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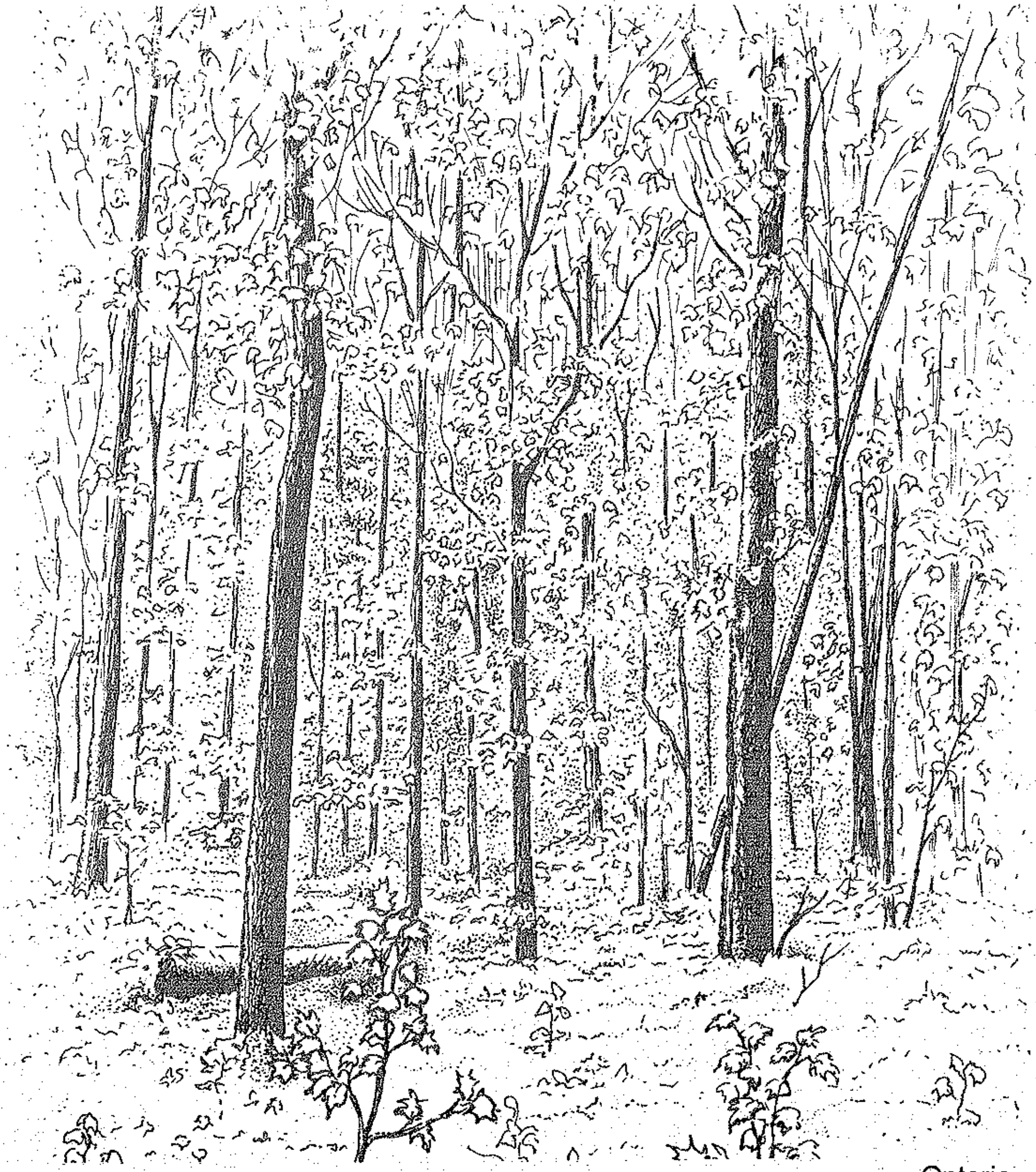
Forest Research Information Paper No. 130

Validation of NE-TWIGS for Tolerant Hardwood Stands in Ontario



Funded by the Sustainable Forestry Initiative

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Validation of NE-TWIGS for Tolerant Hardwood Stands in Ontario

by

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1996

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Canadian Cataloguing in Publication Data

Main entry under title:
Validation of NE-TWIGS for tolerant hardwood stands in Ontario

(Forest research information paper, ISSN 0319-9118 ; no. 130)
Issued by Ontario Forest Research Institute.
Includes bibliographical references.
ISBN 0-7778-4945-3

1. Hardwoods—Ontario—Growth—Computer simulation.
I. Bankowski, Jacek, 1963-.
II. Ontario. Ministry of Natural Resources.
III. Ontario Forest Research Institute.
IV. Series.

SD397.H3V34 1996 634.9'72'09713 C96-964003-X

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Abstract

Bankowski, J., D. Dey, E. Boysen, M. Woods, J. Rice. 1996. Validation of NE-TWIGS for tolerant hardwood stands in Ontario. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, Ontario, Forest Research Information Paper No. 130, 21 p.

The individual-tree, distance-independent stand growth simulator NE-TWIGS has been tested for Ontario's tolerant hardwood stands using data from long-term permanent sample plots. NE-TWIGS provides reliable short-term (5-year) predictions of stand basal area (modelling efficiency from 77% to 99%), but in longer projections the efficiency of the model drops significantly. Basal area is underestimated an average of 2% to 5% for 5-year projections (with exception of the data set representing low-productivity sites). The error of basal area for individual stands ranges from -22% to 37%. NE-TWIGS is not reliable for predicting basal area by timber size classes, particularly those for medium and large sawlogs. In over 51% of stand projections, the predicted diameter distribution is significantly different from the actual distribution, primarily due to the ingrowth function. Thus, calibrating the ingrowth model is recommended for Ontario conditions. NE-TWIGS uses Site Index as a measure of site productivity, but this data was not available for this analysis. Inclusion of site productivity data may have improved the performance of NE-TWIGS.

Keywords: growth model, tolerant hardwood, thinning, timber class, basal area, stand density, stand volume

Acknowledgments

The authors are thankful for support from the Great Lakes-St. Lawrence Silviculture Program, OFRI; Forest Growth and Yield Program, OFRI; Central Region Science and Technology Development Unit, North Bay; and Southern Region Science and Technology Transfer Unit, Brockville. We are especially grateful to Voyteck Zakrzewski for initiating this project and Michael Ter-Mikaelian, both from OFRI. Kadiroo Jayaraman, visiting scientist at OFRI, also provided valuable suggestions.

Table of Contents

Table of Contents

Introduction

This paper presents the results of a validation test of the stand growth simulator NE-TWIGS (version 3.0) -- the Northeastern United States version of TWIGS: The Woodsman's Ideal Growth Projection System (Belcher 1982). The test methods and data sets used in this validation are the same as those used in the validation of FIBER 3.0 (Bankowski et al. 1995a) and SILVAH 4.0 (Bankowski et al. 1995b). The results of this work will be used to recommend the most appropriate stand growth simulators for tolerant hardwood stands in Ontario. Other variants of TWIGS, such as for the Lake States, should be tested as additional funding becomes available.

Description of NE-TWIGS

NE-TWIGS uses individual-tree, distance-independent growth and mortality models to project stand growth. This model is applicable to the following 14 northeastern states: Connecticut, Delaware, Kentucky, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia. NE-TWIGS operates much like TWIGS (Belcher 1982). The mathematical functions used for predicting individual-tree diameter growth and probability of survival are unique, with coefficients derived from permanent, remeasured, 1/5-acre plots, which contain a total of 90,000 trees.

Stand growth projections using NE-TWIGS are based on simulating the growth and mortality for trees in the 5" DBH and larger classes. The ingrowth into the 5" DBH class can be input manually or simulated using an automatic ingrowth function (see flowchart on page 2). The growth equation annually estimates a diameter for each sample tree and updates the crown ratio of the tree (Miner et al. 1988):

$$\textbf{Annual diameter growth} = \textbf{potential growth} * \textbf{competition modifier}$$

$$\textbf{Potential growth} = b_1 * SI * [1.0 - \exp(-b_2 * D)]$$

where,

Potential growth = potential annual basal area growth of an individual tree (sq. ft./yr),

D = current tree diameter (DBH in inches),

SI = site index (feet at age 50), and

b_1, b_2 = species-specific coefficients.

Potential growth is calculated from the top 10% of the fastest growers in each DBH and Site Index class. The competition modifier is:

$$\textbf{Competition modifier} = e^{-b_3 * BA}$$

where,

Competition modifier = index of competition, always bounded between 0 and 1,

BA = current basal area (sq. ft./acre), and

b_3 = species-specific equation coefficients.

