Recovery of Forest Density After Intensive Logging in the Southern Forest of Western Australia

by G.L. Stoneman, P.W. Rose and H. Borg

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G.L. Stoneman
Department of Conservation and Land Management
Dwellingup
Western Australia 6213

P.W. Rose
Western Australian Chip and Pulp Co.
Manjimup
Western Australia 6258

formerly
Department of Conservation and Land Management
Manjimup
Western Australia 6258

H. Borg
Water Authority of Western Australia
Leederville
Western Australia 6007

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1. SUMMARY

Measurements of forest density were made in a series of stands of different ages in the lower rainfall jarrah forest (< 1100 mm), high rainfall jarrah forest (> 1100 mm) and karri forest (> 1000 mm), in the southern forest of Western Australia. The objective was to determine the recovery of forest density following logging, as an indication of trends in forest hydrology.

In both types of jarrah forest, both overstorey canopy cover and total cover exceeded 80 per cent of the unlogged value within five years of regeneration, and had exceeded 90 per cent of the unlogged value within ten years. They reached values similar to the unlogged value in about 20 years, and thereafter remained at that value. The pattern of recovery of crown density index was similar to that of overstorey canopy cover and total cover. Crown density index of high rainfall jarrah stands reached the unlogged value in 30 years, and crown density index of lower rainfall jarrah stands reached the unlogged value in 20 years.

In karri forest, total cover reached the value of unlogged stands five years after the beginning of regeneration, rose for five more years, and then stabilised at a value above the unlogged value. Overstorey canopy cover reached the unlogged value within ten years, and crown density index reached the value of unlogged stands within 15 years. The values of overstorey canopy cover and crown density index for the regenerating stands continued to increase for another ten years and then stabilised at a higher value than in the unlogged stands.

The quick recovery in forest density indicates that evapotranspiration is probably close to the pre-logging value within five to ten years of regeneration.

On poorly drained site-types forest density recovered more slowly and did not reach the same value as on the better site-types. There was a high proportion of marri and coppice in the young regrowth stands, but the proportion of these diminished in the older stands.

2. INTRODUCTION

The permanent removal of native forest and its replacement with annual crops or pastures can lead to large increases in stream salinity in the south-west of Western Australia (Wood 1924; Peck and Hurle 1973). When logging in the southern forest of Western Australia increased in intensity in the late 1960s and early 1970s, there was concern that the changes in forest density would alter the hydrologic balance and lead to increases in stream salinity.

Logging changes the water and salt regime of a forest by removing vegetation and therefore reducing transpiration and interception. More water thus becomes available for other hydrologic processes. Streamflow, soil water and ground water recharge and evaporation from the soil surface may all increase. The increase in ground water recharge leads to a rise in the ground water table which mobilises some of the salt stored in the soil profile. As a result, salt discharge to the streams may increase. This in turn causes increases in stream salinity if the increase in salt discharge is not diluted by an increase in discharge of less saline water (Borg *et al.* 1987a; Borg *et al.* 1987b).

How fast and to what extent a change of the water regime can be reversed depends on how quickly and how well the vegetation, and hence transpiration and interception, recover.

Transpiration from a forested area is difficult to measure directly. Some deductions, however, can be made from estimates of forest density, since both transpiration and interception generally increase with increasing forest density (Wilm 1943; Brookes 1950; Butcher 1977; Langford and O'Shaughnessy 1979).

A survey of forest density in stands of varying ages since logging was therefore conducted.

The primary aim of this study was to quantify changes in forest density following logging, to identify factors which may affect these changes, and to discuss their hydrologic significance. Secondary to this aim was that of identifying features of forest density which may have important silvicultural (and therefore hydrological) implications for future management.

3. METHODS

3.1. Study Area and its Hydrology

The study was carried out in the southern forest of Western Australia which is defined as the forested land in the State which drains into the Southern Ocean. For the purpose of this study three forest types were distinguished: lower rainfall jarrah forest (< 1100 mm mean annual rainfall), high rainfall jarrah forest (> 1100 mm mean annual rainfall) and karri forest (which occurs naturally in areas with > 1000 mm mean annual rainfall).

The mean annual rainfall in the southern forest ranges from over 1400 mm in some locations near the coast, to less than 700 mm further inland (Fig. 1). Transpiration typically returns 60 to 80 per cent of the annual precipitation to the atmosphere. Interception of rainfall by vegetation accounts for another 10 to 20 per cent. Evaporation from the soil surface and organic litter generally removes less than 10 per cent, and streamflow accounts for between 0 and 20 per cent of the annual precipitation (Borg *et al.* 1987b; Schofield *et al.* in press).

Rain and dry fall introduce salt (transferred into the atmosphere from oceanic spray) to the soils of the region (Hingston and Gailitis 1976). The top 2 to 4 m of the soil profile are generally well leached, but substantial amounts of salt have accumulated at greater depths. The amount of accumulated salt increases as the mean annual rainfall decreases (Johnston *et al.* 1980).

3.2. Site Selection

The location of the study sites is shown in Figure 1. The intention was to sample only even-aged stands. However, all jarrah sites had been selectively cut at some time in the past. The sites therefore contained varying amounts of regrowth from the cutting, and varying amounts of old-growth which had been retained in the selective cut and which contributed to the forest density measured in this study. A range of potential jarrah sites was subjectively assessed so that only those sites which were relatively even-aged were sampled. All karri sites had been clear-felled and regenerated, and were therefore even-aged.

The year of logging is recorded for all forest areas logged under Department of Conservation and Land Management (and formerly Forests Department) supervision. These records were examined to identify potential study sites with a given number of years since logging.

It was intended to sample a wide, and evenly spread range of regrowth ages within each forest type so that trends in the recovery of forest density with time after logging would be identified. However, in the lower rainfall jarrah forest no relatively even-aged regrowth stands between seven and 46 years of age could be found, so no stands in this range of ages were assessed.

The sites in the jarrah forest were generally between 100 and 200 ha (Appendices 1 and 2). Those in the karri forest were 5 or 10 ha with a few up to 200 ha (Appendix 3).

