History of disturbances in the white cypress pine *(Callitris glaucophylla)* forests of the lower Snowy River Valley, Kosciusko National Park.

by

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Declaration

I declare that this thesis is my own work, except where specifically indicated to the contrary, and that it is not substantially the same as any other thesis which has already been submitted to any other university.

Ian Frank Pulsford

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Preface

This study was initiated in response to increasing concern by the National Parks and Wildlife Service over the condition of the ecosystem in the lower Snowy River. This area had been subject to grazing for about 150 years and was believed to be still degrading under the onslaught of rabbits. While rabbits remain a cause for concern fuller understanding of this ecosystem could only be obtained by considering the impact of man's activities in the valley since European settlement.

To achieve this the study was undertaken in three parts. The first is a review of the historical evidence both from the literature and oral anecdotal sources, for ecological changes in the valley over the past 150 years. This includes: (1) the decline of the Aborigines with the arrival of the Europeans, the land use practices of the new settlers, and current National Park management practices, and (2) a review of relevant knowledge of the white cypress pine - white box alliance.

The second part presents evidence from fieldwork of the pre-European forest structure and changes in forest structure since European arrival. The inferred changes to forest structure are discussed in the context of historical land use. The laboratory tools of dendrochronology[1] are then used to age white cypress pine regrowth and old growth trees. Fire histories for one stand and the study area as a whole are constructed from the tree fire scar and historical records. The history of fire in the lower

[1] Dendrochronology is the systematic use of tree ring "cross dating" which uses the variation in ring width or ring characteristics to establish the exact year in which the ring was formed (Fritts, 1976). Sometimes past forest disturbances such as indicated by fire scars or flooding scars on trees can be dated and their importance evaluated. Dendroecology refers to the application of dendrochronological techniques to problems in ecology (Fritts and Swetnam, 1989). It is the branch of dendrochronology in which emphasis is placed on the historical ecology of the sites being investigated (Ogden, 1978).

Snowy River Valley is interpreted in the context of the fire histories of the Australian Alps.

The third part discusses the important environmental and anthropogenic factors which have contributed to the dynamic changes in forest structure since European settlement.

Abstract

The study investigates anecdotal, historical and dendrochronological evidence for changes in the structure of the white cypress pine stands since European settlement in the white cypress pine - white box forest zone in the valley of the "lower" Snowy River in Kosciusko National Park. Anecdotal and historical information provided evidence of major changes to the white cypress pine stands from essentially open stands to the dense forest stands of today. Field survey provided numerical data on the magnitude of these changes, but there remained uncertainties as to the historical timing of the critical factors which brought about these changes. Dendrochronological techniques were adapted and applied to the white cypress pine for tree ageing, the dating of historical fires from fire scars and the dating of distinctive tree growth periods. This enabled age estimates to be made for the old growth trees, they dated from 150-200 years ago, and the recognition of the period 1935-45 as a major decline for old growth trees which survived into this century. The enumeration and dating of historical fires provided a detailed fire record, this suggested the most frequent fires occurred in the second half of the 1800's, with fires continuing into this century and declining after the 1940's. Many trees in the extensive regrowth stands were estimated to date from 90-105 years ago, regenerating after the destructive fires of the late 1800's and before the arrival of rabbits around 1900. Subsequent tree regeneration was inferred to have occurred only when climatic conditions were suitable and rabbit populations were low. Soil erosion has been extensive and severe in the white cypress pine zone, most occurred in the 1800's prior to the major tree regeneration phase. Implications for the future National Parks and Wildlife Service management of this forest are discussed.

Part I

Introduction and review

Chapter 1 Introduction

In common with many woodland and forest ecosystems in eastern Australia the white cypress pine stands in the lower Snowy River Valley have been significantly modified over the past 150 years. Much of this modification has been brought about by the direct and indirect effects of European land use practices. A measure of this change can be gauged by comparing descriptions of the lower Snowy River Valley reported by Robinson in 1844 (Mackaness, 1941) and Costin (1954). Robinson described the area in 1844 in the following terms:

> "Callitriss (sic) from four to five feet in circumference grew amid shrubs of every variety of tint. The Country is well grassed and abounds with Cattle, the Soil varies from a rich black mould to a chocolate."

In contrast, Costin (1954) reported in the early 1950's that the condition of the area was characterised by dense regenerating thickets of white cypress pine and bare eroded soils. The effects of rabbits and fire were suggested by Costin as the major disturbance factors causing these changes. He made a plea for urgent State intervention to protect the catchment by implementing programmes for the control of rabbits and policies for exclusion of fire from the alliance. Policies for the suppression of all fires and the non implementation of fuel reduction burning programmes in the alliance have been implemented by the National Parks and Wildlife Service.

Continuing concern regarding the state of these forests was expressed by Clayton-Greene (undated) after working in the valley (Clayton-Greene, 1981) and by Worboys (1982) in his investigation of the Byadbo area of the catchment. These reports drew attention to widespread sheet and gully erosion, the presence of large rabbit populations and the severe effects of drought on the landscape. These reports and continuing concerns expressed by officers of the National Parks and Wildlife Service resulted in a seminar held at Queanbeyan on the status and management of the area in October 1983. The findings of this seminar were that the present condition of this ecosystem posed serious and significant problems for the management of the catchment. These were identified as:-

(a) widespread sheet and gully erosion;

(b) apparent lack of continuous white cypress pine recruitment;

(c) lack of ground cover in many areas;

(d) periodic occurrence of large numbers of rabbits;

(e) invasion by large numbers of introduced plants.

The need for further study of the area was highlighted. The main aspects requiring further information were: (a) the dynamics of the white cypress pine - white box alliance and in particular ecological changes to forest structure since European settlement, possibly caused by land use practices introduced by Europeans; and (b) whether the ecosystems were still undergoing the processes of degradation initiated during the grazing era.

This current study aims to evaluate the first aspect, ie to determine the changes which have occurred since European settlement in the white cypress pine dominated stands and to investigate the causes of these changes. The second aspect became the subject of a separate vegetation monitoring study.

White cypress pine stands (*Callitris glaucophylla* Thompson & Johnson *sp. nov. syn. C. columellaris* F. Muell., *syn. C. glauca* R. Br ex R.T. Baker et H.G.Sm.) are found in the lower Snowy River Valley of Kosciusko National Park. Here the species occurs as a co-dominant with

Eucalyptus albens Benth. to form the white box *E. albens* - white cypress pine *C.glauca* alliance (Costin, 1954). This alliance extends along the valley of the Snowy River into Victoria's Alpine National Park (which incorporates Cobberas-Tingaringi National Park and is soon to incorporate the Snowy River National Park). The area of the alliance defined by Costin (1951) both outside and within Kosciusko National Park is approximately 115,500 ha. Using the vegetation province classification of McRae (1989) the area where white cypress pine stands are predominant within the alliance is approximately 7,084 ha or 1.1% of the Park area (Fig. 2.5). This relatively small area means that careful management is required to ensure conservation of this resource.

Appropriate management of ecosystems requires knowledge of their history (Clark, 1990). Managers also need to understand the causes, rates, direction and magnitude of changes to wisely set objectives and make appropriate prescriptions for land management. Simple descriptions during the short work experience of a manager are essential but inadequate for understanding or predicting trends (Clark, 1990) or the outcomes of management actions. For example, the management history of Yellowstone National Park is filled with examples of land management philosophies and practices which have resulted in gross and inappropriate changes to the functioning ecosystems of the park since the arrival of Europeans (Chase, 1987). This was due to ignorance of the role of crucial components and ecological processes in the Yellowstone ecosystems.

1.1 Objectives

This study had four main objectives.

(1) To investigate the ecological and historical evidence for changes in the structure of the white cypress pine - white box forests.

(2) To evaluate dendrochronological methods for dating the white cypress pine.

(3) Using 1 and 2 investigate the fire history in the white cypress pine stands and the proposition that the white cypress pine stands in the lower Snowy River are essentially composed of two age class groups.

(4) Use the evidence from 1-3 to characterise the type and occurrence of disturbances and their impact on the forest since European settlement.

Through the above investigations of evidence of patterns, changes and processes in the past, predictions for management may be considered through explanations of how the present came to be.

1.2 Previous ecological studies

1.2.1 In the study area

Costin (1954) investigated the ecosystems of the Monaro Region. He analysed the primary independent variables of the ecosystem, climate, physiography, primary edaphic factors, primary biological complex, time and man and their interactions. As part of this study he described the interaction of these factors which produced the soils and vegetation found in the white cypress pine - white box alliance in my study area.

Clayton-Greene (1981; 1990) investigated aspects of the autecology of *Callitris glaucophylla* in the lower Snowy River Valley of Kosciusko National Park and compared this site with a flat land site at Savernake in Riverina district of NSW. He investigated the contrast in reproductive strategies and influences of temperature, moisture and photo-period on seedling growth of white cypress pine with associated Eucalypt species. The fire ecology of white cypress pine was briefly examined. From these studies he elucidated the major factors which limit populations of these plant species and explain their distribution. For example, he found that whilst they occupy separate niches they compete strongly; the current distribution and structure of these woodlands may (in part) be explained by the differing seed dispersal and germination behaviour; adaptation of each species to fire and survival of differing regimes of fire is related to aspect; allelopathic behaviour of white box causes a negative association with its seedlings; an important cause of the negative or regular association of white cypress pine and its seedlings is drought exacerbated by intense intra-specific competition; and the distinct altitudinal limit of white cypress pine at around 600 m may be caused by lower temperatures associated with increasing altitude which may be critical to seedling establishment.

1.2.2 Outside the study area

This study reviews the evidence of Horne and Robinson (1987), Johnston (1969), Lacey (1972, 1973) and Lindsay (1948) on white cypress pine west of the Great Dividing Range to determine whether the same factors which affected the dynamics of white cypress pine out west affected my study area. My study area contains the most major occurrence of white cypress pine in a catchment east of the Great Dividing Range.

Prolific “wheatfield regeneration” of white cypress pine occurred west of the Great Dividing Range between 1880 and 1905, and in 1952 following the introduction of Myxoma virus to rabbits. The suggested causes of these wheatfield regeneration events were a succession of exceptionally wet years, combined with a decline in fire frequency which provided openings for regeneration (Commission of Inquiry into Forestry 1908 in Lacey, 1972). The reduction of grazing pressure from rabbits in the 1950’s coinciding with wet years is given as the cause of the 1950’s regeneration pulse. Regeneration was almost completely absent during the intervening period (Lacey, 1972), white cypress pine seedlings and young trees being palatable to rabbits, sheep and to a lesser extent cattle. Fenced exclosures to stock and rabbits in many western forests have been have been shown to allow some white cypress pine regeneration to occur (Johnston, 1969; Lacey, 1972).

Chapter 2 Background to the study

2.1 The study area

The study area takes in the white cypress pine zone along the Snowy River Valley within the Kosciusko National Park (Fig. 2.1, Fig 2.5). This section of the Snowy River catchment is referred to locally as the "lower" Snowy River. The Snowy River arises on the upper slopes of Mt. Kosciusko at 2228 m and flows in a wide arc from the alpine zone in Kosciusko National Park out across rural grazing land on the Monaro tableland and re-enters the park west of Bombala. Within the study area the Snowy River flows south through a gorge in the deeply dissected eastern edge of the Monaro Plateau. It continues south into Victoria through Alpine National Park entering the sea near Orbost.

Within the study area, the Snowy River Valley runs along a north-south axis with steep slopes rising from the valley floor at 200-300 m A.S.L. to rounded peaks and ridges up to 1200 m elevation. Two major tributaries to the west are the Pinch and Jacobs Rivers. The white cypress pine occupies a sharply defined zone extending from the valley floor to about the 650 m contour.

2.2 Climate of the lower Snowy River Valley

The study area is surrounded on all sides by high mountains which form the dissected edge of the Monaro Tableland. As a result it lies in a deep rain shadow (Fig. 2.4) in the lee of the progression of a predominantly north-easterly air stream which passes over the Great Dividing Range. No long term meteorological data were available for the study area except at nearby Suggan Buggan. Rainfall records were kept at Suggan Buggan from 1956 to 1977 by Mr. V. Richardson (Fig. 2.2). From these records mean annual rainfall was 583 mm (Clayton-Greene, 1981) lying well within the limits of the 700 mm mean annual rainfall isohyet predicted by a fitted rainfall surface and digital elevation model for the area (Adomeit *et al*., 1987). These are therefore a useful data set for the study area. Rainfall events result from an easterly movement of frontal air associated with the easterly progression of anticyclones. There is a slight bimodal peak in rainfall in the summer months with the highest rainfall occurring during November and December. Lowest rainfall occurs during the winter months and the lowest month is June (Fig. 2.2). The driest year on the record for Suggan Buggan was 1977 (152 mm) and the wettest year was 1978 (784 mm) (Clayton-Greene, 1981). An important characteristic of rainfall is that it is often locally intense with up to 100 mm falling in a singe event (Clayton-Greene, undated). This means that the effective rainfall on steep hillsides is substantially less than the total rainfall.

The mean monthly temperature was reported by Costin (1954) as 24°C in mid summer and 7°C in mid winter. The area lies within the 10-11°C mean annual isotherm (Adomeit *et al*., 1987). During this study from 1984 to 1989 the mean monthly maximum temperature was 28.1°C for mid summer (December to February) and mean monthly minimum was 1.1°C in mid winter (June to August) recorded from an automatic recording weather station located near the junction of Running Waters Creek and the Snowy River (Fig 2.3, Table 2.1). This station was established in October 1984.

Frosts are reported to be common by Clayton-Greene (1981). Geering (1981) reported severe frosts on ten out of thirty mornings during one winter with ice lying on the edge of the river in some places all day. Severity of frosts would have diminished upslope of the valley floor where cold air collects. During this study from October 1984 to December 1989, the mean estimated number of frosts, where temperatures fell below -2.5 °C in the screen during the study, was 19.6 (2-34) days per year. Temperatures were greater than or equal to 38°C on 5.6 (1-8) days per year during the study and exceeded 40°C on 3 occasions. Clayton-Greene (1981) estimated that temperatures would exceed 40°C 20 - 30 times per year.

Snow fell on at least two occasions in the white cypress pine - white box forests during mid-winter 1987 but did not accumulate (pers. obs.). The coldest temperature recorded during the study period was -6.5 °C on 26th July 1986 and the highest recorded rainfall for one month was 110 mm in March 1985.

2.3 Geology

The rocks of the study area are predominantly intrusive granitoids such as late Silurian biotite granodiorite and tonalite (Brown *et al.*, 1959). These rocks are part of a series which has previously been referred to as the Kosciusko granodiorite (Geological Survey of Victoria, 1964). These rocks are overlain unconformably by highly folded Ordivician quartz rich greywackes. The greywackes consist of a sequence of well bedded sandstone, slate, siltstone, mudstone and shales, known in the vicinity of the Suggan Buggan Range as the Ingeegoodbee beds (Menzies, 1965) or Suggan Buggan schists (Talent, 1965), and areas of higher elevation east of the Snowy River as the Byadbo beds (Wyborn, 1977). The Ingeegoodbee beds are unfossiliferous and metamorphosed rocks whereas the Byadbo beds contain fine grained black graphitic slates containing Gisbornian to Estonian graptolites. These Ordivician sediments were possibly laid down in a marine environment below storm wave base (Wyborn, 1977) and later metamorphosed.

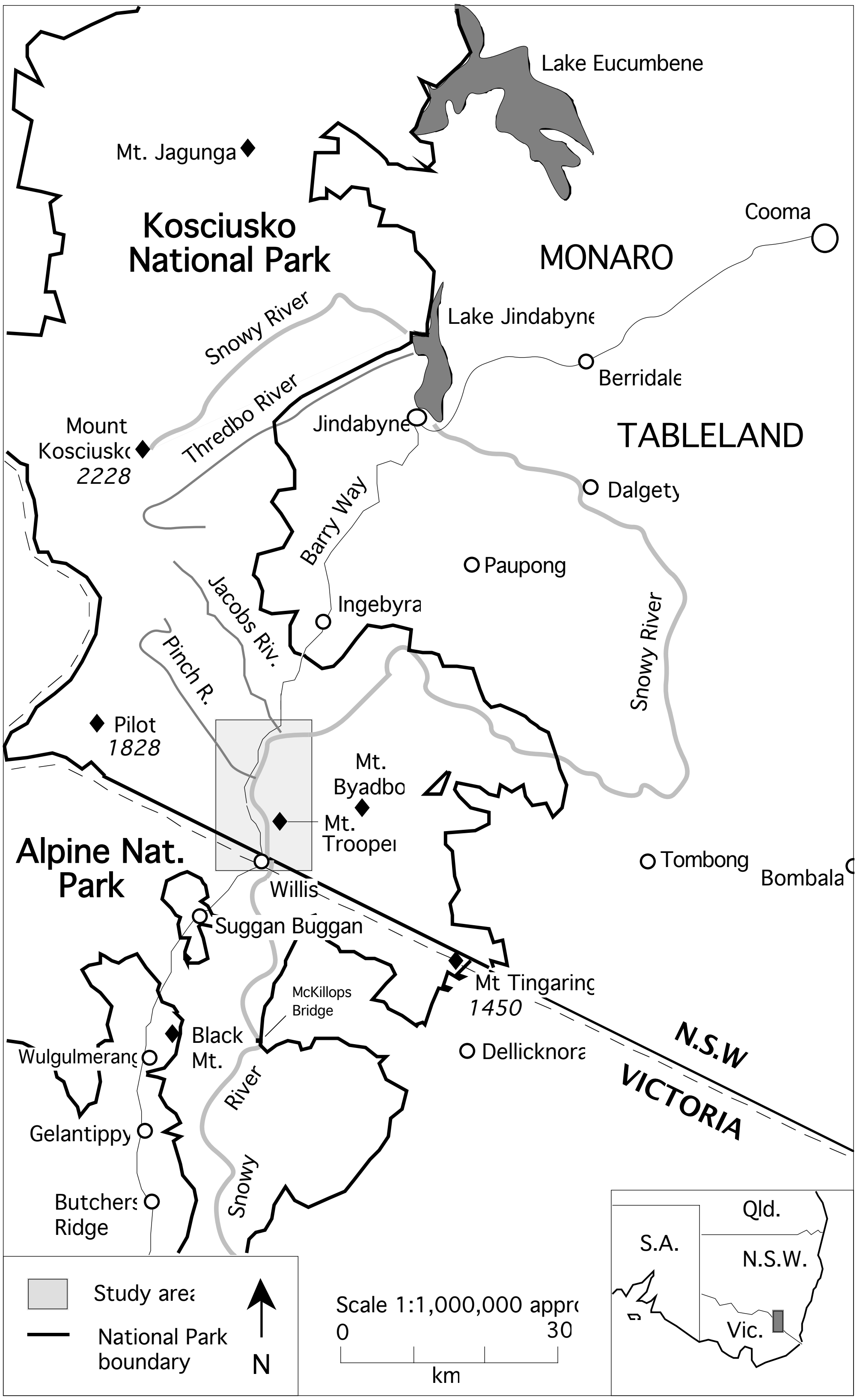


Figure 2.1 Location of study area within Kosciusko National Park.

Table 2.1 Mean maximum, minimum and standard deviations of monthly temperatures over 4 years from 1985 to 1988 from an automatic weather station near the junction of Running Waters Creek and the Snowy River in the study area (source, National Parks and Wildlife Service).

