# PRODUCTION OF HABITAT HOLLOWS BY WHEATBELT EUCALYPTS

FINAL REPORT

SAVE THE BUSH RESEARCH GRANT 1991/92 - PROJECT R053

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## SUMMARY

Stands of wandoo *(Eucalyptus wandoo)* and salmon gum *(Eucalyptus salmonophloia)* provide most of the hollows used by wildlife in the Wheatbelt of Western Australia. Stands generally occur as isolated remnants or scattered individual trees amongst large tracts of cleared agricultural farmland. Stands of both species were sampled to investigate stand dynamics and associated hollow occurrence. Characteristics of both varied across the annual average rainfall gradient (west to east) with fire and past disturbance history exerting strong influence.

Tree ages were estimated using stem analysis and dendrochronology techniques. Age/tree diameter relationships were established for both species dependant on average annual rainfall occurrence. Limited sample size, slow growth rates and hollowing of the boles, constrained the accurate estimation of age of larger trees, with results being obtained from extrapolation from available data.

Growth rates of trees were directly related to annual average rainfall in both species, decreasing in drier, eastern stands.

Hollows occurred in smaller trees in eastern stands compared to western stands although age estimates for hollow occurrence were similar across the rainfall zones. Hollows first occurred after approximately 100 years in wandoo and 120 years in salmon gum. Larger size hollows take longer to form, occurring after trees reach an age of 150 to 200 years. Significantly, hollows occur across a range of tree sizes and ages with most hollows in natural stands occurring in mid-diameter class trees, as these trees generally occur most frequently. As trees age they are likely to contain more hollows of large size. Large veteran trees of both species had age estimates of 400 to 500 years.

Hollows were found to occur frequently in most stands sampled, however the provision of an ongoing supply of hollows for wildlife habitat in the long term can only be achieved by maintaining a broad tree size-class distribution and ensuring adequate regeneration replacement. Livestock grazing, weed and grass intrusion and the small size of many remnant stands provide major obstacles to the long term health and conservation of these stands.

Further input is required to identify the most important stands in terms of wildlife habitat and overall conservation, appropriate management strategies can then be investigated and targeted appropriately.

CONTENTS

# 1. INTRODUCTION

Many vertebrate species within Australia use hollows in standing trees for resting, nesting and feeding including 119 species of birds (17% of all bird species) and 95 species of mammals (42% of all mammal species). (Ambrose 1982). Indeed 11% of all bird species in Australia are obligate hollow nesters (Saunders et al. 1982).

The importance, availability and use of hollows by cockatoos (Psittaciformes) has been investigated in the WA Wheatbelt with questions raised as to the long term sustainability and management of hollow-tree stands (Saunders et al. 1982, Saunders 1979, Saunders 1977). Hollow formation in trees has been studied extensively in eastern Australia (Lindenmayer et al. 1991, Mackowski 1984, Ambrose 1982) and specifically in Western Australia by Inions (1985) and Faunt (1992). Knowledge of the processes involved and life histories of hollows in trees will provide a basis for management of an increasingly threatened resource. This is especially the case in wheatbelt Western Australia where natural vegetation has been largely denuded through agricultural clearing. Native stands are generally isolated within large tracts of cleared land with stand remnants and individuals along roadsides and within private property.

The dimensional stability of tree canopies and thus their capacity to form hollows, is largely dependent on tree age (Mackowski 1984), although fire can play an important role (Faunt 1992, Abbott & Loneragen 1983, Ambrose 1982).

Relationships can be established between tree age and diameter of dominant trees allowing trees to aged from simple diameter measurements. Stem analysis and dendrochronological studies are often used to determine tree age (Raynor 1992).

Annual rainfall, decreasing generally from west to east in WA is likely to exert a major influence on stand development and the age/diameter relationship. Also past and current management practises and disturbance events (eg. timber harvesting, fire history, agricultural clearing, grazing) are likely to exert an overriding influence on stand structure.

This study aims to investigate the factors which influence habitat hollow production across the climatic range in the Western Australian wheatbelt. The implications that these have for future management for wildlife and overall long term conservation will be discussed and recommendations made in light of the study.

# 2. METHODS

## 2.1. Species Selection

Wandoo (Eucalyptus wandoo) and Salmon Gum (E. salmonophloia) have a wide geographic distribution across the Western Australian wheatbelt, with Wandoo extending across the higher rainfall Western areas and Salmon Gum overlapping and extending in the lower rainfall eastern zones. It is these two species which are recognised as producing the majority of habitat hollows throughout the region (Saunders et al. 1982, Saunders 1979).

(a) Wandoo

Distribution ranges from the west, associated with jarrah (E. marginata) and marri (E. callophylla) forest types in the 700-800 mm/year rainfall zone, to the east, in woodland associations in the 350-400 mm/year rainfall zone (Figure 1A). This west to east gradient extends 300 to 400 kilometres. Western stands lie within large tracts of forested land while eastern stands are mainly restricted to relatively isolated remnants within cleared farmland surrounds.

(b) Salmon Gum

Distribution extends from the western zone of approximately 500 mm/year rainfall (in the Narrogin Region) to the Goldfields in the east with 200 to 250 mm/year rainfall (Figure 1A). Although Salmon gum is widely dispersed geographically, agricultural clearing has greatly depleted natural stands leaving mainly isolated remnants along roadsides, within small crown reserves and scattered within cleared farmland.

## 2.2. Study Areas

Sites were chosen within representative stands across the climatic range for both species (see Appendix 1 for site details).

(a) Wandoo

Study areas were selected around three climatic (rainfall) zones: (Figure 1B)

Western Zone - 600 to 800 mm/year rainfall. Ten sites selected in the Jarrahdale and Mundaring areas.

Central Zone - 450 to 550 mm/year rainfall. Seven sites selected in the Dryandra State Forest area.

Eastern Zone - 300 to 400 mm rainfall. Three sites selected within the Dongolocking nature reserves.

(b) Salmon Gum

Sites were classified across the rainfall gradient into two zones: (Figure 1B)

Western Zone - 400 to 450 mm/year. Five sites on reserves and private property in the Dumbleyung and Wickepin Shires.

Eastern Zone - 300 to 350 mm/year. Four sites in the Dragon Rocks nature reserve south of Hyden.

Time and cost constraints did not allow for sampling in the drier (200-250 mm/year) east salmon gum stands which extend to the eastern wheatbelt and goldfields. Limited diameter increment data was available from a site near Coolgardie (Dept. of CALM 1983) and was utilised to comparing growth rates.

## 2.3. Soils and Landform

Both Salmon Gum and Wandoo Stands are associated with heavier clay / loam soils generally lower in the topography which gain moisture in the wet winter months.

Soils influence the growth characteristics of trees both within and between sites in a complex matter. Sample sites were selected on similar soil and landform associations in order to minimise these effects, as the broad scale of this survey was not be sensitive to soil and micro-site influences.

## 2.4. Sampling

The methodology of this project consisted of carrying out stand analysis over a range of sites across the rainfall gradient. Bole and core sections were taken from standing and windthrown trees providing representative samples for each species in the various rainfall zones.

### 2.4.1. Stand Analysis

Representative sites were selected within each species association in the climatic zones. Line samples were randomly selected at each site providing 0.4 to 2.0 ha samples. Sample size depended on stand and site variability, accessibility and stocking density of the stands.

Assessment at each site included individual tree parameters of species, dbhob, and height as well as stand parameters of basal area and stocking density.

The status and condition of individual trees was assessed by recording tree dominance, crown condition and form (see Lindenmayer et al. 1991). Hollow assessment for each tree was carried out using visual scanning from the ground. Each tree was scored for hollows in terms of a size and frequency rating (Refer to Appendix 2 for assessment criteria). Because of the difficulties in accurately determining the number of hollows in a crown (see 2.5.2), the numbers of hollows observed were recorded as one of the 3 classes.

### 2.4.2. Age Estimation

#### 2.4.2.1. Stem Analysis

Bole sections or radial core samples were taken from dominant trees across a range of diameter classes in each climatic zone. A minimum of five samples were obtained from each zone with more samples available in the western and central wandoo areas. Whole discs were taken on smaller size class trees however larger trees often lacked a solid core. Radial core sections were taken from standing trees allowing for non-destructive sampling.

#### 2.4.2.2. Permanent Plots

Available data from eight 0.4 ha plots in the Jarrahdale and Mundaring Districts (Western Wandoo) was utilised to obtain annual diameter increment figures based on a 17 year period. Data from Wandoo thinning plots (Dept. of CALM 1990) was also utilised to obtain diameter increment data over a four year period. (Appendix 3A & 3B).

Limited data on mean diameter growth rates was also obtained for Salmon gum in the more eastern Coolgardie area (200-250 mm/yr rainfall) from Dept. CALM records (Dept. of CALM 1983). (Appendix 3C).

2.4.2.3. Ring Counting

Both wandoo and salmon gum display seasonal trends in diameter increment. Annual growth rings are produced comprising of dark latewood and lighter earlywood which allows trees to be aged by counting the growth rings thus laid down. (Schweingruber 1988, Hopkins 1968).

Rings were visually counted (using a magnifying lamp). The entire surface of intact trees was planed to detect false or partially complete rings. Mean ring counts and subsequent growth rates were determined by averaging two representative stem radii.

Young wandoo trees of known age (29 years) were assessed using this method and the corresponding number of annual rings were easily discerned. The Astbury remnant near Harrismith regenerated after clear-felling in the mid-1920's (P. Piggott Personal Communication). Two edge-dominant trees sampled from this site had an average age of 72 years as determined by ring counting, while suppressed and subdominant trees had an average age of 46.5 years. This indicates that only dominant trees possess ring numbers which accurately correspond to true stand age (Raynor 1992). Accuracy also decreases as trees age and growth rings become less distinct (see 2.5.3.).

Core samples only were available from large veteran trees, necessitating ring counting on single radii in each of these samples. An average ring count was available where two or more cores were taken from each tree. Large veteran trees generally lacked a central core, ages for these trees were obtained using proportional estimation.

## 2.5. Constraints of Study

### 2.5.1. Site Selection

The range and intensity of field sampling was constrained by:

- the broad geographical distribution of sample sites (over 300 to 400 km) imposing time and cost constraints.
- the isolated nature of eastern wandoo and salmon gum stands and their limited distribution which restricted sample site selection.
- Restrictions in conducting extensive stem analysis sampling in nature reserves (eastern wandoo and salmon gum sites).

Because of these constraints most sites were selected in the more accessible western and central wandoo areas and no sampling was undertaken in the lower rainfall extremes of the salmon gum distribution area (ie goldfields and northern wheatbelt). It is regarded however that sample sizes were adequate within the rainfall zones studied to enable indicative trends to be identified.

### 2.5.2. Hollow Assessment Accuracy

As has been found with previous studies (Lindenmayer et al. 1991, Inions 1985, Mackowski 1984, Ambrose 1982), ground observations provide difficulties in accurately assessing hollow numbers and opening diameters, especially in larger trees with spreading crowns. Furthermore the quality (depth, internal characteristics) and usage of hollows was not able to be assessed from ground level.

### 2.5.3. Stem Analysis

#### 2.5.3.1. Heartwood Decay

Most trees with diameter greater than 45 to 50 cm had heartwood decay and various degrees of internal hollowing - proportionately increasing with increasing diameter. Extrapolation using average annual diameter increment estimates was required to obtain estimates of age. Knowledge of the age of trees of similar diameter to the internal hollow was also used to estimate hollow tree age.

#### 2.5.3.2. Tree Dominance

Growth rates of individual trees are highly dependent on their position in the stand and the competitive interaction with neighbouring trees (White 1971, Rotheram 1983). The effect of tree competition and subsequent suppression is clearly evident in Wandoo and Salmon Gum stands, with trees of the same age having great variations in diameter (and other parameters) depending on the competitive influences of other trees. Thus a reasonably accurate tree diameter / age relationship is only attainable when dominant trees in a stand are considered. Raynor (1992) noted that in Karri (E. diversicolor) only the dominant trees possess ring numbers which accurately correspond to true stand age.

#### 2.5.3.3. Growth Ring Recognition

An overriding problem with the relatively slow growing Wandoo and Salmon Gum is the difficulty in recognising individual growth rings. Ring counting is especially difficult with older trees (>60cm) which generally have lower diameter increments than younger dominant trees (Raynor 1992) with narrow and often poorly defined rings. Older Wandoo were found to be especially difficult with rings often missing, fused and generally difficult to identify.

#### 2.5.3.4. Time Requirements of Stem Analysis

Ring counting and stem analysis of these species is especially time consuming because of the difficulties in growth ring identification as outlined above. The scope of the study did not allow for more extensive stem analysis sampling.

The effects of the above factors (as well as site, climatic and other ephemeral influences) on annual growth ring deposition are varied, and they cumulatively affect tree ageing accuracy. However for the purpose of this study it is assumed that the age estimations thus obtained are sufficiently accurate to be indicative of the underlying trends.

# 3. RESULTS

## 3.1. Stand Structure

### 3.1.1. Diameter Distribution

(a) Wandoo

The diameter distribution for most Wandoo stands is highly skewed in favour of smaller diameter classes. However, size class distribution varies in each, reflecting the level of intensity of man induced or natural disturbance event (Appendix 4).
Stands subject to intense past disturbance such as heavy logging and silvicultural treatment (for example site 6, Figure 2), or clearing for agriculture (Figure 3), are predominantly even aged with a restricted size class distribution. Most trees are in lower dbhob classes with variation resulting from competition and suppression.

Stands with a history or periodic selective logging, providing less intense disturbance, show irregular structure with scattered even aged "cohorts" amongst mature and over mature veterans. This stand structure is predominant in western (Figures 4 & 5) and some central (Dryandra), sites which generally have a higher proportion of smaller dbhob regrowth resulting from logging activity. These stands also have reduced frequencies of mid-size class mature trees compared to the unlogged or lightly logged eastern stands, due to more intensive log harvesting operations. These reduced frequencies of mid to large trees in Western sites are reflected in lower hollow frequency results (discussed later).

In contrast, the relatively undisturbed virgin stands (Figures 6 & 7) have fewer trees in smaller size classes and more even distribution throughout the range of size classes.

(b) Salmon Gum

There is visual evidence of past opportunistic log, removal probably for agricultural use in most Salmon Gum stands. Also fire and other natural events have led to irregular, unevenaged stands with even-aged regrowth cohorts, similar to many of the Wandoo stands (Figure 8). In the sites within the Dragon Rocks area, which are representative of natural stands, there was a high stocking of naturally regenerated trees in smaller size classes (0 - 10cm dbhob) likely resulting from a relatively recent fire event (Figure 9).

However, the majority of Salmon Gum stands are restricted in the wheatbelt to isolated remnants within cleared agricultural surrounds, or as isolated paddock and roadside trees in narrow reserves. Grazing and grass intrusion within many of these stands inhibits regrowth recruitment. The stand tables of Salmon Gum sites 2 (Figure 10) and 10 (Figure 11) reflect this, with relatively low numbers in smaller size classes.

### 3.1.2. Top Height

The average height of the 5 tallest trees was determined for each site and averaged for each rainfall zone. Table 1 below.

**TABLE 1**

| | Average Top Height (metres) | Top Height Range (metres) |
|---|---|---|
| **Wandoo** | | |
| Western | 26 | 22.8 - 27.6 |
| Central | 23 | 17.8 - 26.3 |
| Eastern | 15 | 14.2 - 15.8 |
| **Salmon Gum** | | |
| Western | 25 | 22.5 - 25.8 |
| Eastern | 22 | 20.0 - 22.8 |

The average top height is greatest in the higher rainfall stands for both salmon gum and wandoo. Height, however, is highly influenced by various microsite characteristics, especially soils and moisture availability (Raynor, M. E. Department of CALM Manjimup, personal communication 1993). This factor accounts for the great variations between sites within the same rainfall zone.

### 3.1.3. Basal Area

Basal area is a measure of stem cross sectional area and it reflects the density of a stand.

**TABLE 2**

| | Average Basal Area ($m^2$/ha) | Basal Area Range ($m^2$/ha) |
|---|---|---|
| **Wandoo** | | |
| Western | 15 | 10 - 20 |
| Central | 20 | 12 - 30 |
| Eastern | 13 | 8 - 18 |
| **Salmon Gum** | | |
| Western | 10 | 8 - 16 |
| Eastern | 8 | 5 - 10 |

Abbott & Loneragan (1983) found that basal area decreased as site quality and rainfall decreased in the jarrah forest. This trend is evident from the results in Table 2, although the high rainfall wandoo sites have lower average basal area than the central sites. This is probably attributable to past log harvesting reducing basal area in many of the western sites sampled.

## 3.2. Habitat Hollows

### 3.2.1. Hollow Occurrence

(a) Wandoo

Figure 12 shows hollow distribution (expressed as a percentage of total number of hollows) within each diameter class. It is evident that hollows occur in smaller diameter trees as rainfall decreases. In eastern wandoo stands 75% of hollows occur in trees less than 60cm dbhob, 47% in central wandoo and 21% in western wandoo. Conversely in high rainfall western sites 56% of hollows occur in trees greater than 70cm dbhob compared to 25% in the central zone and 16% in the eastern zone.

The results also indicate that most hollows occur (corresponding to peaks in graph Figure 12) at 30-50cm dbhob on eastern sites, 50-70cm dbhob on central sites and 70-90cm dbhob on western sites. However, there are significantly more hollow trees per hectare on eastern and central sites than in the west (Figure 14, Table 3). This can be partly attributed to the fact that timber harvesting has reduced the numbers of larger trees likely to carry hollows in western stands.

When comparing an unlogged virgin stand to selectively cut stands, there are more stems per hectare in larger (>50cm dbhob) diameter classes, and greater hollow trees per hectare in these size classes as a result. However, it can be seen that total hollow trees per hectare are less in virgin stands than in selectively cut stands, reflecting reduced stocking density and regeneration recruitment in the natural stand compared to the more disturbed logged stands. This result implies that some form of disturbance is necessary within stands, in the long term, to initiate regeneration and hollow development.

The smallest diameter of trees where hollows were recorded is 20 to 30 cm. A greater proportion of hollow trees occur in eastern stands at this diameter range (14%) than in central (4%) and western stands (2%).

TABLE 3

| | Stems/ha | | Hollow stems/ha | |
|---|---|---|---|---|
| | Total | >50 cm | Total | >50 cm |
| **Wandoo** | | | | |
| Western | | | | |
| a. combined | 396 | 20 | 23 | 14 |
| b. site 7 (virgin) | 120 | 42 | 20 | 18 |
| Central | 255 | 39 | 74 | 36 |
| Eastern | 290 | 27 | 84 | 27 |
| **Salmon gum** | | | | |
| Western | 165 | 39 | 32 | 26 |
| Eastern | 320 | 23 | 21 | 13 |

(b) Salmon Gum

The trend for salmon gum also similar to that shown in wandoo, where eastern stands have more hollows in smaller size classes than those on more western sites (Figure 13). Conversely the western sites had greater proportions of hollows in larger diameter classes, with only 10% of hollows in trees less than 40cm dbhob compared to 28% in eastern stands. Western sites, however show greater numbers of hollow trees per hectare (Figure 15), probably reflecting the greater stocking of larger trees (Table 3) and greater basal areas.

Salmon gum have shown to have fewer hollow trees per hectare than wandoo, with most hollows in comparatively larger size classes. This may be a reflection of different wood characteristics (and subsequent decay patterns), or of the observations that salmon gum are generally taller, of better form, and have less damaged crowns than wandoo in the same rainfall zones.

The smallest trees in which hollows were recorded ranged from 21 to 40 cm dbhob with approximately 4% of hollows found in these size classes. Saunders et al. (1982)

found that the smallest size salmon gum trees with a hollow of suitable size for black cockatoos was 22 cm dbhob, while the smallest tree actually nested in ranged from 25cm dbhob for cockatoos to 32 cm dbhob for corellas and red-tailed black cockatoos.

3.2.2. Hollow Size

(a) Wandoo

As may be expected, there were generally more small hollows than larger ones with small and medium hollows usually occurring in the crowns and branches, and larger hollows (>20cm) often associated with larger branch decay and bole damage.

