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THE DIVERGENCE/CONVERGENCE QUESTION

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EXECUTIVE SUMMARY

Trial data were obtained from three Bay of Plenty Forests in order to examine the relative performance of plots (of the same final crop stocking) that differ in basal area as a result of management intervention. Three types of intervention were examined: timing of thinning, timing and intensity of pruning, and selection ratio.

Although there was considerable variation in behaviour among the 41 thinning comparisons, it appears that basal area differences between plots caused by timing of thinning tended to decrease (i.e. converge) with time, after diverging for the initial two or three years. There is some indication that the extent of convergence is influenced by final crop stocking, the number of thinnings, and the level of available nitrogen present.

The most recent growth model developed for the Bay of Plenty Region is PPM88 (Garcia 1990). Basal area growth, when simulated with this model, will converge immediately after thinning. Despite this initial disparity with trial data, PPM88 tends to express convergence in a way that closely resembles the averaged long-term trend of the data.

In contrast to the thinning effect, basal area differences caused by pruning (16 comparisons) tended to continue to widen for at least six years, and sometimes for the duration of the data - in some cases as long as 15 years. PPM88 did not predict this.

Basal area differences due to selection ratio (one trial only) resulted in parallel development.

It is to be expected that all plots will ultimately "converge" as the sites attain their ultimate "carrying capacity" for basal area. For management purposes, it is important to discover whether this convergence takes place within a normal rotation length, as there are profound implications for regime evaluation, estate modelling and forest valuation.

INTRODUCTION

Although most of the performance of a stand of trees may be determined by tree genetics and site characteristics, managers can influence stand growth to a limited extent by varying establishment procedures (cultivation, fertiliser, weed control, planting techniques), and by controlling the timing and intensity of thinning and pruning.

Early work by Fenton and Sutton (1968), Sutton (1976) and others suggested that early management was critically important. For example, a stand that was thinned early would have a higher basal area, at the same age and stocking, as one that had been thinned late. The Kaingaroa Growth Model (KGM2) predicted that these initial differences would be maintained or even increase over time and become quite substantial at harvest. For this and other reasons, early regime evaluations did not favour production thinning: the crop element was heavily penalised by its early suppression, and the benefits of branch suppression and the intermediate yield did not fully compensate for this.

When KGM2 was replaced by the later model KGM3 (which, with a few modifications, became PPM88), regime evaluators discovered a difference in model behaviour: early differences in basal area tended to decrease with time. Production thinning appeared to be a more favourable option than had been assumed (West 1990). The contrasting behaviour of KGM2 and PPM88 is illustrated in Fig 1. Two stands are generated by the EARLY Growth Model (EGM), one with early thinning to waste, and one with a later (production) thinning.

Production thinning is, of course, only one of many management policies affected by the choice of growth model. All early site and stand treatment must be evaluated in the light of model behaviour. Furthermore, if growth models are **biassed** - for example, for or against production thinning or pruning - this could have serious repercussions on forest estate modelling and valuation. Growth models are used to calculate the yield tables that are an intrinsic part of estate modelling and forest statistics. The composition of the national forest estate is changing to a predominance of clearwood regimes, and the trend towards pruning and early final thinning could have some unexpected consequences in terms of yields and valuations, if existing models are deficient in modelling such regime changes.

There are also implications in regional comparisons. Companies may, for example, wish to compare the advantages of investment in the Bay of Plenty as against Hawkes' Bay. It would seem rational to use growth models that have been developed for the region in question. But an examination of regional models for thinning effects (Fig 2), indicates that some models cause basal area divergence or parallel development, while others converge. Is this a genuine reflection of the natural state or is it an artifact of the models? Note for example that NZ Forest Products model and PPM88 represent almost opposing extremes of the spectrum, and yet the growth characteristics of trees within their data collection area are most unlikely to vary greatly.

The implications are particularly dramatic when a regime evaluator is attempting to calculate a breakeven stumpage for production thinning. Changing from KGM2 to PPM88 results in a shift in production thinning breakeven stumpage of S8/m^3 for pruned stands (Whiteside et al 1989).

Only two models (EARLY and PPM88) currently attempt to account for pruning. The relative performance of the two models when used to compare pruning with no pruning is given in Fig 3.

It is sometimes argued that - given the complexity of real forest ecosystems - growth models should not be expected to provide the precision necessary to distinguish between convergence and divergence. But it should be noted that the comparison here is between treatments applied on the same site. Site effects are the major source of imprecision in growth models, and these are eliminated from consideration. Because of this, it does not seem unreasonable to expect growth models to reflect accurately the effects of management decisions on basal area convergence or divergence.

METHOD

In order to test the realism of model behaviour, we obtained data from trials that would tend to highlight the phenomenon. A postal survey of 23 forest managers and an initial search of the PSP system revealed that there was unlikely to be adequate data outside the pumice plateau. The PSP system for this region was therefore interrogated in depth in order to obtain comparisons of plots, of the same stocking, that differed in basal area as a result of management intervention.

It was decided to eliminate some categories of management intervention, as they have the potential to influence tree growth over a prolonged period, rather than for a limited period in the early life of the tree. Fertilisation is in this category: if a nutrient deficiency is corrected at age 6, for example, the tree could still be receiving benefit from this at age 30. For the same reason, all types of site preparation were excluded.

Initial stocking differences affect selection ratio, which presumably affects genotype - and we know that genetically improved trees will grow faster at advanced ages. In spite of this, one initial stocking trial was included as an interesting comparison.

The three categories of management intervention that we deemed suitable were therefore the timing of thinning, the timing and intensity of pruning, and selection ratio.

Some examples may assist:

Example A, a thinning comparison. Trial R905 contains plots that were thinned to a range of stockings at 11 m top height (age 7) and also at 16 m top height (age 9). At age 9 the two early-thinned plots at 200 stems/ha had a mean basal area of 13 m^2/ha, whereas the two later-thinned plots at 200 stems/ha had a mean basal area of 9.5 m^2/ha. This 3.5 m^2/ha difference had declined by age 29 to 2.8 m^2/ha, thus demonstrating the phenomenon of **convergence**.

Example B, a pruning comparison. Trial R699 contains plots that have been medium pruned, and also left unpruned. At age 8 the 395 stems/ha unpruned treatment had a mean basal area of 12.4 m^2/ha whereas the 395 stems/ha pruned treatment had a basal area of only 10 m^2/ha. This 2.4 m^2/ha difference had increased to 6.7 m^2/ha by age 21, thus demonstrating the phenomenon of **divergence**.

Example C, a comparison of selection ratio. Trial R972 was planted at six different initial stockings which were eventually thinned to the same final stocking of 250 stems/ha. Superior initial basal area could occur both from wider initial spacing, and - in opposition to this - from the better selection that higher initial stockings conferred. Differences in basal area did not significantly increase or decrease. This is an example of **parallel** development.

In total, some 12 trials (10 from Kaingaroa, 1 from Rotoehu and 1 from Tarawera), each containing one or more paired comparisons between treatments, were found suitable for this investigation. Each comparison involved differences in timing of thinning, pruning severity, or selection ratio, but the same final crop stocking. Where plots suffered excessive mortality they were eliminated from the comparison, but lower levels of mortality were accepted as being part of normal stand development.

The difference in basal area between each pair of treatments was plotted against the time since the final treatment (thinning or pruning). For ease of comparison, each line was standardised by subtracting its starting value. This resulted in a series of lines, the slopes of which indicated convergence (negative slope), divergence (positive slope) or parallel development (horizontal line).

The observed trends were scrutinised further in order to discover if divergence/convergence was related to:

- the nature of the management intervention (i.e. thinning, pruning or selection);
- the absolute level of basal area at the time of the intervention;
- the final crop stocking;
- the starting age of the basal area difference;
- the level of fertilisation used.

Unfortunately, it was not possible to examine the effect of site index on divergence/convergence, as there was too little variation in the data base.

RESULTS

1. Thinning effects

The rate of convergence/divergence caused by timing of thinning can be seen in Fig 4. There tends to be an initial adjustment period after thinning, of two to three years, during which the stand with the delayed thinning needs to occupy the new space that has recently become available, and where a certain amount of divergence in basal area tends to occur. We would assume that the degree of initial divergence is influenced by differences in green crown and root mass after the delayed thinning.

After this lag time, in the majority of cases it can be seen that the basal area growth of the suppressed trees is at least equal to, and in many cases greater than that of the others. There is hardly a single case of sustained divergence among all the comparisons. Over two thirds of the comparisons have shown a decrease in the initial basal area difference by the last date of measurement, although one trial (R955 from Tarawera Forest) is heavily influencing this trend.

From 3 years after the final treatment until the last measurement, convergence averaged 0.13 m^2/ha/year (Table 1). It should be noted that not all comparisons are strictly independent as several are made against the same base treatment. Nevertheless, judging by the standard error, the level of convergence appears to be strongly significant.