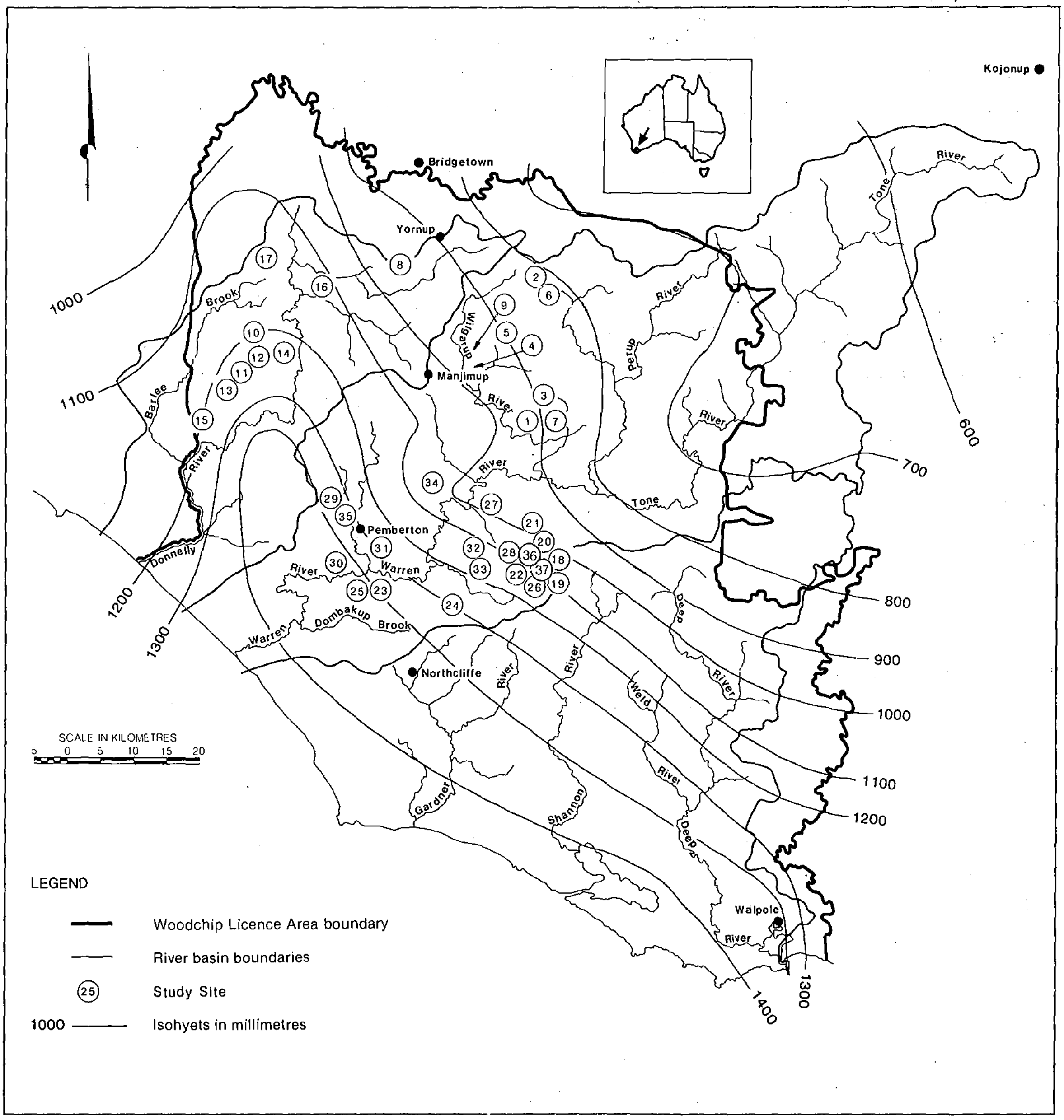


Figure 1

Location of the study area and study sites.

3.3. Forest Density Measurements

Cover, crown density index, basal area and stocking were the measures of forest density collected in this study.

3.3.1. Cover

Cover refers to the percentage of ground area covered by a vertical projection of the vegetation canopy onto the ground surface. It was assessed with a crownometer similar to one described by Montana and Ezcurra (1980). This instrument is designed to give a narrow, vertical line of sight. If the line of sight intercepts vegetation (that is a leaf, a branch or a stem), a 'hit' is recorded. When a number of readings have been taken, vegetation cover is calculated as the number of hits divided by the total number of observations. Two forms of vegetation were computed for each stand. Firstly an overstorey vegetation cover, using only intercepts with tree species, and secondly a total vegetation cover, using all intercepts.

Where the probability of intercepting a crown is 0.5 a maximum of 384 samples is required to be 95 per cent confident that the error in estimating cover will be less than 5 per cent. In more dense or less dense forest where the probability of intercepting a crown is 0.9 or 0.1, respectively, only 138 samples are required for the same degree of confidence (Walpole 1974). Accordingly, approximately 400 measurements of cover were made on each of the jarrah sites (which were known to have an unlogged cover of about 50 per cent) and 100 to 200 measurements in each of the karri sites (which were known to have an unlogged cover of about 90 per cent). Sample points were located at 10 m intervals along line transects.

The use of the crownometer gives a relatively precise measure of planimetric cover. The measure takes no account of crown height or stand structure and is not sensitive to crown density differences.

Overstorey canopy cover and total cover were recorded as either old-growth or regrowth. This allowed an estimate to be made of the old-growth component immediately following logging. These values were used in Figures 2, 3, 4, and 5 as the overstorey canopy cover and total cover of one-year-old stands.

3.3.2. Crown density index

The estimates of crown density index were obtained with a spherical densiometer (Lemmon 1956), the basis of which is a spherical mirror overlain 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 incorporated in the cover measure with the crownometer. The estimate was taken at every tenth cover sample point, i.e. at 100 m intervals on the line transects.

3.3.3. Basal area

Basal area is the cross sectional area of trees, measured at 1.3 m above the ground, per ha. Basal area was estimated using a wedge prism with a basal area factor of 2. Sampling frequency was the same as that for crown density index.

3.3.4. Stocking

Stocking is the number of trees per ha. Total stocking of trees (accounting for all trees 10 cm d.b.h. or greater) was estimated visually at each of the basal area measurement points. The mean of these estimates represents an average stocking of the site.

3.4. Site-Types

At each point where crown density index was sampled on the jarrah sites, the site-type was assessed, based on the site-type classification being developed for the southern jarrah forest (Strelein in press). Site-types throughout the southern jarrah forest can be broadly categorized into:

(i) moisture gaining sites, and

(ii) free draining sites.

Site-types were not identified for the karri sites.

4. RESULTS AND DISCUSSION

4.1. Recovery of Forest Density With Time

4.1.1. Lower rainfall jarrah stands

Overstorey canopy cover recovered rapidly after logging (Fig. 2A). Within three years, overstorey canopy cover was up to 75 per cent of the unlogged values. Retained old-growth accounted for around 10 per cent of the overstorey canopy cover on most sites (Table 1). The curve in Figure 2A indicates that within 10 years overstorey canopy cover reaches about 90 per cent of that of unlogged values. Within 20 years it stabilises near unlogged values.

Within five years, more than 80 per cent of total cover is replaced, and within 10 years, total cover is very close to unlogged values (Fig. 2B). Total cover then stabilises at that value.

Crown density index gives an alternative impression of crown changes with time (Fig. 2C). The crown density index of regrowth stands is about 70 per cent of the unlogged value within 10 years, approaches that of unlogged stands within 20 years after logging, and continues to rise thereafter.

4.1.2. High rainfall jarrah stands

About 85 per cent of the unlogged value of overstorey canopy cover is replaced within five years, and within 10 years overstorey canopy cover recovers to more than 90 per cent of unlogged values (Fig. 3A). After 20 years overstorey canopy cover is close to the unlogged value, and thereafter remains at that value.

Total cover on these sites builds up rapidly to about 85 per cent of total cover replacement in the first five years after logging (Fig. 3B). Within 10 years total cover is 90 per cent of the unlogged value, and is very close to the unlogged value after 20 years, at which it subsequently remains.

Similar trends are shown for crown density index (Fig. 3C). After 10 years crown density index recovers to about 70 per cent of the unlogged value, and after 20 years it is very close to the unlogged value. It subsequently continues to rise. The effect of retained old-growth overstorey is reflected in the relatively high values gained from the one-year-old stand (Table 2).