Hollows in smaller size class trees (<50cm dbhob) were mostly small (<10cm) with occasional medium hollows and few larger hollows. (Figures 16, 17 and 18). In larger trees however, larger hollows were in comparatively higher proportions. This trend is similar to findings of Mackowski (1984) and Ambrose (1982) for E. pilularis and E. regnans respectively, where large hollows did not occur in significant numbers in most stands in trees below 50cm dbhob.

Eastern wandoo sites had higher proportions of larger (>20cm diameter) hollows in small size class trees (20-30 cm dbhob). However on these sites, 74% of large hollows were found in trees having fire induced damage to tree boles.

The proportions of trees in each size class with different size hollows are shown in Figures 21, 22 and 23. As would be expected, as tree size increases, more of the available trees have hollows.

There are fewer larger hollows in smaller trees generally with larger size trees having a greater likelihood of having hollows of all sizes.

(b) Salmon Gum

Hollow size distribution in Salmon Gum shows similar trends to wandoo (Figures 19 and 20).

The western salmon gum sites generally have greater total numbers of all types of hollows, especially within the 50-80 cm dbhob classes, than the eastern stands. Similarly to Wandoo, results suggest a positive relationship between hollow size and tree diameter, with larger trees having proportionally more hollows, especially of larger sizes (Figures 24 and 25).

### 3.2.3. Crown Condition and Fire Damage

A high proportion of the trees with hollows on all sites have damaged crowns ie crowns with many stags, broken branches and evidence of wood decay (Table 4).

**TABLE 4**

| | % of hollow trees with crown damage | % of total trees with crown damage |
|---|---|---|
| **Wandoo** | | |
| Western | 69 | 29 |
| Central | 80 | 44 |
| Eastern | 89 | 59 |
| **Salmon Gum** | | |
| Western | 82 | 44 |
| Eastern | 85 | 49 |

There is a trend towards increasing crown damage (ie poor crown condition) on the lower rainfall sites. Apart from overmaturity, fire is the most likely cause of the crown damage and subsequent hollow formation. Although not directly assessed in this study, many trees were observed to have butt and bole scars resulting from fire damage. Indeed studies in the jarrah forest have found fire to be associated with high proportions of log hollows (Faunt 1992).

### 3.2.4. Tree Competition

The results in Table 5 show that most smaller size class trees (<50cm dbhob) with hollows are either suppressed or subdominant. This factor is important when estimating the age of such hollow-bearing trees and will be discussed later.

Conversely in larger size classes (>50cm dbhob) most hollows are found in dominant and codominant trees.

**TABLE 5**

| | % of Hollow Bearing Trees which are Subdominant or Suppressed | |
|---|---|---|
| | < 50 cm dbhob | > 50 cm dbhob |
| **Wandoo** | | |
| Western | 58 | 48 |
| Central | 65 | 29 |
| Eastern | 68 | 24 |
| **Salmon Gum** | | |
| Western | 54 | 22 |
| Eastern | 66 | 33 |

### 3.2.5. Tree Form

In this study, "form" described the branching pattern and crown shape of trees. (See Appendix 2 for assessment criteria).

**TABLE 6**

| | % of Trees with Hollows with Good or Moderate Form | |
|---|---|---|
| | Total Trees | Trees < 50 cm dbhob |
| **Wandoo** | | |
| Western | 72 | 42 |
| Central | 61 | 33 |
| Eastern | 37 | 40 |
| **Salmon Gum** | | |
| Western | 71 | 45 |
| Eastern | 70 | 42 |

In the stands assessed most trees with hollows have moderate to good form, excepting the eastern wandoo stands. The poorer form of trees with hollows in eastern stands reflects the poor quality of these stands generally.

Consideration of smaller size classes (<50cm dbhob), however, shows that most trees with hollows have poor form, or alternatively, better formed trees are less likely to contain hollows.

This result is to be expected, due to the fact that most trees with hollows are suppressed or subdominant in the smaller size classes (Table 6), and that suppressed trees will be more likely to have poor form.

## 3.3. **Stem Analysis**

A diameter/age relationships (Figures 26 and 27) has been established for both species based on stem analysis of sample trees as well as from previous diameter increment records and field measurements. Average increment data gave approximately linear relationships in lower size classes (0-60cm dbhob) while sample tree results were used as a basis to extrapolate the top end of the graphs. It should be noted that the relationships thus obtained are approximate only, as are subsequent age estimations.

### 3.3.1. Diameter Growth Rates

(a) Wandoo

Table 7 summarises diameter increment data for wandoo sites across a range of rainfall gradients.

Results indicate that diameter growth rates are greater in western higher rainfall stands, than in the central and eastern stands. Limited sample data from the Dongolocking Reserves (east) did not allow for a diameter/age relationship to be established, however, average diameter increments from the samples obtained were lower than those gained from similar size trees in western sites.

Such findings are consistent with those of Abbott and Loneragan (1983) who reported that diameter increment of lower quality (lower rainfall) eastern jarrah was significantly less than that of high quality forest in areas of higher rainfall. Indeed, anecdotal evidence from wandoo sawmillers revealed the opinion that timber from western wandoo stands near Mundaring (high rainfall) had different sawing and drying properties than more eastern wandoo, which may reflect different growth rates.

**TABLE 7**

| Location | Approximate average Rainfall (mm/yr) | Average Diameter Increment (cm/yr) | Number of Sample Trees | Standard Error (cm) |
|---|---|---|---|---|
| **Western Wandoo** | | | | |
| Jarrahdale (Bannister) | 700 | 0.47 | 38 | 0.08 |
| Mundaring | | | | |
| (a) < 60 cm dbhob | 650 - 700 | 0.45 | 31 | 0.06 |
| (b) > 60 cm dbhob | | 0.23 | 21 | 0.08 |
| Mt Barker | | | | |
| (a) < 60 cm dbhob | 700 | 0.36 | 6 | 0.02 |
| (b) > 60 cm dbhob | | 0.27 | 3 | 0.04 |
| **Average Western** | | **0.43** | **99** | **0.08** |
| **Central Wandoo** | | | | |
| Dryandra | | | | |
| (a) < 60 cm dbhob | 500 | 0.31 | 36 | 0.02 |
| (b) > 60 cm dbhob | | ns | 0 | ns |
| **Eastern Wandoo** | | | | |
| Dongolocking Reserves | | | | |
| (a) < 60 cm dbhob[1] | 400 | 0.24 | 2 | 0.09 |
| (b) > 60 cm dbhob | | 0.09 | 2 | 0.07 |

1 Three additional trees of under 60 cm dbhob sampled from Dongolocking Nature Reserve were found to have an average Diameter Increment of 0.28mm. (D. Mitchell, Department of CALM, Narrogin. Personal Communication.)

ns Not Sampled

(b) Salmon Gum

As with wandoo, salmon gum diameter increment tends to decrease as rainfall decreases. Any conclusions drawn however should be qualified in light of the relatively small data base and limited degree of sampling across the rainfall gradient.

**TABLE 8**

| Location | Approximate average Rainfall (mm/yr) | Average Diameter Increment (cm/yr) | Number of Sample Trees | Standard Error (cm) |
|---|---|---|---|---|
| **Western Salmon Gum**[1] | | | | |
| (a) Cuballing | 500 | 0.38 | 7 | 0.04 |
| (b) Astbury Remnant | 450 | 0.32 | 6 | 0.04 |
| (c) Tincurrin | 450 | 0.36 | 7 | 0.08 |
| **Average Western** | | **0.35** | **20** | **0.06** |
| **Eastern Salmon Gum**[1] | | | | |
| Dragon Rocks | 330 | 0.28 | 8 | 0.02 |
| Coolgardie[2] | 260 | | | |
| (a)Edge Dominants | | 0.30 | 18 | na |
| (b)Crowded Dominants | | 0.20 | 53 | na |
| (c)Crowded Codominants | | 0.15 | 28 | na |
| (d)Subdominants | | 0.11 | 57 | na |

1 Samples from dominant trees.
2 Dept of CALM (1983) increment measurements from 0.928 ha plot established in 1917.
na Not Available.

Although a positive relationship between average annual rainfall and diameter increment is indicated for salmon gum, tree competition and subsequent growth suppression is likely to have an overriding influence. The results from the Coolgardie plot (Table 8) show that increased stocking density (crowding) greatly reduces diameter growth rates. Dominant trees growing in relatively open spaces (edge trees) have growth rates 50% greater than crowded dominants within the same stand. Such variable stocking density is characteristic of naturally regenerated salmon gum stands. Sample trees within the current study have generally consisted of open grown dominants (edge trees). However samples taken from the Astbury remnants were from "crowded" dominants, perhaps reflected in the comparatively lower growth rates in trees from these sites.

### 3.3.2. Tree Ageing and Hollow Formation

#### 3.3.2.1. Hollow Formation

Using the diameter/age relationships as shown in Figures 26 and 27, the age distribution of trees with hollows can be derived as indicated in Table 9 below.

**TABLE 9**

| | % of Trees with Hollows | | | | |
|---|---|---|---|---|---|
| | Wandoo | | | Salmon Gum | |
| Age | Western | Central | Eastern | Western | Eastern |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 1 | 2 | 0 |
| 120 | 39 | 40 | 19 | 13 | 5 |
| 180 | 100 | 92 | 81 | 41 | 48 |
| 240 | 100 | 100 | 100 | 88 | 97 |
| 300 | 100 | 100 | 100 | 100 | 100 |

(a) Wandoo

The trend of decreasing diameter increment with decreasing rainfall means that smaller trees in the east will be of equivalent age of larger trees in western areas. Hollows first occur in trees in eastern stands at 20 to 30cm dbhob (Figure 12) corresponding to an age of 100 to 120 years (Figure 26). Significant numbers of hollows in western stands do not occur in trees of less than 40 to 50 cm dbhob, which is also equivalent to an age of approximately 100 to 120 years.

It should be noted however that most hollows do not occur until 150 to 180 years (Table 9).

(b) Salmon Gum

Significant numbers of hollows (approx 30%) first occur in salmon gum at 40 to 50 cm dbhob on eastern sites (Figure 13) which is equivalent to an age of 130 to 150 years (Figure 27). In western stands approximately 30% of hollows will be formed in trees at 50 to 60 cm dbhob, at a similar age of 130 to 150 years.

However it is not until trees in stands reach 50 to 60 cm dbhob (east) and 60 to 70 cm dbhob (west), that 50% of total hollows are produced, equivalent to an approximate age of 200 to 220 years (Table 9)

3.3.2.2. Hollow Size

(a) Wandoo

The hollow size distribution is shown in Figures 21, 22 and 23. Generally hollow size increases with increasing age of trees in all stands.

In western stands, larger size hollows (>20cm diameter) are not formed until trees reach diameters of 60 - 70 cm. ie 160 to 180 years old. On central sites large hollows occur in significant proportions in trees of approximately 50cm diameter ie 160 to 180 year old. On eastern sites however, larger hollows occurred in lower size classes at an earlier age of approximately 110 to 130 years. Small (<10cm) and medium (10 to 20cm) hollows occur in smaller size class trees at correspondingly younger ages.

(b) Salmon Gum

As with wandoo there are greater proportions of small and medium hollows formed than large hollows, and proportions of large hollows increase with increasing size class and age. (Figures 24 and 25)

In both western and eastern salmon gum stands it takes 180 to 200 years before 50% of large hollows are formed in a stand. Most large hollows are formed in trees which are older than 200 years.

3.3.2.3. Tree Longevity

Tree longevity estimates for both Wandoo and Salmon Gum were made by extrapolating the top end of the age/dbhob graphs (Figure 26 and 27) by assuming a linear decline in dbhob increment (Mackowski 1984). Extrapolation of this decline leads to a point where diameter increment is zero and the tree dies. The method is very sensitive to variations in assumptions regarding dbhob increment values and as such should only be used as an indicative estimate of longevity. Furthermore, it should be noted that the longevity estimates refer to maximum ages, with very few trees in a stand surviving to become large size veterans.

(a) Wandoo

Trees of 90cm dbhob (on western sites) will be approximately 300 years old, with trees of 110cm dbhob and above, 400 to 500 years old. The largest wandoo tree measured in this study was 128cm dbhob. Trees in the slower growing eastern stands do not grow as large (diameter) as those in the west but probably have similar longevity.

(b) Salmon Gum

Salmon Gum trees of 90cm dbhob will be approximately 350 years old, with veterans of 110 to 120cm, 400 to 500 years old (Figure 27). The largest tree measured in this study was 115cm dbhob although most of the largest trees, in the stands assessed, had diameters of 90 to 100cm.

# 4. DISCUSSION

The study shows that diameter growth rates of wandoo and salmon gum generally decrease with decreasing rainfall. Although trees in drier stands are comparatively smaller when hollows occur, they have approximately equivalent ages of hollow bearing trees in the higher rainfall stands. Because most hollow bearing trees in smaller diameter classes (<50cm dbhob) are subdominant or suppressed, the actual age of many trees is likely to be significantly greater than estimated in this study (which is based on dominant trees with superior growth rates).

Furthermore the size of hollows formed in a tree is related to tree age with larger hollows usually taking longer to form and occurring in larger and older trees. Significant numbers of small hollows(<10cm diameter opening) occur in Wandoo within 100 to 110 years. Larger size hollows take longer to become available with medium hollows (10 to 20cm diameter) after 120 to 130 years and larger hollows (>20cm diameter) occurring after 140 to 150 years.

Results for Salmon gum show that hollow occurrence takes longer with small hollows after 120 to 130 years, medium hollows 140 to 150 years and large hollows becoming frequent after 160 to 180 years.

Studies by Ambrose (1982) in Victorian ash-type forests and Saunders et al. (1982) in salmon gum have suggested ages of 120 and 130 years for initial hollow production. Faunt (1992) has estimated first hollow formation in jarrah trees after approximately 80 years.

The consideration of hollow size is important in order to assess specific requirements for the various hollow users. Saunders et al. (1982) found that the mean entrance diameters of hollows used by Port Lincoln parrots was approximately 14 cm and for black cockatoo 26 cm, with the minimum sized hollow of 9 cm used by the smallest cockatoo. Smaller size hollows are likely to be utilised by bats, reptiles and other vertebrates (Ambrose 1982).

Age and diameter relationships have been established for wandoo and salmon gum which will allow dominant trees in a stand to be approximately aged by measuring tree diameter. The relationship is influenced by annual rainfall as well as site and historical factors. Tree competition greatly influences diameter growth rates and therefore the ability to accurately estimate tree age. The mixed age and diameter classes in naturally regenerated wandoo and salmon gum stands lead to great variability of growth rates between trees. Tree selection for aging is very important and free growing dominants should be selected where possible.

Other site factors such as soil drainage and microclimate will also exert influence on tree growth, although probably to a much lesser extent than competition in wandoo and salmon gum stands. As this study was not sensitive to micro-site characteristics and no recommendations can be drawn as to their effects.

Past management activities and disturbance intensity have strong influence on stand structure and hollow occurrence. Where intensive log harvesting or other disturbance has significantly reduced the frequency of larger diameter logs, habitat hollow frequency is subsequently reduced.

Periodic selective cutting in the western and central wandoo forest areas has reduced the number of trees in larger diameter classes which is reflected in lower habitat hollow frequencies. After selective logging unmerchantable or suppressed trees of generally poorer form remain to provide habitat hollows. It should be noted however that where low intensity selective logging is followed by intensive silvicultural operations such as thinning and cull tree falling (of unmerchantable veterans), hollow frequency is likely to be significantly reduced. Management options including habitat tree retention and untreated buffer zone selection may need to be considered. The extent of such intensive silvicultural operations is limited and have been restricted to the western forest area where wandoo stands are associated with large tracts of jarrah and marri forest. Habitat hollows are unlikely to be limiting in these forest areas in any case.

Tree age and crown and/or bole damage are the main factors influencing hollow occurrence in wandoo and salmon gum. Fire is a major contributor to bole and crown damage, often preceding the wood decaying agents (fungi and termites) which produce hollows (Anon 1971). Indeed, fire damaged stands are likely to have hollows induced at an earlier age than those with less damage. The manipulation of fire regimes could be used to induce hollow occurrence in smaller trees or younger stands. Conversely however, intense fire events may contribute to stand degeneration and tree death resulting in reductions of hollow numbers (Saunders 1979). Any such fire management should be carefully considered and implemented and further research into fire effects may be warranted.

More importantly in the long term, fire affects stand structure and regeneration capacity. In eastern wandoo and salmon gum relict stands in agricultural surrounds, recent fire frequency and intensity has necessarily been altered from that with which the stands have naturally evolved. This, combined with grass encroachment and intermittent stock grazing, has often led to reduced regeneration recruitment which is reflected in low numbers of small size class trees compared to natural stands. Maintaining both wandoo and salmon gum stands to provide a broad size class distribution, with adequate regrowth for regeneration replacement, should be the aim of management. Maintenance of a "healthy" stand structure will naturally provide for a continuing resource of habitat hollows and conservation of the relic stands.

Appropriate fire regimes, weed and/or stock control or artificial manipulation (eg. gap creation, seeding/replanting) may be required to achieve this aim.

Ground observations in this study have found that wandoo and salmon gum stands across the climatic zones generally possess significant numbers of hollows. The study is limited however in that the use of these hollows by wildlife was not assessed. The physical characteristics of the hollow cavity, including depth and internal dimensions, have been shown to affect the use of hollows by various species (Inions 1985, Saunders et al. 1982, Lindenmayer et al. 1991). Lindenmayer et al. (1990) suggested, following their studies of hollow-bearing trees and arboreal marsupials in Victoria, that the number of trees with suitable hollows may be overestimated using ground observations. This however may be compensated for by the failure of ground observations to detect hollows in some trees. Dissection and detailed hollow analysis of sample trees (as in Mackowski 1984), in combination with ground observations, may be necessary to enable adjustment of hollow estimates obtained from ground scanning to more accurately reflect the numbers of suitable habitat hollows.

Specific characteristics of hollows such as aspect, height above ground and position in crown, may be significant in terms of hollow usage (Lindenmayer et al. 1990, Saunders et al. 1984). Such micro-site variables however, were not assessed in this broadscale study. Future studies may need to address these issues.

The nature of the surrounding habitat is likely to exert an overriding influence on the use of hollows by wildlife. Many salmon gum remnants for instance, form isolated "islands" surrounded by large tracts of cleared farmland or low sandplain heath. The behavioural characteristics of some species in these situations may limit the use of available hollows with large numbers of hollows remaining unused (Saunders 1979). Indeed many remnants, although containing adequate habitat hollows, may be either too small or too remote to allow for effective migration of certain wildlife species. Aspects of food supply and/or cover or shelter may also be limiting. Study into the more complex issues of habitat hollow usage and population dynamics of specific fauna species is required, before meaningful conclusions can be drawn regarding management recommendations.

In the wheatbelt many stands consist only of larger remnant trees isolated on roadside reserves or left standing in paddocks and around buildings. There are also a number of reserves on Crown Land, vested in various authorities for various purposes, which provide much of the nesting and feeding areas for hollow using species. Saunders (1979) has outlined the problems of grazing and stock damage and has expressed concern for future rehabilitation and conservation of many woodland relicts. This study supports these concerns, especially in salmon gum stands on private property.

Assessment across the climatic range in salmon gum stands has been necessarily restricted in this study. A wider investigation of salmon gum stands extending throughout the wheatbelt and into the goldfields (east) is required in order to more fully assess the distribution and status of this important wildlife habitat. Priority may then be given to identifying areas on which to concentrate more detailed studies. Further assessment of growth rates and subsequent rates of hollow formation is also warranted. Protection of the most important stands, whether on private or state owned land, should be an initial step in management. Maintenance of the regeneration capacity of these stands can then be undertaken to provide for their long term conservation.

Other priorities for research include:

i) More detailed inventory of stands of wandoo and salmon gum throughout the Wheatbelt.

ii) Investigate the actual usage of stands (of different sizes), lines of trees and isolated individual trees by vertebrate species. Identify the most important stands based on the usage patterns, and allocate priorities for future management.

iii) Investigate stand maintenance and rehabilitation techniques eg. fire regimes, artificial regeneration (seeding/planting)

iv) The actual processes of hollow initiation, formation and growth.

