AN ASSESSMENT OF FOREST DAMAGE FROM THE DWELLINGUP FIRES IN WESTERN AUSTRALIA

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SUMMARY

The monetary loss due to timber damage resulting from the Dwellingup fires of 1961, was determined from assessment in fire damage categories interpreted on air photos. The timber loss values enabled a "least cost plus damages" approach to forest fire control economics to be illustrated.

The relationship of fire damage to crown damage, crown recovery, marketability, bark thickness, species and increment loss is described.

Timber loss from controlled burning is compared to the loss which occurred in the fire damage categories associated with the Dwellingup fire.

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INTRODUCTION

During January, 1961 the Dwellingup fires burnt over approximately 360,000 acres of prime jarrah forest in the south west region of Western Australia (Rodger, 1961).

These fires started from numerous lightning strikes on the 19th and 20th of January when fire dangers were extreme. A large area of forest was defoliated or fully scorched but other areas appeared relatively undamaged.

Wallace (1965) described the high fire resistance of jarrah and its ability to recover from intense fires. Crown recovery was evident in the years after the fire but the degree of recovery appeared to be associated with the severity of crown damage and with tree vigour. Assessments were completed to compare stand recovery in defoliated, scorched and less damaged stands and to compare these strata with damage in an adjacent area of controlled burning.

These assessments were completed between 1963 and 1965 and levels of recovery may have changed since.

The ability of jarrah to produce an epicormic crown made assessments of volume losses fairly hypothetical, except for dead trees. Losses associated with the entry of fungi and borers were not considered, and increment failed to receive the attention it deserves (Peet, McCormick, Rowell, 1968)

FOREST TYPE

The jarrah forest near Dwellingup is a dry schlerophyll type. It is usually associated with a sparse scrub cover and with undulating topography.

Jarrah (Euc marginata Sm.) is usually found in association with marri (Euc calophylla Lindl.) which, in the Dwellingup area, comprises about 10 to 15 per cent of the forest stocking. Both trees are rough-barked and the outer bark of jarrah, in particular, ignites easily during the summer months (Peet and McCormick, 1965).

The weight of scrub foliage in the Dwellingup area may range between 3 and 13 tons per acre (McCormick, 1968) and this foliage will ignite easily during high fire dangers. Jarrah trees drop about one quarter of their leaves each year as litter, and at the time of the Dwellingup fires accumulations of 8 tons per acre were common (Table 1).

TABLE 1 : Fuel Classification over 306,656 Acres of Dwellingup Fire Area.

Fuel Age	Litter weight tons/acre EODW	Area Burnt by Dwp.Fires (acres)	Area as a percentage of total area
1 to 2 years	0.0 to 2.5	27,238	8.8
2 to 3 years	0.0 to 3.0	36,634	12.0
4 to 5 years	1.5 to 4.5	56,115	18.3
6 to 10 years	2.6 to 8.0	72,730	23.7
11 to 15+years	8+	113,030	37.2
Totals		306,656	100.0

The understorey species usually include casuarina, (C. fraseriana), and bull banksia, (B. grandis), and both have a highly inflammable litter.

A group selection system of cutting has resulted in stands with a wide range of size classes in the Dwellingup forests. Appendix 1 lists the number of trees per acre in girth classes, from 220 randomly located one acre plots in the fire area. By far the highest number of trees per acre lies in the sapling and small pole size classes.

WEATHER, FUEL AND FIRE INTENSITY

The year 1960 was dry by average standards and rainfall deficits contributed to the extremely dry fuel in January, 1961 (Table 2).

Table 2 : Rainfall Deficits for Dwellingup, 1960

	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Deficit Points	211	219	733	961	1,121	1,243	1,297

At the time of the Dwellingup fires about ten per cent of this forest was control-burnt annually. The area of protected forest was being steadily reduced but there still remained over 100,000 acres of very heavy litter (Table 1). Fuel reduction undoubtably reduced forest damage (McArthur and Cheney, 1966) and although not effective in enabling the suppression forces to control the massive southern spread on the 24th of January, certainly assisted fire control during the preceding days.

The main spread of the Dwellingup fires occurred on Tuesday the 24th of January when massive headfire fronts swept southwards through the forest and three townships. During this time much of the head-fire was crownfire which spread to about 80 chains per hour. In addition spot fires were thrown one to two miles ahead of the fronts creating an impossible situation for the suppression forces.

The daily 3 p.m. weather readings at Dwellingup, local fire danger indexes (Peet, 1965) and estimated fire intensities are shown in Table 3. Fire intensity was calculated from Byram's formula I = Hwr, using 8 tons per acre of available fuel and a heat yield of 8000 B.T.U. per pound (McArthur 1968).

TABLE 3 : 3 p.m. Weather Readings at Dwellingup, with Local Fire Danger Index and Estimated Fire Intensity for 8 tons/acre Fuel.

