PLOT, STAND, AND COVERTYPE AGGREGATION EFFECTS ON PROJECTIONS WITH AN INDIVIDUAL TREE BASED STAND GROWTH MODEL

Melinda Moeur and Alan R. Ek

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The authors are respectively, Graduate Research Assistant and Professor, College of Forestry, University of Minnesota, St. Paul, Minnesota.

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ABSTRACT

A distance-independent individual-tree-based growth model (MFPS) was used to project changes in stand structure on aspen, red pine, and jack pine covertypes in northern Minnesota for 37 years. Individual .058 ha plot projections, projections of plots aggregated within stands, and projections of plots aggregated within covertypes were compared to each other and to observed plot conditions. Actual plot observations were available for up to 17 years. Individual plot, stand, and covertype aggregations produced very similar projections in terms of number of trees, average diameter, basal area, and biomass. Plot by plot projections were most accurate in comparison with observed conditions, followed by stand and then covertype aggregations. Differences from actual values and among projections generally increased with longer projections.

INTRODUCTION

The usefulness of an individual-tree-based computer growth model in forecasting stand response to treatment is due in part from the sensitivity gained from considering each tree as a separate entity. A projection system capable of accurately predicting future forest growth for different species over a range of site and stand conditions has many management applications (see the bibliography by Dudek and Ek 1980).

Conversely, there are operational and estimation efficiencies possible when plot data can be aggregated or averaged in developing forecasts. Since models of this type frequently incorporate nonlinear prediction functions, an examination of aggregation-induced error is appropriate. With nonlinear components, a projection made for an average or mean plot condition can clearly depart from the mean of individual plot projections. This paper reports on trials designed to assess the magnitude of this error.

CONDUCT OF THE STUDY

MFPS Model Description

The growth model used for these trials was MFPS (Multipurpose Forest Projection System). This model is, in the terminology of Munro (1974), a distance-independent, individual tree-based growth model, i.e., it does not require information about the spatial orientation of trees relative to competitors. The MFPS model (see Ek *et al*. 1980) incorporates sub-models and coefficients for individual tree diameter growth and mortality from STEMS, a tree growth projection system developed by the U.S. Forest

Service North Central Forest Experiment Station (USDA Forest Service, 1979). MFPS follows the framework of STEMS but is written in a shorter and structured FORTRAN code and makes projections for multiple-year length growth periods (Ek 1980). It consists of separate deterministic component models for survivor tree growth and mortality, and includes functions for estimating total tree height, product volumes and whole tree biomass. It allows growth projections for pure or mixed species stands for numerous species groups in the Lake States.

Input to MFPS consists of a list of trees by species, diameter, status (ingrowth or harvest), a trees per acre expansion factor, and a major or predominant species site index value (based on two dominant trees per plot). Site index is calculated for other species on the plot from relations provided by Carmean (1979), and Carmean and Vasilevsky (1971). Diameter increment is calculated for individual trees for each growth period by species-specific nonlinear functions of current tree diameter at breast height (dbh), computed crown ratio, stand basal area, and site index. Probability of mortality is a nonlinear deterministic function of the computed diameter increment and new diameter. After each projection period, a projected tree list can be written that contains the new diameters and adjusted expansion factors based on the plot size and calculated probability of mortality. An external summary program produces stand and stock tables for the updated tree list.

Data Base

The data used in this study were drawn from permanent plot measurement records obtained in 1959, 1964, 1969, and 1976 on the 3,308 acre University of Minnesota Cloquet Forestry Center near Cloquet, Minnesota. Data from 134 plots (each 0.058 ha in size) located in 55 distinct stands were used in the projections. Plots were initially established according to a systematic sample design with multiple random starts.[3] Covertypes (species group-size class combinations) considered here were aspen, red pine, and jack pine pole size classes. Delineation of stand boundaries and covertype determination was by interpretation of 1:15,840 scale aerial photography flown for each survey year. Species group was defined by the predominant overstory component, and the pole size class was defined as consisting of predominantly trees 12.7 to 22.9 cm dbh.

Approximate areas for the three types, based on the 1959 covertype map, were 113 ha for aspen, 118 ha for red pine, and 187 ha for jack pine. Ground survey data was limited to measurement of trees 12.7 cm diameter and larger. Consequently, all per hectare values given for number of trees, basal area, and biomass refer to this size and larger trees only. Biomass values further refer to weights of stem and branch wood and bark above a .15 m stump, i.e., excluding leaves. These values were based on equations for individual trees using dbh and height as predictor variables.

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3 Swenson, D. V. 1960. Effecting distribution of CFI sample points by means of a systematic sample with multiple random starts and the collection of field data. Unpublished Master of Forestry paper, Univ. Minnesota, St. Paul. 60 p.

The number of trees on a plot in 1959 ranged from 1 to 59 for the aspen covertype, 16 to 122 for the red pine type, and 6 to 73 for the jack pine type. The number of plots and stands per covertype and the number of stands in aerial photo-interpretation based density classes were as follows:

	Number of plots	Number of stands	Number of stands by crown density class percent		
			1-40	40-70	70-100
Aspen pole	36	19	8	9	2
Red pine pole	35	11	1	6	4
Jack pine pole	63	25	3	9	13

Plot site indices ranged from 16 to 21, 15 to 20, and 17 to 20 m for the aspen, red pine, and jack pine pole covertypes, respectively.

Aggregation Methods

For each covertype, three sets of projections were made. First, individual plot tree lists were projected. The program projected each plot according to its own initial conditions, i.e., number of trees, basal area, and site index. At the end of each growth period (five growth periods of length 5, 5, 7, 10, and 10 years were used beginning from the 1959 records) covertype values for number of trees, average diameter, basal area, and biomass were then obtained by averaging over the projected plot tree lists.