## 5. REFERENCES

Abbott I & Loneragan O. (1983) - Growth rate of jarrah (Eucalyptus marginata) in relation to site quality in cut-over forest, Western Australia. Australia Forestry. 46, No.2, 91-102

Ambrose G.J. (1982). An ecological and behavioural study of vertebrates using hollows in eucalypt branches. Ph. D Thesis, Latrobe University, Bundoor Victoria 419pp.

Anon (1971). Forestry in Western Australia (Forests Department of Western Australia, Perth)

Calder T.G., Golding B.G. Manderson A.D., (1983). Management for arboreal species in the Wombat State Forest. Environmental Report No. 16. Monash University, Graduate School of Environmental Science.

Department of Conservation and Land Management, W.A. (1990). Inventory section, growth plot data. 1976 - 1992.

Department of Conservation and Land Management, W.A., (1983). Silviculture branch report. Salmon Gum growth rates, Coolgardie.

Faunt. K. (1992). Formation, frequency and longevity of hollows in jarrah. Interim report to Department of Conservation and Land Management.

Hopkins E.R. (1968). Fluctuations in the Girth of Regrowth Eucalypt Stems. Australian Forestry 32,95-110.

Inions G (1985). The interactions between possums, habitat trees, and fire. B.Sc Hons. Thesis, Australian National University, Canberra. 220pp.

Lindenmayer D.B., Cunningham R.B., Tanton M.T., Smith A.P., Nix H.A. (1990). The conservation of arboreal marsupials in the montane ash forests of the central highlands of Victoria, South East Australia: I. Factors influencing the occupancy of trees with hollows. Biological Conservation, 54, 111-131.

Lindenmayer D.B., Cunningham R.B., Tanton M.T., Smith A.P., Nix H.A. (1991). Characteristics of hollow-bearing trees occupied by arboreal marsupials in the montane ash forests of the central highlands of Victoria, South East Australia. Forest Ecology & Management, 40, 289-308.

Mackowski C.M. (1984), The ontogeny of hollows in blackbutt (Eucalyptus pilularis) and its relevance to the management of forests for possums, gliders and timber. pp. 553-67. in Possums and gliders ed. by A.P. Smith & I.D. Hume, Australian Mammal Society, Sydney

Raynor M.E. (1992), Application of Dendrochronology, stem analysis and inventory data in the estimation of growth rate in Karri (Eucalyptus diversicolor). Department of Conservation and Land Management, W.A. Technical Report No. 27.

Rotheram I. (1983), Suppression of growth of surrounding regeneration by veteran trees of Karri (Eucalyptus diversicolor) Australian Forestry. 46, 8-13.

Saunders D.A. (1977), The Effect of Agricultural Clearing on the Breeding Success of the White-tailed Black Cockatoo. Emu 77 : 180-184

Saunders D.A. (1979), The availability of tree hollows for use as nest sites by white-tailed black cockatoos. Australian Wildlife Research. 6, 205-16.

Saunders D.A., Smith G.T. & Rowley I. (1982), The availability and dimensions of tree hollows that provide nest sites for cockatoos. (Psittaciformes) in Western Australia. Australian Wildlife Research. 9, 541-56.

Schweingruber F.H. (1988), Tree Rings : basics and applications of dendrochronology. D. Reidel, Boston.

White B.J. (1971), Karri Silvics. Forests Department of WA, Research note no. 1.

## 6. ACKNOWLEDGMENTS

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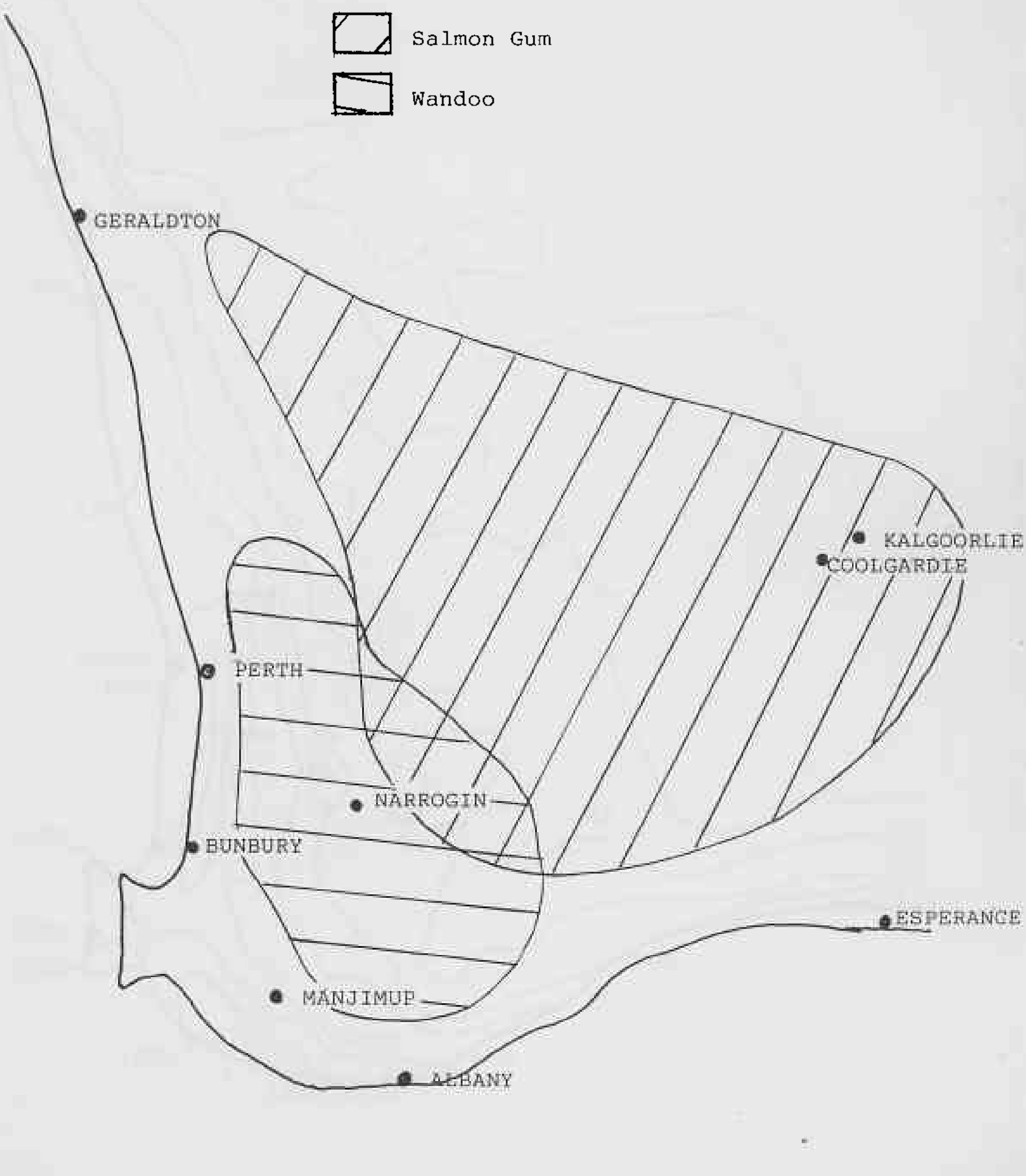
Special thanks to Karin, Anne and Christine of Bourne Griffiths Soldo for their hard work, patience and good humour in typing and drafting this report.

Finally, we wish to acknowledge the generous financial support of the Australian National Parks and Wildlife Service - Save the Bush Program.

## 7. LIST OF FIGURES

Fig 1A.

Wandoo (*E Wandoo*) and Salmon Gum (*E Salmonophloia*) natural distribution in Western Australia.



AVERAGE ANNUAL RAINFALL

SOUTH WEST, WESTERN AUSTRALIA

Fig 1B - Site Localities

| Ai) Wandoo West | Sites | Bi) Salmon Gum West | Sites |
|---|---|---|---|
| WW1 Mt Barker | 1 | WS1 Cuballing | SG1 |
| WW2 Jarrahdale | 2,7,8 | WS2 Ticurrin | SG2,3 |
| WW3 Mundaring | 3,4,5,6 | WS3 Harrismith | SG4,5 |
| WW4 Julimar | 9,10 | WS4 Kulin | SG10 |
| ii) Wandoo Central | | ii) Salmon Gum East | |
| CW Dryandra | 11-14,18-20 | ES Dragon Rocks | SG6-9 |
| iii) Wandoo East | | iii) Coolgardie | |
| EW Dongolocking Res | 15-17 | EES Dept CALM Plot (approx locality) | |