Date	Temp ^{o}F Max.	Min.	R.H. %	Open Wind Dir.	Vel. mph	Local Fire Danger	Estimated fire intensity B.T.U. per sec per ft.
19/1/61	104	65	19	N.W.	17 to 20	Red	2,100
20/1/61	103	73	16	E.	4 to 6	Yellow	1,300
21/1/61	101	71	20	W.NW.	11 to 16	Yellow	700
22/1/61	99	70	27	S.W.	4 to 6	Brown	380
23/1/67	98	64	27	0	0	Brown	380
24/1/61	106	74	13	N	40 - 45	Red	4,800

METHOD OF ASSESSMENT

(a) Interpretation of Aerial Photographs

The area of the fire and the different categories of damage were determined from air photos taken one to two months after the fire at a height of 7,920' with a camera having a 6" focal length lens, on panchromatic film which was printed at 1:15,840 on 9" x 9" prints.

The aim of the interpretation was to delineate fire damage categories with real differences which could be recognised on the photo as well as on the ground. After many miles of road cruising to check possible categories, the following simple and successful classification was used :

Type	Appearance on Ground	Appearance on Photo
Defoliated	Complete defoliation.	Bare black stems, black ground.
Fully scorched	All leaves present are scorched : some defoliation.	Overall light tone due to scorched crowns.
Lesser damage	Maximum scorch to height of lower leaves only.	Both crowns and ground appear medium to dark grey.

The areas identified in each fire damage category were :

Defoliated	65,000 acres
Fully scorched	190,000 acres
Lesser damage	105,000 acres
Total	360,000 acres

(b) Assessment

The objectives of the assessment were : To measure the volume of merchantable timber which was fire killed and to record the degree of crown recovery in the remainder. To determine the amount of crown damage in sapling sizes especially those considered to be potential crop trees.

These objectives were achieved by measuring randomly located one-acre plots in each of the three fire damage categories and in the control-burnt area.

For measurement purposes the stands were divided into trees over 36 inches G.B.H.O.B. and trees under 36 inches. The former represented trees of merchantable size and the latter potential crop trees or surplus trees.

For the over 36 inch G.B.H.O.B. class, trees were divided into those considered merchantable for sawmilling and those too defective for sawmilling. The unmerchantable trees were useless before the fires. Trees which had burnt down, or suffered severe butt damage, but still retained a useful log, were considered merchantable.

Within the two grades of merchantability the trees were divided into three classes of crown recovery. These were (i) crowns replaced after the fires; (ii) trees with no crowns but with epicormic shoots on the bole and (iii) entirely fire killed.

Tree volumes were calculated from the jarrah volume tables using measurements of G.B.H.O.B. and estimates of log length. The volumes were true volume under bark.

Trees in the under 36 inch size class were counted. They were divided into potential crop trees (Peet, 1967) and those considered surplus to the stand. Where possible the potential crop trees were spaced on a 20 feet grid, and were either dominants in a group, trees with space to grow or overtopped trees which would be released in the next trade cut.

The potential crop trees and surplus trees were divided into two crown damage classes. These were : crowns fire killed, and crowns replaced. The former class did not mean that the saplings were necessarily dead, in some cases a crown was forming from epicormic shoots on the bole, or the whole sapling was being replaced by a new shoot from the lignotuber. In both cases, however, the original sapling was badly damaged and considered to be a direct loss to the stand.

(c) Plot Establishment

The randomly located one acre plots were 10 chains in length and one chain in width. Because of budget limitations the number assessed in each stratum was designed to achieve a sampling error of 15 per cent at the 68 per cent confidence level.

The number of plots established in each stratum was defoliated 100; fully scorched 220; lesser damage 50 and controlled burning 45.

The control burnt area covered approximately 80,000 acres to the east of the fire area. The quality of this burning compared favourably with the general standard for the jarrah forest at that time.

RESULTS OF THE ASSESSMENT

The results of the assessments for the three fire damage categories in the fire area, and in controlled burning are listed in Table 4. This table shows the average volume or number per acre and the standard error of the mean.

TABLE 4 : Forest Damage from the Dwellingup Fire.