For the second set of projections, plots located in the same stands (based on the 1959 covertype map) were aggregated. This entailed combining the tree lists for plots within stands, then projecting the stand tree lists under initial stand average stand conditions, i.e., number of trees, basal area, and average site index. At the end of each growth period, covertype values for variables of interest were computed using a weighted average, with the weights w_i = number of plots in ith stand divided by the number of plots in covertype.

The third set of projections involved the construction of one large tree list aggregated from all the plots in a covertype. Initial conditions were represented as number of trees, initial basal area, and site index averaged over all of the plots in the covertype.

For all three methods (sets of projections) the procedure for handling observed ingrowth and cut was as follows. The projection was initiated with the 1959 tree measurement list. During subsequent projection years a tree was added to the list when it was observed to be an ingrowth tree (by testing for status code), or a tree was removed from the list when it was observed to have been cut. After 1976, the projections assumed zero ingrowth and harvest.

Performance Tests

Performance of the projections for the three aggregation methods was assessed on the basis of tabular and graphical comparisons of actual and predicted number of trees, average diameter, basal area, and biomass. Actual values were compared with end-of-growth period values obtained from the plot, stand, or covertype projections by the ratio:

$$\frac{\text{Predicted average covertype value for aggregation method}}{\text{observed average covertype value}}$$

The ratio of stand or covertype aggregation projection values to that from individual plot projections was also determined at the end of each growth period.

RESULTS AND DISCUSSION

Actual and predicted number of trees, average diameter, basal area, and biomass for the three aggregation methods are shown in Table 1. Table 2 presents the ratios of predicted to actual variable values summarized after 5, 10, and 17 years of projection. Results for these variables are discussed below.

Variables

Projection of total number of trees by plot, stand, and covertype aggregations over a 10 year period were within 2 percent of actual values for each of the three covertypes. After 17 years, projections for the aspen type differed by 7 to 9 percent, red pine by 4 to 7 percent, and jack pine by 1 to 6 percent, depending on the aggregation method. Actual and predicted number of trees per hectare by size class is shown in Table 3.

Predicted average diameter did not differ from observed values by more than 4 percent after 17 years for both the red pine and jack pine types for any aggregation method. Average diameter was more grossly overpredicted for the aspen type, however, from 5 percent after 5 years to 16 percent after 17 years.

Table 1. Actual (A) mean number of trees, average diameter, basal area, and biomass, and predicted values based on plot (P) aggregations, stand (S) aggregations, and covertype (C) aggregations, all species.

		Number of trees per hectare Years after initial measurement					Average Diameter (cm) Years after initial measurement					Basal area per hectare (m^2/ha) Years after initial measurement					Biomass per hectare (met.tons/ha) Years after initial measurement				
Covertype	Aggregation Method	0	5	10	17	37	0	5	10	17	37	0	5	10	17	37	0	5	10	17	37
Aspen Pole	A	263	250	263	202	--	19.1	19.2	19.9	22.5	--	7.6	7.2	8.2	8.0	--	28.0	27.0	31.8	32.2	--
	P	--	249	266	219	165	--	20.1	21.7	25.0	33.8	--	7.9	9.8	10.7	14.8	--	30.3	39.0	44.5	63.0
	S	--	249	266	216	163	--	20.2	21.9	25.4	35.0	--	8.0	10.1	11.0	15.7	--	31.2	40.6	46.4	66.8
	C	--	249	267	220	168	--	20.3	22.2	26.1	36.5	--	8.1	10.3	11.8	17.6	--	31.6	41.7	50.3	73.4
Red Pine Pole	A	642	610	642	570	--	19.4	20.3	21.4	24.1	--	19.0	19.8	23.2	26.1	--	64.7	69.3	83.4	99.0	--
	P	--	614	647	604	540	--	20.6	21.7	24.3	30.8	--	20.4	24.0	28.1	40.2	--	71.2	86.0	105.8	163.1
	S	--	598	631	592	535	--	20.7	21.9	24.5	31.0	--	20.1	23.7	27.9	40.3	--	70.2	85.2	105.2	164.9
	C	--	616	651	611	548	--	20.7	21.9	24.6	31.3	--	20.7	24.5	28.9	42.1	--	72.5	88.6	109.4	173.7
Jack Pine Pole	A	648	623	559	451	--	20.3	21.1	22.1	23.9	--	21.0	21.8	21.5	20.2	--	72.2	76.4	77.3	74.6	--
	P	--	623	558	455	349	--	21.3	22.5	24.5	30.1	--	22.1	22.2	21.5	24.9	--	77.8	80.4	79.8	96.0
	S	--	626	565	464	364	--	21.3	22.6	24.7	30.5	--	22.3	22.7	22.3	26.6	--	78.7	82.4	83.3	102.5
	C	--	631	573	478	384	--	21.4	22.7	24.9	30.8	--	22.6	23.3	23.2	28.7	--	79.7	84.3	86.0	109.7

Table 2. Ratio of predicted to actual (A) mean number of trees, average diameter, basal area, and biomass based on plot (P) aggregations, stand (S) aggregations, and covertype (C) aggregations, all species.