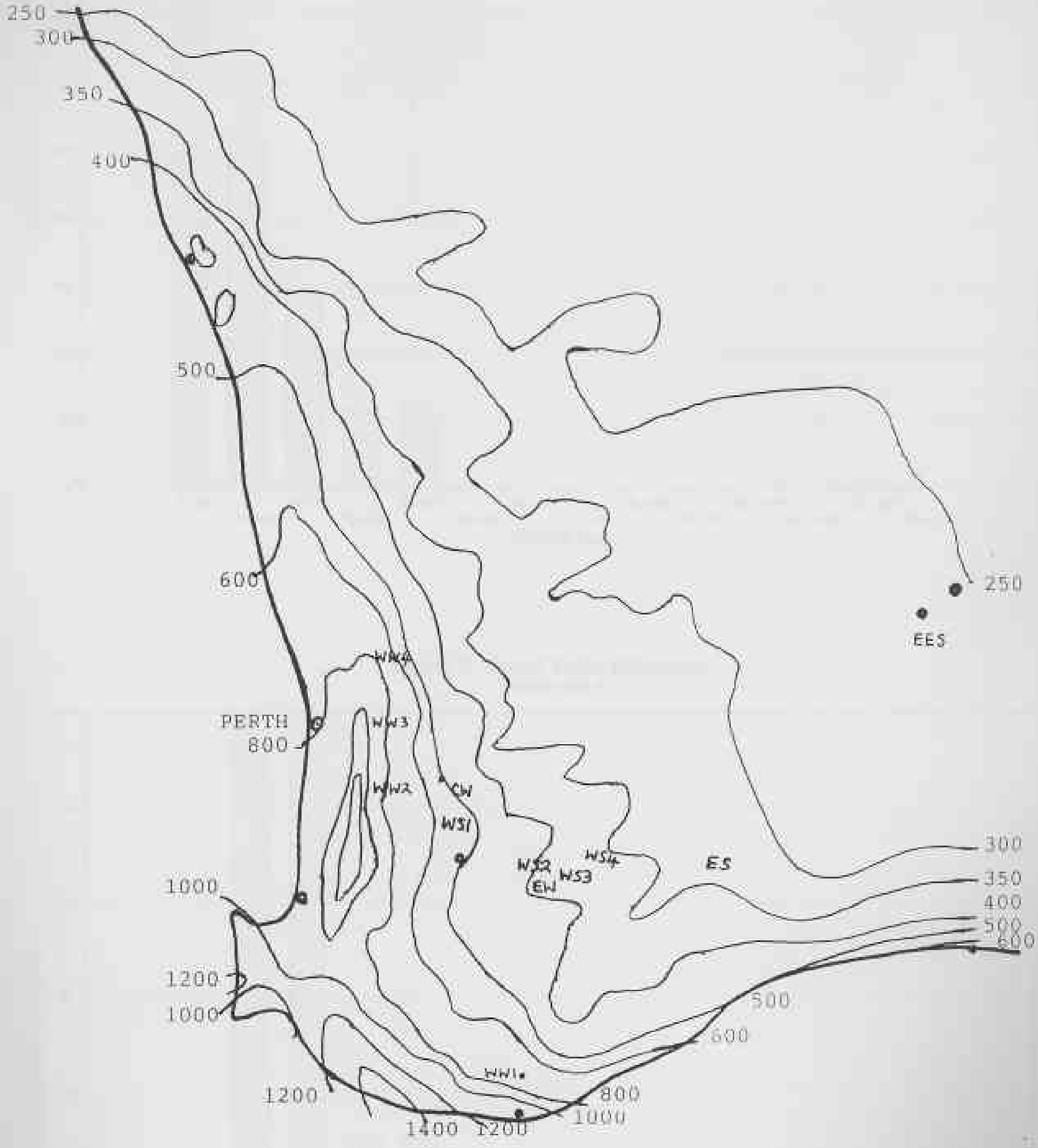


Figure 2. Stand Table Histogram
Wandoo Site 6

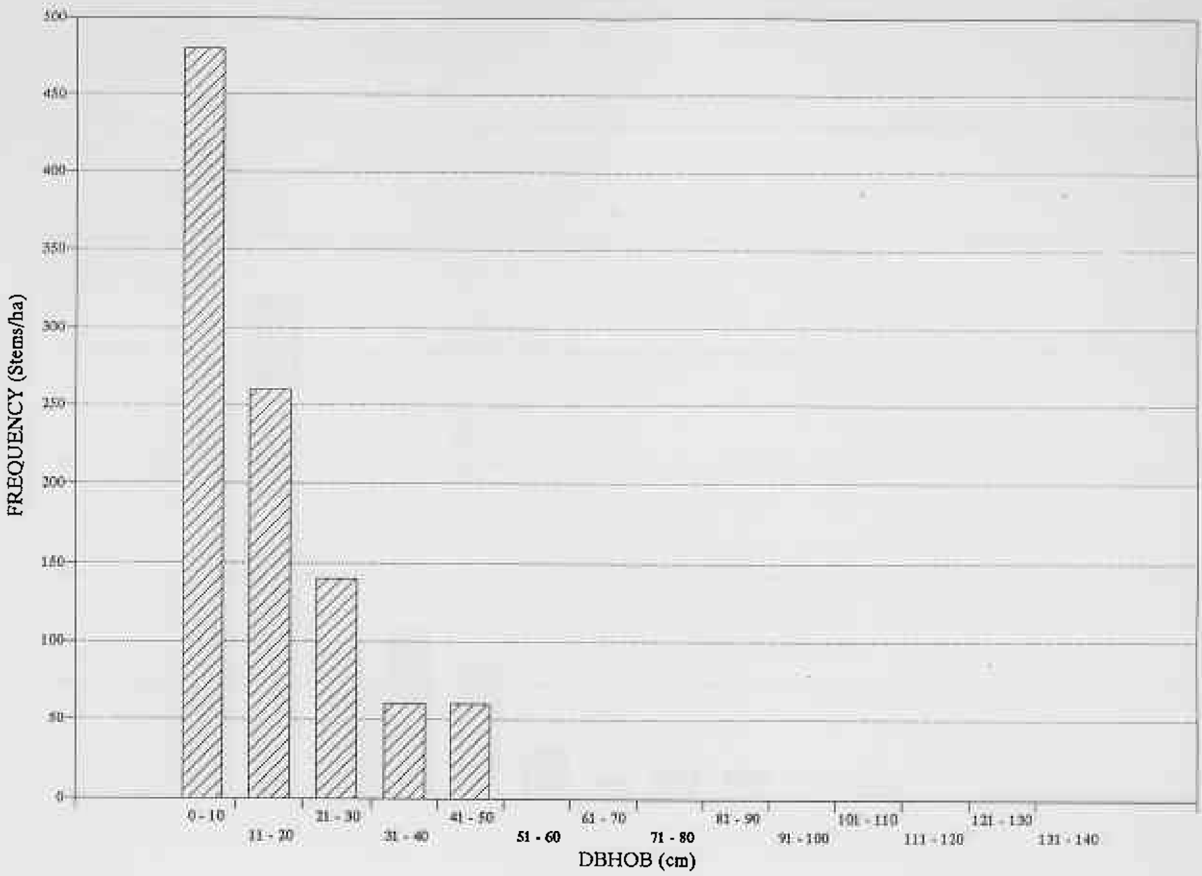



Figure 3. Stand Table Histogram
Wandoo Site 4

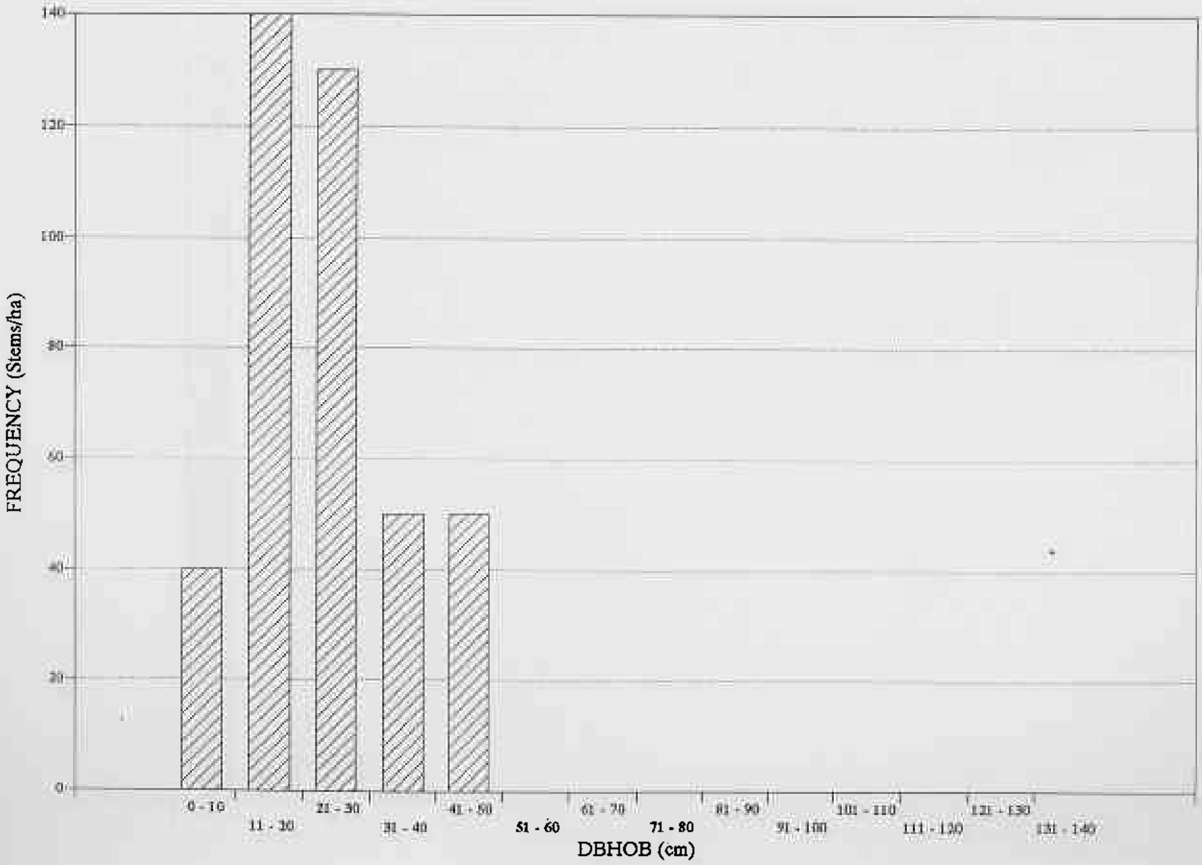


Figure 4. Stand Table Histogram
Wandoo Site 2

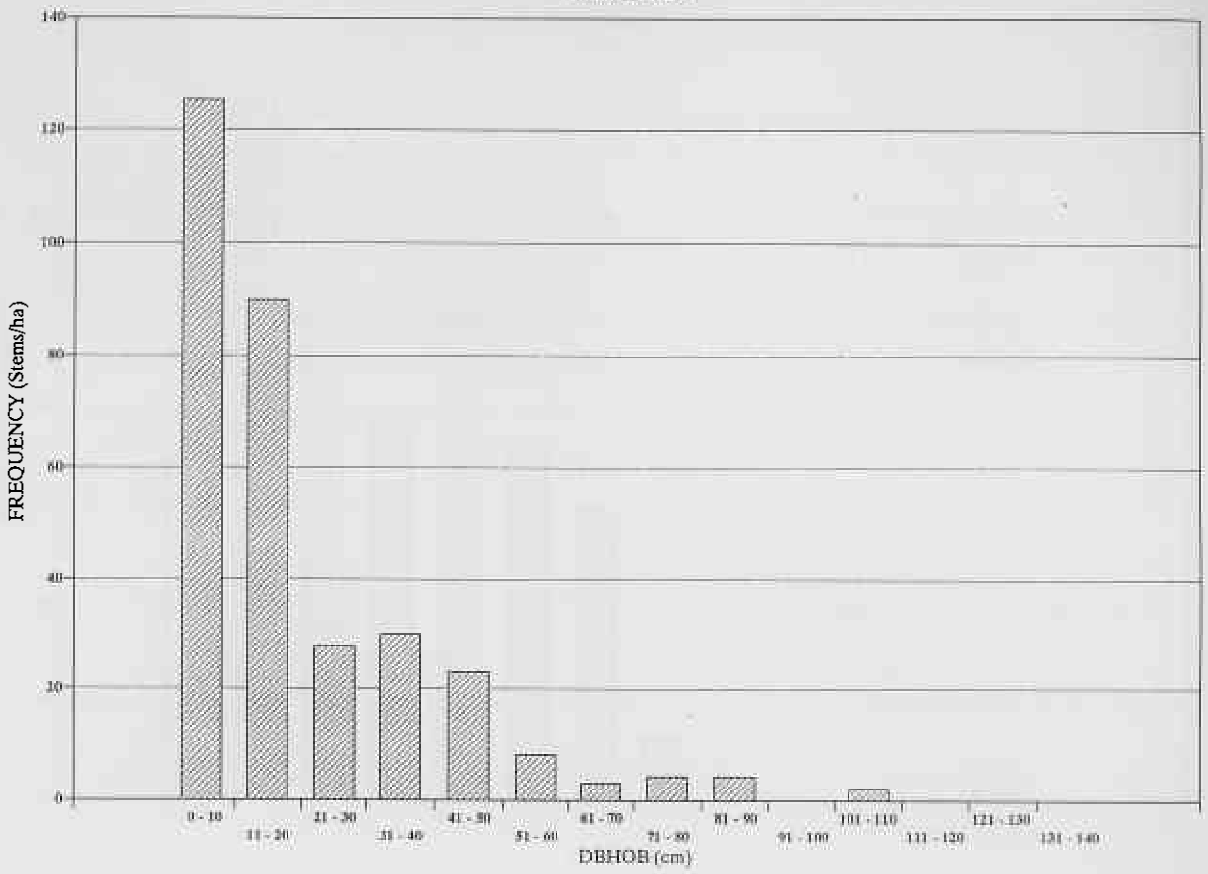



Figure 5. Stand Table Histogram
Wandoo Site 3

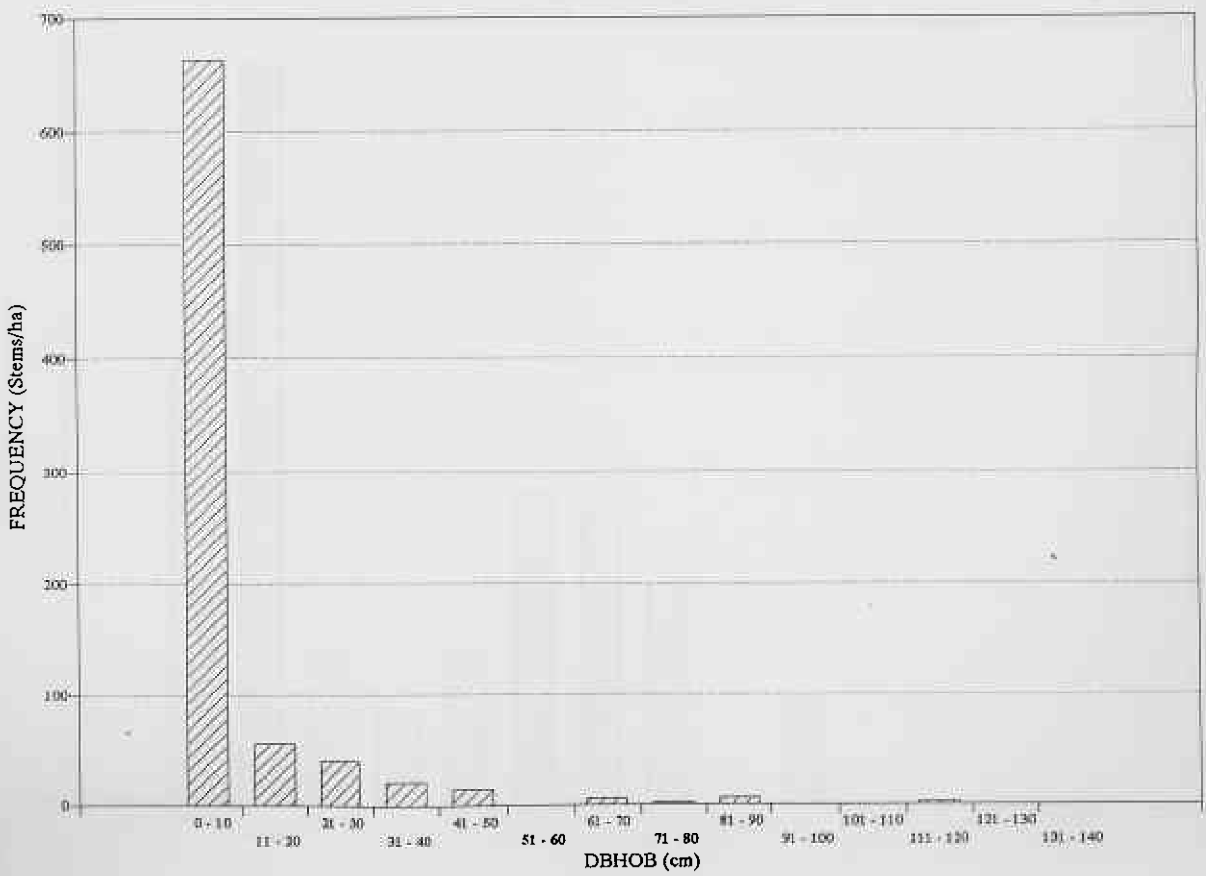


Figure 7. Stand Table Histogram
Wandoo Site 11

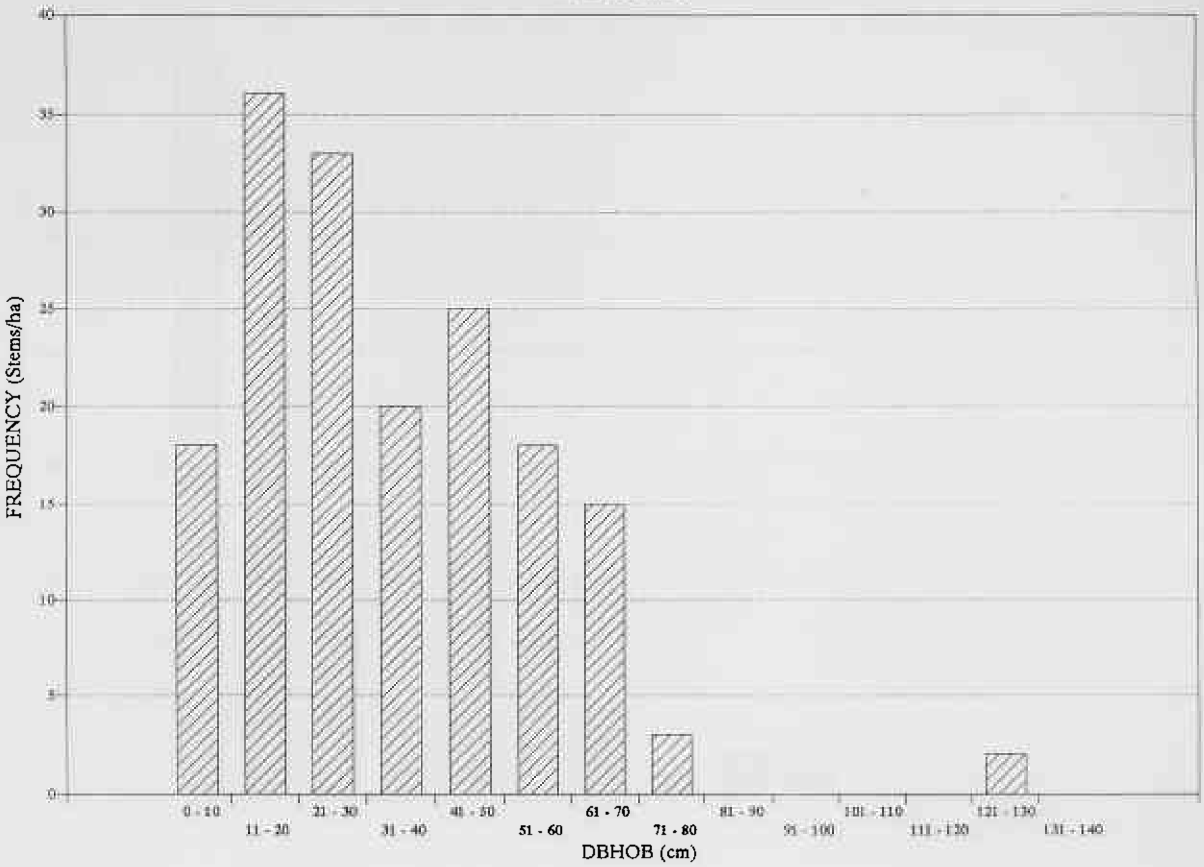



Figure 6. Stand Table Histogram
Wandoo Site 7

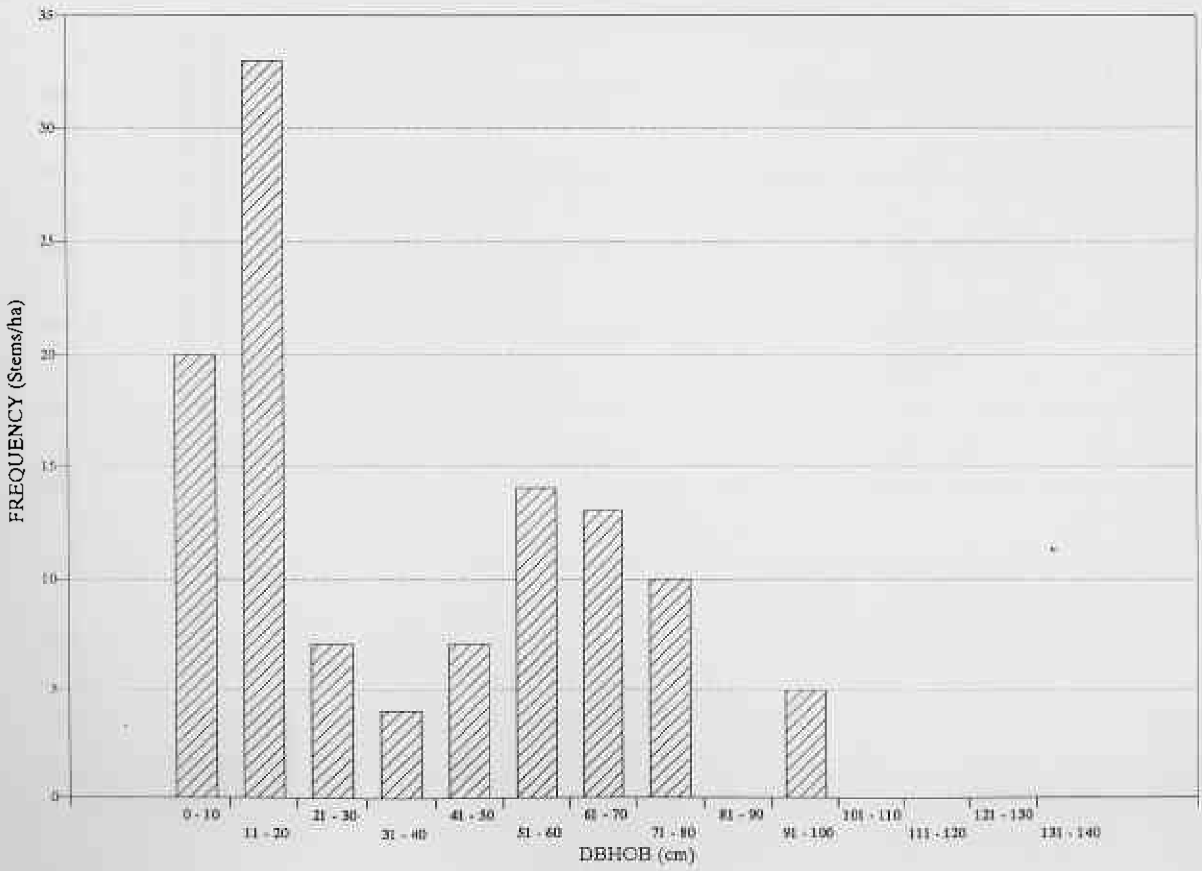