TABLE 1

Average rates of basal area divergence

Comparison Type	Initial BA difference (m^2/ha)	Rate of Divergence (+) or Convergence (-) (m^2/ha/year)			
		0-3 yrs		after 3 yrs	
		mean	s.e.	mean	s.e.
Timing of thinning	5.18	0.14	0.14	-0.13	0.03
Severity of pruning	4.02	0.54	0.13	0.11	0.03
Selection ratio	-0.38*	-0.45	0.13	0.03	0.03

* The "control" was planted at final stockings, and tended to have a slightly higher basal area than the other treatments.

When rate of divergence from final treatment onwards, was plotted against basal area and stocking (Figures 5a, 5b, 6a, 6b), there is a suggestion that convergence occurs more strongly at higher basal areas and stockings. The exception is that higher stockings do not appear to greatly affect convergence for the first three years after treatment. Table 2 gives the correlation coefficients and their significance.

TABLE 2

Effect of basal area and stocking on rate of divergence

	Timing of thinning		Intensity of pruning	
	1st 3 yrs	> 3 yrs	1st 3 yrs	> 3 yrs
Basal Area	-0.08**	-0.46**	-0.78**	-0.22
Stocking	0.08	-0.40*	-0.53*	-0.43

where * is significant at $p = 0.05$
** is significant at $p = 0.01$

A closer examination of Trial R905 tended to confirm the hypothesis that stocking and/or basal area affect the rate of convergence. When trees thinned at 9 years were compared with those thinned at 7 years, divergence of 0.10 m^2/ha/yr occurred at 200 stems/ha, and convergence of 0.64 m^2/ha/yr at 500 stems/ha, this trend being statistically highly significant. However, when the final thinning was delayed to age 13 or 16 years, strong convergence of 0.41 m^2/ha/yr occurred even at the lowest stocking of 200 stems/ha.

2. Pruning effects

Figure 3 demonstrates how two models, EARLY and PPM88, respond to basal area differences due to pruning. If PPM88 is used by itself (lower line) there will be divergence for 2 or 3 years followed by convergence, resulting in almost no basal difference at time of harvest. On the other hand, EARLY (top line, left-hand part) predicts extreme divergence for at least five years. EARLY is not designed to model growth after a Mean Top Height of 18 m, and a switch is made to PPM88. There is a drastic reversal of model behaviour as PPM88 whittles down the basal area differences generated by EARLY.

The effects of pruning, as recorded by trial data, are illustrated in Figs 7, 8, and 9. It can be seen that the pruning effect differs from the thinning effect observed earlier. There is a greater period of "lag", in which the pruned trees are presumably restoring their lost volume of green crown and thereby their photosynthetic capacity. The data indicates that this adjustment period can last 6 years or longer.

Following the adjustment period, most of the comparisons seem to indicate that there is parallel growth, although the number and duration of available comparisons make a definitive conclusion difficult. Some of the longest-running data indicate that the divergent effect may continue for as long as 15 years.

Figure 10 illustrates how the depth of green crown changes under pruned and unpruned conditions. The top line represents the top of the tree. The bottom line shows how the base of the green crown rises with time at 600 stems/ha, as lower branches become suppressed and die. Thus the difference between the two lines is the depth of the green crown. The middle line represents the base of the green crown as artificially raised by pruning. It can be seen that it may take 9 years after final pruning for the pruned tree to have the same crown length as the unpruned tree. This may explain the extensive "lag" observed above, although it should be remembered that pruning may also have dramatic effects on root production, which being out of sight, tends to get overlooked by modellers.

The absolute level of basal area and stocking encountered appear to influence the rate of divergence, at least for the first three years after the treatment (Table 2, and Figs 8a, 8b, 9a, 9b). That is, higher levels of basal area and stocking will generate a propensity for convergence to occur.

It is clear that the behaviour of PPM88 is greatly at variance with the observed data.

3. Selection Ratio Effects

Limited data from a single trial suggests approximately parallel development in stands with difference selection ratios (Figure 11). The initial differences in basal area, however, are much less than those created by the intensity of pruning or the timing of thinning, and the convergence issue appears to one of little practical significance.

DISCUSSION AND CONCLUSION

It appears that, at least in the Central North Island, trees partially "catch up" as a result of early suppression because of tight stocking, but they do not do so if the cause of suppression was loss of crown or other damage inflicted by pruning. In fact, the observed loss of growth as a result of pruning is sufficiently severe to merit concern by forest managers: it is not well simulated by the Pumice Plateau Model.

In this study we have merely presented the data: further analysis is needed to understand the underlying physiological processes that cause these effects. Clues may be provided by the indications that the convergent or divergent basal area trends are stocking dependent, basal area dependent, and influenced by timing of thinning or number of thinnings.

A further clue may be supplied by two trials (RO1083/1 & /2), involving pruning and thinning treatments with and without nitrogen (urea) fertiliser. It is interesting to note that the fertiliser had a significant impact in reducing the cumulative level of divergence by the pruning and thinning treatments. This implies that site fertility is a factor that must also be examined.

We do, however, caution readers against extrapolating these results to other regions. The observed pruning effect, for example, could conceivably be connected to the magnesium deficiency observed (FRI 1991) in the pumice soils.

Basal area trends could be explained by different allocation strategies: two stands may be photosynthesising at the same rate, but the growth in one - as recorded by a diameter tape - is less than the other. This may be because photosynthate is being preferentially stored elsewhere in the tree: higher up the stem, for example, or else in roots or branches.

Although this analysis has largely endorsed the performance of PPM88 for thinning effects at stockings in excess of 250 stems/ha, it suggests that further work is necessary to examine the long-term consequences of pruning.

Nothing can be said about the behaviour of growth models from regions outside the Central Plateau: these have to tested against data from those regions. As long-term trials are generally lacking elsewhere, it is difficult to conceive of a suitable approach. Even if trial data were obtained that supported each regional model, it would still be desirable to explain the reasons for the widely different behaviour of regional models.

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APPENDIX 1

The trials used in the study

TRIAL NUMBER	PLOT NUMBERS	COMPARISON TYPE
R681	(1-4,49-52)	Timing of thinning
	(17-20)	
	(45-48)	
	(5-8)	
	(33-36)	
	(9-12)	
	(13-16)	
R363	(13-14)	Intensity of pruning
	(1-6)	
	(7-12)	
R231/2	(7,24)	Timing of thinning
	(1,18)	
	(6,22)	
	(2,5,11,12)	
	(3,14)	
R699/2	(13,19)	Intensity of pruning
	(3,9)	
R699/3	(5,14)	Intensity of pruning
	(6,20)	
R590	(31)	Intensity of pruning
	(8,15,30)	
	(4,24,27)	
	(13,22,32)	
	(9)	
	(23,28)	
	(5,16,17,26)	
	(14)	
	(12)	
	(2,20)	
	(3,10)	
R680	(13-16)	Timing of thinning
	(33-36)	
	(25-28)	
	(9-12)	
	(1-4)	
	(37-40)	
	(5-8,17-20)	

R686	/3 (11,12) /2 (8) /1 (3)	Timing of thinning
R911/1	(1,3,4) (2,7,8)	Timing of thinning
R688	/1 (4) /2 (5,6) and /3 (11) /2 (7) and /3 (9,10) /3 (12)	Timing of thinning
R905	(17,21) (9,13) (25,28) (26,29) (27,30) (31,34) (32,35) (33,36) (18,22) (14) (19,23) (11,15) (20,24) (12,16)	Timing of thinning
R972	(7,15) (2,14) (4,16) (3,6) (1,12) (10,11)	Selection ratio
R955/9	(1,4,8) (6,7,18)	Timing of thinning
R955/7	(12,15,30) (1,4,13) (14,20,26) (10,27,28) (31-33)	Timing of thinning
R955/6	(5,12,15) (3,10,14) (2,4,18)	Timing of thinning
R955/4	(6,14,18) (7,11,19)	Timing of thinning

R1083/1	(15,17) (2,12) (10,11) (13,16) (18,20) (14,19)	Combination of thinning, pruning, and N fertiliser
R1083/2	(2,15) (16,18) (1,17) (7,9) (3,4) (13,14)	

Figure 1

Comparison of basal area trends for direct and production thin regimes using EARLY plus KGM2 and PPM88 growth models