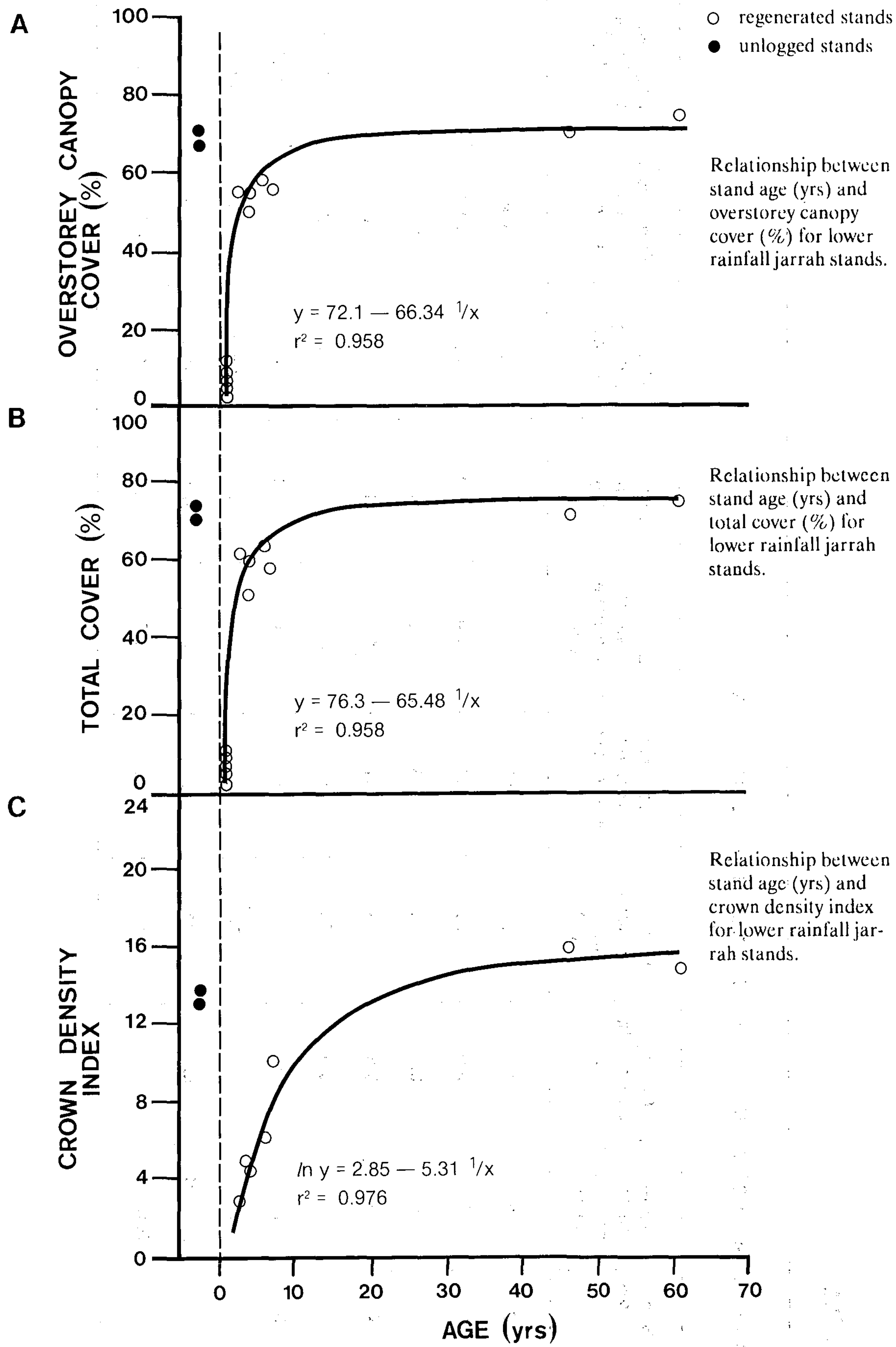
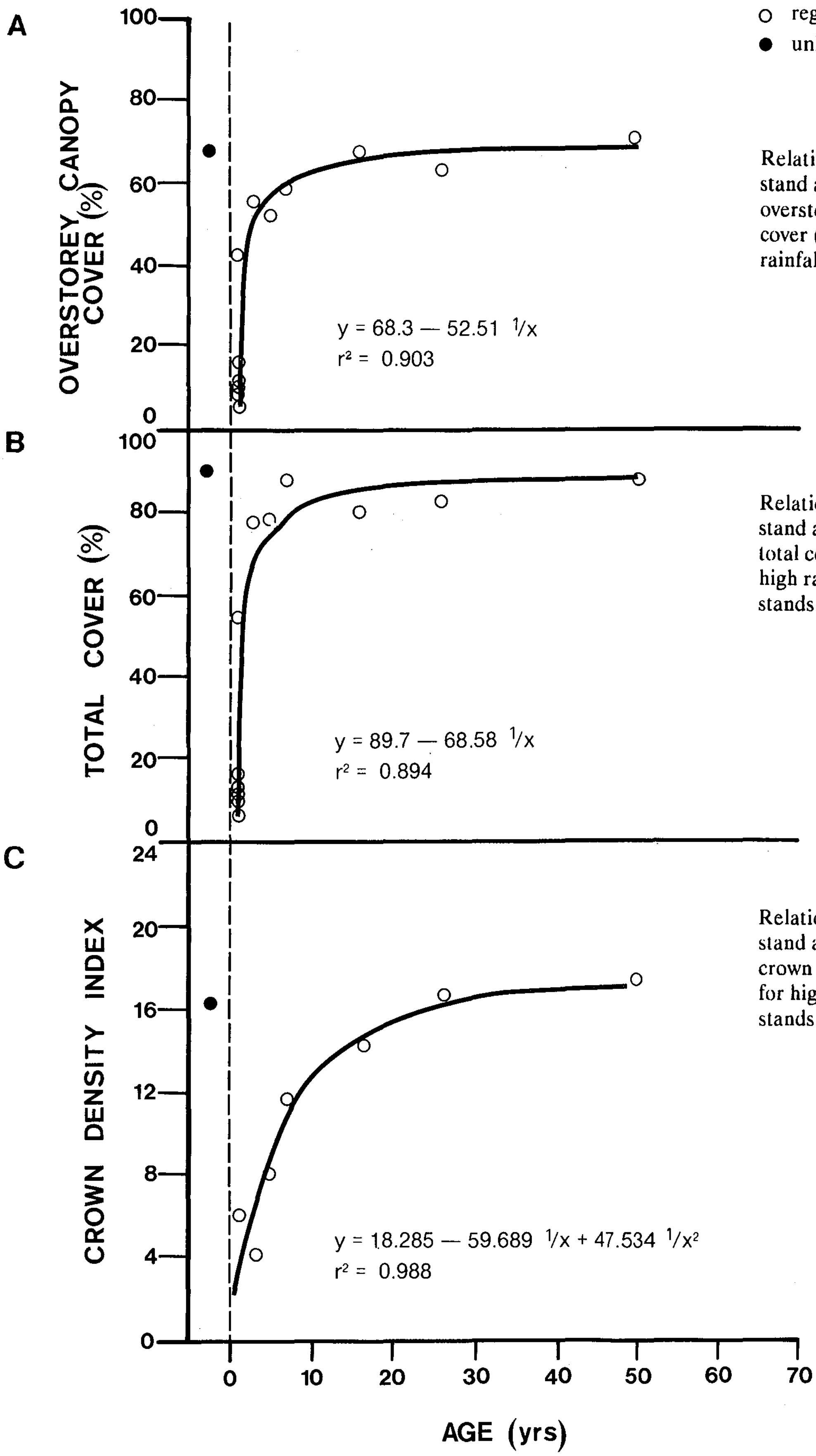

A
B
C
OVERSTOREY CANOPY COVER (%)
TOTAL COVER (%)
CROWN DENSITY INDEX
○ regenerated stands
● unlogged stands
Relationship between stand age (yrs) and overstorey canopy cover (%) for lower rainfall jarrah stands.
y = 72.1 — 66.34 1/x
r² = 0.958
Relationship between stand age (yrs) and total cover (%) for lower rainfall jarrah stands.
y = 76.3 — 65.48 1/x
r² = 0.958
Relationship between stand age (yrs) and crown density index for lower rainfall jarrah stands.
ln y = 2.85 — 5.31 1/x
r² = 0.976
AGE (yrs)
0 10 20 30 40 50 60 70

Figure 2

TABLE 1

Forest density of the lower rainfall jarrah forest study sites.

