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Analysis of Three Rotating Panel Designs using Generalized Least Squares fit of Loblolly Data From Georgia

The USDA Forest Service, Forest Inventory and Analysis program's inventory cycles are moving from a 6 to 10 year average rotation, where every plot is measured in a state its rotation year, to an annual forest inventory system using a rotating panel design. There is concern about annual change estimates and overall error of values such as volume per state. Recent applications to estimating change from permanent plots (Gregoire and others 1995, Urquhart and others 1993) are based on the linear model:

$$y = X\beta + \epsilon$$

or, algebraically,

$$y_t = \beta_0 + \beta_1 t + \epsilon_t$$

where y_t is the value at time t, t is number of years since the initial measurement, β_0 is the initial or baseline value, β_1 is the annual change in y_t, and ϵ_t are random errors which may be correlated over time and/or space. An equivalent formulation is

$$y_j = y_i + b(t_j - t_i)$$

where y_i is the initial value at time t_i and y_j is the value at time t_j, and b is the estimate of the annual change in y.

Measurements of most forest characteristics that are repeated over time are serially correlated; that is, the measurement values at time 2 are influenced by the values at time 1. Annual empirical data from 1990-1995 from Forest Health Monitoring (FHM) Plots in Georgia were available for estimating serial correlation. For loblolly pine volume on plots in Georgia the serial correlation vector is:

$$\mathbf{r} = [.95,\ .90,\ .86,\ .82,\ .78,\ .74,\ .70,\ .67,\ .63,\ .60]'$$

where the first value is the correlation between time periods 1 and 2, the second value is the correlation between time periods 1 and 3, and so on.

The following three rotating panel designs were examined:

1/5 Rotating Panel - All plots measured in year 1

year→ panel ↓	1	2	3	4	5	6	7
1	X	X					X
2	X		X				
3	X			X			
4	X				X		
5	X					X	

1/7 Rotating Panel - All plots measured in year 1

year→ panel ↓	1	2	3	4	5	6	7	8	9
1	X	X							X
2	X		X						
3	X			X					
4	X				X				
5	X					X			
6	X						X		
7	X							X	

1/9 Rotating Panel - All plots measured in year 1

year→ panel ↓	1	2	3	4	5	6	7	8	9	10	11
1	X	X									X
2	X		X								
3	X			X							
4	X				X						
5	X					X					
6	X						X				
7	X							X			
8	X								X		
9	X									X	

Using the GLS procedure outlined by Gregoire and others (1995) and Smith and others (1996), we ran the model with the specified serial correlation against the most recent survey data from unit 3 in Georgia, restricting ourselves to loblolly pine plot volume. Results for estimating annual change estimates in loblolly pine ft^3 per ac (Standard Error of *b*) and for estimating the standard error of the mean volume per ac are given in Tables 1, 2, and 3 and shown in Figures 1 through 6.

For these data the overall loblolly pine volume variance is 1,461,681 based on all 675 plots. The standard error of the mean therefore is $\sqrt{1,461,681/675} = 46.5\ ft^3$. This is the smallest std. err. of the mean possible since it is based on all plots. We expect the rotating panel schemes to approach this value. As can be seen in Tables 1-3 and Figures 2, 4, and 6; after 10 years all three schemes approach the lower limit. The 1/5 scheme after 10 years comes to within 10.2 percent of the lower limit {(51.22-46.5)/46.5 = .1015} The 1/7 scheme comes to within 17.8%, and the 1/9 scheme comes to within 26% of the lower limit. In Figures 2, 4, and 6 it can be observed that the std. err. increases at year 3 then starts decrerasing. While it may seem counter intuitive that the std. err of mean volume should increase in year 3 (and for the 1/9 scheme in years 3 and 4), it is a consequence of the serial correlation, the influence of measuring all plots initially, and the rate at which new information is added (the panel scheme). The standard errors on the slope coefficient are all comparable after 10 years and indicate all three schemes do a reasonably good job of estimating annual change after 10 years of data.

