Table of Contents

1.0: Introduction

Old-Growth Forest is a descriptive term in a popular sense and as such has caused confusion when it comes to definition. It means different things to different groups of people and yet there is no all encompassing definition which covers the various types of old-growth forest existing.

The term originated in the United States of America as a field of scientific study in the 1970's, however, this type of forest has been recognised long before, as shown in Australia's early historical records. (Lines, 1991)

According to the Forest and Timber Inquiry (1992), old-growth forests are both negligibly disturbed and ecologically mature and further, have high conservation and intangible values. This is similar to the broad conceptual definition proposed by M.L. Hunter: Old-Growth Forests are relatively old and relatively undisturbed by humans. (Dyne, 1992) Hunter suggested that specific definitions for each forest type could then be derived from the broader definition.

In defining old-growth Douglas Fir forests in the Pacific Northwest, the Society of American Foresters, has narrowed it down to:

> an acre of old-growth contains at least 10 living trees that are 40 inches or more in diameter at breast height, at least four snags and four downed logs 25 inches in diameter and 50 feet long, at least 10 snags 20 feet long and at least 20 tons of assorted coarse woody debris on the forest floor. (Bolgiano, 1989)

Yet in the eastern hardwood forest in America, the amount of deadwood may be less than one-fourth that amount. (Bolgiano, 1989)

Kaufmann and associates (1992) opted for a 'description' rather than a definition for old-growth forest, for the central and southern Rocky Mountains and Southwest, of the structural features Some, but not necessarily all, of the following attributes distinguish old-growth forest from younger forests:

* Large trees for species and site.
* Wide variation in tree sizes and spacing between trees.
* Relative to earlier stages, high accumulations of large, dead standing and fallen trees.
* Decay in the form of broken and deformed tops or bole and root rot.
* Multiple canopy layers.
* Canopy gaps and understorey patchiness.

Franklin et.al. (1981) stresses the importance of three structural components in old-growth forests. These are the individual, live, old-growth trees; the large, standing dead trees or snags; and the large, dead, down trunks or logs.

How do these broad definitions or descriptions transfer to Australia's forests?

The definition proposed by R.A.C. is a broad concept. The Australian Conservation Foundation (A.C.F.) goes further. Its definition of old-growth forest is as follows:

> Old-growth forest is forest that has not been, or has been minimally, affected by timber harvesting and other exploitative activities by Australia's European colonisers (McIlory, 1990)

This can be put even more briefly by stating that the old-growth forest type is undisturbed native forest. Thus, it may be naturally multi-aged or even young regrowth, providing the regrowth was initiated by a natural event. Broadscale wildfires are not considered natural events but instead resulting from man-induced fire regimes. (ACF, pers. comm.) The young regrowth is part of the undisturbed forest and when placed in context with the surrounding undisturbed forest, it then has the potential to develop into mature forest. The emphasis is not necessarily the requirement of very old trees and nothing else, but on including the full compliment of the natural vegetation diversity before exploitation and an awareness of the dynamics of the forest ecosystem.

It would seem that the Australian Conservation Foundation is one step ahead in the old-growth forest debate. Looking at the forest in context is relevant for the maintenance of the full genetic component of these forests and thus in their ability to regenerate from natural disturbances. Still, young regrowth that has been undisturbed by man's exploitation is a forest type of its own and should not be confused with the old-growth forest component of the ecosystem.

Forests that have been selectively logged at a low intensity may still contain attributes of 'old-growthness', to be above a certain threshold level. This view is held by the North-East Forest Alliance (N.E.F.A.) and the Australian Heritage Commission (A.H.C.). It may be that this disturbance could be likened to natural disturbance, in the sense that moderately-sized gaps are formed and needs to be genuinely assessed on a case by case basis giving full consideration for the mechanisms involved. For example, the method of extraction, the topography of the site and the regenerative capacity of the forest type. Inherent in this is the evaluation of threshold values for each forest community.

In the study of the south-east forests, Scotts (1991) found that old-growth characteristics are broadly applicable to those described in the United States of America, in particular, those of Franklin (refer above). Scotts considered the more important characteristics of old-growth forest as:

* vertical diversity produced by a deep, multi-layered canopy.
* individual live trees that are either old (well past the phase of maximum exponential growth, e.g. 150 years) or have become large (>1.0 m dbh).
* stags (standing dead trees) and logs of large dimensions present in significant numbers (e.g. 4/ha for stags and 10/ha for logs).

Thus, the extension of old-growth forest attributes to Australia's vegetational types appears to be relatively straightforward for forests on highly productive sites. However, in drier forests, additional consideration will be required in determining their old-growth status. This is generally due to the lower site productivity, an increased likelihood of disturbance and a greater diversity of age-classes associated with drier forests. (N.E.F.A., 1991)

There are many other definitions that have been proposed for old-growth forests. (Dyne, 1992) Care must be taken in delineating the concept of old-growth forests too simply. Old-growth forest does not equate with unlogged forest (as it may not have developed the characteristics to be stated as such) nor to undisturbed forest. It is apparent that the developmental age of the forest is a necessary attribute to be included in any definition. However, there are others, such as, structure, function and diversity of species. These others may not be able to be put into one definition of old-growth but can only be considered in the study of specific forest associations.

2.0: Attributes of Old-Growth Forests

2.1: The Age of Old-Growth Forests

The most visual aspect of old-growth forests is the size of the trees and implicitly, their age. Yet, old-growth forest is not simply old forest. Old age refers to a chronological state that may or may not have direct relation to ecosystem attributes. (Harris, 1984.) As Moir (1992)noted, some 200 to 300 year-old stands may not have achieved some or any old-growth characteristics. Thus, a small stand of old trees or isolated old trees within a forest, will not necessarily constitute an old-growth forest.

However, the mortality of old trees does affect the structure and processes occurring in old-growth forest. The mortality rate generally declines as the forest ages, yet the natural mortality of trees provides a continuum of many of the vital roles of old-growth forests. (Franklin, 1987) Franklin divides the forest succession, occurring in the Douglas Fir region of the Pacific Northwest, into five stages. This begins with a catastrophic disturbance, for example, wildfire or clearcutting. Thus, during recolonization, the seedlings are exposed mainly to environmental stresses, such as high temperature and the associated drought stresses. As the stand ages, competition causes 'thinning mortality'. This can continue for sometime in a Douglas Fir forest as shown in Table 1. Once the forest is beyond 200 years of age, the mortality rate decreases, although the causes of death become more complicated and the resulting change in the forest structure and composition is slow. (Franklin, 1987)

The above example of mortality in a forest represents an extreme. It serves to show that the successional stage or developmental age of the forest effects the rate of change likely to occur. In general, tree death is irregular and episodic. (Franklin, 1987) It can begin with the decaying of the heartwood and the formation of hollows, in some tree species and continue with the occurrence of standing dead trees and large logs on the forest floor.

The potential age of the forest depends on the longevity of the dominant/co-dominant trees. The old-growth characters of wide crowns, hollow stems and large stem diameters are attained only after long periods of time, for example, 120 to 150 years for blackbutt (*Eucalyptus pilularis*) and more than 200 years for slower growing eucalypts. (Baur, 1992)

Species with much slower growth rates, such as, Huon Pine (*Lagarostrobos franklinii*), the attainment of large stem diameters will take considerably longer. For Huon Pine, the diameter increase is in the order of 1mm/year. (Gibson, 1986) Thus to reach one metre in diameter, it could take 1000 years.