VOLUME	DEFOLIATED			FULLY SCORCHED			LESSER DAMAGE			CONTROLLED BURNING		
	Vol/acre cu.ft UB	S.E. cu.ft.	% S.E.	Vol/acre cu.ft UB	S.E. cu.ft.	% S.E.	Vol/acre cu.ft UB	S.E. cu.ft.	% S.E.	Vol/acre cu.ft UB	S.E. cu.ft.	% S.E.
(1) Over 36" G.B.H.O.B.												
(a) Crowns replaced :												
Merchantable	645.0	34.4	5.3	774.2	28.1	3.6	592.1	35.06	5.9	632.7	48.1	7.6
Non-merchantable	69.4	12.5	18.0	131.0	11.3	8.6	263.9	31.55	11.6	284.4	38.0	13.4
(b) Bole epicormics only :												
Merchantable	206.4	21.5	10.4	76.9	10.8	14.0						
Non-merchantable	92.0	14.2	15.4	41.3	5.6	13.5						
(c) Fire killed :												
Merchantable	69.6	11.9	17.1	28.5	3.8	13.3						
Non-merchantable	65.0	11.3	17.4	55.7	7.3	13.1	39.9	11.54	28.9	1.8	0.25	13.9
	1147.4			1107.6			895.9			918.9		
	Number per acre	S.E. No.	% S.E.	Number per acre	S.E. No.	% S.E.	Number per acre	S.E. No.	% S.E.	Number per acre	S.E. No.	% S.E.
(2) Under 36" G.B.H.O.B.												
(a) Crowns replaced :												
Potential crop	44.1	4.0	9.1	55.7	2.3	4.1	92.6	3.83	4.1	82.0	6.29	13.1
Surplus trees	24.8	3.4	13.7	49.7	3.4	6.8	141.74	14.97	10.6	93.0	13.3	7.1
(b) Crowns dead												
Potential crop trees	58.3	3.9	6.7	19.4	1.2	6.2	2.9	0.38	13.4	7.0	0.82	11.7
Surplus trees	167.2	18.0	10.7	114.3	6.6	5.8	100.9	11.76	11.7	89.0	11.6	13.0

It was evident that the amount of crown recovery was related to the degree of crown damage. This observation was supported by the histograms in Figures 1 and 2. These histograms show the percentage of total merchantable and non-merchantable volume per acre in the three crown recovery classes, and the percentage of total potential crop tree and surplus tree numbers per acre in two crown recovery classes.

In both figures there was a sensible correlation between crown damage and crown recovery, with less recovery in the defoliated and fully scorched classes than in lesser damage and controlled burning. Also evident were differences in crown recovery between merchantable and non-merchantable trees and potential crop trees recovered better.

Figure 2 shows a higher percentage of damaged potential crop trees in the control burnt area than in lesser damage, but this may be due to sampling error (Table 4). These errors indicate more significant differences between these two classes and defoliation or full scorching.

The number of potential crop trees may be higher than required, but envisaged progressive removals by thinning. For the control burnt area the same losses are likely to be repeated with rotational controlled burning because of increasing fire resistance with increasing height growth (Peet, McCormick, Rowell, 1968). They may be repeated after the next trade cut if prescriptions are not rigidly controlled to a minimum potential crop tree height of 15 feet and a fire intensity less than 12 B.T.U. per sec per ft. (Peet, McCormick, Rowell, 1968).

VALUATION OF FOREST DAMAGE

This study is confined to timber losses and does not consider the other losses associated with fire. Timber losses were estimated by an expectation value method in which present timber values were calculated with and without the effect of fire (Davis, 1954).

The assumptions used in the calculations were :

1% M.A.I. volume increment)
½" girth increment/year) Working Plans Section, unpublished data

10c/cu.ft. royalty value of timber
4% compound interest rate.

Tree Class	Effect on increment	Effect on merch. timber
Crowns replaced, merch. over 36"	Not lost	Not lost
Bole epicormics only, merch. over 36"	Lost	Not lost
Fire killed merch. over 36"	Lost	Lost unless salvaged
Crowns replaced, potential crop trees under 36"	Not lost	Pot. merch. timber not lost
Crowns dead, potential crop trees under 36"	Lost	Lost

Because the actual timber loss depends on the amount of timber salvaged, three estimates of loss have been calculated, namely :

Maximum loss : when no salvage takes place.
Most likely loss : when trees are salvaged to the extent of existing facilities.
This meant cutting 5,000 acres/year on salvage work. For this estimate it was also necessary to consider timber degrade. The following figures were used :

Merch. life of fire killed trees 36" - 60" girth = 1 year
Merch. life of fire killed trees over 60" girth = 15 years.
(McCoy and Campbell, F.J., 1962. Unpublished opinion).

Minimum loss : when all trees worth salvaging are salvaged.

The value of timber losses due to the Dwellingup fire, calculated in this way, are summarised in Table 5, from which it can be seen that :

1. Salvage can reduce the total loss in "defoliated" types from $513,000 to $297,000 and in "complete scorch" types from $568,000 to $328,000.

2. "Lesser damage" can reduce the minimum loss in the "defoliation" type from $4.58/acre to $0.16/acre, a saving of $4.42/acre.

3. 360,000 acres at the "lesser damage" loss of $0.16/acre = $57,600. As it has been shown that the "control burnt" type is very similar to "lesser damage" (Table 5) it could be concluded that if all the area covered by the Dwellingup fire had been control burnt it would have

suffered "lesser damage" and the timber loss would have been of the order of $60,000 instead of over $600,000.

TABLE 5 : Summary of Timber Loss Due to Dwellingup Fire.