		J	F	M	A	M	J	J	A	S	O	N	D
Max °C	$\bar{x}$	29.[illegible]	27.5	27.3	22.3	16.3	12.7	12.[illegible]	13.7	12.4	20.2	19.3	21.3
	s	3.1	3.2	2.8	0.8	0.[illegible]	0.8	1.5	1.3	7.[illegible]	0.8	6.3	8.[illegible]
Min °C	$\bar{x}$	13.5	12.[illegible]	12.5	9.4	5.7	1.7	1.7	1.9	12.3	8.1	17.8	20.4
	s	2.1	2.8	1.7	1.9	0.7	2.3	1.[illegible]	1.8	11.[illegible]	-	10.5	10.2

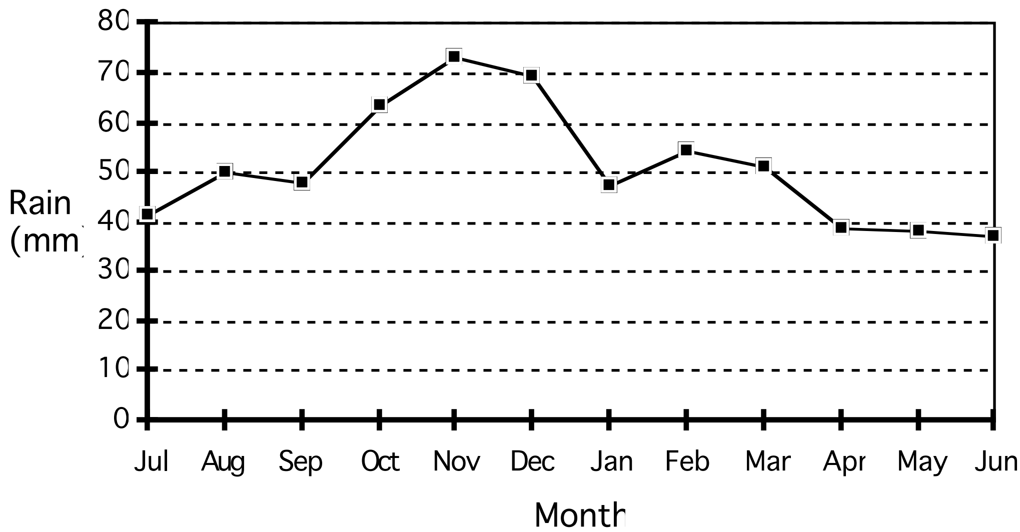


Figure 2.2 Mean monthly rainfall for Suggan Buggan for the period 1957-1977 after which the station closed. Note the dip in January rainfall and the peak in rainfall distribution which occurs in spring. (Data courtesy of Dr. K. Clayton-Greene and Ms.M. Adomeit, CSIRO).

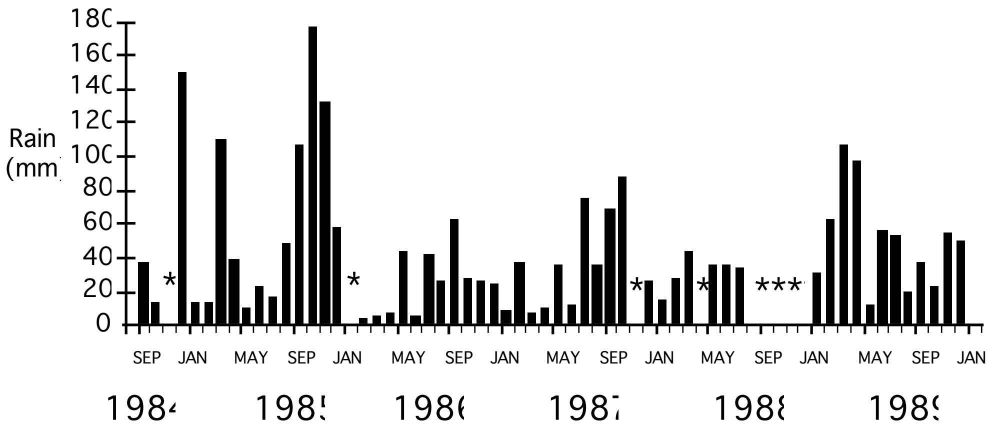


Figure 2.3 Monthly rainfall (mm) at the Running Waters automatic weather station in the lower Snowy River Valley. Missing data points are due to equipment failure and stolen equipment.

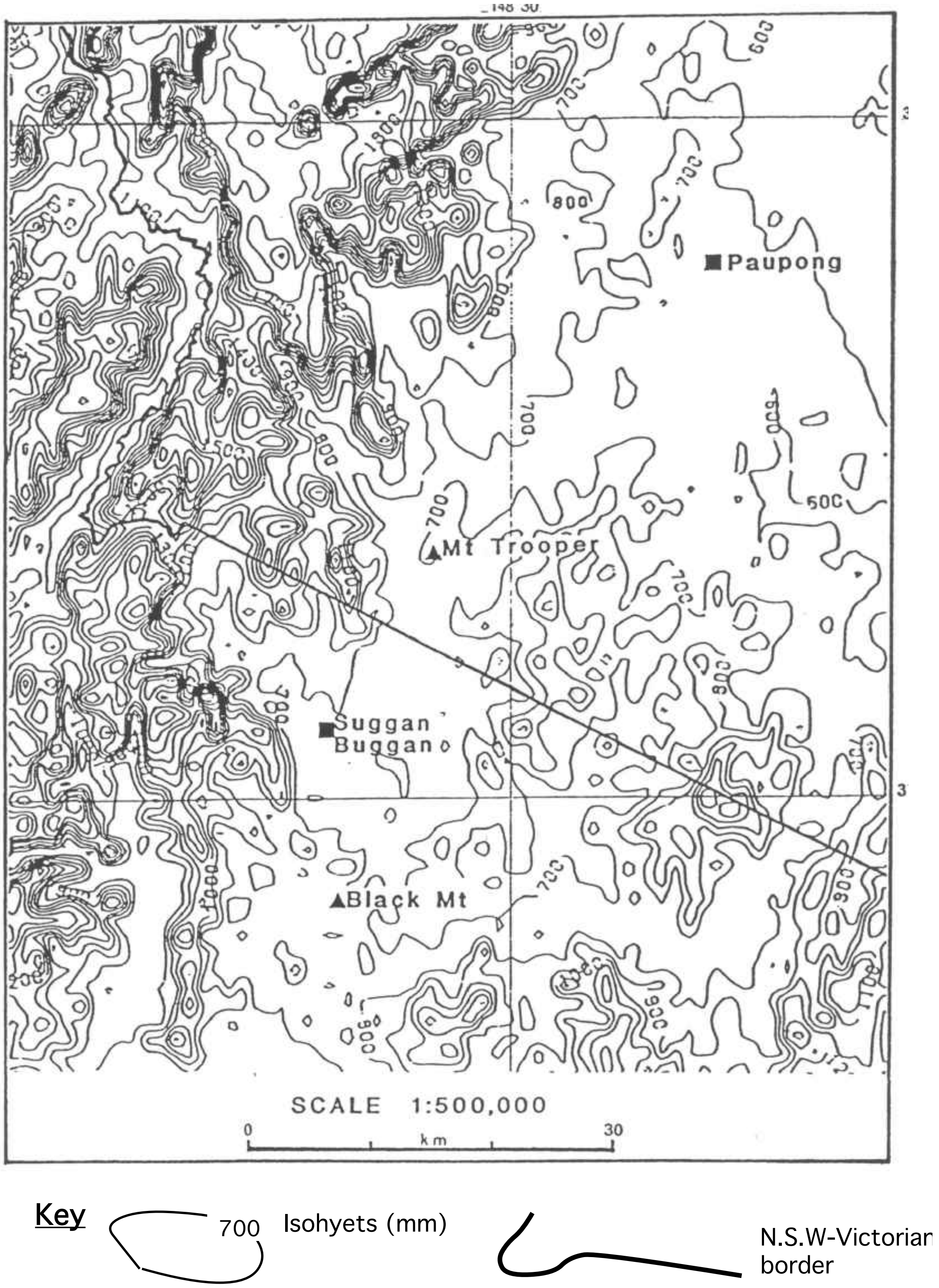


Figure 2.4 Annual mean rainfall isohyets fitted surface using a digital terrain model (after Adomeit *et al*. 1987) for the southern edge of the Monaro Tableland and the Great Dividing Range including the study area. The study area centred on Mt. Trooper lies in a rain shadow area within the 700 mm isohyet. Note the steep increases in mean annual rainfall which coincide with the higher elevations on the Great Dividing Range. Contour interval is 100 m.

Igneous late Silurian granodiorite, tonalite and quartz monzodiorite occur at the Pinch River junction with the Snowy River and around Suggan Buggan to Willis (Wyborn *et al*. 1990).

The drier forest types such as the white cypress pine-white box alliance are restricted to the granitoid series of rocks which extend to the lowest elevation in the Snowy River Valley within the study area (Wyborn, 1977).

2.4 Soils

Costin (1954) described the soils in the white cypress pine - white box alliance as "somewhat lithosolic" and included grey-brown podsolics, brown podsolics and colluvial brown earths derived from granitoid rocks and metamorphosed sediments. The soils on which white cypress pine typically occurs are often of very low fertility derived from coarse grained parent material with a sandy loam or loam texture and a pH range of 5.0 to 7.9 (Lacey, 1972; Lacey, 1973). The pH of soils in the study area ranged from 6.5 to 7.0 (Clayton-Greene, 1981; pers. obs.). In the study area white cypress pine occurs on coarse grained soils derived from the decomposition of granodiorites.

Extensive slope areas, particularly on the warm aspect white cypress pine dominated sites, have suffered sheet erosion on a large scale (pers. obs.). On such sites most of the A and B horizons have been removed. Erosion is less severe on gentle slopes and on the cooler aspects which often retain a good soil depth with the A horizon intact. Much of this erosion is likely to have occurred in the recent past. Most of the material has been transported by energetic ephemeral streams into the Snowy River where the coarse material has formed sand bars and the fine material has been transported to the coast particularly during periods of flood.

Typically, exposure of roots around the bases of old growth trees on north facing slopes indicate they have lost 15 to 30 cm of soil during their lifetimes. An estimate of the soil loss from the north aspect of Mount Trooper was approximately 2,200 tonnes ha^{-1} (A. Spate pers. comm.; pers. obs.). Examples of the present condition of two sites and the degree of soil loss are illustrated (Plates 2.1 and 2.2). In contrast there was no evidence for loss of soil around the bases of regrowth white cypress pine. This suggests that erosion occurred mostly before the establishment of the regrowth stands.

2.5 Vegetation

The white box - white cypress pine alliance is the principal vegetation type in the rain shadow area which embraces the lower Snowy River Valley in the Kosciusko and Alpine National Parks (Fig. 2.5). It includes components of those plant communities typically found today west of the Great Dividing Range. This isolated eastern occurrence must have been once more widespread and linked to the western occurrences possibly as recently as the warmer and more sub-humid period during the final late Pleistocene Recession (Costin, 1954). In the study area the alliance occurs almost entirely within the 200-650 m elevation zone. On the slopes above the white box - white cypress pine zone the vegetation grades rapidly through dry sclerophyll forest to wet sclerophyll forest, subalpine woodlands and forests and finally to alpine herb fields over a distance of 70 km. This truncated vegetation sequence reflects the steep altitude and climate gradients. Small numbers of black cypress pine *(Callitris endlicheri)* are scattered throughout the area on the lower slopes and on the upper altitudinal perimeter of the white cypress pine distribution. The two species appear not to hybridise and this may be controlled by different cone development times.

The white box - white cypress pine alliance is a refuge area for mesothermal frost sensitive species within the Snowy Mountains, which lies south east of the Great Dividing Range (Costin, 1954). The most frost sensitive species would be largely absent from the valley floor which is the zone of most severe frosts.

Two gradient models have been used to describe the distribution of vegetation types in the study area. Kessel *et al*. (1982) presented a generalised environmental gradient model of the mosaic of forest and woodland in the lower Snowy River area (Fig. 2.6). In this diagram the abscissa represents the topographic moisture gradient combining the effects of topography and aspect on site moisture regimes, whilst the ordinate represents the community elevation (Kessel *et al*. 1982).

In the second gradient model Clayton-Greene (1981), used a MULTBET analysis to recognise five woodland community types within the white cypress pine - white box alliance in the lower Snowy River area (Fig. 2.7). These were a low altitude, hot aspect white cypress pine community; a higher elevation cool aspect white box community; and three white cypress pine - white box community types. The composition of these communities varied with changes in elevation and aspect. In general white cypress pine dominated sites of warmer north facing aspects, while white box dominated sites of cooler south and south - easterly aspects and extended to higher elevations than white cypress pine. In the mixed white cypress pine - white box communities there was a sparse shrubby understorey on warm aspects and a grassy understorey on cooler aspects. In the hot aspect white cypress pine stands there was no understorey or a sparse cover of grasses, forbs and shrubs.

These models provide a useful starting point to describe the pattern of distribution within the white box - white cypress pine alliance, but do not provide information about the changes within the stands over time (stand dynamics).

<u>Plate 2.1</u> Exposure of white cypress pine tree root systems on a hot dry north aspect site about 2 km north west of Willis. Soil loss on such sites varies between 15 and 30 cm or more.

Plate 2.2 Gully erosion 2 km north west of Willis. Note the exposure of bed rock. Such gullying is mostly confined to the steeper slopes however major gullies have also formed in some lower slope areas.

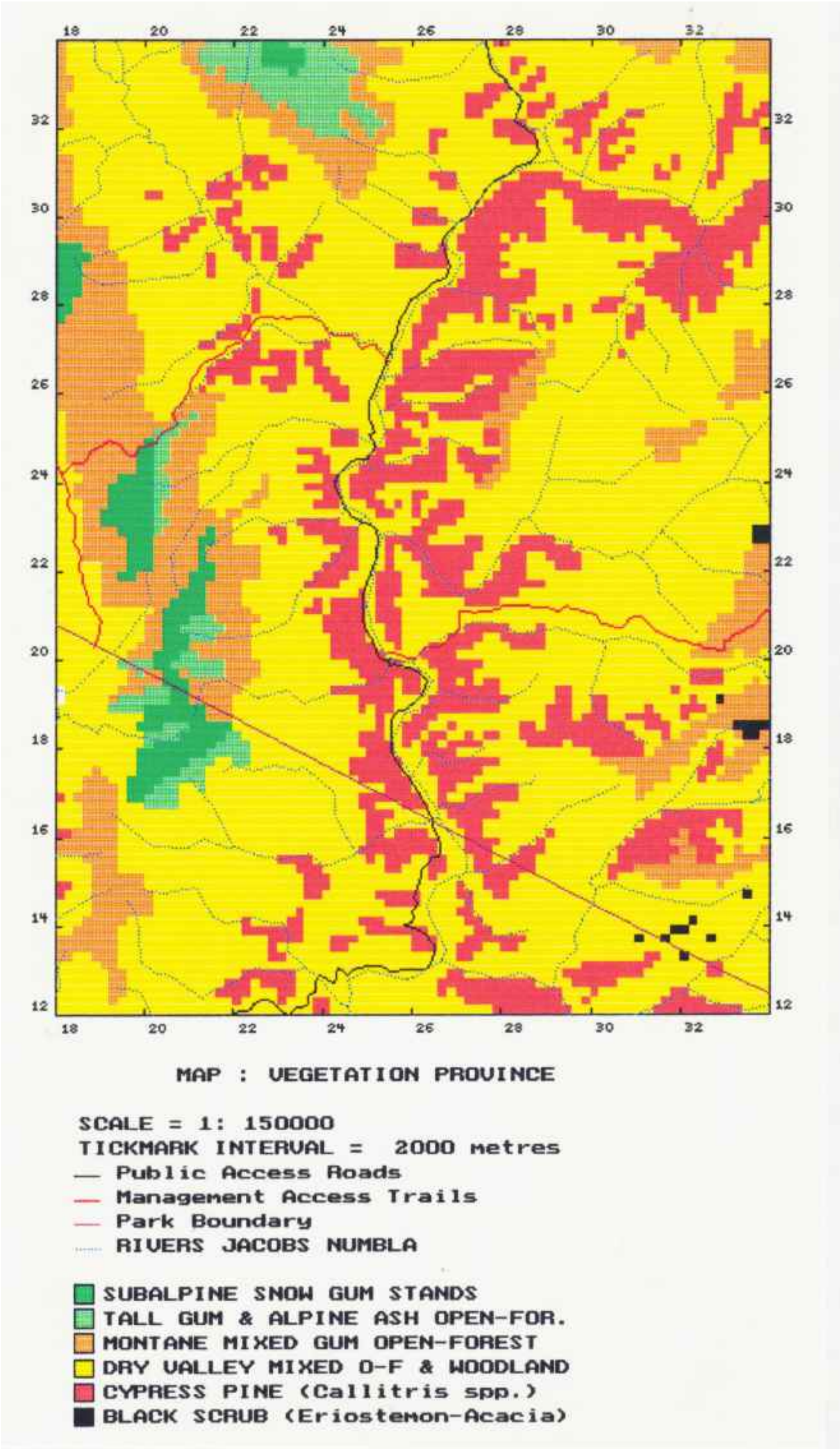


Figure 2.5 Map of vegetation provinces along the corridor of the lower Snowy River in the study area, revised after McRae (1989), source NPWS. Grid cell size is 200 m.

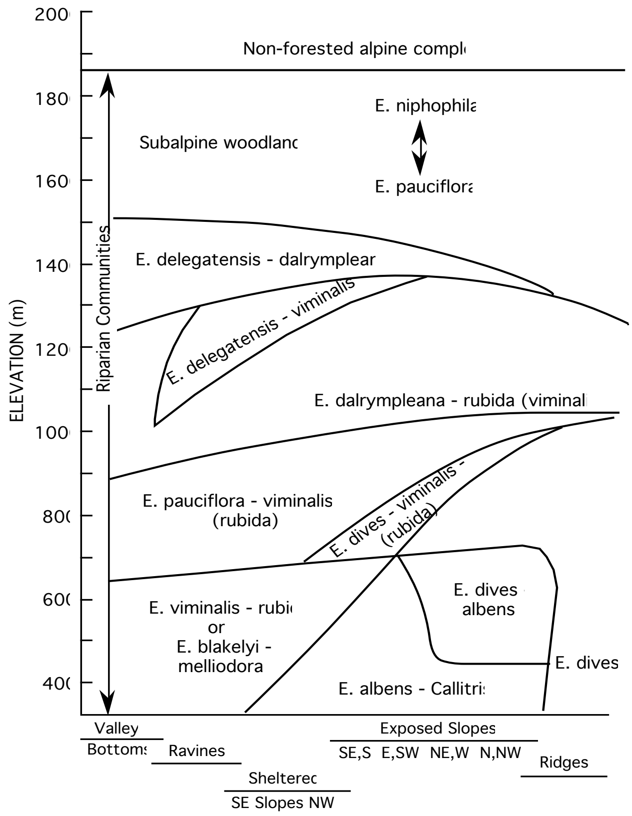


Figure 2.6 Generalised environmental gradient representation of the forest and woodland communities in the lower Snowy River region of Kosciusko National Park, after Kessel *et al.,* (1982).