Baur (1992) noted that the radiocarbon dating found a brush box (*Lophostemon confertus*) to be 1300 years old for a 165 cm dbh (diameter at breast height), while a 190 cm dbh tree was 350 years old, so showing little relationship between true species age and size. This was also shown in a dendrochronological study conducted in the karri forests of south-west Western Australia. (Graph 1) The imprecision between stand age and the size of the trees, was attributed to the variation in site quality and scale of sampling. (Rayner, 1992) However, this broad indication of the possible range of stand ages within old-growth karri forest showed that the majority of stands were less than 350-400 years of age. (Rayner, 1992)

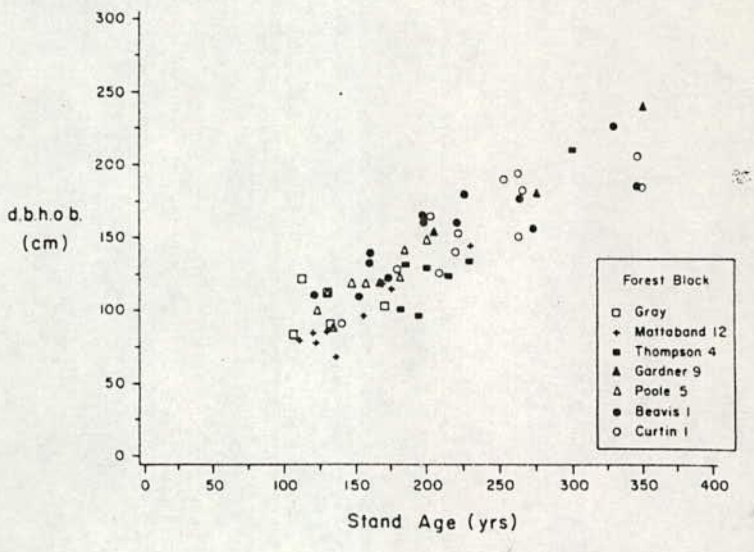
There is no need to go to the extremes of a tree's longevity to attain the characteristics of old-growthness. This can be seen in the oldest living trees sampled by Swetnam and Brown (1992).A limber pine (*Pinus flexilis*)

TABLE 1: CHANGES IN CAUSES AND RATES OF TREE MORTALITY DURING FOREST SUCCESSIONAL STAGES.

	Stage				
	Prevegetative closure	Full vegetative cover	Closed tree canopy	Mature forest	Old forest
Approximate period (years)	0–5	5–20	20–100	100–200	>200
Mortality rate	Very high	High	High to medium	Medium to low	Medium to low
Typical mortality causes	Environmental stress, predation, pathogens	Interspecific competition, environmental stress, pathogens, predation	Intraspecific competition, pathogens, wind	Pathogens wind, competition	Wind, pathogens physiological disorders

(FRANKLIN, 1987)

GRAPH 1: D.B.H VS TREE AGE (ANNUAL GROWTH RING COUNTS) FOR DOMINANT KARRI TREES, IN SEVEN OLD-GROWTH STANDS



(RAYNER, 1992)

sampled at Elephant Rock, New Mexico is 1,670 years old. It is located on a steep site, amongst stunted trees and as such the stand is not an old-growth forest.

2.2: The Individual Old-Growth Tree

As already emphasized, old-growth trees in the canopy layer, are large in size. This depends on the site productivity, which involves such factors as slope, aspect, rainfall, nutrient availability and soil type; and the tree density of the stand. For old-growth Douglas-Fir forests, the larger trees occur at low elevations and in the river valleys of the Cascade Mountains in Washington and Oregon, (Harris, 1984) while the tall old-growth forests, of northern N.S.W., occur on sites with relatively fertile soils and moderate topography. (N.E.F.A., 1991)

Old-growth trees can show their age in the deformities, signs of activity by other organisms, such as, trunk-rot, plant parasitism, rusts and herbivory and in mechanical and storm damage to the crown and stem. (Moir, 1992) The inclusion of mechanical damage, shows that Moir believes human disturbance is compatible with old-growth forests, which he later states to be selective harvesting. Yet, Moir does agree that this is still an unresolved issue. Other natural disturbances, such as spot fires, can leave fire scars, while tree-fall can damage other surrounding trees on the way dowm. In addition, Franklin (1981) notes that old-growth trees are also shaped by their own genetic heritage.

In the Douglas fir forests, the sloping of many tree trunks, forms an upper moist side, that is colonized by epiphytic plants, e.g., mosses and a lower side, supporting lichen. (Franklin, 1981) Lichens produce a significant amount of nitrogen - approximately 10 Kg.ha-1.yr-1 - but are generally absent for the first 100 to 150 years of the forest development. (Scotts, 1991) This is just one example of the increased complexity found in old-growth forests.

In Australia, the formation of hollow stems by the activity of termites and fungus, takes a considerable amount of time. These old-growth trees provide hollows of various sizes. Scotts (1991) states that some hollow-dwelling species require large, deep hollows, found in eucalypts generally older than 200 years of age. In Brush Box, it can take in excess of 1000 years to develop large hollows. (N.E.F.A., 1991)

2.3: Patchiness and Diversity

Webb (1972) attributed the patchiness in subtropical rainforest to the pattern of various regeneration processes. Determinate processes produce a predictable floristic composition, where each patch in the rainforest is an ecological group formed from a matrix of species dependent on certain environmental factors. Within this, there are probabilistic and rare fortuitous processes, so that randomness is created. This is reflected in the large number of possible species combinations, the wide variety of reproductive strategies and the continuous regeneration of canopy trees which result in a representation in all size classes.

Shugart (1987) developed a gap model to predict the regeneration that follows the death of a single tree, either violently and thus forming a gap immediately or slowly dying to form a snag before eventually falling to the forest floor. Tree species are divided into four ecological roles, which are shown in figure 1. The corresponding graph (graph 2) shows the episodic regeneration of Role 1 species, while in Role 3 species this is less apparent, forming an uneven-aged forest structure. Role 2 species exhibit bursts of regeneration and Role 4 species show relatively consistent regeneration. Combinations of all the Role species, forms

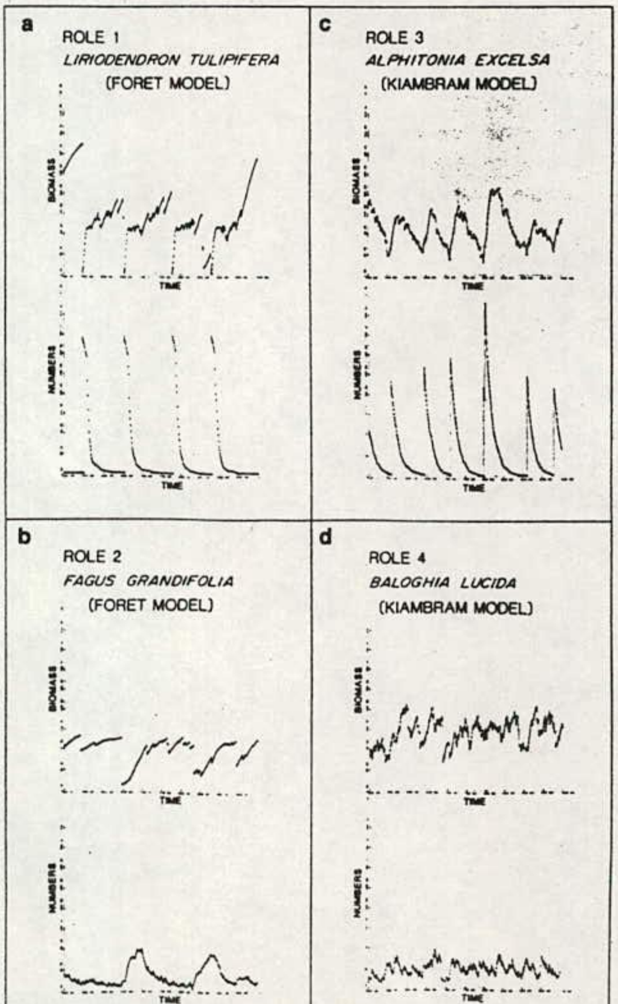
FIGURE 1 : CATEGORIZATION OF FOUR ECOLOGICAL ROLES

MATURE TREE MORTALITY

REGENERATION	PRODUCES GAP	DOESN'T PRODUCE GAP
REQUIRES GAP	ROLE 1 *Liriodendron tulipifera* FORET MODEL	ROLE 3 *Alphitonia excelsa* KIAMBRAM MODEL
DOESN'T REQUIRE GAP	ROLE 2 *Fagus grandifolia* FORET MODEL	ROLE 4 *Baloghia lucida* KIAMBRAM MODEL

(SHUGART, 1987)

GRAPH 2



(SHUGART, 1987)

complexity in the forest structure; in favouring light-demanding cverstorey species, as is done in some forestry pracitices, an even-aged forest is created.