Site Number	Time since logging (yrs)	Average tree height (m)	Overstorey canopy cover (%)	Regrowth overstorey canopy cover (%)	Dead overstorey canopy cover (%)	Scrub cover (%)	Crown density index	Total basal area (m^2 ha^{-1})	Regrowth basal area (m^2 ha^{-1})
2	3	1.5	55	45	1.7	6.8	2.8	NA	NA
3	4	3.0	50	47	1.4	17.2	4.9	10.3	3.5
9	4	3.0	55	45	1.0	4.8	4.6	11.1	2.8
4	6	3.5	58	51	1.2	5.8	6.0	10.3	5.1
1	7	8.0	56	51	4.1	11.8	10.1	16.0	9.0
5	46	20	70	65	10.4	1.8	16.1	34.8	33.6
8	61	23	75	67	18.2	0.1	15.0	47.4	43.1
6	Control	35	68	22	12.7	5.1	13.7	45.5	NA
7	Control	37	71	22	18.2	1.7	13.2	41.6	16.4



Relationship between stand age (yrs) and overstorey canopy cover (%) for high rainfall jarrah stands.

Relationship between stand age (yrs) and total cover (%) for high rainfall jarrah stands.

Relationship between stand age (yrs) and crown density index for high rainfall jarrah stands.

Figure 3

TABLE 2

Forest density of the high rainfall jarrah forest study sites.

Site Number	Time since logging (yrs)	Average tree height (m)	Overstorey canopy cover (%)	Regrowth overstorey canopy cover (%)	Dead overstorey canopy cover (%)	Scrub cover (%)	Crown density index	Total basal area (m^2 ha^{-1})	Regrowth basal area (m^2 ha^{-1})
13	1	0.6	42	26	1.2	11.7	6.1	11.7	NA
11	3	2	55	44	0.9	21.8	4.1	9.0	2.2
14	5	3.0	52	42	0.5	26.0	8.0	12.3	5.4
15	7	7.5	59	49	1.6	28.8	11.7	19.0	11.0
10	10	10	67	60	3.6	13.2	14.2	27.1	22.6
17	26	18	63	44	9.6	20.0	16.7	40.2	24.8
16	50	25	70	53	10.8	18.2	17.4	40.5	29.4
12	Control	40	67	NA	7.3	23.3	16.3	44.4	NA

4.1.3. Karri stands

Overstorey canopy cover reaches 95 per cent of unlogged values in five years, and after 10 years is greater than the unlogged values (Fig. 4A). After increasing for another 10 years it stabilises at a value some 10 per cent above the value for unlogged stands.

Total cover recovers to equal the unlogged values within five years, and is greater than unlogged values within 10 years (Fig. 4B). Total cover subsequently remains about 5 per cent above unlogged values. Although the understorey is an important component of total cover in the early years following logging, it is the overstorey which is the major contributor to the recovery in total cover (Table 3).

Crown density index is about 70 per cent of the unlogged value within five years of logging, and builds up to unlogged values within 15 years (Fig. 4C).

4.1.4. Comparison of time trends

Comparison of the overstorey canopy cover of the three forest types (Fig. 5A), shows little difference in the pattern of the recovery. However, the value for karri stands attains a higher value than that of the jarrah stands. While the pattern of recovery of total cover is similar for all three forest types, the value which total cover reaches is different in each type. Karri stands reach a higher value than high rainfall jarrah stands, both of which attain a higher value than the lower rainfall jarrah stands (Fig. 5B).

The jarrah stands in the high rainfall zone generally tend to have more total cover than those in the lower rainfall zone because of the greater amounts of understorey rather than more overstorey canopy cover (see Tables 1 and 2).

The pattern of recovery in crown density index is similar to that for total cover (Fig. 5C). However, the rate of increase in crown density index is not as great as for either overstorey canopy cover or total cover.

The time taken for overstorey canopy cover, total cover and crown density index to reach prelogging values is slighly greater than that reported for leaf area index by Carbon *et al.* (1979). They found that jarrah forest re-established the prelogging leaf area index within five years, and that the leaf area index of six-year-old karri was about double that of mature karri. Grove and Malajczuk (1985) found that a four-year-old karri stand had as much karri leaf biomass, and nearly as much total leaf biomass as a 36-year-old stand. Their eight and 11-year-old stands had considerably more karri leaf and total leaf biomass than their 36-year-old stand.

The estimates for understorey cover show that the understorey is an important component of stand density, particularly in the first few years of regeneration. However, the understorey cover does not generally increase with stand age. Grove and Malajczuk (1985) have also shown this to be the case in karri stands.