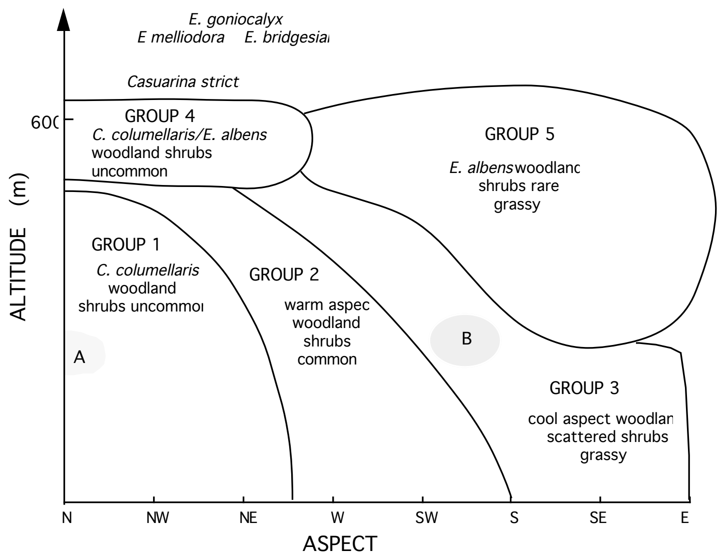


Figure 2.7 Schematic model for the white cypress pine - white box communities based on quadrat groups derived from MULTBET computer analysis in the lower Snowy River, after Clayton-Greene (1981). “A” and “B” indicate the approximate position of tree sampling sites in this study, Chapters 5 & 6.

Chapter 3 Anthropogenic factors

3.1 The Aboriginal people

The central and southern parts of the Monaro tableland including the study area, were occupied by the Ngarigo linguistic group prior to European settlement (Hancock, 1972). The Ngarigo was a sub group of the Bemeringal or “mountain people” who lived in the southern highlands (Howitt, 1904). The Bemeringal were a group of people who apparently spoke related languages (Cooke, 1988). Archaeological surveys of Aboriginal relics (Flood, 1973; Flood, 1980; Lewis, 1976; Margus, 1970) have revealed that in the southern highlands Aboriginal occupation may have been concentrated in comparatively frost free, low elevation valleys (Geering, 1981). Areas such as the lower Snowy River Valley would have been suitable for year round occupation as fish and other native foods were plentiful and the climate relatively warm. In the summer months, subalpine areas of the mountain ranges were visited to seek out Bogong moths and hold ceremonies (Flood, 1973; 1980).

Surveys by (Flood, 1973; 1980; Geering, 1981; Lewis, 1976; Margus, 1970) revealed that the lower Snowy River from Jindabyne to Buchan was particularly rich in the distribution of archaeological sites. Lewis (1976) recorded 90 sites between Dalgety and Devils Hole Creek and Geering (1981) recorded 130 sites in the section from Devils Hole Creek to the NSW/Victorian border. Examination of the National Parks and Wildlife Service Aboriginal Sites Register suggests that this valley contains the highest density of recorded sites in the southern highlands (although recent work by Kaminga *et al*. (1989) in the nearby Thredbo Valley may now dispute this claim). These sites were mostly surface camp sites consisting of stone artefacts. Scarred trees, rock shelters, stone tool quarries and stone arrangements were also recorded. The combined evidence of these surveys suggests a long occupation of the area. Flood (1980) recorded a radiocarbon date for a basal deposit in a cave at Buchan on the Snowy River south of the study area, indicating occupation of the cave since 17,720 ± 840 B.P. In contrast she considered that the "Southern Uplands" were only effectively occupied 500-700 years ago after climatic warming to present conditions following the late Holocene.

The Ngarigo people occupied the study area up to the period of European invasion by graziers and squatters in the early 1830's. Numbers, which were never more than about 500 people, diminished rapidly after 1856 (Hancock, 1972). They diminished due to persecution, diseases and rapid dispossession of their lands. It has been stated that only two of the Ngarigo remained in 1886 only 50 years after first contact with Europeans of whom Biggenhook, the last full blood survivor, died in 1914 (Hancock, 1972). However mixed race descendants of the Aboriginal people of the Monaro and Snowy Mountains still live in communities on the Monaro Tableland and far South Coast (C. Griffiths pers. comm.). Their disappearance from the lower Snowy is not recorded but from the above evidence it seems likely to have occurred within one to two decades of the arrival of Europeans and may even have begun to occur in advance of the arrival of Europeans in the region due to epidemic spread of disease (Flood, 1980). This view is supported in the writings of Robinson who mentions that syphilis and other European diseases were prevalent in the Aboriginal population near Omeo and Cooma (Mackaness, 1941). He mentions that warring tribes killing each other in bloody battles was also taking its toll on the population. No mention of murder by Europeans, as occurred in other areas was found. However Kaminga *et al*. (1989) suggests that this may also have happened. According to Lhotsky (1835) the tribes were disintegrating in 1834, the time when the first Europeans entered the study area.

3.1.1 Aboriginal impact on the landscape

Flood (1980) found evidence that the Ngarigo did not set fire to the snow country (alpine and subalpine) on their summer migrations to feast on the plentiful supply of Bogong moths. No anecdotal or other evidence appears to be available to indicate the use of fire by Aborigines in the lower Snowy River Valley. It could be argued that there was evidence of firing of the vegetation implicit from the white cypress pine woodland structure as found in this study (see chapter 4) and from reports of early explorers such as Robinson (Mackaness, 1941). He described the landscape as an open woodland with large widely spaced white cypress pine trees. Lacey (1972) suggests that in the absence of rabbits white cypress pine more or less continually recruits seedlings, forming multi-aged stands. Thus open woodland of white cypress pine may have been promoted by occasional burning of ground cover (and thus white cypress pine seedlings) by people living in the lower Snowy Valley but not by fires occurring at high frequencies or at high intensities.

The observations and opinions of the early explorers, surveyors and officials such as Paul Strezelecki, Richard Helms (Hadley, 1915), T.S. Townsend and A.W.Howitt (Walker, 1971) on the Aboriginal use of fire were reviewed by Hancock (1972). These reports provide a confusing and inconclusive account of Aboriginal use of fire in the southern highlands. Many of the fires reported by the above were also attributed to the squatters, who in the words of Strezelecki, were ".... not improvers but spoilers of the land..." (Hancock, 1972). Hancock expresses the opinion that Aboriginals did not burn the alpine areas but certainly used fire in the forests at lower elevation. Recently, a palaeontologist Dr. G. Hope, has suggested that there is evidence of frequent fires caused by natural and human agencies indicated by high levels of charcoal particles in Holocene sediment cores from cirque lakes and bogs in the alpine and subalpine zones (Kaminga *et al.*, 1989). Further discussion on human use of fire and its role in these forests is presented in chapters 7 and 8.

3.2 History of European settlement and land use

The history of early European land use and landscape changes are poorly documented, although some data exist for example Banks (1982) and a few accounts such as Hancock (1972) which suggest factors likely to have brought about changes resulting from European occupation in the Australian Alps. This study therefore relies largely on evidence of past land use. This includes observations of changes in forest structure and composition of species, changes in the condition of streams or other natural phenomena, fire scarred trees, loss of topsoil, introduction of exotic plant and animal species, relics of grazing such as yards, fences, and old buildings.

3.2.1 Occupation of the Monaro and the study area

The Monaro Region was first explored and settled in the 1820's and 1830's. Prior to the formal establishment of the land administration system in the early 1840’s uncontrolled grazing commenced in the lower Snowy River area. Thus the framework for the registration of land title and the carrying out of land survey of the Monaro was established some 28 years after settlement had begun (Hancock, 1972). By 1840 the study area was part of the Monaro squattage district, and later the lower Snowy River formed the boundary of the new Counties of Wallace and Wellesley. Thus little was recorded of the early settlement in the lower Snowy River

Valley. It was not until 1848 that the three Monaro counties of Wellesley, Wallace and Beresford were gazetted.

Establishment of the first grazing runs

It appears that Richard Brooks, who occupied Gejedric (sic) also known as Gegedzerick station near Berridale in 1827, was the first to move cattle down to the lower Snowy River Valley in about 1834 (Stephenson, 1980; C. Allen, pers. comm.). Brooks occupied the Black Mountain - Suggan Buggan run near the NSW/Victorian border for a few years. Harnett (1948) suggested that grazing commenced in the area in 1832 but did not indicate who were the first graziers. The years 1832-34 roughly mark the commencement of the movement of people and stock from the Monaro via the study area to Omeo and Gippsland as well as the establishment of runs on the lower Snowy River.

One of the earliest remaining settlements near the study area was established at Black Mountain on the Wulgulmerang Plateau by James and Christopher O'Rourke in the 1840’s after the run was abandoned by Brooks (Stephenson, 1980). Suggan Buggan station was first selected by the O'Rourke's in 1838. An old adzed timber slab schoolhouse at Suggan Buggan built by O’Rourke (circa 1860’s) to educate his children serves as a reminder of the living conditions of the early settlers to the lower Snowy River Valley.

Another early run which had been established further up the valley was that of Amos Crisp who settled on “Jimen Buen” in 1836 (Hancock, 1972; Harris, 1929). His family owned at one time Jimen Buen, Ironmungie Matong and Springvale consisting of a 70 mile frontage to the lower Snowy River. Further evidence that grazing was well established by the 1840’s is provided by the 1842 maps and notebooks of Surveyor Townsend who indicated three “Heifer Stations” (sic) on the river bank between Paupong and Willis and the location of “Scotchy's Old Yards” and “Willis Yards” during his survey of the valley in 1842 (Harnett, 1948). The remains of “Scotchy's Yards” on the former “Willis run” which was occupied at the time by Brooks can still be seen next to the Barry Way 2.8 km from Willis on the NSW/Victorian border (Fig. 4.1).

By the time of Commissioner John Lambie’s Census and travels in 1840 the following squatter runs were established in the study area: Waugilmoran (probably Woologoramarang) occupied by Richard Brooks; Suggan Buggan - occupied by David P. O’Ridon (probably O’Rourke); Inchbyra owned by Rob Cunningham and Martin Hyland; and Biddi occupied by Thomas Barker and Richard Tilsey. Each are reported to have had 300-500 head of cattle, a hut, grew some wheat and all except Biddi run had yards (Government Gazettes; C. Allen pers. comm.).

Among the first “official” settlers along the lower Snowy River was William Whittakers who paid for a run on the Snowy River in 1839. Whittakers moved to Tombong in 1846 and 4 years later moved to Tubbut (40 km south west of Willis) and lived there for 20 years (Hancock, 1972). It appears that the only runs which were gazetted in 1848-1850 in the study area were Inchbyra (Ellen Woodhouse), Matong (Ben Boyd) and further up the river Jimen Buen (Amos Crisp)(see map 7 in Hancock, 1972). Thus most if not all of the land in the study area was taken up for grazing in the 1830’s and early 1840’s and the remainder, which includes the Pinch and two Ingeegoodbee runs, were “officially” taken up by the early 1870’s.

Stock routes

Most runs were not formally gazetted for 10-20 years after their establishment but it can be assumed that stock were moving and grazing through the study area on their way to and from Gippsland and the Monaro. For example, William Whittakers and Amos Crisp drove their cattle initially to market in Goulburn and later to markets in East Gippsland. Cattle were the predominate stock until the 1860's when sheep were introduced on the Monaro (Hancock, 1972). There were several stock routes through the study area to markets in Bairnsdale. These included the most important stock routes from the Monaro to East Gippsland. The earliest routes ran from Buckley's Crossing (Dalgety) through Ingebyra, down the Gulph Crossing at Biddi then either across to Willis behind Pinch Mountain or down the Snowy River and then up the Nine Mile and across to Victoria. From Willis the route extended to Buchan (C. Allen pers. comm.). A later route went down Jacob's Ladder to the Snowy River at Biddi and down to Willis. Another variant included Jacob's ladder then along the Snowy River and up the Nine Mile Pinch possibly to avoid the Customs house at Willis.

The Customs Post and yards were built in about 1870 and operated by Hector R. Mackenzie at Willis on the NSW/Victorian border. He collected taxes for the Victorian Government for passage of stock into East Gippsland from the Monaro (Perkins, undated). A few years later he moved to Black Mountain Station where the taxes continued to be collected (Stephenson, 1980). No structure associated with the Customs Post remains today other than some remnants of the yards and other archaeological evidence (C. Allen pers. comm.). These buildings and yards were constructed of local timber and are likely to have taken a substantial toll locally particularly on the larger old growth white cypress pine.

When the feed in the lower Snowy was poor cattle were often taken up to the Ingeegoodbee flats and head-water areas of the Pinch River by stockmen such as Bill Pendergast before being taken down to Suggan

Buggan (Wellsmore, 1986). This practice occurred more frequently after the

1920's when the damaging effects of rabbits on pasture had been experienced for 20 years (Rogers, 1987). During cattle drives many cattle were lost and wild cattle, often referred to as 'stragglers', roamed freely through the area.

Although the valley had been used as a stock route for many years the first official stock route in the area was gazetted in 1883. It was TSR 642, an area of 4 square miles on the west side of the Snowy River. TSR 812 at the Pinch River, the Jacobs Ladder route to the Snowy River and TSR 22198 from Pinch River to the border were gazetted in 1895 (Government Gazettes). These have since been cancelled.

3.2.2 Early observations on the impacts of grazing

William Crisp, a son of Amos Crisp of Paupong, recorded that prior to the passing of the Robertson Land Act in 1861, Matong Creek above and below its junction with Jimenbuan Creek "... was a succession of deep water holes ..." (Hancock, 1972). Crisp stated that five years later the river was silted up, caused by soil erosion. During this period the best grasses for cattle disappeared and these were replaced by finer, less nourishing grass. The coarse grass was probably kangaroo grass *Themeda australis* and the finer grass *Poa spp*. or *Stipa spp*. It is worthwhile to further quote William Crisp from Hancock (1972) who had access to his letters.

> "Trampling by stock damaged the grass, laid bare the soil and changed the quiet stream into a deeply incised water-course bone dry except after exceptionally heavy rain when a rush of water scoured the banks and braided the bed of the creek."

Most tributary watercourses in the study area fit this description today. Crisp's observations of changes in the condition of the land due to European land use are credible because much of this part of Kosciusko National Park still bears the scars of soil erosion and shows considerable changes to plant communities (Costin, 1954; Worboys, 1982; Clayton-Greene and Ashton, 1990 and pers. obs.).

3.2.3 Other evidence and reports of past land use

Relics of the grazing era

The most obvious relics of the grazing era are a number of old yards such as Scotchy's (Scotchies) yard built of white cypress pine logs on the Barry Way which date from Brooks' occupation in the 1830's. (Harris, 1929) refers to the diaries of a man who worked for Crisp at Jimenbuan in 1835 who claimed to have built some yards for Crisp (who possibly was in association with Brooks) at Mount Trooper. Others yards include Willis, several over the Victorian border such as at Guttamurh, on the Willis run and at the Pinch River junction with the Snowy River and the Jacobs River near the Barry Way bridge.

During the grazing era very few fences were erected. Although runs were often registered in an individual's name, local informants suggest that some graziers did not recognise run or lease boundaries but rather ran their cattle over substantial areas (Wellsmore, 1986). In such circumstances a cattleman would only have an approximate idea of the number of stock he owned. The best preserved of the relatively few fences constructed in this era is an unusual timber fence which runs over a saddle near the summit and onto the lower slopes of Mount Trooper. No wire or nails were used in the construction and it consumed hundreds if not thousands of white cypress pines (Plate 3.1 and Fig. 3.1). The fence was built at the turn of the century (Stephenson, 1980) by Ned Williams as a "Bull Paddock" (Wellsmore, 1986) or a mustering paddock. It was used by the Williams' and Woodhouses' for holding wild unbranded cattle. The fence has in subsequent years collapsed and partially decayed and although flammable it had not been burnt prior to this study.

Clearing and ring barking

Some parts of the valley in the study area were ring barked as part of the conditions of the lease. Signs of such clearing can be seen on the ridge known as Jacobs Ladder. Some ring barking was carried out between the Pinch and Jacobs River in 1905 (Anon., 1971). In most places this must have been fairly selective or the evidence has been removed by subsequent fires and regeneration.

Snow leases

A system of snow leases which operated in the NSW section of the Australian Alps until 29th May 1969, was introduced by the NSW Government in 1889 by the amendment of 1884 Land Act. Snow leases provided for transhumant grazing of the alpine and subalpine areas during summer. Areas such as the lower Snowy River would have been grazed all year round and provided a winter refuge for stock. Some snow leases extended from the lower Snowy River Valley up to the high elevation subalpine providing for varied pasture conditions which could be utilised as the seasons demanded. Initially there was resistance by the occupiers to take up the snow leases or other forms of tenancies offered by the Lands Department because up to this time grazing had been free (Hancock, 1972). In general it appears from Hancock's comments that the use of leases for the most part was fairly free and easy with considerable poaching of one and another's pastures.

Prospecting

The first prospecting in the area was carried out by prospectors on their way to the Omeo gold diggings. The Rev. W.B. Clarke found traces of gold in the lower Snowy River Valley at the Jacobs and Pinch Rivers (Clarke, 1860). In 1897 the Border prospecting party reported earlier prospecting in the study area and found evidence of copper below Mount Trooper. The signs of this excavation are still evident (C. Allen pers. comm.). In 1961 the Jacobs River copper prospect was worked briefly. Both here and throughout the Monaro Tableland last century prospectors used fire to expose the ground to make it easier to find minerals (Banks, 1989; Jacobs, 1963) and are likely to have done so in the white cypress pine communities causing additional tree losses and soil erosion.

Cropping, logging and hunting

Small areas of cereal crops such as wheat or oats were grown occasionally on the fertile alluvial flats. Some limited sawmilling of white cypress pine possibly occurred near the Jacobs River. The Bald Hills trail to Jacobs River was built for timber extraction (C. Allen pers. comm.). The weathered cut stump of a large white cypress pine which may date to this era was found near Willis study site 2. Some white box was cut for fence posts in the 1960's (Golby, 1988).

Early this century and up until the 1960's trapping possums for skins was carried out in the study area. Other species likely to have been hunted include rabbits, foxes, horses and occasionally kangaroos (G. Byrne pers. comm.).

3.2.4 Introduced species

Rabbits

Wild-type rabbits were first successfully introduced in 1859 to the Australian mainland near Geelong in Victoria (Rolls, 1977; Stoddart and Parer, 1988). The spread of rabbits and their impact on the ecology and economy of southern Australia have been extensively documented by Rolls and many others. Most studies on the history and impact of rabbits on *Callitris* communities have been conducted in areas west of the Great Dividing Range (Johnston, 1969; Jones, 1963; Lacey, 1973; Rolls, 1977; Rolls, 1981; Stoddart and Parer, 1988) but little if any work has been carried out on this question on stands east of the Divide.