This is a simple version of the many natural disturbances which occur within the forest. Cyclones, lightning strikes, marginal forest fires, droughts and landslumps resulting from excessive rain, periodically disturb a subtropical rainforest and led to changes in the forest constituants. (Hopkins, et.al., 1977) The patchiness of the understorey species is one component of the diversification of old-growth forests. This occurs as a result of many factors, such as the irregular patterning of gaps and shaded areas and the provision of new substrates like logs and root wads. (Franklin, 1981)

A further increase in diversity is discussed by Harris (1984). This is the rough canopy surface generated by the uneven age and/or size distribution of the dominant and co-dominant trees, which increases the interchange of gases, the amount of dew drip, the interception or rain and snow and the solar radiation reaching the forest floor. The result is an increase in the vertical species diversity of the forest.

2.4: Stags and Logs

Standing dead trees are commonly known as stags (or snags in America). They allow light to reach the forest floor, by opening up the canopy and causing a regenerative event. The greatest volume of stags and logs is produced by old-tree mortality. (Moir, 1992)

In Douglas Fir forests, stag densities decrease with age, while the mean dbh increases. (Franklin, 1981) The decrease in density appears to be relative to the combination of decreased tree mortality, with developmental age and the increase in stag size.

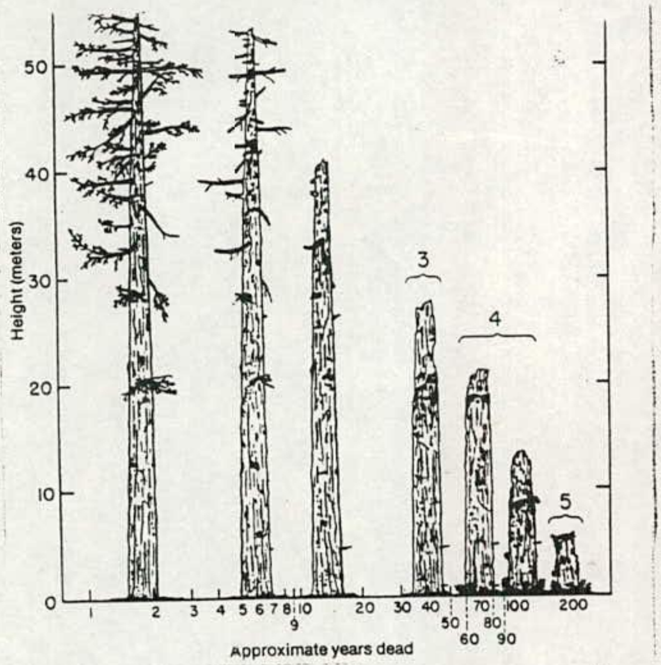
Large stags survive longer. The longevity of stags depends on the rate of decay, gravity and environmental conditions. (Franklin, 1981) As shown in figure 2 , a Douglas Fir stag, 60 metres tall, will continue to stand for a couple of centuries more. In Australia, stags resulting from a wildfire, in a regrowth forest, are rapidly falling and the leadbeater's possum is threatened as there are few alternative nesting sites. (Scotts, 1991) This illustrates the increased reliability of habitat trees in an old-growth forest as compared with regrowth forest.

Stags also act as perching sites and continue to prevent erosion. The gradual decomposition of stags and logs, including the accumulated litter and debris, is part of the tight recycling of nutrients in old-growth forests. Logs are a major source of nutrients, such as nitrogen and phosphorous. (Franklin, 1981)

Logs can also provide regenerative seed-beds. The accumulation of humus and debris and the retention of significant quanities of water, year-round, also serves as fauna habitat and nitrogen-fixation sites. (Franklin, 1981; 1987)

It is apparent that old-growth forests are relied upon by certain species. This alone makes old-growth forest invaluable. With the combination of the above attributes - and there are many others, including genetic diversity, the large biomass of the canopy trees, and a relatively stable microclimate - which makes these forests unique, and not simply an older version of a young forest.

FIGURE 2 : STAGES IN STAG DECAY



(FRANKLIN, 1981)

3.0: The Occurrence of Old-Growth Forests in Australia

The true extent of old-growth forest is not known in Australia and an A.P.I. survey is suggested by the National Forestry Inventory. (Dyne, 1991)

The Resource Assessment Commission, in the Forest and Timber Inquiry, gives statistics on the amount of unlogged forest, as shown in Table 2, however, this does little to describe the extent of old-growth forest. Even when old-growth forest is regarded as a subset of unlogged forest, the percentage remains obscure.

An A.P.I. survey conducted in the East Gippsland Forest Management Area (1992). In the design, disturbances were considered to include timber harvesting, wildfires, fuel-reduction burning, weed infestations, roading and other cultural features. A negigible disturbance was defined as a disturbance which is unlikely to have altered the structure or the usual floristic composition of species for that community, or if the alteration occurred in the past, the effect is no longer significant.

It was found that peak old-growth forest, where more than 50% of the total crown cover remains, occupied 39,133 ha. Near-peak old-growth forest, where there is less than 50% but more than 25% total crown cover, occupied 139,314 ha.

In Western Australia, the proportions of old-growth in reserves, and in production forest are given, in Table 3. Whether this is an adequate reservation of old-growth forest is not stated, nor the management regimes of these forest; although it was indicated that part of this forest will be kept unburnt.

Baur (1992) roughly estimated the extent of old-growth forests as being one-fifth to one-third of the remaining native forest land in N.S.W. Part of this estimate was 362 000 ha regarded as old-growth forest that was intended to be logged.

Generally, old-growth forest is perceived as rare. This is in part due to the loss of these forests upon European settlement. At this time, in 1788, Australia's forests and woodlands covered an area of approximately 245 million hectares, and in the last 200 years, there has been the destruction of approximately two- thirds of the temperate forests and three-quarters of the tropical and temperate rainforests. (Mercer, 1991)

Historical accounts of the timber-getting, speak of the forests seeming an inexhaustible resource that was dwindling in size. *Araucaria cunninghamii*, through logging was accounted to be almost 'a tree of the past' on the Lower Richmond, N.S.W. (Baker and Smith, 1910)

4.0: Logging in Old-Growth Forest

The perceived rarity of old-growth forests, is also due to the continued logging of these forests. According to the Forest and Timber Inquiry (1992), old-growth forests represent a significant part of the forest resource that is available for conversion to productive forest. Table 4 shows that 33% unlogged forest is in production tenure. These are only gross estimates and the proportion of old-growth in this estimate is uncertain. This also raises the question of the amount of unlogged forest is production tenure that is available for logging.

Baur (1992) considered that old-growth forests, in N.S.W., currently provide about 50% of the total annual sawlog yield prescribed for state forests.

TABLE 2: UNLOGGED FOREST AND ITS EXTENT IN CONSERVATION RESERVES AND PRODUCTION FORESTS

Forest type	Total unlogged forest ('000 ha)	Unlogged conservation reserves ('000 ha)	Unlogged conservation reserves (%)	Unlogged production forests ('000 ha)	Unlogged production forests (%)
Northern rainforest	354	245	69	110	31
Southern rainforest	559	284	51	275	49
Sub-total	913	529	58	385	42
Mangrove forest[a]	170	55	32	115	68
Swamp forest[a]	931	788	85	142	15
Sub-total[a]	1 101	843	77	257	23
South-western forest	433	165	38	268	62
SE dry eucalypt forest	262	246	94	16	6
SE wet eucalypt forest	2 664	1 112	42	1 552	58
SE coastal eucalypt forest	354	234	66	120	34
Central coastal eucalypt forest	352	139	39	213	61
NE coastal eucalypt forest	260	121	47	139	53
NE eucalypt forest	619	345	56	274	44
River red gum forest[a]	51	51	100	0	0
Sub-total	4 995	2 413	48	2 582	52
Northern and eastern woodland[a]	8 958	1 014	11	7 944	89
Dry woodland[a]	282	270	96	12	4
Sub-total[a]	9 240	1 284	14	7 956	86
Total	16 249	5 069	31	11 180	69

(R.A.C., 1991)

TABLE 3:

REGENERATION STATUS OF THE FORESTED AREAS (ha) IN THE SOUTHERN FORESTS (as at 31 December 1989)

