FOREST DENSITY RESPONSE FOLLOWING WOODCHIPPING OPERATIONS IN SOUTH WESTERN AUSTRALIA

Paul Rose

Department of Conservation and Land Management,
Walpole,
W.A. 6398

and

Geoff Stoneman

Department of Conservation and Land Management,
Research Station,
Dwellingup,
W.A. 6213

June 1986

Summary

Woodchip operations in the southern jarrah-marri and karri forests were recognised as having the potential to adversely affect the water resources of the region. Measures of forest density, structure and composition were taken over an age series of stands in the low to intermediate rainfall jarrah-marri forest, intermediate to high rainfall jarrah-marri forest and intermediate to high rainfall karri forest in the Manjimup Woodchip Licence Area. Forest density was found to respond rapidly following logging, indicating that evapotranspiratiion is probably close to pre-logging levels within 5 years. The timing and magnitude of the forest density response is influenced only a little by rainfall zone. Salinity problems from woodchipping in the lower rainfall areas therefore appear unlikely. However the changes in forest density, structure and composition may result in reductions in streamflow in the longer term and this concern should be investigated. On the poorer drained site-types forest density is slower to respond and does not reach the same levels as the better site-types, and more intensive management of these areas may be required. Insect attack on the overstorey trees was found to reduce crown cover and this could have adverse hydrological effects. However, insect problems were much less in the young regrowth stands. A high component of marri and coppice was found in the young regrowth stands, but the contribution of these was small in the older stands. This combined with the higher proportion of sound trees in the regrowth stands means that wood production from the regrowth stands is likely to be greater than from the old growth stands they replaced.

Introduction

The hydrology of the forest of south Western Australia is unusual, the feature being that evapotranspiration dominates the water balance and consequently there is little streamflow from the moderate rainfall. This is particularly so in the northern jarrah (Eucalyptus marginata Donn ex Sm) forests, less so in the southern jarrah forest and less so again in the karri forest. The dominance of evapotranspiration is attributed to the very deep soil profiles and large soil water storage capacity which the overstorey trees, and particularly jarrah, are well adapted to exploit, as well as to the evaporative potential of the atmosphere (Shea et al. 1975; Doley 1967; Dell et al. 1983; Colquhoun et al. 1984). Superimposed over this is a climatic and landform gradient across the forest. From west to east across the forest rainfall falls from 1400mm to 700mm, evaporative potential increases, streamflow decreases, saltfall decreases, and the valleys become progressively less incised and the slopes more moderate (Shea et al. 1975; Hingston and Gailitis 1976; McArthur et al. 1977). In the higher rainfall area there is sufficient rainfall and steep enough topography to keep the soil leached of salt, however in the lower rainfall area this is not the case and virtually all rainfall is evapotranspired resulting in substantial accumulations of salt in the soil (Johnston et al. 1980; Johnston 1981; Stokes et al. 1980). In the lower rainfall area there is very real potential for the mobilization of this soil salt to cause massive pollution to streams if the water balance is disturbed. This has been well documented for the case following agricultural clearing (Peck and Hurle 1973; Peck 1983; Williamson et al. 1986).

Forest density has been shown quite conclusively to have a direct effect on the hydrological cycle of the forest (Hinckley et al. 1981). Forest density affects the hydrological cycle principally through the water loss processes of transpiration and evaporation i.e. evapotranspiration; which as previously mentioned dominates the water balance in forests of south Western Australia. Therefore these forests might be expected to be more sensitive than most to changes in forest density.

Hibbert (1967) reviewed a number of catchment studies and concluded that water yield was increased by reductions in crown cover, but the increased yield tended to decrease with time after logging as the forest regrew. The rate of this decline was principally dependent on the rate of growth of the forest. A more recent review by Bosch and Hewlett (1982) came to essentially the same conclusions, and they were prepared to predict the increase in water yield that would result from a given reduction in crown cover.

In the Victorian Eucalyptus regnans forests, increases in streamflow have also been shown to result following clearfalling. However, in this case the regrowth of the forest was so dense and water useage so great that very substantial reductions in streamflow resulted after several years and have continued for many years (Langford 1976, Kuczera 1985). Similar results of a reduction in streamflow from the conversion of the forest from oldgrowth to regrowth have also been found in the northern jarrah forest (Stoneman, unpublished results).

The Western Australian Woodchip Industry Environmental Impact Statement recognized the importance of the need to protect the water resources of the Manjimup Woodchip Licence Area (hereafter called the Licence Area) from the percieved salinity risk and other potential water quality problems. Detailed studies have consequently been undertaken, within selected experimental catchments in the Licence Area, in order to test the hydrological effect of woodchip logging operations. This includes the comparison of water and salt yields from cutover catchments to that from adjacent uncut control catchments in the different forest types and rainfall zones (Steering Committee 1980).

However, these studies presently only have relatively short term results. In order to predict broadscale long turn effects of woodchipping on water resources, the hydrological data needs to incorporate a quantitative understanding of forest density changes following logging. The primary aim of this project is to quantify changes in forest density, structure and composition following logging, as well as to identify factors which may affect these changes, and to discuss their hydrological significance. Secondary to this aim is that of identifying features of forest density, structure and composition which may have important silvicultural (and therefore hydrological) implications for future management.

Methods

Priorities

Existing evidence shows that jarrah-marri forest in the low rainfall zone (<900mm/yr), to the north east of Manjimup, has the greatest potential for salinity problems arising from heavy logging for woodchipping (Steering Committee 1980, Department of Agriculture 1974). Consequently this area of greatest concern was allocated highest priority for this study. Jarrah-marri areas in the intermediate rainfall zone (900-1100mm/yr) receive second priority ahead of karri in the intermediate rainfall zone mainly because this would help to build a more thorough understanding of the response of jarrah-marri forests. Lower priorities were allocated to high rainfall karri, thinned karri stands and selection cut jarrah-marri forest in the low rainfall zone.

Constraints

Time constraints restricted this study to the three highest priorities. Eight sites were sampled in each of two jarrah-marri forest rainfall zones. Because of lack of representative even-aged jarrah-marri areas, the sites fell within two general rainfall zone groupings (see Fig. 1), rather than strictly within the low and intermediate zones.

The aim was to sample a relatively even spread of regrowth ages within each zone to enable trends to be identified. The range of sample ages in the lower rainfall sites was however, less than optimum, with no sites between 9 and 45 years old. Furthermore the jarrah-marri regrowth stands sampled, contained varying amounts of retained old growth contributing to forest density.

It may therefore be misleading to extrapolate too much from these results. However, there are enough samples in the early regrowth years of mostly even-aged stands, to provide reasonable indication of initial response pattern after logging. Furthermore because of time limitations, only four karri sites (including 3 experimental catchments) were sampled. This data was supplemented with that from permanent increment plots within adjacent karri stands. Although derived differently, the two sets of data are combined to indicate general trends.

Site Selection

With the aid of aerial photographs and past logging records, sites were selected to provide a range of regrowth ages in each forest type and rainfall zone. The logged and control experimental catchments were included in each group of sample sites. The forest density results obtained can therefore be related directly to the available hydrological data. Further sample sites were selected to provide a spread of regrowth ages within each group.

The site areas averaged between 100 and 200 hectares, although two smaller 10 and 30ha areas (sites 4 & 10) were sampled. Plot data was obtained from 0.09, 0.16 and 0.25ha permanent increment plots in karri stands of similar rainfall.

Forest Density Measures

Leaf area is recognized as being the most fundamental measure of forest density, as it refers directly to the area of transpiring and photosynthesizing plant surfaces. However the method of measuring leaf area is presently both expensive and time consuming, and was not practically feasible in this study. Other measures of forest density (which thus relate to leaf area) were used, the three most important ones being:

(i) crown cover,
(ii) basal area, and
(iii) crown density.

Sampling

Systematic sampling was carried out in order to ensure a broad coverage of each site. It also allowed for more rapid and easier sampling which was of great practical importance in the study.

Investigation of aerial photography was undertaken to determine broad visual crown density patterns relating to forest type, soils or topography. Sample line transects were then located in order to gain a representative sample over the site. In even-aged regeneration, patterns were difficult to distinguish and stratification of the site into crown density classes was not undertaken. In the mature forest sites, where crown density patterns were apparent, sample lines were located proportionally within the crown density strata identified from aerial photos.

Crown Cover

Crown cover was assessed using a crownometer, an instrument which gives a vertical line of sight, similar to one described by Montana and Ezcurra (1980). Based on probability statistics, a maximum of 384 samples are required to be 95% confident that the error in estimating crown cover will be less than 0.05 (Walpole 1974). Therefore approximately 400 measurements of crown cover were made on each site in this study. Sample points were located at 10 metre intervals along line transects.

The use of the crownometer gives an accurate and consistent measure of planimetric crown cover. It is relatively easy to obtain in the field although problems arise with windy conditions. The measure takes no account of crown height or stand structure and is not sensitive to canopy density differences. The latter is especially relevant in stands which have extensive canopy thinning due to leaf degradation by insect attack.

Basal Area

Basal area was estimated using a wedge prism with a basal area factor of 2. The estimate was taken at every tenth crown cover sample point, i.e. at 100m intervals on line transects, therefore approximately 40 points were sampled on each site. The basal area increment of a stand is dependent on the photosynthesizing leaf area of that stand (Waring 1983), therefore estimates of stand basal area and basal area increment over time should give an indication of leaf area.

However, estimates of basal area increment derived from measurement of different aged stands on different sites, (as in this study) must be interpreted with some caution as site is also likely to influence basal area and basal area increment.

Crown Density

Sampling was the same as for basal area i.e. approximately 40 assessments per site. The estimates of crown density were obtained with a spherical densiometer (Lemmon 1956), the basis of which is a spherical mirror overlayed with a grid of 24 squares. Holding the instrument horizontally, at a constant height, the number of squares covered or uncovered by the canopy image from above is counted. This measure incorporates components of crown depth and height which are not incorperated in the crown cover measure with the crownometer, but are important determinants of a tree's leaf area (Whitford and Stoneman 1985).

Stocking

Total stocking of trees (> approximately 10cm dbh) was visually estimated at each of the basal area measurement points. The mean of these estimates represents an average stocking of the site.

Scrub

At each of the basal area sample points, scrub characteristics were recorded including visual assessment of:

(i) scrub type,

(ii) scub density, and

(iii) average scrub height.

Southern jarrah site types

At each basal area sample point, on the jarrah-marri sites, the site-type was assessed, based on the site-type classification being developed for the southern jarrah forest (Strelein pers. comm.). Site-types throughout the southern jarrah-marri can be broadly categorized into:

(i) Moisture gaining sites

(a) Soil types - sands, humus podzols and grey yellow podzols with no gravel, surface clays.

(b) Often (but not necessarily) low in profile or in depressions.

(c) Scrub - often T-tree (Agonis parviceps) predominates.
- Kingia spp and green kangaroo paw (Aginozanthus flavida) often present.

(ii) Free draining sites

(a) Soils - lateritic and gravelly podzols

(b) Mid and upper slopes, higher in profile

(c) Many associated species including Zamia, Bossiae spp and Acacia pulchella.

Such a broad and insensitive site-type classification was required for this study, to enable meaningful comparison of the widely varying sites and ready field identification.

This low intensity study did not warrant site-type identification on the karri sites. However, the karri permanent increment plots, from which forest density information was obtained, had a similar site index (age vs height) and geographical location as the March and April Road sites.

Crown Vigour

The crown condition and vigour of old growth and regrowth was visually assessed and classified. The cause of crown degradation was also recorded as well as the likely impact of crown damage on the growth of the stand.

Stand Structure

The basal area estimates at each point included the following stand structure information:

(i) species - including understorey >10cm dbh

(ii) structural classification of stems:

(a) stump coppice - from stumps 25cm diameter

(b) saplings - to 15cm dbh

(c) pole - 15 to 45cm dbh

(d) pile - 46 to 60cm dbh

(e) tree - 60 to 120cm dbh

(f) veteran - 120cm

(g) cull - severely damaged stem

(iii) old growth or regrowth

Stand structure information was also obtained from the crownometer observations which were assessed as to the height class intercept of the crownometer contact:

(i) 0 - 1 m

(ii) 1 - 5 m

(iii) 6 - 10 m

(iv) 11 - 25 m

(v) 26 + m

Results and Discussion

Forest Density Response

Low - intermediate rainfall jarrah-marri stands

Figure 2 indicates that crown cover responds rapidly after clearfelling. Within 3 to 5 years after logging, overstorey crown cover is up to 50%, representing approximately 75% of the original levels. Retained old growth accounted for around 10% of the crown cover on most sites. The estimation of time taken for crown cover to build up to original stand levels (i.e. approx 70%) is difficult because of gaps in the data, however the curve on figure 2 indicates that crown cover would be very close to pretreatment levels within 20 years. Crown density gives an alternative impression of crown changes with time (Figure 3). The crown density of regrowth stands approaches that of control stands within 20 years after logging.

The basal area results (Figure 4) show a basal area increment which is linear. Assuming that the efficiency of growth does not change with age, then this indicates that leaf area is constant with time after woodchipping. The basal area increment may have been expected to decrease with time once the regrowth has established itself, however, the data in figure 4 do not support this contention

However, the comparatively high basal area on the 61 year old site (Yornup) may not be representative of most sites in this rainfall zone.

The inclusion of scrub intercepts (Table 4) represents a measure of total vegetation cover, and within 3 years 80% of this total vegetative cover is replaced.

Intermediate to high rainfall jarrah-marri stands

Figure 5 illustrates that within the first year following logging, more than half of the original crown cover is replaced, although retained old growth makes up part of this. More than 75% of crown cover is replaced within 3 years, and within 15 years crown cover has recovered to original levels.

Similar trends are shown for crown density (Figure 6), with total recovery to original levels within approximately 15 years. The effect of retained old growth overstorey is reflected in the relatively high results gained from the one year old stand.

Figure 7 shows stand basal area to accumulate rapidly up to about 20 years of age after which a rapid decrease occurs. This is also refected in the basal area increment curves. These curves again suggest that the leaf area of the regroeth stands is of the same order as the old growth stands.

Total vegetative cover on these sites builds up to pre-logging levels within 3 years, with greater than 50% of cover replacement in the first year following logging (Table 5).

Intermediate rainfall karri stands

The general trend is of increasing crown cover following logging until pre-logging levels are attained within 40 years (Figure 8). Crown density responds quickly in the first three years after logging to build up to pre-logging levels in 10 years (Figure 9). This reflects the rapid height growth of karri scrub and regrowth in the early years. Basal area shows a similar trend, with basal area increment decreasing rapidly after approximately 20 years (Figure 10). The field measurements of total vegetation cover on the 3 year old sites confirm the importance of the scrub component in the initial replacement of vegetation cover on karri sites (Table 6).

The crown cover results from field sampling of regrowth karri sites tend to be greater than those derived from crown radius figures from the permanent increment plots (Figure 8). This may be due to inherent differences and bias between the two methods of crown cover estimation. Also high proportions of marri regrowth on the field sites contributed significantly to crown cover, and may account for the differences.

Comparison of forest density responses

Comparison of the crown cover of the lower rainfall jarrah-marri sites to the higher rainfall sites (Figure 11), shows little difference in the magnitude or timing of crown cover response. However, jarrah-marri stands in the higher rainfall zone generally tend to have more total vegetation cover resulting from the greater amounts of dense scrub. This scrub component, as well as the fact that stands are generally taller in the higher rainfall zone, contributes to the crown density being slightly higher in the higher rainfall sites (Figure 12). The karri sites show a slower crown cover response than do the jarrah-marri sites (Figure 11). This may be attributed to the form of regrowth karri crowns; they tend to be very narrow but deeper than jarrah and marri regrowth crowns. Crown density is greater and responds more rapidly after logging in karri than in jarrah-marri stands. This again reflects the greater height growth and deeper crowns on karri regrowth, as well as the rapid development of dense karri scrub.