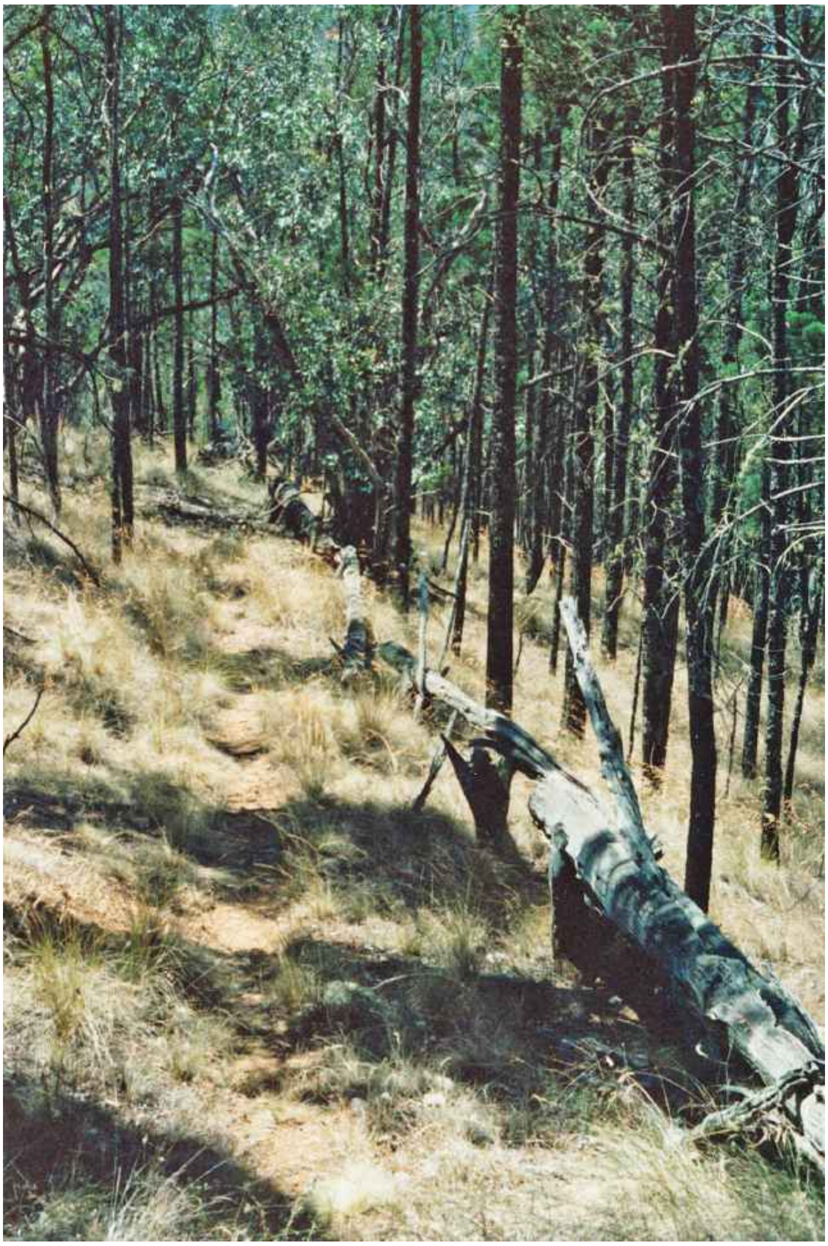


Plate 3.1 Remnants of an old timber fence around Mount Trooper built before c1900 which was constructed of white box supports and white cypress pine rails. No other materials were used in construction. The existence of the fence is evidence that fire has not burnt these slopes this century.

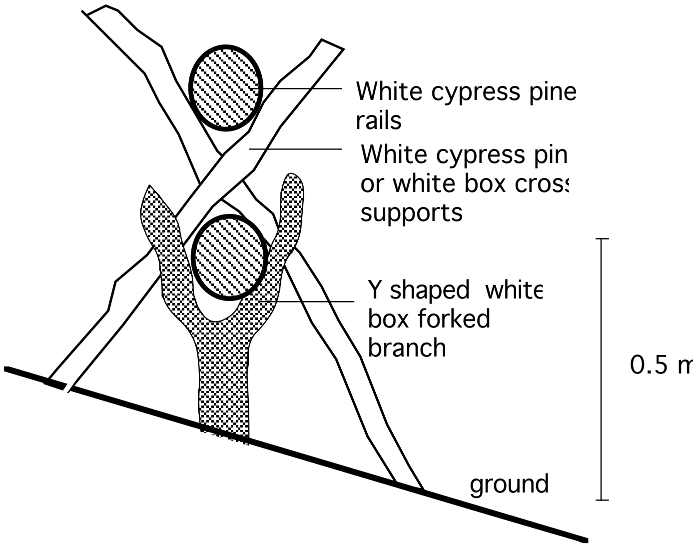


Figure 3.1 Diagram of the unusual construction of the "bull paddock" fence around Mt. Trooper. This fence consumed hundreds of the old growth woodland white cypress pine trees on the slopes of Mount Trooper and may have been used to hold wild cattle after muster. Termite attack of white box components may have caused collapse of the fence.

In the 1880's to the early 1900's rabbits spread rapidly across the Monaro (Platts, 1989; Stoddart and Parer, 1988). The following are examples of early reports for locations near the study area. On Thursday 28th October 1897, the minutes of the Gippsland Rabbit Suppression League record that 300 rabbits were killed at Swifts Creek to the south-east of the study area. The first sightings of rabbits at Cathcart to the south of the study area, were at "Glenvale" in 1898 (Platts, 1989). By 1899 rabbits were entering Orbost Shire south of the study area. On 24th September 1900 the Cooma Express reported: "Rabbits are rapidly spreading in the vicinity of Cooma." ie north of the study area. Large numbers of hares were often reported a few years prior to and during the arrival of rabbits. Hare numbers then declined to very low numbers after rabbits became permanently established. Large numbers of hares were killed in organised drives in the region. For instance during a hare drive at Tom Groggin on August 16, 1901, 53 hares, 2 rabbits and a few wallabies were killed. On 7th June 1903, the Cooma Express quoted Mr. Wright of Tombong, who reported the presence of rabbits on the banks of the Snowy River. He said that after an initial rise in rabbit numbers there was a decline compared with a few months previously, and that one could ride all day without seeing more than a few rabbits. From these accounts in source material collected by Stoddart and Parer (1988) from newspapers and other records (Wakefield, 1970) there is strong evidence that rabbits established in the lower Snowy River by 1900 or possibly a little earlier and they rapidly built to plague proportions as they did elsewhere in eastern Australia. For example, Harnett (1948) commented that: "The rabbits came in 1900 and now in the very best of seasons I see only corkscrew grass and the odd thistle" in the lower Snowy River Valley.

Historically rabbit numbers have fluctuated considerably and occasionally reached plague proportions in the lower Snowy River Valley (Wakefield, 1970). O. Wellsmore (1986) a Paupong landholder, recalls a rabbit plague in 1914-15 following favourable seasons and J.K. Rogers (1987) of Black Mountain stated: "...rabbits were bad on the Snowy and Ingeegoodbee.." areas during the period 1923 to 1930. During field work in the lower Snowy Valley from 1979-1982, rabbits were visible on the slopes and river flats in any part of the study area at any time of the day (K. Geering pers. comm.; K. Clayton-Greene pers. comm.).

Rabbit numbers would have fluctuated as the natural controls of drought, fires and food supply regulated their numbers. The carrying capacity of the area for rabbits would have diminished as widespread sheet and gully erosion progressed. The carrying capacity of the area for stock was decreased to about one-tenth its previous level (Wakefield, 1970) after the rabbits denuded the ground. The response of plant communities to reduced rabbit grazing in the study area following the release of Myxoma virus in Australia in 1952 is not known. Wakefield (1970) suggested that in some areas near Suggan Buggan significant survival of white cypress pine seedlings occurred. It is possible that rabbits in this remote area were not as significantly affected by the disease or have become resistant to some strains since its release. Rabbit numbers were again particularly high during the late 1970's and early 1980's in the study area when the Victorian Department of Conservation Forests and Lands released Myxoma virus in the lower Snowy Valley south of the study area at McKillops Bridge, Campbells Knobs and Gattamurrh Creek in 1980 and 1983. The "Louisiana" strain of the virus was inoculated into young trapped rabbits and the rabbit flea was released at the same time (Smith, 1986). Rabbit numbers since 1983 have been low throughout the study area (pers. obs.).

Wellsmore (1986) found many dead rabbits at Paupong 7-8 years ago (1982-83) which coincides with the above release. He considered that rabbit numbers had never been lower in the area than from 1982-83 to 1986.

The impact of rabbits on *Callitris* communities is caused mainly by grazing of understorey plants and browsing of seedlings preventing the normal recruitment of stands (Johnston, 1969; Lacey, 1972). In the study area rabbit grazing may have resulted in episodic recruitment particularly on the hot aspect sites and more continuous recruitment on cool aspect sites (Clayton-Greene and Ashton, 1990). In 1979-81 when rabbits reached high numbers, they removed much of the ground cover, gnawed bark off white box stems and chewed saplings, occasionally ring barking white box trees (K. Geering pers. comm.). Photographs and an account published by Costin (1954) indicate widespread areas of bare eroding soil in the white cypress pine stands which he attributed to rabbit grazing.

Other introduced mammal species (horses, deer, goats, wild dogs, foxes and cats)

Other introduced mammals have had a lesser impact on the white cypress pine communities than rabbits. Feral horses have roamed the area since the early days of settlement and remain in relatively low numbers in the low country whilst larger populations occur at higher elevations in the Pilot wilderness today (Dyring, 1990; pers. obs.). During the last drought in 1981-82 150 dead brumbies were counted along the Snowy River and slopes over a 5 months period (K. Geering pers. comm.). Many of these animals moved down from higher elevations to be near reliable water, but they starved to death because of the lack of feed. The major obvious impact from horses is the presence of eroding brumby trails (which are also used by macropods, wombats, dogs and foxes) and occasional dust wallows on most ridge lines, disturbed stream banks, occasional dung piles and white box trees scarred by brumbies who chew the bark particularly in drought times. Other impacts include the selective removal of palatable plants which contributes to further reducing the ground cover.

Occasional sightings of red deer *Cervus elaphus* have been made in the Quidong area of the Snowy River Valley near the study area (C. Griffiths pers. comm.; C. Allen pers. comm.) There is anecdotal evidence that fallow deer *Dama dama* may also be present, although this has not been confirmed (J. Dunn pers. comm.). Sambar deer *Cervus unicolor* may possibly pass through the area but resident populations are unlikely to occur in the white cypress pine habitats (J. Dunn pers. comm.; Dunn, 1980). This extremely shy solitary species is sighted infrequently in Kosciusko National Park. The impact on vegetation from these species is likely to be small due to relatively low numbers.

The population of a small colony of goats near Mulligans Mountain is regularly reduced by the National Parks and Wildlife Service. The area of their impact on vegetation is therefore restricted.

Wild dogs and dingoes are the only large predator and are subject to control programmes along the park perimeter to protect neighbour's sheep from attack. Foxes and cats are common but not under any management control. These species have only an indirect and limited effect on vegetation.

Introduced plants

The riparian habitats along the Snowy River are heavily infested with a wide variety of introduced plant species. Over 210 species have been recorded in the central regions of Kosciusko National Park (Mallen-Cooper, 1990) and at least this number are likely to occur in the lower Snowy River (J. Mallen-Cooper pers. comm.). The willow *Salix babylonica* dominates the frequently flooded river flats and river banks. The number of introduced plant species diminishes rapidly with distance from the river. A number of small grasses and forbs persist particularly on the more disturbed north facing sites and ridge lines (pers. obs.). Many species may have been introduced during the grazing era. Other species, particularly those colonising the river banks, are likely to have been transported downstream by the Snowy River which re-enters the Park after traversing agricultural lands. Further more recent plant introductions have followed the disturbed road corridor of the Barry Way opened in 1961. The presence of such large numbers of introduced plant species suggests the existence of a highly disturbed ecosystem with an abundance of niches suitable for the establishment of such species (Costin, 1954; Mallen-Cooper, 1990).

3.3 Effects of European land use

3.3.1 Impact of land use on the vegetation

Little has been recorded of observations of changes in vegetation or environment since European settlement. The most useful observations of the study area were recorded by C.J. Harnett (1948) in a letter to A.B. Costin, the Soil Conservation Officer at Cooma at that time.

> "The old stockmen told me that the Willis was 'good' until the young pine came like wheat in 1878, before that there were only large trees and in 1935 I saw only about a dozen of these, mostly dead but some 2'6" in diameter - the young pine extends to the 2000 ft. contour and has now thinned out, but it killed all the grasses and clovers and the topsoil then washed away except on a thin fairly level patch to east of top of Pinch Mt."

Costin (1954) described the alliance at that time as containing dense even aged regrowth secondary scrub of white cypress pine with bare eroded soils and large numbers of introduced plants. Except for the removal of cattle from the area it appears that little has changed in this community during the last 36 years (pers. obs.).

3.3.2 Soil erosion

Widespread soil erosion in the white cypress pine - white box alliance has been described by Costin (1954), Clayton-Greene (1981) and Worboys (1982). Gully erosion has occurred in most ephemeral stream beds. Sheet erosion has resulted in the loss of topsoil and in many places the removal of both the A and B soil horizons (Clayton-Greene, 1981). The worst affected sites are the dry north facing sites where there is usually less herbaceous cover to bind soils. The extent of erosion prompted Costin (1954) to recommend a policy of fire prevention and rabbit eradication,

> "...the latter having assumed such proportions that State intervention would appear to be necessary."

As elsewhere in Australia soil erosion was considered by Costin (1954) to be caused by severe overgrazing practices, hard-hoofed animals churning up the soft loose soils, burning and the rabbits removing the herbaceous vegetation followed by floods or heavy rains.

A feature which may be important in preventing soil erosion and stabilizing the soil surface which has not been previously reported, are the dense firm mats of mosses and possibly lichens which occupy the soil surface inter-tussock spaces on all but the most disturbed sites. These moss mats are easily broken by animal or human traffic and would have been severely damaged by cattle and horse traffic during the grazing era. They appear to be an important feature in maintaining catchment stability by preventing soil erosion caused by rain splash and sheet wash (pers. obs.).

These fragile living mats may perform a vital soil binding role similar to the fragile cryptogramic soils found in some arid areas in North America.

3.4 Management by the National Parks and Wildlife Service

The area to the west of the Snowy River from Willis to above Wallace Craigie Lookout, known as the Pilot Wilderness, was proclaimed as National Park under the Kosciusko State Park Act in 1944. The whole study area was proclaimed under the National Parks and Wildlife Act, 1967 and the remainder of the Byadbo Wilderness, to the east of the study area added to Kosciusko National Park in 1970.

Grazing of cattle and sheep was prohibited west of the Snowy River in 1961 and east of the Snowy River in 1967. Occasional small groups of cattle strayed into the area or were illegally introduced into the park, particularly during droughts for some years. A stock route is provided along the Barry Way but has been rarely used in the past 15 years. Other management policies which have been implemented include the suppression of all fires. No fuel hazard reduction burning is carried out in the white cypress pine - white box alliance in accordance with Costin’s (1954) recommendations.

Since becoming National Park the major causes of disturbance of the area have been removed but the question remains as to whether the ecosystems are recovering or still undergoing processes of degradation initiated during the grazing era.

Part II

Field and laboratory

Chapter 4 Changes in forest structure

4.1 Introduction

Historical evidence (Chap. 1) described the lower Snowy River white cypress pine - white box alliance as open woodland with a grassy understorey and scattered shrubs prior to and during the early phase of European settlement of the study area (Mackaness, 1941; Wellsmore, 1986). Extensive stands of dense regrowth of white cypress pine are reported to have established since European settlement in the lower Snowy River Valley (Clayton-Greene, 1981; Costin, 1954; Harnett, 1948; Wellsmore, 1986) and throughout western NSW (Horne and Robinson, 1987; Johnston, 1969; Lacey, 1972).

Clayton-Greene (1981) investigated spatial patterning in the present day white cypress pine woodland at Savernake (west of Albury) and the lower Snowy River by constructing profiles of the distribution of white cypress pine along transects. Whilst detailed work was carried out on many aspects of the autecology of the alliance no attempt was made to reconstruct the pre-European condition of these communities. I therefore aimed to document evidence of tree sizes, density and crown cover for the forest structure prior to the commencement of European land use practices and compare and contrast this structure with that existing today.

4.2 Methods

Three transect sites were selected on the western side of the Snowy River. These contained what appeared to consist of two distinct age/diameter/height classes of white cypress pine and white box. Dense stands of narrow crowned regrowth white cypress pine were interspersed with mostly dead emergent old growth trees with wide spreading branches. A priori criteria were established to distinguish old growth woodland trees from regrowth. Old growth woodland white cypress pine trees had mostly large diameter boles, heavy spreading branches and light coloured, thick, fissured bark. Most were dead. Some trees were fire scarred but none had charred bark. Regrowth trees typically had relatively narrow crowns, were conical, lightly branched with a small diameter at breast height over bark (d.b.h.o.b.) and dark bark. Differences between large and small white box trees were less pronounced and trees with a d.b.h.o.b. greater than 35 cm were classed as old growth woodland trees and smaller trees as regrowth since European settlement. This criterion was based on the typically larger spreading crowns of trees greater than 35 cm which were often multiple stemmed and clearly older mature trees. This assessment was also based on growth rate estimates of white box (Dr. R. Florence and Dr. J. Banks pers. comm.) which were most probably established mature trees of variable age when the first Europeans settled the area in the mid 1830's and 1840's.

Sampling sites were selected on slopes containing both old growth woodland and younger regrowth trees. Three transects of 490 m, 270 m, 930 m in length were set out. These were perpendicular to the prevailing direction of the long east-west ridges, which descend from the surrounding high country into the Snowy River Valley, to include contrasting north and south facing slopes (Fig. 4.1).

Two sampling strategies were used. Old growth trees within 30 m each side of the transect centre line were mapped on graph paper. Tree species, tree condition (dead or alive), number of fire scars, d.b.h.o.b. and notable site features such as gullies, creek lines and ridges or old fallen trees were mapped or recorded. The number of stems and the d.b.h.o.b. of the largest stem were recorded for the multi-stemmed white box trees.

For the regrowth trees, the number of individuals greater than 2 m high in 5 cm d.b.h.o.b. increment classes were recorded in 5 x 10 m contiguous plots, i.e. 5 m either side of the transect centre line. The height of individual white cypress pine seedlings less than 2 m high and position of clumps of white box seedlings were recorded. The belt transect design for field data collection is presented in Figure 4.2.

4.3 Analysis

The transect data were analysed as follows.

4.3.1 Tree density, stem diameter and basal area

Mapped data were coded and entered into a computer database for analysis. Density, d.b.h.o.b. and basal area were calculated for four tree classes using the criteria described above. The classes were:

(a) low density woodland represented by the mostly dead old growth woodland white cypress pine stags, a few live white cypress pine with heavy wide spreading branches and occasional live old growth white box;

(b) low density woodland represented by live old growth woodland white box with d.b.h.o.b. >= 35 cm;

(c) and (d) high density regrowth white cypress pine and white box respectively.

Density of each class was calculated from the number of stems occurring in each 10 x 60 m section along the transect in the case of old growth woodland trees and 5 x 10 m section along the transect for regrowth. Basal area was calculated for both species of old growth woodland trees for each aspect class transect section.