Figure 8. Stand Table Histogram
Salmon Gum Site 9

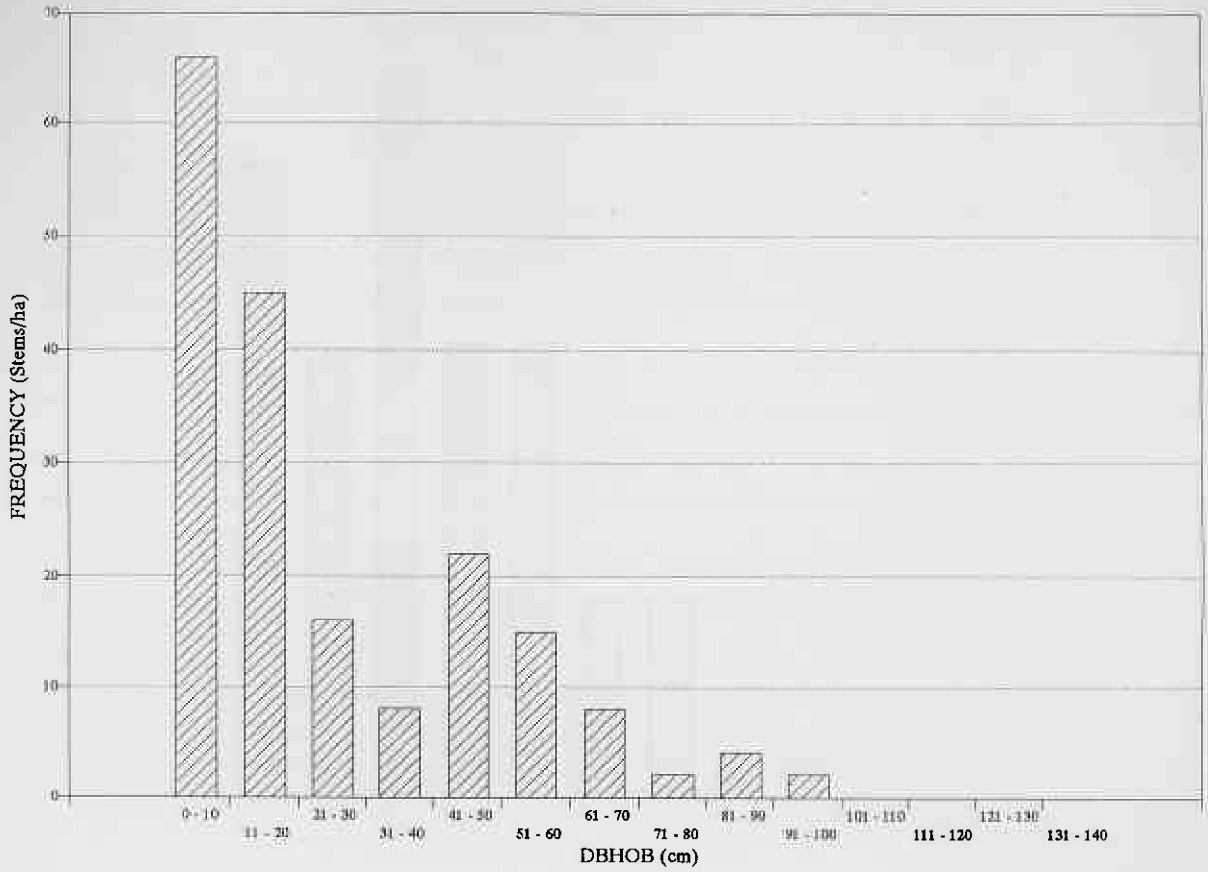



Figure 9. Stand Table Histogram
Salmon Gum Site 6

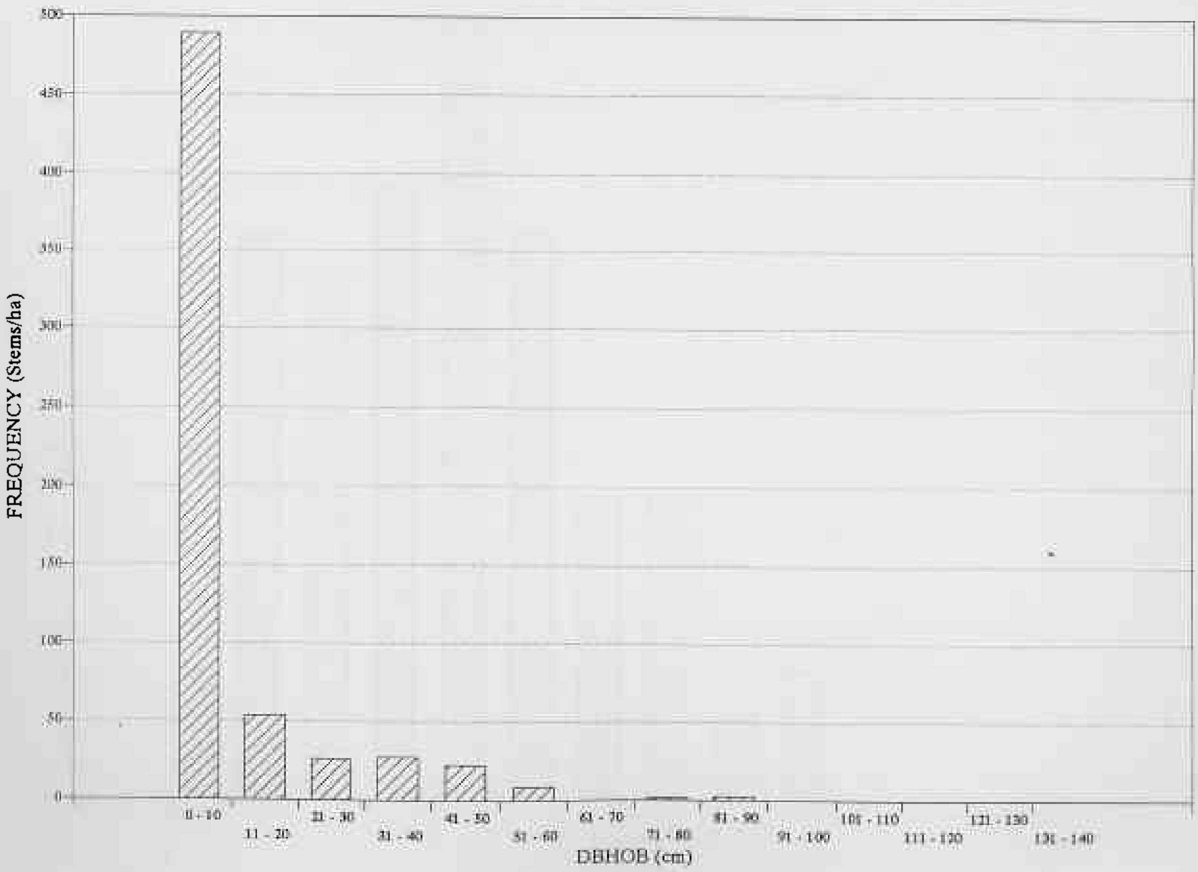


Figure 10. Stand Table Histogram
Salmon Gum Site 2

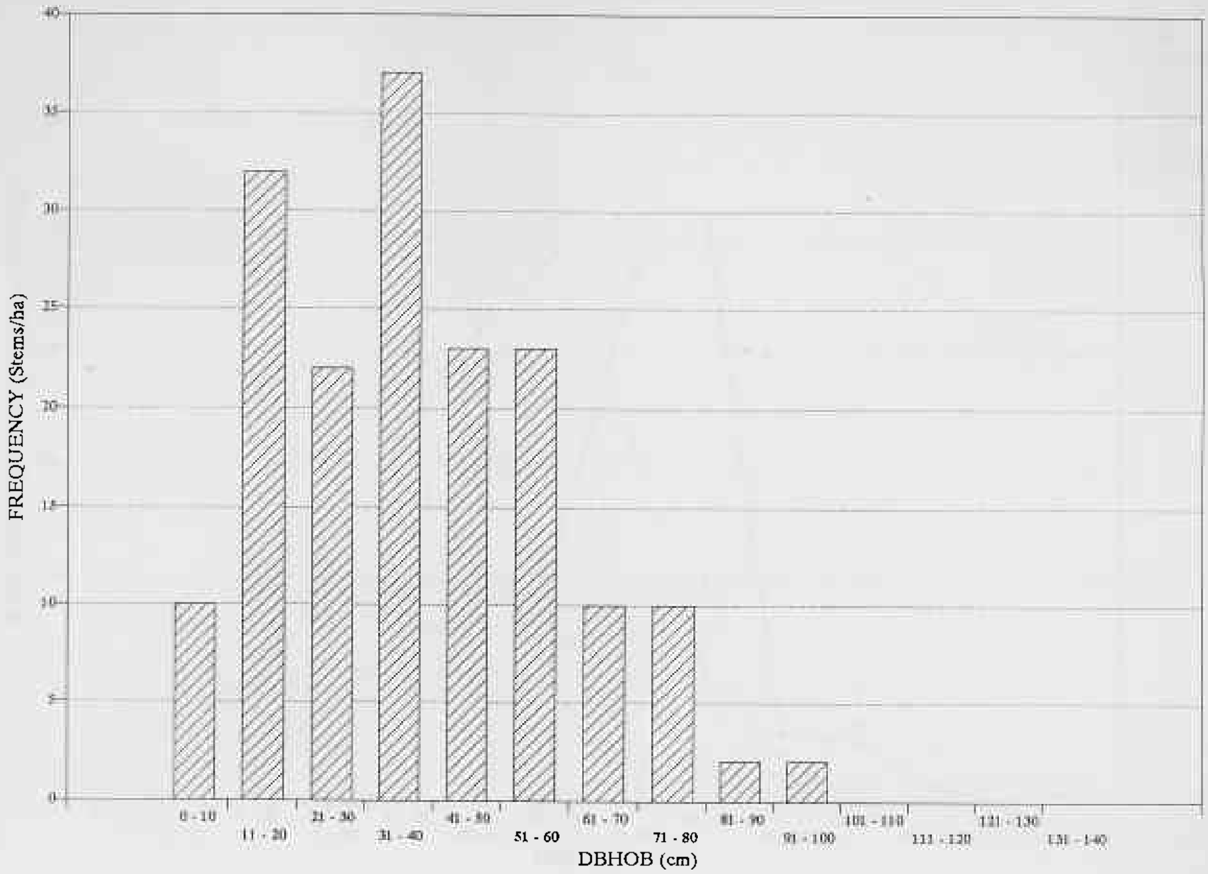



Figure 11. Stand Table Histogram
Salmon Gum Site 10

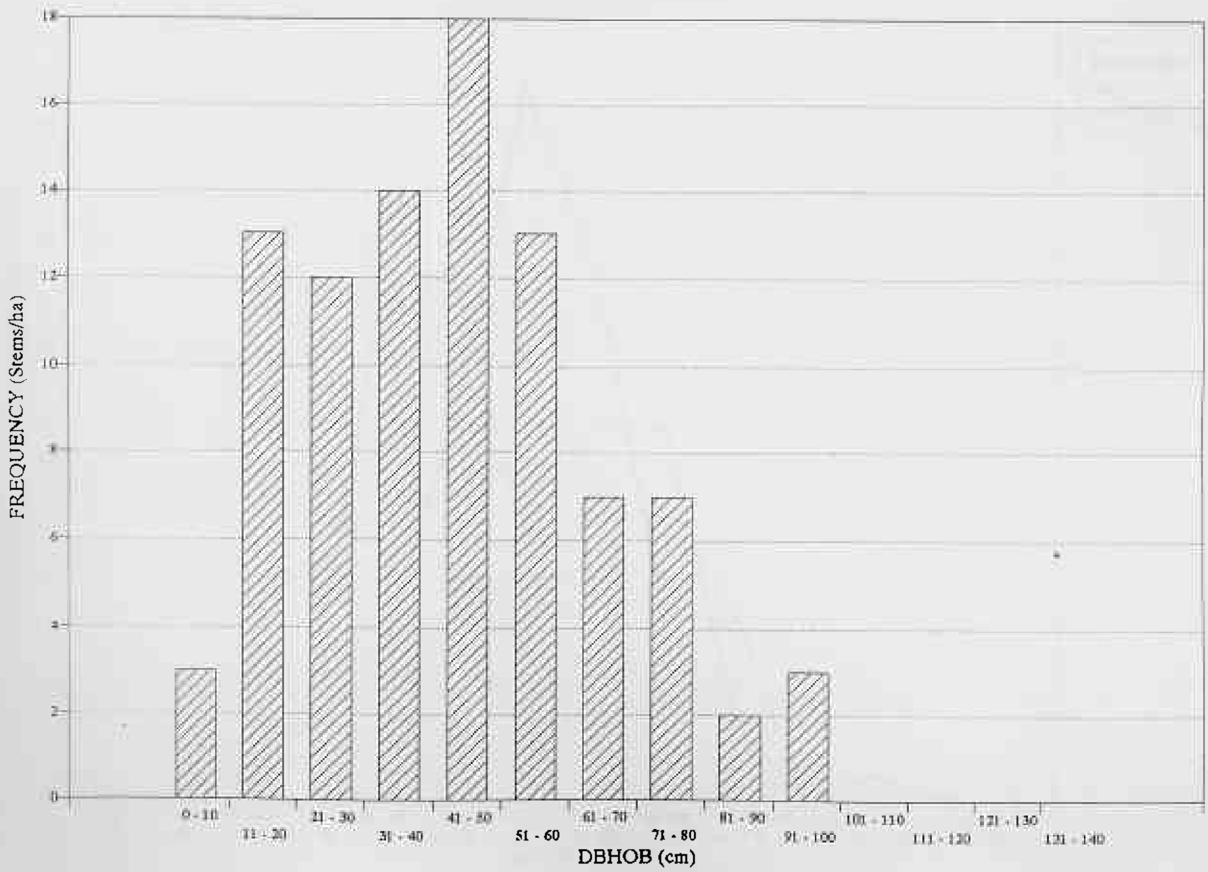


Figure 12. Total Hollow Production
Wandoo

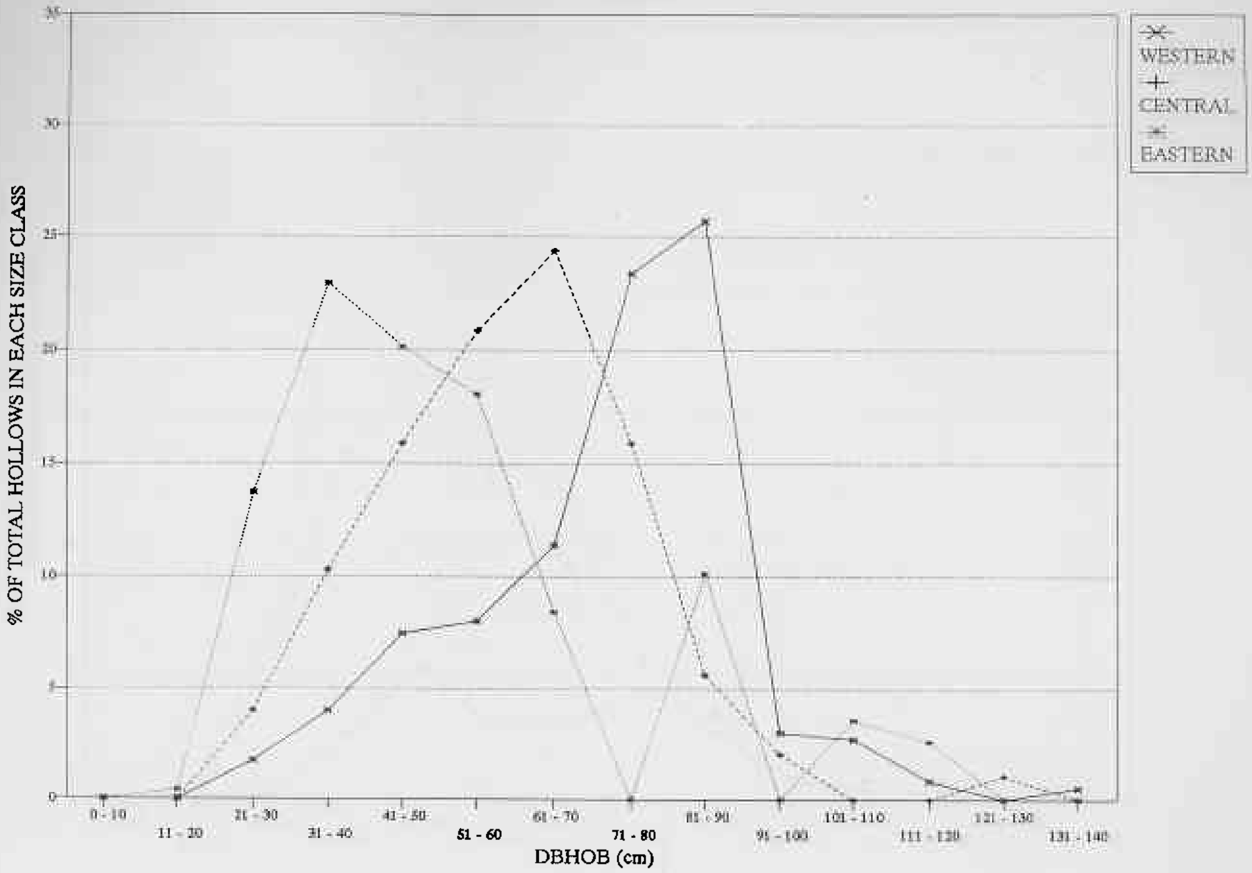
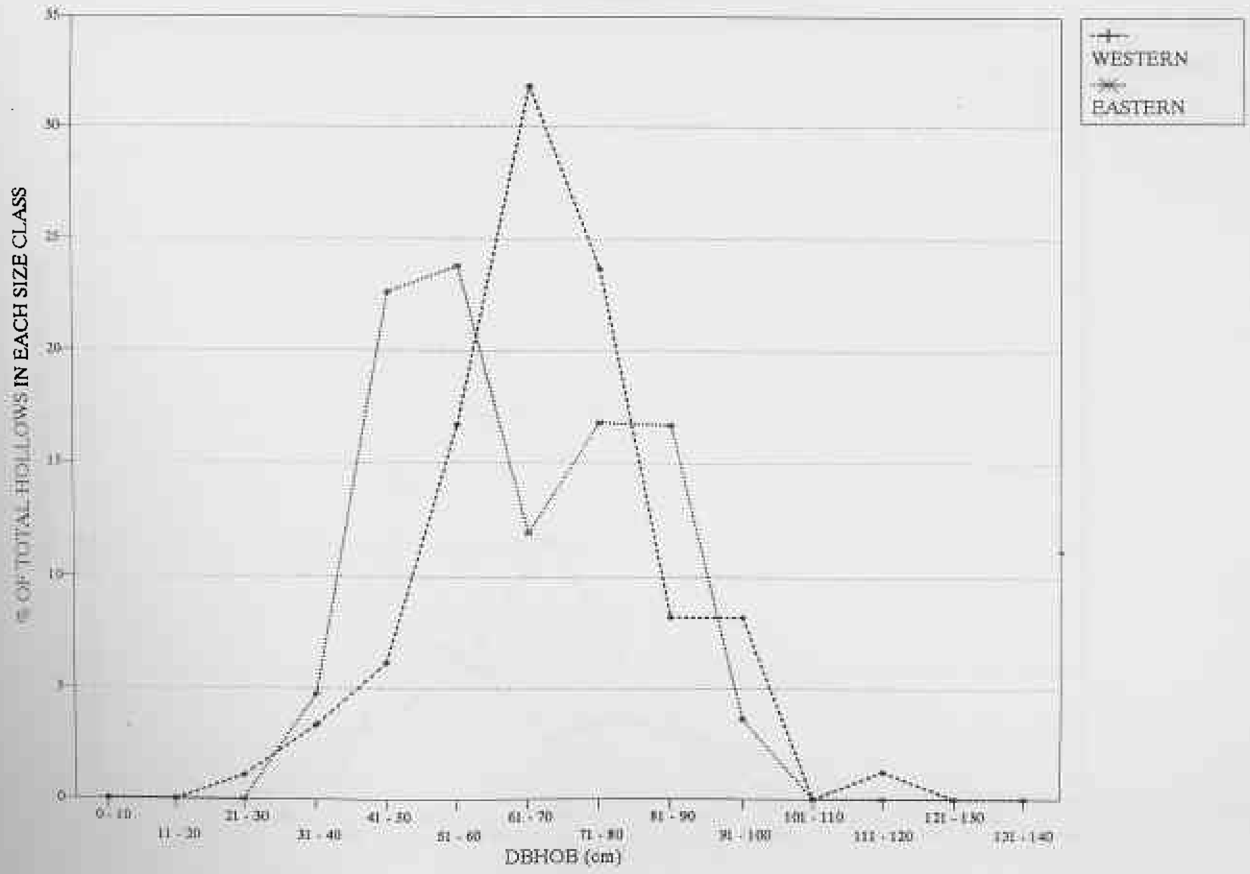
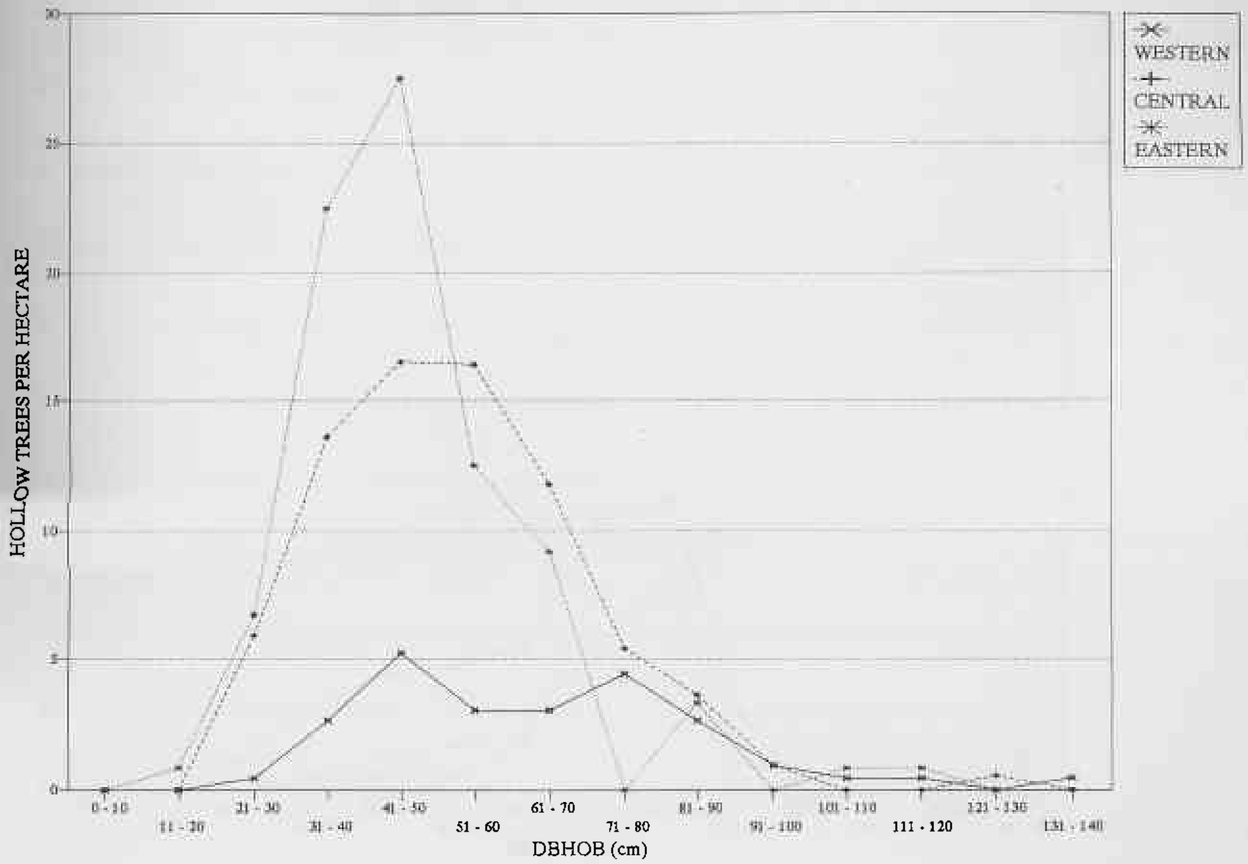