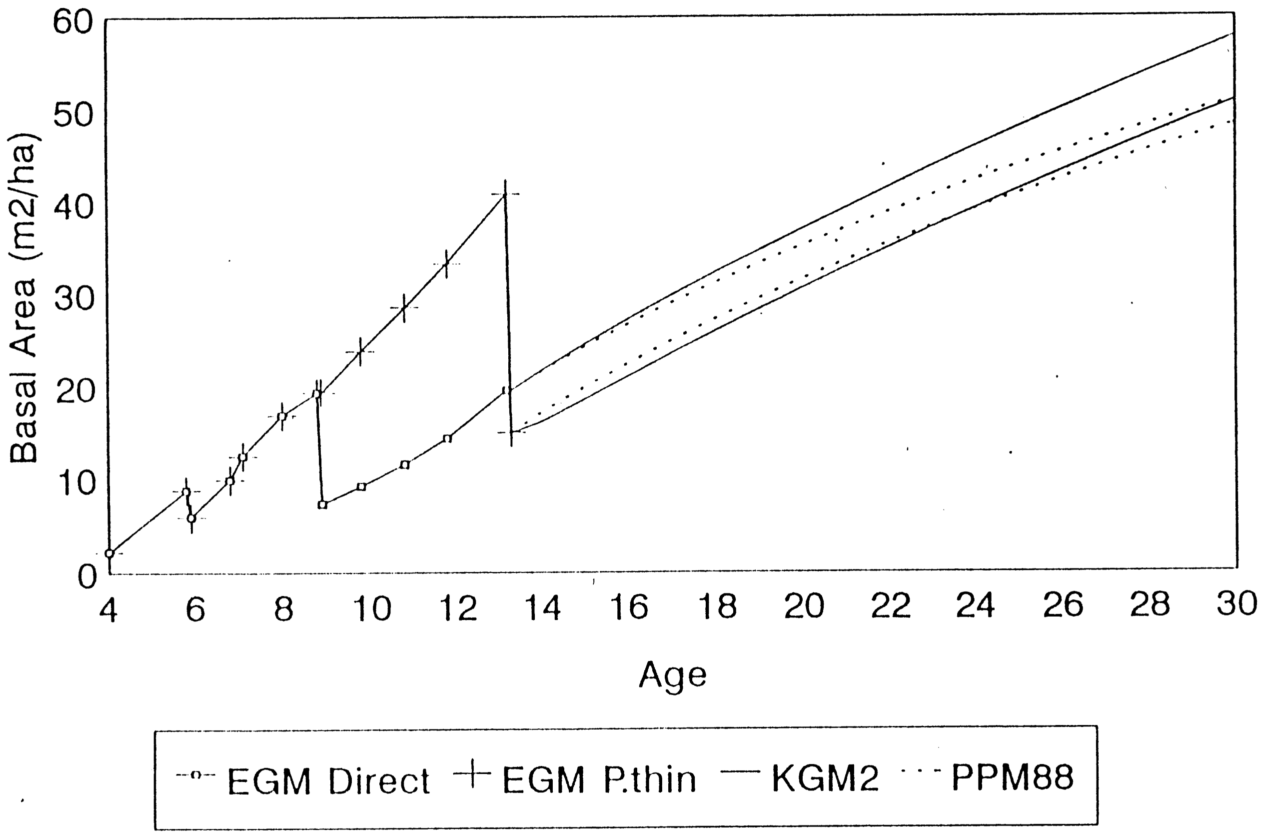


Figure 2

Regional predictions of basal area convergence and divergence from the time of thinning

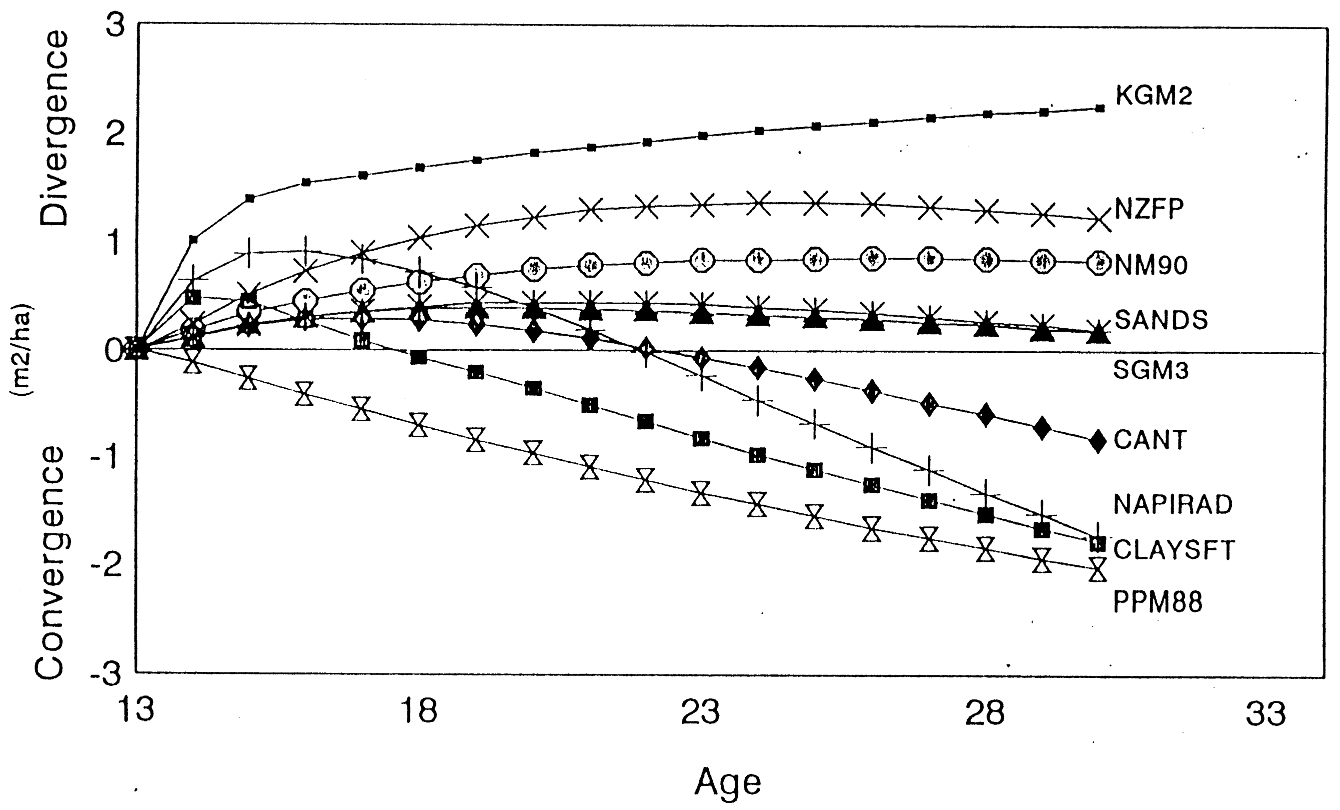
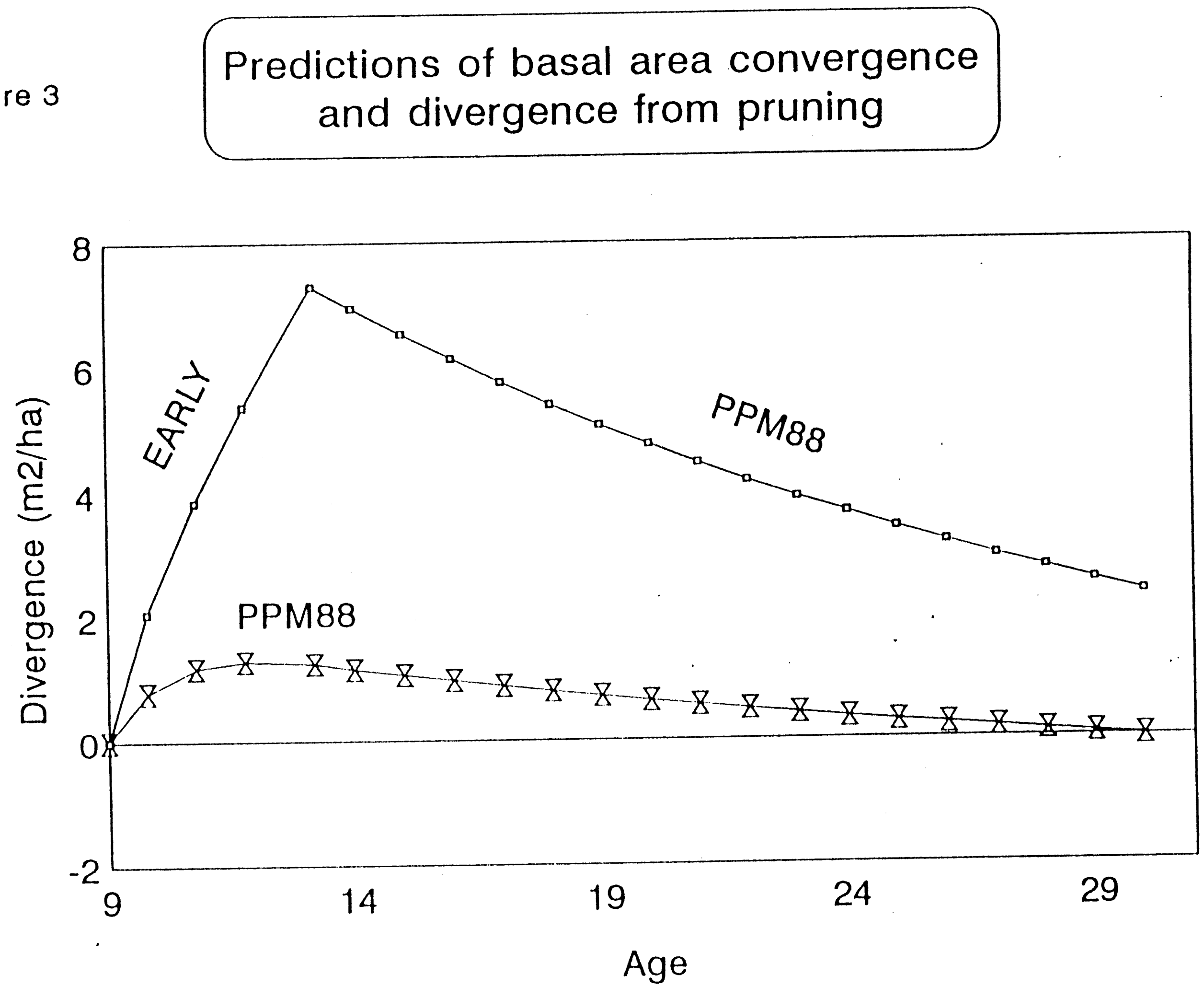