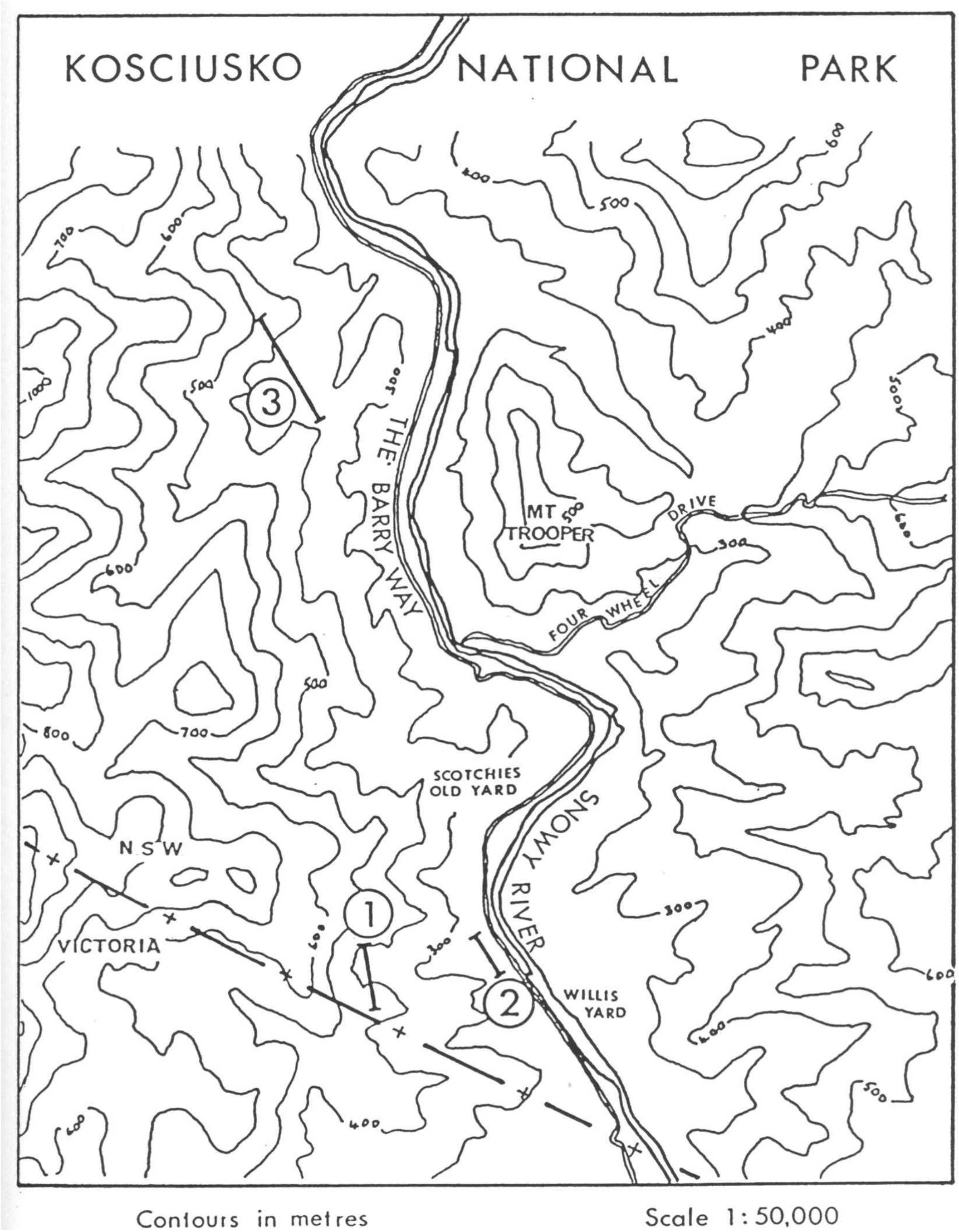


Figure 4.1 Location of tree transects 1, 2 and 3 in the lower Snowy River Valley of Kosciusko National Park.

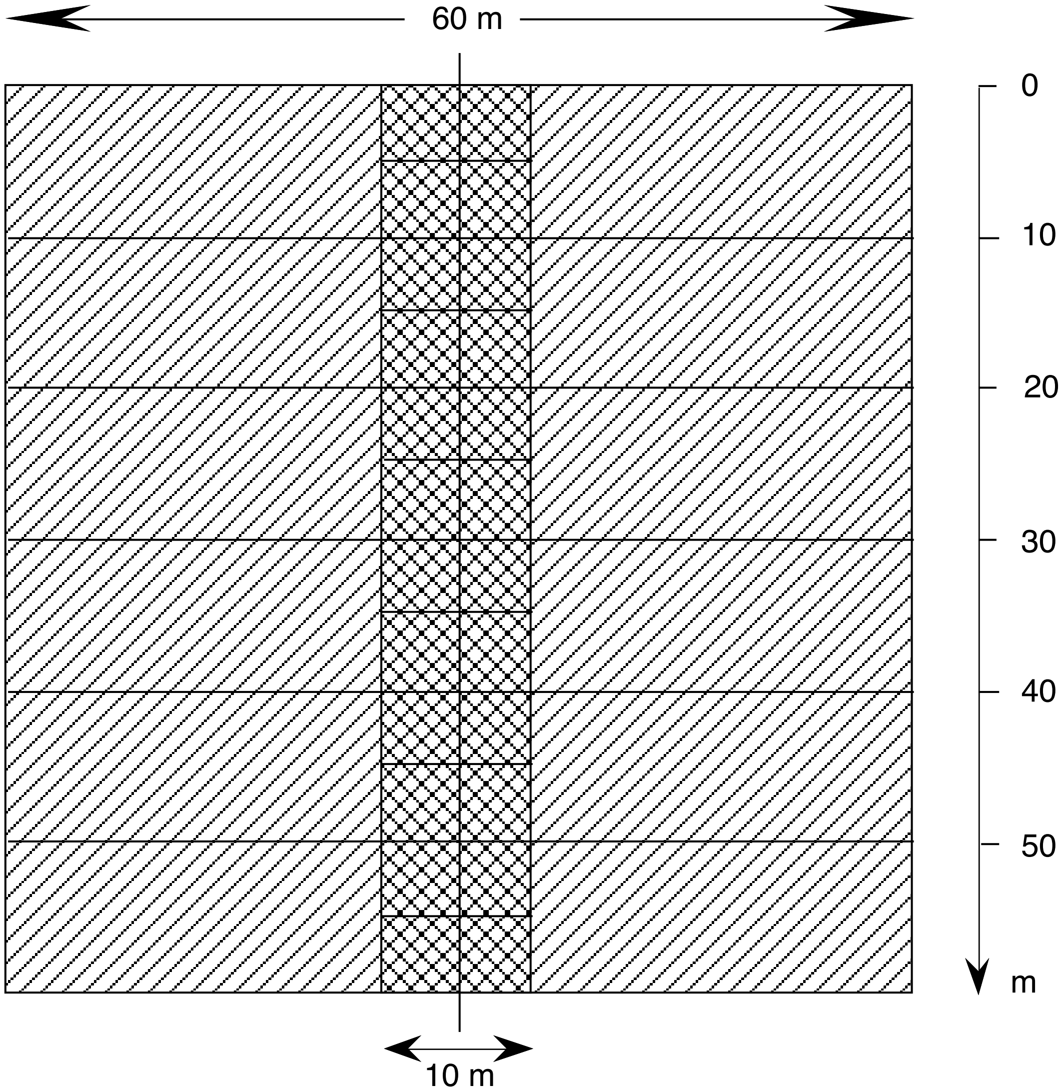
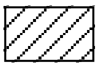
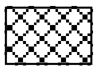


Figure 4.2 Belt transect showing the contiguous plot layout for field data collection.

 10 x 60 m plot for recording species, tree number and position of old growth trees.

 5 x 10 m plots for recording the tree species and number of trees in 5 cm diameter increment classes of regrowth trees up to 30-35 cm dbh.

4.3.2 Estimation of projected tree crown cover

In this study the terms crown cover projection and crown cover percentage are defined as the projection of the area covered by foliage as a percentage of the total area estimated by the ratio of the crown diameter to bole diameter.

Projective foliage cover, i.e. the percentage of area covered by foliage measured by a vertical point quadrat technique (Specht, 1970), is conventionally applied to estimates of crown cover. Direct field measurement of crown cover is time consuming and in this study many of the old trees had lost most branches making the task more difficult. An alternative method was therefore used. For a given species crown diameter and breast height diameter of a tree bole are closely correlated (Philip, 1983). The crown diameter can therefore be predicted from measurement of bole diameter with reasonable precision thus eliminating the need for measuring crown diameter in the field. The crown width/d.b.h.o.b. ratio (K/d ratio), (Husch *et al*. 1982) or crown ratio (Jacobs, 1955) can then be used to calculate crown cover projection as distinct from projective foliage cover (Specht, 1970) provided the K/d ratio for a given species is known or can be reasonably estimated. Curtin (1962) estimated a K/d ratio of 21 for *Eucalyptus obliqua* in open stands. To obtain estimates for these species it was assumed that *E. albens*, whilst not as tall as *E. obliqua* has a general morphology similar to *E. obliqua* when growing in open stands. A K/d ratio of 20 was adopted for white box growing in open woodland.

No published K/d ratio for *C. glaucophylla* was available. Jacobs (1955) suggested a crown ratio of 15 for Eucalypts growing in closed canopy conditions. The morphology of white cypress pine suggests that its crown ratio is likely to be smaller than Eucalypts growing in close conditions. The crown width of white cypress pine is approximately half the width of white box in open conditions for stems of similar diameter (pers. obs.; Dr. J. Banks pers. comm., Dr. R. Florence pers. comm.). Thus, after careful consideration, a K/d ratio of 10 was adopted for white cypress pine growing in previously open conditions. These above values take into account the different growth habits of respective species.

It was assumed that no substantial diameter increment to old growth woodland trees had occurred since the mid to late 19th century. Any overall stem diameter or basal area increase may have been approximately balanced by loss of some standing trees. To gain an impression of the number lost in this way dead and down specimens were recorded however this does not account for trees which have disappeared.

Using the above K/d ratios and the measured d.b.h.o.b., the crown diameter for each old growth woodland tree was calculated. Crown cover was estimated using the formula $C = \pi r^2$, where C = crown cover area and r = crown radius, determined from the K/d ratio.

Crown cover percentages were calculated for old growth woodland white cypress pine and white box and regrowth white cypress pine on the two major aspect groups on each transect. These were classified as hot/dry for north and north-west aspects, and cool/moist for south and south-east aspects. Within each aspect class, trees were grouped into 5 cm diameter mid-point classes and projected crown cover calculated for each tree d.b.h.o.b. class.

Thus crown cover (CC) for d.b.h.o.b. class *(a)* for species x on aspect i was defined by:

$$CC_{d.b.h.o.b.\ (a)xi} = \{(A*K/d_i) \ / \ 2\}^2 * \pi * N_{(a)i} \qquad \{\mathrm{m}^2\}$$

where $CC_{d.b.h.o.b.\,(a)xi}$ is the crown cover for d.b.h.o.b. class *(a)* for species *x* on aspect *i* in m^2 and *A* is the value of the d.b.h.o.b. class *(a)* in m;

K/d_i is the K/d ratio for species *x;*

$N_{(a)i}$ is the number of trees in d.b.h.o.b. class *(a)* on aspect *i* (Husch *et al*. 1982).

Crown cover percentage was calculated for each species on each aspect as:

$$CCP_{xi} = [\sum_{a=1}^{a=n} CC_{dbh(a)xi} \div SA_i] * 100 \qquad \{\%\}$$

where CCP_{xi} is the crown cover percentage for species *x* on aspect *i* in %;

$CC_{d.b.h.o.b.(a)}$ is the crown cover for species *x* for d.b.h.o.b. classes for species *x* in m^2;

SA_i is the surface area of aspect *i* in m^2.

Total crown cover for each species and each aspect was calculated by adding the crown covers for each d.b.h.o.b., species and aspect class. The total crown cover percentage was calculated by dividing the total cover of each aspect/species class by the aspect area expressed as a percentage.

Weighted averages were calculated for the crown cover percentage for each aspect group because there were different proportions of each aspect in each transect. The weighted average (WA) per species x for each group *g* of aspects *i* was calculated as follows:

$$WA_{x\,g} = [\sum_{i=1}^{i=n}(CCP_{xi} * L_i)] \div \sum_{i=1}^{i=n} L_i \qquad \{\%\}$$

where n is the number of aspects in group g and L_i is the length of aspect i in metres. That is the weighted average crown cover percentages were calculated by dividing each of the two aspect total crown cover percentages by the length of the aspect segments from which they were first derived.

A total weighted average crown cover percentage for old growth woodland white cypress pine - white box and regrowth white cypress pine was calculated by multiplying the values for the two aspect classes and dividing by total transect length. The above calculations were used to prepare a crown cover projection map illustrating the projected crown cover of each old growth woodland tree of each species on each transect.

4.4 Results

4.4.1 Tree stem density and live/dead stem ratio

A comparison of the stand density of (1) old growth white cypress pine and white box woodland and (2) regrowth white cypress pine and white box forest for (a) cool and (b) hot aspect slopes is presented in Table 4.1 and Figures 4.3 to 4.5. Old growth woodland white cypress pine was found almost exclusively on hot aspect slopes with a mean stand density of 30.3 (3.9-58.3) stems ha^{-1}. Regrowth white cypress pine density on hot aspect slopes was the highest of the two aspect groups investigated. Mean density of regrowth white cypress pine was 2,609.8 (2,266.0-3,105.0) stems ha^{-1}. In contrast white box mean stem density for this aspect was low both for old growth woodland 9.0 (4.6-14.7) and regrowth 95.0 (44.4-192.2) stems ha^{-1} (Table 4.1). This community was characterised by dense stands of small diameter white cypress pine with scattered old growth woodland white cypress pine and white box (Plate 4.1).

On cool south aspect slopes old growth woodland white cypress pine was virtually non-existent, with only a few stems appearing on the lower elevation section of transect 3. In general these south aspect slopes contained no old growth woodland white cypress pine, whilst regrowth occurred in varying densities from very low, 24.0 ha^{-1} at upper elevations (400-480 m) to 3,988.9 ha^{-1} on a low protected site on transect 3. High densities at this location are probably due to the proximity to adjacent north facing slopes containing seed trees which could be blown by wind onto the favourable lower inter-gully ridge (Fig. 4.5). On the long steeper south facing slopes, regrowth white cypress pine densities of 1,000 stems ha^{-1} or less were predominant, in contrast with 2,609.8 stems ha^{-1} on hot dry aspects. Both old growth and regrowth white box achieved higher densities on the cool aspect than the hot aspect slopes (Table 4.1).

Comparison of the number of dead old growth woodland trees with fire scars, the total number of old growth trees and the live/dead stem ratios for north and south aspect slopes on each transect section was made. Many of the old growth woodland trees were stags, i.e. dead standing stems, with an occasional tree collapsed on the ground. Whilst many of the old trees and stumps remain over wide areas in the study area, an unknown number may have disappeared since the commencement of European activity. The majority of standing dead trees with fire scars were old growth woodland white cypress pine on hot dry north aspect slopes. White cypress pine had a mean live/dead stem ratio of 0.4 (0.3-0.5) on these northerly slopes. In old growth woodland white box the mean ratio of live to dead stems on north aspect slopes was 5.1 (2.3-8.0) and south aspect slopes 5.3 (0.0-15.0). This suggests that old growth woodland white cypress pine experienced greater mortality than white box (Table 4.2).

4.4.2 Stem diameter and basal area

The mean d.b.h.o.b. and basal areas for old growth woodland species for each transect section by aspect were calculated (Table 4.3). D.b.h.o.b. and basal area for regrowth trees were not recorded. Instead useful comparisons of stem densities for old growth woodland from this study were made with Clayton-Greene's (1981) results which included both regrowth and old growth woodland trees in his analysis of mean stem diameter (Table 4.4).

Old growth woodland white cypress pine on hot-dry sites had relatively smaller mean stem diameters (d.b.h.o.b.) but greater basal area than white box reflecting the higher density of white cypress pine (Table 4.3). Comparison of these results with those of (Clayton-Greene, 1981) for the whole forest shows that the proportional dominance of each species on each aspect has not changed, despite a considerable increase in stem density.

4.4.3 Crown cover

Crown cover projection maps illustrate the pattern and distribution of old growth woodland white cypress pine and white box as they may have appeared prior to and during the early period of the introduction of European land use practices (Figs. 4.6 to 4.8).

On hot dry slopes old white cypress pine had a projected crown cover percentage of 3.1% and white box 5.4%, in contrast to regrowth white cypress pine which had 19% cover. On cool moist aspects mean crown cover for old growth woodland white cypress pine was 0.1% and white box 18.3%. On these aspects white cypress pine had increased its cover to 8.9%. The increase in crown cover from regrowth white cypress pine on moist slopes was highly variable (1.5%-23.7%) (Table 4.5).

4.4.4 Trees with fire scars

On high southerly aspects the most common dead trees with fire scars were white box (Table 4.2). Most dead trees with fire scars on northerly aspects were white cypress pine. Between 12% and 44% of the dead old growth woodland white cypress pine trees on hot-dry north facing aspects displayed fire scars. Some trees had 4 or more visible overlapping fire scars. Fire scars on white cypress pine were mostly located on the uphill side of trees, giving some indication of the direction of fire spread.

Five fire scarred live white box were recorded on hot aspect slopes. The majority of white box were live trees which lacked visible fire scars. The highest incidence of fire scarred white box trees occurred at higher elevations (360-490 m A.S.L.) on cool moist south facing slopes with between 67% and 75% of old growth woodland live and dead white box displaying fire scars. No regrowth white cypress pine and very few regrowth white box exhibited fire scars.

Plate 4.1 (a) & (b) Dense regrowth white cypress pine on a hot north facing slope in the vicinity of transect 1. The understorey consists mainly of scattered *Acacia amoema* shrubs, sparse *Poa spp*. and *Themeda spp*. grasses. The presence of large numbers of exposed rocks indicates high levels of soil loss. A typical dead old growth white cypress pine with thick light coloured bark and exposed roots is in the foreground.