Figure 13. Total Hollow Distribution
Salmon Gum



## Figure 14. Hollow Trees per Hectare
Wandoo




## Figure 15. Hollow Trees per Hectare
Salmon Gum

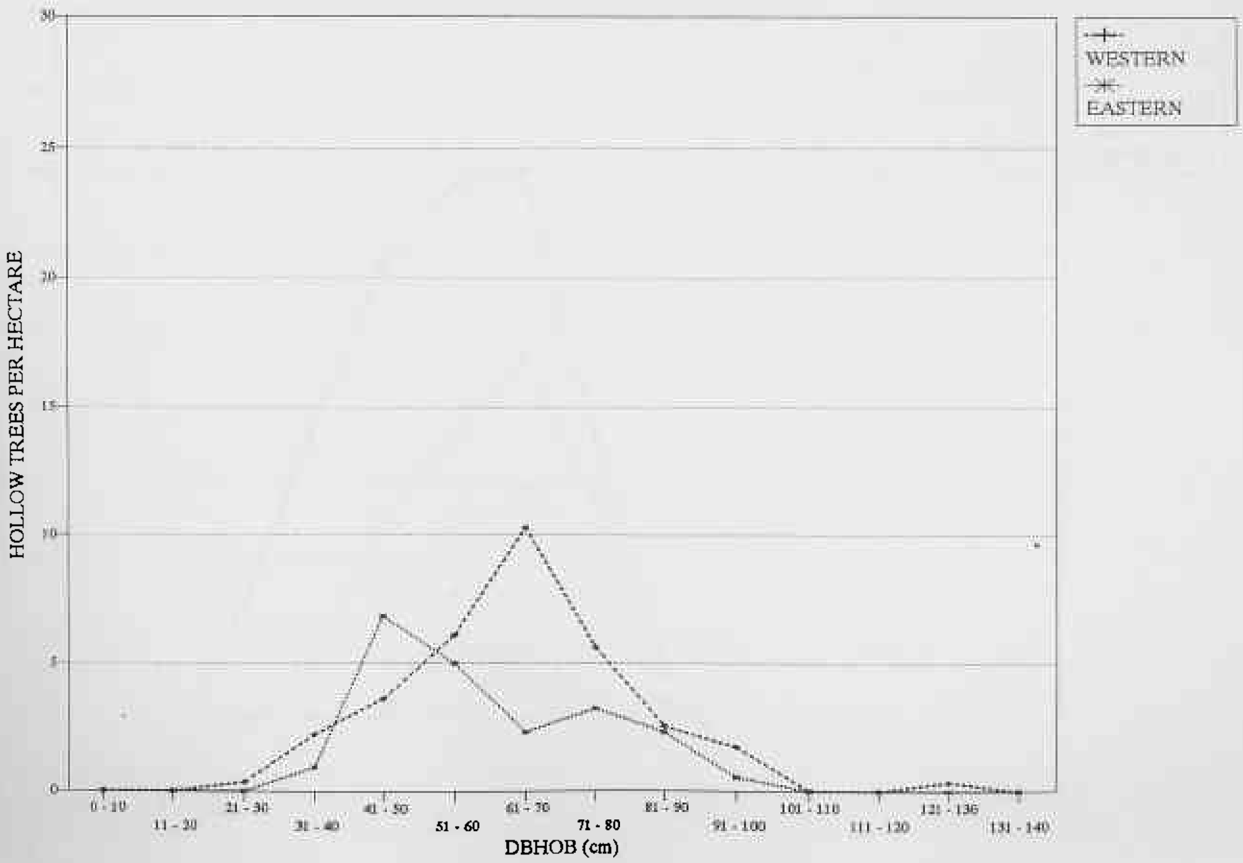


Figure 16. Hollow Size Distribution
Wandoo - West

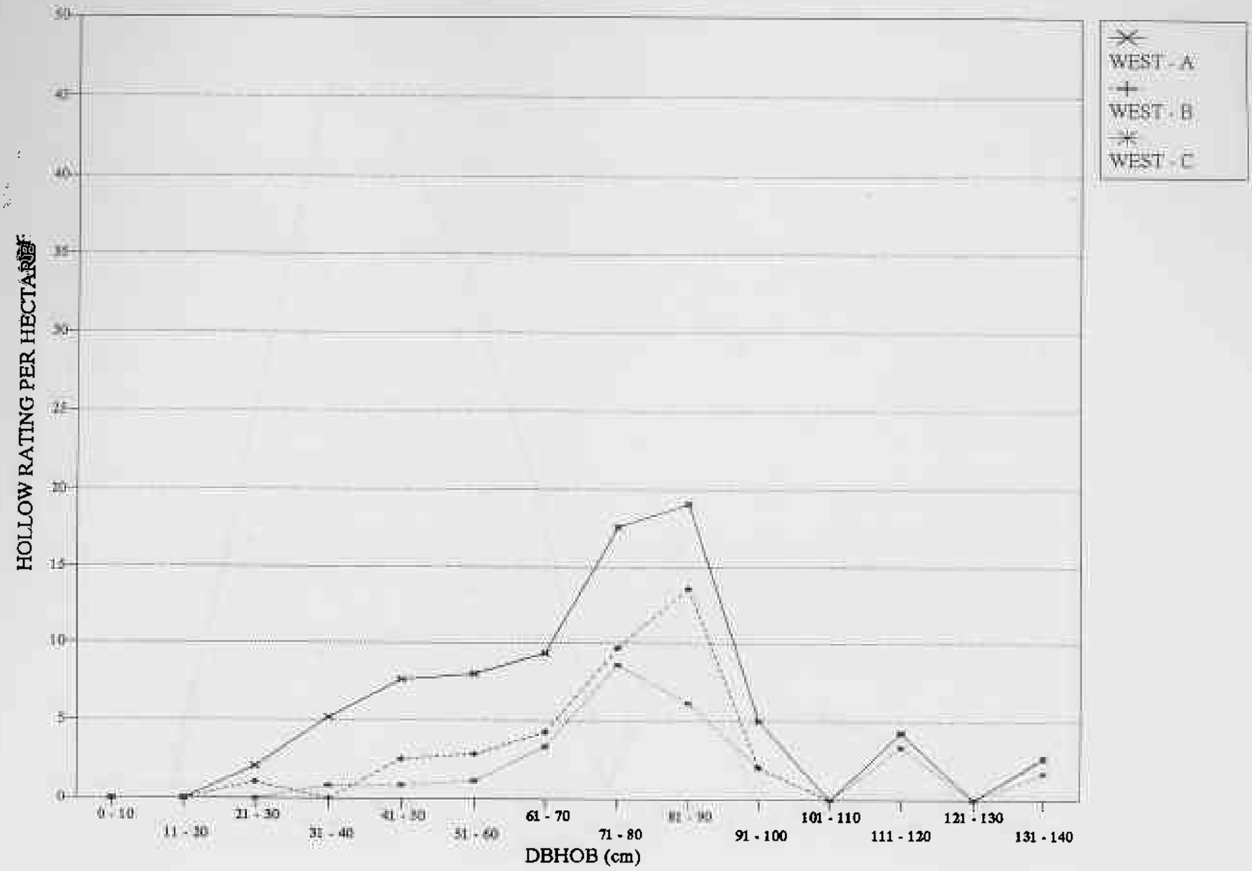



Figure 17. Hollow Size Distribution
Wandoo - Central

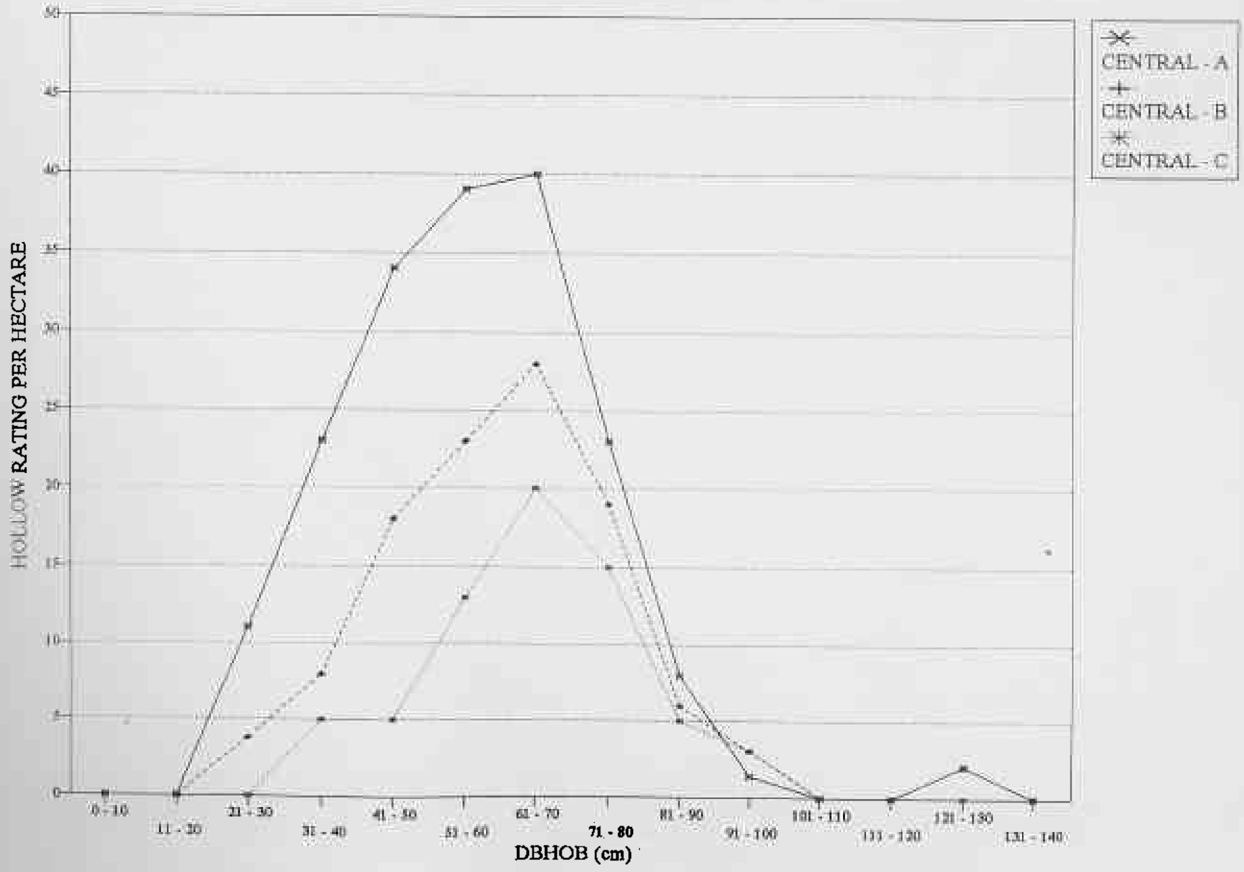


**Figure 18. Hollow Size Distribution**
Wandoo - East

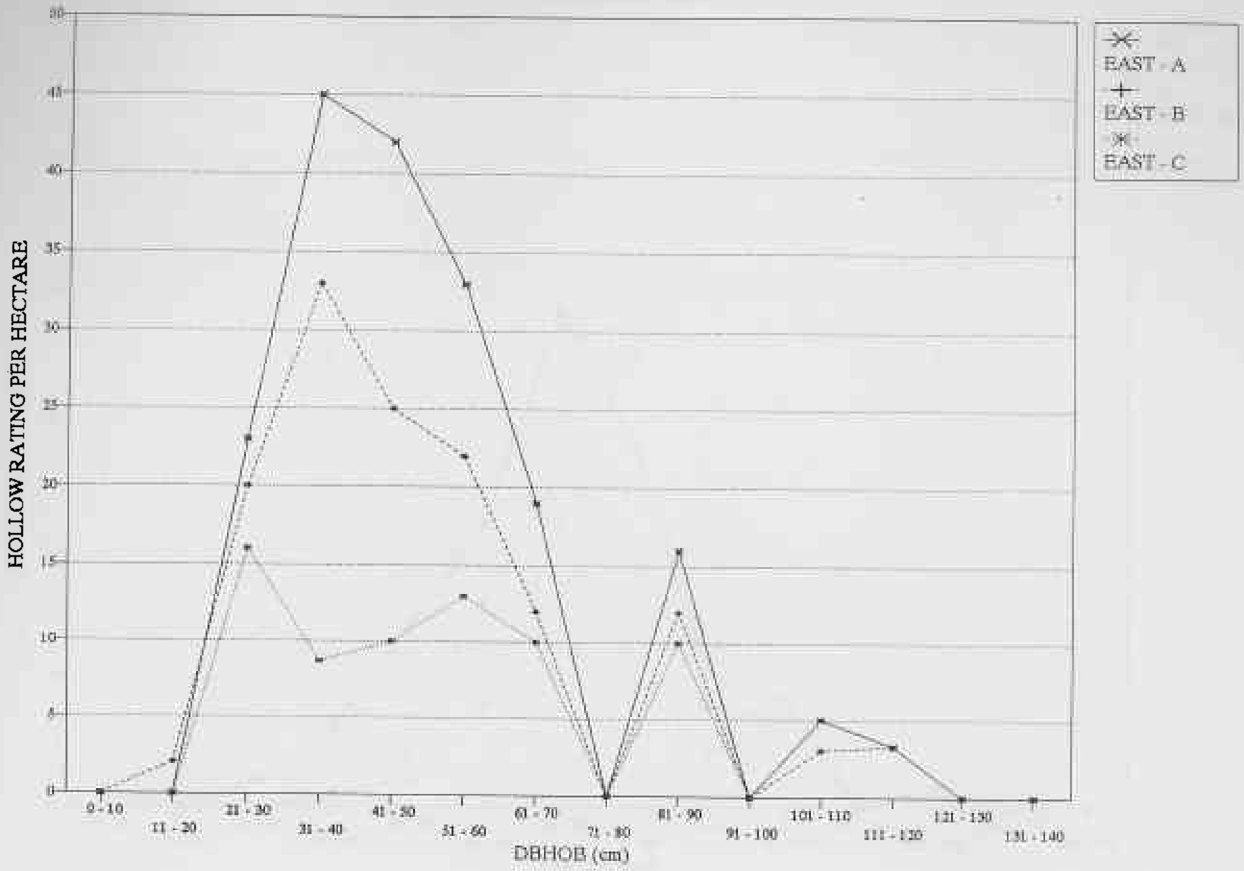


Figure 19. Hollow Size Distribution
Salmon Gum - West

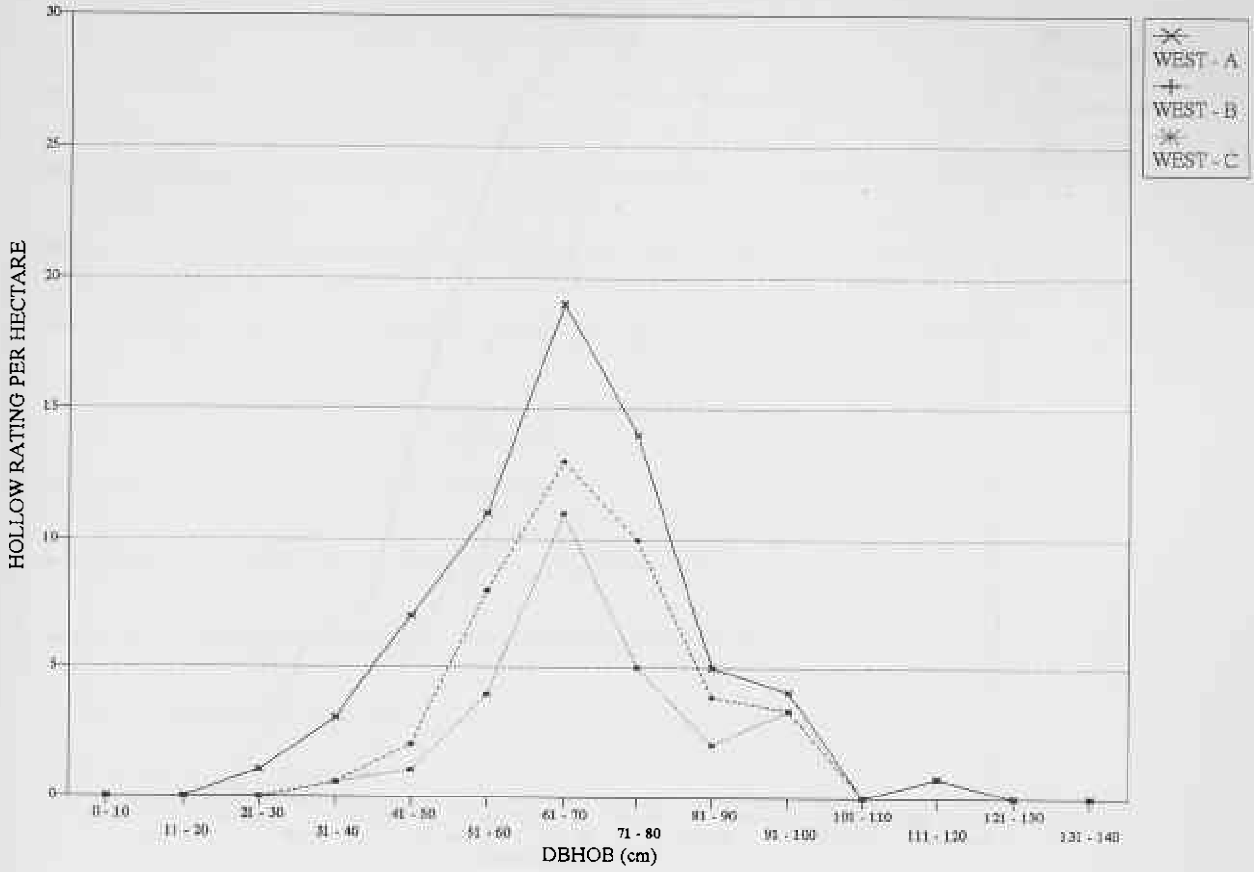



Figure 20. Hollow Size Distribution
Salmon Gum - East

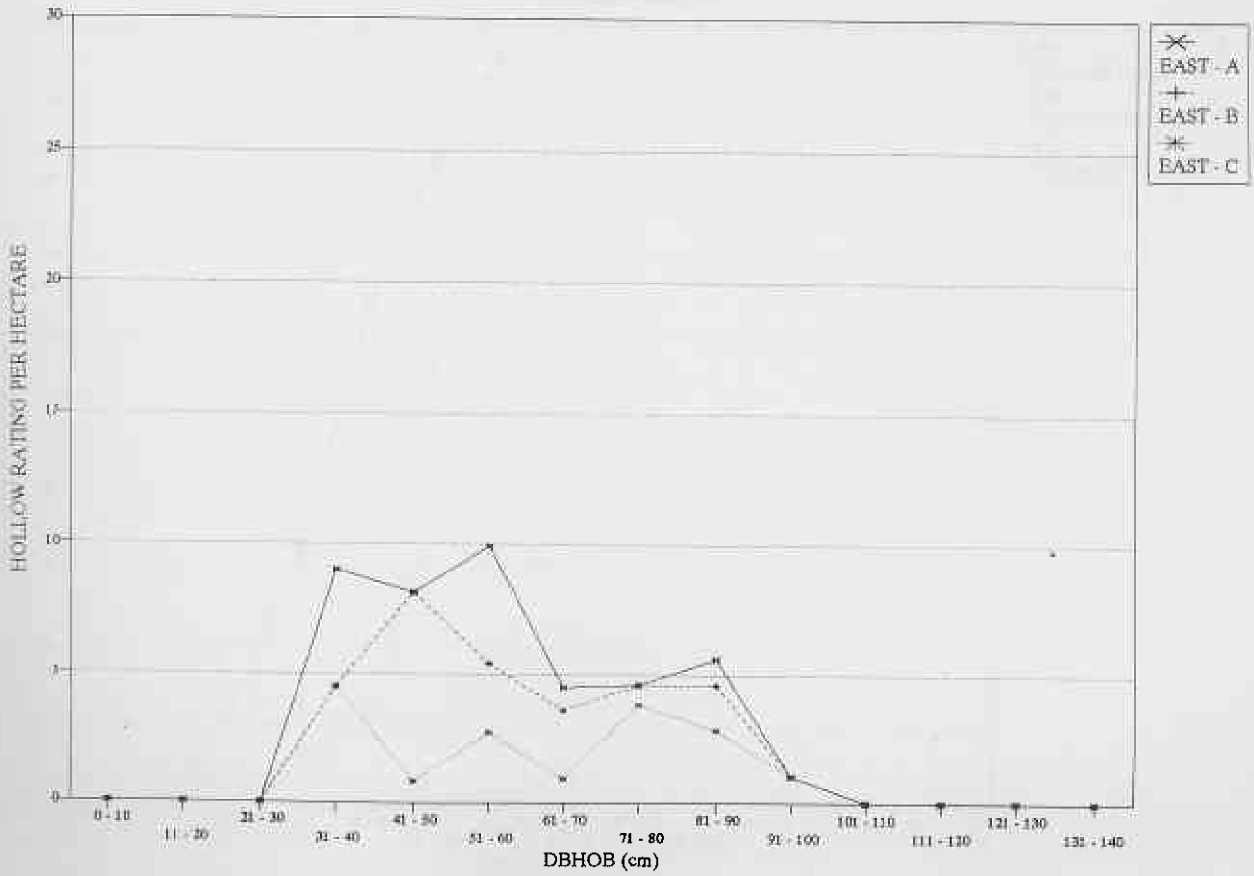