NE-TWIGS calculates tree mortality by estimating the probability of death for each tree in a given year:

$$\textbf{Survival} = 1 - [1/(1 + e^{n})]$$

where,

$$n = c_1 + c_2 * (D + 1)^{c_3} * e^{-c_4 * D - c_5 * BA - c_6 * SI}$$

BA = stand basal area per acre (square feet),
D = current tree diameter (DBH in inches),
SI = site index, and
$c_1, \ldots, c_6$ = species-specific equation coefficients.

The NE-TWIGS program does not incorporate catastrophic mortality, such as from fire or insect epidemics, into the equation.

Data Description

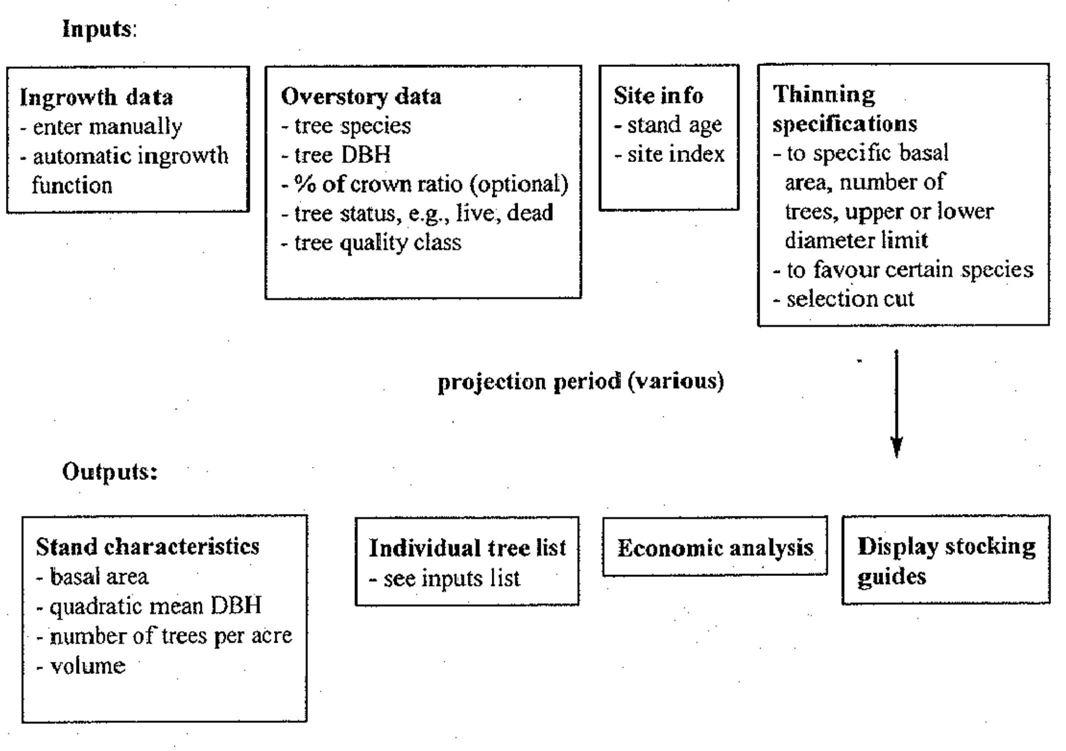
A detailed data description is presented in the previous report (Bankowski et al. 1995a). A summary of data sets used to test NE-TWIGS is shown in Table 1.

Testing Procedures

Trees were grouped into 1" DBH classes (from 5" to 32") for each tree species and quality class. The 2 quality classes were "acceptable" and "undesirable growing stock" based on stem quality. Only trees from DBH classes ≥ 5" were considered in this validation. Data sets were tested separately because of differences in data-collection methods, age structure, and management system.

Measurements from plots were grouped by stands (plot/systems), and growth of stands were projected by the number of 5-year periods equal to the actual measured intervals, which ranged from 1 to 4 remeasurements at 5-year intervals depending on the data set.

NE-TWIGS inputs and outputs are shown below:



Data set	Latitude	Elevation (m)	Area of plot/ system (ha)	Number of plots per plot/ system	Proportion of sugar maple (% basal area)	Prediction periods (years)	Period of data collection	Number of stands (plot/ system)	Basal area of plot/ system (m^2/ha)	Age (years)	Stand density (trees/ha)	Mean quadratic DBH (cm)	Basal area thinned (m^2/ha)	Basal area removed (%)
Algonquin Regional Growth Study	44° 40'- 45° 50'	240-480	0.20 -1.33	5 - 33	38 - 84	5	1977-1982	10	20.9 - 27.1	UA[1]	350- 530	24.2 - 30.3	n/a	-
						10	1977-1987	10	20.8 - 28.2	UA	340- 490	25.6 - 30.9		
Turkey Lakes	47° 03'	330	0.10 - 0.80	1 - 8	82 - 98	5	1980-1985	13	19.2 - 33.2	UA	390- 550	23.6 - 31.1	n/a	
						10	1980-1990	13	20.6 - 30.9	UA	370- 525	23.1 - 31.5		
Beckwith	43° 56'- 44° 54'	80 - 350	0.04 - 0.26	1	10 - 98	5	1971-1991[2]	20	9.8 - 38.8	46- 95	296-1125	16.4 - 28.7	n/a	
						10		16	11.9 - 40.7	55-100	315-1125	16.6 - 30.1		
						15		11	14.3 - 42.9	60-100	330-1175	18.8 - 31.5		
						20		4	15.8 - 44.7	65-105	320- 750	22.5 - 32.2		
Corry Lake Woodlot	46° 00'	150	0.65 - 0.66	4 - 8	12 - 50	5	1973-1978	4	17.7 - 25.3	UA	380- 510	23.5 - 28.3	2.3 - 10.3	9 - 49
						10	1973-1983	8	17.7 - 28.2	UA	360- 560	22.5 - 28.7	2.3 - 10.3	9 - 49
						20	1973-1993	8	19.9 - 27.8	UA	380- 530	23.1 - 29.9	3.3 - 13.6	18 - 48
Algonquin Polar Plots	45° 10'- 46° 00'	390 - 540	0.04 - 0.48	1 - 12	9 - 100	5	1986-1991	88	8.1- 29.4	UA	100- 490	21.5 - 37.6	2.1 - 23.3	10 - 23

[1] UA indicates uneven-aged stands.

[2] Measurements for each period were done in various calendar years.

For most projections, the information about site quality was unknown and an average value of site index was selected (e.g., 70 feet at age 50 for sugar maple (*Acer saccharum* Marsh.)). For the Turkey Lakes projections, however, 2 site index options were evaluated: average value (70) and value determined from stand description (60).

Thinning option in managed stands

The objective was to use a thinning procedure that best approximated the actual harvest conditions. NE-TWIGS has a thinning option that allows the removal of trees in each DBH class. For each stand, the removal of trees mimicked actual field conditions in the test data sets.

Diameter distribution projections

The Kolmogorov-Smirnov Two-Sample Test (Steel and Torrie 1980) was used to examine if observed and predicted DBH distributions were identical. With this test, all trees from each diameter class were assumed to have a DBH equal to the midpoint of the diameter class. The test was performed for all stands and prediction periods.

Error evaluation

Results of the stand growth simulation for each data set were examined by comparing the predicted and observed values of stand density, mean quadratic DBH, and basal area. To evaluate NE-TWIGS' ability to predict basal area by merchantable timber classes, trees were grouped by DBH into the following product classes:

- Poles (10 to 24.9 cm)
- Small sawlogs (25 to 40.9 cm)
- Medium sawlogs (41 to 49.9 cm)
- Large sawlogs (≥ 50 cm)

The observed basal area of each class was compared to the predicted basal area for each product class in each stand. All values were processed in imperial units and then translated to metric units.

Residual values were computed as follows:

$$r = \frac{y - y'}{y'}$$

where,

y' = predicted value, y = observed value, r = residual value.

The prediction error was analysed using plots of the residuals (r) versus predicted values of density, basal area, and mean quadratic DBH. Similarly, residuals were plotted versus basal area for each of the 4 merchantable timber classes.

Model performance in relation to stand characteristics and merchantable timber classes was evaluated using the following criteria:

- average model bias or average error ($\Sigma r/N$; N = number of stands)
- absolute error ($\Sigma |r|/N$)
- range of error (minimum and maximum values of r)

Average model bias is a measure of the expected error when several observations are combined by totalling or averaging, while absolute error indicates the average error associated with a single prediction (Vanclay 1994). The Wilcoxon Rank Test was used to evaluate statistical significance of the model bias (Steel and Torrie 1980).