Basal area increment is also greater in the karri stands than in the higher rainfall jarrah-marri stands, which are in turn higher than the lower rainfall stands (Figure 13).

The rapid responsefollowing logging of crown coverand crown density indicate that evapotranspiration quickly returns to close to pre-logging levels. The basal area and basal area increment curves also support this conclusion. It therefore appears unlikely that salinity problems would be generated by logging of this sort. Whilst it may be argued that quite small reductions in evapotranspiation can lead to stream salinization, these small reductions in evapotranspiation are associated with very large permanent reductions in forest density. For example, permanent clearing of 50% of a catchment in the low rainfall zone may only reduce evapotranspiration by 10% (Williamson et al. 1986).

Stocking

The visual estimates of stocking accounted for all stems greater than approximately 10cm dbh, rather than just dominant and codominant stems. Thus in older regrowth and mature stands, suppressed and regrowth stems were included, contributing to relatively higher stocking estimates than may be expected. The younger regrowth stands were characterized by wide ranges in stocking density.

Figure 14 indicates that where stocking was low (<1000 stems/ha) in young regrowth jarrah-marri stands, crown density was less than the average for the site. In older stands, as would be expected, crown density was not sensitive to stocking densities of below 1000 stems/ha. This relationship was not investigated in the karri sites because of lack of data.

Hence, it is important that young regrowth stands be well stocked (>1000 stems/ha), if canopy density is to recover rapidly after logging. The regrowth stocking following logging in jarrah-marri stands is dependant largely on,

(i) the original status of advance growth (a function of site type, scrub characteristics and past logging and burning influences), and

(ii) the magnitude and severity of logging disturbance.

Stand Structure

An impression of stand structure for each site was obtained by grouping crown cover hits into height classes. The changes in stand structure, brought about by logging, and in time after logging are represented in figure 15. These changes in stand structure affect the water balance of the site through their effect on:

(i) the absorption, reflectance and emittance of radiation,

(ii) the distribution of roots and leaves,

(iii) stomatal characteristics, and

(iv) aerodynamic roughness (Rutter 1968).

Crown Quality

Within the southern jarrah-marri forest, jarrah leafminer (Wallace 1970, Mazanec 1974, Abbott 1985) and jarrah leaf skeletonizer (Abbott 1985, Abbott 1986) have a devastating effect on the leaf area of jarrah trees, stands and catchments. Although the estimates of crown cover on a number of sites show up to 18% of dead crown cover (Tables 4 and 5), this is misleading in that only totally dead crown was so assessed. Neither measurement of crown cover or crown density is sensitive to leaf area reductions involving thinning or degradation of the canopy. Thus, the relatively high crown cover and crown density in stands with heavy insect attack, may not accurately reflect the relative leaf area at the time of measurement. However, the ephemeral nature of crown degradation by insect attack or heavy seeding and the insensitivity of the methods to pick this up means that the general trends of forest density with age are reliable.

These insect problems do however appear to be increasing in their distributionn and impact (Abbott 1985) and certainly have the potential to cause substancial reductions in stand leaf area over considerable periods of time. Thus there are potential impacts not only on the silvicultural aspects of forest management, but also on the hydrological aspects, these being particularly adverse in the lower rainfall, salt sensitive zone.

Tables 4 and 5 show that the dead crown cover is much less in the young regrowth stands than in the older and control stands. Woodchipping and regeneration of the forest is therefore associated with a reduction in the impact of insect attack.

Site-Type Effects

Figures 15, 16 and 17 illustrate how forest density was less on the poorer-drained site-types compared to the freely-drained type in both the higher and lower rainfall jarrah-marri forest. Of special interest is crown density which shows that not only is the crown density lower on the poorer-drained sites, but it is also slower to respond after logging (20yr+ to return to original levels compared to 10-15 years on freely-drained sites). The lower stocking and generally denser and taller scrub on the poorer-drained site-types means that crown density does not respond as quickly, or to as high levels.

In order to gain rapid canopy cover replacement after logging on the poorer-drained sites, measures to increase regeneration stocking and/or growth rate may need to be implemented. Such measures may include the retention of a standing seed source after logging, site and scrub manipulation to allow regeneration establishment, artificial seeding or planting, or fertilizer application to improve growth rates. The question would then arise as to whether the poorer *site-types should be cut at all, especially when they often contain only small volumes of utilizable resource with and the returns from the logging may be less than the cost of adequately regenerating and managing the stand.*

Logging Disturbance

Within the regrowth jarrah-marri stands, on a particular site-type, crown cover and crown density variations appeared to be due mainly to disturbance from snig tracks and landings. It was evident that logging disturbance had serious effects on stocking of regeneration on some winter-logged sites. Landings and snig tracks on clay soil types and moisture gaining sites were extensively damaged by heavy machinery activity in wet soil conditions. Reductions in regrowth stocking and crown responses are a refection of this, although we have no data to test these effects. It is important that recovery of snig tracks and landings be as rapid as possible on severely damaged sites and artificial rehabilitation is a necessity on these sites.

Other Silvicultural Aspects

Species composition of regrowth

Figure 18 and 19 show that whilst there is a great deal of variability in the species composition, particularly in the young stands, there is still a definite trend for the jarrah component of the stand to increase as the stand ages. The jarrah component moves *back toward the levels found in the control stands. The jarrah component probably increases as a result of jarrah's greater fire tolerance compared to marri, rather than jarrah having a faster growth rate or competitive ability. The high marri component of the young stands does not fulfill the silvicultural objective of woodchipping, but probably does fulfill a hydrologic objective in salt sensitive areas.*

In the older regrowth stands the jarrah component is higher, and these stems would generally have much greater potential for utilisation for higher value products than the old growth jarrah in the control stands. Therefore the silvicultural objective of increasing the productivity of the forest is probably being met in the longer term.

Schuster (1980) points out that the options for increasing the jarrah component of the stand include thinning and fire. Both of these may be able to achieve this objective but have potential drawbacks, thinning is likely to be non-commercial and very expensive, and fire is likely to induce damage to potential crop trees. These options should however be tested and costed, and their hydrologic impact assessed if they are considered potentially viable options. The high proportion of coppice and marri in these young stands and the problems of dealing with this is another example of the silvicultural problems which often result from past intensive treatment of stands (Stoneman 1986).

Stump coppice

Figures 20 and 21 show that the coppice component of the stand is very high in the early years but drops rapidly with time and is only a very minor component of the older stands. Schuster (1980) found that 8 years after the clearfelling of coupes, coppice had an effect on the growth of other forms of regeneration, and he postulated that this may increase in importance as the stand ages. Figures 20 and 21 show quite the opposite trend. However, the proportion of the resources of the stand going into coppice which is unlikely to ever be merchantable, is an opportunity cost as some of these resources could have gone into the growth of more silviculturally desirable forms of regeneration.

On the other hand, the rapid growth and dominance of coppice in the early years probably makes a large contribution to the evapotranspiration on these catchments and in salt sensitive areas this coppice serves a hydrologic purpose. In terms of the justification for woodchipping i.e. the conversion of a largely unproductive forest into a more productive forest (Bradshaw and Lush 1981), the dominance of coppice in the early years makes the achievement of this objective in the short term unlikely. In the longer term though, coppice does not hamper the fulfillment of this objective.

Recommendations For Future Research

Development of methods to estimate leaf area

This report has been largely concerned with predicting the leaf area of a number of forest stands, yet we have done so indirectly using other measures of forest density and assumed relationshiops between these and leaf area. It is obviously to difficult to estimate directly the particular parameter that is required. Methods to estimate leaf area need to be able to cope with a range of temporal and spatial scales. The leaf area of a tree changes markedly in very short periods of time, therefore the method needs to be able to predict both the actual leaf area at that time and the leaf area over the last "x" years (depending on the use these estimates are to be put). Methods are required that are able to predict the leaf area of individual trees, of stands and research catchments and of regional catchments. These methods are currently being developed in the northern jarrah forest (Whitford and Stoneman 1985, Mauger 1985), and this work needs to be extended to the southern forests and for each of the major tree species.

Water production from regrowth stands

Reductions in streamflow have been found in regrowth E. regnans forest in Victoria (Langford 1976, Kuczera 1985) and also in regrowth catchments in the northern jarrah forest (Stoneman, unpublished *data), and is a distinct possibility in the southern forests now being converted from oldgrowth to regrowth. These forests will be required for water supply purposes purposes in the future (Sadler and Field 1976, Western Australian Water Resources Council 1984) and these effects could have very significant implications for future water resources development.*

Studies to enable the optimization of both these (e.g. Ronan et al. 1982) and other forest values will be required as competition for these forest products becomes more intense. It is not necessarily the case that reductions in forest density at any stage in the life cycle of a stand will return the stand to the water production capacity of the old growth forest (Ronan et al. 1982).

Effects of changes in stand structure on the water balance

Changes in stand structure affect the water balance of a site through changes in:

i) *the energy balance,*
ii) *the distribution and quantity of roots and leaves,*
iii) *stomatal characteristics, and*
iv) *aerodynamic roughness.*

The relative effect of these changes requires investigation.

Costs and benefits of silviculturally treating young regrowth stands

The high component of marri and of coppice in these young stands is of concern. Thinning and/or fire may help in gaining a more desirable stand structure and composition, and these options should be tested and costed, and their hydrological implications assessed.

Forest desnity response in high rainfall karri and selection cut jarrah-marri stands

No work was done in this area in this project, yet these areas are of considerable significance both silviculturally and hydrologically. It is recommended that work in these areas should address changes in the more fundamental measures of forest density i.e. leaf area.

Acknowledgements

Financial support for this project was provided by the Steering Committee
We would also like to gratefully acknowledge support of the Manjimup Research Station of the Department of Conservation and Land Management and in particular Evonne Woods for data management and analysis, and for his technical assistance.

References

Abbott, I. (1985). Forest entomology research in Western Australia. Department of Conservation and Land Management, Technical Report No. 2.

Abbott, I. (1986).

Bosch, J.M. and Hewlett, J.D. (1982). A review of catchment experiments determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology, 55: pp 3-23.

Bradshaw, F.J. and Lush, A.R. (1981). Conservation of the karri forest. Forests Department of Western Australia.

Colquhoun, I.J.; Ridge, R.W.; Dell, D.T.; Loneragan, W.A. and Kuo, J. (1984). Comparative studies in selected species of eucalyptus used in rehabilitation of the northern jarrah forest of Western Australia. I. Pattern of xylem pressure potential and diffuse resistance of leaves. Aust. J. Bot. 32: pp 367-373.

Dell, B.; Bartle, J.R. and Tacey, W.H. (1983). Root occupation and root channels of jarrah forest subsoils. Aust. J. Bot. 31: pp 615-627.

Department of Agriculture, Western Australia. (1974). The influence of land use on stream salinity in the Manjimup area, Western Australia. Technical Bulletin No. 27.

Doley, D. (1967). Water relations of Eucalyptus marginata Sm. under natural conditions. J. Ecol. 55: pp 597-614.

Hibbert, A.R. (1967). Forest treatment effects on water yield. International Sympsium on Forest Hydrology. Sopper, W.E. and Lull, H.W. (Eds): pp 527-543.

Hingston, F.J. and Gailitis, V. (1976). The geographic variation of salt precipitated over Western Australia. Aust. J. Soil Res. 14: pp 319-335.

Hinckley, T.M. and Teskey, R.O. (1981). Temperate Hardwood Forests. In "Water Deficits and Plant Growth", Kozlowski, T.T. (Ed), Vol.6: pp 153-208.

Johnston, C.D. (1981). Salt content of soil profiles in bauxite mining areas of the Darling Range, Western Australia. CSIRO Land Resources Management Technical Paper No. 8.

Johnston, C.D.; McArthur, W.M. and Peck, A.J. (1980). Distribution of soluble salts in soils of the Manjimup Woodchip Licence Area, Western Australia. CSIRO Land Resources Management Technical Paper No. 5.

Kuczera, G. (1985). Prediction of water yield reductions following a bushfire in Ash-mixed species eucalypt forest. Melbourne and Metropolitan Board of Works, Report No. MMBW-W-0014.

Langford, K.J. (1976). Change in yield of water following a bushfire in a forest of Eucalyptus regnans. Journal of Hydrology, 29: 87–114.

Lemmon, P.E. (1956). A spherical densiometer for estimating forest overstorey density. Forest Science, 2(1): pp 314–320.

Mauger, G.W. (1986). LANDSAT evaluation of the impact of logging, burning and dieback in the jarrah forest of south Western Australia. 1986 National Environmental Engineers Conference.

Mazanec, Z. (1974). Influence of Jarrah lefminer on the growth of jarrah. Australian Forestry, 37(1): 32–42.

McArthur, W.M.; Churchward, H.M. and Hick, P.T. (1977). Landforms and soils of the Murray River catchment area of Western Australia. CSIRO Division of Land Resources Management. Land Resources Management Series No. 3.

Montana, C. and Ezcurra, E. (1980). A simple instrument for quick measurement of crown projections. J. For. 78(10): pp 699.

Peck, A.J. (1983). Response of groundwaters to clearing in Western Australia. International Conference on Groundwater and Man, Sydney. Vol. 2: pp 327–335.

Peck, A.J. and Hurle, D.H. (1973). Chloride blance of some farmed and forested catchments in southwestern Australia. Water Resources Research, 9(3): pp 648-657.

Ronan, N.M.; Langford, K.J. and O'Shaughnessy, P.J. (1982). Simulation of the long-term hydrological effects of different approaches to timber harvesting in a large forested catchment. First National Symposium on Forest Hydrology: 139-144.

Rutter, A.J. (1968). Water consumption by forests. Water Deficits and Plant Growth. Vol. II. Plant Water Consumption and Response. Kozlowski, T.T. (Ed) p 23-84.

Sadler, B.S. and Field, C.A.R. (1976). Population and water needs. Groundwater Resources of the Swan Coastal Plain. Carbon (Ed): 37-60.

Schuster, C.J. (1980). Regeneration in a jarrah (Eucalyptus marginata Sm.) and marri (E. calophylla R.Br.) forest following logging and burning. Forests Department of Western Australia, Research Paper No. 64.

Shea, S.R.; Hatch, A.B.; Havel, J.J. and Ritson, P. (1975). The effect of changes in forest structure and composition on water quality and yield from the northern jarrah forest. Managing Terrestrial Ecosystems. Kikkawa, J.; Nix, H.A. (Eds). Proc. Ecol. Soc. Aust. 9: pp 58-73.

Steering Committee (1980). Research into the effects of the woodchip industry on water resources in southwestern Australia. Department of Conservation and Environment, Bulletin No. 81.

Stokes, R.A.; Stone, K.A. and Loh, I.C. (1980). Summary of soil storage characteristics in the northern Darling Range. Water Resources Branch, Public Works Dept. Western Australia, Technical Report No. WRB 94.

Stoneman, G.L. (1986). Utilising thinnings from the northern jarrah forest. Ausralian Forestry

Wallace, M.M.H. (1970). The biology of the Jarrah leafminer, Perthida glyploda Common (Lepidoptera Incurvariidae). Australian Journal of Zoology, 18: 91-104.

Walpole, R.E. (1974). Introduction to statistics. 2nd Edition. MacMillan, New York.

Waring, R.H. (1983). Estimating forest growth and efficiency in relation to canopy leaf area. Advances in Ecological Research, Vol. 13. Macfadyen, A. and Ford, E.D. (Eds): pp 327-354.

Western Australian Water Resources Council (1984). Water resources and water needs.

Whitford, K. and Stoneman, G.L. (1986). Leaf area measurement studies. Bauxite Hydrology Update No. 3: pp 5-8. Water Authority of Western Australia. Schofield, N.J. (Ed).