Covertype	Aggregation Method (Ratio)	Number of trees per hectare Years after initial measurement 5	10	17	Average Diameter (cm) Years after initial measurement 5	10	17	Basal Area per hectare Years after initial measurement 5	10	17	Biomass per hectare Years after initial measurement 5	10	17
Aspen	P/A	1.00	1.01	1.08	1.05	1.09	1.11	1.10	1.20	1.33	1.12	1.23	1.38
Pole	S/A	1.00	1.01	1.07	1.05	1.10	1.13	1.11	1.23	1.36	1.16	1.28	1.44
	C/A	1.00	1.01	1.09	1.06	1.12	1.16	1.12	1.26	1.47	1.17	1.31	1.56
Red Pine	P/A	1.01	1.01	1.06	1.01	1.01	1.01	1.03	1.03	1.08	1.03	1.03	1.07
Pole	S/A	.98	.98	1.04	1.02	1.02	1.02	1.01	1.02	1.07	1.01	1.02	1.06
	C/A	1.01	1.01	1.07	1.02	1.02	1.02	1.04	1.06	1.11	1.05	1.06	1.11
Jack Pine	P/A	1.00	1.00	1.01	1.01	1.02	1.02	1.02	1.03	1.06	1.02	1.04	1.07
Pole	S/A	1.00	1.01	1.03	1.01	1.02	1.03	1.03	1.05	1.10	1.03	1.06	1.12
	C/A	1.01	1.02	1.06	1.01	1.03	1.04	1.04	1.08	1.15	1.04	1.09	1.15

Table 3. Actual (A) mean number of trees per hectare by size class, predicted values based on plot (P) aggregations, stand (S) aggregations, and covertype (C) aggregations, all species.

		Years after initial measurement														
		0			5			10			17			37		
		Diameter Class (cm)														
Covertype	Aggregation Method	12.7-22.8	22.9-30.4	30.5+	12.7-22.8	22.9-30.4	30.5+	12.7-22.8	22.9-30.4	30.5+	12.7-22.8	22.9-30.4	30.5+	12.7-22.8	22.9-30.4	30.5+
Aspen Pole	A	230	22	13	221	19	10	217	35	11	140	48	13	--	--	--
	P	--	--	--	215	24	10	201	51	14	108	85	25	14	54	97
	S	--	--	--	212	27	9	194	58	14	99	88	29	10	48	105
	C	--	--	--	210	30	9	185	69	13	90	90	36	6	49	114
Red Pine Pole	A	520	102	20	464	112	34	454	138	49	312	172	86	--	--	--
	P	--	--	--	470	114	30	462	139	45	328	197	78	84	217	239
	S	--	--	--	452	116	30	442	142	47	314	203	75	84	206	245
	C	--	--	--	464	121	32	453	149	49	337	191	83	56	249	242
Jack Pine Pole	A	506	116	27	450	143	31	370	149	40	245	154	52	--	--	--
	P	--	--	--	449	143	31	357	157	44	236	157	61	68	144	136
	S	--	--	--	449	145	32	361	157	47	241	155	69	70	144	150
	C	--	--	--	450	146	36	360	163	50	243	159	76	73	145	166

Relative differences between predicted and observed basal area and biomass were larger than for number of trees or average diameter, especially for the aspen covertype. Predicted basal area for aspen differed from the actual by 10 percent after 5 years to 47 percent after 17 years. For red pine the range in differences after 5 and 17 years was 1 to 11 percent, and for jack pine the range was 2 to 15 percent. Biomass figures for the three covertypes were similar to basal area differences, with slightly greater overestimation.

Covertype differences. Of the three covertypes tested, projections made for the red pine type were usually closest to observed values. The jack pine projections also performed well, but with generally larger differences, especially after 17 years with covertype projection. Aspen prediction was fair for number of trees and average diameter and poor for basal area and biomass.

Aggregations vs. actual. With the exception of the red pine type, projections made for individual plot tree lists were generally more accurate when compared to actual values than those made for stand or covertype aggregations. Aspen and jack pine stand projections were usually second closest to actual values. This pattern was reversed for the red pine type, with projections made for stand aggregations usually being most consistent with actual values. For all three covertypes, prediction by covertype aggregation always differed by the greatest amount from actual after 5, 10, and 17 years of projection. These trends are illustrated in Figures 1 and 2.