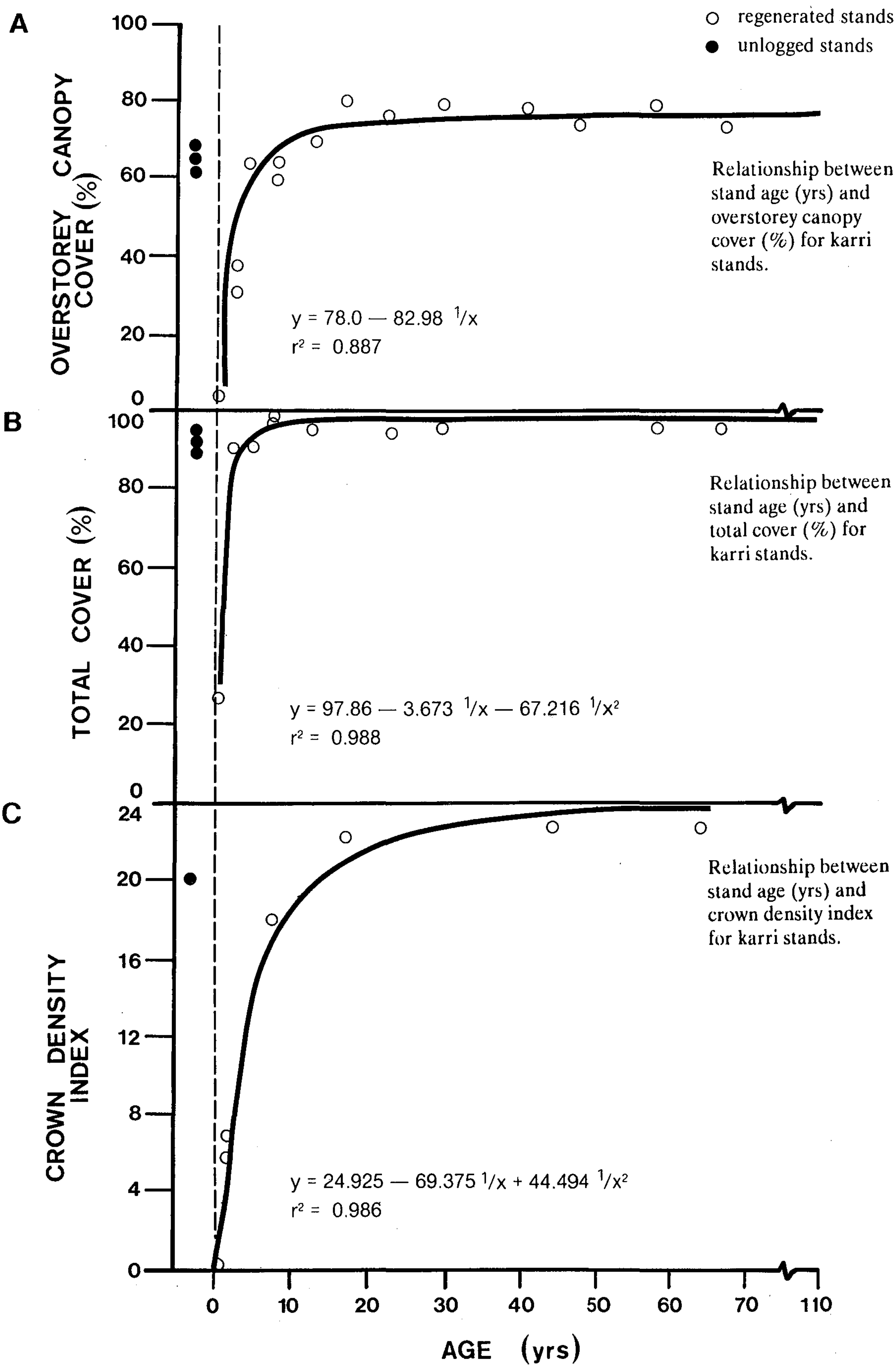

A
B
C
○ regenerated stands
● unlogged stands
OVERSTOREY CANOPY COVER (%)
Relationship between stand age (yrs) and overstorey canopy cover (%) for karri stands.
y = 78.0 — 82.98 1/x
r² = 0.887
TOTAL COVER (%)
Relationship between stand age (yrs) and total cover (%) for karri stands.
y = 97.86 — 3.673 1/x — 67.216 1/x²
r² = 0.988
CROWN DENSITY INDEX
Relationship between stand age (yrs) and crown density index for karri stands.
y = 24.925 — 69.375 1/x + 44.494 1/x²
r² = 0.986
AGE (yrs)

Figure 4

TABLE 3

Forest density of the karri forest study sites.

Site Number	Time since logging (yrs)	Average tree height (m)	Overstorey canopy cover (%)	Scrub Cover (%)	Basal area (m^2 ha^{-1})	Crown density index
21	1	0.8	5	22	0	0.1
18	3	2.8	38	49	1.2	7.0
20	3	2.7	31	60	1.4	5.8
22	5	5.3	64	28	NA	NA
23	8	8.9	64	34	NA	NA
24	8	9.7	60	39	NA	NA
39	8	NA	NA	NA	14.0	18.0
32	13	17	70	26	NA	NA
25	17	24	80	12	NA	NA
38	17	NA	NA	NA	31.0	22.2
33	23	24	76	19	NA	NA
26	30	33	79	18	NA	NA
34	41	44	78	11	NA	NA
37	44	NA	NA	NA	32.4	22.8
27	48	46	75	24	NA	NA
35	58	55	79	18	NA	NA
36	64	NA	NA	NA	41.6	22.8
28	67	52	73	24	NA	NA
29	110	60	78	22	NA	NA
19	Control	53	64	26	41.2	20.1
30	Control	59	66	24	NA	NA
31	Control	57	63	32	NA	NA

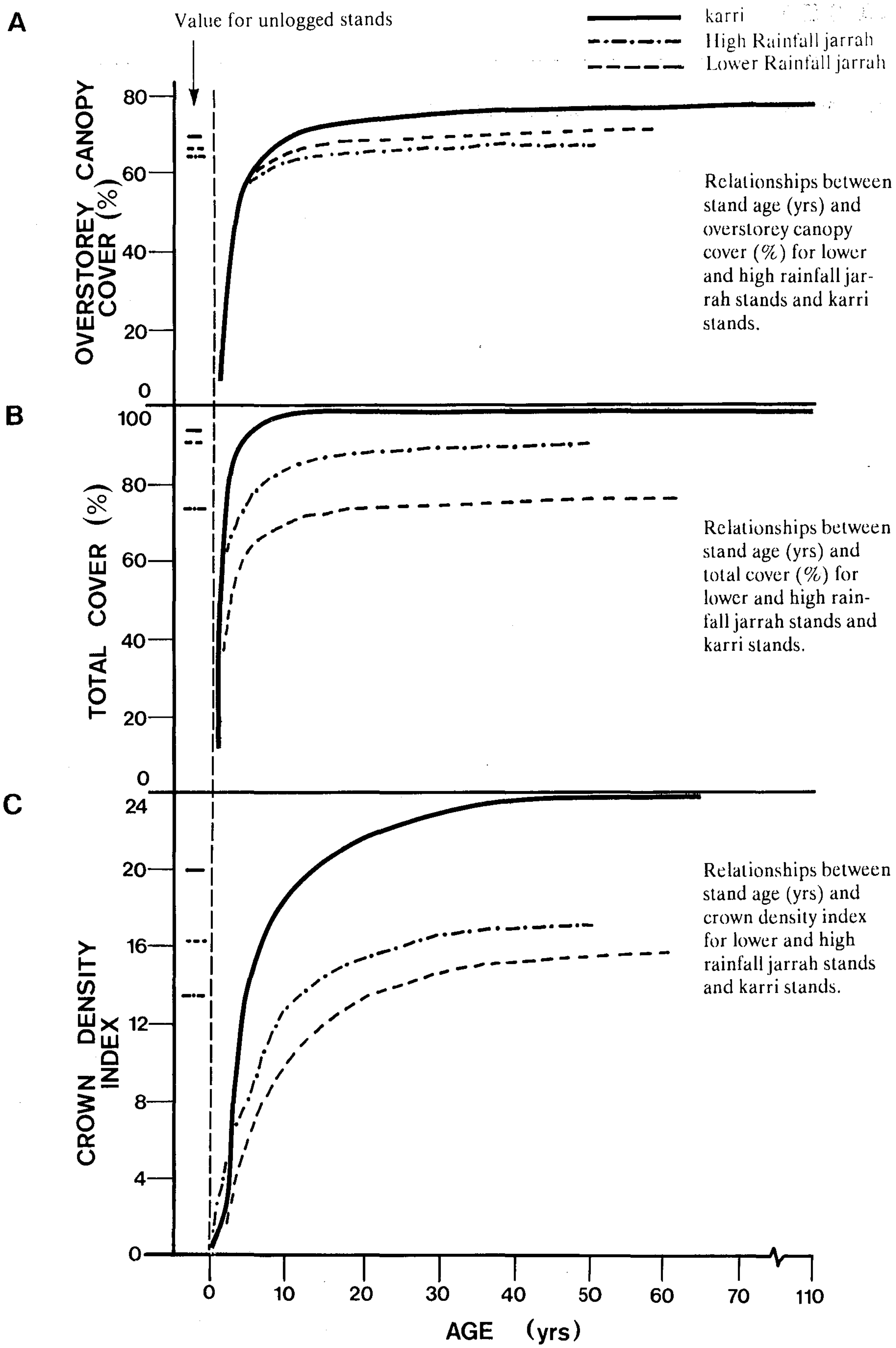

A
B
C
Value for unlogged stands
karri
High Rainfall jarrah
Lower Rainfall jarrah
OVERSTOREY CANOPY COVER (%)
80
60
40
20
0
Relationships between stand age (yrs) and overstorey canopy cover (%) for lower and high rainfall jarrah stands and karri stands.
TOTAL COVER (%)
100
80
60
40
20
0
Relationships between stand age (yrs) and total cover (%) for lower and high rainfall jarrah stands and karri stands.
CROWN DENSITY INDEX
24
20
16
12
8
4
0
Relationships between stand age (yrs) and crown density index for lower and high rainfall jarrah stands and karri stands.
0
10
20
30
40
50
60
70
110
AGE (yrs)