Fire Damage Category	Area	Minimum		Most Likely		Maximum	
		$/ac.	Total	$/ac.	Total	$/ac.	Total
	Acres						
Defoliated	65,000	4.58	297,700	4.64	301,600	7.89	512,850
Fully Scorched	190,000	1.73	328,700	2.05	389,500	2.99	568,100
Lesser Damage	105,00	0.16	16,800	0.16	16,800	0.16	16,800
			643,200		707,900		1,097,750

LEVEL OF FIRE PROTECTION

A useful guide to the most desirable level of fire protection for an area is the "least cost plus damages" approach (Arnold, 1950). The greatest handicap in applying it is generally the lack of fire damage values. However, the values just calculated for the Dwellingup fire enable the method to be illustrated for Western Australia. Figure 4 which is based partly on Departmental records and partly on estimates, indicated that the zone of "least cost plus damages" occurs when the amount of protection is in the range 900,000 acres to 1,000,000 acres of controlled burning each year.

This means that, because of the relative shapes of the cost and damages "curves", for every dollar spent on controlled burning up to 1,000,000 acres per year, more than one dollar of potential damage cost is prevented. The zone of "least cost plus damages" is thus the break even point or the point where the benefit cost ratio is one.

A refinement of this approach would be to prepare least cost plus damages curves for the major forest types (both hardwoods and softwoods) under management.

DISCUSSION

(a) Bark Thickness and Fire Resistance

These assessments showed better crown recovery for merchantable trees than for non-merchantable trees and for potential crop trees than surplus trees. The merchantable and potential crop trees were the vigorous ones and it was possible that differences in bark thickness were associated with crown recovery or damage.

Thirty jarrah poles were treated with intense fires in spring 1964 and another 30 were treated in autumn 1965. Six spring trees and eight autumn trees were killed while six spring trees appeared to be undamaged, (Peet, McCormick, Rowell, 1968). The remainder developed dry siding which ranged from 12 to 52 per cent of the surface area for the eight-foot butt log.

Analyses of variance were used to test for significant relationships between bark thickness, GBHOB and percentage area killed. These analyses were summarized in Table 6 which shows the variance ratio, significance of the variance ratio, and the percentage of variability within the data accounted for by the analysis.

TABLE 6 : Summary of Analyses of Variance Showing Relationships between Tree Size (GBHOB) Bark Thickness (Inches) and Percentage of the Eight-Foot Butt Log Killed (Arc-Sine).

	SPRING			AUTUMN		
Analysis	Variance Ratio	Sig of V.R.	% Variability	Variance Ratio	Sig of V.R.	% Variability
1. Bark thickness and percentage area killed	40.03	* *	41	10.86	*	16
2. GBHOB and percentage area killed.	41.78	* *	42	76.82	* *	57
3. GBHOB and bark thickness.	741.3	***	93	1363.1	***	96

For both autumn and spring there were significant relationships between bark thickness, G.B.H.O.B. and percentage area killed. It is likely therefore that large vigorous trees, with thick bark, will have a higher resistance to butt damage than smaller thin barked trees. Destruction of the cambium should be an important variable in the ability of trees to replace a crown.

Cambium temperatures for the spring trees were measured by Vines (1968). For fires of this intensity these results indicated that bark thickness under half an inch would result in some cambial damage, while thicknesses under a quarter of an inch would result in extensive damage.

(b) Species Resistance

Assessments in the defoliated and fully scorched classes included marri (Euc. calophylla Lindl.) over 36 inches G.B.H.O.B. This species was classified as either alive or fire killed.

Table 7 compares the relative fire resistance of jarrah and marri by listing the percentages of total volumes per acre which were fire killed.

TABLE 7 : Percentages of Total Volume per Acre (over 36 inches GBHOB) which was Fire Killed.

	Crown Damage	Percentage Killed
a.	Defoliation	
	Jarrah	11.7
	Marri	23.1
b.	Fully Scorched	
	Jarrah	7.6
	Marri	12.4

In both the defoliated and fully scorched classes the percentage volume killed for jarrah was less than for marri. These results indicate that jarrah is more fire resistant.

(c) Increment Loss

For valuation it was assumed that trees with bole epicormics only were not growing. Figure 3 shows that this assumption may not be valid for individual trees. This figure shows the average monthly GBHOB growth for two plots, each consisting of five 'bole epicormic only' trees which were burnt by the Dwellingup fires. Each tree was fitted with a band dendrometer (Liming, 1956) at breast height. Some growth was recorded for most of the months between January and August 1966.

Short term measurements of jarrah poles treated by intense fires failed to show significant differences in girth growth at either breast height or 10 feet 6 inches above ground level, when compared with growth of unburnt control trees (Peet, McCormick and Rowell, 1968).

However, a growth ring analysis (Podger and Peet, 1965) left doubts whether increment remains constant up the bole length of defoliated jarrah poles. In 1964 nine poles were selected in an area defoliated by the Plavins Fire (February 1950) and nine were selected in an adjoining fully scorched area.

Sections were taken from each pole at 5, 10, 20, 30 and 40 feet above ground level. Radial growth was measured along ten axes for each section, from the Plavins growth ring to the cambium. The radial growths at each height were averaged. Linear regressions were then calculated to express relationships between radial growth and height.

The linear regression for the defoliated trees was :

$$y = 0.897 - 0.007x$$

where y = radial growth in inches.
x = height in feet above ground level.