Williamson, D.R.; Stokes, R.A. and Ruprecht, J.K. (1986). Response of catchment water and chloride to experimental clearing for agriculture near Collie, Western Australia. Symposium on Catchment Salinity, Perth, 16-18 April. CSIRO Division of Groundwater Research.

no page 34

SITE NO.	LOCATION ~~BLOCK~~ + ~~COMPARTMENT~~	AREA (HA)	FOREST TYPE	RAINFALL (MM)	TIME SINCE LOGGING (YRS)	SOIL TYPE
1.	MOORALUP 2 (Logged + Catchment)	200.	Jarrah-Marri	890.	9.	laterites + yellow podzols clays.
2.	Warrup 2 (Yerraminup South).	160.	Jarrah Marri	850.	3.	laterites + yellow podzols.
3.	Yeticup 7.	120.	Jarrah Marri	900	4	Laterite, yellow podzols, Clays.
4	Cardac 3.	30	Jarrah Marri	950.	6.	laterite Yellow podzols.
5.	Yardup 1	160.	Jarrah Marri	900.	46.	laterites. Yellow podzols.
6.	Warrup 1. Yerraminup North. (Control).	200.	Jarrah Marri	850.	Control.	laterites. Yellow podzols.
7.	Mooralup 2 (Control)	200	Jarrah Marri	890.	Control.	laterites. yellow podzols.
8.	Yornup 3.	180.	Jarrah Marri	920.	61.	laterites. Yellow podzols.
9.	Cardac 4.	140	Jarrah Marri	1000	4.	laterites. Yellow podzols.

TABLE 2 GROUP O SITES HIGHER RAINFALL JARRAH-MARRI

Site No	LOCATION ~~BLOCK~~ ~~COMPARTMENT~~	AREA (HA)	FOREST TYPE	Rainfall (mm)	Time since logging (yrs)	SOIL TYPE
10	Lewin Plot.	10	J-M	1220.	16.	Podzols, surface clays.
11	Lewin 4. ~~[illegible]~~ (South) Logged catchment	100.	J-M.	1220.	3.	Laterites, podzols. surface clays.
2	Lewin 4. (North) CONTROL	150.	J-M.	1220	Control.	laterites red earths. podzols,
3.	Iffley 2.	200.	J.M.	1200.	1.	laterites red earths. podzols.
4.	Lewin 5.	250.	J-M.	1230.	5.	laterites. podzols. surface clays.
5.	Iffley 9 Logged catchment.	150.	J-M	1220.	9.	yellow podzols. red earths. surface clays.
6.	Wheatley 4	100	J-M.	1150.	50.	Laterite. Yellow podzols.
17.	Mack 1.	150	J-M.	1130.	26.	laterites red earths. Yellow podzols.

TABLE 13.

GROUP C. SITES INTERMEDIATE RAINFALL KARRI.

Site No	LOCATION	AREA (ha)	FOREST TYPE	Rainfall (mm)	Age (yr)	Soils
18.	Sutton (April Rd North)	100	Karri, Marri some Jarrah.	1150 -1250.	3	Podzols Red Earths
19.	Sutton (April Rd Sth) CONTROL	200.	Karri, Marri + Jarrah.		CONTROL	Podzols, Red Earths
20	Sutton (MARCH RD.)	200	Karri, Marri some Jarrah.		3	Podzols, Red Earths
21	Sutton II	70	Karri, Marri.		1	Podzols, Red Earths

(Details of karri plots required)

5

TABLE ~~3.2~~ FOREST DENSITY RESULTS – GROUP B – HIGHER RAINFALL JARRAH/MARRI

CHP2.

E.	AGE.	AVERAGE HEIGHT (m)	TOCC.	CROWN COVER %. REGROWTH CC.	DEAD CROWN	SCRUB ONLY	CROWN DENSITY INDEX	BASAL AREA m²/ha. TOTAL BA	REGROWTH	SPECIES BA m²/ha. J. REG.	M REG.	TOCC – REGROWTH CC	TBA – RBA
)	16	10	67	60	3.6	13.2	14.2	27.1	22.6	11.2	11.4		
ENT	3	2	55	44	0.9	21.8	4.1	9.0	2.2	1.3	0.9	11	6.8
ENT CONTROL	CONTROL	40	67	N/A	7.3	23.3	16.3	44.4	N/A	28.1	16.3.		
)	1	0.6	42	26	1.2	11.7	6.1	11.7	—	—	—	16	
-	5	3.0	52	42	0.5	26.0	8.0	12.3	5.4	2.3.	3.1	10	6.9
ATCHMENT -	9	7.5	59	49	1.6	28.8	11.7	19.0	11.0	3.5	7.5	10	8.0
)	50	25	70	53	10.8	18.2	17.4	40.5	29.4	18.9	10.5.		
7	26	18	63	44	9.6	20.0	16.7	40.2	24.8	12.8	12.0		
)	0	0	12	0			0	7.2	0			TCC 12	7.2

Tab 4 many?

...LE 33. FOREST DENSITY RESULTS GROUP C. INTERMEDIATE RAINFALL KARRI

CHIP3.DAT

PLOT	Age	CROWN COVER% TREE	CROWN COVER% SCRUB ONLY	BASAL AREA m²/ha	CROWN DENSITY INDEX
18	3	38	49	1.2	7.0
19	CONTROL	64	26	41.2	20.1
20	3	31	60	1.4	5.8
21	1	5	22	0	0.1
866	4	11 } 8	N/A	1.7	N/A
867	4	6 }		0.2	
868	9	30 } 29		23.8	
869	9	28 }		14.3	
950	17	56 } 43		27.0	
951	17	30 }		16.0	
980	38	65 } 64		38.0	
982	40	62 }		36.0	
959	44	69 } 59		39.0	
960	44	49 }		32.0	
884	56	46		43.6	
840	59	67 } 64		32.2	
839	59	61 }		34.0	
886	62	52 } 75		38.5	
887	62	98 }		41.5	
Field	64	N/A	N/A	41.6	23.8
...ervations	44	N/A	N/A	32.4	22.8
"	17	N/A	N/A	31.0	22.2
	8	N/A	N/A	14.0	18.0
>	0	0		0	0

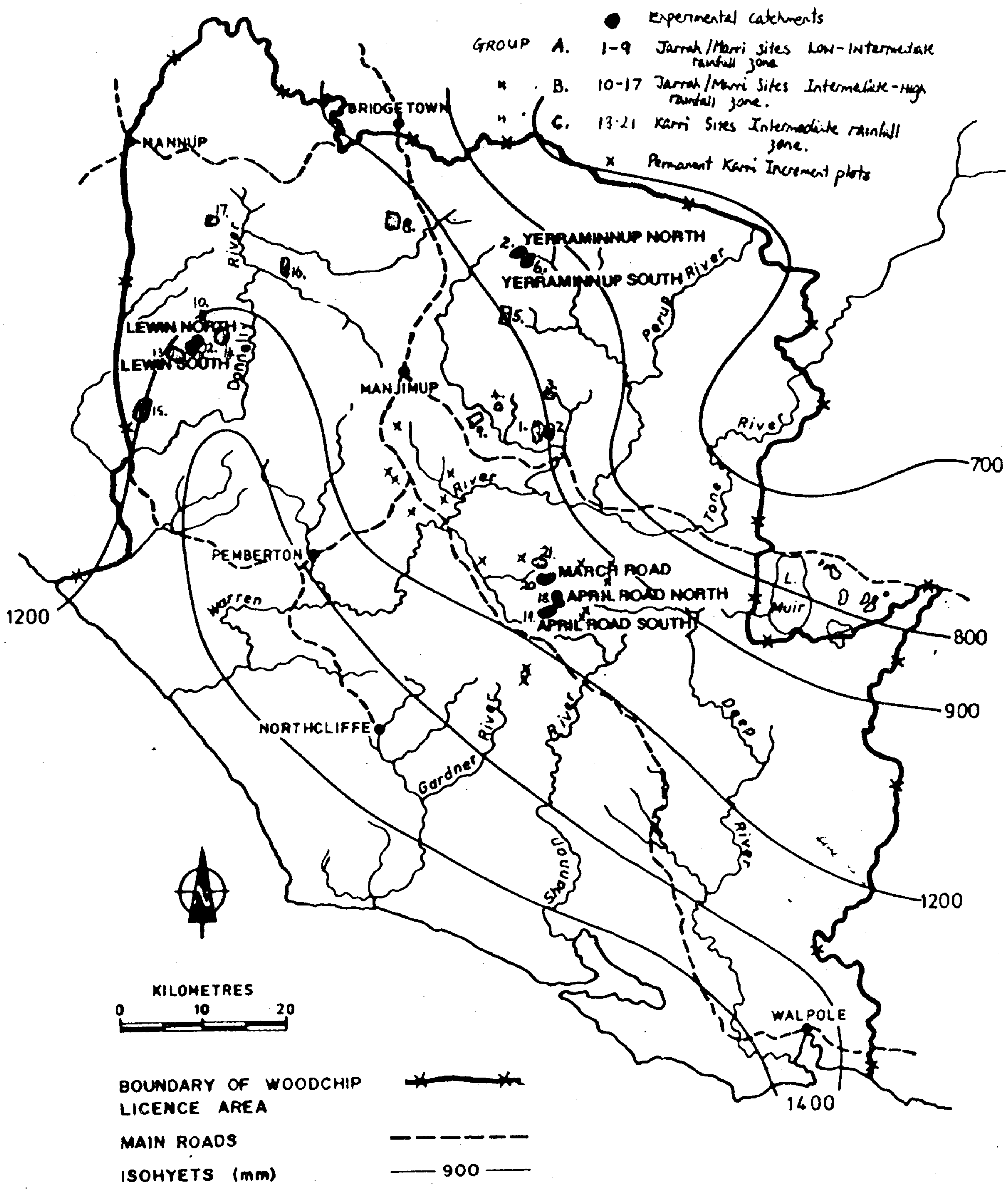

Experimental catchments
GROUP A. 1-9 Jarrah/Marri sites Low-Intermediate rainfall zone
" B. 10-17 Jarrah/Marri sites Intermediate-High rainfall zone.
" C. 13-21 Karri sites Intermediate rainfall zone.
x Permanent Karri Increment plots
BRIDGETOWN
NANNUP
YERRAMINNUP NORTH
YERRAMINNUP SOUTH
LEWIN NORTH
LEWIN SOUTH
MANJIMUP
PEMBERTON
MARCH ROAD
APRIL ROAD NORTH
APRIL ROAD SOUTH
NORTHCLIFFE
WALPOLE
Donnelly River
Warren River
Perup River
Tone River
Deep River
Gardner River
Shannon River
L. Muir
700
800
900
1200
1400
KILOMETRES
0 10 20
BOUNDARY OF WOODCHIP LICENCE AREA
MAIN ROADS
ISOHYETS (mm)
900

Fig 2 CROWN COVER vs AGE - GROUP A SITES. - LOWER RAINFALL JARRAH/MARRI.