Conclusions

- The first few years of rotating panel schemes result in increased errors of change estimates and overall mean estimates.
- For the 1/5 scheme, the std. err. of mean drops to a reasonable level at the 6th year and approaches to within 10% of the minimum possible after 10 years. Of the three schemes tested, the 1/5 provides the best results.
- For the 1/7 scheme, the std. err. of mean drops to a reasonable level at the 8th year and approaches to within 18% of the minimum possible after 10 years.
- For the 1/9 scheme, the std. err. of mean is still dropping after 10 years and has only approached to within 26% of the minimum value possible.
- For all three rotating panel schemes error on annual change estimates drop to a reasonable level by the 5th year and give comparable results by year 10.

Table 1. Results for 1/5 rotating panel.

Nplots	N	Years	Std err. b	Std Err Mean
675	810	2	32.47	54.81
675	945	3	18.53	55.82
675	1080	4	12.98	55.31
675	1215	5	9.99	54.26
675	1350	6	8.12	53.01
675	1485	7	6.98	52.30
675	1620	8	6.18	51.84
675	1755	9	5.58	51.49
675	1890	10	5.11	51.22

Table 2. Results for 1/7 rotating panel.

Nplots	N	Years	Std err. b	Std Err Mean
675	770	2	38.68	58.71
675	865	3	22.04	60.71
675	960	4	15.41	60.65
675	1055	5	11.82	59.87
675	1150	6	9.58	58.78
675	1245	7	8.05	57.54
675	1340	8	6.94	56.25
675	1435	9	6.16	55.40
675	1530	10	5.57	54.78

Table 3 Results for 1/9 rotating panel.

Nplots	N	Years	Std err. b	Std Err Mean
675	750	2	43.52	62.00
675	825	3	24.78	64.79
675	900	4	17.31	65.09
675	975	5	13.26	64.50
675	1050	6	10.72	63.53
675	1125	7	8.99	62.37
675	1200	8	7.73	61.12
675	1275	9	6.78	59.85
675	1350	10	6.04	58.57