Figure 3



Predictions of basal area convergence
and divergence from pruning
Divergence (m2/ha)
8
6
4
2
0
-2
9
14
19
24
29
Age
EARLY
PPM88
PPM88

Fig. 4: Trends of Basal Area Convergence or Divergence due to Timing of Thinning

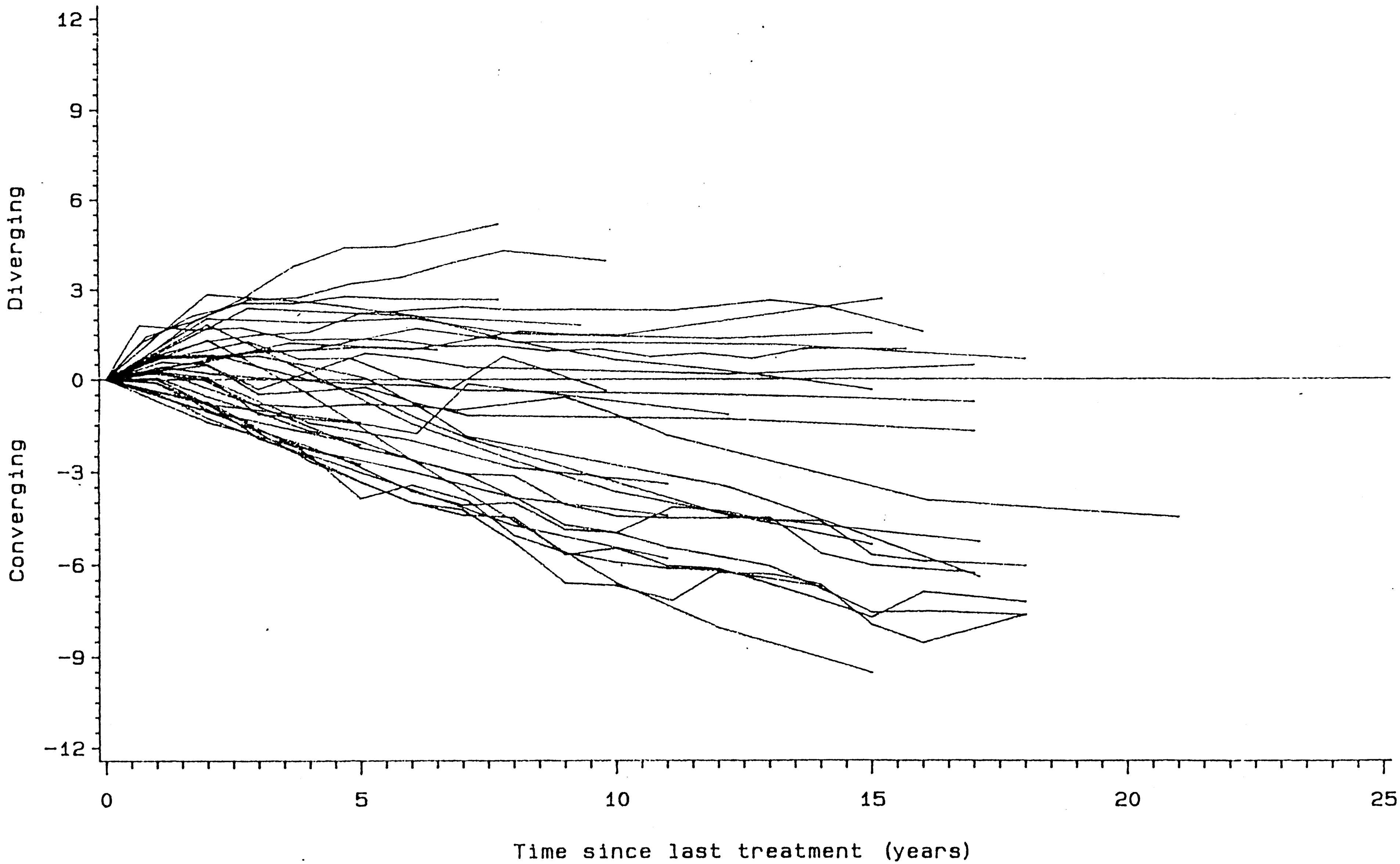


Fig. 5a: Rate of Divergence due to Timing of Thinning vs. Basal Area, for first 3 years

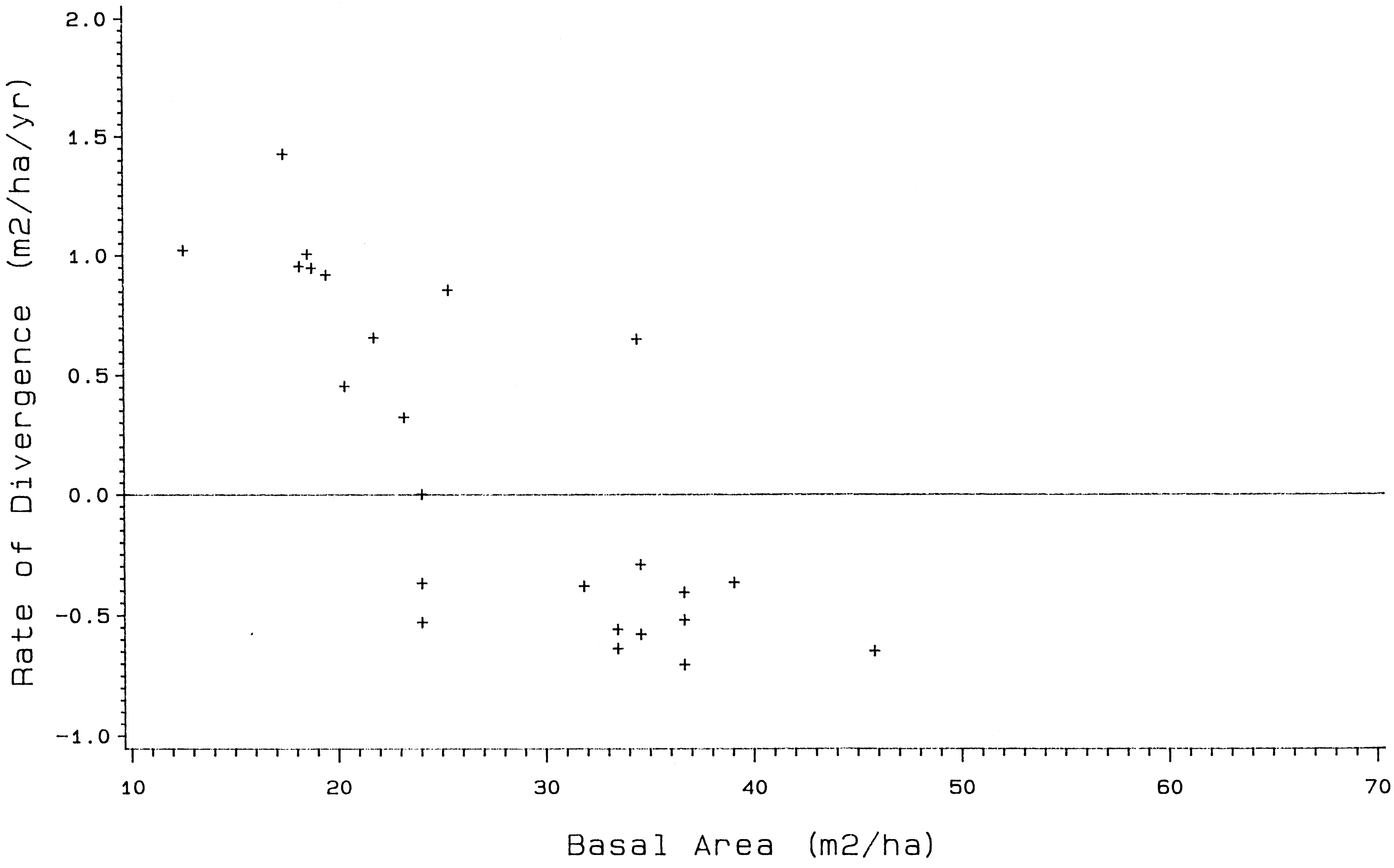


Fig. 5b: Rate of Divergence due to Timing of Thinning vs. Basal Area, after the first 3 years