Another technique used to compare predictions with observed data is modelling efficiency (E_m), a statistic that is analogous to R^2:

$$E_m = 1 - \frac{\sum(y_i - y'_i)^2}{\sum(y_i - \mu)^2}$$

where,

E_m = modelling efficiency; y = observed value; y_i' = predicted value; and μ = mean observed value.

Modelling efficiency provides a simple index of performance on a relative scale, where "1" indicates a "perfect" fit, "0" reveals that the model is no better than a simple average, and negative values indicate a poor model fit.

Finally, trends in residual distribution were examined by plotting residuals of basal area versus sample plot area and species composition (proportion of sugar maple).

Results and Discussion

Diameter distribution

The Kolmogorov-Smirnov test showed that more than 51% of all 5-year predicted diameter distributions were statistically ($P<0.05$) different from observed DBH distributions (Table 2). Predictions of DBH distribution were especially poor for Beckwith stands (even-aged), with 80% of stands failing ($P<0.05$) the Kolmogorov-Smirnov test.

Table 2. Summary of Kolmogorov-Smirnov Two-Sample Test for the null hypothesis that predicted and observed DBH distributions are identical.

Data set	Prediction period	N	Stands with significant difference in DBH distribution (number)
Algonquin Growth Study	5	10	5
	10	10	9
Turkey Lakes	5	13	8
	10	13	7
Beckwith Plots	5	20	16
	10	16	13
	15	11	9
	20	4	3
Corry Lake Woodlot	5	4	2
	10	8	8
	20	8	8
Algonquin Polar Plots	5	88	39

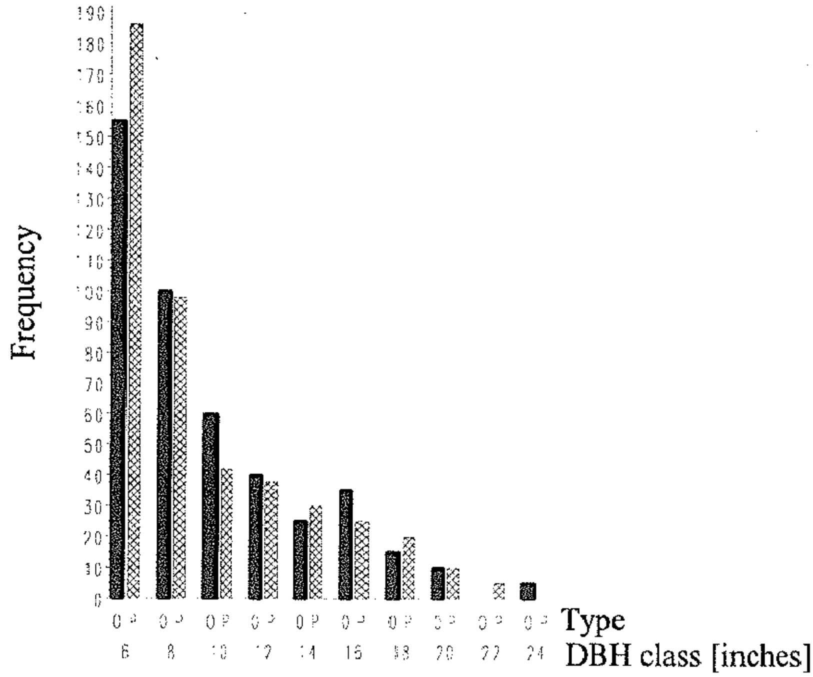


Figure 1. An example of unequal diameter distributions (predicted = "p"; observed = "0") for a stand that failed the Kolomogorov-Smirnov Two-Sample Test of equality of distributions (P<0.05).

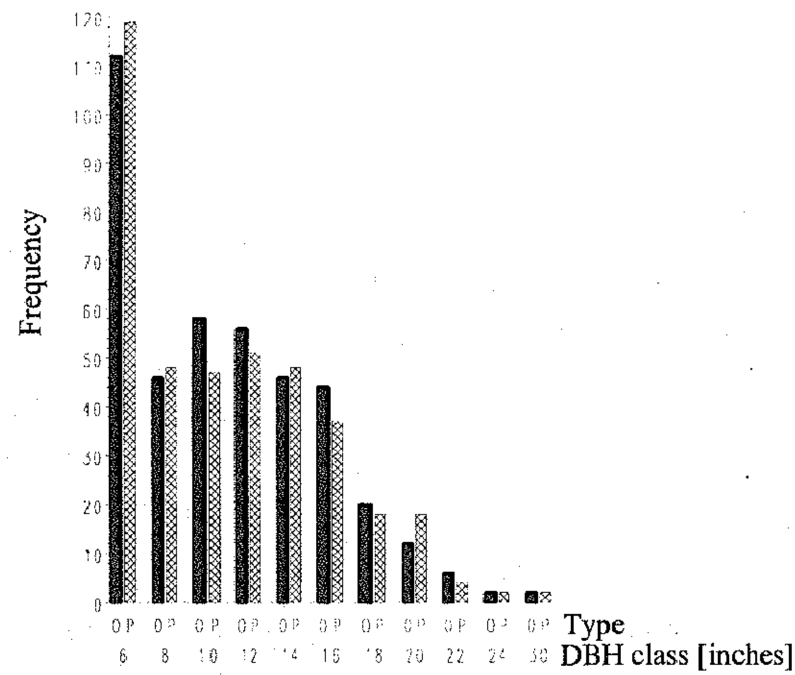


Figure 2. An example of equal diameter distributions (predicted = "p"; observed = "0") for the 5- year projection. The hypothesis of equality of distributions was supported by Kolmogorov-Smirnov Two-Sample Test (P<0.05).

The trend of overpredicting the number of small DBH trees is illustrated in 2 stands (Figures 1 and 2). Thus, the default ingrowth function, used here, which determines the increase in number of trees in the 5" DBH class, is not accurately calibrated for Ontario conditions.

Error evaluation for predictions of stand density, basal area and mean quadratic DBH

The variation among data sets resulting from the size of plot/system area significantly influences the magnitude of prediction errors. Figure 3 illustrates the impact of the plot/system area on residuals of basal area predictions. When sample plots are larger, the basal area is predicted more accurately, and the variance of basal area residuals is smaller. The species composition, e.g., proportion of sugar maple, does not influence model performance (results are not shown).

The Turkey Lakes projections, with 2 site index options, show slight discrepancies in basal area, stand density, and mean quadratic DBH predictions (results are not shown).

These stands are relatively low-productivity sites. Setting site index equal to 60 (feet at age 50) in 5-year growth simulations increased modelling efficiency slightly and reduced the biases in stand density, mean quadratic DBH, and stand basal area predictions. Thus, site index values substantially affect model performance.

In this study the basal area is underpredicted up to 5% on the average (excluding Turkey Lakes data) (Table 3 and Figure 4). The bias in stand density and mean quadratic DBH estimations does not show consistent trends, ranging from -1% to 8% (Tables 4 and 5, Figures 5 and 6). These results are similar to those reported by Schuler et al. (1993) for short-term projections by NE-TWIGS in northern hardwoods in the United States.

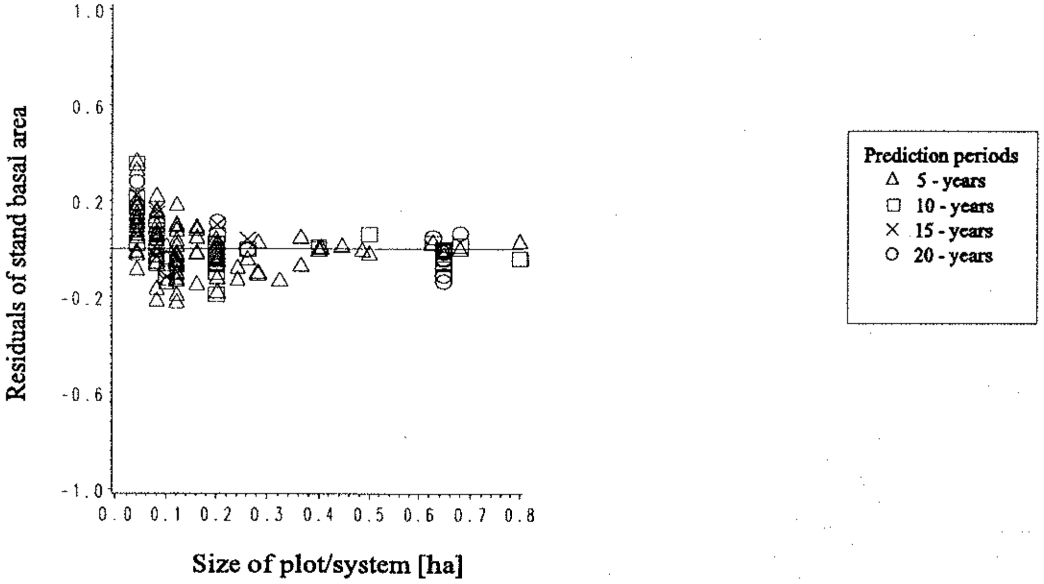


Figure 3. Relationship between residuals of stand basal area and size of plot/system. Data from all data sets and all available prediction periods were used in this analysis. A residual value equal to "0" indicates a perfect fit.