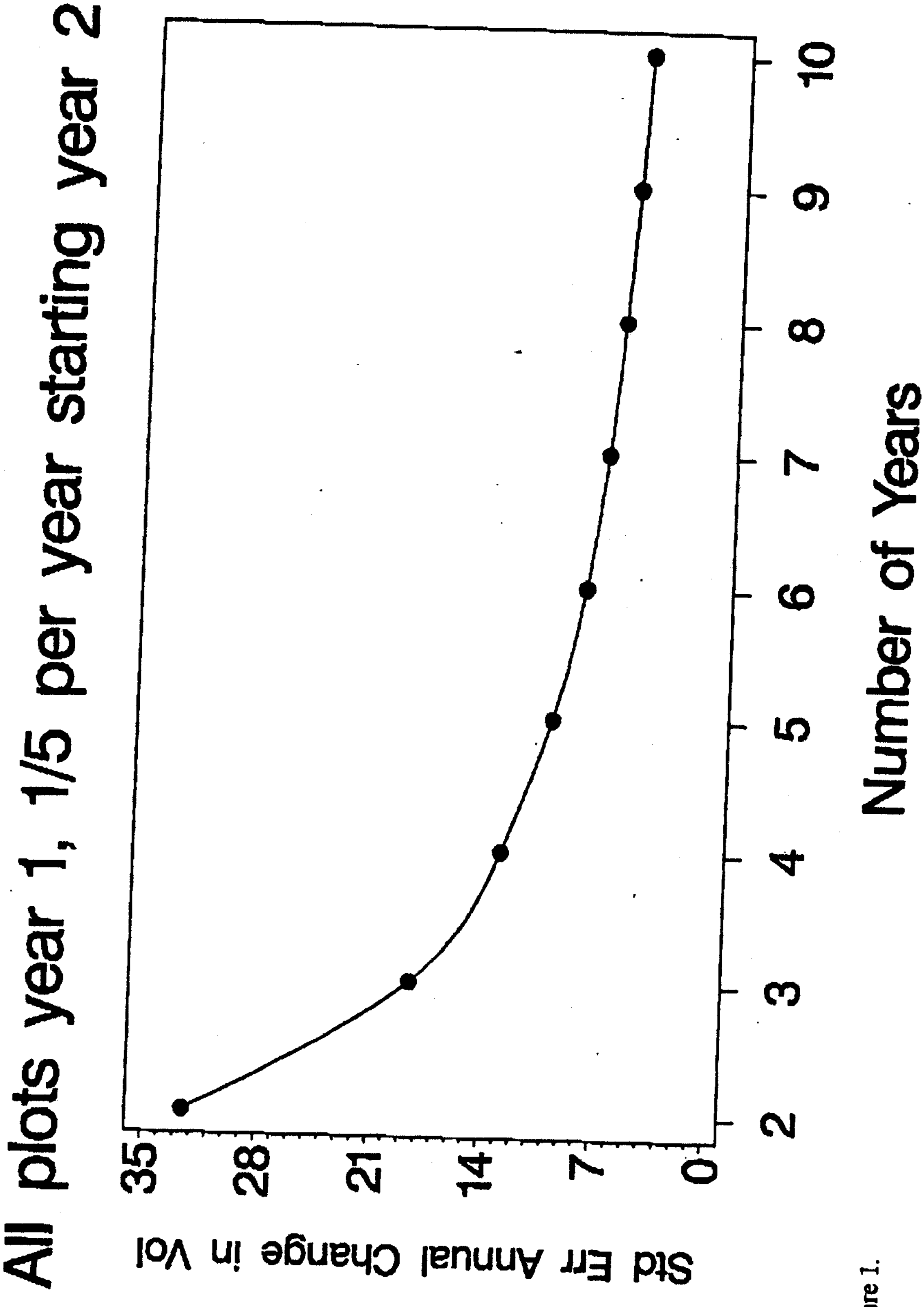

All plots year 1, 1/5 per year starting year 2
Std Err Annual Change in Vol
35
28
21
14
7
0
2
3
4
5
6
7
8
9
10
Number of Years

Figure 1.