Figure 5

4.2. Other Effects on Recovery of Forest Density

4.2.1. Stocking

The visual estimates of stocking accounted for all stems greater than approximately 10 cm d.b.h., 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 6 indicates that where stocking was low (< 1000 stems ha^{-1}) in young regrowth jarrah stands, crown density index was less than the average for this age. In older stands crown density index was not sensitive to stocking densities of below 1000 stems ha^{-1}. This is because in older stands, stockings of less than 1000 stems ha^{-1} would still give full site occupancy, and thus a similar crown density index to stands with more than 1000 stems ha^{-1}. This relationship was not investigated in the karri sites.

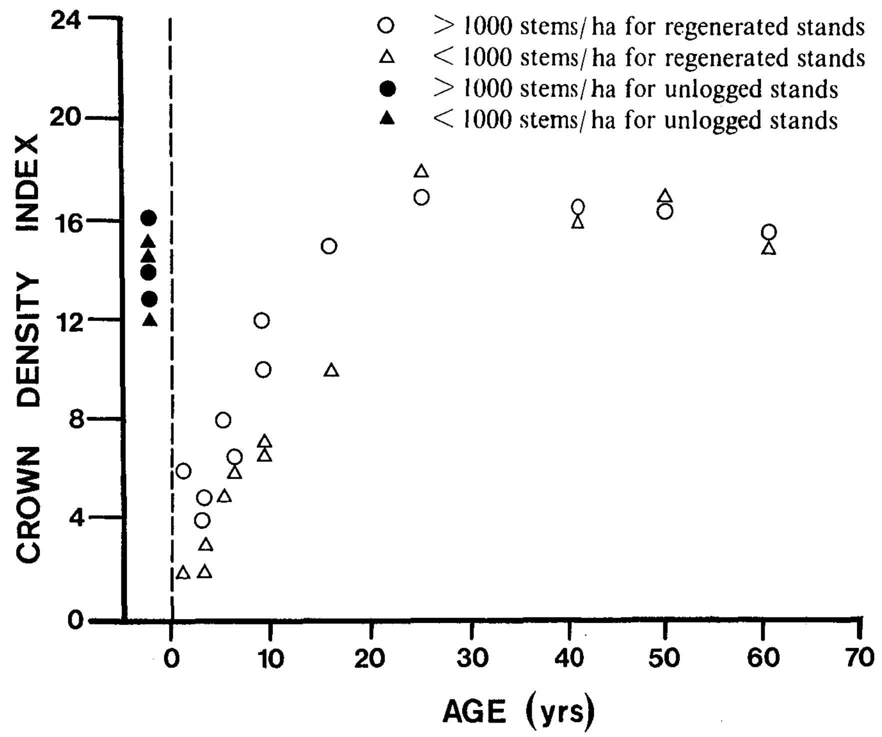


Figure 6

Relationships between stand age (yrs) and crown density index for jarrah stands with different stocking levels.

Hence, it is important that young regrowth stands are well stocked (> 1000 stems ha^{-1}) if crown density is to recover rapidly after logging. The regrowth stocking following logging in jarrah stands is dependent largely on:

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

(ii) the severity of logging disturbance and the degree to which it encourages regeneration by overstorey tree species.

4.2.2. Site-Type

Forest density was less on the poorer-drained site-types compared with the freely-drained type in the jarrah forest (Fig. 7). Crown density index in particular is lower on the poorer-drained sites, and slower to recover after logging (Fig. 7B). Crown density index takes more than 20 years to return to original values compared with 10 to 15 years on freely-drained sites.

For rapid recovery of the overstorey canopy cover regeneration after logging on the poorer-drained sites, it may be necessary to increase the stocking of regenerating trees, increase their growth rate, or both. This may require retention of standing seed trees after logging, soil and understorey manipulation to allow regeneration establishment, artificial seeding or planting, or fertilizer application to improve growth rates. Cutting of the poorer sites may itself be questionable, especially when they often contain only small volumes of utilizable resource and the short term economic returns from the logging may be less than the cost of adequately regenerating and managing the stand.

4.3. Other Silvicultural Aspects

4.3.1. Species composition of regrowth

As the stand ages the jarrah component increases towards the values found in unlogged stands (Fig. 8).

Schuster (1980) points out that the options for increasing jarrah's share of the stand include thinning and fire. These options may work but have potential drawbacks. Thinning of the young regrowth stands is likely to be non-commercial and very expensive, and fire is likely to damage potential crop trees. If considered viable options, however, they need to be evaluated and their hydrological impact assessed.

4.3.2. Stump coppice

The contribution of stump coppice to the stand is generally high in the early years but drops rapidly with time to be negligible in stands of 20 years and older (Fig. 9).

Schuster (1980) found that eight years after the clearfelling of coupes, stump coppice had an adverse effect on the growth of other forms of regeneration, which he postulated may increase with time. Our data indicates otherwise.