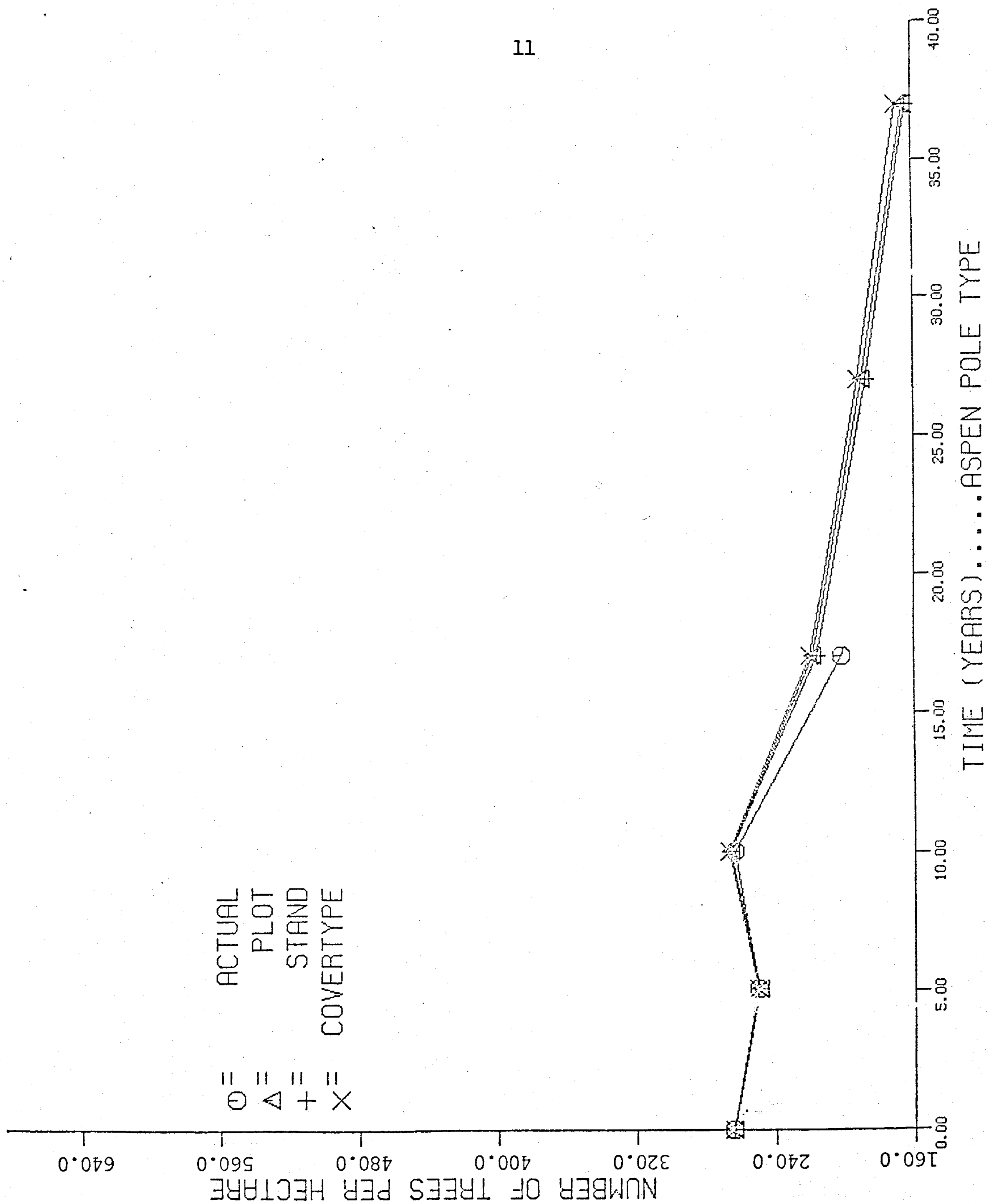

Figure 1a. Actual number of trees and projections based on plot, stand, and covertype aggregations: aspen pole type.

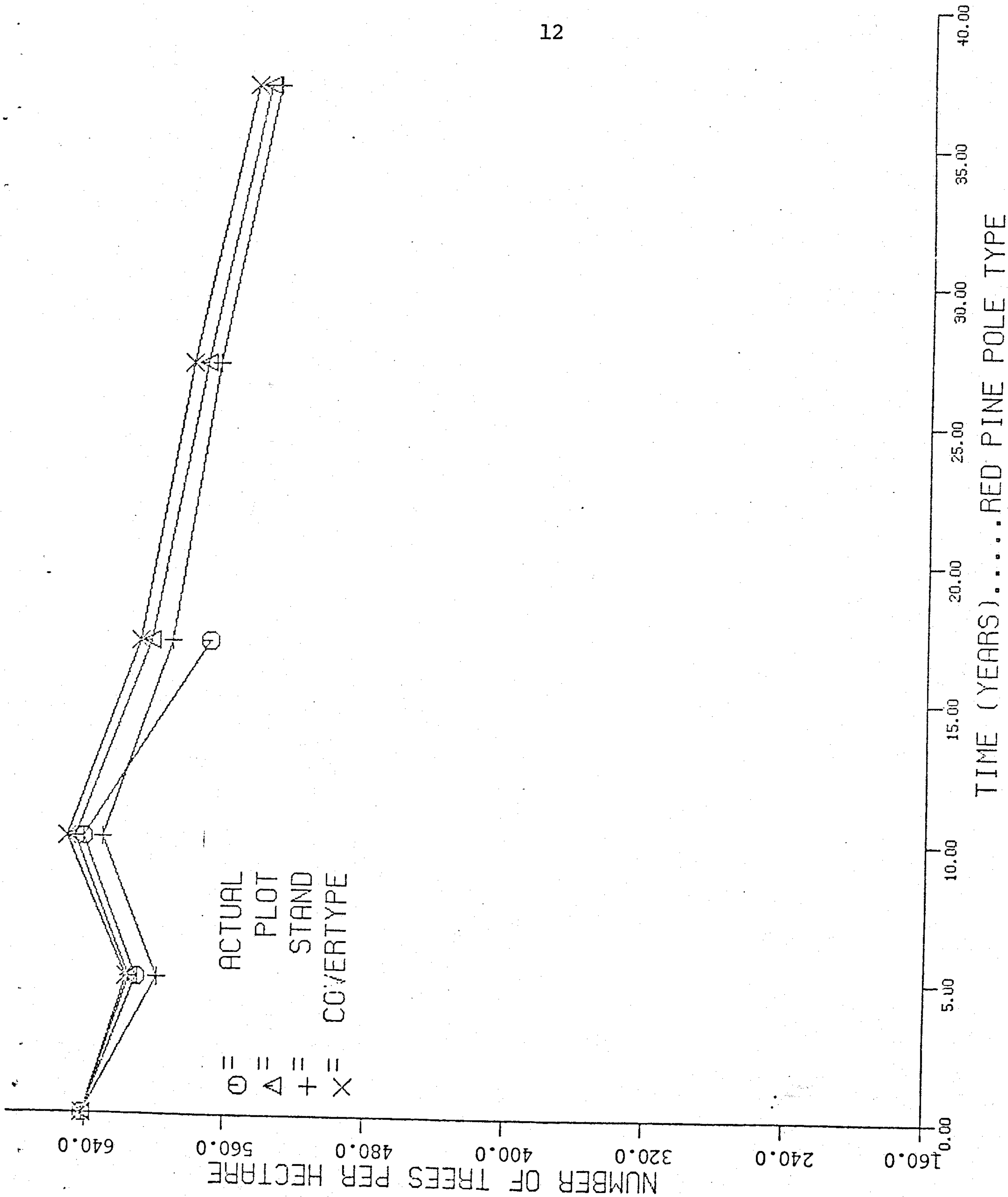

Figure 1b. Actual number of trees and projections based on plot, stand, and covertype aggregations: red pine pole type.