Analysis of variance showed this regression to be significant at the 95 per cent level of confidence, but it only accounted for 13 per cent of the growth rate variation in the data.

The regression for the fully scorched trees showed no significant changes in radial growth with height. The results for the defoliated trees left the possibility that radial growth may decrease with height, if the trees are badly damaged.

(d) Prediction of Fire Damage

The possibilities of predicting fire damage in jarrah forest will depend on these results being reproducible. This has not been proven for intense fires, but was readily achieved with girth growth responses, from mild fires (Peet, McCormick and Rowell, 1968).

Assuming that the results are reproducible and fire killed and bole epicormic trees are to be salvaged : 30 per cent of the merchantable volume will need cutting after a defoliating fire and 12 per cent after a fully scorching fire (Figure 1). If the bole epicormic trees are retained these percentages should fall to 8 for defoliation and 3 for fully scorched.

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APPENDIX 1

DWELLINGUP FIRE AREA

NUMBER OF TREES PER ACRE IN G.B.H.O.B. SIZE CLASSES

(Means from 220 randomly located one-acre plots)

G.B.H.O.B. Size Class	Number of trees per acre
1 inch to 3.0 feet	239.100
3'1" " 4.0 "	6.700
4'1" " 5.0 "	3.700
5'1" " 6.0 "	2.500
6'1" " 7.0 "	2.000
7'1" " 8.0 "	1.500
8'1" " 9.0 "	0.900
9'1" " 12.0 "	1.000
12'1" " 15.0 "	0.200
15'1" " 18.0 "	0.020
Over 18.0 feet	0.005
TOTAL	257.625

APPENDIX 2

CALCULATION OF TIMBER VALUE BEFORE THE DWELLINGUP FIRE

DEFOLIATED - Before Fire

		Crowns re-placed merch. over 36"	Bole epic merch. over 36"	Fire killed merch. over 36"
Volume before fire (Table 11) (cu.ft./ac.)		645	206	69.6
Volume in 54 years at 1% M.A.I.		994	317	107.2
Value in 54 years (harvest size) at 10c/cu.ft.	(cents)	9940	3170	1072
Value now at 4% interest from $Vo = \frac{Vu}{(1+p)^u}$	(cents)	1191	381	129
Value of increment now	(cents)	417	134	45
Value after fire : Maximum	($/ac.)	$11.91	$2.47	$0.84
Most likely		$11.91	0	$0.78
Minimum		$11.91	0	0
Loss : Maximum	($/ac.)	0	$3.81	$1.29
Most likely		0	0	$0.51
Minimum		0	0	$0.45

FIGURE 1

VOLUME PER ACRE OVER 36 INCHES G.B.H.O.B.
PERCENTAGE OF TOTAL MERCHANTABLE AND NON-MERCHANTABLE
VOLUME WITH CROWNS REPLACED (C.R.), BOLE EPICORMICS
ONLY (B.E.) OR FIRE KILLED (F.K.)