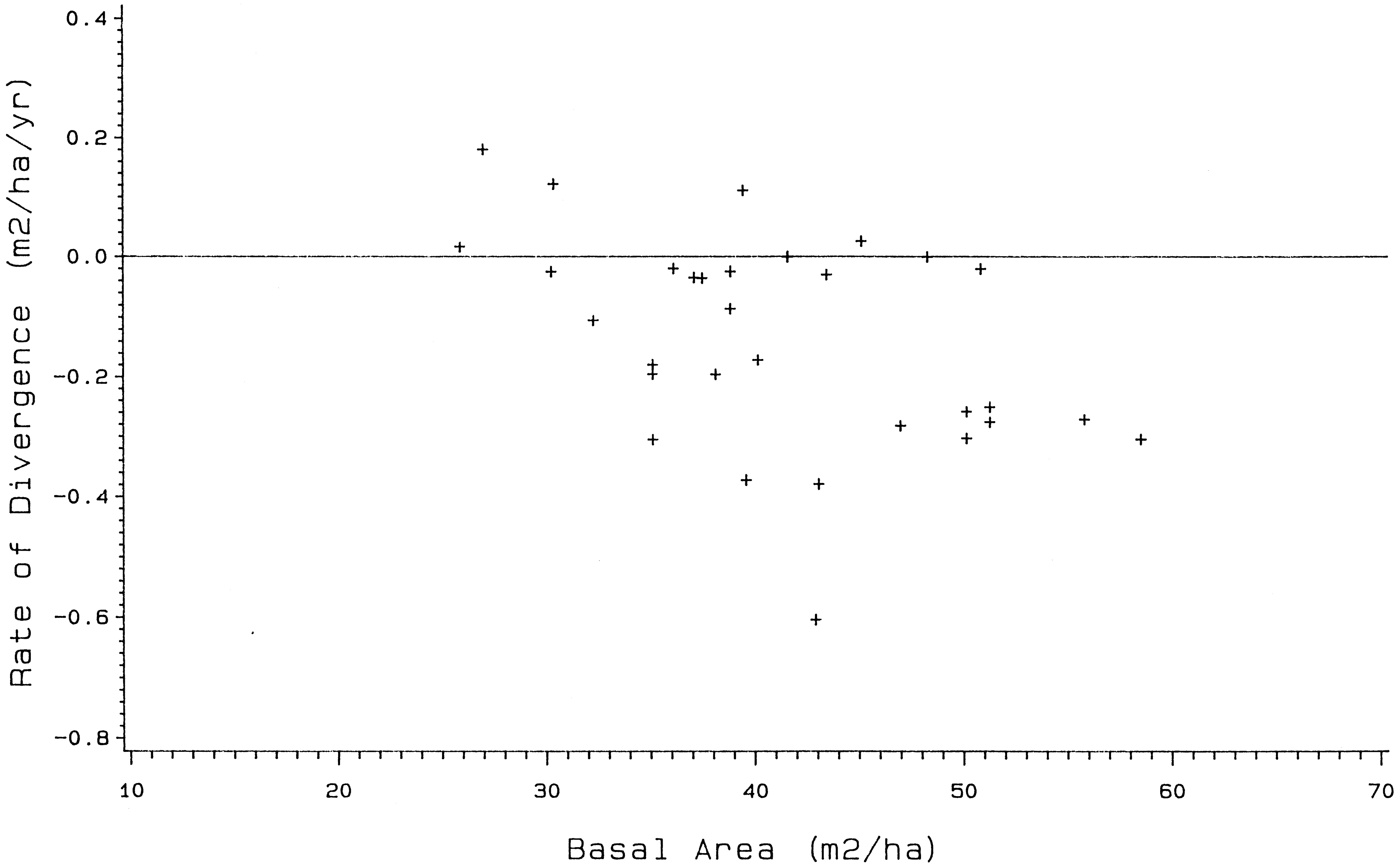


Fig. 6a: Rate of Divergence due to Timing of Thinning vs. Stocking, for first 3 years

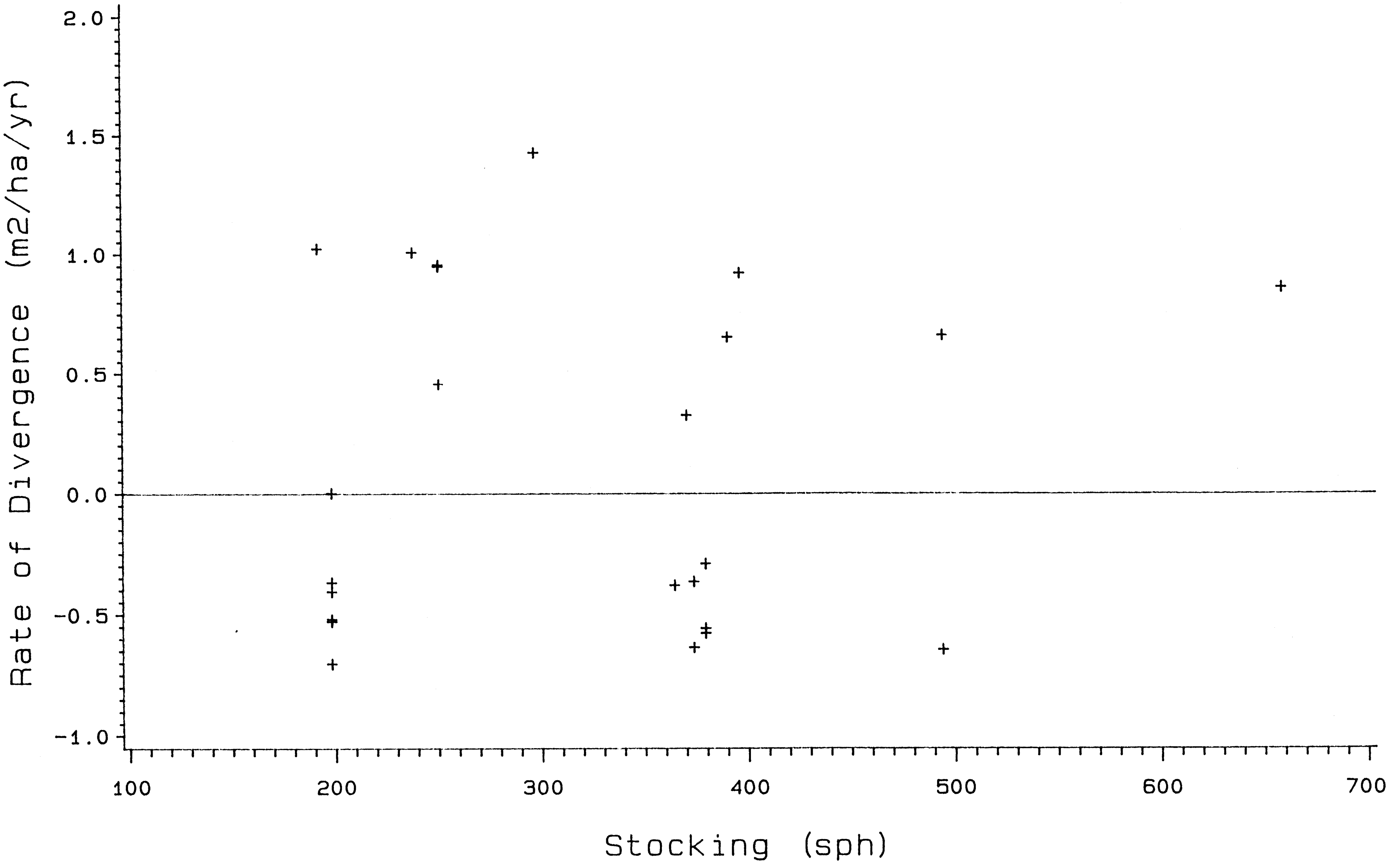


Fig. 6b: Rate of Divergence due to Timing of Thinning vs. Stocking, after the first 3 years