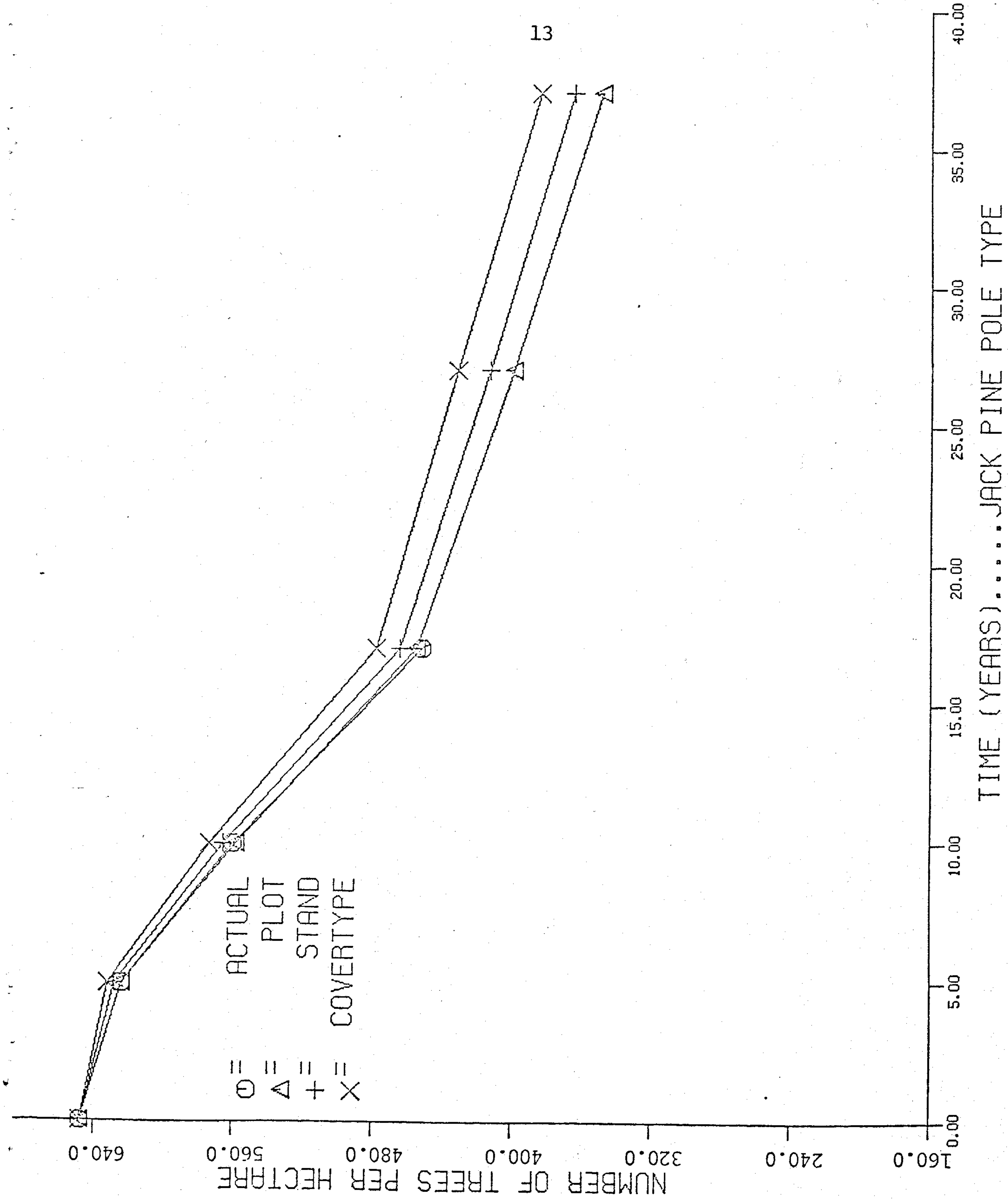

Figure 1c. Actual number of trees and projections based on plot, stand, and covertype aggregations: jack pine pole type.