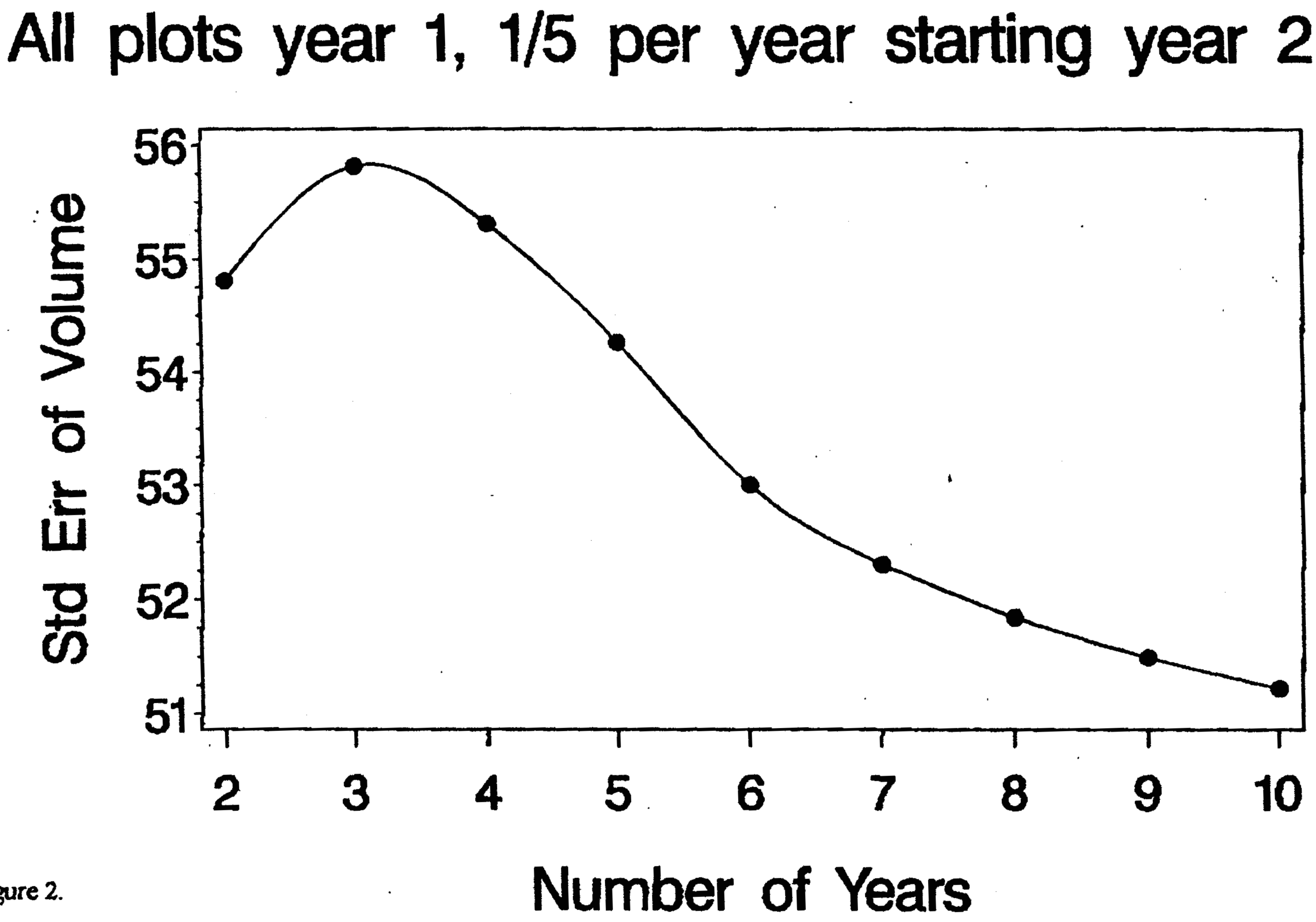

All plots year 1, 1/5 per year starting year 2
Std Err of Volume
56
55
54
53
52
51
2
3
4
5
6
7
8
9
10
Number of Years

Figure 2.

