MINNESOTA ENVIRONMENTAL QUALITY BOARD
REGIONAL COPPER-NICKEL STUDY

A REASSESSMENT OF KOTAR'S DATA ANALYSIS

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Minnesota Environmental Quality Board

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INTRODUCTION

A study was undertaken in 1974 to determine the effects on forest productivity of SO_2 emissions from a copper smelter in White Pine, Michigan (Kotar 1977). Annual radial growth over a period of 30 years was determined for three tree species located at various distances and wind directions from the smelter. Kotar concluded that, on the more severely impacted sites, a substantial reduction in radial growth had occurred for balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*). Kotar's analysis indicated, however, that trembling aspen (*Populus tremuloides*) was unaffected.

A re-examination of Kotar's data was conducted for two reasons. First, we feel that basal area is a more desirable measure of actual growth or productivity than width of annual rings, since basal area increment is less dependent upon stem size than is radial increment (i.e. radial increment usually decreases as stem diameter increases whereas basal area increment does not).

Secondly, and perhaps of greater significance, we feel that a comparison of average annual growth rates of impacted versus control trees at a given point in time is not valid. Instead, a comparison of growth rates of trees at similar ages is preferred. This is because the rate of growth is a function of age (Figure 1), and this will vary with the age of individual trees. Comparing the annual growth of one tree with that of another that is ten years older may be misleading. Kotar acknowledges this problem but states that "most sample trees have attained only 1/3 to 1/2 of their expected ages and therefore would not be expected to show a decline of radial growth under normal conditions." This is true, however, only if the growth curve during the first 20 to 50 years is linear, which it may not be. Although a decline of radial growth would not be expected during this age interval, it is possible that different rates of growth may occur. When the average age of control trees is younger than the impacted trees, as in the case of balsam fir and white spruce, a decline in growth that is not necessarily related to SO_2 emissions may be observed in the impacted trees.

PROCEDURE

Since the raw field data were unavailable, yearly estimates of average radial growth for each species at each site were extracted from graphs (Figures 2 and 3) in Kotar's paper. Ring widths were estimated to the nearest .1 mm. Average tree diameters of each species on the various sites were obtained from Kotar. From this information basal area (BA= r^2) can be calculated.

It should be noted that there are difficulties in utilizing averages instead of raw data. Using average tree diameters to calculate approximate basal area (BA= r^2) is theoretically incorrect and will result in an underestimation of the actual basal area (BA= r^2). Also, making group comparisons utilizing average ages when the individual tree ages varied as much as 20 years (e.g. balsam fir) may reduce our ability to identify real relationships. Because the raw data were unavailable within our time requirements and because only general trends and relationships were of interest, these problems were ignored.

Both average accumulated and average annual increase of basal areas were graphed against average tree age for each species at each site (Figures 2-9). Also, the differences in average annual growth rates for impacted sites minus differences for control sites were plotted against average tree age (Figures 10-13). A percent reduction in basal area growth attributed to the effects of SO_2 was determined by projecting the growth curves of the impacted sites to give an estimate of expected growth.

An estimate of expected growth was determined by extrapolating the growth curves of the impacted sites. For white spruce the growth curve was extended roughly parallel to the control growth curve which it had been paralleling prior to smelter construction. The control growth curve for balsam fir, however, was of little use as a guide to determining expected growth of the impacted sites because of its atypically slow rate of growth. As a result, expected growth was determined by assuming that growth would have continued at a rate similar to that of the five-year period prior to smelter construction.

Because initial fumigation occurred at an early age on Site 3, when growth had just begun to accelerate, only four years instead of five years were used to predict the future growth rate.

RESULTS

Comparison of Data Presentation

The conclusions reached from the three methods of graphing do not significantly differ from those of Kotar. The trends revealed by the more comprehensive analysis are generally much clearer, however.

The three methods of data expression show the same trends, although they differ in clarity and emphasis. Plotting average accumulated growth (Figures 4-6) has the advantage of producing a smooth curve and is thus less confusing to read. Graphing the differences in rates of growth (Figure 10-13) allows a comparison of an impacted and control site to be made on one curve.

Comparison of Sites

Balsam Fir--A reduction in the rate of growth following the construction of the smelter was observed for balsam fir at Sites 1, 3, and 4. Although the growth rate of Site 2 declined in relation to the control, this decline was initiated prior to the activation of the smelter. The magnitude of the reduction in growth corresponds well with the relative SO_2 toxicity that would be expected, based on distance and direction from the smelter. Over a 20-year period balsam fir at Site 3 had the greatest reduction in growth (19-27 percent; Figure 14). This was followed closely by Site 4 (20-23 percent) which was almost twice the distance from the smelter but located downwind from the smoke stack. A smaller reduction in growth (11-18 percent) was found on Site 1 which was slightly closer to the smelter than Site 4 but in a position that was more favorable with respect to the wind rose. Site 2, which had no observable decline in growth, was much further from the smelter than Sites 3 or 4 and was rarely downwind from the smelter.

There are factors other than SO_2 concentration that may have influenced the observed reduction in growth. Trees exhibiting differing growth rates and of differing age may respond differently to the same level of SO_2. The greatest growth reduction occurred on trees at Site 3 which at the time the smelter was built averaged 9.0 years old (range=3-17 years). On the other hand trees at Site 2, for which no reduction in growth was detected, had an average age of 14.6 and ranged from 9 to 21 years. Although the average ages of the trees at the two sites seem quite close, differences of 5 years may be important in sapling size trees. It is during juvenile stages that trees begin rapid development. Thus a given SO_2 level may effect a 30 and 35 years old tree in a similar manner while having greater effect on a 5 than a 10 year old tree. Because of greater photosynthetic rates, hence greater SO_2 uptake, high SO_2 levels may have a greater affect on the rapidly growing trees at Site 4 than the slowly growing trees on Site 2. Thus, even if SO_2 concentration were known it might not be possible to derive an equation relating SO_2 concentration to percent reduction in growth.

The method of predicting expected growth may also influence the estimated growth reduction to an unknown degree. The validity of extrapolating a linear growth rate for the next 20 years may be questioned. Although the growth curves appeared to be leveling off just before the smelter was built, it is possible that growth would have decreased or accelerated. Because the impact of SO_2 occurred at an early age, when growth had not yet stabilized on Site 3, the extrapolation of the growth rate prior to smelter construction may be particularly inaccurate. It is possible that the growth curve may have continued to parallel the growth curve of Site 4, making the calculated reduction a gross underestimate.

There may also be factors which would result in a natural decline in basal area increment after the smelter was built. Successional changes may bring about a closing of the forest canopy, increasing competition between individual trees and between species. This may result in an adjustment to a more moderate level of growth.

White Spruce--Of the three sites with white spruce only those on Site 3 showed signs of reduced growth. Site 6 was downwind of the smelter about the same amount of time as Site 3 but was almost four times further from the smelter. Figure 5 graphically displays the impact of SO_2 on white spruce at Site 3. Prior to smelter construction the growth curves of all three sites were similar. After SO_2 emissions began the basal area on the control site and Site 6 continued to parallel each other and resulted in growth curves which closely correspond to the theoretical growth curves of a nonsuppressed tree (Husch, Miller, and Beer 1972). The rate of growth at Site 3 did not keep pace with the other sites, however. The similarity of the growth curves of white spruce make extrapolation of expected growth at Site 3 more accurate than could be done for the widely varying growth curves of balsam fir.

Aspen--Sulfur dioxide concentrations at Sites 3 and 4 apparently did not affect the growth of aspen. The basal area on Site 3, which is the closest to the smelter, decreased only slightly from the control.

Because of the greater fluctuations in annual growth compared to balsam fir and white spruce (probably due to greater sensitivity to precipitation differences and insect infestations), this slight decrease in growth can probably be explained by natural influences.