Table 3. Error statistics of basal area predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	0.02[1]	0.00;0.05	0.02	0.90
	10	10	0.03	-0.09;0.10	0.06	0.28
Turkey Lakes	5	13	-0.02	-0.14;0.05	0.03	0.90
	10	13	-0.05[1]	-0.19;0.06	0.06	0.63
Beckwith Plots	5	20	0.05	0.11;0.37	0.07	0.87
	10	16	0.06[1]	-0.06;0.35	0.08	0.71
	15	11	0.07[1]	-0.11;0.22	0.10	0.66
	20	4	0.07	-0.09;0.27	0.02	0.62
Corry Lake Woodlot	5	4	0.00	-0.02;0.03	0.01	0.99
	10	8	-0.02	-0.06;0.03	0.03	0.93
	20	8	-0.03	-0.14;0.06	0.06	0.62
Algonquin Polar Plots	5	88	0.02	-0.22;0.23	0.09	0.77

Table 4. Error statistics of stand density predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	-0.01	-0.05;0.03	0.03	0.93
	10	10	-0.04	-0.20;0.05	0.06	0.31
Turkey Lakes	5	13	0.02	-0.09;0.12	0.05	0.73
	10	13	0.01	-0.06;0.10	0.04	0.75
Beckwith Plots	5	20	0.08	-0.18;0.71	0.12	0.58
	10	16	0.08	-0.16;0.56	0.12	0.57
	15	11	0.07	-0.19;0.30	0.14	0.67
	20	4	-0.04	-0.28;0.18	0.03	0.32
Corry Lake Woodlot	5	4	0.00	-0.02;0.04	0.01	0.96
	10	8	-0.02	-0.08;0.13	0.06	0.74
	20	8	-0.04	-0.17;0.11	0.09	-0.10
Algonquin Polar Plots	5	88	-0.01	-0.22;0.82	0.10	0.70

[1] This value is statistically significant (Wilcoxon Rank Test $P<0.05$).

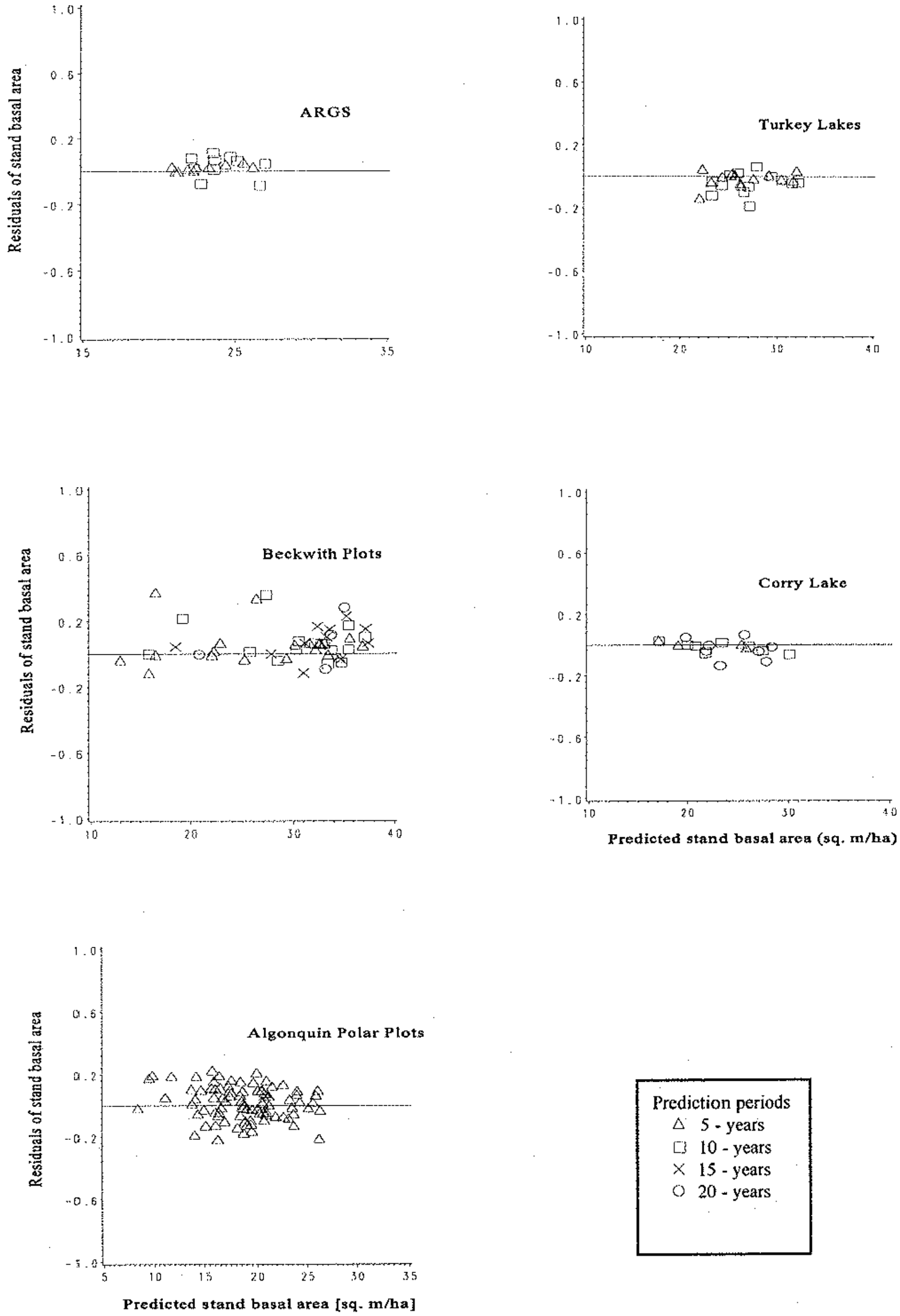


Figure 4. Residuals of stand basal area for the 5 data sets and all available prediction periods.

Table 5. Error statistics of mean quadratic DBH predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	0.02[2]	0.00;0.03	0.02	0.89
	10	10	0.04[2]	0.01;0.08	0.04	0.32
Turkey Lakes	5	13	-0.02[2]	-0.03;0.01	0.02	0.90
	10	13	-0.03[2]	-0.07;0.01	0.03	0.81
Beckwith Plots	5	20	-0.01	-0.10;0.04	0.03	0.94
	10	16	-0.01	-0.12;0.09	0.04	0.90
	15	11	0.01	-0.12;0.13	0.05	0.84
	20	4	0.06	0.01;0.18	0.01	0.73
Corry Lake Woodlot	5	4	0.00	-0.01;0.01	0.00	0.99
	10	8	0.00	-0.04;0.04	0.02	0.87
	20	8	0.01	-0.03;0.04	0.02	0.88
Algonquin Polar Plots	5	88	0.02[2]	-0.20;0.14	0.05	0.66

Table 6. Summary of error statistics for stand basal area, stand density and mean quadratic DBH predictions. Data is grouped by management systems and prediction periods.

Data set	Prediction period (years)	N	Average error (min;max)	Range of error (min;max)	Absolute error (min;max)	Modelling efficiency (min;max)
Unmanaged/ uneven-aged	5	23	-0.02;0.02	-0.14;0.12	0.02;0.05	0.73;0.93
	10	23	-0.05;0.04	-0.20;0.10	0.03;0.06	0.28;0.81
Unmanaged/ even-aged	5	20	-0.01;0.08	-0.18;0.71	0.03;0.12	0.58;0.94
	10	16	-0.01;0.08	-0.16;0.56	0.04;0.12	0.57;0.90
	15	11	0.01;0.07	-0.19;0.30	0.05;0.14	0.66;0.84
	20	4	-0.04;0.07	-0.28;0.27	0.01;0.03	0.32;0.73
Managed/ uneven-aged	5	92	-0.01;0.02	-0.22;0.82	0.01;0.10	0.66;0.99
	10	8	-0.02;0.00	-0.08;0.13	0.02;0.06	0.74;0.93
	20	8	-0.04;0.03	-0.07;0.11	0.02;0.09	-0.10;0.87

[2] This value is statistically significant (Wilcoxon Rank Test P<0.05).