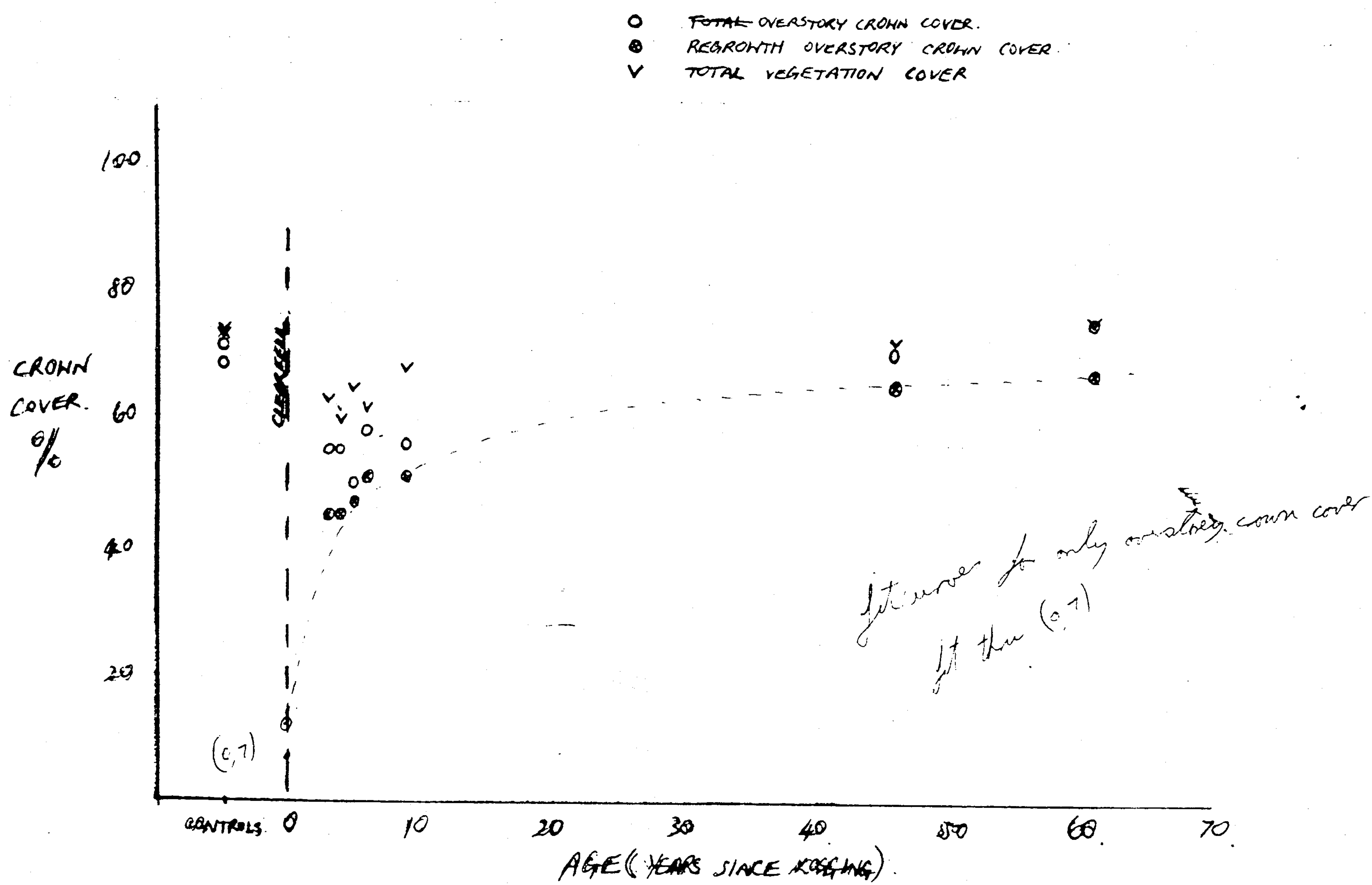


Fig 3 ~~index~~ Crown Density vs age Group A sites

Lower rainfall Jarrah/Marri

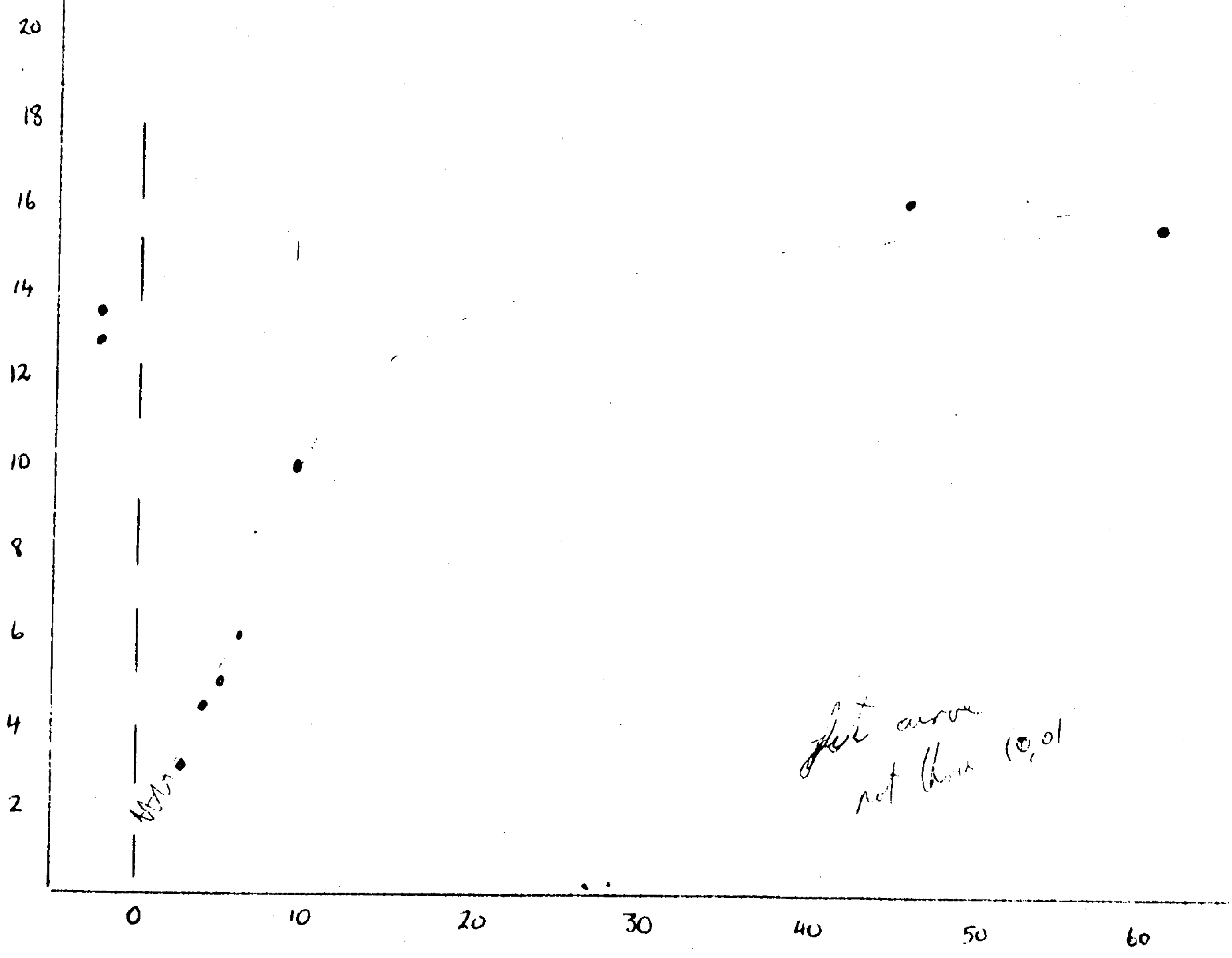


Fig 4

Regrowth Basal Area vs Age. Group A sites - Lower rainfall Jarrah/Marri

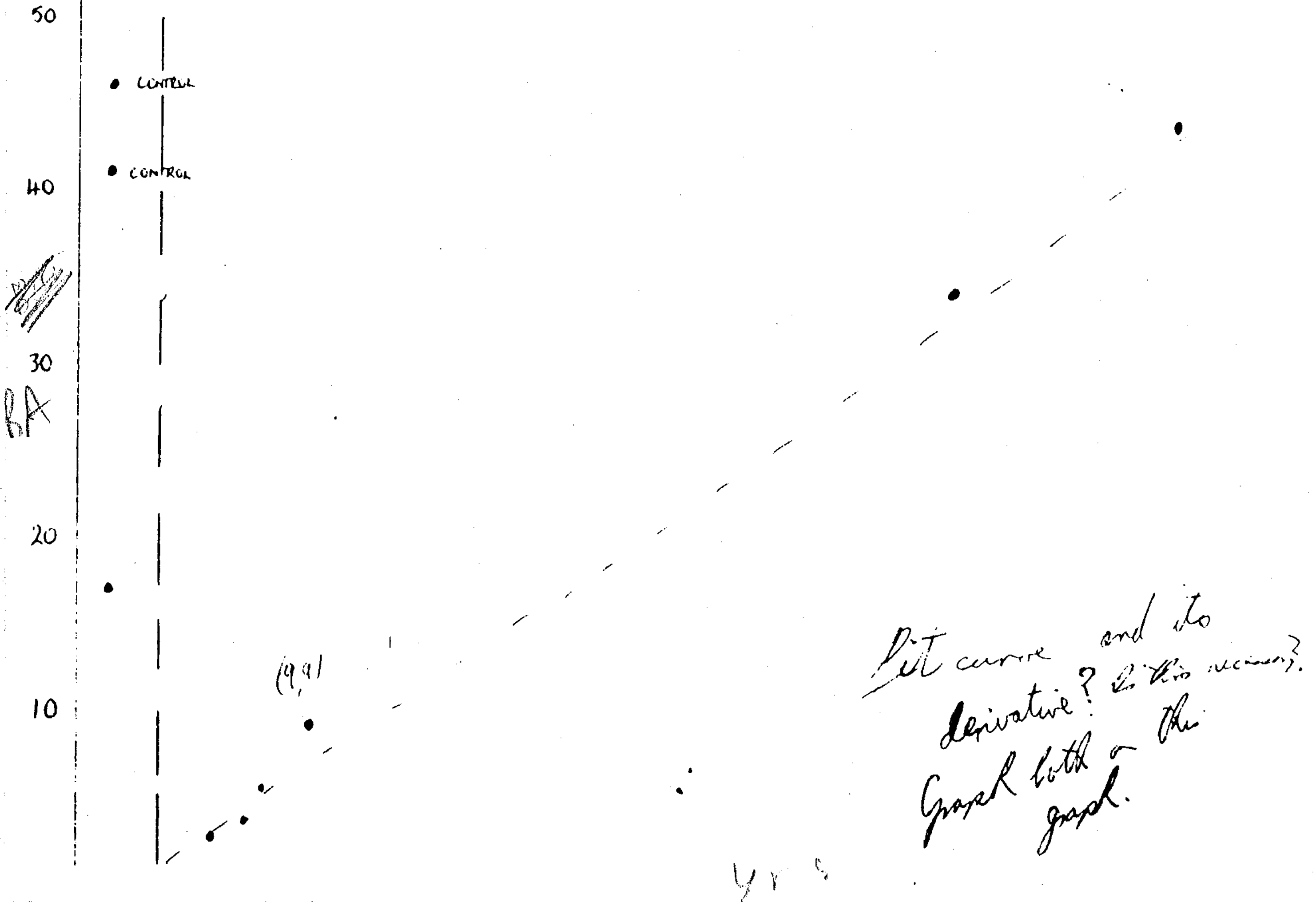


FIG ~~3-4~~ CROWN COVER Vs AGE - GROUP B SITES - HIGHER RAINFALL JARRAH/MARRI

- ○ TOTAL OVERSTORY CROWN COVER
- ● REGROWTH OVERSTORY CROWN COVER
- V TOTAL VEGETATION COVER

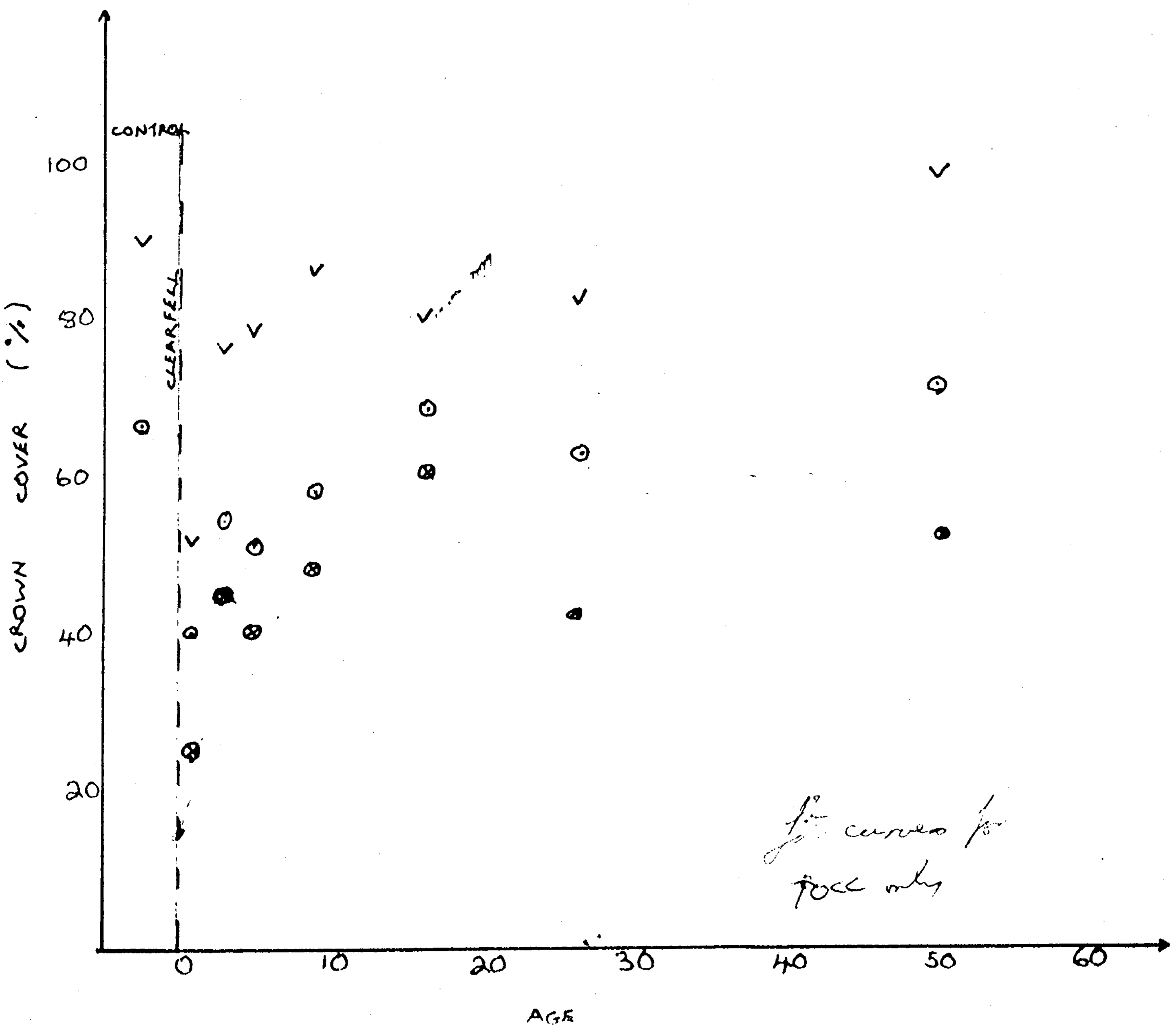


Fig ~~3.5~~ 6 Crown Density ~~Index~~ vs Age

Group B sites - Higher rainfall Jarrah / Marri.