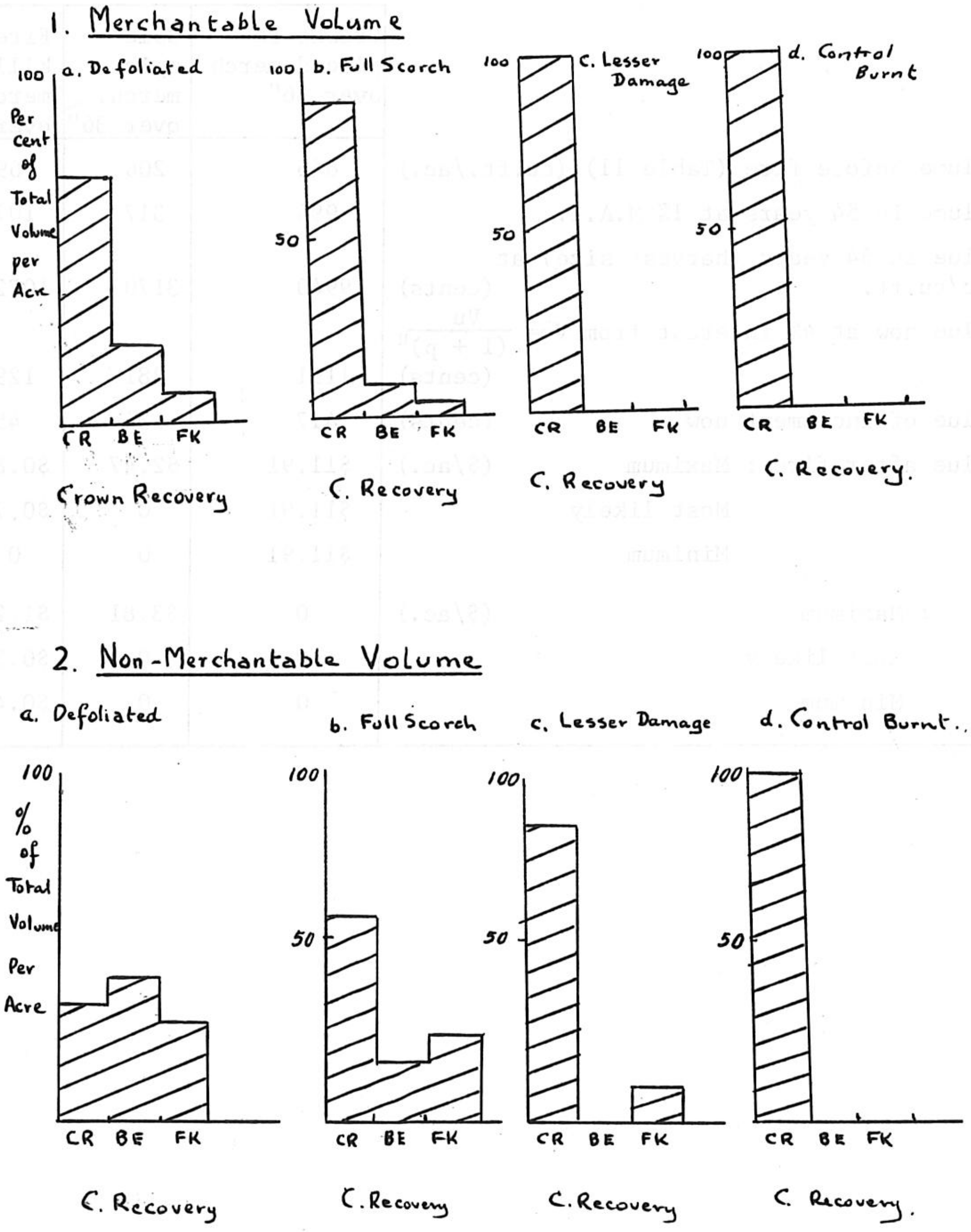
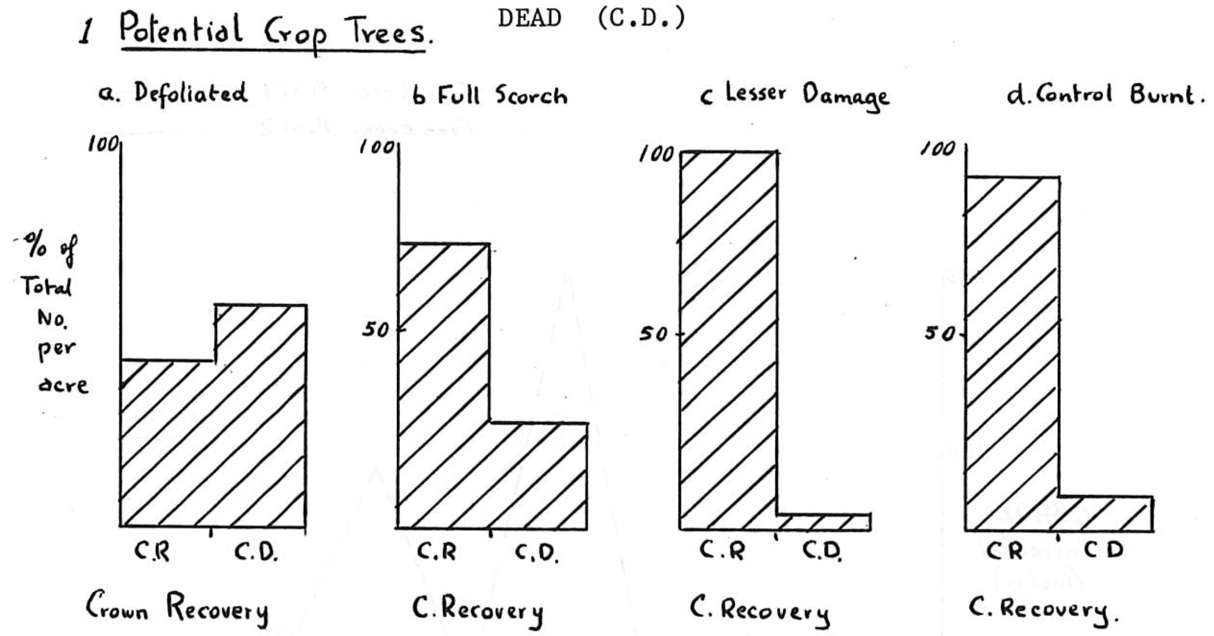


FIGURE 2

NUMBER PER ACRE UNDER 36 INCHES G.B.H.O.B.

PERCENTAGE OF TOTAL POTENTIAL CROP TREE AND SURPLUS TREE NUMBERS PER ACRE WITH CROWNS REPLACED (C.R.) OR CROWNS DEAD (C.D.)