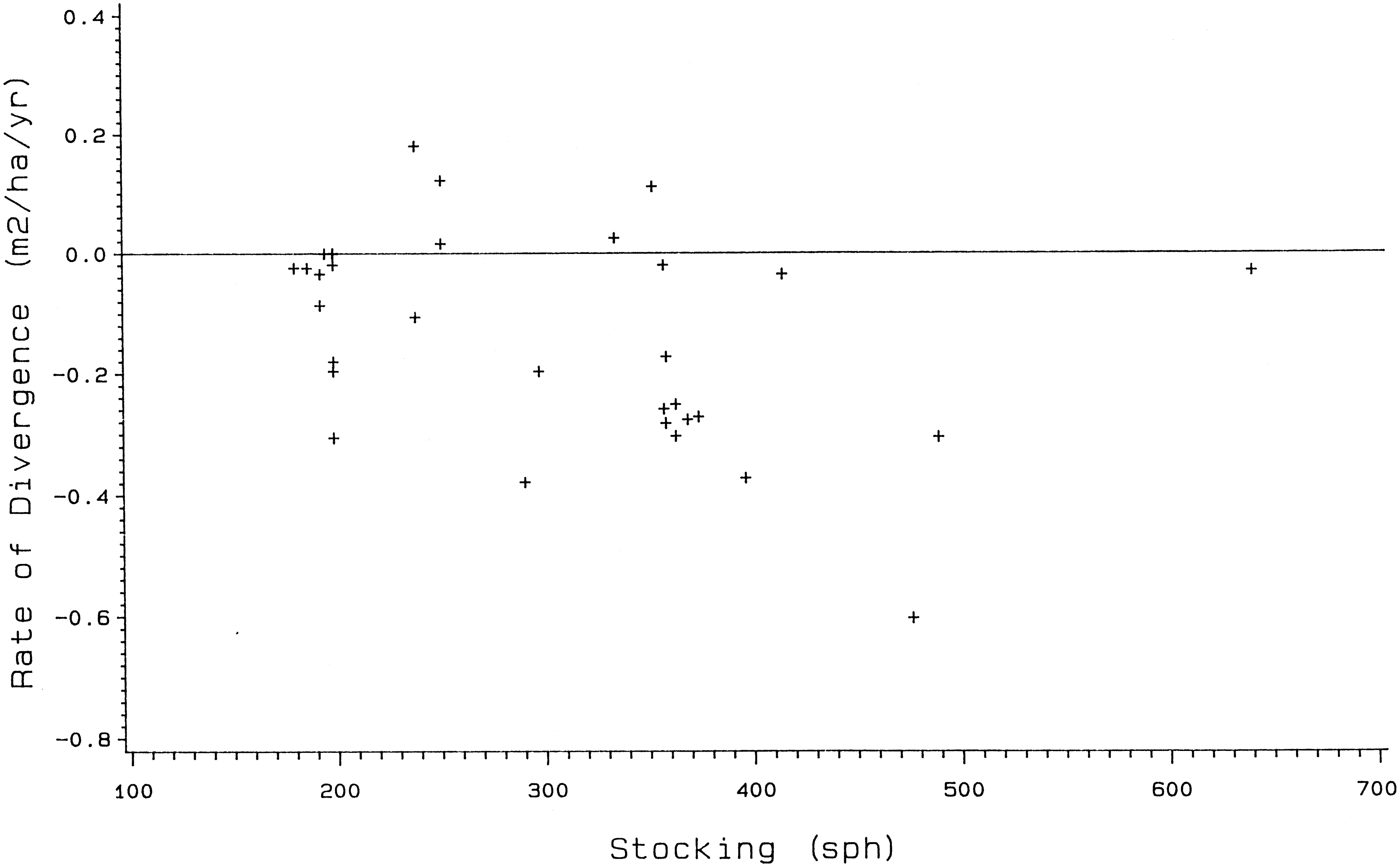


Fig. 7: Trends of Basal Area Convergence or Divergence due to Severity of Pruning