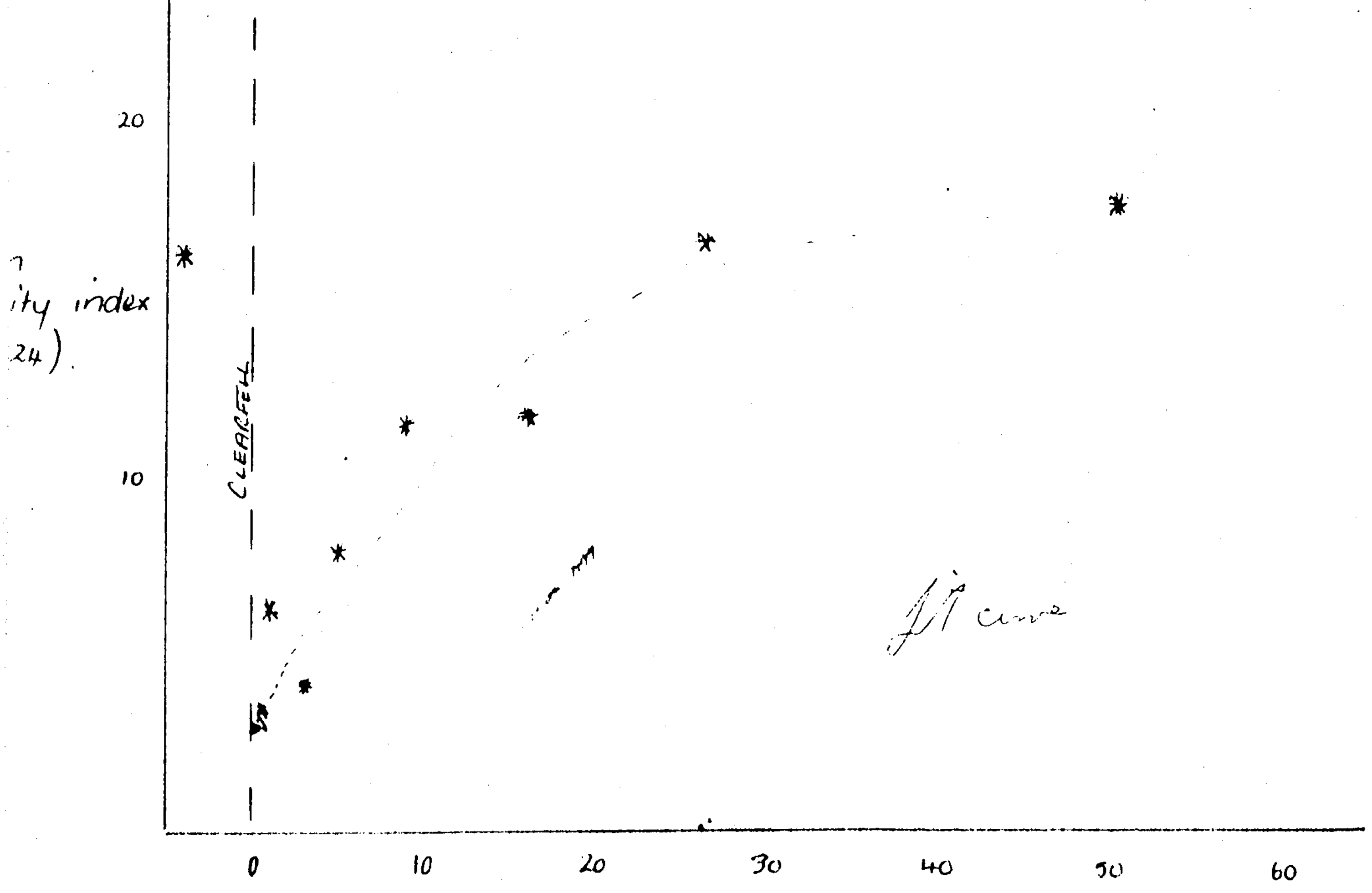


Fig 3.6. Regrowth basal area vs age.
Group B sites Higher rainfall jarrah/Marri

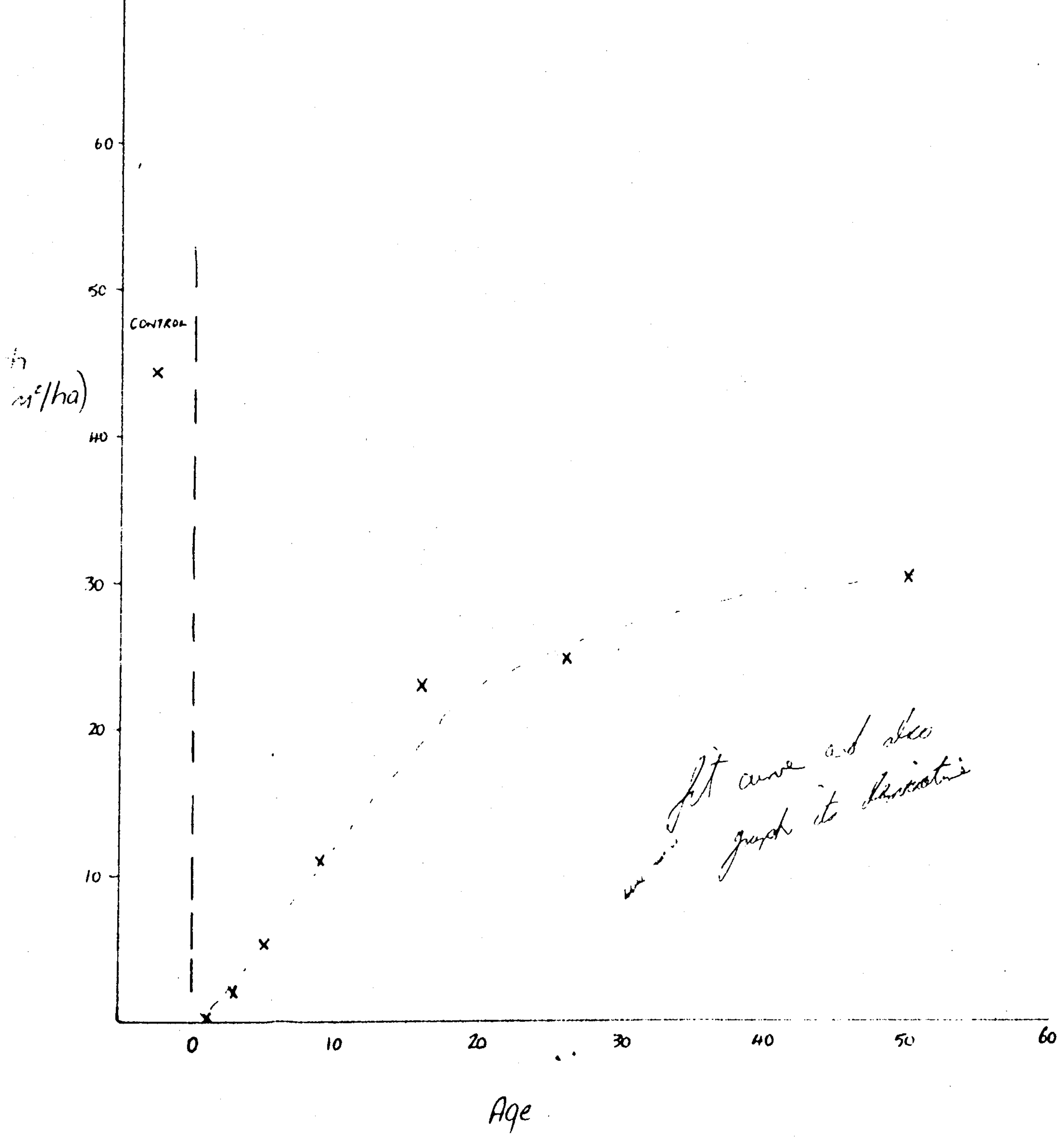


Fig ~~3.7.~~ 8 Overstory Crown Cover vs age
Group C - Intermediate rainfall Karri sites

V Total Vegetation Cover
⊛ T.O.C.C. (Field Sample Sites)
✱ T.O.C.C. (from plot crown radius data)

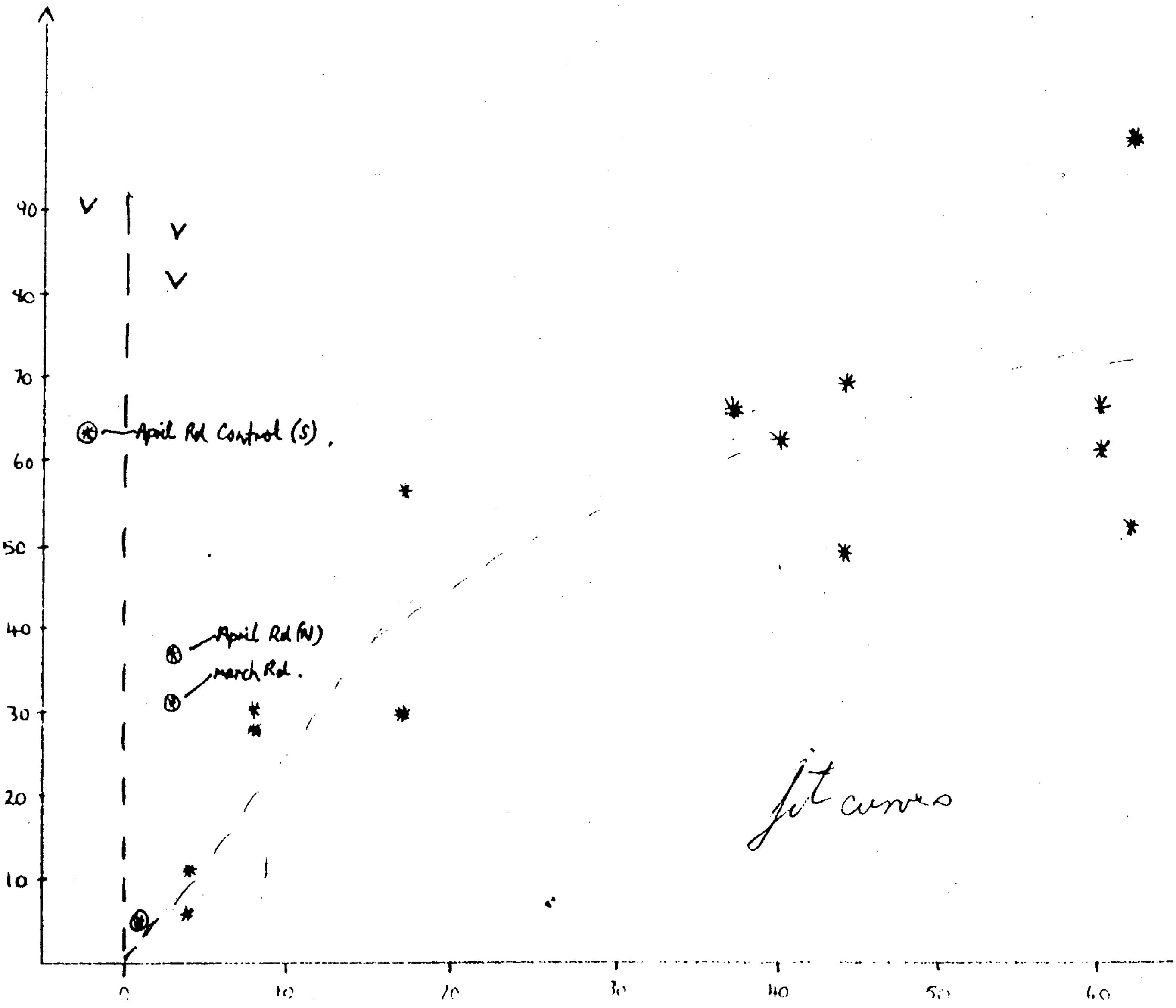
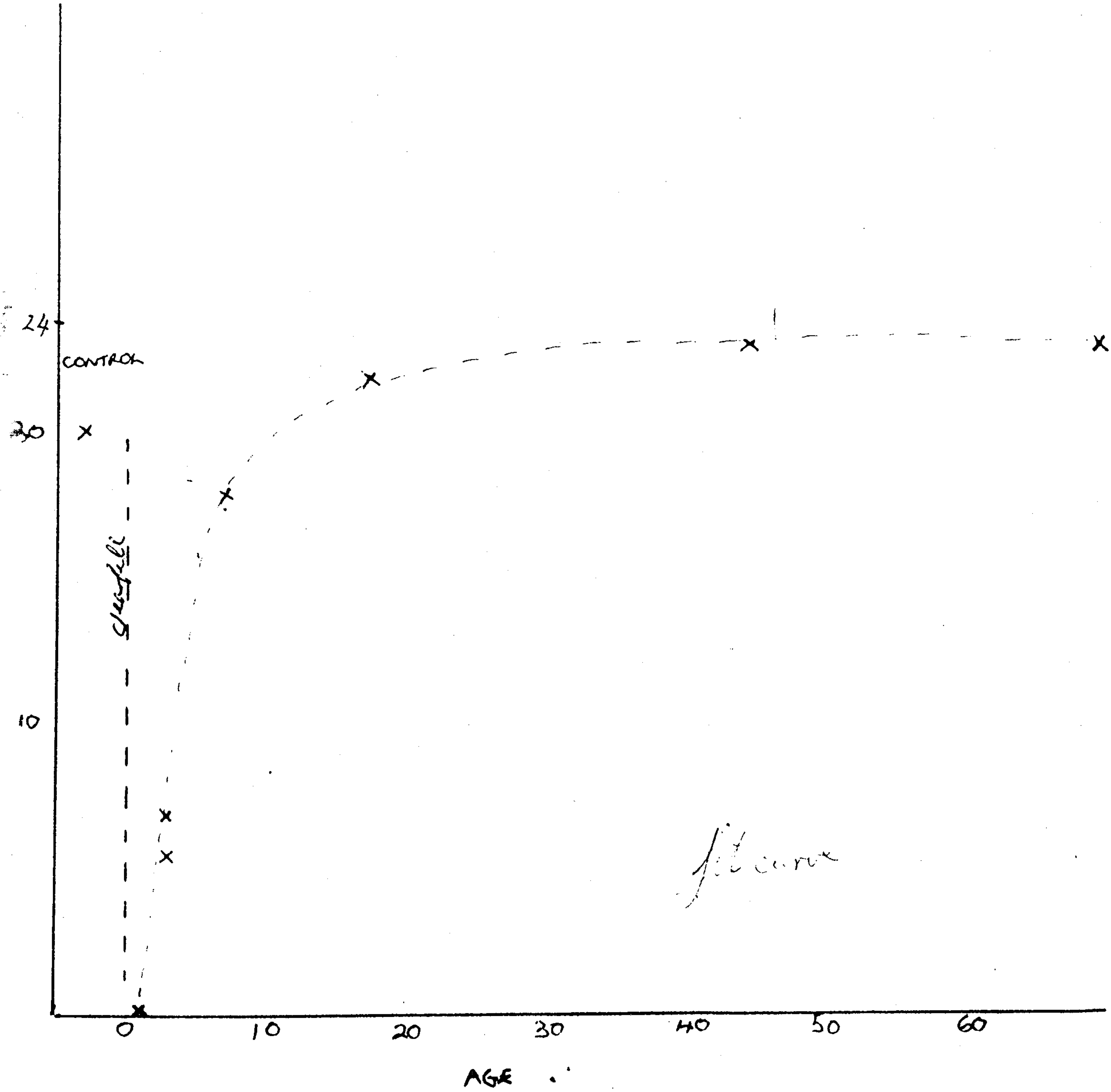


FIG 9 CROWN DENSITY INDEX VS AGE

GROUP C SITES INTERMEDIATE RAINFALL
KARRI



10

Figure ~~3.8~~ ~~9~~ Basal Area vs age. Group C sites - intermediate Rainfall Karri.

x Field Sample Sites (x 2 prism)

• Permanent sample plot data (~~Actual~~ DBHOB measurement)

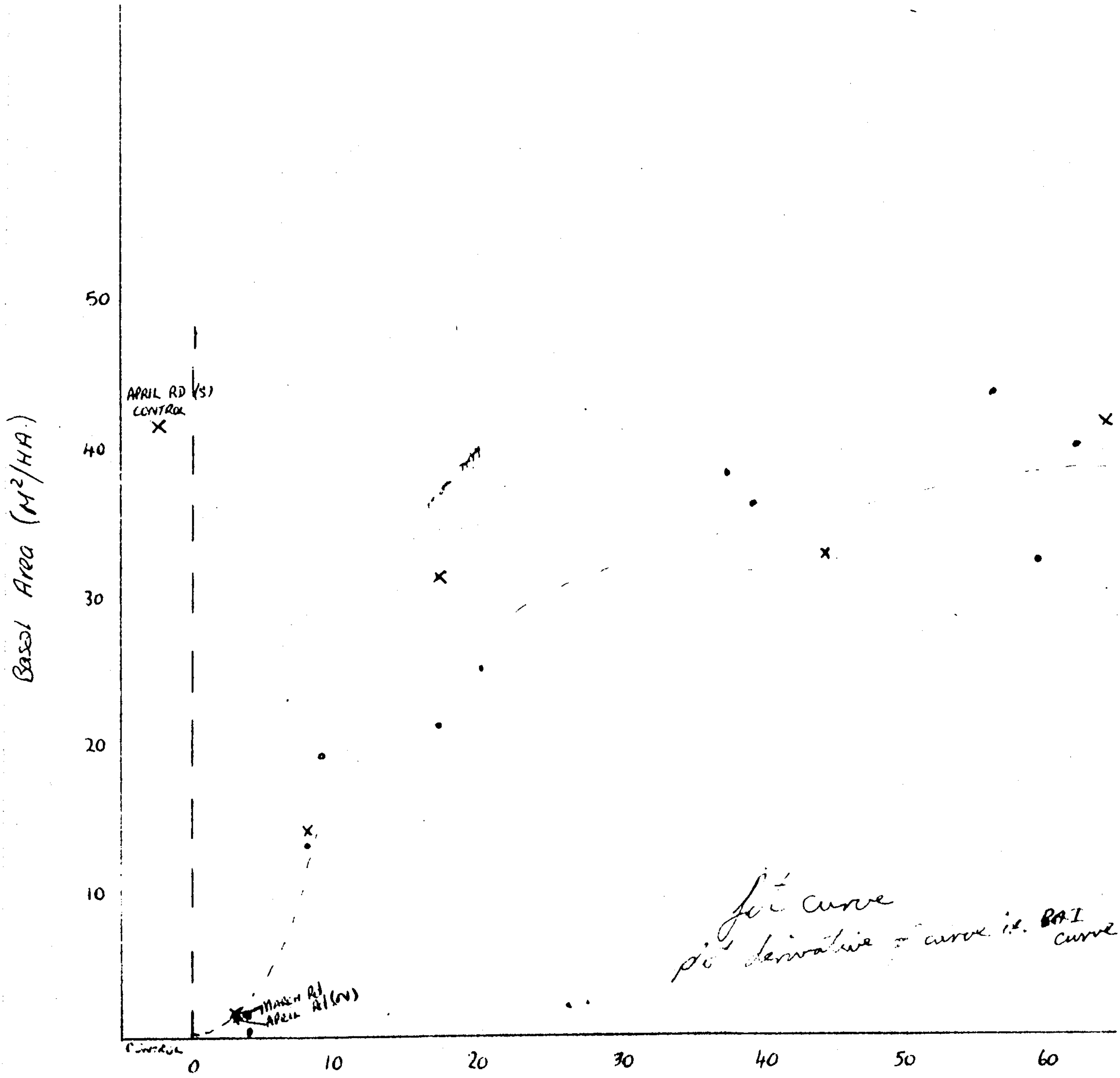
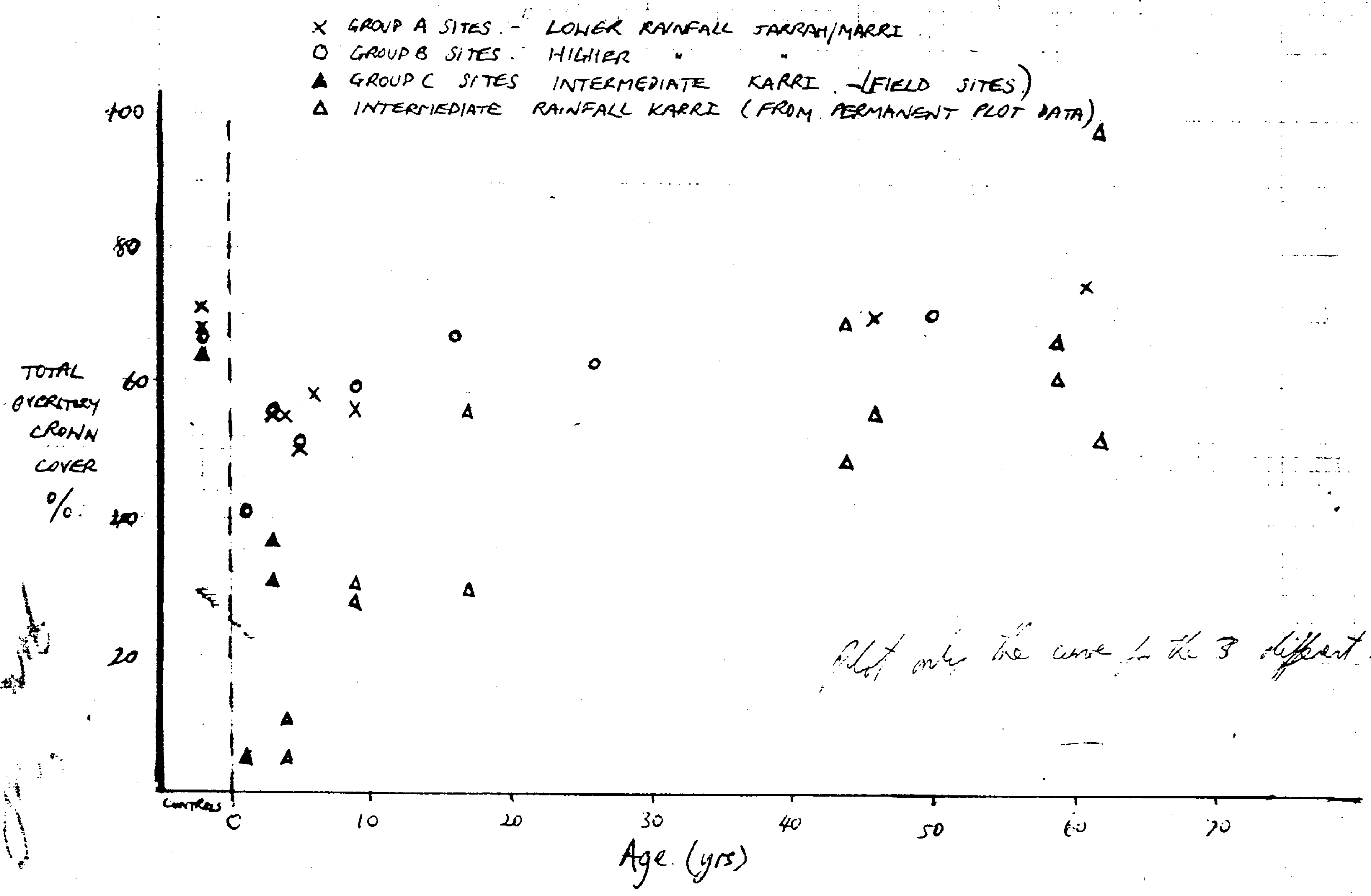