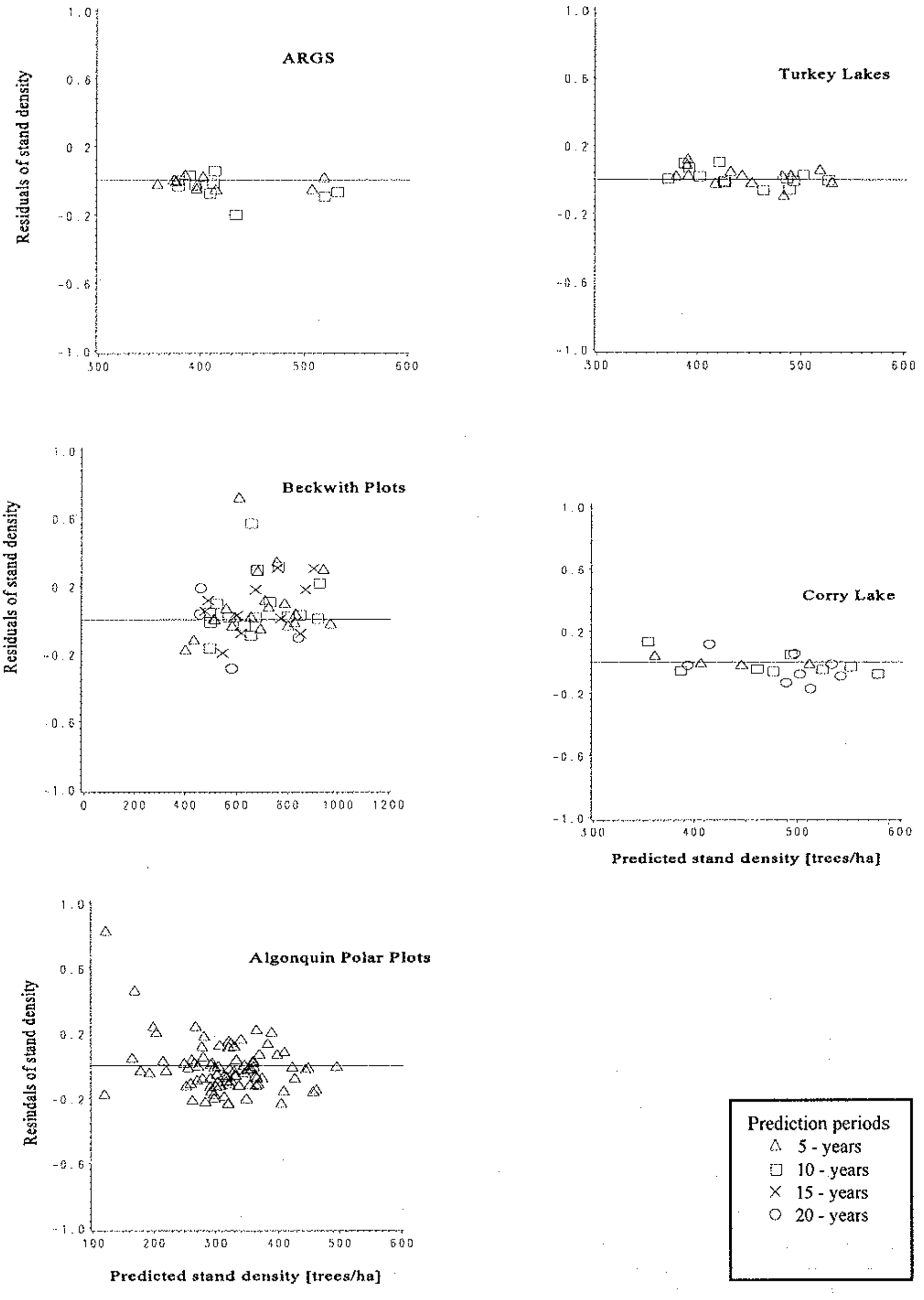


Figure 5. Residuals of stand density for the 5 data sets and all available prediction periods.

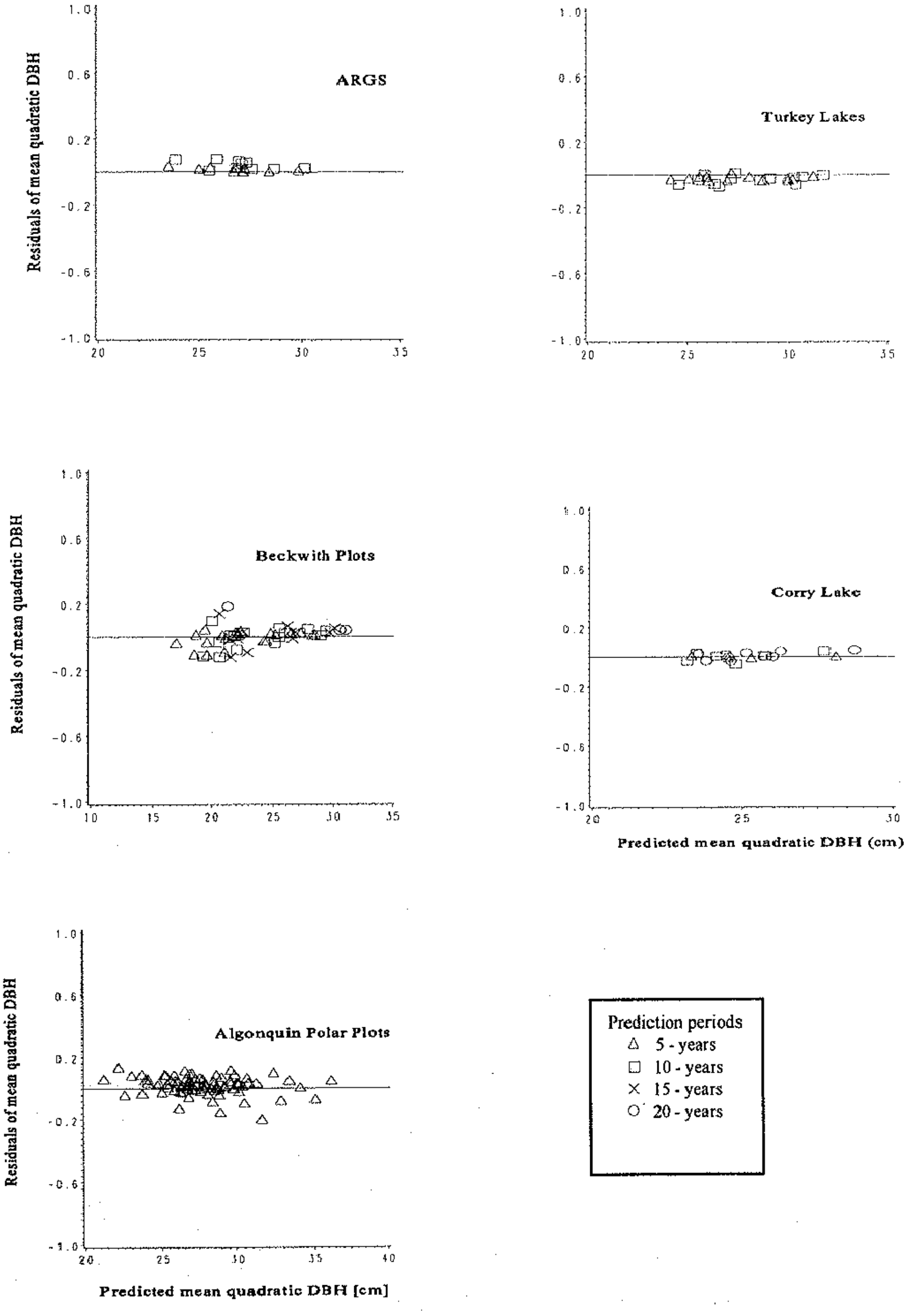


Figure 6. Residuals of mean quadratic DBH for the 5 data sets and all available prediction periods.