	[a] National Park				[a] Nature Reserve				[a] Conservation Land				[a] Multiple Use Forest			
DREST TYPE	SC[b]	CF[c]	Old-Growth	Total	SC	CF	Old-Growth	Total	SC	CF	Old-Growth	Total	SC	CF	Old-Growth	T
ARRAH-TINGLE	-	-	1 800	1 800	-	-	-	-	-	-	-	-	-	100	1 900	2
ARRAH	12 000	500	61 500	74 000	41 900	-	24 600	66 500	9 900		1 600	11 500	418 100	18 400	205 200	64
PURE KARRI	1 700	2 300	12 500	16 500	-	-	400	400	200	100	200	500	12 300	16 400	11 700	4
KARRI-TINGLE	-	400	2 900	3 300	-	-	-	-	-	-	-	-	-	600	1 600	2
ARRI	4 800	2 200	22 600	29 600	300	-	900	1 200	300		400	700	23 800	22 900	33 500	7
ANDOO	-	-	-	-	400	-	200	600	-	-	-	-	100	-	-	
OTHER SPECIES	-	-	4 200	4 200	100		100	700	100			100	27 800	300	3 100	3
TOTAL	18 500	5 400	105 500	129 400	42 700	-	26 200	68 900	10 500	100	2 200	12 800	482 100	58 700	256 000	7

[a] Total areas as proposed by CALM (1987b)
[b] SC - Selection cut and regenerated
[c] CF - Clearfelled - regeneration completed or commenced

(CHRISTENSEN, 1992)

TABLE 4: GROSS EXTENT OF NATIVE FORESTS AND PERCENTAGE UNLOGGED IN PRODUCTION TENURES IN AUSTRALIA

('000 hectares)

Forest groups	State forest	%	Other crown land	%	Private land	%	Total area	%
Northern rainforest	286	13	43	26	92	65	421	26
Southern rainforest	365	40	182	63	70	19	617	45
Sub-total	651	28	225	56	162	45	1 038	37
Mangrove forest[a]	-	-	46	100	69	100	115	100
Swamp forest[a]	-	-	48	100	95	100	143	100
Sub-total			94	100	164	100	258	100
South-western forest	1 443	19	-	-	507	-	1 950	14
SE dry eucalypt forest	348	0	1 929	1	1 748	-	4 025	0
SE wet eucalypt forest	4 620	30	1 071	15	1 724	1	7 415	21
SE coastal eucalypt forest	275	44	1	0	-	-	276	44
Central coastal eucalypt forest	1 459	13	620	3	1 438	-	3 517	6
NE coastal eucalypt forest	375	26	279	15	-	-	654	21
NE eucalypt forest	1 203	9	1 120	15	1 319	-	3 642	8
River red gum forest[a]	-	-	-	-	-	-	-	-
Sub-total	9 723	22	5 020	8	6 736	-	21 479	12
Northern and eastern woodland[a]	1 131	17	5 269	80	4 280	83	10 680	74
Dry woodland[a]	3	10	15	80			18	68
Sub-total[a]	1 134	17	5 284	80	4 280	83	10 698	74
Total area & percentage unlogged	11 508	22	10 623	45	11 342	34	33 473	33

(R.A.C., 1991.)

The Forest and Timber Inquiry also concluded that it is cheaper to harvest old-growth as the logs are mostly the only type suitable to process by the current sawlog industry mills in Australia. More broadly, it is the forest industry's requirement for the continued access to forests that contain trees of a suitable size for its markets. (Resource Assessment Commission, 1992)

Old-growth forest is poorly represented in the reserve system. Approximately nine per cent of all remaining unlogged forest is in conservation reserves, and not all of this would be old-growth forest. (Resource Assessment Commission, 1992)

5.0: Logging Practices

Clearfelling: The coupes vary in size and shape and after logging, regeneration burns are carried out. In the dry eucalypt forest, where there is poor regeneration, mechanical disturbance may be used. It is most commonly used on highly productive sites, although it is also used in drier forests. Other alternative regeneration methods involve the retention of trees, to provide seed, or manipulation of the site via direct seeding or enrichment planting. (Resource Assessment Commission, 1991)

Selective Logging: It involves the removal of mature trees in two or more operations. The first felling removes over half of the stand, leaving partial tree cover, for regeneration to establish. The mature trees are generally removed at a second cutting, typically 20 years onwards. (Resource Assessment Commission, 1991) There is no maximum limit in the amount of timber removed. Generally, the prescription allows for the removal of all merchantable timber (Q.F.S., pers. comm.) thus removing the oldest and largest trees in the logging coupe. The essential characteristic of this method is that the whole stand is never completely cleared. (Horne and Hickey, 1991) The extreme version is the cutting of single, scattered trees, resulting in minimum damage but this is rarely applied. (Resource Assessment Commission, 1991)

In general, there is a concentration of logging on relatively flat or gently sloping ground where the larger trees grow. (Winter, 1987)

6.0: Forest Structure Following Logging

Following logging the most immediate change is an alteration of forest structure. The dominant trees have been removed. The disturbance has a dramatic effect on the condition of the forest. The response of the forest to a logging disturbance will determine whether there is adequate recoveryfor it to again develop old-growth characteristics and in time, return to its old-growth state. One of the successional processes in the development of complex structural form.

In warm temperate rainforest, the return in height and density of the dominant canopy trees and the closure of the canopy, is a pre-requiste of the total recovery of the forest. (King and Chapman, 1983; Horne and Gwalter, 1982)

6.1: Warm Temperate Rainforest

This forest type is considered to be simpler in structure and composition that subtropical rainforest, as it is often stratified into only two distinct tree storeys and predominated by only one or two species. (Horne and Gwalter, 1982)

A study at Moonpar State Forest, N.S.W., predicted that following selective logging, tree diameters were unlikely to exceed 90 cm dbh, in comparision, with the undisturbed mature forest, which contained trees with diameters up to 132.1 cm. (Horne and Gwalter, 1987) This was attributed to the predominance of coachwood (*Ceratopetalum apetalum*) in the post-logging plots, which rarely grows beyond 90cm dbh.

In the more intensely logged forest, where 90% of the large dominant trees were removed, small gaps were still present following a 25 year recovery period since logging. These were mainly associated with the larger openings generated from the log landings and its radiating tracks. Slower regeneration occurred in these areas as winter frosts were able to reach the ground, killing or injuring the less protected seedlings out from the gap edge. (King and Chapman, 1983)

The crown dieback following selective logging, was seperated into three main phases, by Horne and Mackowski (1987). In the first five years, overstorey basal area growth is slow. This is obscured by high mortality of an average 20.6 trees/1000/year. However, a return to low mortality and continued increases in individual basal area, causes higher nett increments of basal area in the overstorey trees, in comparsion to those in the undisturbed mature forest.

6.2: Subtropical Rainforest

In N.S.W., Horne and Gwalter (1982), found the diameters of overstorey species were predicted from their growth model to have a similiar distribution across the size classes, to the control unlogged plots, at recovery, from logging disturbance. Further, the mean diameter growth rates were higher in the logged plots, i.e. 0.31 cm.yr-1 compared to the 0.15 cm.yr-1 in the mature unlogged plots.

The growth rates of the individual trees were found to be highly variable and of little relationship to the diameter of the tree. (Horne and Gwalter, 1982) This was also found in the study conducted by Burgess et.al. (1975), where the growth rates of individual trees were of sufficient growth to regain structure. For example, *Cinnamomum oliveri* (Oliver's sassafras), whose annual diameter increment was 12-15 mm.yr-1. It was concluded that the local practice, of 50% canopy removal,in N.S.W., 'obtained a sufficient volume of timber to make the logging operation worthwhile.' (Burgess, 1975)

6.3: Tropical Rainforest

The effect inmmediately following logging is a reduction in the basal area, by between 8% to 43%, in tropical north Queensland rainforest. (Nicholson, 1988) While the basal area may recover to pre-logging condition, after 40 to 50 years, there is a reduction in the frequency of trees of diameters over 100cm dbh. (Winter, 1987) As was shown in the subtropical rainforest, the diameter increments of the logged stand increase in tropical rainforest, in comparison with undisturbed mature stands. According to research conducted by the Queensland Department of Forestry (1983), post-silvicultural treatment further improves the diameter increment, particularly for the smaller size classes. The nature of the silvicultural treatment is implied to be a further reduction in the canopy cover of the logged forest. Particular emphasis is placed on the species 'A' group, i.e. the 'highest quality' species. The response of these species to canopy removal, which was much greater than any other species, was generally equated with their light-demanding character.