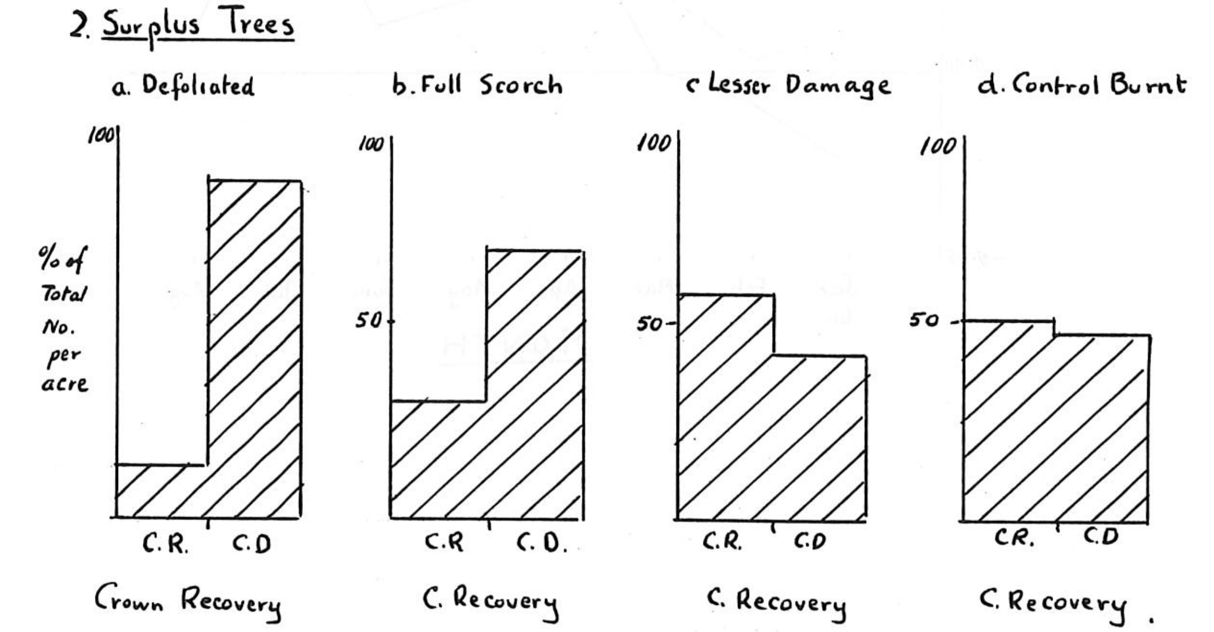
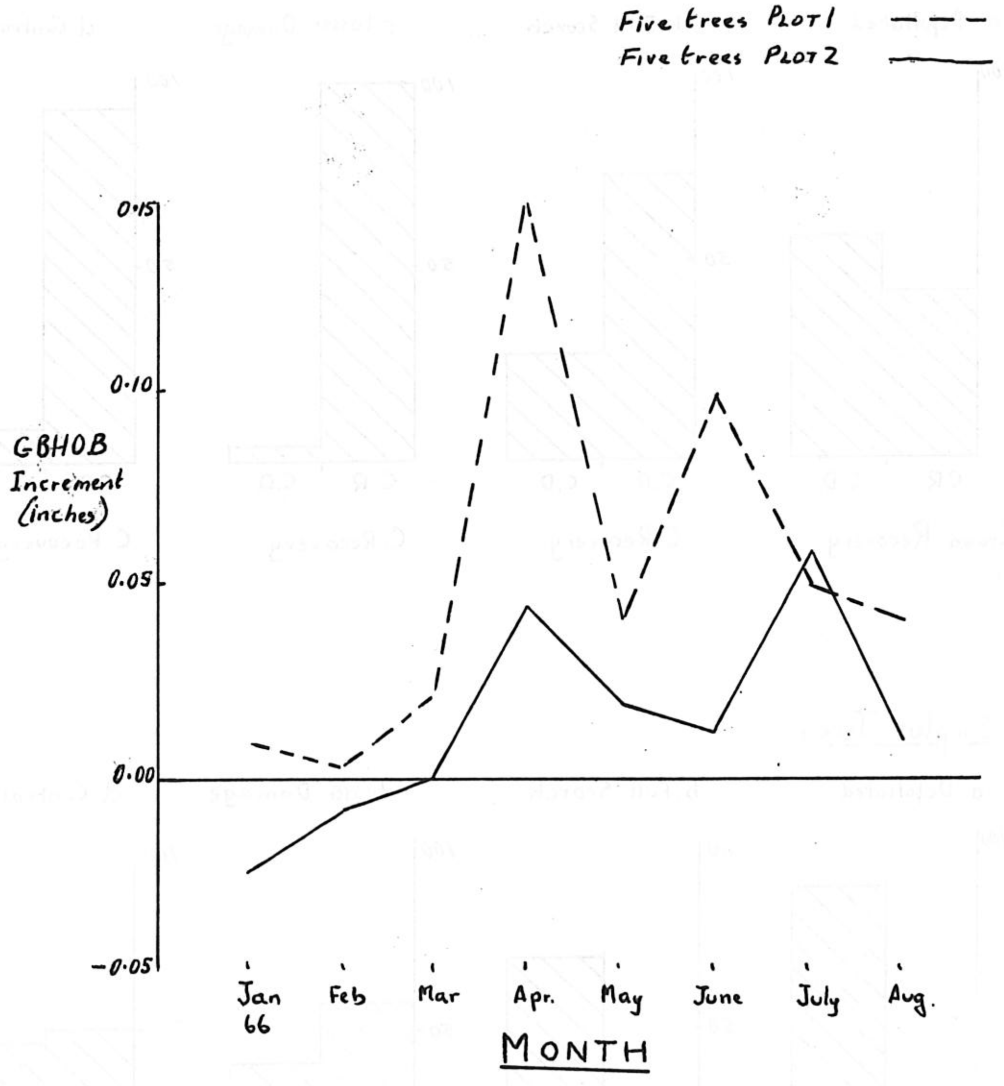