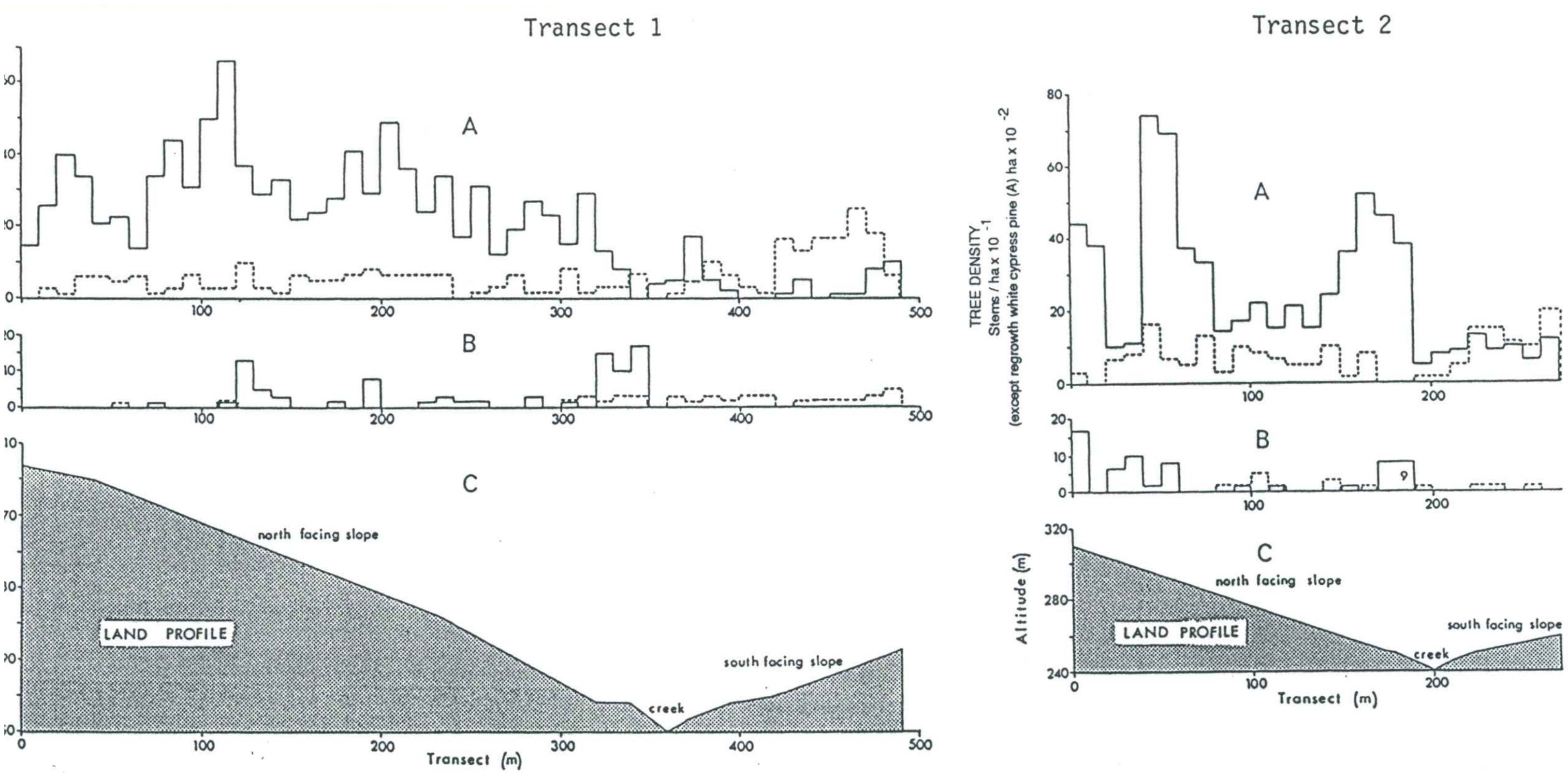
Plate 4.2 Hot north facing slope of transect 1 showing dense regrowth white cypress pine around a fire scarred dead old growth woodland white cypress pine. Note wide spreading branches indicating that this tree developed under more open conditions.

Plate 4.3 Cool south facing lower slopes at about 200 m on transect 2 showing relatively moderate density regrowth white cypress pine and white box. Note the absence of shrubs and good cover of grasses.

Plate 4.4 Cool south facing slope at 700-750 m along transect 3 (390 m elevation) showing an old growth white box (left foreground) and low density regrowth woodland.

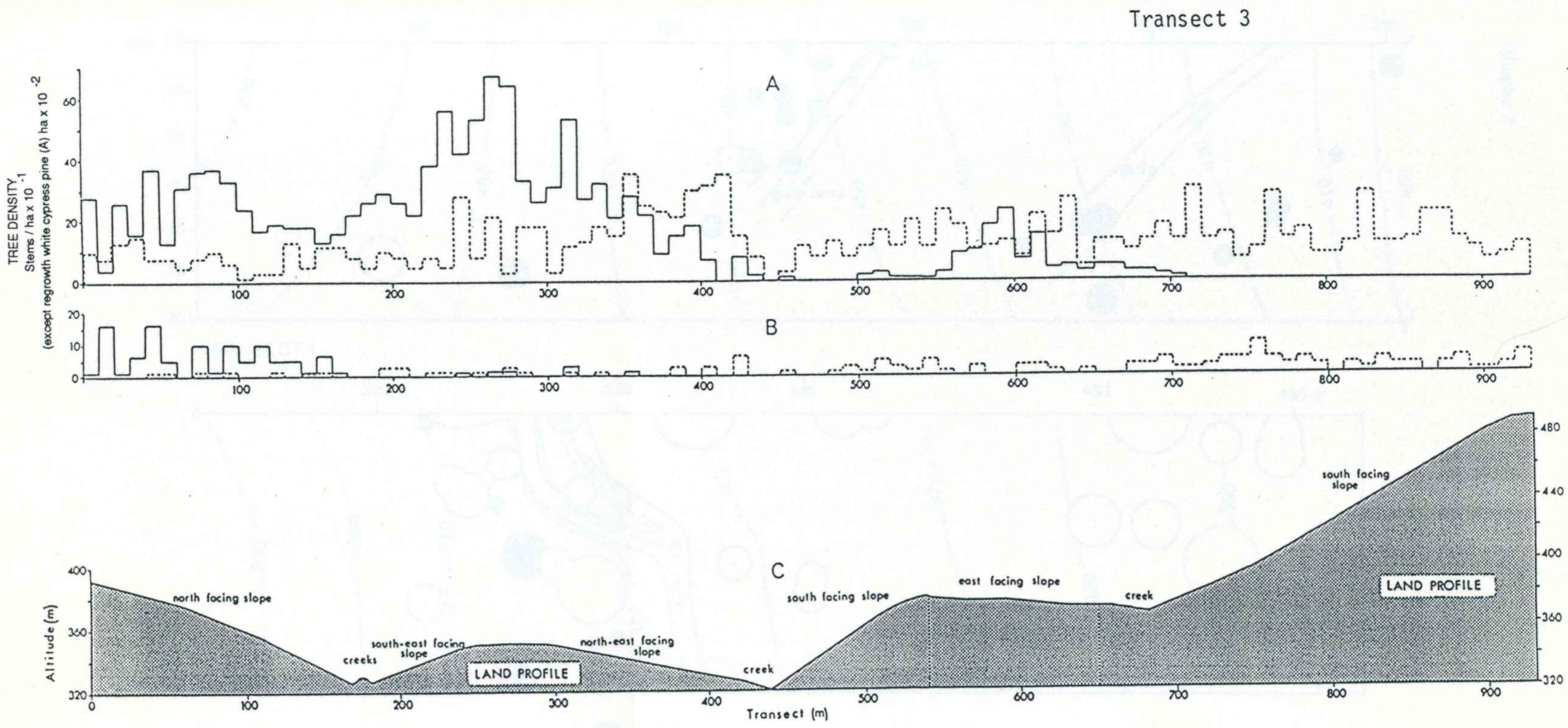
Plate 4.5 Dense regrowth white cypress pine at 100-150 m on transect 3 (approx. 350 m elevation). Note sparse ground cover and bare soil.

Plate 4.6 Aerial view of typical emergent dead old growth white cypress pine stags surrounded by dense regrowth on a north aspect site 1.5 km south of Mount Trooper.



Key white cypress pine *Callitris glaucophylla* ; white box *E. albens*

Figure 4.3 and 4.4 Stem density of white cypress pine and white box along transects 1 and 2. Diagram A. regrowth forest (post-European settlement); B. old growth woodland trees (pre-European), C. land profile along transect.



Key white cypress pine *Callitris glaucophylla* ; white box *E. albens*

Figure 4.5 Stem density of white cypress pine and white box along transects 3.
Diagram A. regrowth forest (post - European); B. old woodland trees (pre-European), C. land profile along transect.

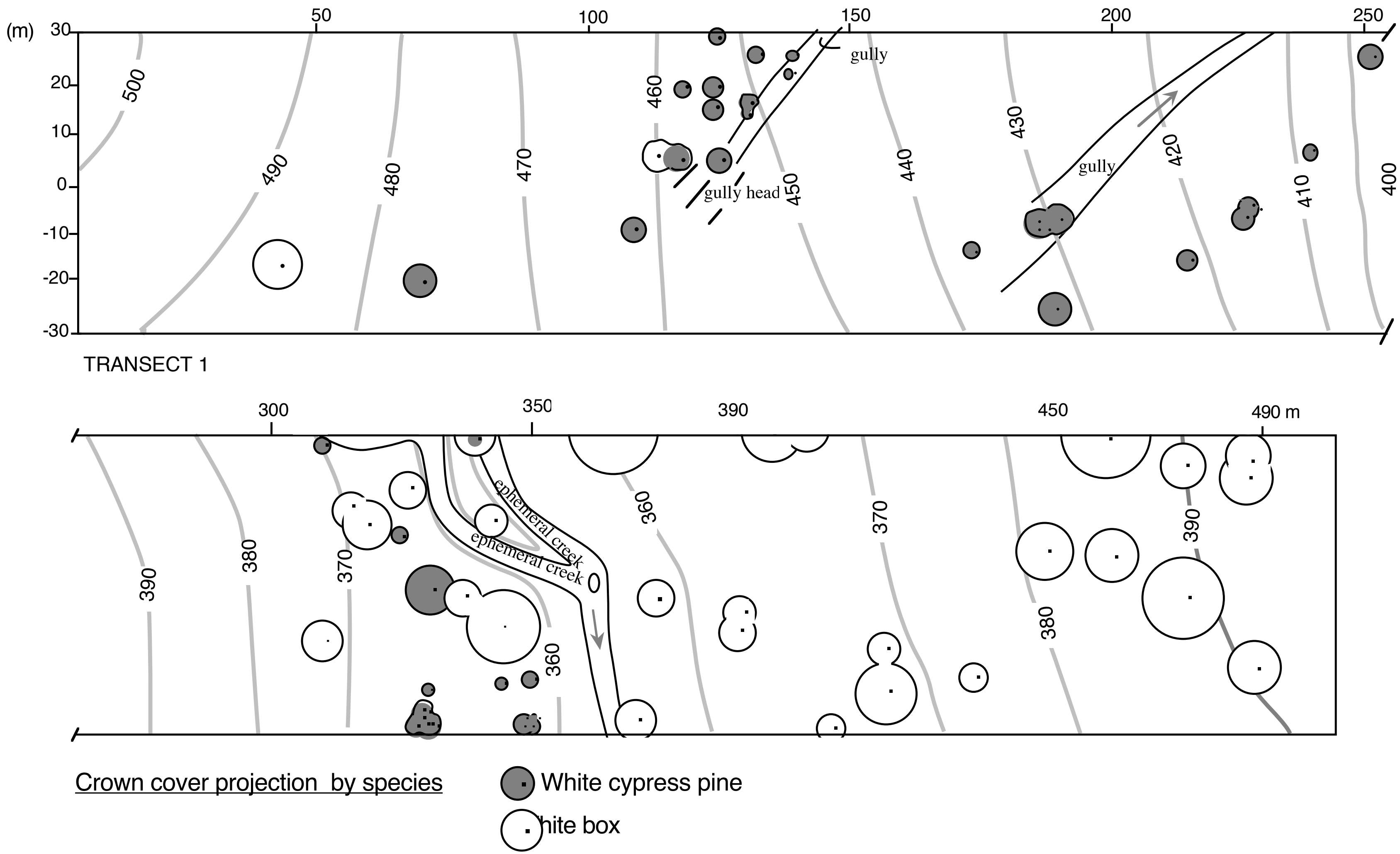


Figure 4.6 . Map of transect 1 showing tree distribution and estimated crown cover projection, for old growth pre-European white cypress pine *(Callitris glaucophylla)* and white box *(Eucalyptus albens)* woodland, in the lower Snowy River Valley of Kosciusko National Park. Note the clusters of white cypress pine on the north aspect slopes (0-350 m), near creek banks and disturbed heads of gullies. White box mostly occcurs on the south aspect slopes (350-490 m).

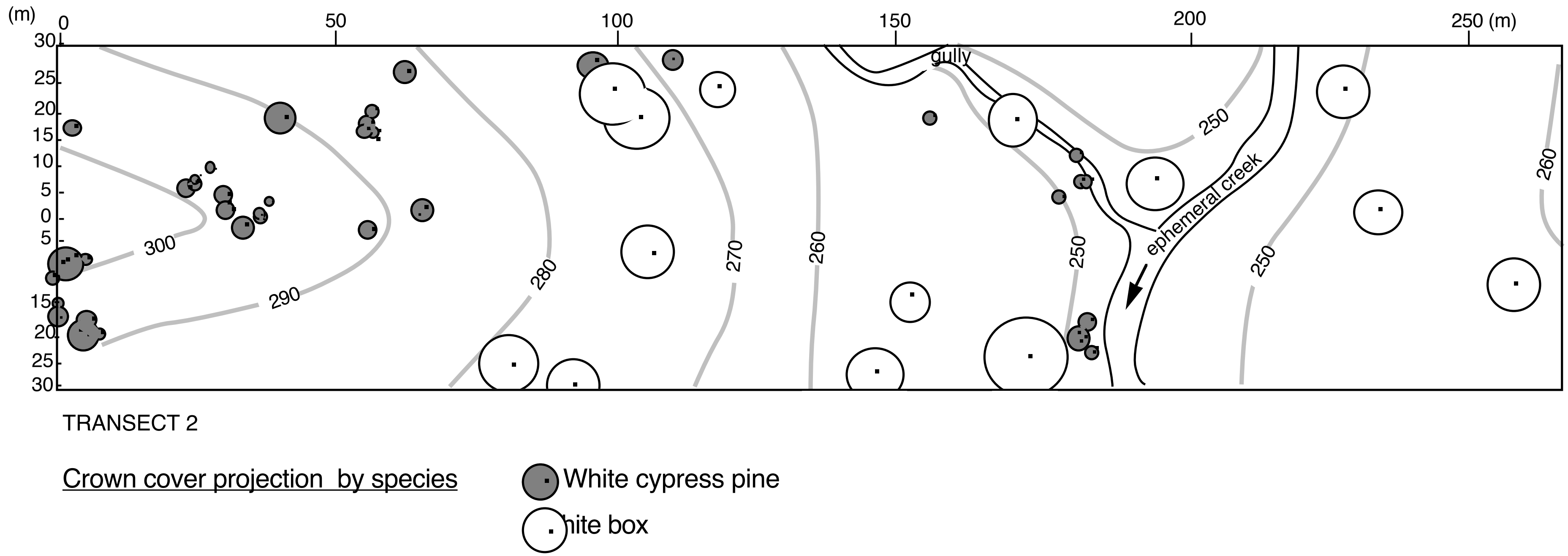


Figure 4.7 . Map of transect 2 showing tree distribution and estimated crown cover projection, for old growth pre-European white cypress pine *(Callitris glaucophylla)* and white box *(Eucalyptus albens)* woodland, in the lower Snowy River Valley of Kosciusko National Park. Note the clusters of white cypress pine on the north aspect ridge line (0-100 m) and in the vicinity of creek banks with occassional white box in between.

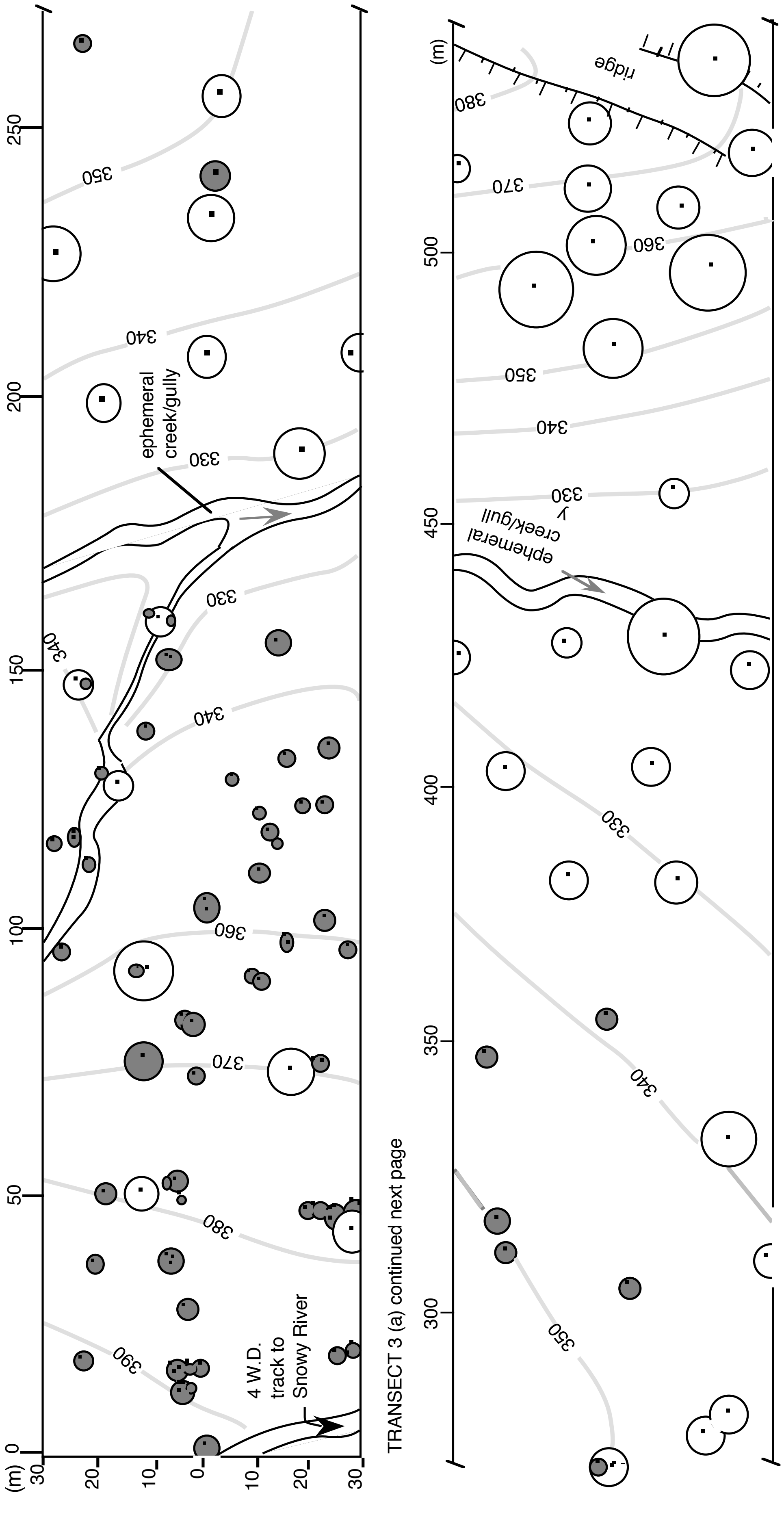
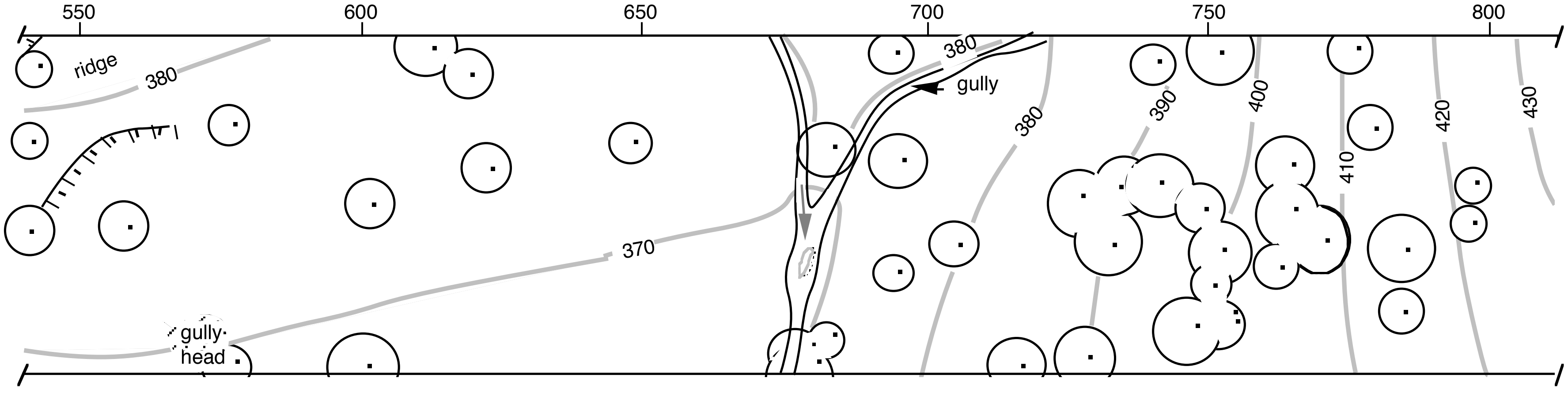
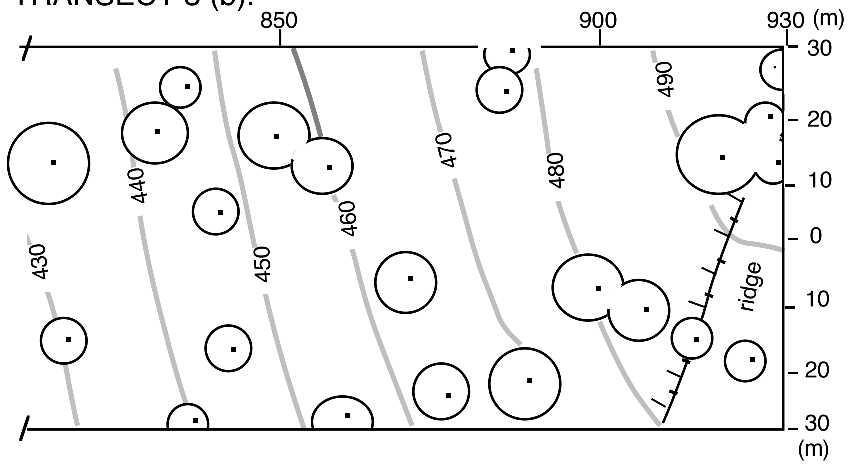


Figure 4.8 (a) (map of transect 3 continued next page)



TRANSECT 3 (b).