The increased diameter increments of a logged stand, reflect the rapid response of the forest to disturbance. In Papua New Guinea, the lowland primary rainforest, also showed comparatively fast growth following logging. After 10 years, the regrowth forest was 20 metres high, in relation to the height of 30 to 40 metres found in the unlogged mature forest. (Saulei and Lamb, 1991)

In Summary, forest structure appears to rapidly recover following a logging event. The increased diameter increment and height growth of the dominant trees in response to the disturbance, reflects this. However, the absence of the largest diameter trees in the regrowth forest, in effect changes the overall structure of the forest, in comparison to old-growth forest. Further, silvicultural treatments which favour the more light demanding, and high quality species, disregards the high vertical diversity created by a rough canopy, as seen in old-growth forest.

7.0: Forest Composition Following Logging

7.1: Warm Temperate Forests

While Horne and Gwalter (1987) predicted no loss of species or introduction of new species, following logging, there was considerable change in the proportional representation of the overstorey species. In particular, the presence of coachwood (*Ceratopetalum apetalum*) increased from 20% of overall representation in the overstorey, to 73%, in the logged forest. In the mature unlogged forest, the dominant species had been coachwood, *Schizomeria ovata* (crabapple), *Doryphora sassafras* (golden sassafras) and *Cryptocarya glaucescens* (jackwood); 20%, 33%, 11% and 26% respectively.

A more detailed study of the composition of warm temperate forests, was made possible by the earlier survey of Burges and Johnston in 1953, two years before logging. On returning to the area in 1981, King and Chapman, found there was no loss of species as a result of logging, despite the heavier logging of over 90% of the canopy trees, in part of the site. This included the understorey species, i.e. shrubs and ground covers and lower plant species, i.e., mosses and epiphytes. The continued presence of all the original moss species was attributed to either (1) the occurrence of greater phenotypic plasticity or (2) adequate number of suitable microhabitats for the mosses to later recolonize the site. However, the epiphyte species appear to be more vunerable to logging disturbance, as although all the original species are present, only five of the 11 species recolonized on regrowth trees. This illustrates the need for the retention of remnant overstorey trees, as was done in this selectively logged site.

7.2: Subtropical Rainforest

Horne and Gwalter (1982) found the same overstorey present following logging as in the unlogged forest, however, differences were found in the relative frequencies of the species making up the overstorey. This is due to the varying growth rates of individual species. There was a decrease in the frequency of corkwood (*Caldcluvia paniculosa*), red carabeen (*Geissois benthami*) and black apple (*Planchonella australis*) and an increase in the frequency of yellow carabeen (*Sloanea woolsii*), black booyong (*Heyitiera actinophylla*), purple cherry (*Syzigium crebrinerve*), oliver's sassafras, prickly ash (*Orites excelsa*) and golden sassafras.

Burgess et.al. (1975) concluded that following 50% removal of the canopy trees, there was adequate regeneration of a 'range of tree species', i.e. those of potential forestry interest. However, species with narrow seed dispersal tended to form clumps of regeneration and thus an increase in seedling mortality than those species which dispersed more widely.

There are several processes within a rainforest that are particularly susceptible to certain disturbances. These are related by Hopkins et.al. (1977) and are as follows:

* the availability of seeds in all seral stages, i.e. pioneer; early secondary; late secondary and mature stages. Following clearfelling, regeneration will only occur beyond the early secondary stage if the surrounding areas are 'self-maintaining.'

* following the creation of high proportions of a particular species, there is an increase in its corresponding predator population. The outcome of this is a generally unhealthy forest.

* the introduction of weed species. This is most likely to occur in the earlier pioneer stages. The effect of their presence is likely to be minimal in a logging disturbance.

* increasing the regeneration opportunities of nomad species. These species will increase in abundance with disturbances which favour their reproductive strategies. Selective logging can increase the number of early secondary species by increasing the number of large gaps; however, as the later stages develop, these species should lower in number. Problems arise with the occurrence of more permanent disturbances, such as the roading system associated with logging. In this case, nomad species could become more permanent.

7.3: Tropical Rainforest

Nicholson et.al. (1988) considered a downward trend to be occurring in virgin plots, as species diversity and richness decreased with time. Virgin, mature tropical rainforest was seen to be a 'non-rigorous' environment. In collaboration with this conclusion, logging was reputated to reverse the natural decline and in general, increase species diversity. The use of treatments, which basically remove all the non-commercial trees and saplings, was seen to always lead to an increase in species diversity.

To support these conclusions, Nicholson extends Connell's theory of intermediate disturbance (1978), by adding selective logging as a mechanism of creating higher species diversity. Connell proposed that the processes of competitive exclusion and the formation of an equilibrium in a tropical rainforest could be counter-acted by natural disturbances, such as, the falling of a tree, windthrows or storms, at intermediate intervals, to cause non-equilibrium and high species diversity.

In a critique of Nicholson's paper, Saxon (1990) re-examines the data and finds large discrepancies in its interpretation:

* for three of the sites the logging event documented is not the first cut.
* the complete disregard for the increase in diversity in two virgin plots as a result of natural disturbance.
* species richness was found to be consistently lower after artifical disturbance once all the data were taken into account.
* species diversity declined in treated sites and moderately on logged sites with relatively low basal area reduction.
* two logged sites, with the highest basal area reduction, showed an increase in species diversity but a decrease in species richness. This was seen as not comparing favourably with the long-term mechanism of increased diversity and richness found in the naturally disturbed sites.

How can such opposing views be generated from the same set of data? It serves to show that the manipulation of data needs to be carefully monitored. The only plot logged once, showed a decrease in species richness, and questions the use of selective logging to the degree of disturbance, 43.3% basal area removal, carried out. However, further study will need to be conducted before the effect of once-only selective logging on tropical forests can be determined. As for the plots logged more than once, the intervals between logging events, between seven to 21 years, is shorter than the average logging cycle, and shows the trend in selective logged sites described in the Forest and Timber Inquiry, discussed above in section 4.0. The total basal area removed from these forests is not disclosed, but if indeed there is a decrease in species diversity and richness, as described by Saxon, then the corresponding change in the forests, would take a long time to recover to pre-logging values.

In Papua New Guinea, 11 years since clearfelling, 56% of the regeneration consisted of secondary species, compared to the 19% present in unlogged forest. (Saulei and Lamb, 1991) The main mechanisms of regeneration were coppicing, particularly in the primary species, and from the soil seed bank. Species which disperse seed via gravity are disadvantaged in areas were large gaps are generated by clearfelling; while some bird species, including frugivores are sensitive to the disturbance and are only returning some time after the event, thus effecting the dispersal of plant species reliant on them.

In summary, there have been no reported losses of species as a result of logging. However, the changes in the proportion of species, as in the extreme case of WTRF, where coachwood dominated the stand, to the less obvious changes in the STRF, are of importance when considering the values of old-growth forests. How this affects the long term abundances of species is not known. According to Hopkins et.al, these pioneer or opportunistic nomad species will eventually be replaced by species from the mature seral stages. This will depend on the size of the disturbance. If clearfelling occurs, the process to recovery is slowed down, as species with limited dispersal ranges are disadvantaged. Further, the microclimate created in the gap can affect the survival of species. It will also depend on the frequency of the disturbance following the logging event. This is discussed in the next section.

8.0: Time to Recovery

What is the time period involved before a forest disturbed by logging will recover to pre-logging values?