Figure 21. Proportion of Trees with Hollows
Western Wandoo

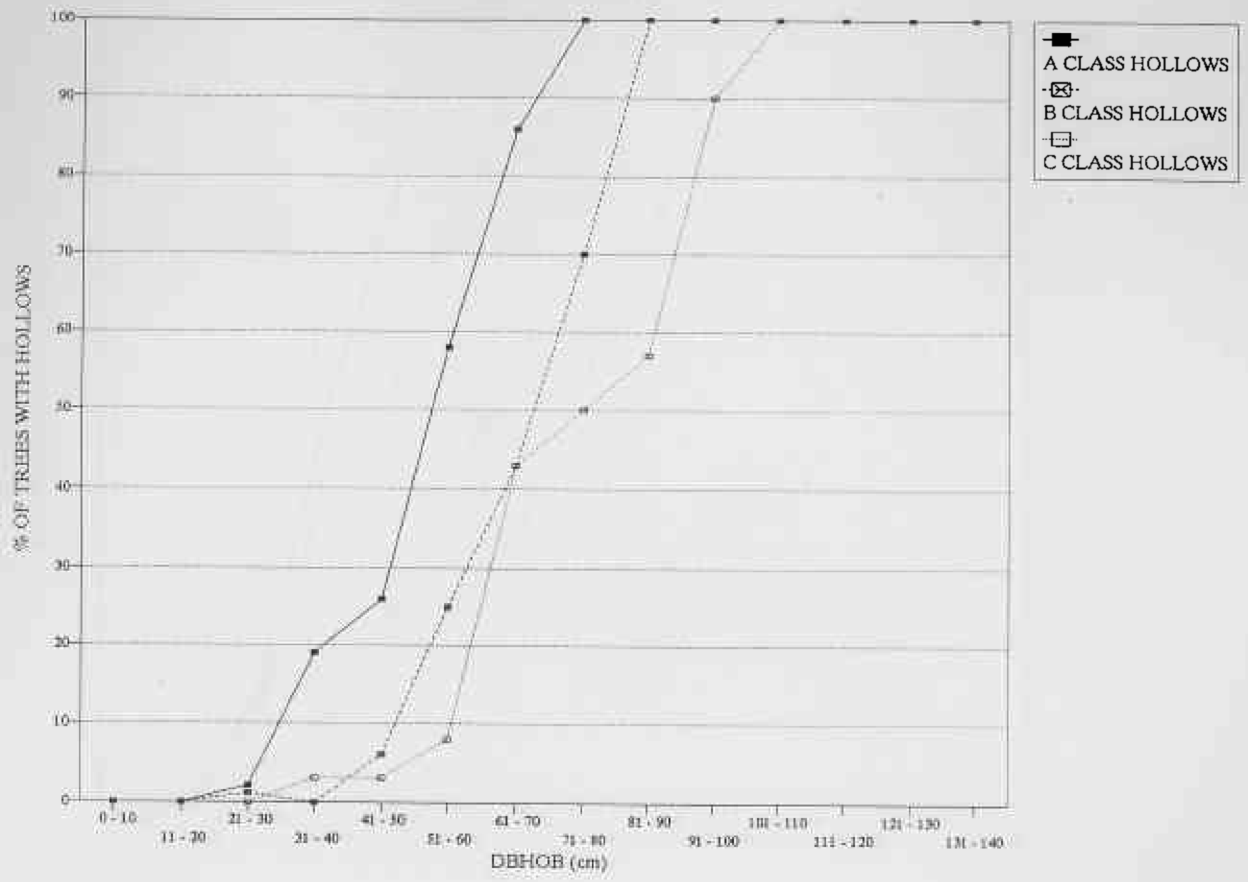



Figure 22. Proportion of Trees with Hollows
Central Wandoo

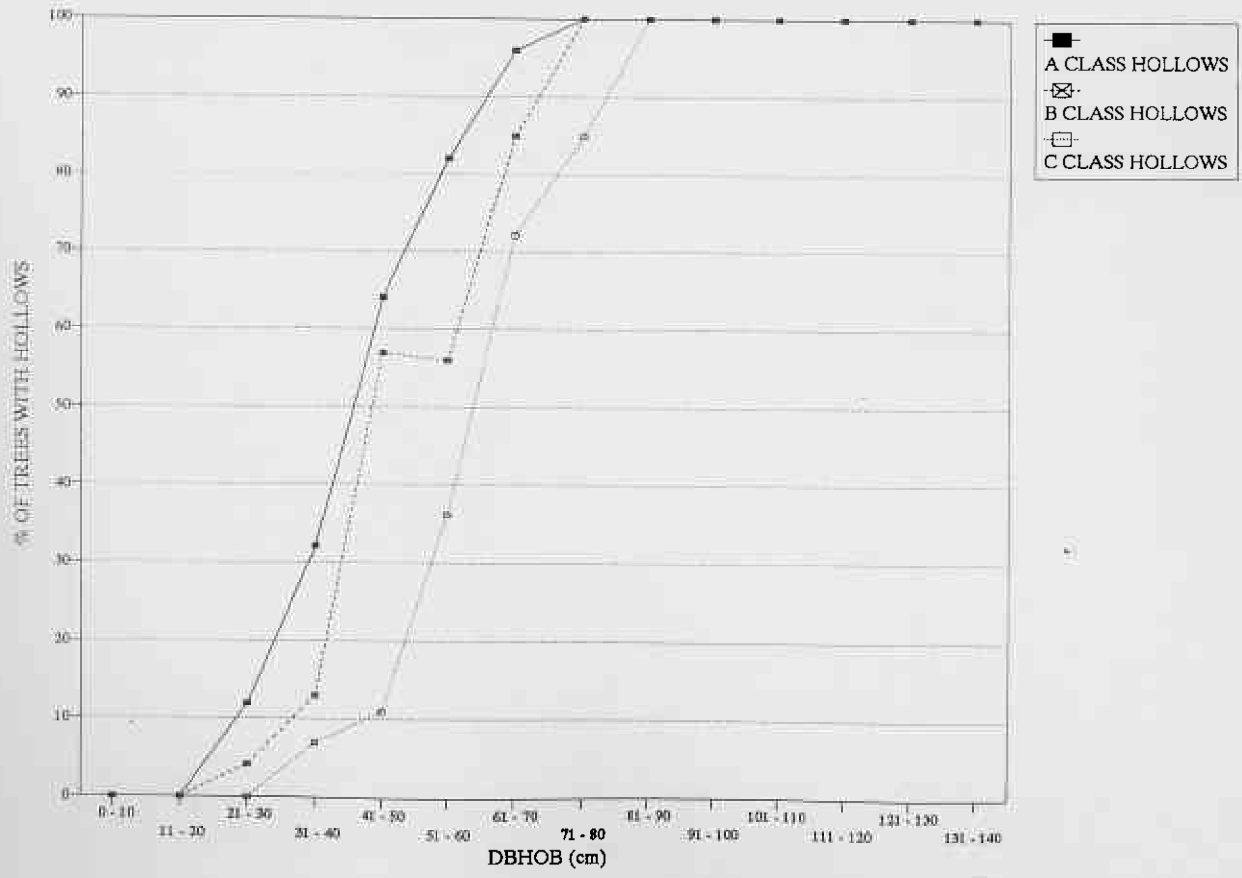


Figure 23. Proportion of Trees with Hollows
Eastern Wandoo

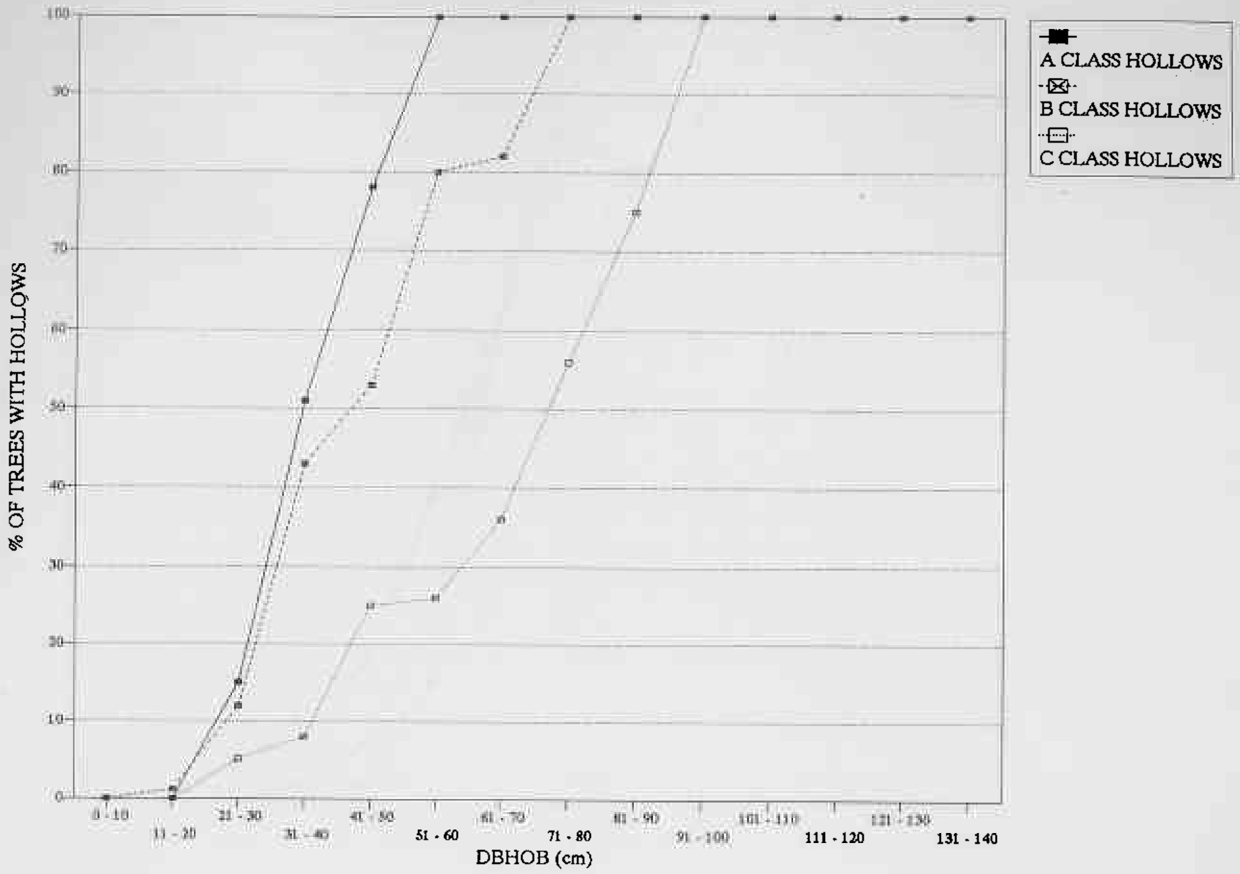


Figure 24. Proportion of Trees with Hollows
Western Salmon Gum

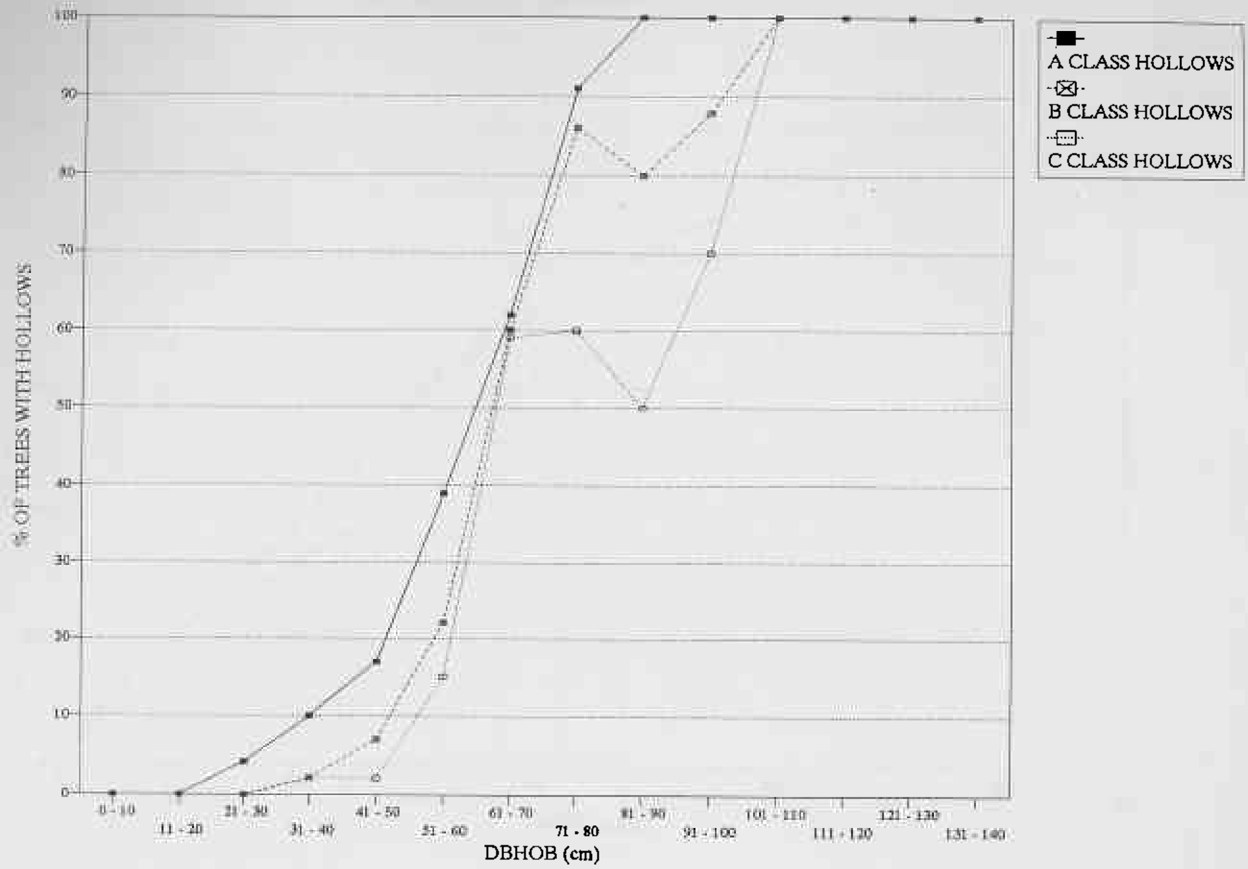



Figure 25. Proportion of Trees with Hollows
Eastern Salmon Gum

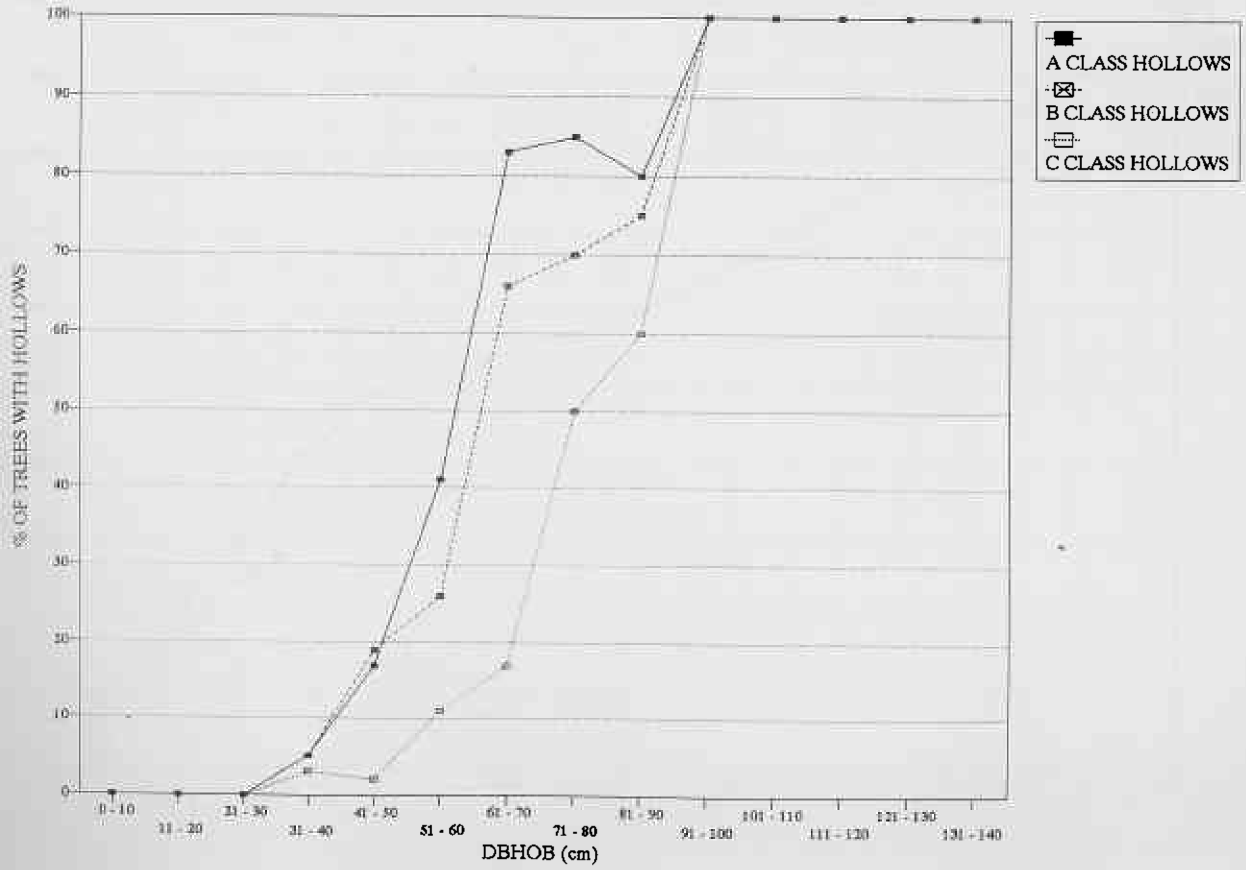


**Figure 26. Diameter vs Age Relationship**
Wandoo

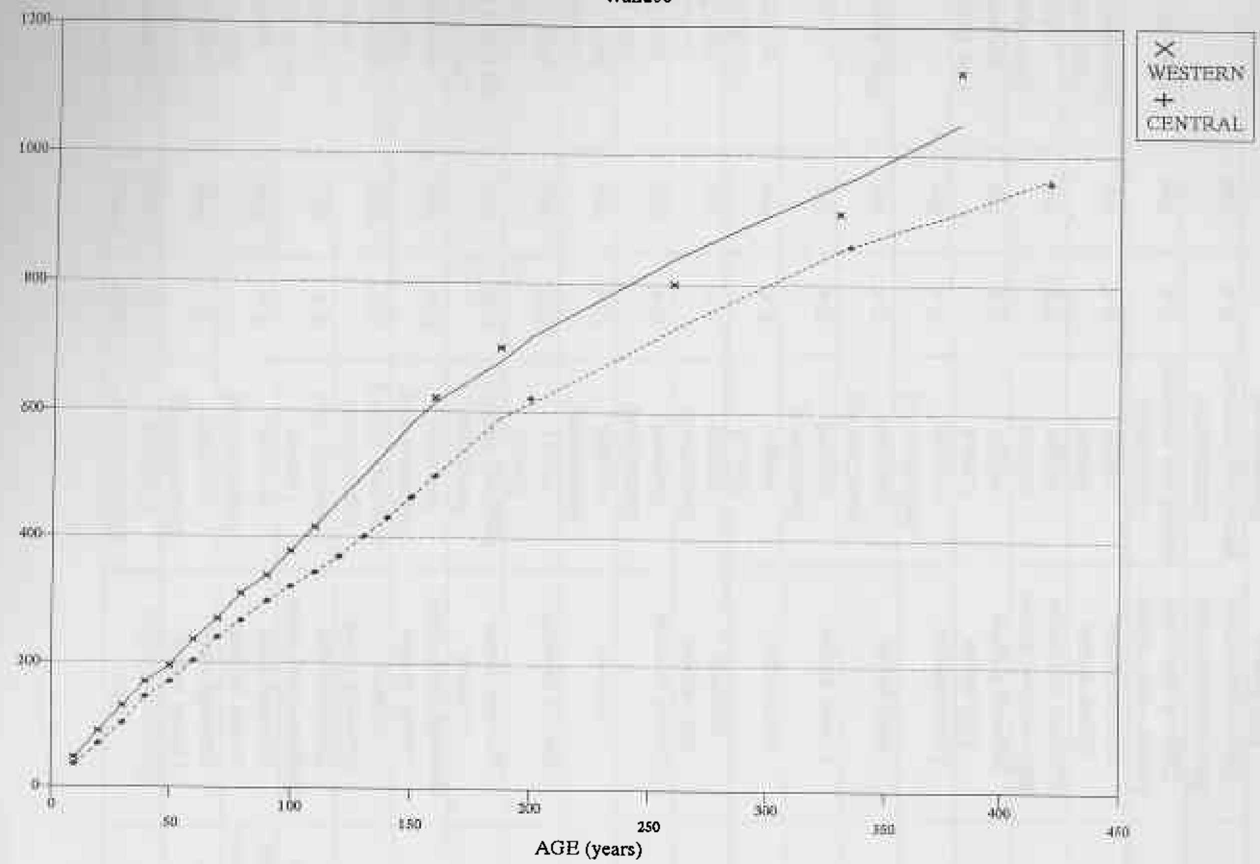
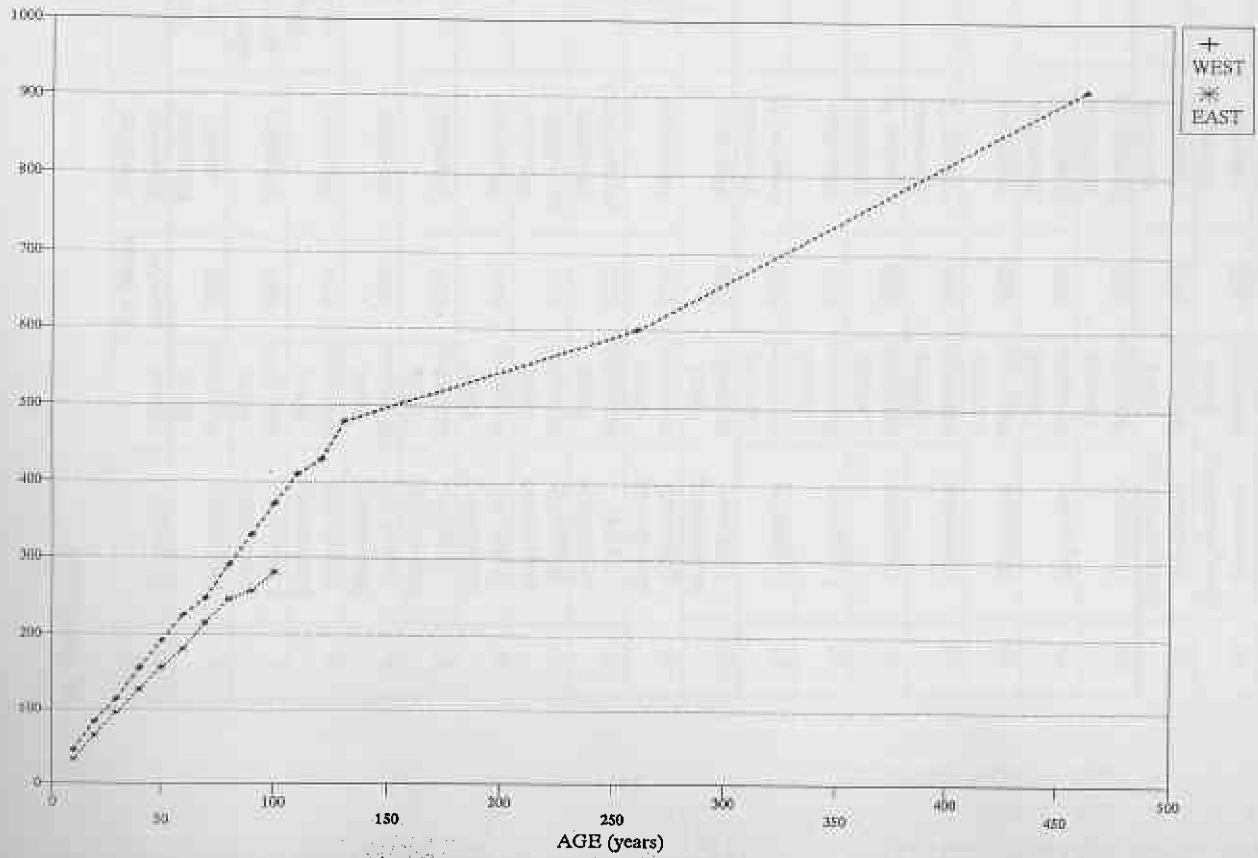