Species Comparison

Only at Site 3 can a comparison be made of relative sensitivities of the three species. White spruce had the greatest reduction in growth after 15 years (47.5 percent) followed by balsam fir (15.0 percent). No reduction in growth was shown for aspen. These results differ from those of Davis and Wilhour (1976) who indicate that of the three species aspen is the most sensitive, and white spruce is the least sensitive to SO_2 damage. The findings of Davis and Wilhour are, however, based on visible injury and not growth reduction. Kotar states that firs (Abies spp.) are the most sensitive and aspen is the least sensitive, but does not give the criteria on which these ratings are based.

The differences in the relative sensitivities of the three species to SO_2 as indicated by the apparent reduction in growth may have been influenced by several factors. The methods used to estimate the expected growth of impacted balsam fir and white spruce are not directly comparable. The extrapolation of the growth curve of balsam fir is less certain than for white spruce. Therefore, the difference between the two species may actually be greater or smaller. Also, as previously discussed, variables such as age at which fumigation begins, the relative rates of growth, and differing species response to changing forest conditions may influence the effect that SO_2 has on tree growth. The inverse correlation of growth reduction and average tree age, for example, makes the assumption that age is a variable which can be ignored very questionable (see Table 1).

SUMMARY

Conclusions reached in this paper are similar to those of Kotar (1977). A reduction in growth was shown for balsam fir on Sites 1, 3, and 4 and for white spruce on Site 3. Aspen did not appear to be affected. The extent of growth reduction corresponds to the relative SO_2 concentration

expected based on observation of distance and direction from the smelter. In agreement with Kotar's literature findings, conifers are much more sensitive to SO_2 then aspen. The greater reduction in growth of white spruce compared to balsam fir, however, conflicts with previous findings. Several factors (e.g. method of extrapolating projected growth, variation in tree age at which fumigation began, variation in growth rates prior to fumigation, and varying species response to changing forest conditions) may have influenced the results to an unknown degree.

REFERENCES

Davis, and R.G. Wilhour. 1976. Susceptibility of woody plants to sulfur dioxide and photochemical oxidants. USEPA Ecological Research Series EPA-600/3-76-102. 72p.

Husch, B., C.I. Miller, and T.W. Beers. 1972. Forest Mensuration. 2nd Ed. The Ronald Press Co. New York. 410p.

Kotar, J. 1977. Effects of low-level SO_2 emission from a modern smelter on tree growth. Unpublished paper. 11p.

BALSAM FIR

SITE	% Reduction in Growth*		Age at Start of Fumigation (yrs)		Growth Rate
	Ave.	Range	Ave.	Min.	(Rank)
3	23.0	19-27	9.0	3	3rd
4	21.5	20-23	16.7	8	1st
1	14.5	11-18	14.6	9	2nd
2	0	0	22.6	14	4th

WHITE SPRUCE

SITE	% Reduction in Growth**		Age at Start of Fumigation (yrs)		Growth Rate
	Ave.	Range	Ave.	Min.	(Rank)
3	47.5	46-49	5.7	1	2nd
6	0	0	5.9	-1	1st

SITE 3

SPP	% Reduction in Growth**		Age at Start of Fumigation (yrs)		Growth Rate
	Ave.	Range	Ave.	Min.	(Rank)
White Spruce	47.5	46-49	5.7	1	1st
Balsam Fir	15.0	11-19	9.0	3	3rd
Aspen	0	0	14.6	12	2nd

* after 20 years

** after 15 years

Table 1. Comparisons of age and growth rate with percent reduction in growth.

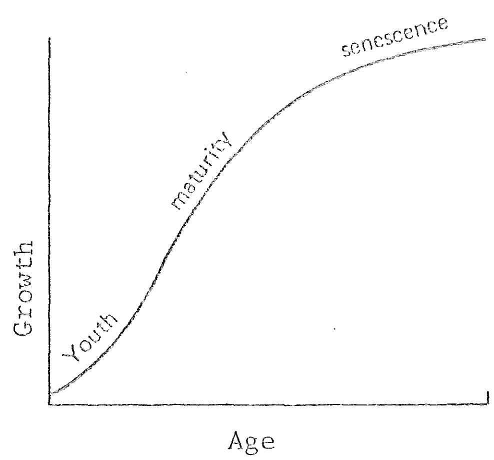


Figure 1. Typical accumulative growth curve for trees (From Husch, Miller and Beers 1972).

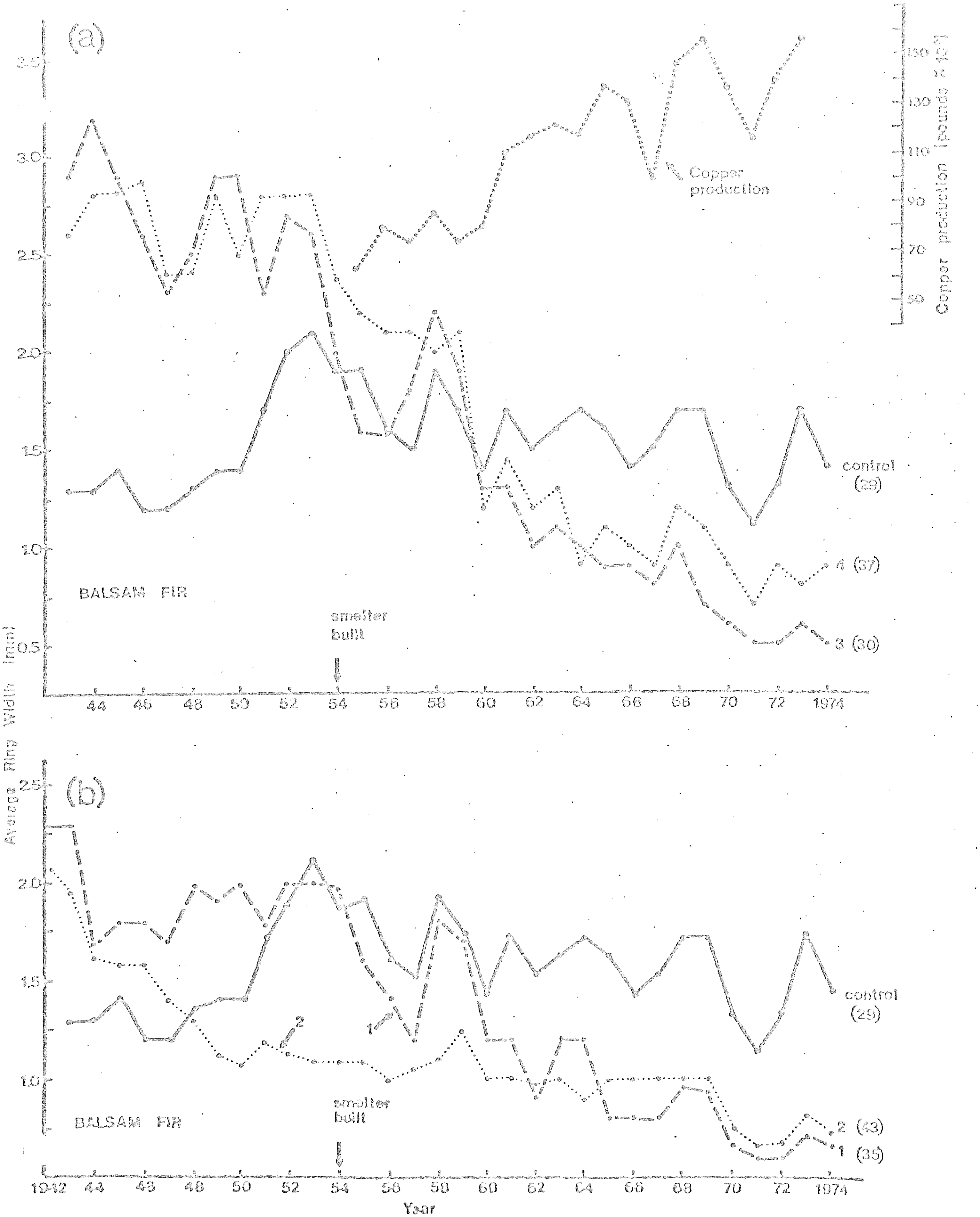


Figure 2. Radial growth of balsam fir (From Kotar 1977).