Some indication of the time necessary has been proposed by several authors and this is detailed below:

> Warm Temperate Rainforest: 140-190 years, after 90% basal area removal of overstorey species, to allow for adequate stocking and canopy cover; up to 250 years for the log landing and radiating tracks to completely regenerate.(King and Chapman, 1983)
>
> :<60 years for 25% B.A.R., 50 to 100 years for 65% B.A.R., >100 years for 75% B.A.R. (Horne and Gwalter, 1987)
>
> Sub-Tropical Rainforest: 30 to 60 years for 33% B.A.R., 50 to 100 years for 45-47% B.A.R., 100 to 220 years for 78% B.A.R. (Horne and Gwalter, 1982)
>
> :At least 200 years, following a conservative logging programme. (Hopkins et.al., 1977)

Tropical Rainforest: 150-200 years following clearfelling, as the forest does not age much beyond this due to natural phenomena. (Saulei and Lamb, 1991)

The nominal logging cycle of the Queensland Department of Forestry is 40 to 50 years. (Winter, et.al., 1987) Once a forest has been logged, the structure and composition are drastically changed. If the forest is logged again before recovery, subsequent recovery time will be extended and the forest will be fundamentally changed. Logging cycle regimes need to be altered to natural disturbance frequencies if it is to continue in old-growth forest. Otherwise, logging in effect will create regrowth forest that is prevented from developing old-growth characteristics due to the frequent disturbance of the extraction process. By truncating the natural processes, forest will no longer age. The question is whether logging cycles will be extended, for old-growth forests, to reflect the need to recover from various intensities of logging. As was shown above, forests which are logged at low intensities, can recover relatively quickly. This needs to be investigated further.

9.0: Forest Recovery Following Logging and Slash-burning

9.1: Eucalypt forest - in the understorey

Species in the understorey generally return following selective logging and slash-burning, however. there are differences in their relative abundances. (Loyn et.al, 1983) This was related to the pattern of recolonization. This was categorized by Floyd (1976) in a study of dormant buried seeds in wet sclerophyll forests in northern N.S.W. :

(1) Early maturers, shade intolerant - germination trials show a virtual absence of seed after 30 years without fire.
(2) Early maturers, shade tolerant - viable seed was present in both the 14 and 30 year samples after the fire.
(3) Late maturers, small seeds, shade tolerant - less viable seed in the 14 year sample. One species, *Piptocalyx moorei,* had been virtually eliminated as a result of frequent fires.
(4) Late maturers, large seeds, shade tolerant - the 30 year sample had slightly more viable seed.

The rates of recolonization can be related to the site conditions, the method of regeneration and so on. The shade tolerance of the species establishing some time since fire, enables them to regenerate under the canopy cover of shade intolerant species and eventually exclude them.

The early stages of succession following fire are described for wet sclerophyll forest, in Tasmania (Cremer and Mount, 1965) The earliest colonizers are stimulated by fire; these are the liverworts and fire mosses. Collectively, their expansion depends on the fire conditions, the presence of burnt ground, the moisture regime and the weather conditions. Liverworts decline rapidly four years after fire, as do the fire mosses; while the flowering herbs tend to increase with time since fire. This type of succession is common after fire, in cold to temperate climates, where there is rich organic soil and high moisture availability. Eventually the herbs are replaced by soft ferns, bracken and woody perennials.

The response of species to logging and slash-burning can be related to their adaptability to fire. Loyn (1983) found that while some species were favoured by the post-firing, for example, the lacy wedge fern (a rare plant in East Gippsland) increased in abundance, other species were not favoured by fire, for example, *Dianella caerulea, Gahnia radula, Helichrysum baxteri* and *Kunzea ambigua;* or the soft ferns, whose rhizomes can be killed by a

tree fall. These qualities might have included shade intolerance in early. In man-set fires, these nomad species were included in the replacing vegetation. A continuation of fire use has thus resulted in the prevention of the development of the later successional stages, producing today's tall open forests.

9.3: Rainforest

The occurrence of widespread fires in rainforest is very rare, and is associated with severe drought or cyclonic winds causing the breakdown in the forest structure and the drying out of the forest. (Unwin et.al., 1985)

Across a eucalypt-rainforest ecotone, Unwin (1985), found that shrubs and small trees coppicied readily following fire. This resilence to fire was also recorded in the north Queensland tropical rainforest, where of the 82 species that regenerated following logging, treatment and post-fire, 74 coppicied from stumps, 10 produced root suckers, while the remaining species regenerated from seed. (Stocker, 1981) However, this result is not clear, as the forest may have been silviculturally treated, 30 years previously, resulting in an increase in the number of small stems in the plot. Stocker noted that small stumps <20 cm in diameter coppicied more readily than larger stumps; which coppicied following logging but failed to re-coppice following fire. Further, seven species present in the original stand failed to recover from the disturbance; while subsequent fires will eliminate most or all regeneration of certain rainforest species, allowing the dominance of grasses and other fire-adapted species not found in the original forest.

The sensitivity of certain species was found in the primary lowland dipterocarp forest, in Indonesia, following fire. The dominant species in the unburnt plots, i.e. the dipterocarps, were rare in the burnt plots, with only one seedling of *Shorea parvifolia* found. The corresponding abundance of the pioneer species in the burnt plots, causes an overall change in the composition of the rainforest. (Riswan and Kartawinata, 1991)

In summary, fire alters the composition of both the overstorey and the understorey species, in both eucalypt and rainforest communities. The species which are favoured are adapted to fire, and can tolerate repeated fire disturbance. There is an apparent succession of species re-colonizing following fire, which may temporarily increase the site diversity, however early species die out and are not replaced, due to the intolerance of their seedlings to decreased light. In eucalypt forest, growth rates may increase with the increased opening of the canopy, as a result of fire, however, it is not always necessary for regeneration to occur.

10.0: Management Implications

10.1: The Need to Slash-burn

Fire intensity and frequency can cause major changes in the understorey vegetation. Rainforest species, in particular, are fire-sensitive and may not regenerate following fire. Although some rainforest species may coppice, this has only been seen in large quanities in the ecotonal vegetation and the small stumps coppicing, within the rainforest. In Australia's tall open forests, rainforest species are prevented from becoming dominant overstorey species as a result of frequent fires, which favour eucalypt species. (Smith and Guyer, 1983)

Generally, many authors have concluded that eucalypt regeneration could be achieved with or without slash-burning, following a logging disturbance. (Loyn, 1983; King, 1985)

While regenerative stocking was significantly higher in post- burnt sites, it was also greater where the soil had been disturbed (King, 1985). It has been suggested by Ovington and Thistlewaite (1975) that fire could be replaced by mechanical disturbance in tall open forests. The use of mechanical disturbance to expose the mineral soil, after logging, was also suggested by Raison (1980), for the wet tall eucalypt forest of south-east Australia; and where this was not possible, to instead plant tube stock in the logged sites. However, adequate stocking, for example, in some uneven-aged Tasmanian forests, could be achieved with slash-burning or even extra mechanical disturbance. (Kirkpatrick and Bowman, 1982)

Still, the problem of protecting regeneration in unburnt stands, from wildfires, remains. Lockett and Candy (1984) saw this as being of overriding importance, and justifies the use of slash-burn, even in areas that may not require it for regeneration. Kirkpatrick and Bowman (1982), differentiate between clearfelling and selective logging. Clearfelling leaves the seedlings and saplings between three to 16 years, following logging, vunerable to disturbances such as fire. In comparison, in a selectively logged forest, potentially merchantable timber will survive all but the severest fire and even then, mortality is low.

Raison (1980) viewed the dangers of the slash left by logging as low in Tasmania's wet tall forests. Drawing on the attributes of these forests, with their moist undergrowth and rapid decay rates, the chances of wildfires occurring would be low, on the provision that there were no man-derived sources of ignition. Loyn (1983) instead encourages the use of fire through mosaic burning, to maintain the diversity of regenerating species; both those favoured and those not favoured by fire.

In Summary, fire is not a necessary source of regeneration. In old-growth forests, given the susceptibility of some species, it would not be desirable to completely slash-burn a logged area. The intensity of the slash-burn fires could further affect the survival of some species, while the potential nutrient losses are alarming. Alternatives to the use of slash-burning have been suggested and should be brought into practice where possible, if an old-growth forest is to retain its original composition. Fire should not be used in rainforest as it is a very rare disturbance, which will severely affect species if it occurs on a more frequent basis.