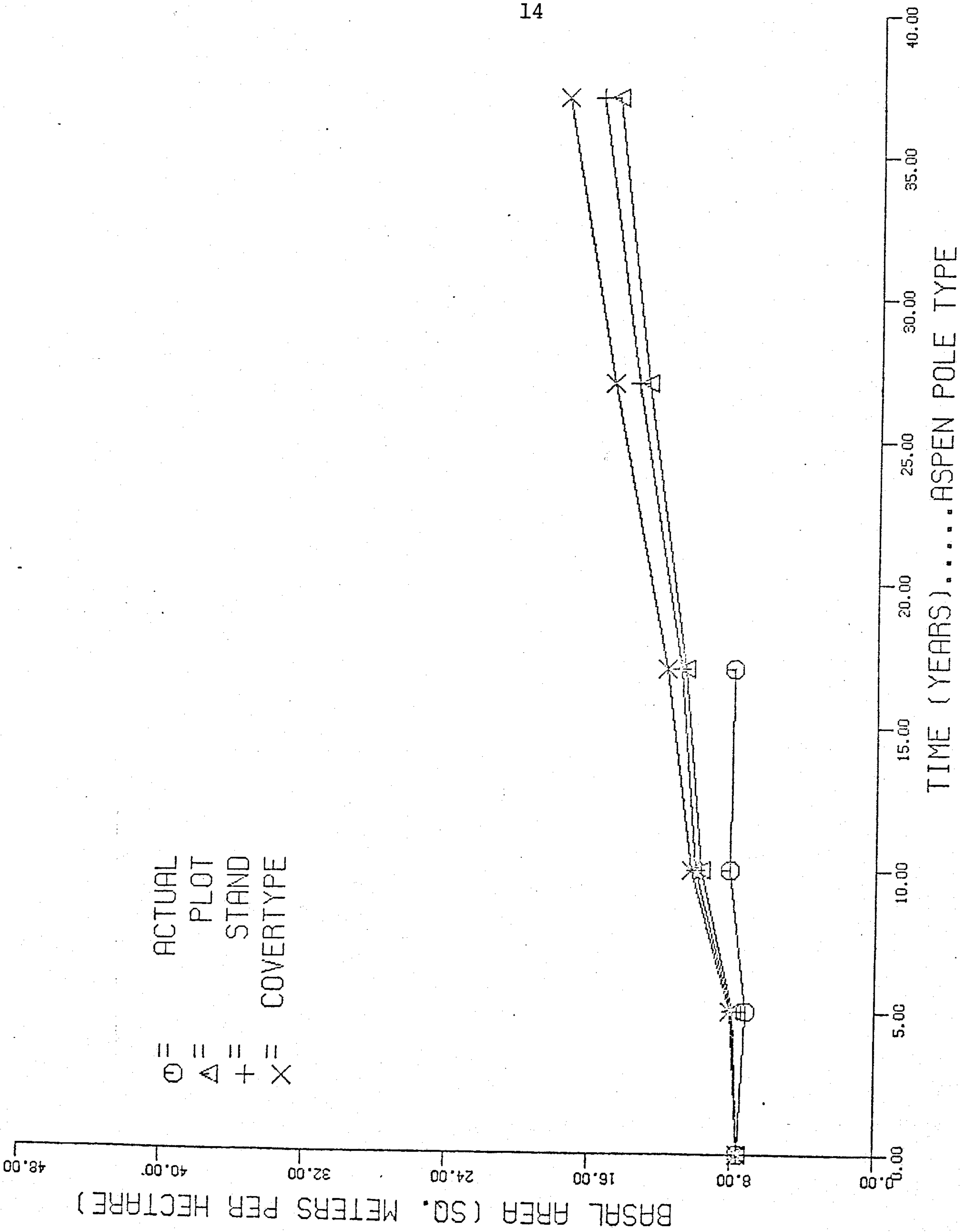

Figure 2a. Actual basal area and projections based on plot, stand, and covertype aggregations: aspen pole type.

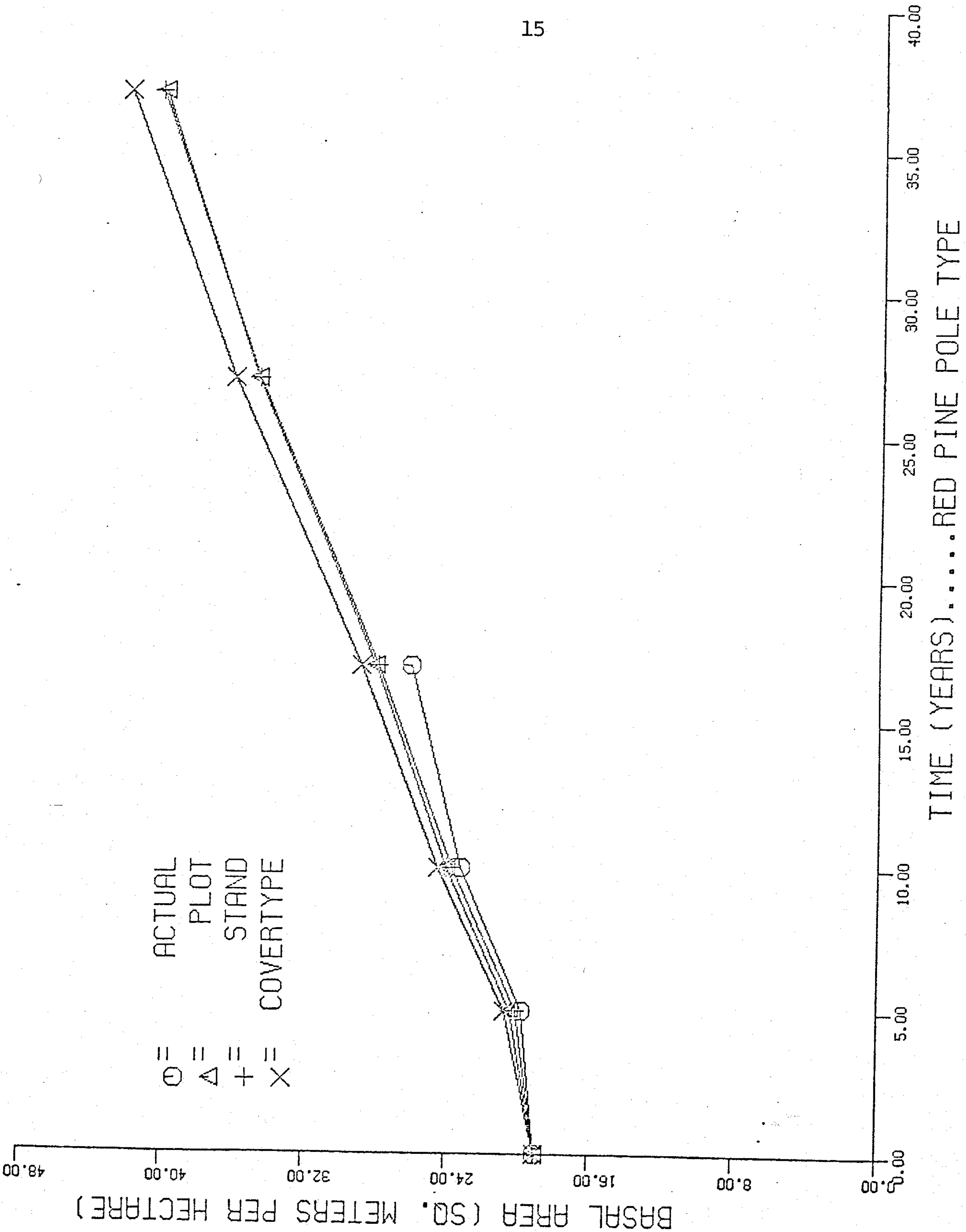

Figure 2b. Actual basal area and projections based on plot, stand, and covertype aggregations: red pine pole type.