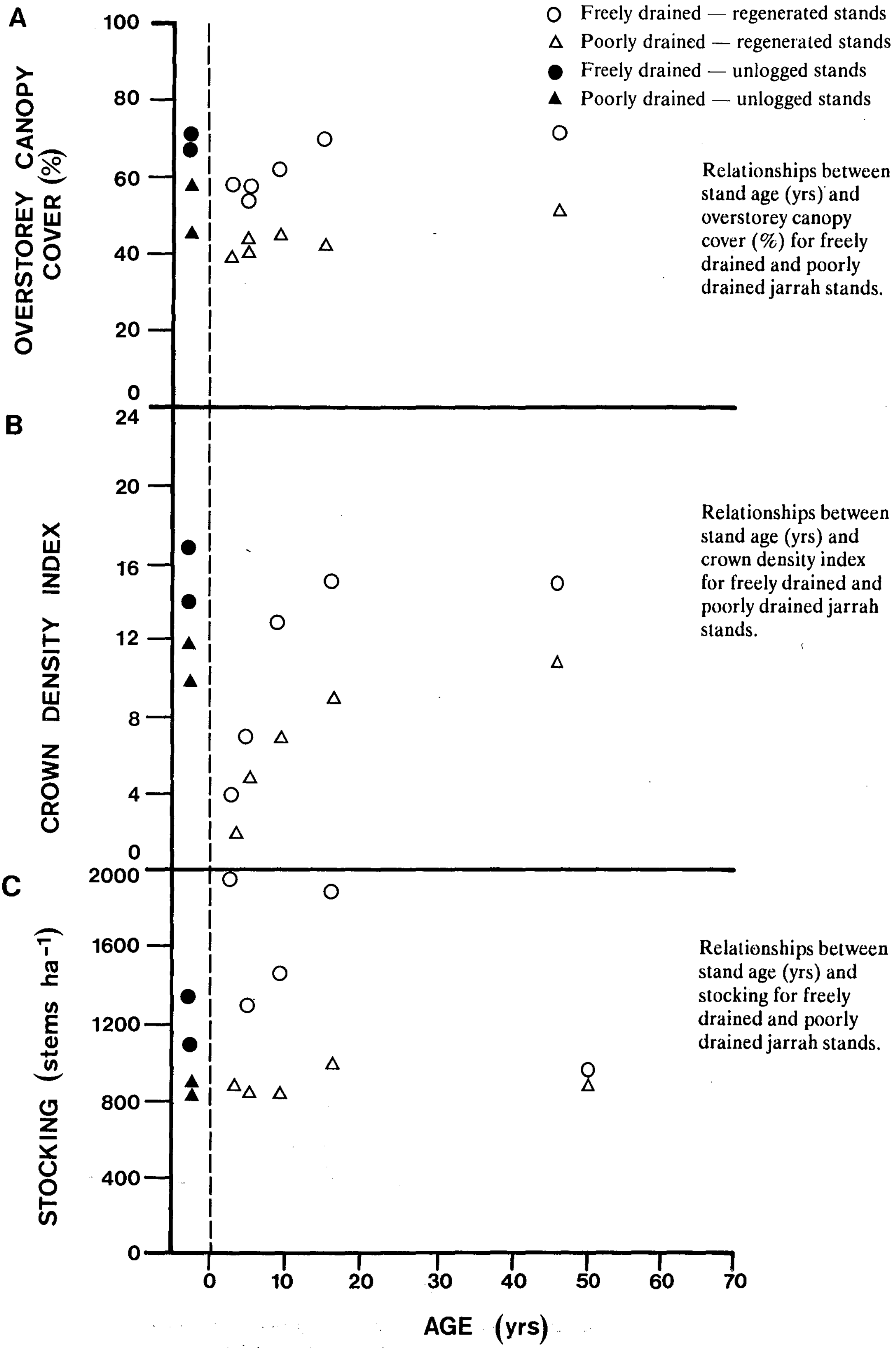

A
B
C
Freely drained — regenerated stands
Poorly drained — regenerated stands
Freely drained — unlogged stands
Poorly drained — unlogged stands
Relationships between stand age (yrs) and overstorey canopy cover (%) for freely drained and poorly drained jarrah stands.
Relationships between stand age (yrs) and crown density index for freely drained and poorly drained jarrah stands.
Relationships between stand age (yrs) and stocking for freely drained and poorly drained jarrah stands.
OVERSTOREY CANOPY COVER (%)
CROWN DENSITY INDEX
STOCKING (stems ha-1)
AGE (yrs)

Figure 7

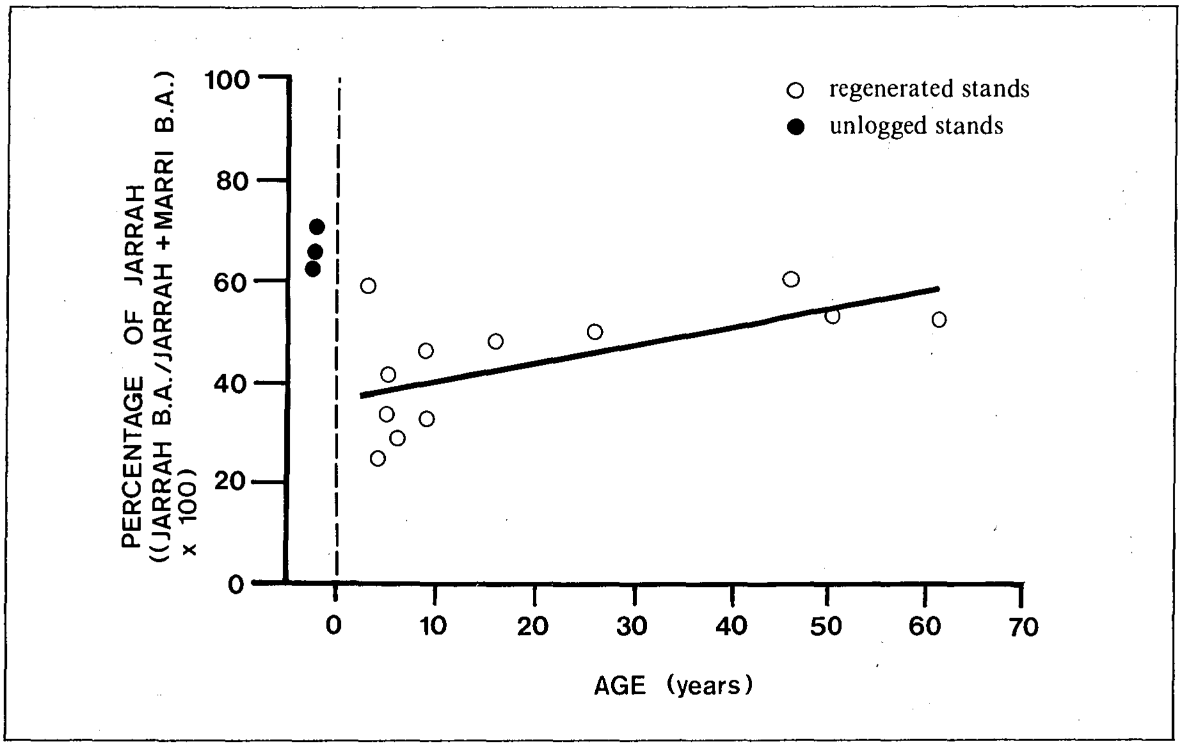


Figure 8

Relationship between stand age (yrs) and the percentage of jarrah in the stand ([jarrah basal area/jarrah + marri basal area] x 100) for all jarrah stands.

$y = 37.7 + 0.35x \qquad r^2 = 0.370$

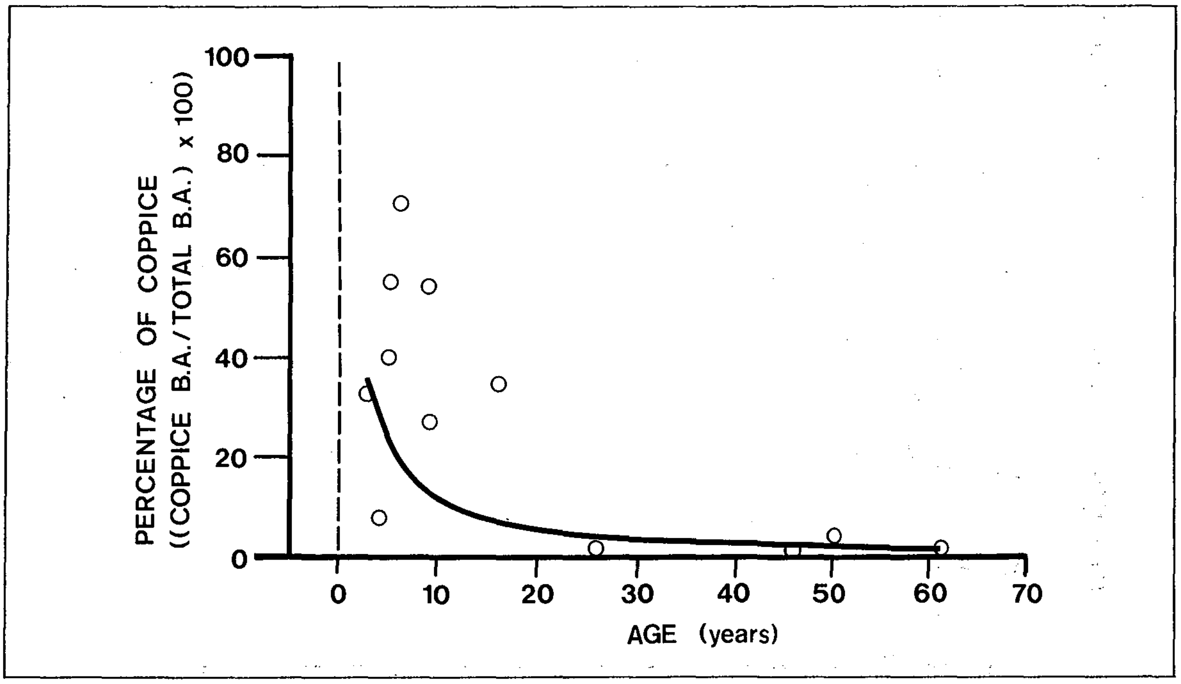


Figure 9

Relationship between stand age (yrs) and the percentage of coppice in the stand ([coppice basal area/total basal area] x 100) for all jarrah stands.