10.2: The Logging Regime

Changes to the logging regime was studied in forests, in west central Victoria, by Kellas (1988). The single selection method favoured the peppermint species such as *Eucalyptus dives* and *Eucalyptus radiata*. When this regime was changed to shelterwood management, the more commercial species, such as *Eucalyptus obliqua*, were favoured, due to increased light. Several silvicultural regimes were studied for their effects on blackbutt forests in northern N.S.W. The highest regeneration of blackbutt occurred under the radical-enrichment and complete- logging regimes. (Florence and Phillis, 1970)

The examples described above are of forests already altered by logging events. This obscures the effect of the different logging regimes, however, it is interesting to note, that both suggested more severe logging regimes on the forests, to favour the desirable commercial species. If the values of old-growth are not to be compromised in favour of the creation of 'production forests', then it is apparent that the thinking within the logging industry will have to be modified.

11.0: Management Options for Old-Growth Forests

The Resource Assessment Commission (1992) recommended that either (1) there is a rapid cessation of all logging operations within old-growth forest or (2) comprehensive management plans are devised, in which old-growth forest is identified and ranked accordingly. This is to be followed by a determination of adequate representation of old-growth forest types in reserves, with the renainder to be made available for logging.

Individual groups have put forward recommendations that fall into five categories:

1. The continuation of current logging practices.
2. The improvement of current logging practices: e.g. the reduction in soil disturbance, and smaller-sized logging areas to quicken regeneration process (Saulei and Lamb, 1991); the retention of a few good quality seed trees to prevent genetic erosion(Kartawinata, 1981); hollow-bearing trees. Lindenmayer et.al. (1990) points out that clearfell harvesting produces even-aged forest, with clusters of hollow-bearing trees, may reduce the actual number available for occupation, due to the territorial behaviour of some species. In addition, streamside reserves may be inadequate for many hollow-dependent fauna, and even in a complete rotation of 80-120 years, the requirements of all the species may not be met.
3. The use of low-impact selective logging: e.g. the use of 'holistic forestry' - this is basically the use of selective harvesting, that is sensitive to the demands of a particular forest, which could be achieved if forests were in the care of local community groups.(Diem, 1992); the use of a conservative harvesting strategy based on plantations, complimented by less intensive operations in native forests. (Norton, 1991) In western Montana, a management plan has been drawn up for the Ponderosa Pine old-growth communities. This utilizes low impact harvesting and reduction burning to return the area to pre-settlement condition. (Habeck, 1990)
4. The use of long-term rotational logging: Harris (1984) stated the need for the preservation of old-growth forests surrounded by long-rotation cycle forests. This in effect, increases the effective size of the old-growth forest and thus buffers it against environmental changes and lowers its susceptibility to fire. Harris extends the island biogeography theory to old-growth forests and as such, an increase in the number of old-growth forest management islands, will facilitate the conservation of endenic species, preserve clinal genetic variation, while decreasing the distance between 'islands', will increase genetic interchange and hence population viability. Further, long-rotation forest can replace the old-growth forest in time.
5. Preservation of old-growth forests: To have an adequate reserve system of all old-growth forest types.

12.0: Conclusion

It is evident from the information which has been drawn upon in this paper, that old-growth forests contain complex structural and floristic forms and fulfil the requirements of many species. The impact of logging alone does not appear to compromise the values of these forests, however, due to the alteration of the abundances of some species, adequate time is required for recovery. This is even more so for forests which have been subjected to a slash-burn. Where possible, slash-burning should be avoided in old-growth forest if it is to maintain its full species compliment.

The time to recovery is the most important aspect of forest management. As the current logging cycles are obviously too short, these cycles need to be extended. The time between logging events needs to reflect the time taken for a forest to diversify to its full complexity. In general, this would be more than 200 years between logging events.

The intensity of the logging event should be reduced and also the randomization of logging extraction should be undertaken to increase the likelihood of recovery to old-growth forest. It may be that low intensity selective logging will be acceptable in old-growth forests and due to its nature, logging can occur on a continual basis, if a mosaic pattern is established (even in the montane ash forests of Victoria, unevenness is present in the forest structure).

Until more information is gathered on the impacts of logging, harvesting these forests is unacceptable. The perceived rarity of these forests, only increases their value as a forest type. The continued logging of old-growth forest, even with modified prescriptions such as the retention of habitat trees may be a completely inadequate way of achieving the initial intentions of sustainable use.

Alternatives to the current logging practices need to be sought now. There are many possibilities, such as an increased reliance on plantations for our timber requirements, the use of low intensity methods of extraction such as balloons, helicopters or 'flying-foxes' to remove single trees or groups of trees, and even the transferral of responsibility to community groups. Whatever the management option put into practice, the ecological requirements of the forest ecosystem must be given full priority on a long-term basis.

13.0: References

Australian Heritage Commission (1990). R.A.C. Submission FT90/085c, pp.26-33.

Baker, R.T. & Smith. H.T. (1910). A Research on the Pines of Australia. Government of the State of New South Wales, Sydney.

Baur, N. (1992). Thoughts on Old Growth Forests. In: Dyne,G. Attributes of Old Growth Forest. Bureau of Rural Resources, Working Paper No.WP/4/90, Appendix 10.

Binns, D.L. (1991). Vegetation Dynamics of *Eucalyptus microcorys - E. saligna* wet sclerophyll forest in response to logging. Masters Thesis, University of New England.

Bolgiano, C. (1989). A Case for Eastern Old-Growth. Am.Forests, May/June, p.26.

Burges, A & Johnston, R.D. (1952). The Structure of a New South Wales Subtropical Rain Forest. J. Ecol. 41:72-83.

Burgess, I.P., Floyd, A., Kikkawa, J. & Pattemore, V. (1975). Recent Developments in the Silviculture and Management of Subtropical Rainforest in New South Wales. Proc. Ecol. Soc. Aust. 9:74-84.

Christensen, P. (1992). The Karri Forest: Its Conservation Significance and Management. Department of Conservation and Land Management, Western Australia.

Connell, J.H. (1978). Diversity in Tropical Rain Forests and Coral Reefs. Science, Vol. 199, pp.1302-1309.

Cremer, K.W. & Mount, A.B. (1965). Early Stages of Plant Succession following the Complete Felling and Burning of *Eucalyptus regnans* Forest in the Florentine Valley, Tasmania. Aust.J.Bot.,13:303-33.

Curtin, R.A. & King, G.C. (1979). Blackbutt Advance Regeneration: Its Persistence and Significance. Aust.For., 42(3):161-167.

Dickinson, K.J.M., & Kirkpatrick, J.B. (1987). The Short-term Effects of Clearfelling and Slash-burning on the Richness, Diversity and Relative Abundance of Higher Plant Species in Two Types of Eucalypt Forest on Dolerite in Tasmania.Aust. J. Bot., 35:601-16.

Diem, A. (1992). Clearcutting British Columbia. The Ecologist, Vol. 22, No. 6, November/December, pp. 261-266.

Dyne, G.R., ed. (1992). Attributes of Old Growth Forest in Australia. Bureau of Rural Resources: Working Paper No. WP/4/92, ACT.

Edgar, J.G., Kile, G.A. & Almond, C.A. (1976). Tree Decline and Mortality in Selectively Logged Eucalypt Forest in Central Victoria. Aust.For., 39(4):288-303.

Florence, R.G. & Phillis, K.J. (1971). Development of a Logging and Treatment Schedule for an Irregular Blackbutt Forest. Aust. For. 35:43-53.

Floyd, A.G. (1976). Effect of Burning on Regeneration from Seeds in Wet Sclerophyll Forest. Aust. For., 39(3):210-220.

Franklin, J.F., et.al. (1981). Ecological Characteristics of Old-Growth Douglas Fir Forests. United States Department of Agriculture and Forest Service, General Technical Report PNW-118.

Franklin, J.F., Shugart, H.H. & Harmon, M.E. (1987). Tree Death as an Ecological Process. BioScience, Vol.37, No.8,pp.550-556.

Gibson, N. (1986). Huon Pine: Conservation and Management. National Parks and Wildlife, Wildlife Division Technical Report 86/3, Tasmania.

Habeck, J.R. (1990). Old-Growth Ponderosa Pine-Western Larch Forests in Western Montana: Ecology and Management. The Northwest Environmental Journal, 6:271-292.

Harris, L.D. (1984). The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. The University of Chicago Press, Chicago.

Hopkins, M.S., Kikkawa, J., Graham, A.W., Tracey, J.G., Webb, L. (1976). An Ecological Basis for the Management of Rain Forest. In: Monroe & Stevens. The Border Ranges - A Land Use Conflict in Regional Perspective. Royal Society of Queensland.