FIGURE 3

AVERAGE MONTHLY G.B.H.O.B. GROWTH OF "BOLE EPICORMIC ONLY" TREES



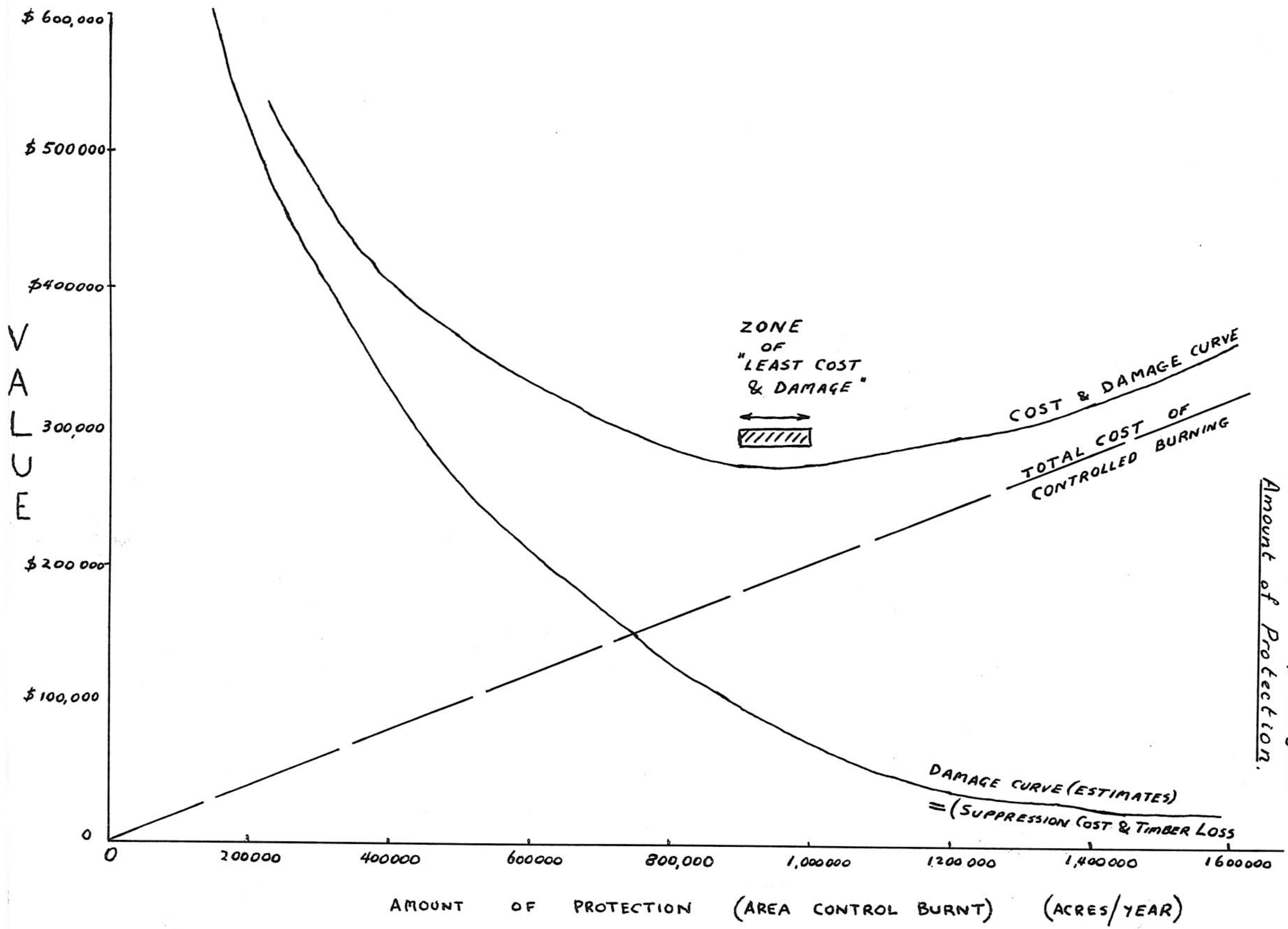


Figure 4. Protection and Damage Costs, Corresponding to Amount of Protection.