I. Uneven-aged, unmanaged stands

The modelling efficiency for 5-year basal area predictions is 90% for all stands. In longer predictions (10 year), the modelling efficiency decreases significantly (Table 3 and Figure 4).

For both data sets representing uneven-aged, unmanaged stands (Algonquin Regional Growth Study and Turkey Lakes), the 5- and 10-year predictions for mean quadratic DBH, stand density, and basal area are relatively unbiased. Average error for stand characteristics ranges from -5% to 4% (Table 3, 4 and 5; Figures 4, 5 and 6). Ten-year predictions of stand basal area for Turkey Lakes are overestimated by 5% on the average, but for the ARGS stands, they average 3% lower (Table 6). To understand the cause of bias in basal area predictions would require the analysis of the residuals generated by the growth and mortality equations. However, the ingrowth function may be the cause of some errors when predicting stand density and mean quadratic DBH (Tables 4 and 5). In both the smallest and medium DBH classes, the number of trees is over-estimated. The lack of accurate site index values also may have influenced the results. When the Turkey Lake stands are projected using a lower site index (60), then the biases of stand density, mean quadratic DBH, and basal area are smaller.

The expected error for a single stand prediction (absolute error) is from 2% to 6% in 5- and 10-year predictions for both data sets and all stand characteristics (Table 7).

II. Even-aged, unmanaged stands

For the Beckwith (even-aged) stands, the modelling efficiency of basal area projections decreases as the prediction period increases – from 87% in 5-year projections to about 62% for 20-year estimates (Table 3).

NE-TWIGS projections for the Beckwith data underestimate (on average up to 5%) basal area and stand density for the 5-year simulation (Tables 3 and 4, Figures 4 and 5). Model biases increase slightly to 7% for 20-year basal area predictions. Average errors (bias) of mean quadratic DBH are from -1% to 1% for 5- and 15-year predictions (Table 5 and Figure 6).

III. Uneven-aged, managed stands

Trends in 5-year projections of stand density, mean quadratic DBH, and basal area are comparable between stands managed by the selection system (Corry Lake and Algonquin Polar Plot) and those that were not harvested (Tables 3, 4, 5 and 6, Figures 4, 5 and 6). However, the range of error for all stand characteristics is larger than for unmanaged stands (from -22% to 82% for all predictions). The performance of NE-TWIGS varies significantly between the 2 data sets. The large range of prediction errors and the low modelling efficiency (from 66% to 73%) of basal area predictions for the Algonquin Polar Plots may be related to the small size of sample plots rather than to the effect of harvesting. For 5-year projections, the modelling efficiency for Corry Lake, representing large sample plots, is high (from 96% to 99%).

The longer (10- and 20-year) predictions for Corry Lake stands overestimate stand basal area from -2% to -3%. Similarly, stand density is overestimated an average of -2% to -4% in the same periods.

Error evaluation for basal area predictions by merchantable timber classes

NE-TWIGS does not reliably project basal area for medium and large sawlogs (Tables 9 and 10, Figures 9 and 10). For small timber classes (pole and small sawlog), the reliability of basal area predictions is also low, ranging from 57% to 78% in modelling efficiency for 5-year periods (Tables 7 and 8, Figures 7 and 8).

The pole basal area is overpredicted (on average from 6% to 9%) in 5-year projections, with the exception of the Beckwith data. Table 8 illustrates the positive biases (up to 17%) in the small sawlog class. Biases increase with longer projections, especially for medium and large sawlogs. The large timber class projections are overestimated for all periods. For one stand, the model failed to predict the presence of the pole timber class. For a few other stands, it failed to predict the medium and large sawlog classes.

Table 7. Error statistics of pole (10 to 24.9 cm) basal area predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	-0.09[3]	-0.18;0.01	0.09	0.69
	10	10	-0.04	-0.33;0.15	0.10	0.59
Turkey Lakes	5	13	-0.02	-0.17;0.15	0.08	0.71
	10	13	0.05	-0.08;0.32	0.09	0.76
Beckwith Plots	5	20	0.06	-0.22;0.54	0.14	0.78
	10	16	0.03	-0.45;0.55	0.19	0.70
	15	11	0.09	-0.43;0.50	0.25	0.71
	20	4	0.04	-0.39;0.62	0.27	0.40
Corry Lake Woodlot	5	4	-0.08	-0.17;-0.03	0.08	0.65
	10	8	-0.02	-0.10;0.05	0.04	0.91
	20	8	-0.12	-0.30;0.18	0.17	-0.02
Algonquin Polar Plots	5	87 (1)[4]	-0.06[3]	-0.56;1.91	0.21	0.575[5]

[3] This value is statistically significant (Wilcoxon Rank Test P<0.05).

[4] The number in parentheses represents the number of stands excluded from calculations due to missing predicted or observed values.

[5] Missing values of residuals are excluded from calculations.

Table 8. Error statistics of small sawlog (25.0 to 40.9 cm) basal area predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	0.17[6]	0.07;0.27	0.17	0.30
	10	10	0.12	-0.07;0.57	0.14	-0.32
Turkey Lakes	5	13	0.07	-0.08;0.28	0.10	0.74
	10	13	0.10[6]	-0.17;0.28	0.15	0.36
Beckwith Plots	5	20	0.00	-0.44;0.30	0.17	0.92
	10	16	0.04	-0.54;0.32	0.22	0.81
	15	11	0.09	-0.42;0.49	0.17	0.77
	20	4	0.09	-0.01;0.30	0.10	0.67
Corry Lake Woodlot	5	4	0.14	0.10;0.23	0.14	0.55
	10	8	0.06[6]	0.02;0.12	0.06	0.89
	20	8	0.22[6]	0.08;0.35	0.21	-0.01
Algonquin Polar Plots	5	88	0.16[6]	-0.40;1.17	0.22	0.57

Table 9. Error statistics of medium sawlog (41.0 to 49.9 cm) basal area predictions.

Data set	Prediction period	N	Average error	Range of error	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	-0.01	-0.28;0.30	0.18	-0.28
	10	10	-0.03	-0.40;0.27	0.21	0.22
Turkey Lakes	5	12(1)[7]	0.20	-0.60;1.35	0.36	0.21[8]
	10	12(1)	-0.23[6]	-0.74;0.27	0.27	-0.26[8]
Beckwith Plots	5	7(2)	-0.19	-0.47;0.03	0.21	0.54[8]
	10	7(4)	-0.21	-0.49;0.16	0.27	0.76[8]
	15	7(1)	0.11	-0.52;0.96	0.30	0.67[8]
	20	3	0.39	-0.23;0.70	0.54	0.51
Corry Lake Woodlot	5	4	-0.25	-0.35;-0.15	0.25	-1.90
	10	8	-0.06	-0.37;0.36	0.20	-0.09
	20	8	-0.12	-0.36;0.18	0.21	-0.03
Algonquin Polar Plots	5	72(9)	0.07	-0.75;3.44	0.28	0.52[3]

6 This value is statistically significant (Wilcoxon Rank Test $P<0.05$).

7 The number in parentheses represents the number of stands excluded from calculations due to missing predicted or observed values.

8 Missing values of residuals are excluded from calculations.

Table 10. Error statistics of large sawlog (≥ 50 cm) basal area predictions.

Data set	Prediction period (years)	N	Average error	Range of error (min;max)	Absolute error	Modelling efficiency
Algonquin Growth Study	5	10	-0.18[9]	-0.42;0.08	0.20	0.81
	10	10	0.00	-0.33;0.23	0.14	0.88
Turkey Lakes	5	11(1)[10]	-0.28[9]	-0.71;0.01	0.26	0.33[11]
	10	11(1)	-0.27[9]	-0.63;0.07	0.24	0.55[11]
Beckwith Plots	5	2	-0.02	-0.08;0.04	0.05	0.99
	10	2 (1)	0.02	-0.01;0.05	0.03	0.93[11]
	15	3 (1)	0.15	0.07;0.32	0.15	0.62[11]
	20	2 (2)	0.17	0.14;0.20	0.17	0.74[11]
Corry Lake Woodlot	5	3	-0.20	-0.41;0.04	0.22	-1.97
	10	6	-0.45[9]	-0.74;-0.19	0.45	-1.21
	20	7(1)	-0.60[9]	-0.91;-0.42	0.60	-6.47[11]
Algonquin Polar Plots	5	57(7)	-0.12	-0.69;1.02	0.21	0.22[11]

9 This value is statistically significant (Wilcoxon Rank Test $P<0.05$).

10 The number in parentheses represents the number of stands excluded from calculations due to missing predicted or observed values.