Horne, R. & Gwalter, J. (1982). The Recovery of Rainforest Overstorey Following Logging. Aust. For. Res., 13:29-44.

Horne, R. & Gwalter, J. (1987). The Recovery of Rainforest Overstorey Following Logging: 2. Warm Temperate Rainforest. For. Ecol. Manag., 22:267-281.

Horne, R. & Mackowski, C. (1987). Crown Dieback, Overstorey Regrowth and Regeneration Response in Warm Temperate Rainforest Following Logging. For. Ecol. Manag., 22:283-289.

Horne, R & Hickey, J. (1991). Review: Ecological Sensitivity to Australian Rainforests to Selective Logging. Aust. J. Ecol., 16:119-129.

Institute of Australian Foresters, (1991). R.A.C. Submission FT91/145, pp.1-10.

Kartawinata, K. (1981). The Environmental Consequences of Tree Removal from the Forest in Indonesia. In: Sutlive, U.H., Altshuler, N. & Zamora, M.D. Where Have All The Flowers Gone: Deforestation in the Third World. Virginia, U.S.A.

Kaufmann, M.R., Moir, W.H. & Covington, W.W. (1992). About Their Ecology and Management in the Southwest and Rocky Mountain Regions? In: Old-Growth Forests in the Southwest and Rocky Mountain Regions - Proceedings of a Workshop. United States Department of Agriculture, Forest Service, General Technical Report RM-213, Arizona.

Kellas, J.D., Jarrett, R.G. & Morgan, B.J.T. (1988). Changes in Species Composition Following Recent Shelterwood Cutting in Mixed Eucalypt Stands in the Wombat Forest, Victoria. Aust. For., 51:112-118.

Kershaw, A.P. (1986). Climate Change and Aboriginal Burning in North-East Australia During the Last Two Glacial/Interglacial Cycles. Nature, Vol. 322, pp.47-49.

King, G.C. & Chapman, W.S. (1983). Floristic Composition and Structure of a Rainforest Area 25yr After Logging. Aust. J. Ecol., 8:415-432.

King, G.C. (1985). Natural Regeneration in Wet Sclerophyll Forest with an Overstorey of *Eucalyptus microcorys*, *E. saligna* and *Lophostemon confertus*. Aust. For., 48(1):54-62.

Kirkpatrick, J.B. & Bowman, D.M. (1982). Clearfelling Versus Selective Logging in Uneven-aged Eucalypt Forest. Search, Vol.13, No.5-6, June/July, pp.136-140.

Klinka, K., Carter, R.E. & Feller, M.C. (1990). Cutting Old-Growth Forests in British Columbia: Ecological Considerations for Forest Regeneration. The Northwest Environmental Journal, Vol.6, No.2, pp.221-242.

Lindenmayer, D.B., Norton, T.W. & Tanton, M.T. (1990). Differences Between Wildfire and Clearfelling on the Structure of Montane Ash Forests of Victoria and Their Implications for Fauna Dependent on Tree Hollows. Aust. For., 53(2):61-68.

Lines, W.J. (1991). Taming the Great South Land: A History of the Conquest of Nature in Australia. Allen & Unwin Pty Ltd, Sydney.

Lockett, E.J. & Candy, S.G. (1984). Growth of Eucalypt Regeneration Established With and Without Slash Burns in Tasmania. Aust. For., 47(2):119-125.

Loyn, R.H., Fagg, P.C., Piggin, J.E., Morton, A. & Tolhurst, K. (1983). Changes in the Composition of Understorey Vegetation After Harvesting Eucalypts for Sawlogs and Pulpwood in East Gippsland. Aust. J. Ecol., 8:43-53.

McIlory, D., ed. (1990). The Ecological Future of Australia's Forests. Australian Conservation Foundation, Victoria.

Mercer, D. (1991). "A Question of Balance": Natural Resources Conflict Issues in Australia. The Federation Press, N.S.W.

Moir, W.H. (1992). Ecological Concepts in Old-Growth Forest Definition. In: Old-Growth Forests in the Southwest and Rocky Mountain Regions. United States Department of Agriculture, Forest Service, General Technical Report RM-213.

Mount, A.B. (1978). Natural Regeneration Processes in Tasmanian Forests. Search 10, pp.180-186.

Nicholson, D.I., Henry, N.B. & Rudder, J. (1988). Stand Changes in North Queensland Rainforests. Proc. Ecol. Soc. Aust., 15:61-80.

North.East.Forest.Alliance. (N.E.F.A.), (1991). R.A.C. Submission 480.

Norton, T.W., McKenney, D.W., Mackey, B.G. & Williams, J.E. (1991). Can We Afford Logging? Search 12, pp.6-8.

Ovington, J.D. & Thistlewaite, R.J. (1975). The Woodchip Industry: Environmental Effects of Cutting and Regeneration Practices. Search 7, pp.383-92.

Queensland Department of Forestry. (1983). Rainforest Research in North Queensland: A Position Paper.

Raison, R.J. (1980). Possible Site Deterioration Associated with Slash-Burning. Search 11, pp.68-72.

Rayner, M.E. (1992). Application of Dendrochronology, Stem Analysis and Inventory Data in the Estimation of Tree and Stand Ages in Karri Forest. Department of Conservation and Land Management, Technical Report No.27, Western Australia.

Resource Assessment Commission, (1991). Forest and Timber Inquiry - Draft Report, Volume 1 and Volume 2. Australian Government Publishing Service.

Resource Assessment Commission, (1992). Forest and Timber Inquiry - Final Report, Volume 1. Australian Government Publishing Service.

Riswan, S. & Kartawinata, K. (19-). Regeneration After Disturbance in a Lowland Mixed Dipterocarp Forest in East Kalimantan, Indonesia. Gomez-Pompa, A., Whitmore, T.C. & Hadley, M. Rainforest Regeneration and Management, Man and the Biosphere Series, Vol.6, UNESCO..

Ritman, K.T., et.al. (1992). A Survey of the Forests of East Gippsland with Particular Reference to Old-Growth Characteristics. Department of Conservation and Natural Resources, Victoria.

Saulei, S. & Lamb, D. (19-). Regeneration Following Pulpwood Logging in Lowland Rain Forest in Papua New Guinea. Gomez-Pompa, A., Whitmore, T.C. & Hadley, M. Rainforest Regeneration and Management, Man and the Biosphere Series, Vol.6, UNESCO.

Saxon, E.C. (1990). Disturbance Regimes in North Queensland Rainforests: A Re-evaluation of Their Relationship to Species Richness and Diversity. Aust. J. Ecol. 15:241-244.

Scotts, D.J. (1991). Old-Growth Forests: Their Ecological Characteristics and Value to Forest-Dependent Vertebrate Fauna of South-east Australia. In: Lunney, D. Conservation of Australia's Forest Fauna. Royal Zoological Society of N.S.W.

Shugart, H.H. (1987). Dynamic Ecosystem Consequences of Tree Birth and Death Patterns. BioScience,Vol.37:596-602.

Smith, J.M.B. & Guyer, I.J. (1983). Rainforest-Eucalypt Forest Interactions and the Relevance of the Biological Nomad Concept. Aust. J. Ecol. 8:55-60.

Stocker, G.C. (1981). Regeneration of a North Queensland Rain Forest Following Felling and Burning. Biotropica 13(2):86-92.

Swetnam, T.W. & Brown, P.M. (1992). Oldest Known Conifers in the Southwestern United States: Temporal and Spatial Patterns of Maximum Age. In: Old-Growth Forests in the Southwest and Rocky Mountain Regions. United States Department of Agriculture, Forest Service, General Technical Report RM-213.

Unwin, G.L, Stocker, G.C. & Sanderson, K.D. (1985). Fire and the Forest Ecotone in the Herberton Highland, North Queensland. Ecol. Soc. Aust. 13:215-224.

Webb, L.J., Tracey, J.G. & Williams, W.T. (1972). Regeneration and Pattern in the Subtropical Rainforest. J. Ecol. 60:675-695.

Winter, J.W., Bell, F.C. Pahl, L.I. & Atherton, R.G. (1987). Rainforest Clearfelling in Northeastern Australia. R. Soc. Qld. 98:41-57.