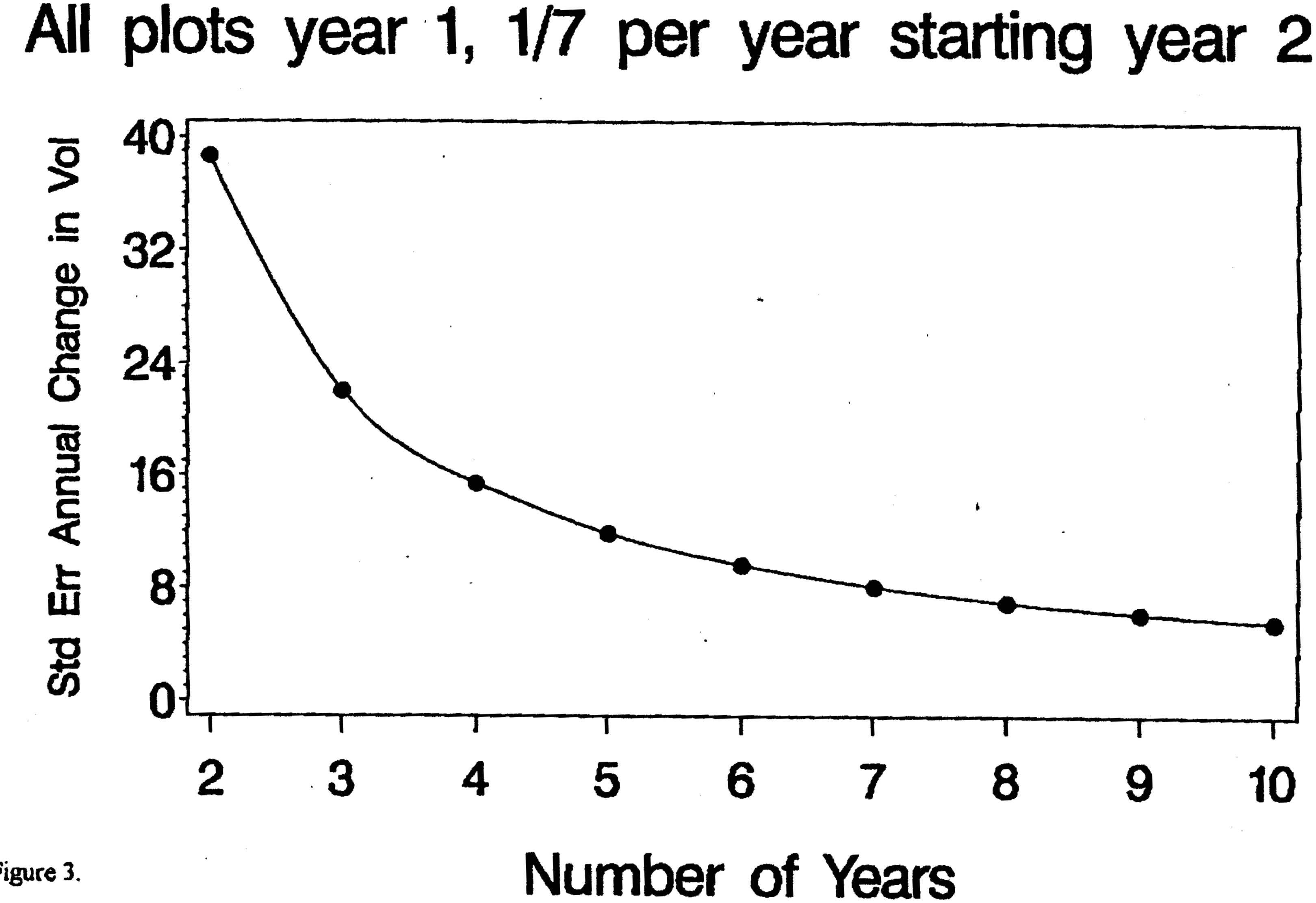

All plots year 1, 1/7 per year starting year 2
Std Err Annual Change in Vol
0
8
16
24
32
40
2
3
4
5
6
7
8
9
10
Number of Years

Figure 3.