11 Missing values of residuals are excluded from calculations.

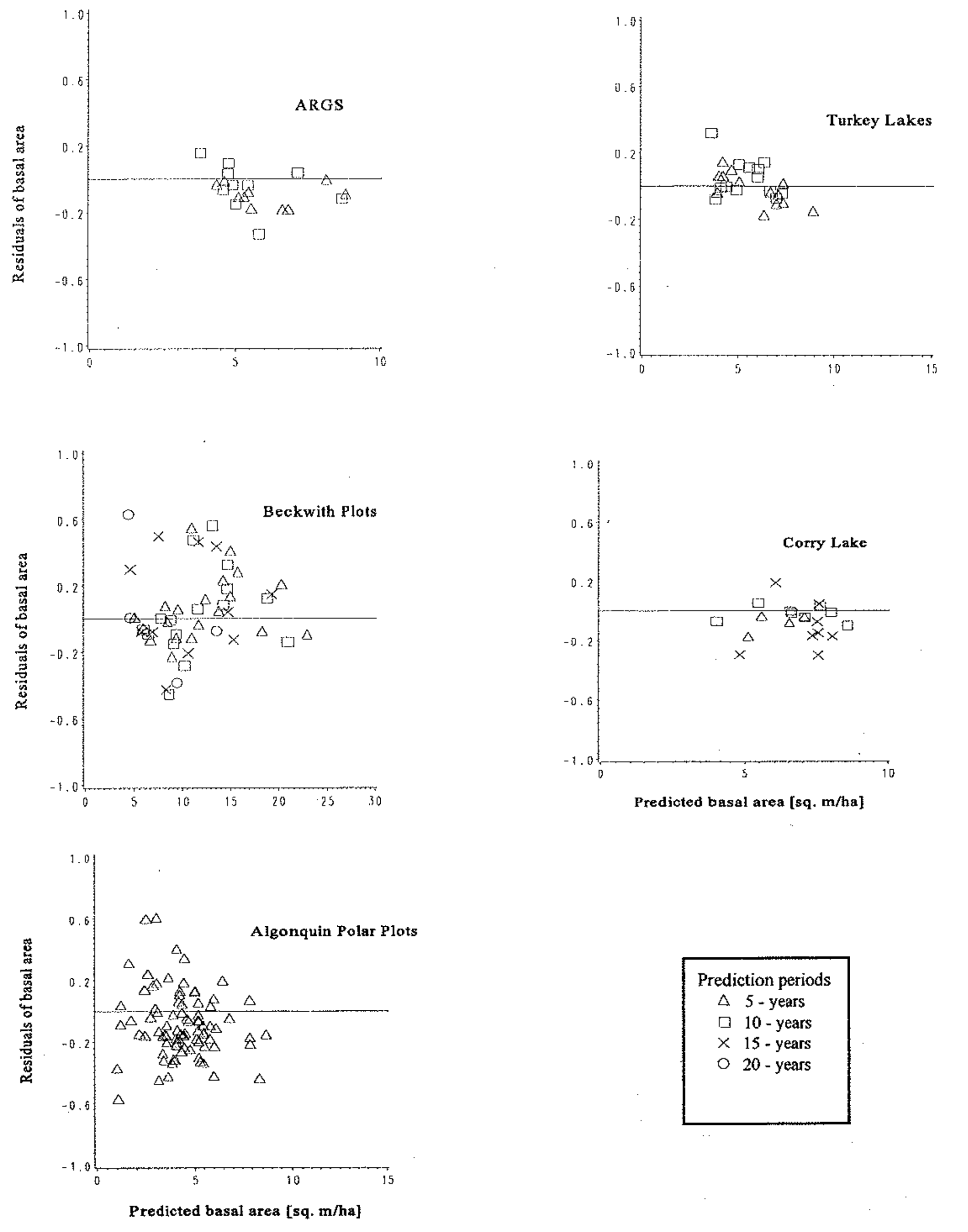


Figure 7. Residuals of the pole timber class basal area for the 5 data sets and all available prediction periods.

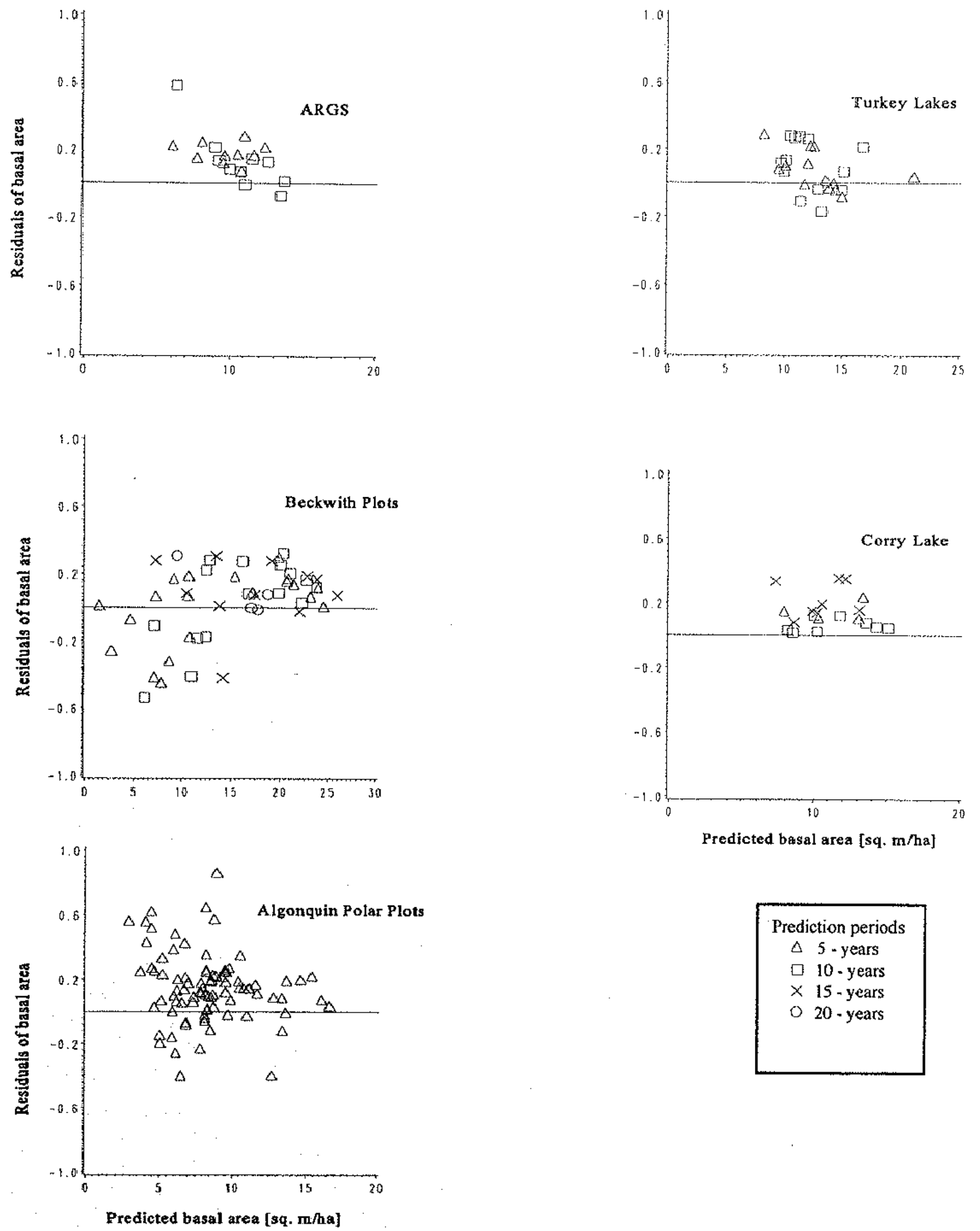


Figure 8. Residuals of the small sawlog timber class basal area for the 5 data sets and all available prediction periods.