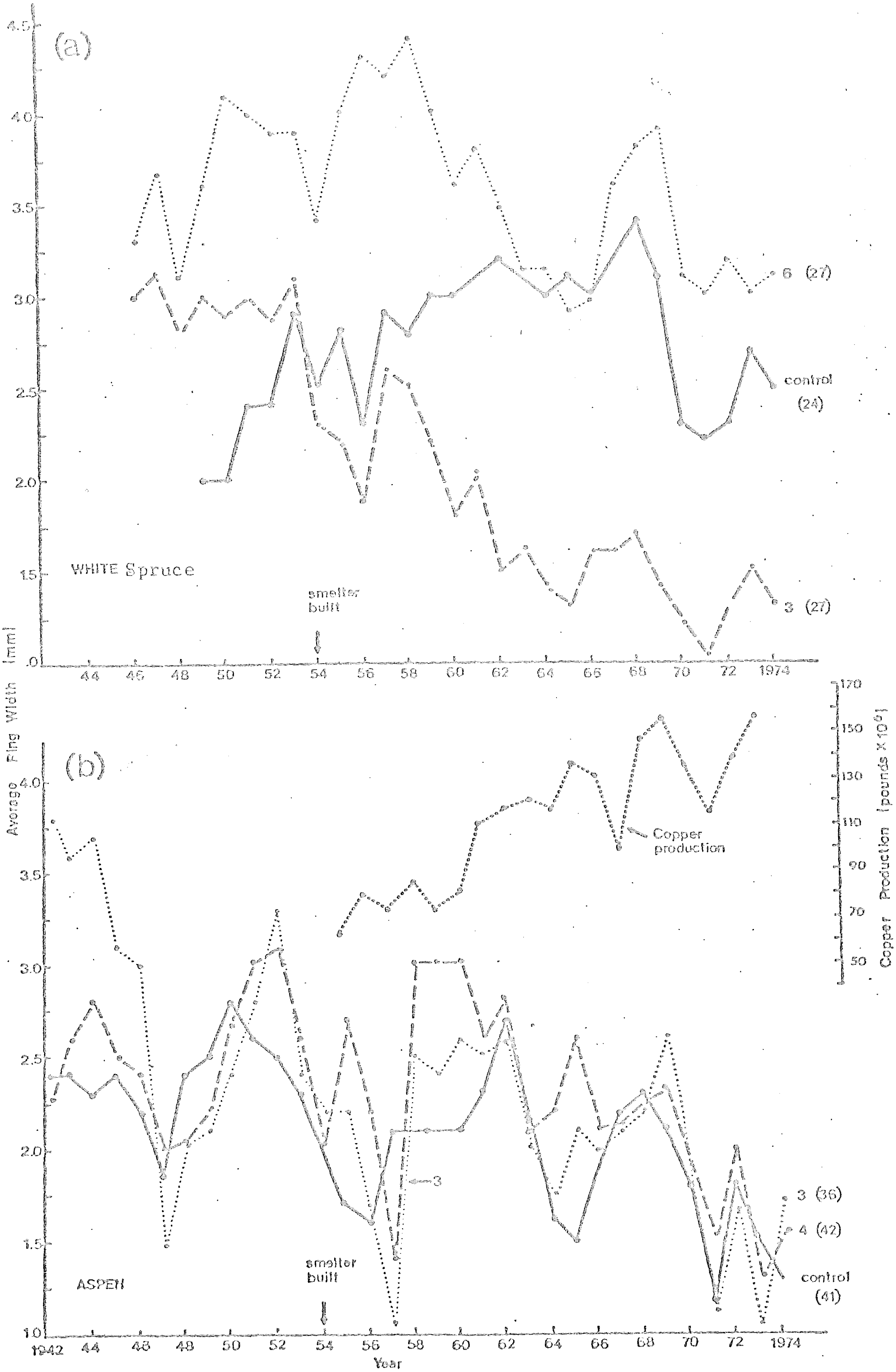


Figure 3. Radial growth of white spruce and aspen (from Kotar 1977).

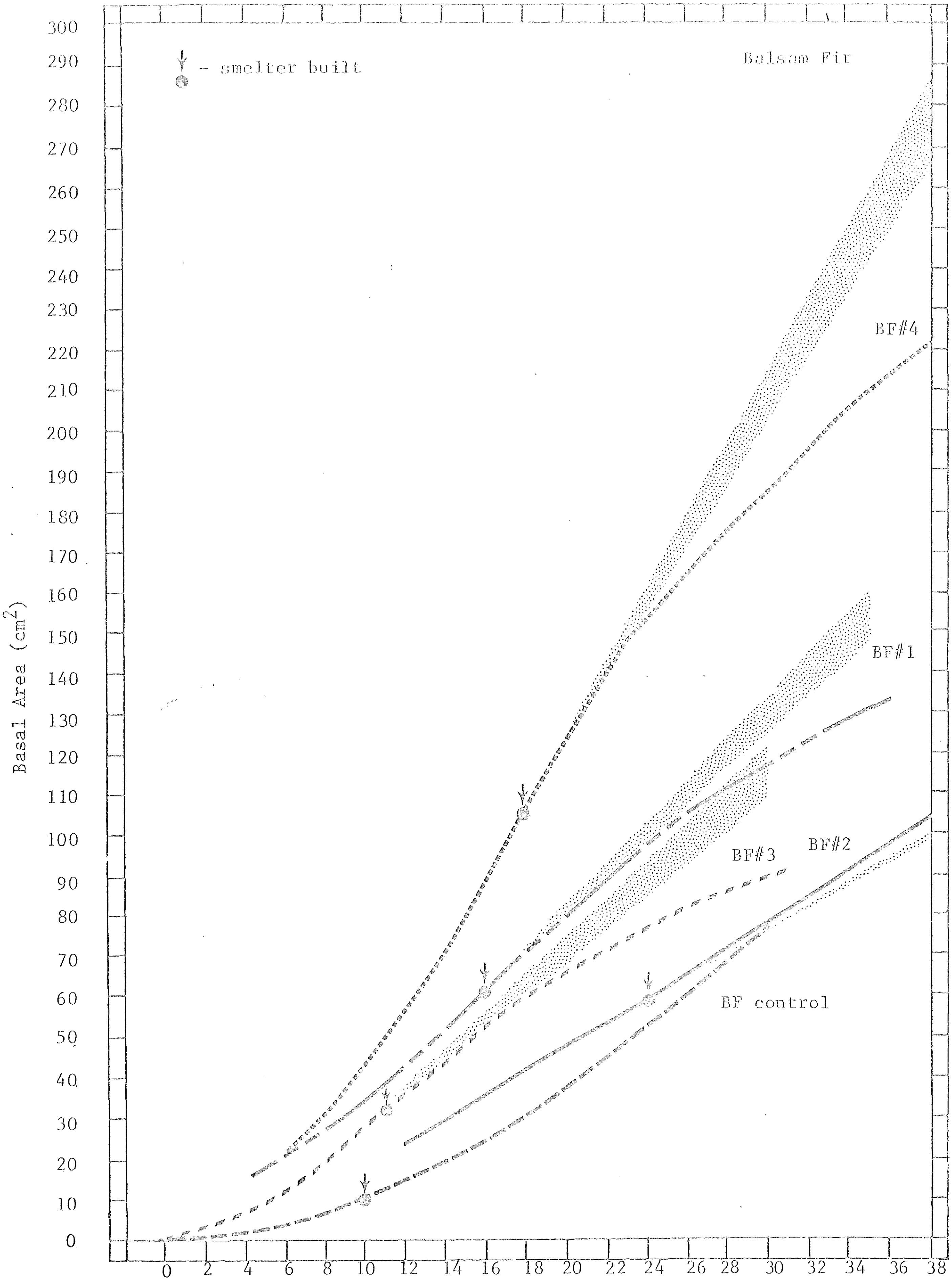


Figure 4. Accumulative basal area of balsam fir (shaded area indicates projected growth in the absence of smelter effects).