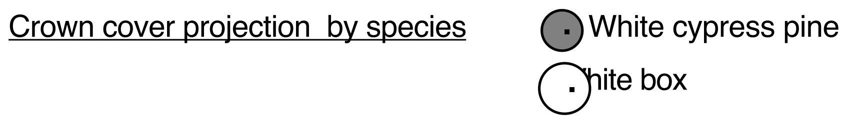


Figure 4.8 (b). Map of transect 3 showing tree distribution and estimated crown cover projection, for old growth pre-European white cypress pine *(Callitris glaucophylla)* and white box *(Eucalyptus albens)* woodland, in the lower Snowy River Valley of Kosciusko National Park. Note the predominance of white cypress pine on only the north aspect slopes (0-150 m) and white box on the south aspect slopes (400-930 m) of the transect.

Table 4.1 Comparison of mean stem density ha^{-1} for two aspect groups between old growth woodland and regrowth stands of white cypress pine and white box.

			Stems ha^{-1}			
Aspect	Transect Number	Section (metres)	Old Woodland		Regrowth Forest	
			C. glaucophylla	*E. albens*	*C. glaucophylla*	*E. albens*
Hot dry north facing	1	0-360	21.3	4.6	2738.9	44.4
	2	0-200	37.5	8.3	3105.0	59.2
	3	0-180	58.3	8.3	2266.0	84.3
	3	270-440	3.9	14.7	2329.4	192.2
		Mean	**30.3**	**9.0**	**2609.8**	**95.0**
Cool moist south facing	1	360-490	0.0	20.5	461.5	109.0
	2	200-270	0.0	9.5	1014.3	121.4
	3	180-270	3.7	16.7	3988.9	111.1
	3	440-540	0.0	20.0	80.0	105.0
	3	540-680	0.0	16.7	792.9	144.0
	3	680-930	0.0	30.7	24.0	144.0
		Mean	**0.6**	**19.0**	**1060.3**	**122.4**

Table 4.2 Comparison of the number of live and dead old growth woodland white cypress pine and white box trees with and without fire scars and the live/dead stem ratio on each transect section for hot dry north facing aspects and cool moist south facing aspects. The mean for each aspect by category is also shown. Note L/D stem ratio is less than 1.0 for white cypress pine and greater than 1.0 for white box. This may indicate that old growth white cypress pine did not survive the changes in growth conditions associated with European land use as well as white box.

			Fire scarred & unscarred old growth woodland trees									
			C. glaucophylla Number					*E. albens* Number				
Aspect	Transect Number	Section (metres)	Dead trees Df	Dt	Live trees Lf	Lt	Ratio L/D	Dead trees Df	Dt	Live trees Lf	Lt	Ratio L/D
Hot dry north facing	1	0-360	4	32	0	16	0.5	0	3	0	7	2.3
	2	0-200	12	34	3	10	0.3	0	2	0	8	4.0
	3	0-180	20	45	8	18	0.4	1	1	1	8	8.0
	3	270-440	0	3	1	1	0.3	0	2	4	12	6.0
		Mean stem/ha	7.6	21.9	2.7	8.3		0.2	1.5	1.2	7.3	
		Mean L/D					0.4					5.1
Cool moist south facing	1	360-490	0	0	0	0	0.0	0	1	0	15	15.0
	2	200-270	0	0	0	0	0.0	0	0	0	4	0.0
	3	180-270	1	1	0	1	1.0	0	2	0	7	3.5
	3	440-540	0	0	0	0	0.0	2	3	6	9	3.0
	3	540-680	0	0	0	0	0.0	3	5	5	9	1.8
	3	680-930	0	0	0	0	0.0	2	3	21	25	8.3
		Mean stem/ha	0.3	0.3	0.0	0.3		1.4	3.0	5.0	14.0	
		Mean L/D					0.2					5.3

Key
- Df = Dead trees with fire scars
- Dt = Total number of dead trees
- Lf = Live trees with fire scars
- Lt = Total number of live trees
- L/D = Lt ÷ Dt

Table 4.3 Comparison of mean (live and dead stem) d.b.h.o.b. (cm) and basal area (m^2 ha^{-1}) for old growth woodland white cypress pine and white box on each transect section on hot north facing and cool south facing aspects.

			Old growth tree diameter (d.b.h.o.b.) and basal area			
Aspect	Transect Number	Section (metres)	*C. glaucophylla* $\bar{X}$ (d.b.h.o.b.) (cm)	*C. glaucophylla* basal area (m^2 ha^{-1})	*E. albens* $\bar{X}$ (d.b.h.o.b.) (cm)	*E. albens* basal area (m^2 ha^{-1})
North facing hot - dry	1	0-360	36.7	2.9	46.6	0.8
	2	0-200	30.2	3.0	54.5	2.0
	3	0-180	31.8	5.2	46.8	1.5
	3	270-440	40.3	0.5	41.9	2.1
		Mean	**34.8**	**2.9**	**47.4**	**1.6**
South facing cool- moist	1	360-490	0.0	0.0	53.4	1.3
	2	200-270	0.0	0.0	44.8	1.5
	3	180-270	50.0	0.8	52.1	4.4
	3	440-540	0.0	0.0	50.1	4.2
	3	540-680	0.0	0.0	48.5	3.3
	3	680-930	0.0	0.0	46.9	3.3
		Mean	**-**	**-**	**49.3**	**3.0**

Table 4.4 Mean stem diameter (d.b.h.o.b.) cm of old growth woodland from this study compared with d.b.h.o.b. for combined old growth woodland and regrowth white cypress pine and white box from Clayton-Greene (1981) for the same study area.

	C. glaucophylla			*E. albens*		
	Old growth woodland only *	Old growth woodl. and regrowth inclusive +		Old growth woodland only *	Old growth woodl. and regrowth inclusive +	
North Aspect	**Hot**	**Hot**	**Warm**	**Hot**	**Hot**	**Warm**
mean d.b.h.o.b. (cm)	34.8	10.5	11.8	47.7	21.0	11.5
South Aspect	**Cool**	**Cool**	**Higher alt cool**	**Cool**	**Cool**	**Higher alt cool**
mean d.b.h.o.b. (cm)	-	13.4	14.0	49.3	23.4	14.1

* Results of this study from Table 4.3
\+ After Clayton-Greene (1981)

Table 4.5 Crown cover percentages and weighted average crown cover percentage for old growth woodland white cypress pine and white box and for regrowth white cypress pine.

Aspect	Transect Number	Section (metres)	Crown cover percentage: Old growth woodland *C. glaucophylla*	Old growth woodland *E. albens*	Old growth woodland Total	Regrowth forest *C. glaucophylla*
Hot dry north facing	1	0-360	2.9%	3.0%	5.9%	21.9%
	2	0-200	3.2%	9.1%	12.2%	20.9%
	3	0-180	5.6%	4.0%	9.6%	15.2%
	3	270-440	0.7%	7.4%	8.1%	16.9%
		Weighted average	**3.1%**	**5.4%**	**8.4%**	**19.0%**
Cool moist south facing	1	360-490	0.0%	24.1%	24.1%	7.5%
	2	200-270	0.0%	4.9%	4.9%	15.7%
	3	180-270	0.8%	8.7%	9.5%	23.7%
	3	440-540	0.0%	16.0%	16.0%	3.0%
	3	540-680	0.0%	11.4%	11.4%	14.6%
	3	680-930	0.0%	27.2%	27.2%	1.5%
		Weighted average	**0.1%**	**18.3%**	**18.4%**	**8.9%**
		Total weighted average			**13.4%**	**14.0%**

4.5 Discussion

4.5.1 Tree density and basal area

The forests of the lower Snowy River on north facing sites were dominated by dense regrowth stands of white cypress pine mostly 8-12 m high at a density of about 2,600 stems ha^{-1} with a scatter of predominantly dead old growth emergent woodland trees at a density of about 30 stems ha^{-1}. South facing sites were dominated particularly at higher elevations by relatively low density regrowth white box at about 122 stems ha^{-1} and old growth (>=35 cm d.b.h.o.b.) at 19 stems ha^{-1}. White cypress pine occurred usually in moderate stand densities of about 1060 stems ha^{-1} on lower south facing slopes and rapidly diminished in density with altitude. Few old growth woodland white box occurred on the hot north facing sites, and almost no old growth woodland white cypress pine occurred on south facing sites. This aspect related distribution suggests that these tree species are best adapted to prevailing environmental conditions, white cypress pine being best adapted to hot dry slopes. In addition Clayton-Greene (1981) has suggested white box was better adapted than white cypress pine to sites which carry more ground fuel and are subject to more frequent and intense fire.

The north aspect sites carried a total mean tree basal area of both species of old growth trees of 4.5 m^2 ha^{-1} which was 50% greater than total basal area of 3.0 m^2 ha^{-1} on south facing sites. Both white box and white cypress pine were of smaller diameter and higher density on north aspect sites than on south aspect sites. This and the eroded appearance of north aspect slopes suggests that they are more susceptible to disturbance and the protective ground cover is slower to recover after fire, drought or grazing by herbivores. Thus the dense narrow stemmed regrowth is likely to be a response to past disturbance which caused exposed and eroding slopes.

South aspect sites usually had relatively dense grasses which competed with seedlings and provided more continuous fuel to support fires resulting in the survival of fewer seedlings. Those that survived had more space to grow into larger trees. Clayton-Greene and Ashton (1990) suggest that the failure of white box to exploit the decline in basal area of white cypress pine with altitude is because at lower altitudes white cypress pine is too dense and/or at higher elevations, above the upper limits of white cypress pine, there is an unfilled niche.

4.5.2 Old growth woodland crown cover

Estimates of the old growth forest crown cover (Figs. 4.6 to 4.8) showed that north and south facing aspects had a woodland type structure with widely spaced large trees. Even accounting for the disappearance of some trees, the evidence suggests a tree crown cover much lower than existing cover. Additional evidence for wide spaced trees was seen in the heavy branched wide crowns on residual old growth trees suggesting that many of these had developed under wide spaced conditions. On north facing sites the old growth woodland was dominated by large white cypress pine together with a scattering of large multi-stemmed white box. These sites probably would have had a grassy understorey *(Poa spp., Stipa spp., Danthonia sp., Themeda sp.)* with occasional shrubs *(Acacia spp.)*.

South facing sites were likely to have been dominated by white box with few, if any, white cypress pine. White box with single stems were probably more common than multi-stemmed trees. The dark rich soils had a cover of dense grasses *(Poa sp., Stipa sp.)* with a scattered shrub layer of *Acacia spp*. in lower areas and *Lissanthe strigosa* in higher areas.

The crown cover projection maps (Figs. 4.6 to 4.8) reveal a pattern of vegetation distribution within the stands which is different to that found in the regrowth forest. These maps indicate a highly contagious distribution of old growth woodland white cypress pine trees occurring mostly in small groups along creek banks, at gully heads, rocky outcrops or scattered on broad slopes. Trees in these groups varied in both height and crown diameter. Evidence for contagion in white cypress pine was also found by Lacey (1972) and Clayton-Greene (1981). Clayton-Greene suggested that contagion was due to the limited seed dispersal ability of white cypress pine which typically dispersed seed to a radius of 20-30 m from the trunk of the parent tree resulting in dense clumped regeneration. Westman and Anderson (1970) suggested that contagious distributions are caused by factors such as fire, ants and allelopathy and (Cooper, 1960) suggested it was a general adaptation to fire. In old growth white cypress pine contagion would have resulted in reduced ground cover and fuels beneath these trees, in contrast to tall dense grass growing in the open spaces between the clumps. Reduced fuels under these trees would have reduced fire intensity in these stands. Solitary trees, young trees and seedlings would be at a significant disadvantage if they were not growing in or near a group of white cypress pine trees. Fires in the dense grassy areas would damage or eliminate seedlings and young trees but merely scar trees growing in clumps. Further evidence of the role of fire is presented in chapters 7 and 8.

The majority, 71% of the old growth woodland white cypress pine on hot northerly slopes were dead. Those old growth trees which were still alive, had dead tops and often only a single branch remained alive. Most old growth trees must have been alive at the time of regeneration to provide seed for the extensive wheat field regeneration. This proposition is supported by dendrochronological evidence (Chap. 6). Old growth trees appear to have gone into decline and death after the regeneration occurred. I suggest that they died due to moisture stress from increased intra-specific competition, increased insolation on their often shallow spreading roots caused by soil erosion and removal of the understorey by a succession of fires, plagues of rabbits, and insect attack. Clayton-Greene (1981) on the other hand, suggested that these trees may have been killed by fire. I found no evidence that any of the dead old growth trees in the study area had been killed by fire. Fire of sufficient intensity to kill the crown is likely to have damaged the boles. Instead most of these trees still retained their thick bark intact showing no evidence of a fire. Even those trees which showed fire scars had survived these fires as indicated by the formation of callus.

White box appeared to be more uniformly distributed than white cypress pine. Crown cover of old growth woodland white box (5.4%) was greater than white cypress pine (3.1%). This is largely due to the small K/d ratio of white cypress pine compared with white box.

4.5.3 Recruitment

There was no seedling regeneration of white cypress pine on north facing sites. Johnston (1975) and Lacey (1972) reported that stem densities <1,000 stems ha^{-1} are required for white cypress pine to regenerate. Whilst regrowth trees are now mature and carry a few cones, the stand densities on these sites of between 2000 and 3000 stems ha-1 far exceed this requirement at present. In contrast, white cypress pine stem densities on south facing slopes were usually less than 1000 stems ha^{-1} (Table 4.1). Pulsford (unpublished data) and Wellsmore (1986) indicate that rabbit numbers have been low since 1983. This combined with favourable weather conditions since 1983 has resulted in a succession of good years suitable for white cypress pine seedling germination and establishment. White cypress pine and white box seedlings are now relatively common in some areas such as on the cool south aspect more open sites on Mount Trooper.

The most recent and dense seedling regeneration occurred in the winters of 1989 and 1990 on some west facing footslope sites about 10 km north of the transects near the Pinch River which were burnt in 1972. Large numbers of white box seedlings were found on higher south facing slopes and 20 white cypress pine seedlings were found in the upper section (680-930 m) of transect 3 (<440 m ASL) where stands were more open (approx. 150 stem ha^{-1}).

White cypress pine seedlings, whilst not occurring in the dense pine stands, are not restricted to the most protected sites such as amongst rocks and under *Lissanthe strigosa* bushes as noted by Clayton-Greene (1981) who studied the area during a drought period. It appears that seedling establishment in recent years is related to a succession of relatively favourable seasons and the relatively low rabbit numbers (pers. obs.) as a result of the successful introduction of a virulent strain of Mxomatosis in 1983.

4.5.4 Evidence of fire

The live and dead fire scarred white cypress pine trees mostly on hot dry north aspects provided evidence of past fires (Table 4.2). To a much lesser extent the white box on the upper south aspect slopes did the same. Many white cypress pine trees displayed three or more visible fire scars. My impression is that fire was more frequent on north aspect sites and that its impact was more severe due to the hot dry conditions which frequently prevail on these exposed slopes. Recovery of the vegetation from fire on these slopes would have been much slower than the cooler south aspect sites.

Suppression of the understorey by competition from white cypress pine together with grazing by periodically high rabbit populations is likely to have reduced the frequency and intensity of fire on these slopes. In the past the higher levels of grass fuel on south aspect sites may have been available for occasional relatively low intensity fires. The presence of faster growing fire adapted multi-stemmed white box on these sites supports this view.

4.6 Conclusion

This study suggests that prior to European settlement the white cypress pine - white box alliance of the lower Snowy River was a woodland with wide open spaces between trees. It is likely that there was a relatively dense grassy ground cover on hot dry north aspects, in contrast to the present cover of sparse grasses with a high percentage of bare eroding soil. Old growth woodland white cypress pine had a highly contagious distribution, whilst white box appeared to have a more random distribution. No major post disturbance shift in the dominance of each species with aspect appears to have occurred. A large increase in stem density of white cypress pine has occurred, particularly on hot dry aspects on steep slopes and more gentle lower slopes due to widespread regeneration events.

This investigation supports anecdotal and historical accounts of the density and structure of white cypress pine woodland recorded by Robinson (Mackaness, 1941) to this area. I suggest that disturbance resulted in dense regrowth of what appears to be relatively even aged stands particularly on north facing slopes in which white cypress pine is predominant. To confirm this hypothesis, investigation of age differences between the classes of “old growth woodland” and “regrowth” white cypress pine was indicated. Thus I investigated the age classes of white cypress pine using dendrochronological techniques (Chaps. 5 and 6).