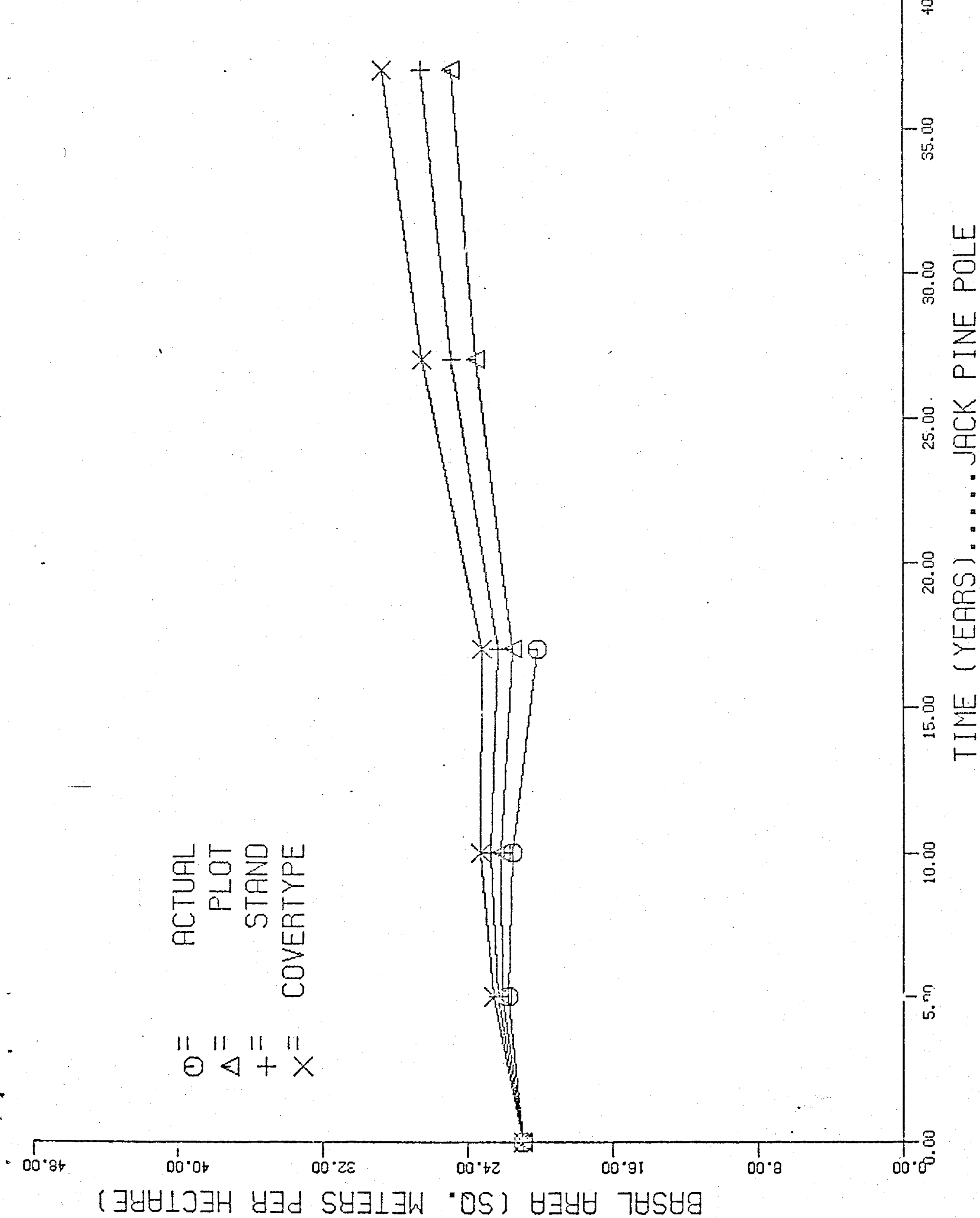

Figure 2c. Actual basal area and projections based on plot, stand, and covertype aggregations: jack pine pole type.

Aggregations. The relationships between projections made by plot, stand, and covertype aggregations over a 37-year period are shown in Table 4 and Figures 1 and 2. Number of trees predicted by plot, stand, and covertype projections were within 0 to 2 percent of each other over 37 years for the aspen type (Figure 1a), and within 0 to 3 percent of each other for the red pine type (Figure 1b). Jack pine values ranged from 1 to 10 percent different after 37 years (Figure 1c), with these differences becoming greater over time.

Plot, stand, and covertype projections of average diameter were very similar for both red pine and jack pine (within 0 to 2 percent over 37 years), while the aspen type showed differences of from 0 to 8 percent. The dispersion in predicted values increased with length of the projection for aspen.

Basal area prediction by the three aggregation methods was more variable over time than was prediction of number of trees or average diameter. For aspen and jack pine, the differences ranged from 1 to 19 percent and 1 to 15 percent respectively, over 37 years (Figures 2a, c). Moderate dispersion of 0 to 5 percent was shown for red pine (Figure 2b). Similar trends were shown for biomass prediction for the three covertypes.

Except for number of trees for the red pine type after 5 and 10 years, all four response variables were consistently overpredicted for each covertype. A likely explanation for overprediction is the absence of trees under 12.7 cm diameter in the data base. Without the competition induced by the presence of smaller trees incorporated in model fitting (Hahn and

Table 4. Ratio of predicted mean number of trees, average diameter, basal area, and biomass for stand (S) to plot (P) and covertype (C) to plot (P) aggregation methods.