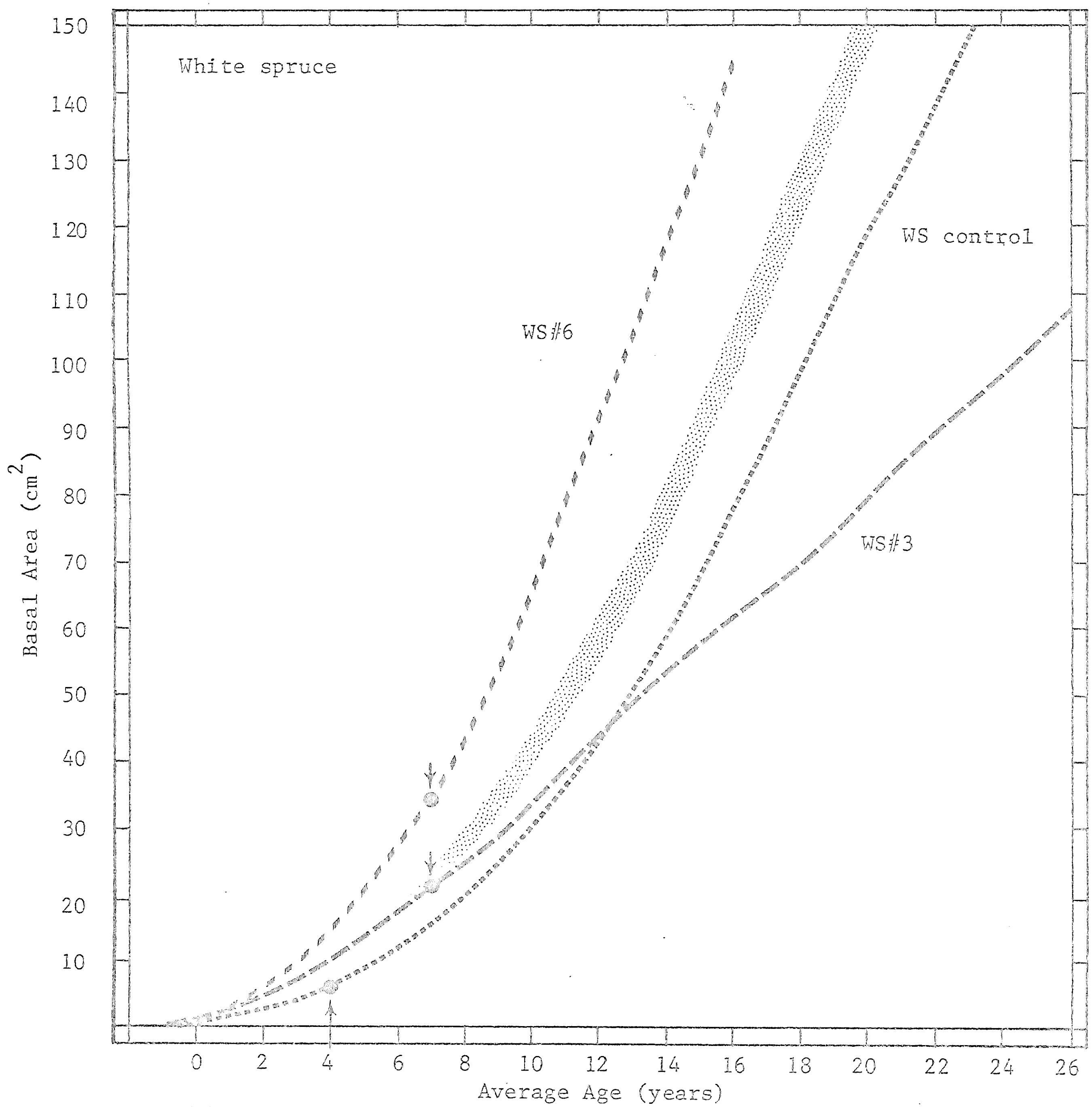


Figure 5. Accumulative basal area of aspen sites (Shaded area indicates projected growth in the absence of smelter effects).

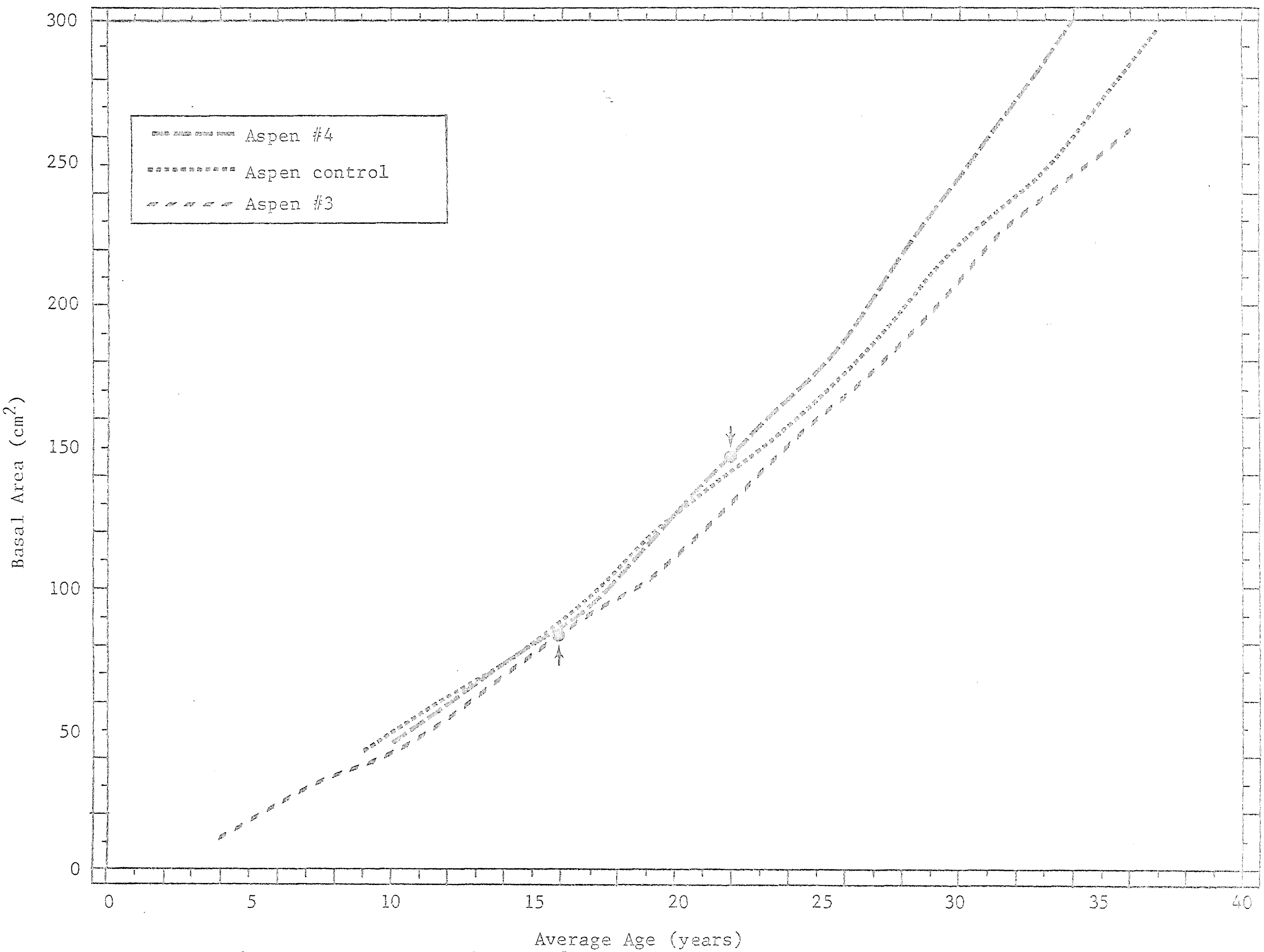


Figure 6. Accumulative basal area of aspen sites.