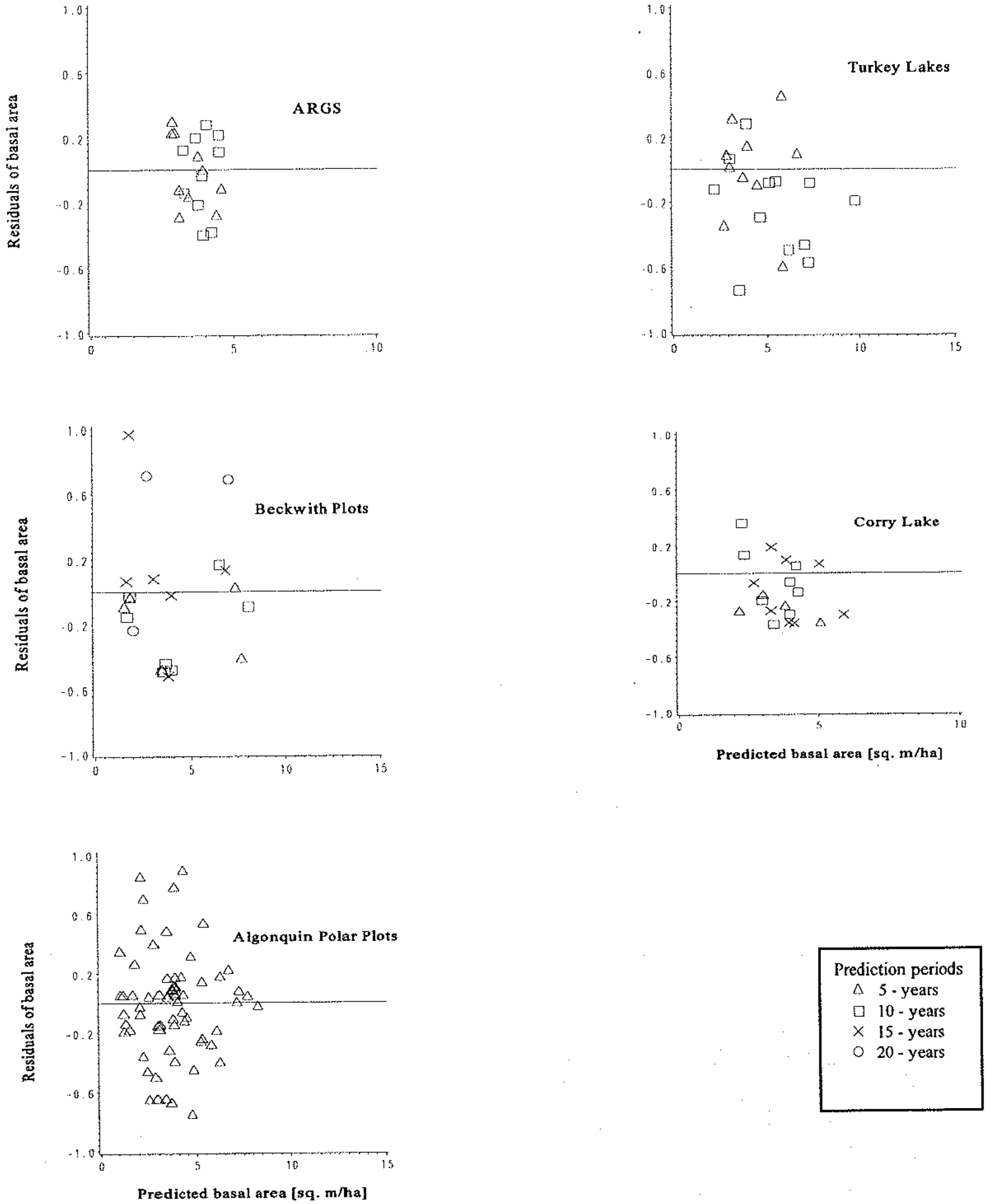


Figure 9. Residuals of the medium sawlog timber class basal area for the 5 data sets and all available prediction periods.

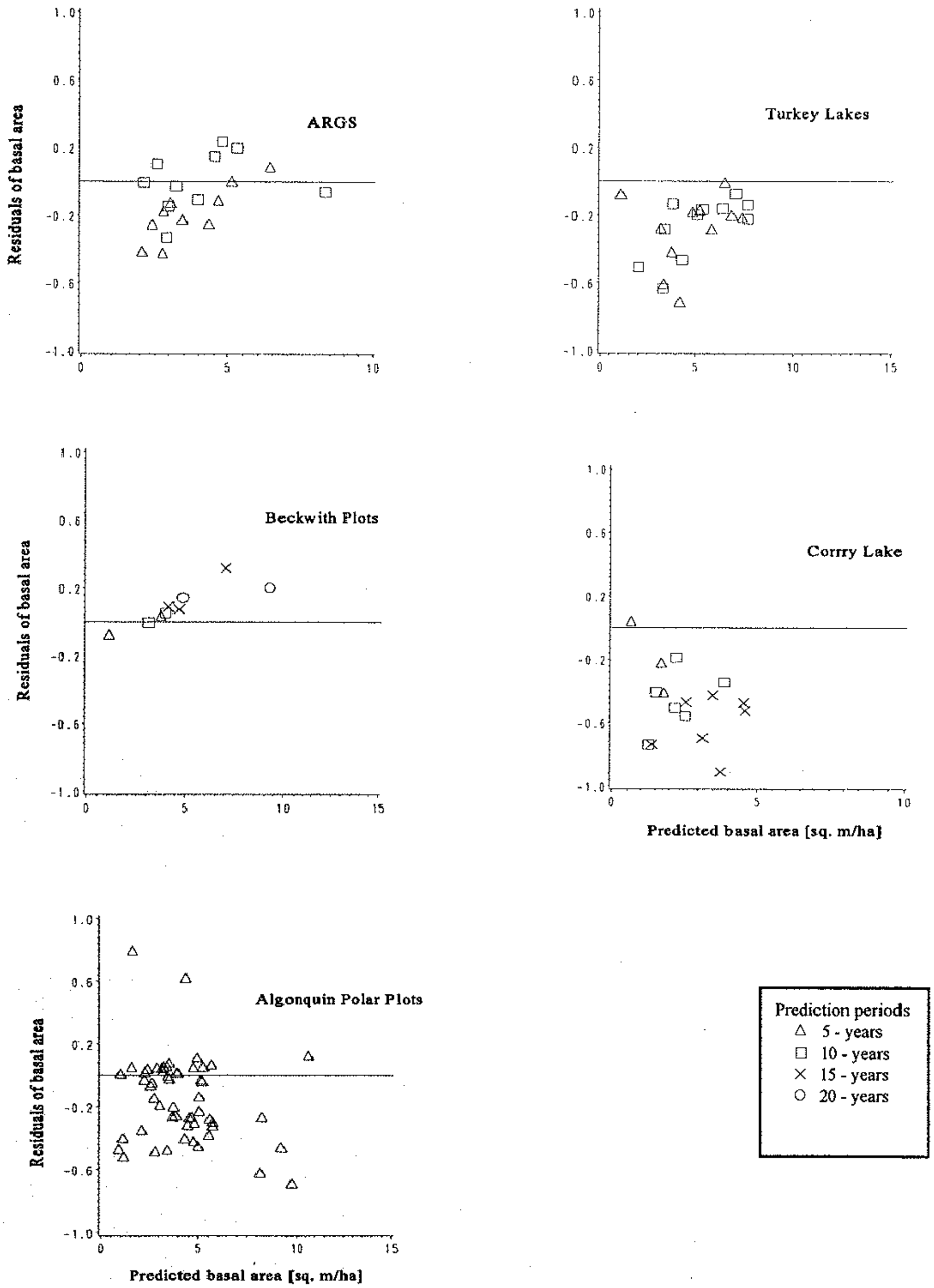


Figure 10. Residuals of the large sawlog timber class basal area for the 5 data sets and all available prediction periods.

Summary

The results of the NE-TWIGS validation test performed on 139 plots/systems can be summarized as follows:

- NE-TWIGS provides a reliable prediction (modelling efficiency from 77% to 99%) of stand basal area for 5 years, but for longer predictions the efficiency of the model drops significantly.
- The model performs equally well for managed or unmanaged stands whether they are even-aged or not.
- Basal area is underestimated from 2% to 5% for 5-year projections (except for the Turkey Lakes data set).
- Error in 5-year projections for basal area ranges from -22% to 37% for all data sets.
- Site index is an important variable in NE-TWIGS projections. The test shows that using site-specific site index values results in slightly better modelling efficiency and reduces biases in basal area, stand density, and mean quadratic DBH predictions.
- Estimations of ingrowth by the automatic ingrowth function results in overestimation of basal area in the smallest DBH class. In contrast, the lack of ingrowth input results in underestimations of basal area in the smallest DBH class.
- Five-year projections of pole and small sawlog basal area are reliable (modelling efficiency from 30% to 92%).
- NE-TWIGS does not reliably predict basal area for medium and large sawlog classes.
- Sample plot sizes ≥ 0.15 ha provide predictions of basal area for individual stands in the range of ±20%.

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