizes (from 25 to 75 obs) may need to be increased for better validation.

6. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenarios (Iterations 1-1 and 1-2), the Bias% values are all within ±10% when totage>=10 years.

   The best performer is AW, which has the relatively smaller Bias% and the higher GoFI. This may be because its model is not influenced by SDFs of other species, like PL and SW. PL has relatively larger Bias% and SW has relatively lower GoFI.

5.3 Basal Area Increment Models (non-spatial)

5.3.1 Projections with observed BA

1. For all species, all models don't show any performance differences between Option 1 and Option 2. This indicates that models have strong stability over data sets.

2. For all species, statistics indicate models perform relatively more poorly when not using the plots with only one observation and not using the first observation (Summary 2) compared to using all data (Summary 1).

3. Sample sizes for SB are relatively small. Its sample sizes may need to be increased for better validation.

4. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenarios (Option 2, Summaries 1 and 2), the Bias% values are all within ±10%, except for SW at Option 2, Summary 2 where the Bias% is 11.514%.

   The best performers are AW and SB, which have the relatively smaller Bias% and the higher GoFI. This may be because their models are not influenced by SDFs of other species, like PL and SW. SW has relatively larger Bias%.

5.3.2 Projections without observed BA

1. For all species, all models don't show any performance differences between Option 1 and Option 2. This indicates that models have strong stability over data sets.

2. Sample sizes for SB are relatively small. Its sample sizes may need to be increased for better validation.

3. For all species, statistics indicate models perform relatively more poorly when projections are made where the observed BA is not included in the BAINC models compared to the projections made where the observed BA is in the models.

4. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenario (Option 2), the Bias% values are all within ±5%.

   The best performers are AW and SB, which have the relatively smaller Bias% and the higher GoFI. This may be because their models are not influenced by SDFs of other species, like PL and SW.

5.4 Gross Total Volume Models

5.4.1 Projections with observed BA

1. For all species, all models don't show any performance differences between Option 1 and Option 2. This indicates that models have strong stability over data sets.

2. Sample sizes for SB are relatively small. Its sample sizes may need to be increased for better validation.

3. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenario (Option 2), the Bias% values are all within ±10%.

   The best performer is SB, then PL, which has the relatively smaller Bias% and the higher GoFI. AW has relatively larger Bias% and lower GoFI.

5.4.2 Projections without observed BA

1. For all species, all models don't show any performance differences between Option 1 and Option 2. This indicates that models have strong stability over data sets.

2. Sample sizes for SB are relatively small. Its sample sizes may need to be increased for better validation.

3. For all species, statistics indicate models perform relatively more poorly when projections are made where the observed BA is not included in the BAINC models compared to the projections made where the observed BA is in the models.

4. Overall, the projected trajectories follow the observed trajectories closely. For the most likely projection scenario (Option 2), the Bias% values are all within ±5%.

   The best performer is AW, which has the relatively smaller Bias% and the higher GoFI. PL has relatively larger Bias% and lower GoFI.

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