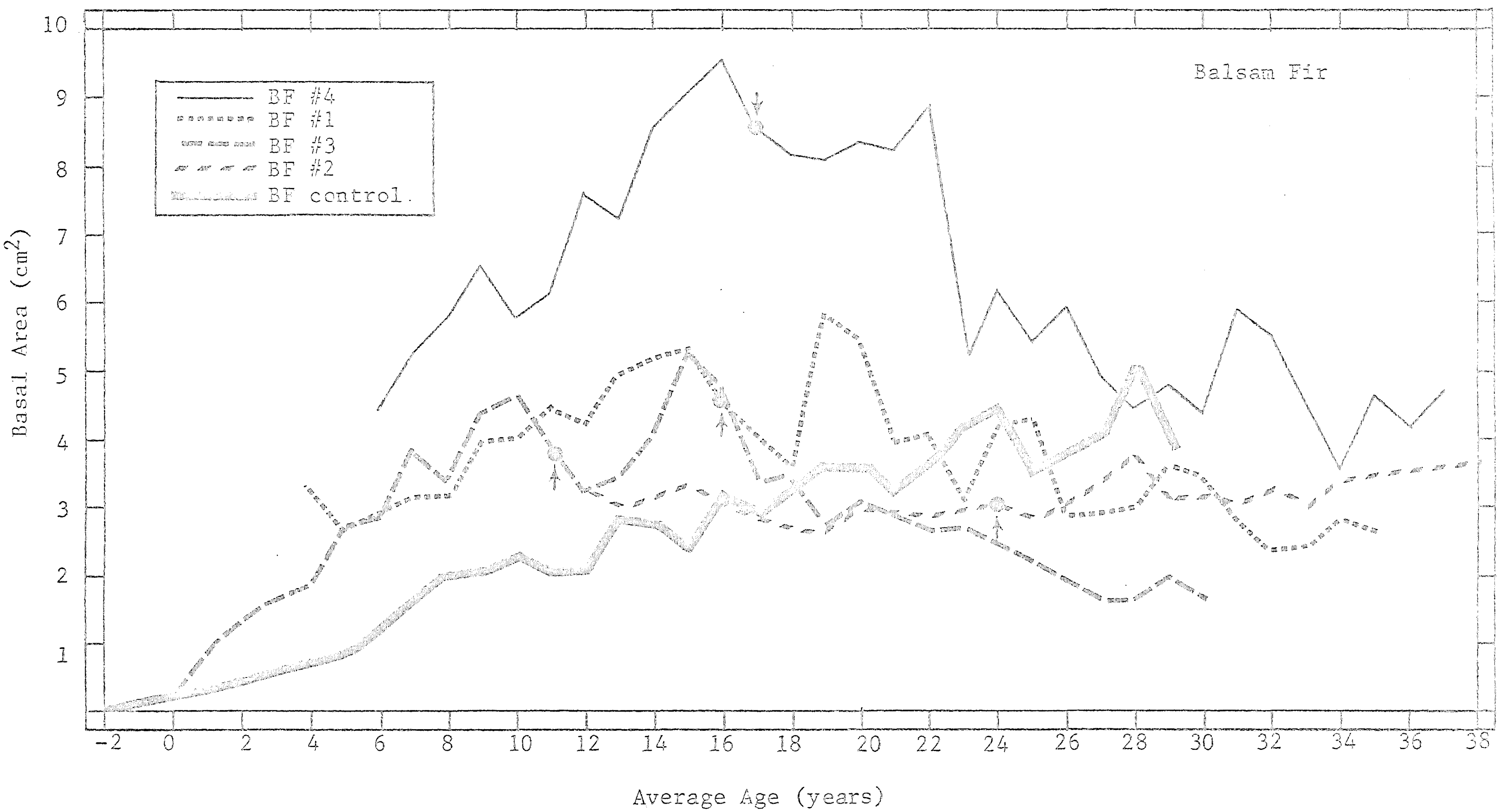
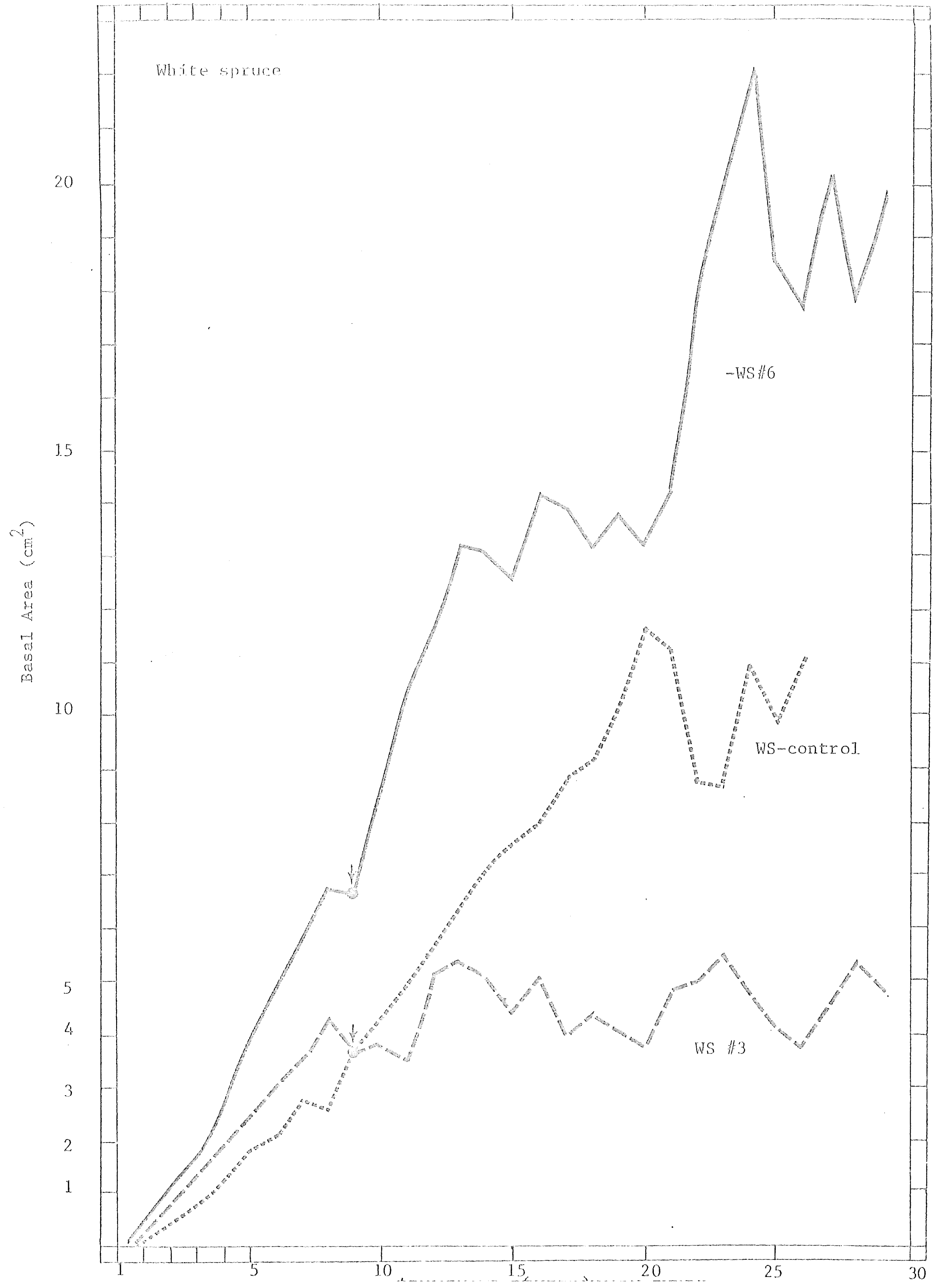


Figure 7. Annual increment of balsam fir sites.