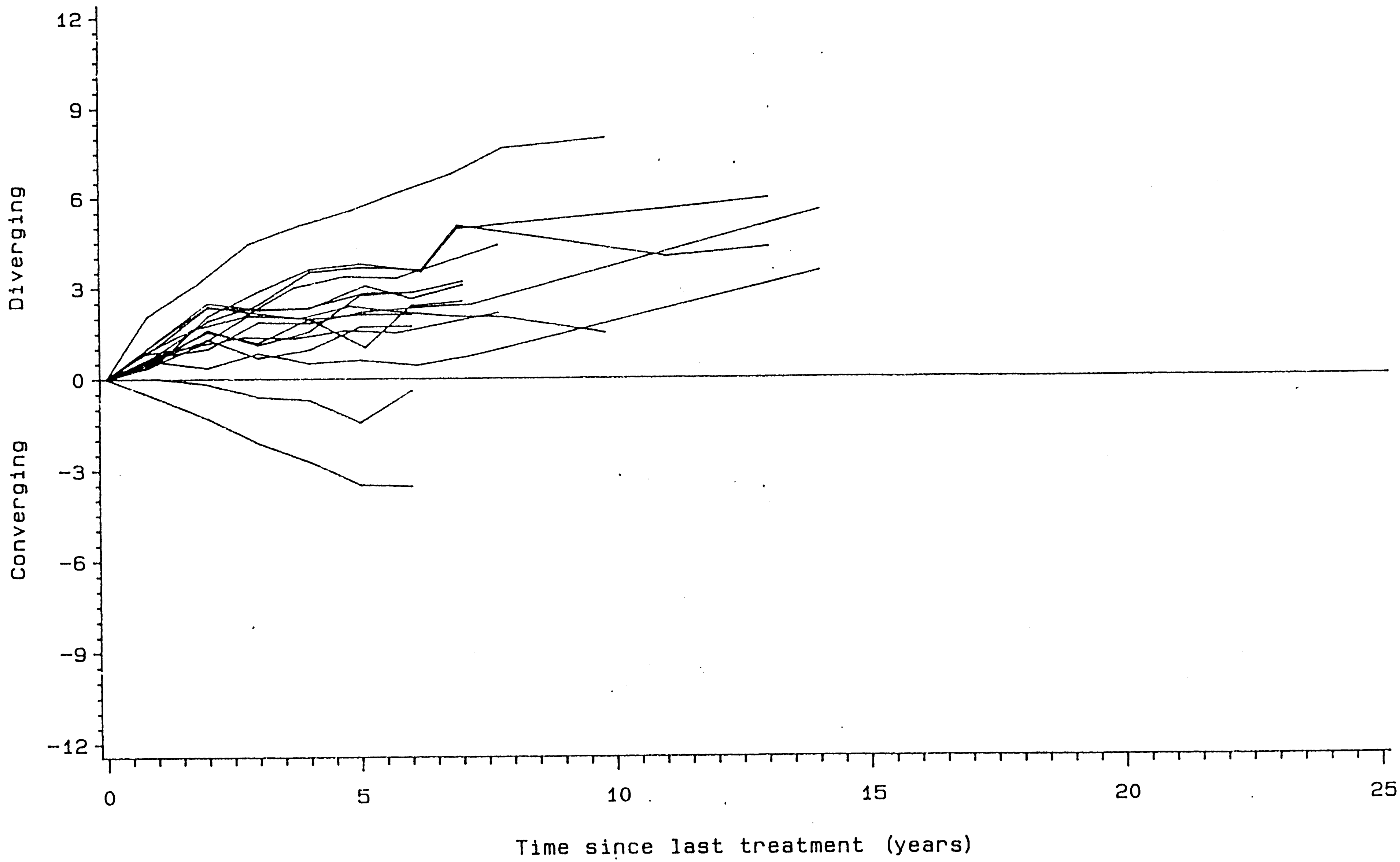


Fig. 8a: Rate of Divergence due to Pruning vs. Basal Area, for first 3 years

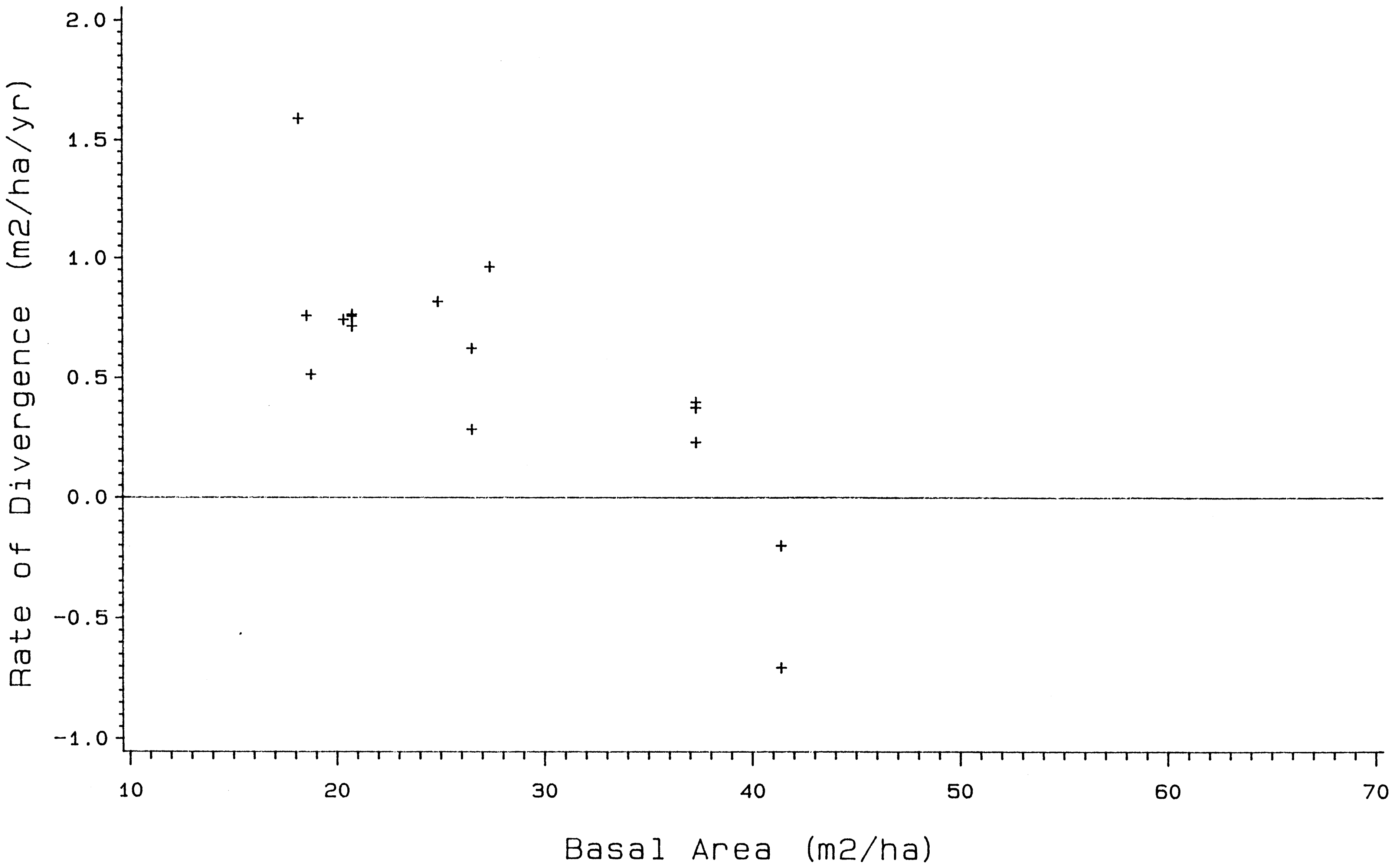


Fig. 8b: Rate of Divergence due to Pruning vs. Basal Area, after the first 3 years