FIG 3.11: TOTAL OVERSTORY CROWN COVER VS AGE – ALL SITES



Plot only the curve for the 3 different ...

FIG. ~~38~~ 12 CROWN DENSITY INDEX vs AGE FOR ALL SITES.

× GROUP A SITES. LOWER RAINFALL JARRAH/MARRI.
o GROUP B SITES HIGHER RAINFALL JARRAH/MARRI.
Δ GROUP C SITES INTERMEDIATE RAINFALL KARRI.

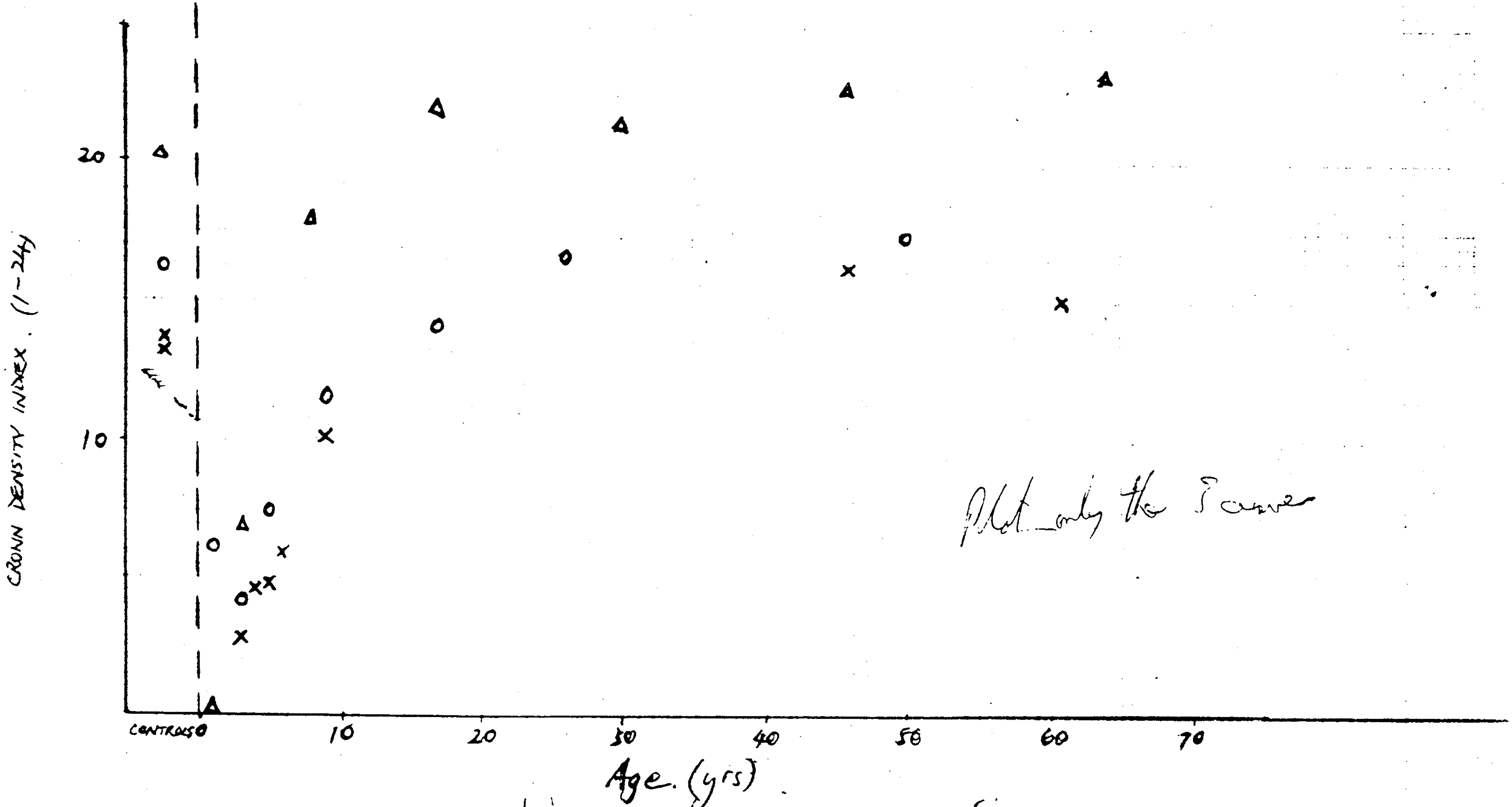
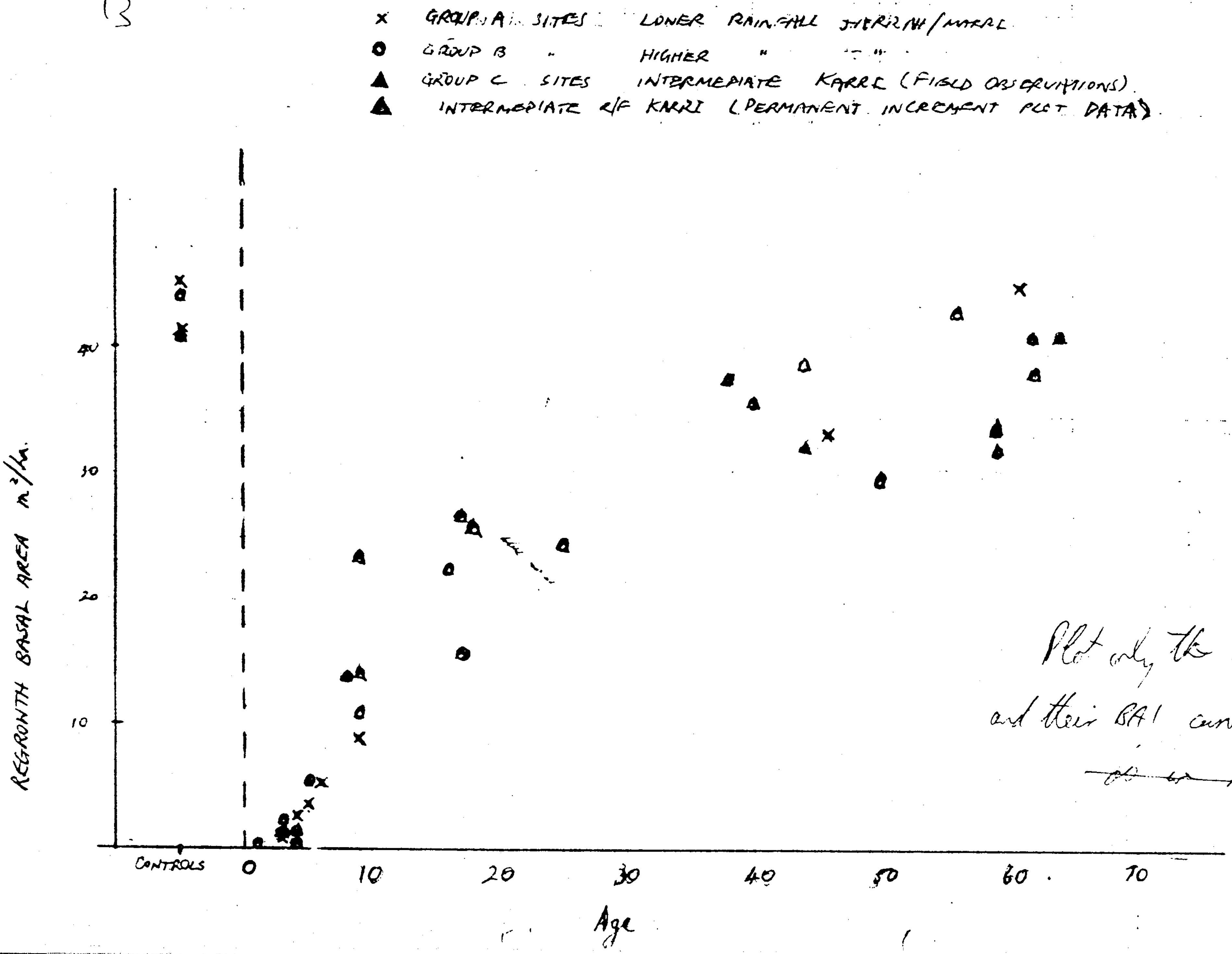


FIG. ~~3.12~~ 13. REGROWTH BASAL AREA VS AGE - ALL SITES.



Plot only the 3 curves and their BA I curves.

~~[illegible]~~

Fig ~~3.13~~ 14 Crown Density Index Vs Age At different Jarrah/Marri stocking (Group A + B sites).

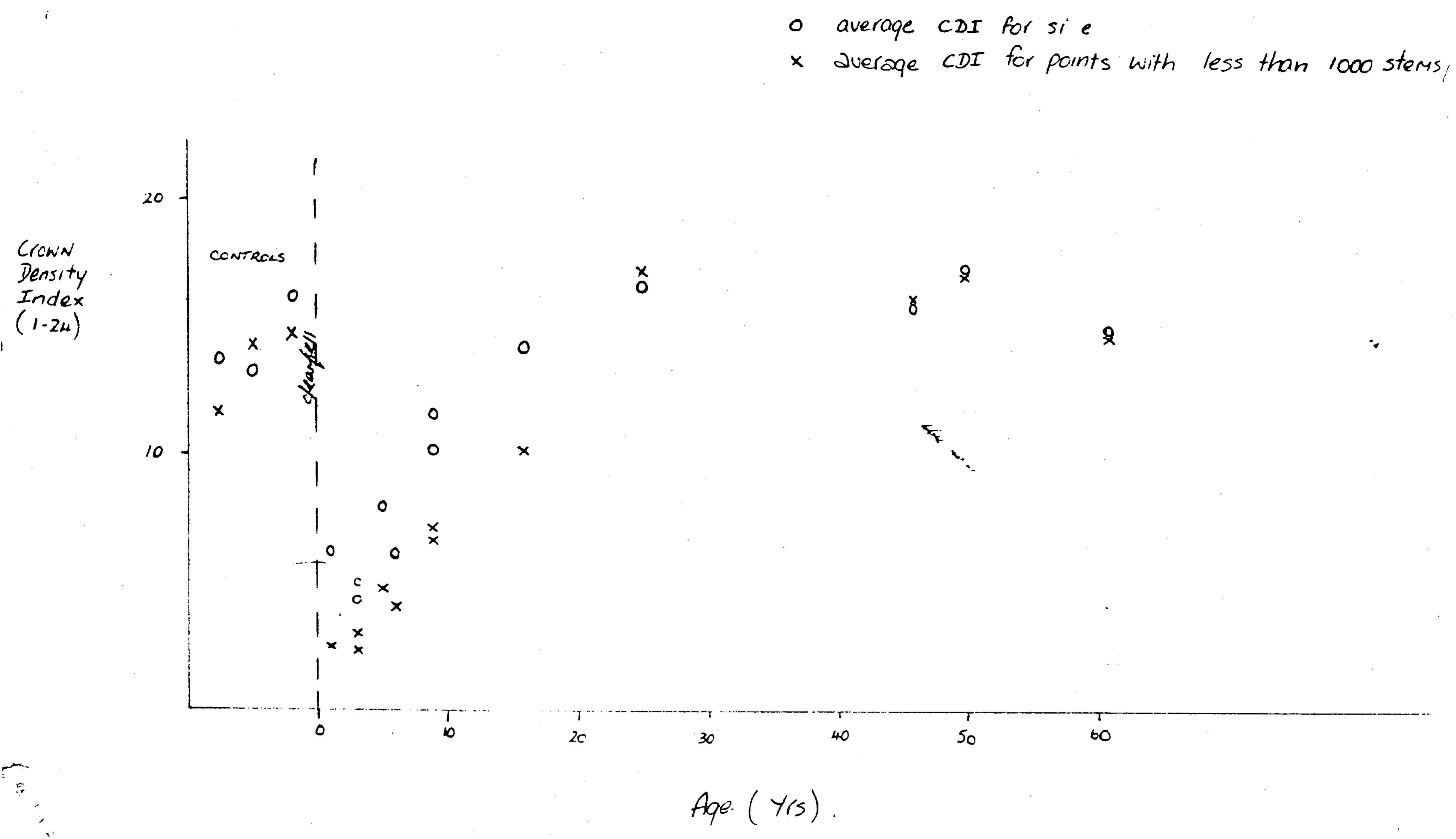
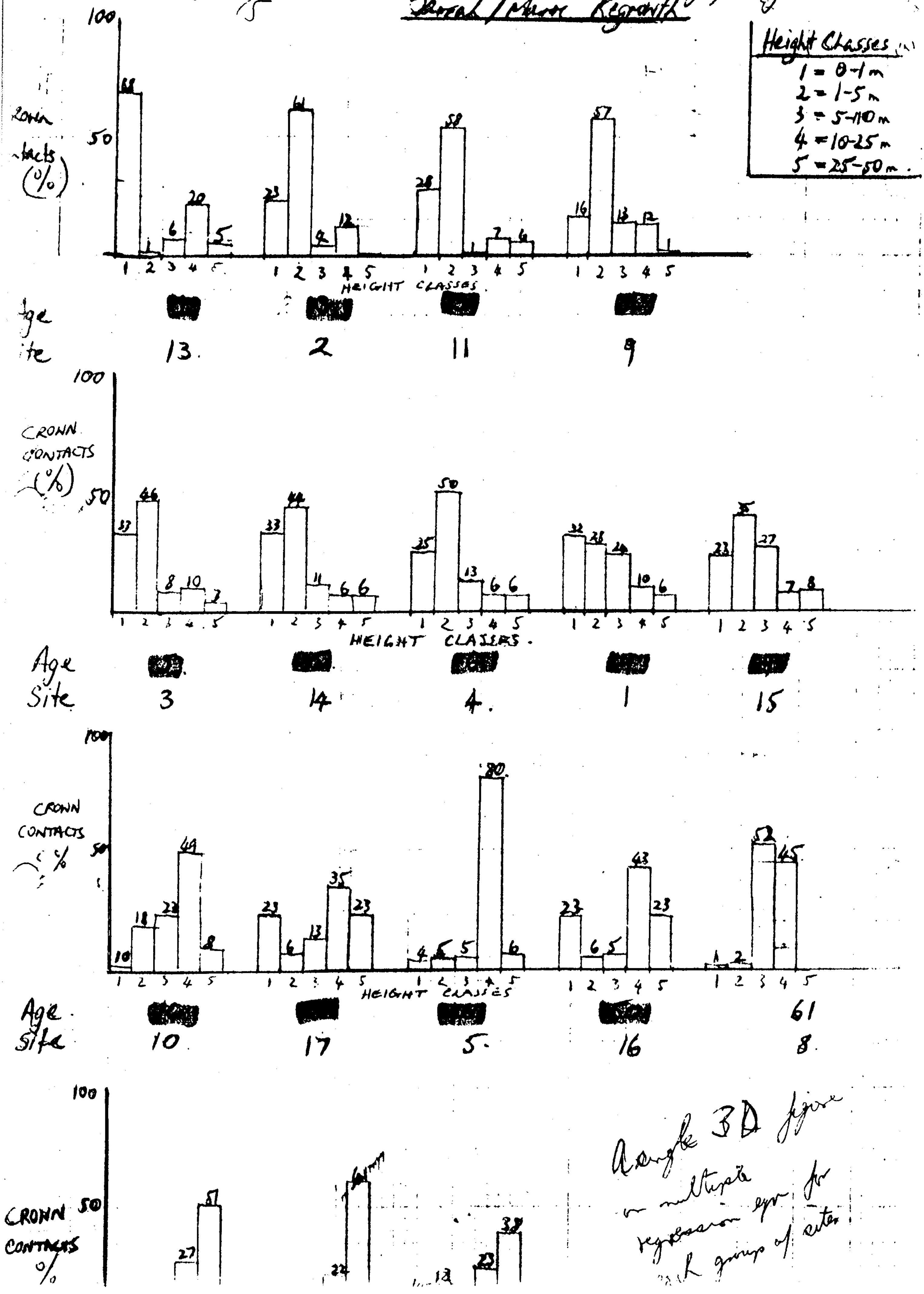