Figure 8. Annual increment of white spruce sites.



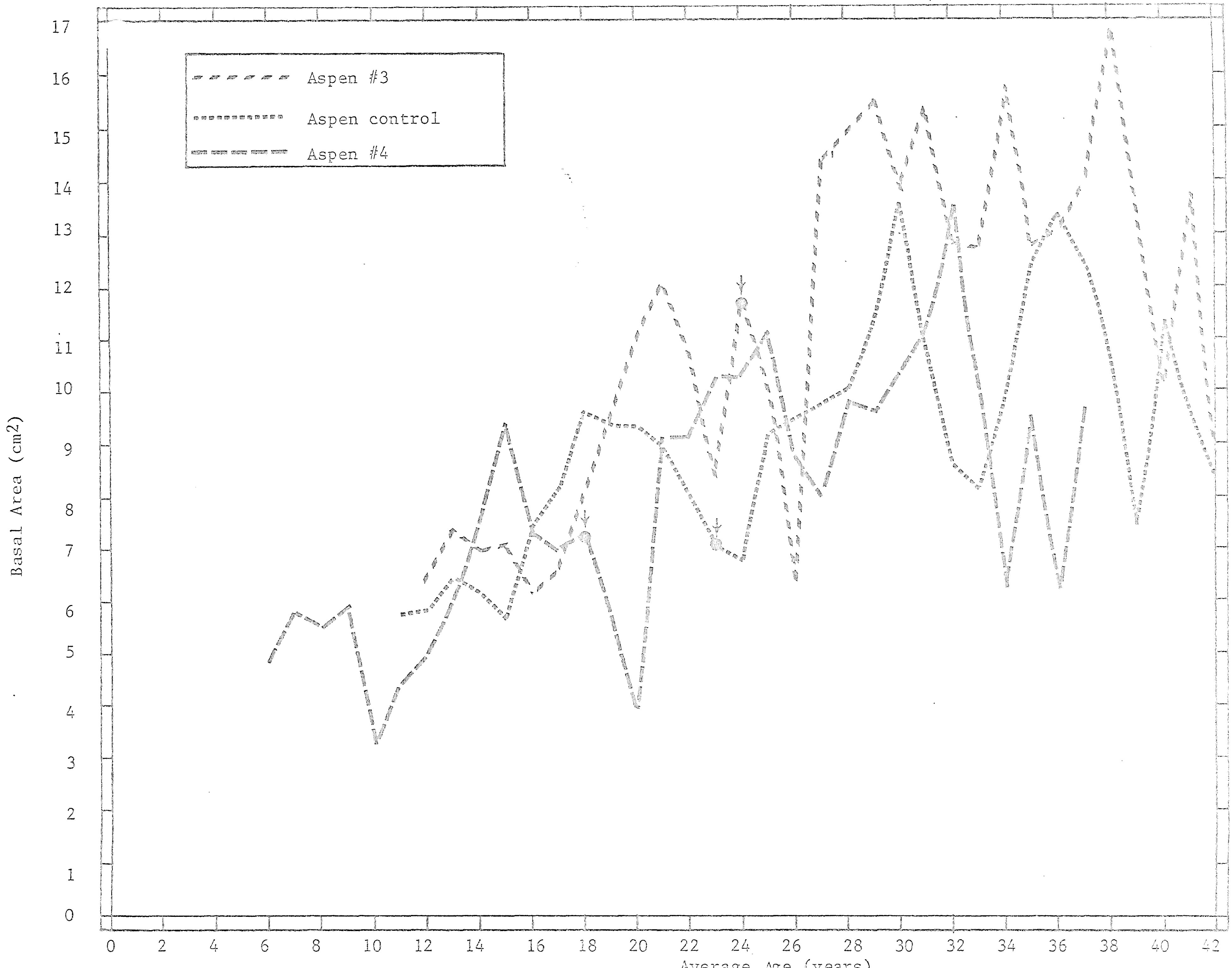


Figure 9. Annual increment of aspen sites

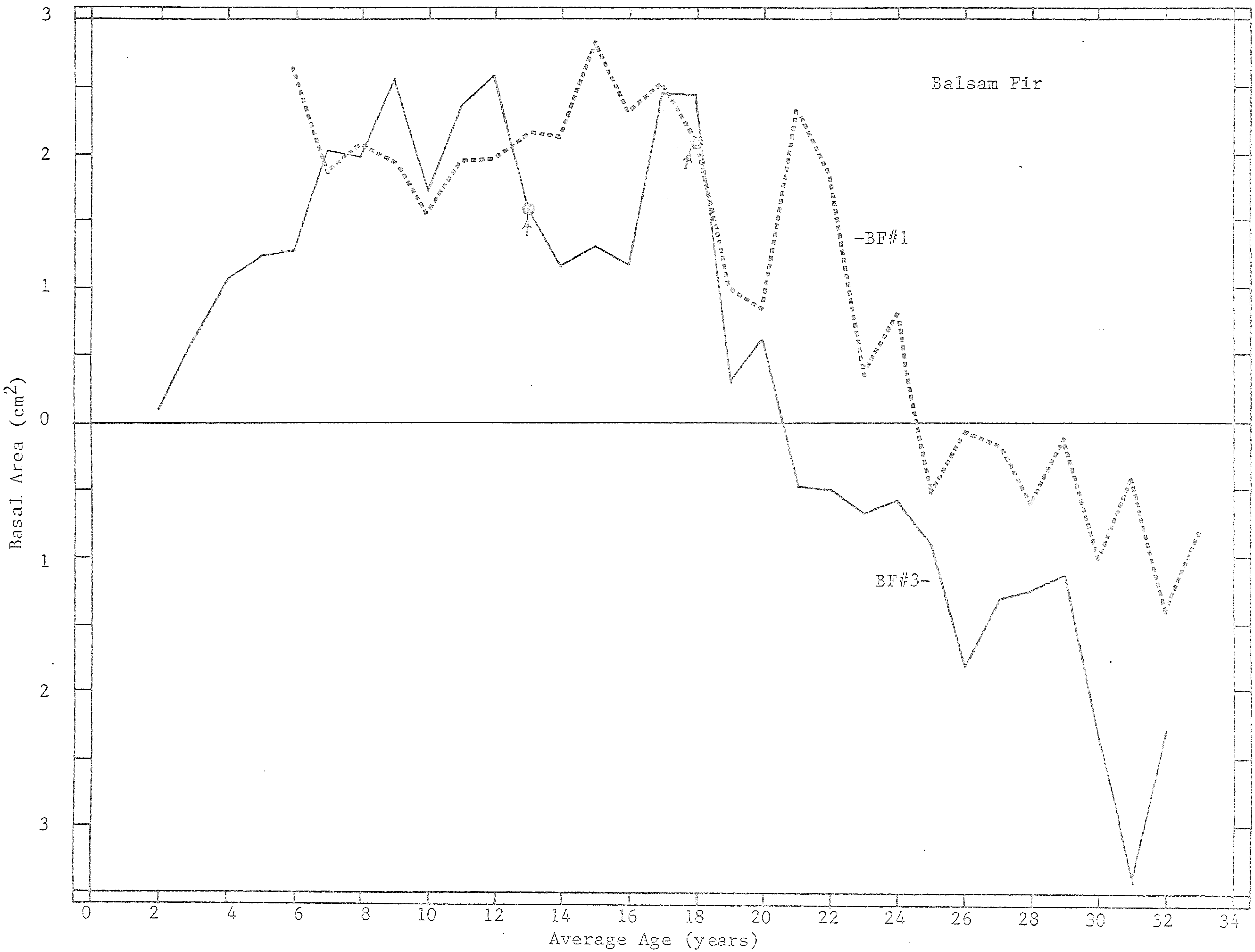


Figure 10. Difference in annual increment of impacted balsam fir sites versus control