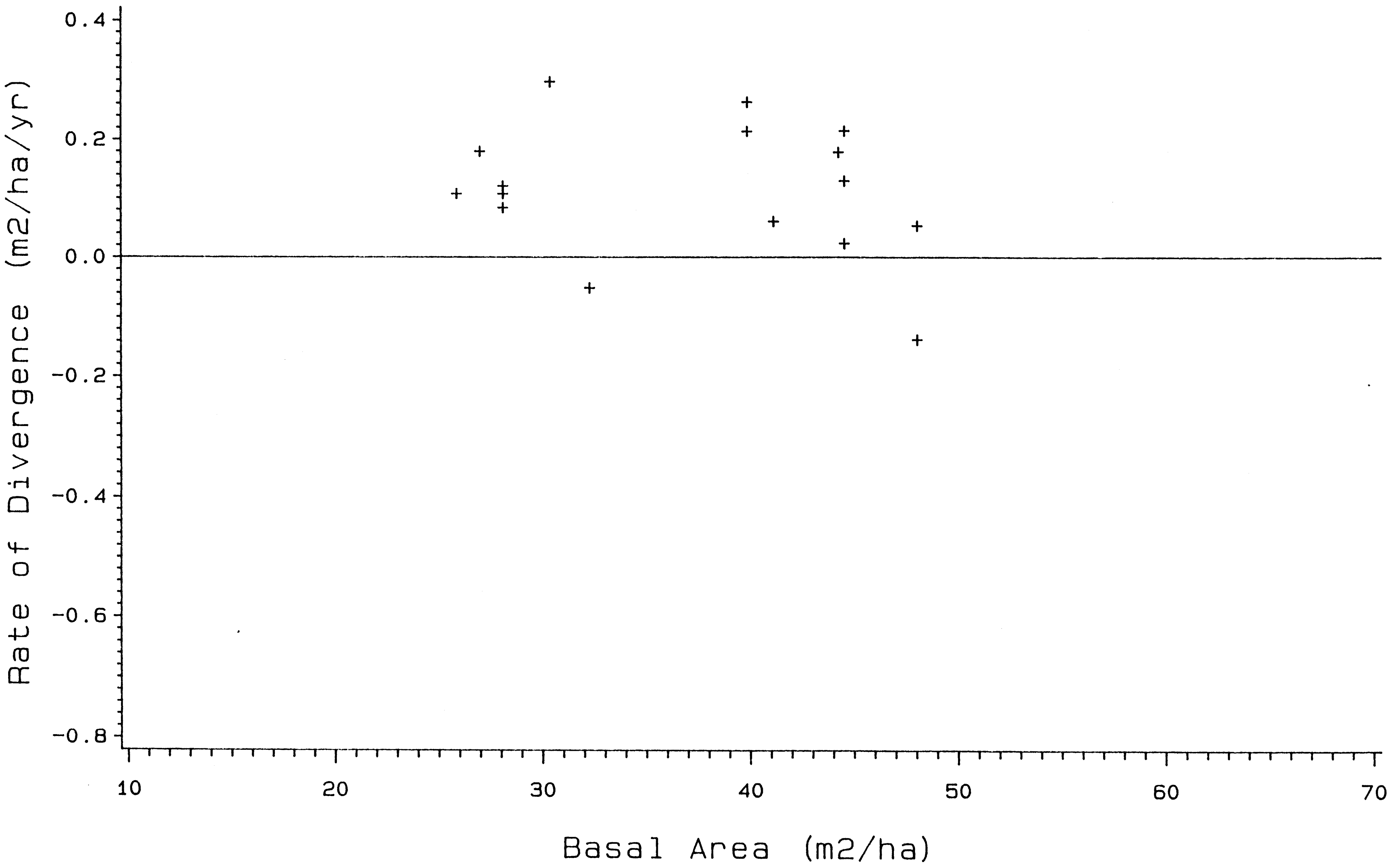


Fig. 9a: Rate of Divergence due to Pruning vs. Stocking, for first 3 years

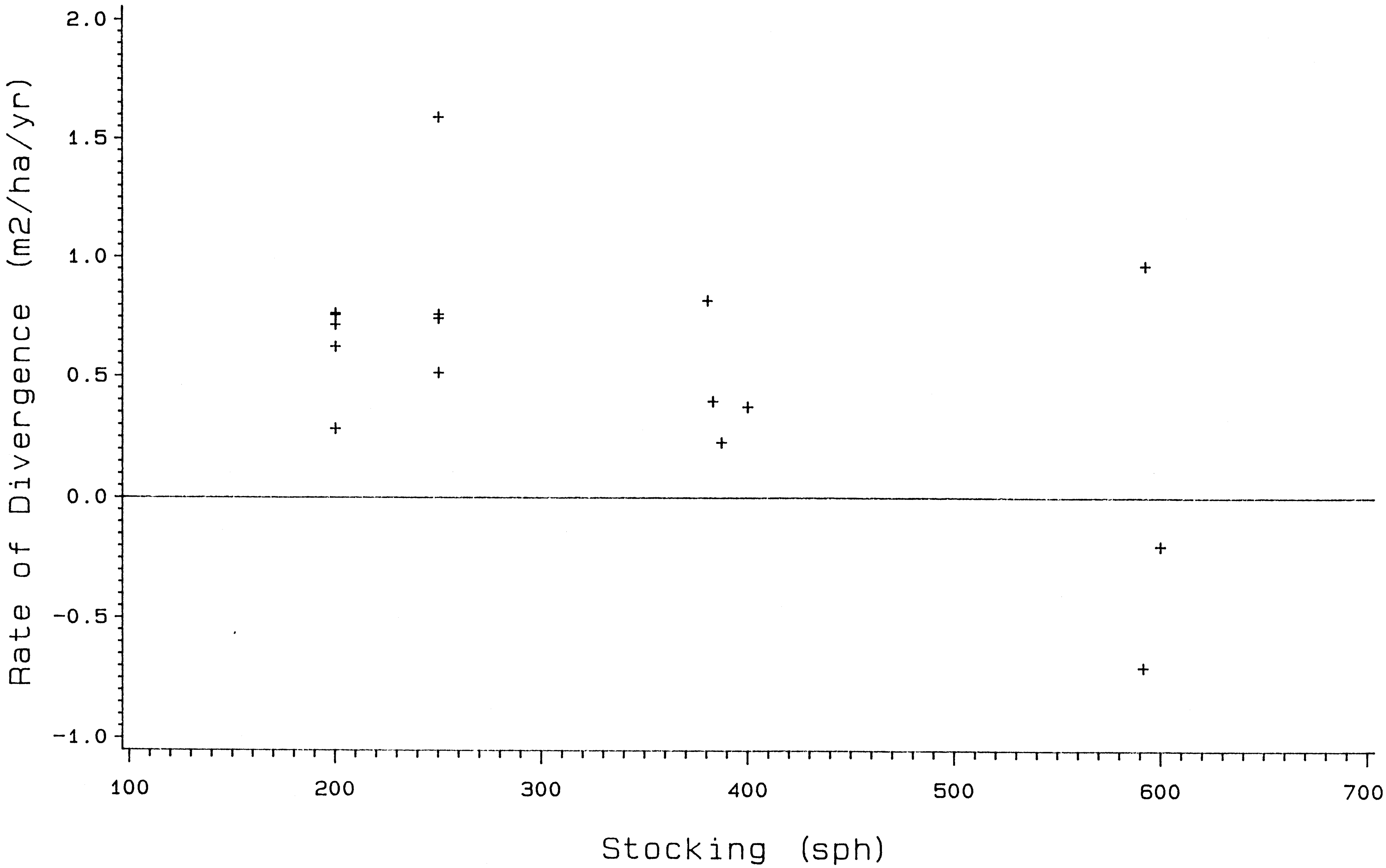


Fig. 9b: Rate of Divergence due to Pruning vs. Stocking, after the first 3 years

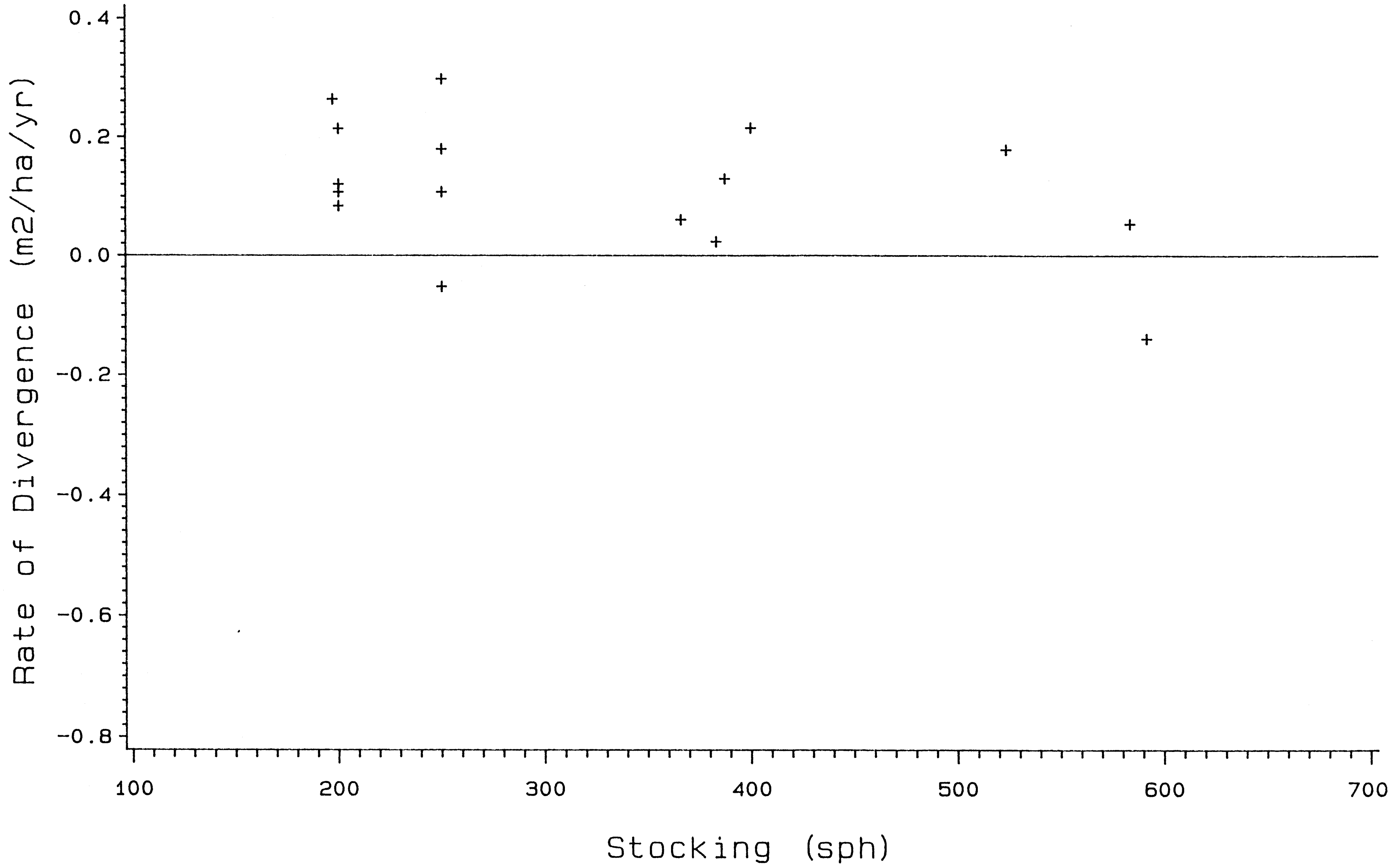


Figure 10

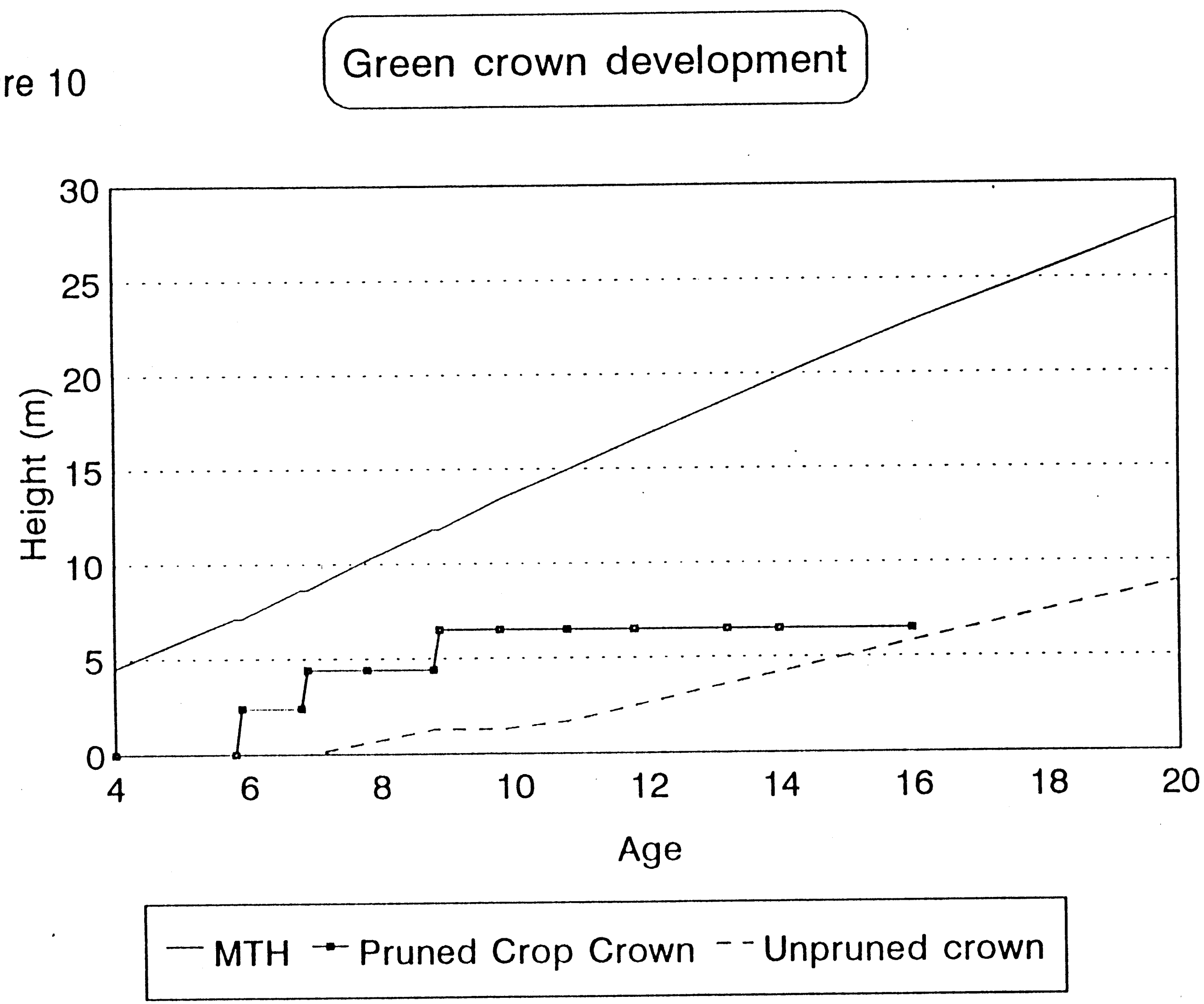

Green crown development
30
25
20
15
10
5
0
Height (m)
4
6
8
10
12
14
16
18
20
Age
MTH
Pruned Crop Crown
Unpruned crown

Fig. 11: Trends of Basal Area Convergence or Divergence due to Selection Ratio