Covertype	Aggregation Method (Ratio)	Number of trees per hectare Years after initial measurement 5	10	17	37	Average Diameter Years after initial measurement 5	10	17	37	Basal area per hectare Years after initial measurement 5	10	17	37	Biomass per hectare Years after initial measurement 5	10	17	37
Aspen Pole	S/P	1.00	1.00	0.99	0.99	1.00	1.01	1.02	1.03	1.01	1.02	1.02	1.06	1.03	1.04	1.04	1.06
	C/P	1.00	1.00	1.01	1.02	1.01	1.02	1.04	1.08	1.02	1.05	1.10	1.19	1.04	1.07	1.13	1.17
Red Pine Pole	S/P	.97	.97	.98	.99	1.00	1.01	1.01	1.01	.98	.99	.99	1.00	.98	.99	.99	1.01
	C/P	1.00	1.01	1.01	1.01	1.00	1.01	1.01	1.02	1.01	1.02	1.03	1.05	1.02	1.03	1.04	1.06
Jack Pine Pole	S/P	1.01	1.01	1.02	1.04	1.00	1.00	1.01	1.01	1.01	1.02	1.04	1.07	1.01	1.02	1.04	1.07
	C/P	1.01	1.03	1.05	1.10	1.00	1.01	1.02	1.02	1.02	1.05	1.08	1.15	1.02	1.05	1.08	1.14

Leary 1979, Leary and Holdaway 1979), mortality would be underestimated (overprediction of number of trees) and individual tree diameter increment overestimated (overprediction of average diameter). Basal area and biomass prediction would show compounded effects, since both involve quadratic functions of predicted diameter.

In addition, some aspen plots on the Cloquet Forest may have been affected by periodic catastrophic insect defoliation during the 1959-1976 period (see for example Duncan and Hodson 1958). Actual growth would then have been expected to be less than predicted growth, since the model runs did not consider such impacts. Also, the data used in model fitting was drawn from a much larger region (Minnesota, Wisconsin, and Michigan) and thus would tend to average affected and unaffected area response.

Predictions by each aggregation method were generally most accurate for the red pine type, followed by jack pine, and then aspen. Despite differences in covertype definition, Belcher[4] and Leary _et al_. (1979) obtained similar results for aspen, red pine, and jack pine predictions with the STEMS model.

Computational efficiency was improved as the level of aggregation increased. The 37 year plot, stand and covertype projections required 137, 129, and 83 seconds or 1.02, .96, and .62 seconds per plot, respectively, on a Cyber 170 computer. These figures include projection time,

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4 Belcher, D. M. 1980. A description of STEMS, the stand and tree evaluation system. USDA For. Serv., North Central Forest Exp. Stn. (in preparation).

writing projected tree lists to output files, and the summarization of the projected tree lists with an external program. Actual projection times with MFPS were approximately one-third of the figures indicated.

Predictions for all three aggregation methods would likely be improved by inclusion of trees under 12.7 cm diameter in the data base, as well as by refined stratification of covertypes by density and site index classes. The latter step would serve to reduce the impact of the nonlinearities inherent in the projection system. Users own requirements for projection accuracy will, of course, dictate the need for these steps. Results here suggest that the nature of the covertype and the length of the projections will be major considerations in deciding on the degree of aggregation.

FIGURE TITLES

LITERATURE CITED

Carmean, W. H. 1979. Site index comparisons among northern hardwoods in northern Wisconsin and upper Michigan. USDA For. Serv. North Central Forest Exp. Stn., Res. Pap. NC-169, 17 p.

Carmean, W. H. and A. Vasilevsky. 1971. Site index comparisons for tree species in northern Minnesota. USDA For. Serv. North Central Forest Exp. Stn., Res. Pap. NC-65, 8 p.

Dudek, A. and A. R. Ek. 1980. A bibliography of worldwide literature on individual tree based forest stand growth models. Univ. of Minnesota, College of Forestry, Dept. of Forest Resources Staff Paper Series No. 12. 33 p.

Duncan, D. P. and A. C. Hodson. 1958. Influence of the forest tent caterpillar upon the aspen forests of Minnesota. Forest Science 4(1):71-93.

Ek, A. R. 1980. A preliminary trial of alternative methods for treating mortality in the multipurpose forest projection system (MFPS) model. Univ. of Minnesota, College of Forestry, Dept. of Forest Resources Staff Paper Series No. 8. 6 p.

Ek, A. R., D. W. Rose, and M. T. Checky. 1980. A brief description of MFPS: A multipurpose forest projection system. Univ. of Minnesota College of Forestry, Dept. of Forest Resources Staff Paper Series No. 16. 6 p.

Hahn, J. T. and R. A. Leary. 1979. Potential diameter growth functions. In: A generalized forest growth projection system. USDA For. Serv., North Central Forest Exp. Stn., Gen. Tech. Rep. NC-49, 96 p. (p. 22-26).

Leary, R. A. and M. R. Holdaway. 1979. Modifier function. In: A generalized forest growth projection system. USDA For. Serv., North Central Forest Exp. Stn., Gen. Tech. Rep. NC-49, 96 p. (p. 31-38).

Leary, R. A., J. T. Hahn, and R. G. Buchman. 1979. Tests. In: A generalized forest growth projection system. USDA For. Serv., North Central Forest Exp. Stn., Gen. Tech. Rep. NC-49, 96 p. (p. 79-89).

Munro, D. D. 1974. Forest growth models - a prognosis. In: Growth models for tree and stand simulation. J. Fries, ed. Royal College of Forestry, Research Notes No. 30, Stockholm. p. 7-21.

USDA Forest Service. 1979. A generalized forest growth projection system applied to the Lake States region. USDA For. Serv., North Central Forest Exp. Stn., Gen. Tech. Rep. NC-49, 96 p.