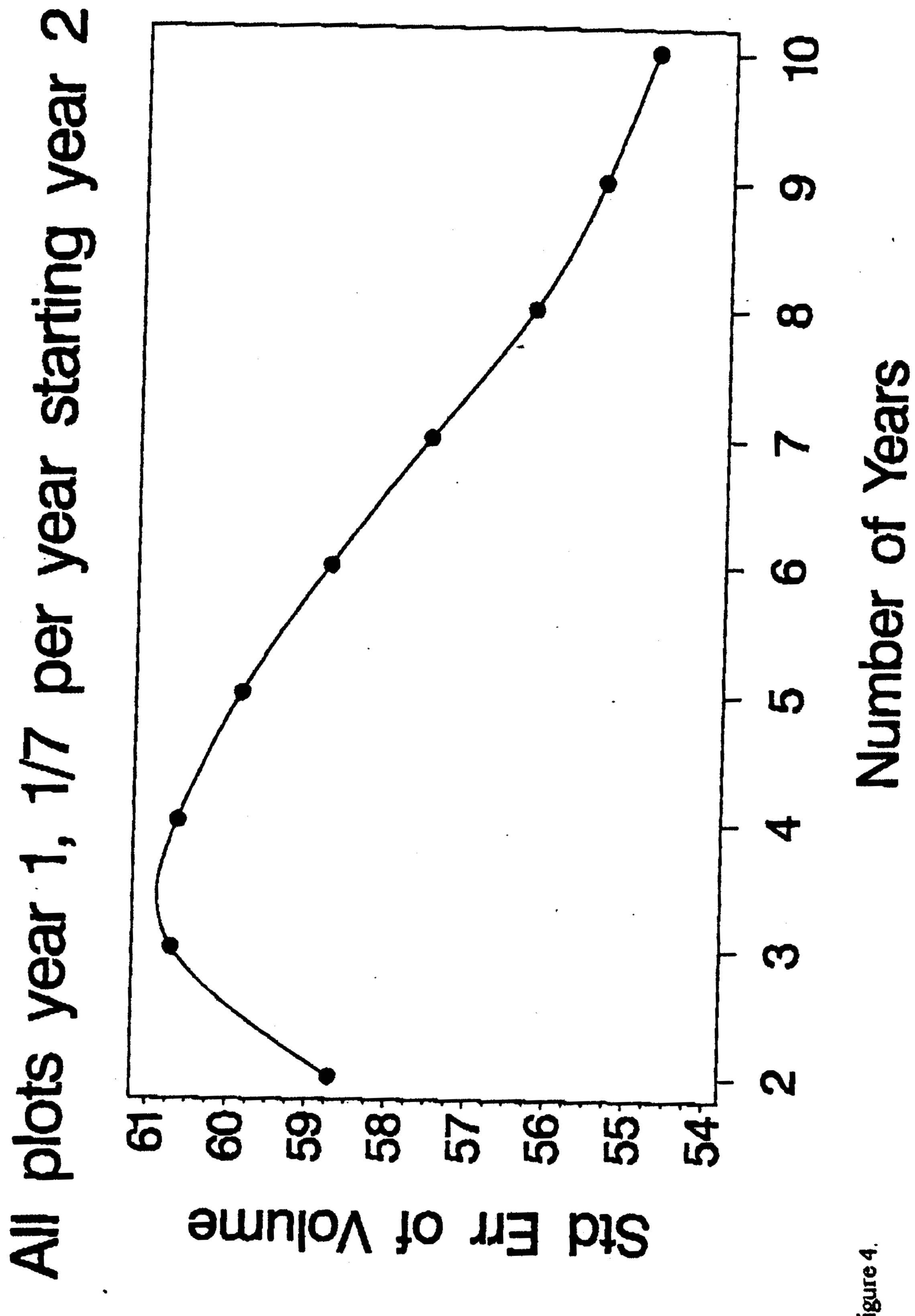

All plots year 1, 1/7 per year starting year 2
Std Err of Volume
61
60
59
58
57
56
55
54
2
3
4
5
6
7
8
9
10
Number of Years

Figure 4.