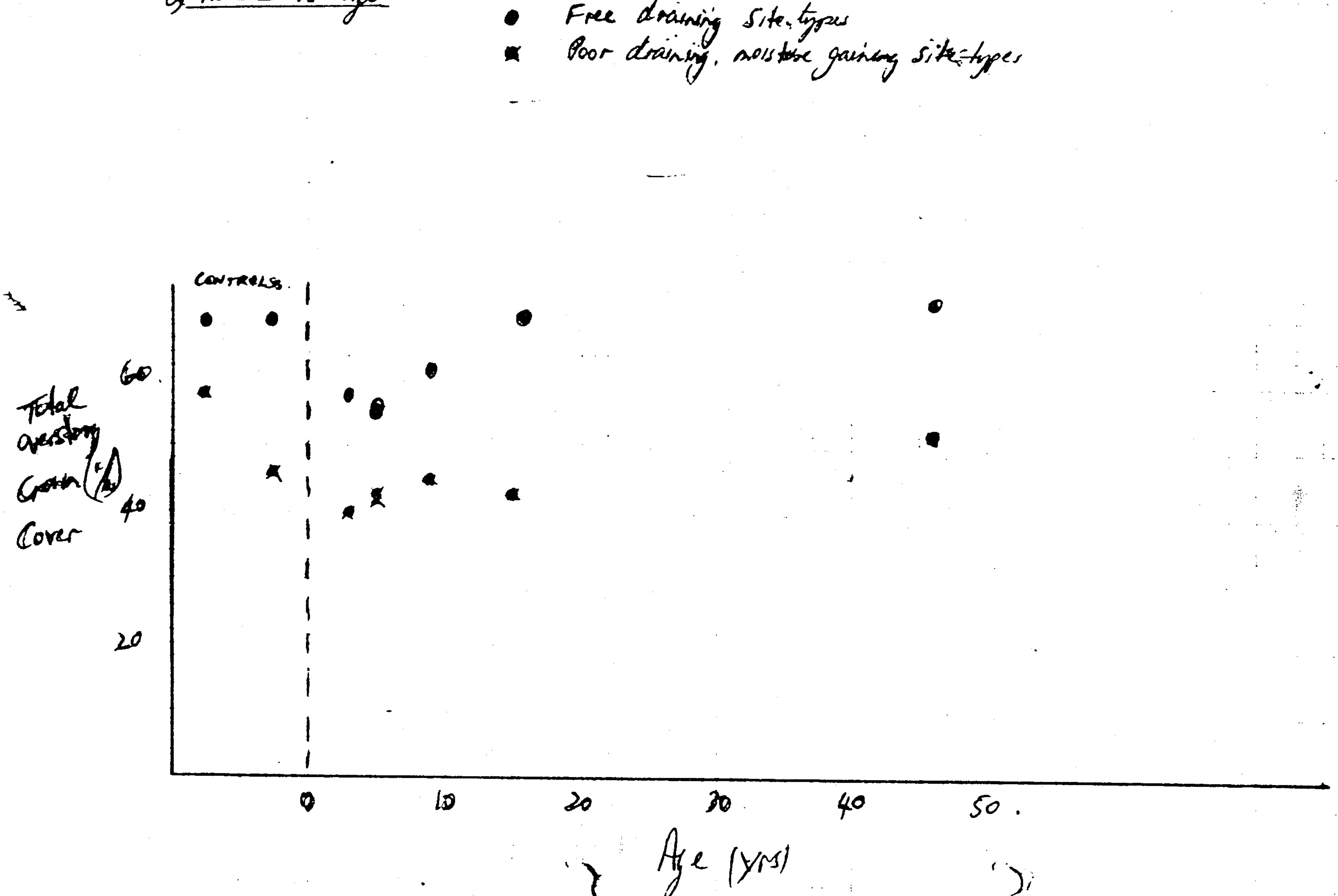
Fig. 3.14(a) Stand Structure Diagrams for Different aged Jarrah/Marri Regrowth



A single 3D figure or multiple regression eqn for ... groups of sites

Figs 15 The Influence of site-type on crown cover. in the Southern Jarrah/Marri Forest

a) T.O.C.C vs Age



~~Fig 3.15~~ 16 b) CROWN Density ~~Index~~ vs Age in different site-types

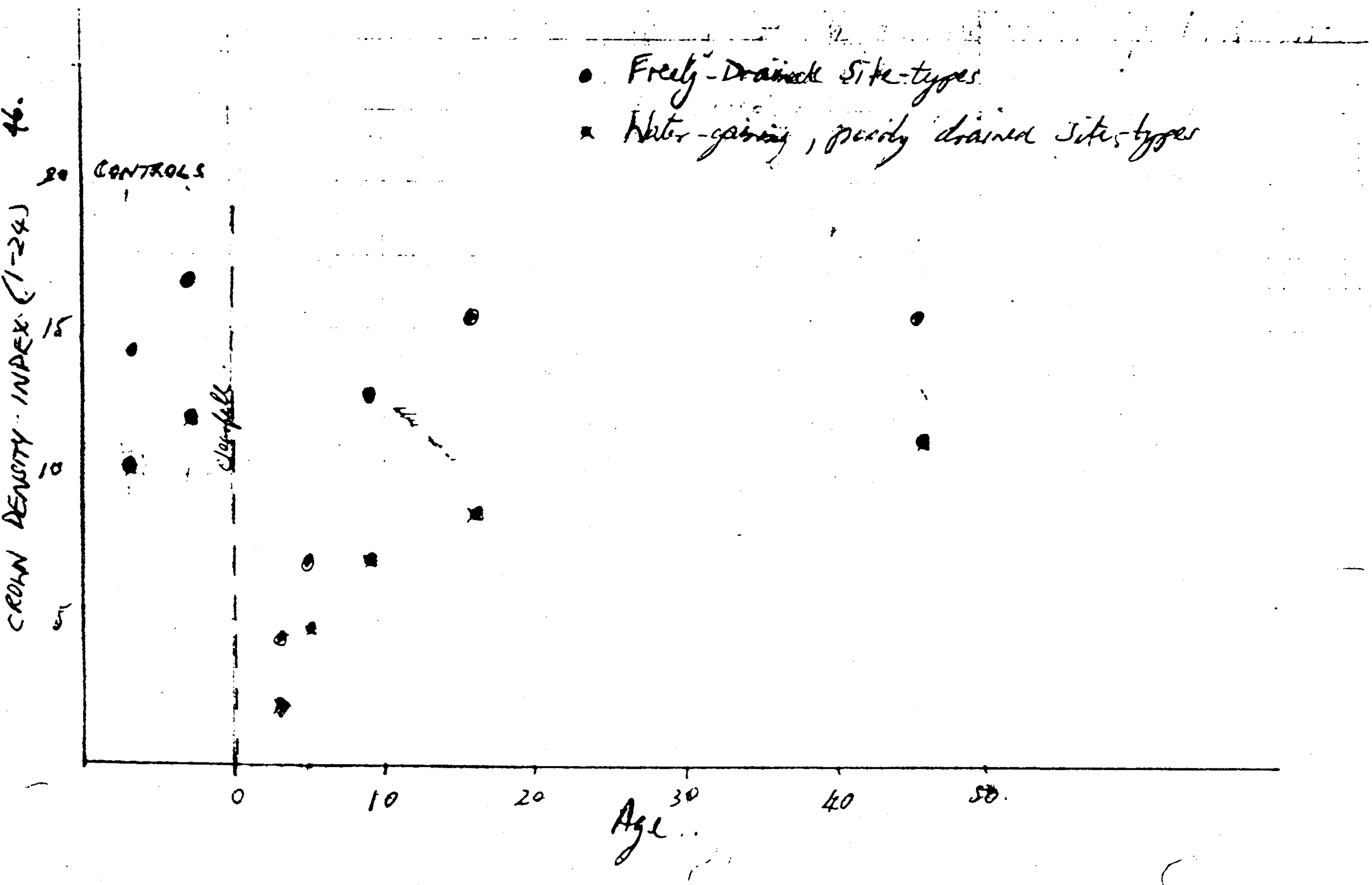
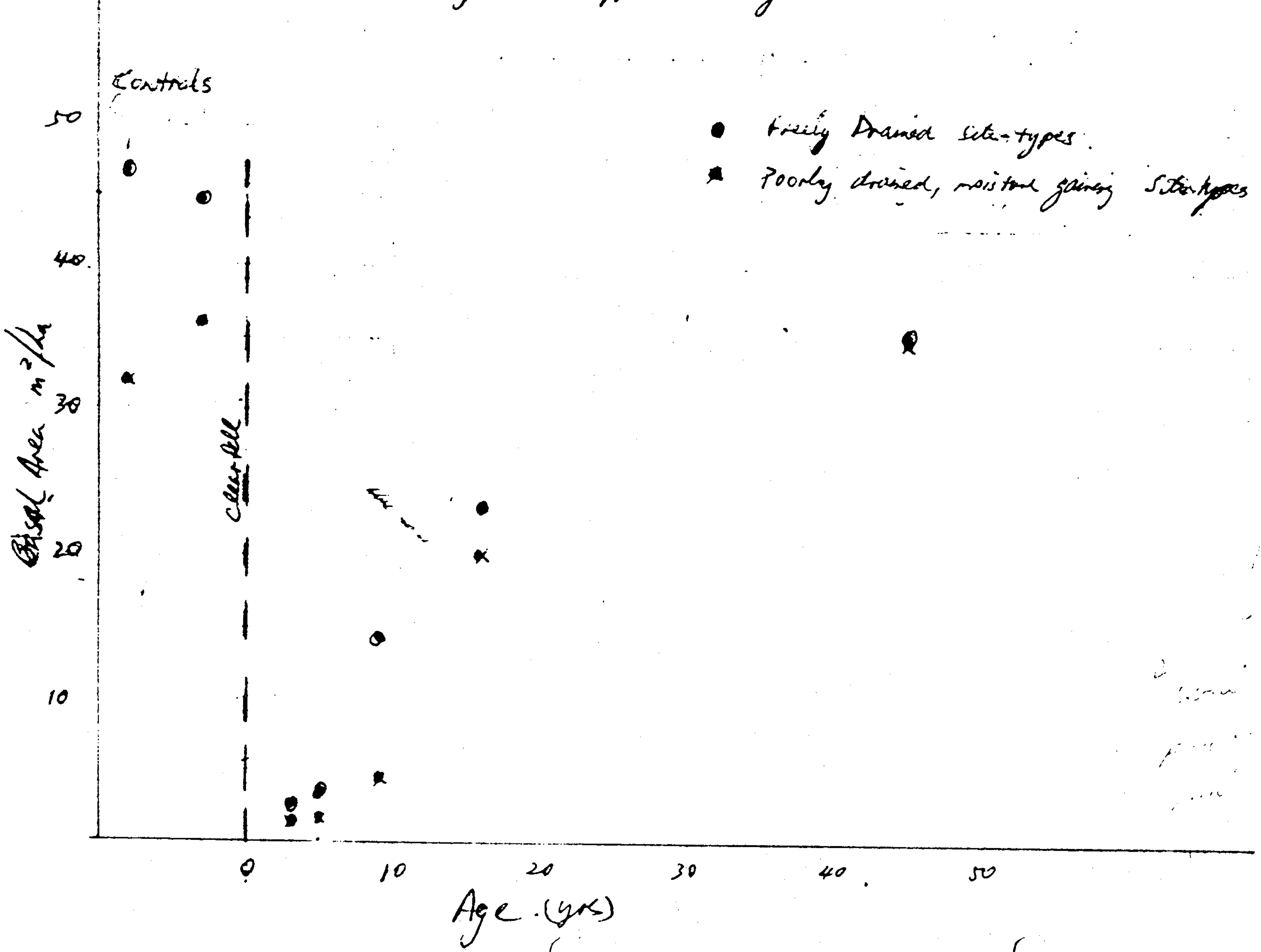