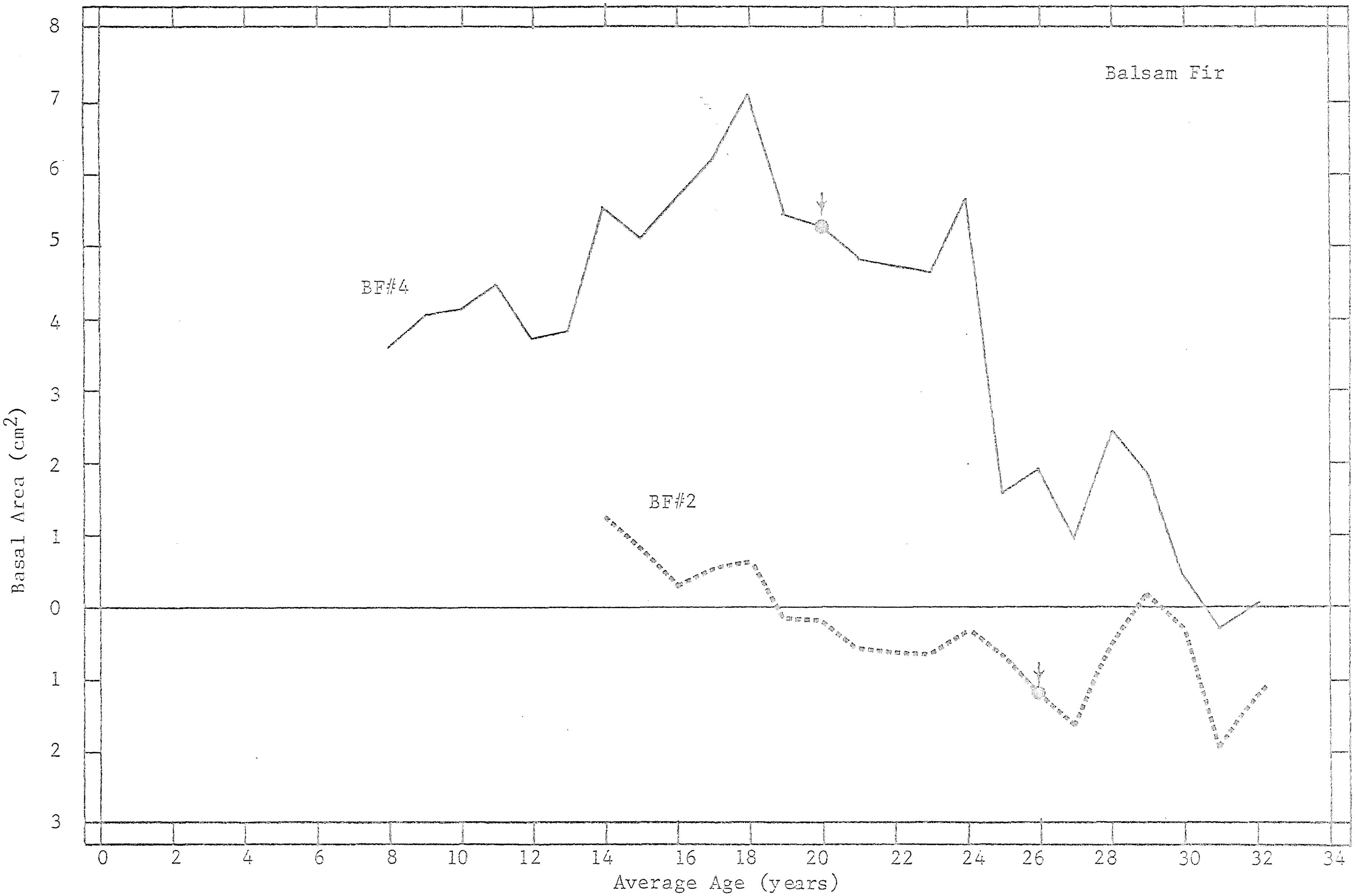


Figure 11. Difference in annual increment of balsam fir sites and control.

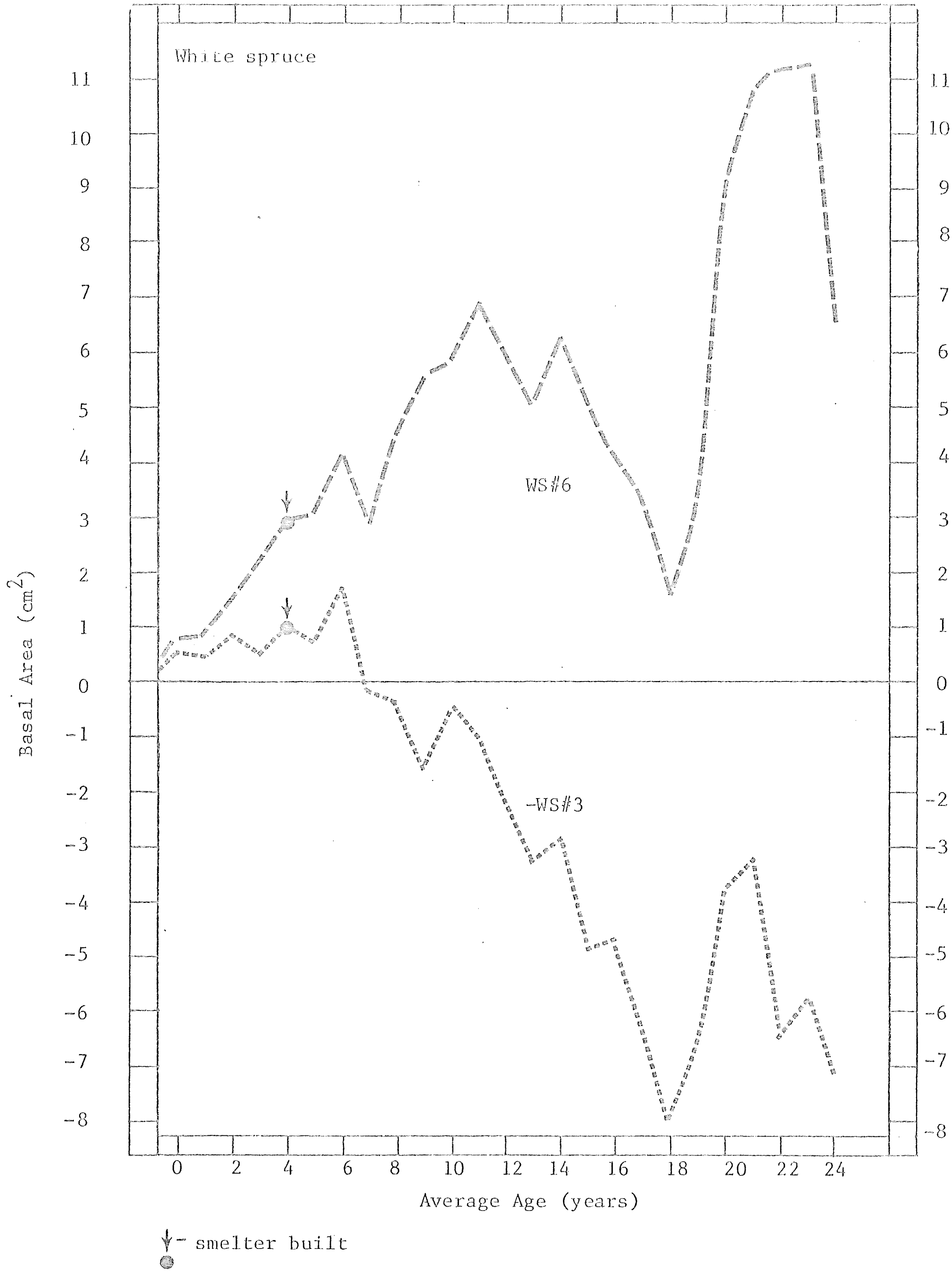


Figure 12. Difference in annual increment of impacted white spruce sites and control.