$^1/y = 0.00842x + 0.00221$

Nevertheless, the proportion of the resources of the stand going into stump coppice, which is unlikely to ever be merchantable, could perhaps go to growth of more useful timber.

This needs to be balanced against the rapid growth and dominance of stump coppice in the early years, which probably makes a large contribution to the evapotranspiration in these catchments (see Section 4.4). In areas with substantial accumulations of salt in the soil profile, this coppice serves a hydrologic purpose by its contribution to evapotranspiration and reducing any rise in the ground water level.

4.4. Impact on water use

Following logging, the rapid recovery of total cover, overstorey canopy cover and crown density index, indicate that evapotranspiration quickly returns to close to prelogging values. Additionally, there is evidence to suggest that water use is greater per unit of cover for regrowth stands of eucalypts than for old-growth stands (Conner *et al.* 1977). It therefore appears unlikely that long term salinity problems would arise if the cut-over areas are regenerated soon after the completion of logging. This is supported by the short term results from the catchment experiments where no significant increases in stream salinity were found, even in areas with high soil salt storages (Borg *et al.* 1987a; Borg *et al.* 1987b).

The results from these catchment experiments (Borg *et al.* 1987a; Borg *et al.* 1987b) show that the short term trends in streamflow and ground water following logging correspond to the trends in forest density. Ground water levels rose for two to four years in all rainfall zones and then started to decline. The lowering of the ground water levels after about five years corresponds with the age at which total cover is within 80 or 90 per cent of unlogged values, and indicates high rates of water use at and beyond this age. Streamflows also show a similar pattern, with an increase for two to three years after logging and then a gradual decline back to prelogging values after perhaps 10 or 12 years. This suggests that water use by regrowth forest after about five to 10 years is similar to that of old-growth forest.

The contribution of ground and stump coppice to restoring the water balance is significant. Where coppice was poisoned following a thinning, ground water levels continued to rise for at least four years, with no indication of the increase levelling off (Stoneman 1986; Stoneman unpublished data). In contrast to this, where coppice grew freely following logging, ground water levels reacted differently. There was a rapid increase for the first one to two years, with a slowing of the increase for the next two to three years, followed by a four-year steady decline in ground water levels (Borg *et al.* 1987a; Borg *et al.* 1987b).

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APPENDIX I

Description of the lower rainfall jarrah forest study sites.

Site Number	Time since logging (yrs)	Location	Area sampled (ha)	Overstorey composition	Annual rainfall (mm)	Soil Type
2	3	Warrup 2 (Yerraminnup South)	160	Jarrah-marri	830	Laterites and yellow podzols
3	4	Yetticup 7	120	Jarrah-marri	900	Laterites, yellow podzols and clays
9	4	Cardac 4	140	Jarrah-marri	1010	Laterites and yellow podzols
4	6	Cardac 3	30	Jarrah-marri	950	Laterites and yellow podzols
1	7	Mooralup 2	200	Jarrah-marri	880	Laterites, yellow podzols and clays
5	46	Yardup 1	160	Jarrah-marri	900	Laterites and yellow podzols
8	61	Yornup 3	180	Jarrah-marri	920	Laterites and yellow podzols
6	Control	Warrup 1 (Yerraminnup North)	200	Jarrah-marri	850	Laterites and yellow podzols
7	Control	Mooralup 2	200	Jarrah-marri	880	Laterites and yellow podzols

APPENDIX II

Description of the high rainfall jarrah forest study sites.

Site Number	Time since logging (yrs)	Location	Area sampled (ha)	Overstorey composition	Annual rainfall (mm)	Soil Type
13	1	Iffley 2	200	Jarrah-marri	1200	Laterites, red earths and podzols
11	3	Lewin 4 (Lewin South)	100	Jarrah-marri	1230	Laterites, podzols and surface clays
14	5	Lewin 5	250	Jarrah-marri	1230	Laterites, podzols and surface clays
15	7	Iffley 9	150	Jarrah-marri	1200	Yellow podzols, red earths and surface clays
10	16	Lewin plot	10	Jarrah-marri	1220	Podzols and surface clays
17	26	Mack 1	150	Jarrah-marri	1130	Laterites, red earths and yellow podzols
16	50	Wheatley 4	100	Jarrah-marri	1150	Laterites and yellow podzols
12	Control	Lewin 4 (Lewin North)	150	Jarrah-marri	1240	Laterites, red earths and podzols

APPENDIX III

Description of the karri forest study sites.

Site Number	Time since logging (yrs)	Location	Area sampled (ha)	Overstorey composition	Annual rainfall (mm)	Soil Type
21	1	Sutton 11	70	Karri-marri	1000	Podzols and red earths
18	3	Sutton (April Rd North)	100	Karri-marri, some jarrah	1070	Podzols and red earths
20	3	Sutton (March Rd)	200	Karri-marri, some jarrah	1040	Podzols and red earths
22	5	Sutton West	10	Karri	1150	Podzols and red earths
23	8	Crowea East	10	Karri	1380	Podzols and red earths
24	8	Poole West	10	Karri	1310	Podzols and red earths
39	8	Quininup	5	Karri	1050	Podzols and red earths
32	13	Nairn	5	Karri	1150	Podzols and red earths
25	17	Crowea West	10	Karri	1400	Podzols and red earths
38	17	Quininup	5	Karri	1050	Podzols and red earths
33	23	Nairn	5	Karri	1150	Podzols and red earths
26	30	Sutton West	10	Karri	1150	Podzols and red earths
34	41	Diamond 2	5	Karri	1100	Podzols and red earths
37	44	Sutton	5	Karri	1050	Podzols and red earths
27	48	Quininup West	10	Karri	1050	Podzols and red earths

APPENDIX III (continued)

Site Number	Time since logging (yrs)	Location	Area sampled (ha)	Overstorey composition	Annual rainfall (mm)	Soil Type
35	58	Big Brook	5	Karri	1400	Podzols and red earths
36	64	Sutton	5	Karri	1050	Podzols and red earths
28	67	Sutton West	10	Karri	1000	Podzols and red earths
29	110	Big Brook	5	Karri	1400	Podzols and red earths
19	Control	Sutton (April Rd South)	200	Karri-marri, some jarrah	1080	Podzols and red earths
30	Control	Warren Nat. Park	5	Karri	1400	Podzols and red earths
31	Control	Brockman	5	Karri	1400	Podzols and red earths