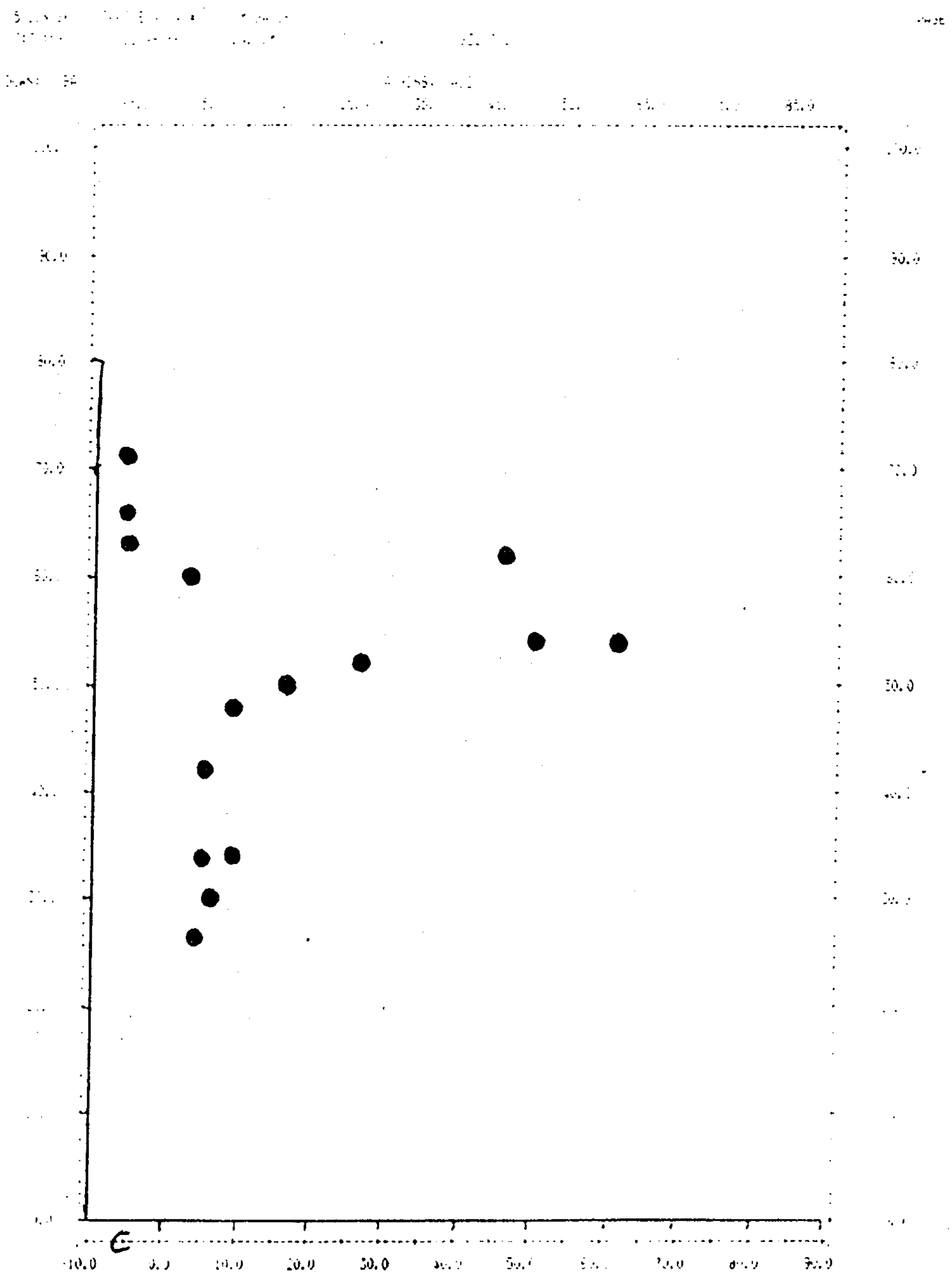
Fig ~~III~~ 17 c) Total Basal Area vs Age on different Site-types



$y = 0.35x + 37.7$

$r^2 = 0.37 \quad \text{sig} = 0.018$

Figure 18



15 JUN 86 COPPICE [illegible]

13130158 DEPARTMENT OF [illegible] [illegible]

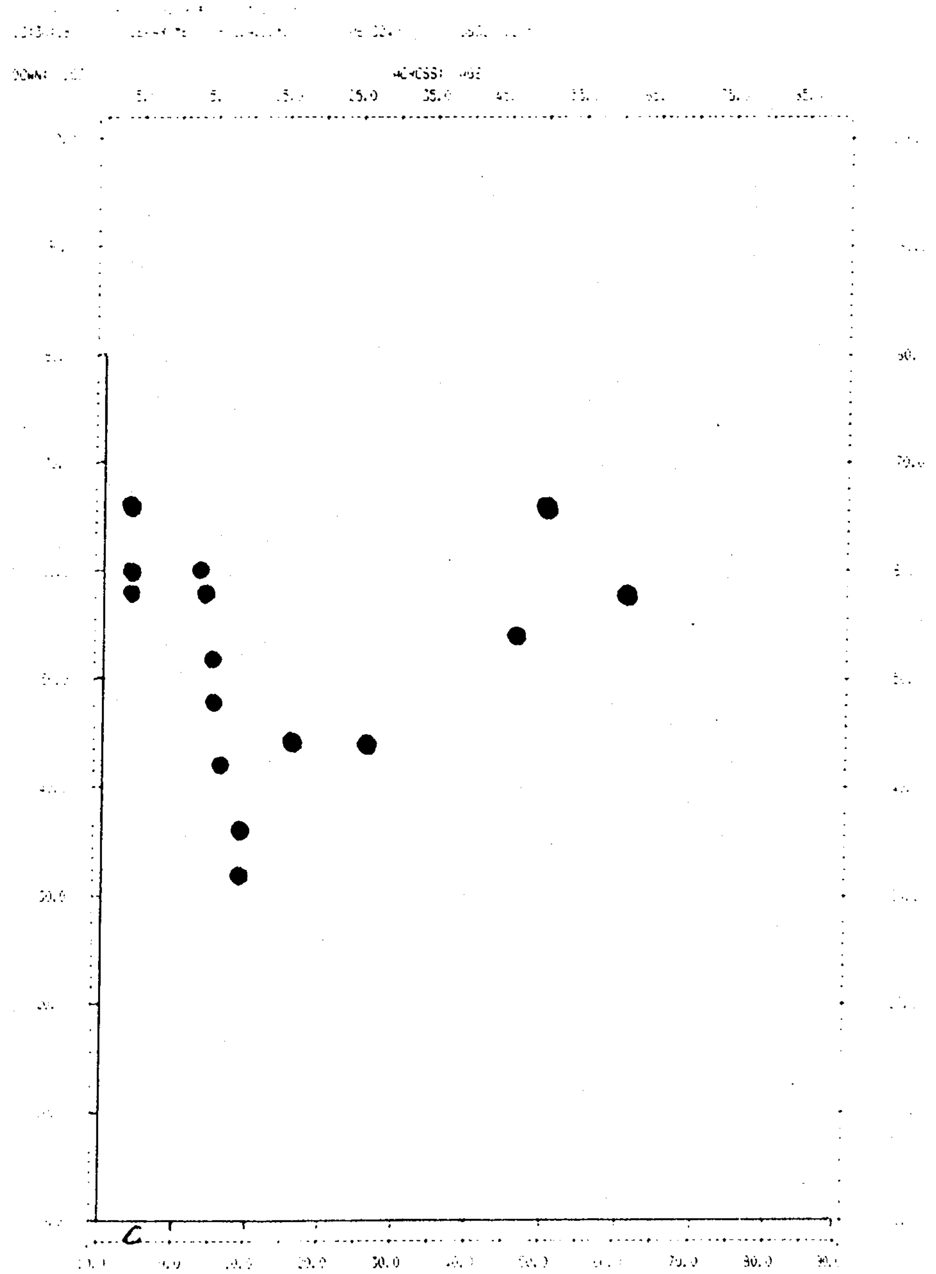
STATISTICS..

CORRELATION (R) -	.60602	R SQUARED -	.36726	SIGNIFICANCE -	.01837
STD ERR OF EST -	[illegible]	INTERCEPT (A) -	37.74873	SLOPE (B) -	.35006
PLOTTED VALUES -	[illegible]	EXCLUDED VALUES	[illegible]	MISSING VALUES -	[illegible]

$y = 0.21x + 44.8$

$r^2 = 0.19$ sig = 0.077

Figure 19



05 JUN 86 CORPICE AS A % OF [illegible]
13:30:59 DEPARTMENT OF [illegible] PE 3240 SSS2 [illegible]

STATISTICS..

CORRELATION (R) -	.43736	R SQUARED -	.19181	SIGNIFICANCE -	.07723
STD ERR OF EST -	9.57723	INTERCEPT (A) -	44.73822	SLOPE (B) -	.21426
PLOTTED VALUES -	12	EXCLUDED VALUES -	0	MISSING VALUES -	0

Figure 20

● CC $\frac{1}{y} = 0.01297\,x + 0.02792$

● BA $\frac{1}{y} = 0.00842\,x + 0.00221$

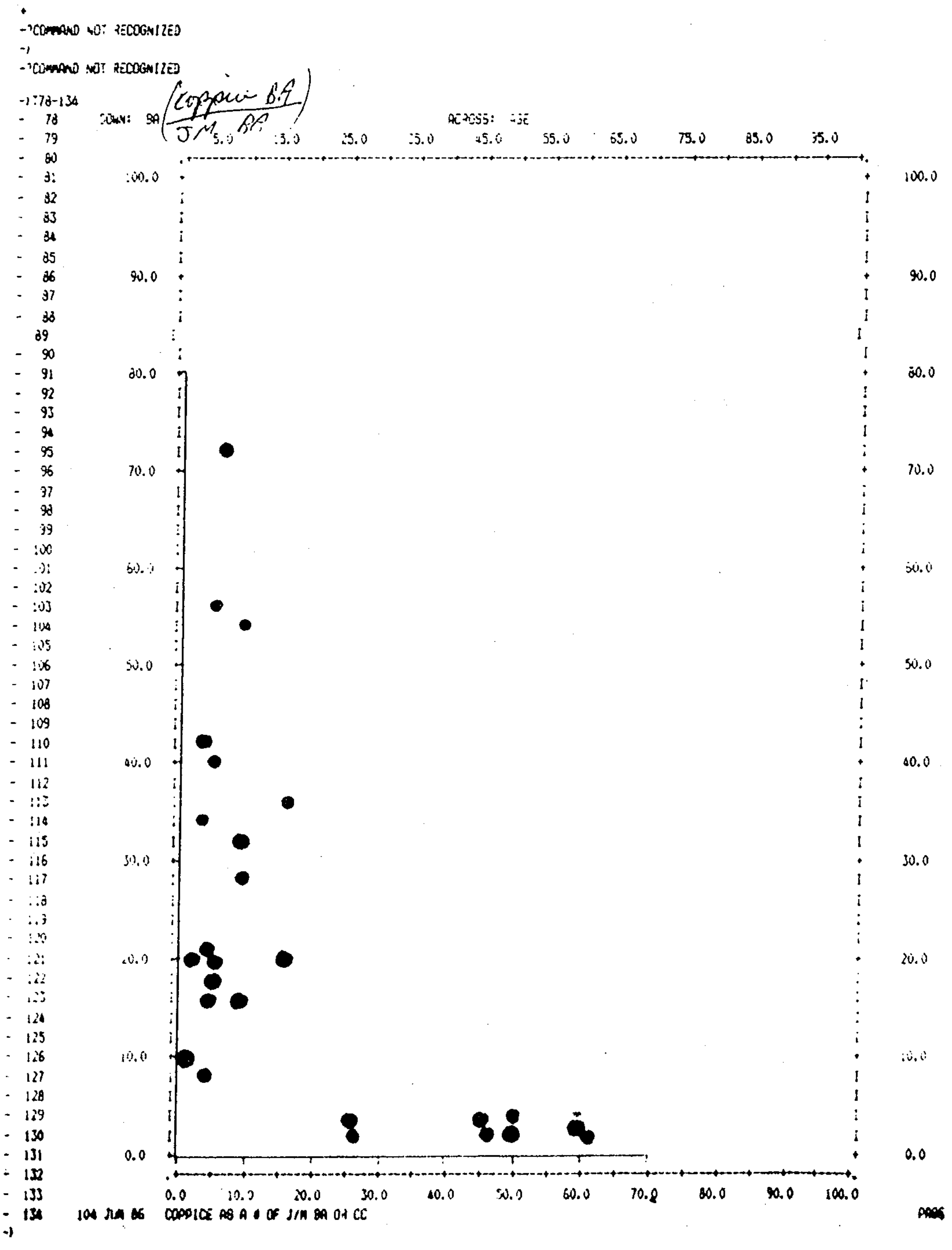
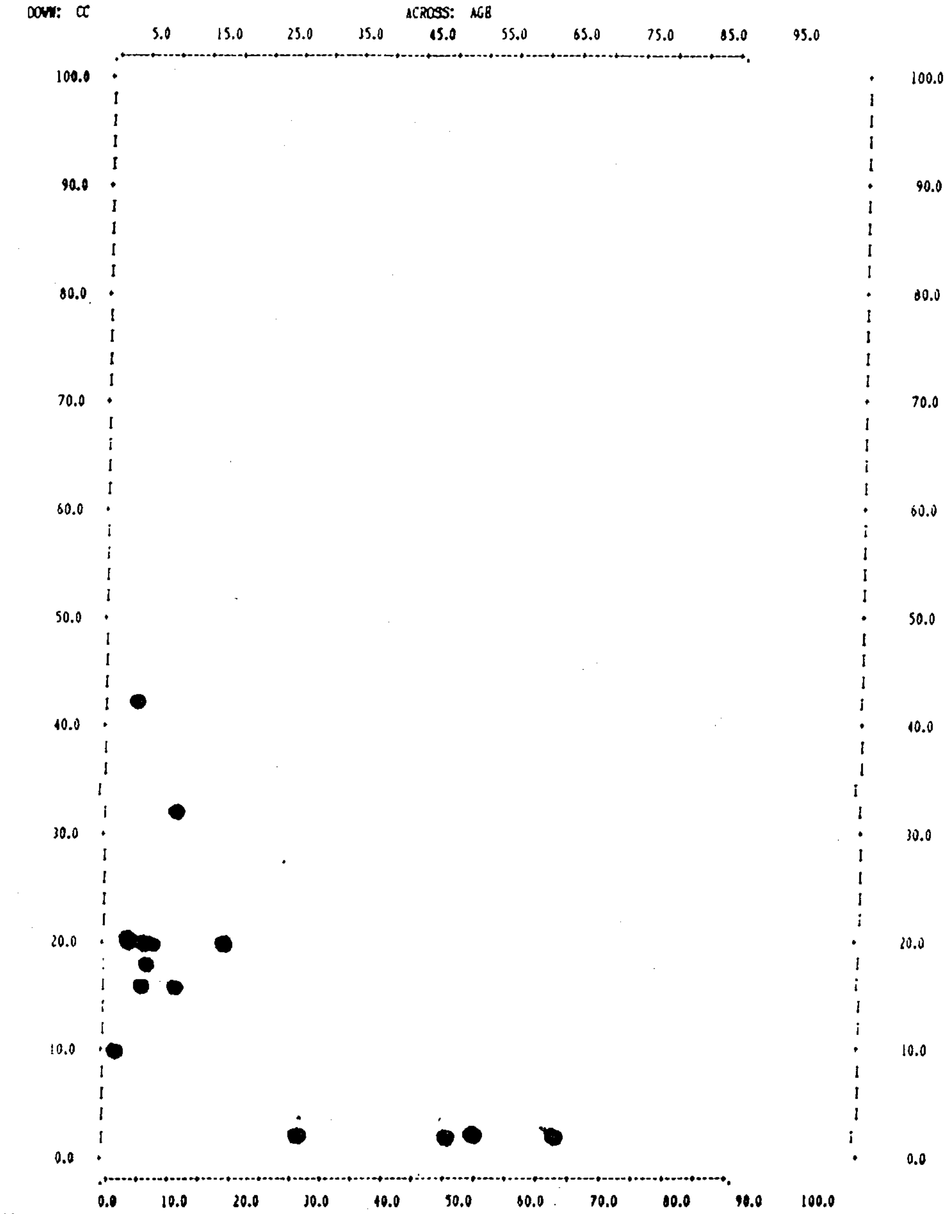


Figure 21

?COMMAND NOT RECOGNIZED

->G T78-134



104 JUN 86 COPPICE AS A % OF J/M BA OR CC PAGE

->