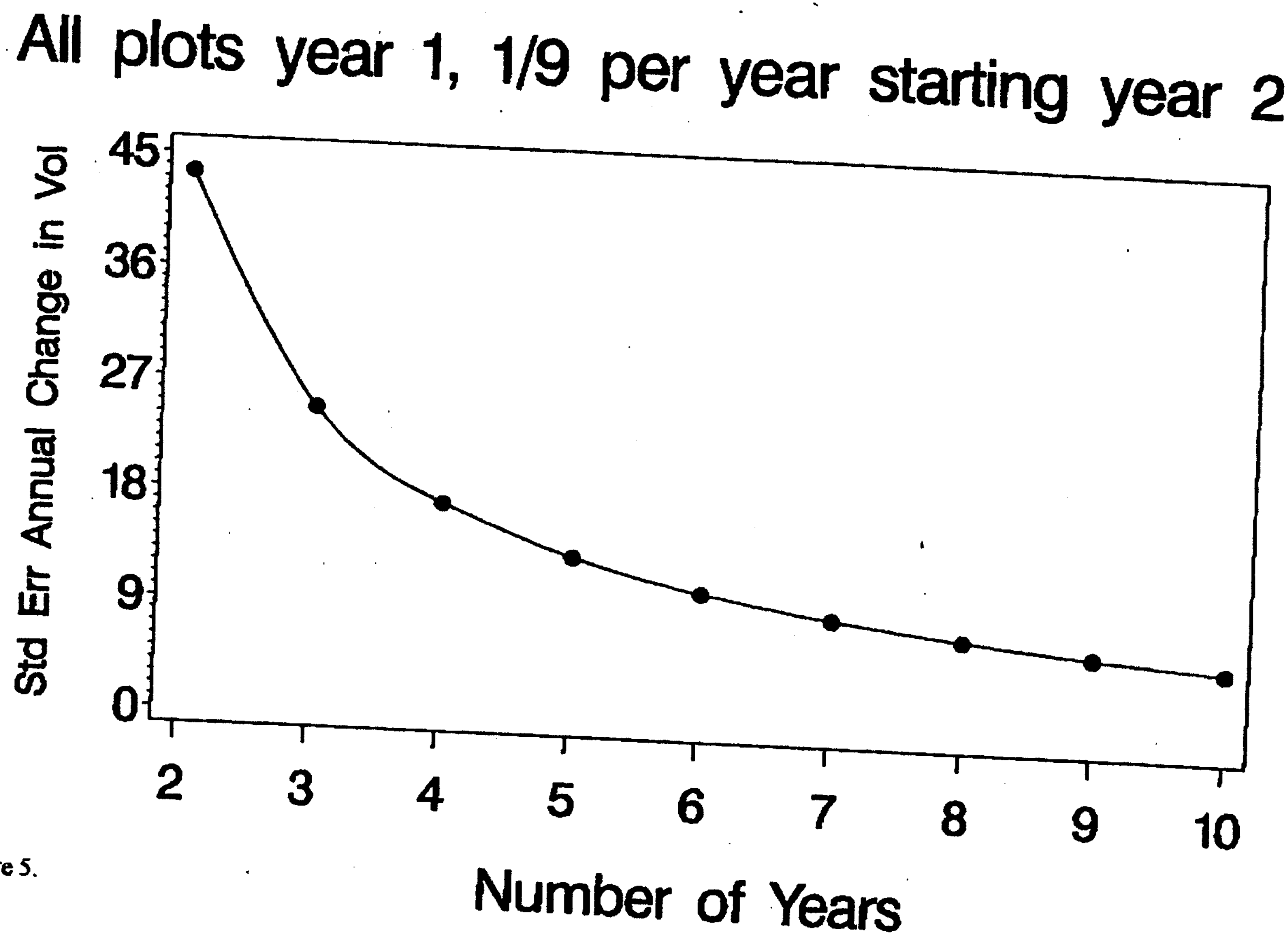
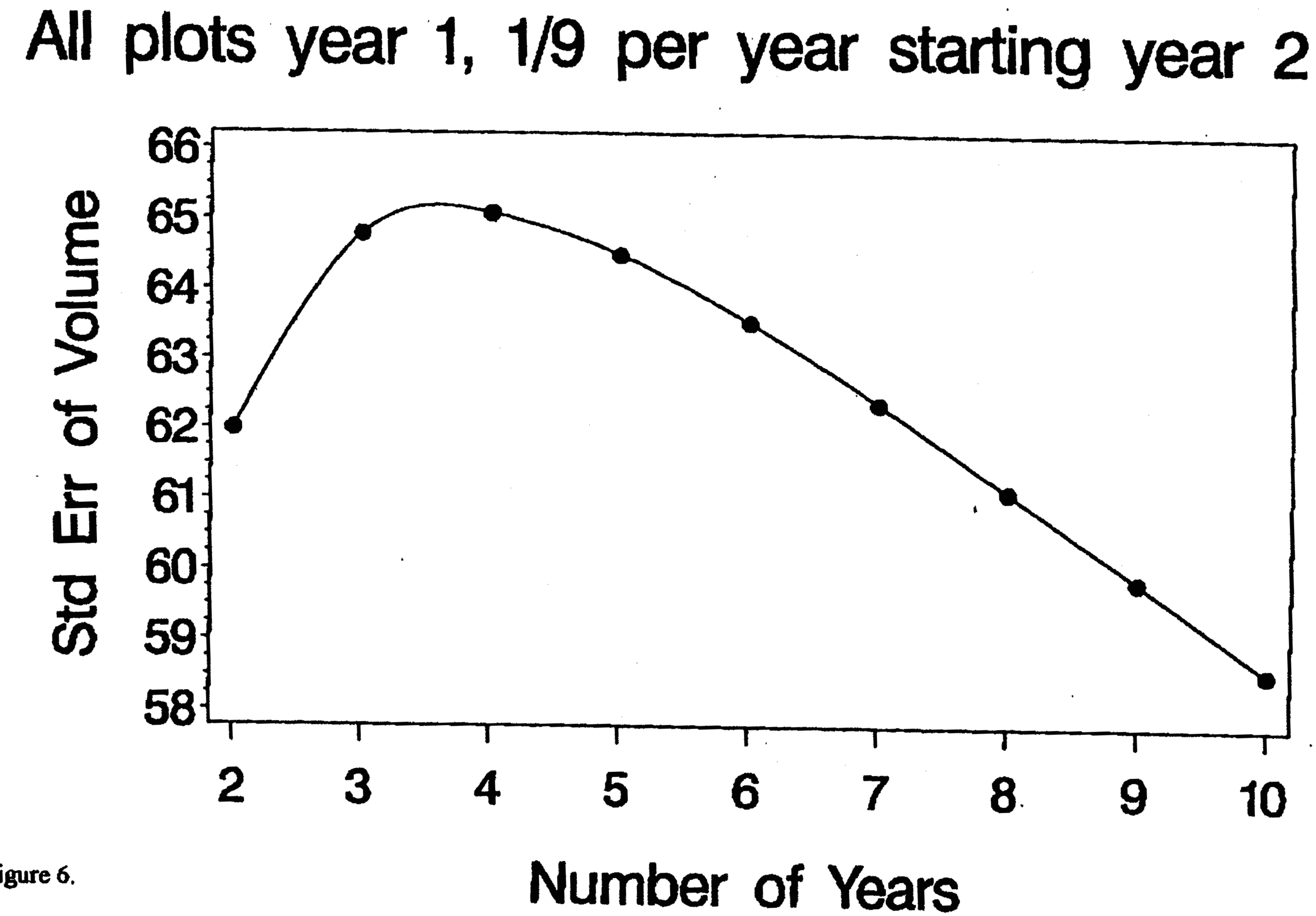

All plots year 1, 1/9 per year starting year 2
Std Err Annual Change in Vol
45
36
27
18
9
0
2
3
4
5
6
7
8
9
10
Number of Years

Figure 5.



All plots year 1, 1/9 per year starting year 2
Std Err of Volume
66
65
64
63
62
61
60
59
58
2
3
4
5
6
7
8
9
10
Number of Years

Figure 6.

References Cited

Gregoire, T.G., O. Schabenberger, and J.P. Barret. 1995. Linear modeling of irregularly spaced, unbalanced, longitudinal data from permanent-plot measurements. Can. J. For. Res. 25: 137-156.

Smith, W.D., M.L. Gumpertz, and G.C. Catts. 1996. An analysis of the precision of change estimation of four alternative sampling designs for forest health monitoring. Forest Health Monitoring Technical Report Series (10/96).

Urquhart, N.S., W.S. Overton, and D.S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: impact of temporal patterns. *In* Statistics for the Environment. John Wiley & Sons, New York.