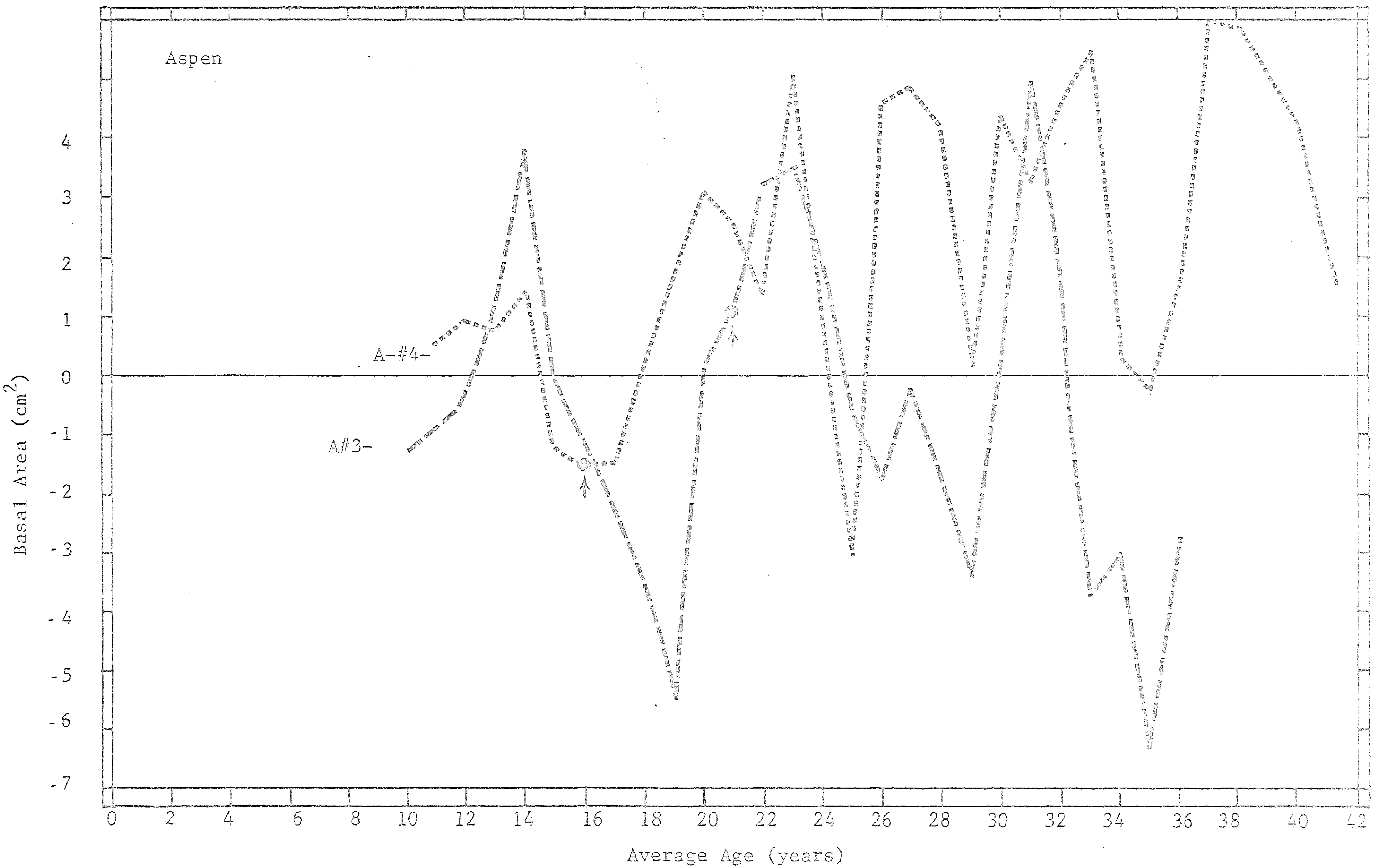


Figure 13. Difference in annual increment of impacted aspen sites and control.

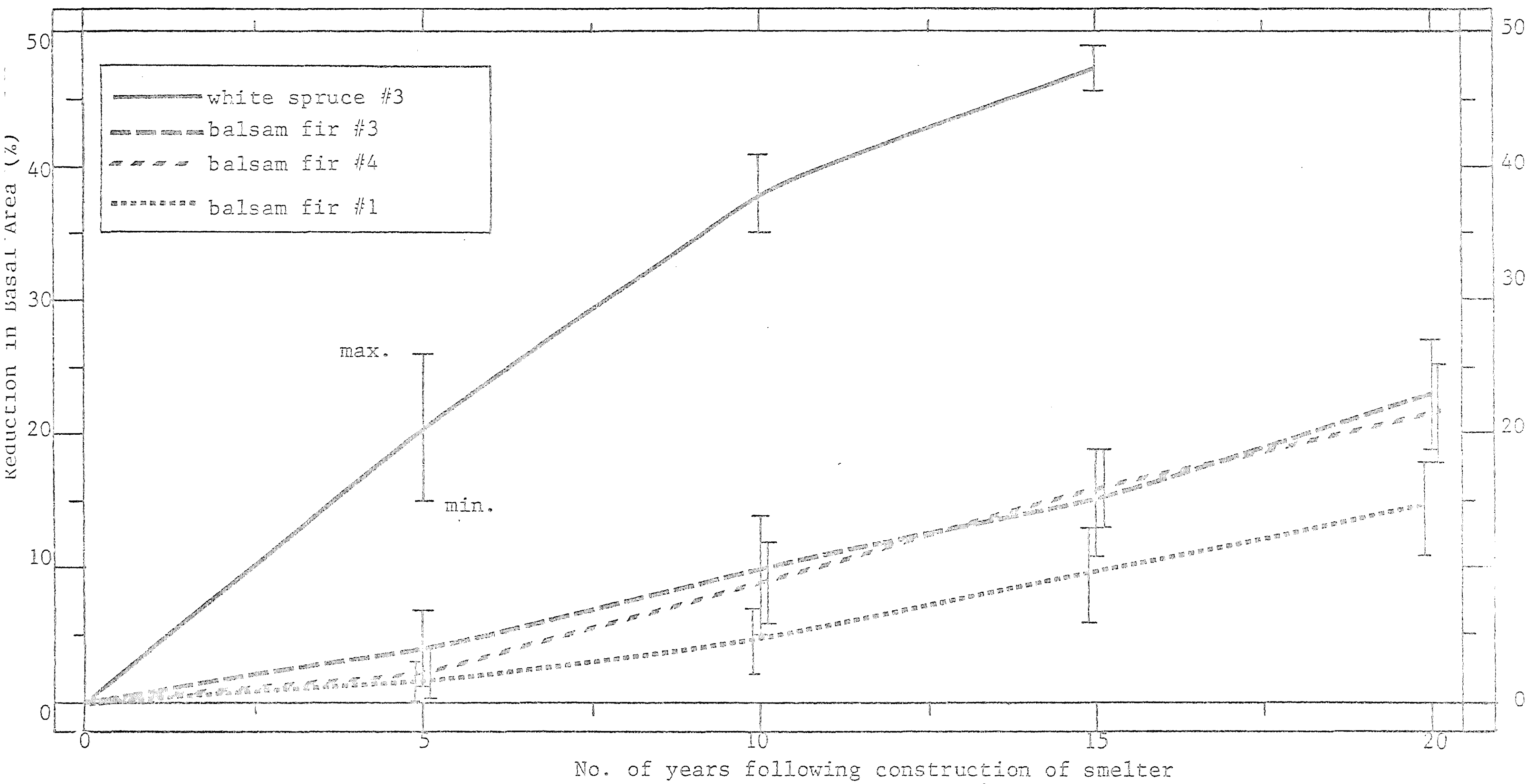


Figure 14. Estimated percent reduction in gowth on impacted sites.