**Figure 27. Diameter vs Age Relationship**
Salmon Gum



## Site Details
*APPENDIX 1*

### A) WANDOO

| Site No. | Locality | Zone | Av Rain mm/yr | Predom Species | Stand Description | Site Characteristics | Disturbance History | Area (ha) | Stem Anlys | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mt Barker | West Wandoo | 750 | Wandoo/ Jarrah | Mixed age remnant on cleared farmland | Lower slope, gravelly clay | Selective log removal | 3 | Yes | No stand analysis |
| 2 | Jarrahdale Lindy Lane | West Wandoo | 860 | Wandoo | Mixed age Wandoo stand within jarrah marri forest | Lower slopes gravelly clay | Selective log removal | 0.4 | Yes | Uneven aged |
| 3 | Mundaring Gorrie Rd | West Wandoo | 800 | Wandoo | Regrowth stand with occasional veterans | Gravelly clay loam lower slopes | Heavy selection cut | 0.4 | No | Three tiered forest |
| 4 | Mundaring Gorrie Rd | West Wandoo | 800 | Wandoo | Regrowth approx. 70 yrs | Gravelly loam upland | Agricultural clearing 1920's | 0.4 | Yes | Few veterans |
| 5 | Mundaring Yetar Rd | West Wandoo | 800 | Wandoo | Mixed age stand | Lower slope gravelly clay loam | Selective log removal | 0.4 | No | Poorly stocked |
| 6 | Mundaring Yetar Rd | West Wandoo | 800 | Wandoo | Even aged regrowth | Upland gravelly loam | Intensive logging 1960's | 0.2 | No | Even-aged no large trees |
| 7 | Jarrahdale (Russell) | West Wandoo | 800 | Wandoo Jarrah Marri | Mixed age stand | Upland gravels | Uncut virgin | 0.4 | No | CALM plot 110 |
| 8 | Jarrahdale FLINT | West Wandoo | 800 | Wandoo Jarrah Marri | Mixed age stand | Lowland | Selectively logged | 0.4 | No | CALM plot 111 |
| 9 | Mundaring (Julimar) | West Wandoo | 700 | Wandoo | Mixed age | Upland gravels | Selectively logged | 0.4 | No | CALM plot 74 |
| 10 | Mundaring (Julimar) | West Wandoo | 700 | Wandoo | Mixed age | Mid slope gravels | Selectively logged | 0.1 | No | CALM plot 75 |
| 11 | Dryandra | Central Wandoo | 500 | Wandoo Powder.B. | Mixed age | Mid slope | Uncut virgin | 0.4 | No | Fire damage evident |
| 12 | Dryandra | Central Wandoo | 500 | Wandoo | Mixed age | Lower slope | Selectively logged | 0.4 | No | |
| 13 | Dryandra | Central Wandoo | 500 | Wandoo Powder.B. | Mixed age woodland | Mid slope | Selective log removal | 0.4 | No | Fire damaged |
| 14 | Dryandra | Central Wandoo | 500 | Wandoo Powder.B. | Mixed age | Lower slope | Selective log removal | 0.4 | No | |
| 18 | Dryandra | Central Wandoo | 500 | Wandoo | Mixed age | Mid slope gravelly loams | Uncut virgin | 0.4 | No | Fire damage apparent |
| 19 | Dryandra | Central Wandoo | 500 | Wandoo Powder.B. | Mixed age | Mid-upper slope Laterite outcrops | Uncut virgin | 0.4 | No | poor quality site |
| 20 | Dryandra | Central Wandoo | 500 | Wandoo Powder.B. | Mixed age | Upper slope shallow soils | Uncut virgin | 0.4 | No | Fire damage Low site quality |
| 15 | Dongolocking Reserves | East Wandoo | 350 | Wandoo Morrell | Mixed age | Lower-mid slope Clay-loam soils | Occasional small log removal | 0.4 | Yes | Fire damage |
| 16 | Dongolocking Reserves | East Wandoo | 350 | Wandoo Morrell | Mixed age Mature stand | Mid-upper slope Clay-loam soils | Occasional small log removal | 0.4 | Yes | |
| 17 | Dongolocking Reserves | East Wandoo | 350 | Wandoo Morrell | Mature stand | Mid slope Clay-loam soils | Occasional small log removal | 0.4 | | Fire damage to larger trees |

## Site Details

*APPENDIX 1*

### B) SALMON GUM

| Site No. | Locality | Zone | Av Rain mm/yr | Predom Species | Stand Description | Site Characteristics | Disturbance History | Area (ha) | Stem Anlys | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| SG1 | Cuballing "Lazaway" | West S.G. | 500 | Salmon Gum | Even aced cohorts in mixed aged stand | Mid-lower slope Sandy-clay loam soil | Occasional log removal | 10 | Yes | No stand analysis |
| SG2 | Old Lake Grace Road | West S.G. | 400 | Salmon Gum Morrell | Mixed age stand few small size class | Clay-loam soils Lower slope | Frequent grazing | 0.6 | No | Grazed farmland remnant |
| SG3 | Fourteen Road | West S.G. | 400 | Salmon Gum | Mixed age stand | Lower slope | Occasional grazing | 0.4 | No | Reserve with weeds & occassional grazing |
| SG4 | Res 10127 Fence Road | West S.G. | 400 | Salmon Gum | Mixed age stand mature veterans | Lower-mid slope | Fire damage evident | 0.8 | No | |
| SG5 | Harrismith | West S.G. | 400 | Salmon Gum | Mixed age | Lower slope | Occasional small log removal | 0.2 | Yes | Mixed size class |
| SG10 | Kulin | West S.G. | 400 | Salmon Gum | Mixed age with few small size trees | Lower slope | Uncut | 1.2 | No | Weed and grass encroachment |
| SG6 | Dragon Rocks Res. | East S.G. | 320 | Salmon Gum | Mixed age woodland even aged cohorts | Lower slope | Uncut | 0.7 | Yes | Natural stand within heathland |
| SG7 | Dragon Rocks Res. | East S.G. | 320 | Salmon Gum | | Lower slope | Uncut | 0.2 | No | |
| SG8 | Dragon Rocks Res. | East S.G. | 320 | Salmon Gum | | Lower slope | Uncut | 0.4 | Yes | |
| SG9 | Dragon Rocks adjacent P.P. | East S.G. | 320 | Salmon Gum | Mature Woodland | Lower slope | Grazing in private property | 0.6 | No | Mature stand with grazing beneath |

Appendix 2A

## Hollow study - ASSESSMENT CRITERIA

A. Tree Class 1. Sapling 2. Pole 3. Mature 4. Over Mature

B. Tree Dominance 1. Dominant 2. Codominant 3. Subdominant
4. Suppressed 5. Edge Tree

C. CROWN CONDITION

| Description | | Branch Condition | |
|---|---|---|---|
| A. | Healthy Intact | 1. | Dead Braches intact (little decay) |
| B. | Stags Apparent | | |
| C. | Many Stags | 2. | Some brances broken at base |
| D. | Broken Boli | | |
| E. | Dead | 3. | Old breaks - evidence of decay or hollow base |

D. FORM

| | | |
|---|---|---|
| Good-fair form | 1. | Good form - bole > 1/2 tree height - no branches on bole |
| | 2. | Lower branches from bole less than 20cm diameter |
| Poor form | 3. | Branches on bole greater than 20cm in diameter |
| | 4. | Forked tree |

E. Hollow Assessment

Each tree was visually assessed from the ground for hollow occurrence using a size (diameter of opening) and frequency (number of hollows observed per tree) rating.

| Hollow class | Size - Diameter of opening |
|---|---|
| A | 0 - 10 cm |
| B | 10 - 20 cm |
| C | > 20 cm |

| Frequency rating | Number of hollows observed |
|---|---|
| 1 | 1 to 3 |
| 2 | 3 to 5 |
| 3 | > 5 |

# APPENDIX 2B

| SITE | | | DATE | | LOCALITY | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NO. | SP | DBH | HT | TREE CLASS | DOMIN | CROWN & COND | FORM | HOLLOWS BA | COMMENTS |
| | | | | | | | | | |
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**APPENDIX 3A**

**DIAMETER INCREMENT - PERMANENT GROWTH PLOTS - WESTERN WANDOO***

| Diameter Class | No. of Trees | Diameter Increment cm/yr | Standard Deviation cm | Standard Error cm | Average Nominal Age |
|---|---|---|---|---|---|
| 10 - 20 | 5 | 0.48 | 0.065 | 0.029 | 31 |
| 21 - 30 | 10 | 0.46 | 0.252 | 0.08 | 53 |
| 31 - 40 | 6 | 0.43 | 0.233 | 0.095 | 76 |
| 41 - 50 | 10 | 0.43 | 0.171 | 0.054 | 99 |
| 51 - 60 | 9 | 0.43 | 0.133 | 0.044 | 122 |
| 61 - 70 | 2 | 0.35 | 0.007 | 0.005 | 151 |
| 71 - 80 | 6 | 0.27 | 0.100 | 0.04 | 187 |
| 81 - 90 | 7 | 0.20 | 0.099 | 0.037 | 237 |
| 90 plus | 6 | 0.19 | 0.107 | 0.044 | 290 |

* 1. Remeasured permanent growth plots - Mundaring & Jarrahdale Districts - Dept. CALM

2. Dominant Wandoo trees only.

APPENDIX 3B

## DIAMETER INCREMENT - WESTERN WANDOO - JARRAHDALE DISTRICT GROWTH PLOTS

| GROWTH RATES DIAM CLASS | AVERAGE DIAMETER INCREMENT CM/YR |
|---|---|
| 10-20cm | 0.48 |
| 20-30cm | 0.45 |
| 30-40cm | 0.49 |
| 40-50cm | 0.47 |

* Refer Jarrahdale District Report - Plots established 1988

APPENDIX 3C

## * SALMON GUM GROWTH RATES - COOLGARDIE

| Co-dom. Height 11.5m Dominance Class | (n) | Mean Diam (cm) | Mai (mm/yr) | n/ha |
|---|---|---|---|---|
| Edge trees | 18 | 25.5 | 3 | 19.4 |
| Dominants, crowded | 53 | 17.0 | 2 | 57.0 |
| Co-dom, crowded | 28 | 13.0 | 1.5 | 30.1 |
| Subdominants - | 57 | 9.0 | 1.1 | 61.3 |
| Total stand | 156 | 14.5 | 1.7 | 167.8 |
| Morality | 62 | | | 67 |
| Total per ha | | | | 235 |

* From Internal Report - Forests Dept. W.A. 1983

Original plot established 1917 and re-established 1982

**NOTE** : Plot 84 years of age (1982)

APPENDIX 3D

## AGGREGATED STEM ANALYSIS DATA

| RINGS/AGE | WANDOO | | | | | | SALMON GUM | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WEST | | | (Dryandra) Central | | | West | | | Dragon Rocks East | | |
| | Mean Diam. (mm) | Increment mm | Standard Dev. | Mean Diam (mm) | Increment mm | Standard Dev. | Mean Diam. (mm) | Increment mm | Standard Dev. | Mean Diam (mm) | Increment mm | Standard Dev. |
| 10 | 47 | 47 | 7.6 | 36 | 36 | 10.7 | 43 | 43 | 5 | 32 | 32 | 5 |
| 20 | 88 | 41 | 14.7 | 68 | 32 | 12.5 | 82 | 39 | 11 | 64 | 32 | 10 |
| 30 | 130 | 42 | 18.3 | 102 | 34 | 11 | 114 | 32 | 16 | 94 | 30 | 13 |
| 40 | 169 | 39 | 16.7 | 144 | 42 | 15 | 154 | 40 | 22 | 127 | 33 | 14 |
| 50 | 194 | 25 | 22.6 | 168 | 24 | 14 | 191 | 37 | 27 | 156 | 29 | 19 |
| 60 | 236 | 42 | 24.8 | 202 | 34 | 15 | 225 | 34 | 34 | 180 | 24 | 21 |
| 70 | 268 | 32 | 28.9 | 240 | 38 | 17 | 248 | 23 | 48 | 216 | 36 | 25 |
| 80 | 310 | 42 | 29.6 | 266 | 26 | 20 | 292 | 44 | 28 | 246 | 30 | 28 |
| 90 | 338 | 28 | 29 | 298 | 32 | 24 | 332 | 40 | 57 | 258 | 12 | 29 |
| 100 | 378 | 40 | 30 | 322 | 24 | 20 | 372 | 40 | 31 | 282 | 24 | 24 |
| 110 | 417 | 39 | 45.4 | 344 | 22 | 23 | 410 | 38 | 30 | | | |
| 120 | | | | 368 | 24 | 26 | 430 | 20 | 33 | | | |
| 130 | | | | 401 | 33 | 28 | 479 | 49 | 42 | | | |
| 140 | | | | 430 | 29 | 30 | | | | | | |
| 150 | | | | 464 | 34 | 28 | | | | | | |
| 160 | | | | 497 | 33 | | | | | | | |
| 170 | | | | | | | | | | | | |

Mean Diameter Increment (from above)

| | | |
|---|---|---|
| 1. Wandoo | West | 0.38 mm/yr |
| | Central | 0.31 mm/yr |
| 2. Salmon Gum | West | 0.35 mm/yr |
| | East | 0.28 mm/yr |

Use this data for Fig 13 a & b
* Age v's diameter (up to 50 cm dbhob)
* Note – Underbarke diameter figures.

# APPENDIX 4A. STAND TABLES - WANDOO

FREQUENCY (Stems/ha)

| | SITE NUMBER | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| DBHOB | | | | | | | | | | | | | | | | | | | |
| 0 - 10 | 125 | 662 | 40 | 150 | 480 | 20 | 123 | 280 | 100 | 18 | 85 | 125 | 63 | 160 | 77 | 40 | 38 | 105 | 108 |
| 11 - 20 | 90 | 55 | 140 | 130 | 260 | 33 | 45 | 115 | 80 | 36 | 20 | 100 | 73 | 122 | 67 | 23 | 25 | 98 | 73 |
| 21 - 30 | 28 | 40 | 130 | 75 | 140 | 7 | 32 | 60 | 30 | 33 | 36 | 48 | 28 | 50 | 35 | 18 | 33 | 60 | 40 |
| 31 - 40 | 30 | 20 | 50 | 10 | 60 | 4 | 8 | 30 | 20 | 20 | 16 | 23 | 28 | 28 | 40 | 25 | 33 | 35 | 28 |
| 41 - 50 | 23 | 13 | 50 | 8 | 60 | 7 | 10 | 15 | 12 | 25 | 10 | 33 | 20 | 28 | 25 | 37 | 20 | 13 | 23 |
| 51 - 60 | 8 | 0 | 0 | 8 | 0 | 14 | 15 | 5 | 9 | 18 | 36 | 18 | 5 | 10 | 10 | 18 | 18 | 10 | 13 |
| 61 - 70 | 3 | 5 | 0 | 5 | 0 | 13 | 10 | 5 | 0 | 15 | 10 | 0 | 12 | 5 | 5 | 18 | 15 | 5 | 12 |
| 71 - 80 | 4 | 2 | 0 | 5 | 0 | 10 | 5 | 4 | 0 | 3 | 0 | 5 | 5 | 0 | 0 | 0 | 10 | 7 | 0 |
| 81 - 90 | 4 | 5 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 10 | 7 | 0 | 5 | 5 | 0 | 0 | 2 | 0 |
| 91 - 100 | 0 | 0 | 0 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 101 - 110 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 111 - 120 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 121 - 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 131 - 140 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 317 | 804 | 410 | 395 | 1000 | 113 | 251 | 517 | 253 | 170 | 223 | 362 | 234 | 410 | 264 | 181 | 192 | 335 | 297 |

# APPENDIX 4B. STAND TABLES - SALMON GUM

FREQUENCY (Stems/ha)

| | SITE NUMBER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| DBHOB | | | | | | | | | |
| 0 - 10 | 10 | 61 | 49 | 65 | 489 | 115 | 95 | 66 | 3 |
| 11 - 20 | 32 | 38 | 33 | 65 | 54 | 30 | 50 | 45 | 13 |
| 21 - 30 | 22 | 16 | 16 | 15 | 26 | 40 | 15 | 16 | 12 |
| 31 - 40 | 37 | 9 | 13 | 30 | 27 | 20 | 18 | 8 | 14 |
| 41 - 50 | 23 | 10 | 16 | 5 | 22 | 15 | 23 | 22 | 18 |
| 51 - 60 | 23 | 10 | 11 | 10 | 9 | 20 | 12 | 15 | 13 |
| 61 - 70 | 10 | 14 | 22 | 20 | 0 | 0 | 3 | 8 | 7 |
| 71 - 80 | 10 | 5 | 2 | 10 | 1 | 5 | 12 | 2 | 7 |
| 81 - 90 | 2 | 3 | 4 | 5 | 2 | 0 | 0 | 4 | 2 |
| 91 - 100 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 3 |
| 101 - 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 111 - 120 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 121 - 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 131 - 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 171 | 167 | 167 | 225 | 630 | 245 | 228 | 188 | 92 |