Chapter 5 The recognition of tree rings in white cypress pine

5.1 Introduction

The analysis of forest structure (Chap. 4) showed there were two major stand types in the white cypress pine forest in the lower Snowy River Valley. These were a low density woodland formation comprised of large and presumably old trees, designated as "old growth woodland", and dense stands of young "regrowth" trees. These two age classes may have developed in response to similar factors reported by Horne and Robinson (1987) and Lacey (1972) which have caused major regeneration events in the white cypress pine forests west of the Great Dividing Range. To test whether there were two age classes and further understand the forest dynamics of these eastern stands required the ageing of representative trees in each apparent age cohort. This required developing a reliable method for ageing trees. Literature review revealed that dendrochronology might be a suitable tool and if a reliable method of dating tree rings could be used it would also be possible to elucidate the fire history of the study sites. Fire history is a powerful tool capable of providing evidence of changes in community structure relating to past land use practices (Banks, 1989; McBride, 1983; McBride and Jacobs, 1978; Stokes and Dieterich, 1980).

Tree species usually considered most suitable for ageing and climatic reconstructions in Australia are the Tasmanian conifer genera *Lagarostrobus, Phyllocladus, Arthrotaxis* (Bird, in press; Dunwiddie and LaMarche, 1980) and *Dacridium* (Ogden, 1978; Ogden, 1982). Several species including some Eucalypts from the Australian Alps have also been found to be suitable (Banks, 1982, 1987, 1989). The suitability of *Callitris* for dendrochronological studies has been the subject of several investigations over the last two decades (Ash, 1983; Clayton-Greene, 1981; P. Cochrane, pers. comm.; Dunwiddie and La Marche, 1980; La Marche *et al*. 1979; Lange, 1965; Ogden, 1978; Pearman, 1971 and Perlinski, 1986).

Hillis and Banks (1976), La Marche *et al*. (1979) and Perlinski (1986) found *Callitris* was suitable for tree ring analysis in strongly seasonal tropical and Mediterranean climates provided that a method for dealing with the problem of intra-annual bands and missing rings could be found. For example, *Callitris intratropica* in the Kimberley Tablelands of far northern Western Australia experiences a distinct wet and dry season producing distinct seasonal growth rings. This species is considered a promising candidate for dendroclimatology (Dr. J. Banks pers. comm.).

Lange (1965), Pearman (1971) and Johnston (1975) presented evidence which suggested that the width of the annual increment in semi-arid zones where the genus *Callitris* was found is determined primarily by rainfall. They did not successfully establish cross dating. In reviewing this work Ogden (1978) concluded that *Callitris*

> "...may provide a proxy rainfall record for semi-arid areas which would be invaluable for their future management."

Pearman (1971), who investigated tree rings in *Callitris preisii* on Garden Island in Western Australia, also suggested there was evidence to relate ring width to rainfall. Attempts to relate ring width pattern to the magnitude of the 11 year sunspot cycle were inconclusive due to uncertainty as to whether rings were annual.

Some of the problems of establishing a chronology were highlighted by Lange (1965) who found that *Callitris columellaris* trees near Woomera in South Australia appeared to have produced two rings in some years and none in others. The problem of recognition of the annual ring was highlighted by the observation that the number of rings varied by about twenty in eighty years between trees sampled.

The usefulness of *Callitris* and other Australian trees for dendrochronology was assessed by Dunwiddie and La Marche (1980). *Callitris preisii* was successfully cross dated from two sites in the Mediterranean type climate near Perth in Western Australia. They had more limited success with *Callitris columellaris*[1] which was cross matched for several locations in South Australia and NSW. They concluded that *Callitris columellaris* presented problems for satisfactory dendrochronology research due the difficulty in differentiating annual rings from false intra-annual bands.

Until recently, the study of tree rings has been virtually restricted to temperate regions because climatic seasonality is sufficient to induce seasonal growth bands (Ash, 1983; Fritts, 1976). In temperate climates temperature is the prime limiting factor in growth. However, in locations where sufficiently regular climatic seasonality of another factor such as water availability occurs, this is often sufficient to induce seasonal growth rings. Ash (1981) found that tracheid diameter patterns may be matched with water availability patterns in *Callitris macleayii* from the Atherton Tablelands, Queensland. A correlation of 0.74 was found between annual ring widths and the duration of the wet season. The deviation of ring width patterns from rainfall was related to competition, disease and leaf herbivores.

The annual growth response of *Callitris columellaris* from measurements of tree ring width was related to observed rainfall and temperature at Menzies, and cross checked with results from Southern

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[1] note now *C. glaucophylla*

Cross, Wiluna and Cashmere Downs in Western Australia (Perlinski, 1986). Over 70% of annual variation in stem growth attributes was attributed to regional climate during a 51 year calibration period. The model was extended for climatic reconstruction for about 650 years. He concluded that the species does respond sensitively to climate. At Lake Barlee in Western Australia, a summer related annual tree ring boundary resulting from high mid summer temperatures and extreme summer drought was found. In this region the lignified structures associated with intra-annual bands were easy to identify by margins which were diffuse compared to true annual ring boundaries. True annual ring boundaries showed dark distinct boundaries indicating a cessation of growth for a prolonged period. This contrasted with the work of previous investigators.

In summary, the problems with the use of *Callitris* for dendrochronological analysis include a high frequency of intra seasonal growth rings and difficulties in recognising the seasonal growth ring, especially in species growing in locations which experience a variable growth season. Ogden (1982) concluded that despite these problems, white cypress pine can be cross dated in some circumstances and deserves considerable attention.

An initial investigation of the temperature and rainfall of the lower Snowy River Valley indicated a reasonably regular annual growth season. Thus while some difficulties could be expected I concluded that the lower Snowy River study area was potentially suitable for white cypress pine tree ring analysis. It was desirable, although not essential, to develop chronologies with absolute dating in order to estimate the ages of the two major age class stands in the lower Snowy River.

The investigation aimed at dating the major white cypress pine age classes was divided into two stages because of the difficulties expected in tree ring analysis. The first stage aimed at developing a methodology for identifying the growth season rings in trees from an optimum site. This would enable a chronology to be established for trees at this site. The second stage (Chap. 6) aimed to utilize this information to establish chronologies for other sites including representatives of both age classes.

5.2 Methods

5.2.1 Site selection

Criteria for site selection for dendrochronological purposes discussed by Douglass (1914), Fritts (1967), Banks (1982) and Perlinski (1986) were considered in this investigation. The principle of site selection relies on the fact that rings of a tree measure its food supply and food supply depends largely on moisture availability and temperature. Where moisture is limiting in some way then the tree is struggling against drought, hence in such places the tree rings are likely to form a measure of precipitation (Douglass, 1914).

A site for sampling white cypress pine was sought to maximise the chance of selecting trees with sufficient sensitivity[1] to produce growth rings in response to climate but not be overly subject to drought, either through exposure due to aspect or from competition from neighbouring trees, or exposed to past excessive disturbances. The site (site 1) which appeared to best fit these criteria was located at mid elevation (350 m) in the white cypress pine zone, on 20-28° slopes with an aspect of 160-170°on Mount Trooper adjacent to the Sandy Creek Fire Trail about 2.8 km east of the Snowy River (Fig. 5.1 and Plate 5.1). The site was subdivided by a minor dry gully. Well formed conical shaped regrowth white cypress

[1] A tree which produces rings with highly variable width indicates that the growth response of the tree is "sensitive" to variations in climate (Fritts, 1976).

pine trees of moderate size with scattered white box occupied the slope. Some recent regrowth white box seedlings occurred on the north east side of the drainage line. The dense grassy ground cover was predominantly *Poa spp.*, *Stipa spp.* and *Themeda australis* under which there was a dense mossy matt. A few *Acacia dealbata, A. deanei and Lissanthe strigosa* shrubs were scattered across the slope. At the foot of the slope where additional tree ring sampling was conducted, the banks of Sandy Creek were marked by large diameter well spaced apple box *(Eucalyptus bridgesiana)*, occasional yellow box *(E. melliodora)* and large well formed white cypress pine trees.

This site was on relatively deep uneroded soils. The presence of an old timber fence built in the late nineteenth century suggested that this site had not been subject to the disturbance of fire since the fence was built (see Chap. 3, Plate 3.1). Trees sampled from this site were therefore unlikely to be subject to the complicating influence of fires on tree ring growth patterns.

Soil sampling

The solum at site 1 was examined using a 4 inch auger to a depth of 0.75 m and by examination of a 1-1.5 m road cutting at site 1 on the Sandy Creek Fire Trail. The cutting was dressed using a shovel and wetted prior to preparing a soil description using Northcote's (1971) key.

5.2.2 Sampling of trees

Six mature regrowth white cypress pine trees between 11-15 m height were cut 30-50 cm above ground on 26 May 1986 (trees 1-6, Fig 5.1). Duplicate 4 cm thick basal disks were cut from each tree with a chainsaw from as near the ground as possible, then labelled and dried for 3 days at 20°C. The diameter of the basal disk, height of each tree, distance from its nearest neighbour and nearest sampled tree were recorded. The slope and aspect at the base of each tree were recorded and the condition of the vegetation photographed. The positions of the sampled trees were mapped (Fig. 5.1). All trees were within 50 m of another sampled tree. Three cores from each of trees 7-9 located near Sandy Creek on deep alluvium were extracted using a 5 mm Swedish corer in October 1987.

The trees selected for sampling exhibited good size and spacing, a well balanced shape, with no evidence of missing limbs or obvious signs of damage to crown or bole. Trees with very fluted or misshapen trunks near the base were avoided. Trees in this location exhibited large numbers of persistent open cones in contrast with relatively few cones on trees in dense stands on hot dry sites. The absence of heavy well developed branches indicated relatively young mature "regrowth" trees.

5.2.3 Preparation of tree ring samples

The tree disks were dry sanded with an electric belt sander then wet sanded by hand with progressively finer grades of wet and dry paper (grades 320, 600 and 1200). One set of the duplicate disks was bleached in a 5% solution of sodium hypochlorite (Dunwiddie and LaMarche, 1980) for up to 2 hours and another set for 10 minutes, to remove the dark staining of resin in the heartwood zone. Although the sections cracked upon drying this did not reduce their usefulness. Excessive time in bleach reduced the visibility of tree rings rendering some samples useless.

5.2.4 Initial identification of tree rings

Skeleton plots and microscopic techniques

Transects were marked on each disk and viewed under a transecting microscope. The traditional methods of making skeleton plots from measurements of tree ring widths using a transecting microscope (Stokes and Smiley, 1968) were used in early attempts to interpret the tree rings. Initial attempts to find a method for dating white cypress pine using total ring counts, measurements and "interpreted" ring counts proved inconclusive and gave a range of possible ages for each tree. The appearance of the tree rings under the microscope (at x 60) was confusing and it was difficult to relate diffuse and incomplete rings to their position on several cross matched specimens. The width of the rings was small often being less than 0.1 mm. All attempts to produce meaningful skeleton plots failed due to the presence of large numbers of double rings and indistinct rings. Problems of severe eye strain using the binocular microscope and the inability to simultaneously view several radii or several disks for cross matching several trees, resulted in the abandonment of microscopic techniques.

Initial analysis of photographic prints

Another approach to tree ring identification and cross matching between radii was attempted using enlarged black and white photographs of tree ring cross sections of selected radii. The photographic methods used by Perlinski (1986) for making photo enlarged cross sections of white cypress pine were improved. Each transect from the tree centre to the outer tree ring was photographed using a mounted Hasselblad 6 x 6 cm format camera with 28

Plate 5.1 Regrowth white cypress pine on a cool south aspect slope at site 1 on Mount Trooper, similar to the trees sampled for tree ring analysis.

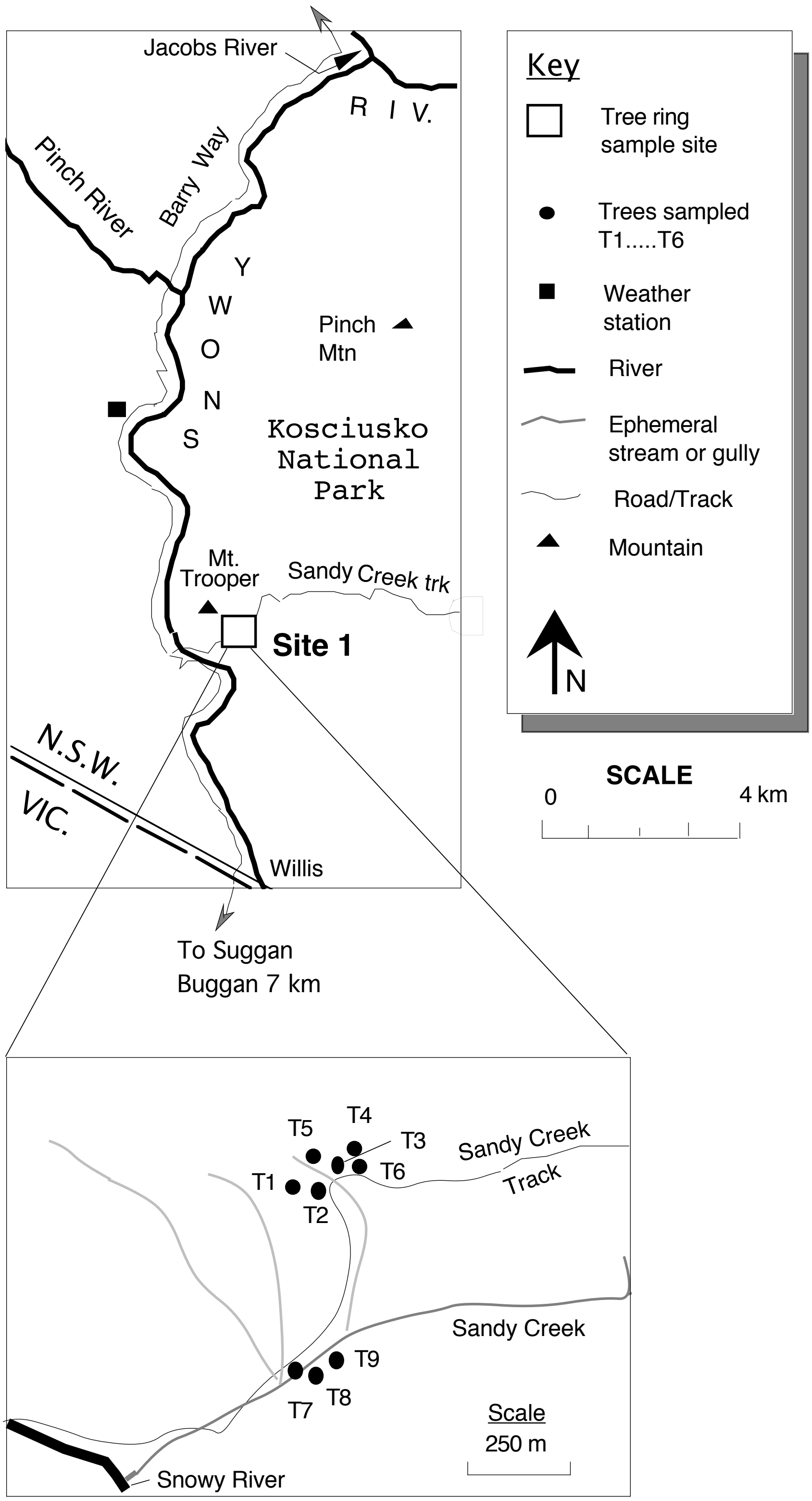


Figure 5.1 Location of trees sampled on Mount Trooper in the study area, where regrowth white cypress pine were sampled for tree ring analysis on a cool south aspect site.

mm macro lens and studio electronic flash lighting set at 45° on each side of the specimen. Kodak 200 ASA Technical Panchromatic film was used. A steel rule scale was included in each photo. Prints were enlarged 6.25 times on multi grade resin coated paper and joined in strips.

Tree rings were marked and numbered using Omnichrom pencil on the photo prints along selected transects for tree disks 2-6 digitised on a Jandel Scientific digitising tablet with Sigma-scan software. Measurement of all identifiable rings as well as interpreted annual growth rings was carried out. Annual growth rings were identified as relatively dark bands usually with distinct boundaries. Intra-annual bands were identified as rings with diffuse and indistinct boundaries. Using this approach it was not possible in the first instance to detect missing rings. Comparison of tree ring measurements and graphs of ring width showed varying results with no consistent relationship between trees. Thus it was concluded that annual rings could not easily be identified using this approach alone and intra growth season rings and false rings confounded the simple approach to ring counting as reported by other workers (Dunwiddie and LaMarche, 1980). This approach was also abandoned.

Core samples were not used because they could not be photographed satisfactorily, and a number of wide sections could not be viewed simultaneously.

Due to the problems experienced in identifying annual rings, tree ring counts on their own did not provide sufficient evidence to determine the age of white cypress pine samples. A method of calibration[1] was required.

5.2.5 Growth Index model

[1] The procedure that estimates statistical growth-environment relationships (Fritts and Swetnam, 1989)

Ash (1983), Clayton-Greene (1981), Lange (1965) and Perlinski (1986) had variously found a relationship between rainfall, temperature and tree growth in *Callitris spp*. Clayton-Greene (1981) found that at Savernake in the southern Riverina of NSW shoot extension in *C. columellaris* occurred in September - October and continued until December (mid spring and early summer), when soil moisture was depleted prohibiting growth. A bimodal growth pulse occurred in the autumn-winter of 1978 due to heavier than normal mid summer and mid autumn rain coupled with higher than normal May temperatures. Moisture was limiting in spring of 1977 and 1980 causing a delay in shoot extension until adequate rainfall occurred. He determined that in general moisture must exceed 30 mm per month for shoot extension to occur. Shoot growth was seasonal, generally occurring from mid spring until early summer, and seasonal growth was dependent on temperature and soil moisture.

Comparison of a climatic variable such as rainfall and temperature with ring width was indicated to assist with tree ring identification in white cypress pine. A system that could more reliably identify rings by the establishment of a priori criteria was also desirable, particularly for trees which were older than the duration of the local climate records. The use of the growth index modelling approach developed by Fitzpatrick and Nix (1973) was investigated.

The Growth Index was developed for modelling the response of Australian pasture plant communities to light, temperature and water regimes (Fitzpatrick and Nix, 1973). Its principle application was for assisting the agricultural industry to develop crop simulation models to select new crop cultivars and to optimise crop management such as sowing times. It can also be used to evaluate areas suitable for growing particular crops (Nix and McMahon pers. comm.).

Fitzpatrick and Nix (1973) developed a set of scalar models which relate plant response in terms of fractional dry matter production to seasonal regimes of light, temperature and water. These were presented as a series of indices with numeric values ranging from zero, representing a completely limiting situation, to one, representing non-limiting conditions.

The Light Index (L.I.) values were computed from the exponential relationship between fractional dry matter production and mean daily total solar radiation. Generally they found that in most of Australia light was a non limiting factor for plant growth. The Thermal Index (T.I.) values were derived mathematically from a combination of power functions from thermal response curves for grasses which were related to fractional dry matter production of three groups of grasses. The Moisture Index (M.I.) values were based on the exponential drying curve for a medium textured soil with an assumed soil depth. Mean weekly rainfall and mean evaporation from monthly normals provided the inputs to the model. The model was expressed as an environmental scalar for fractional dry-matter response to the water regime. Moisture was found to be limiting to plant growth over most of Australia.

A generalised multifactor Growth Index was defined as a multiplicative function of the three indices as:

$$G.I. = L.I. \text{ x } T.I. \text{ x } M.I.$$

where "... in any given week the G.I. can never exceed the value of the single most limiting factor expressed by Light, Thermal and Moisture Indices" (Fitzpatrick and Nix, 1973).

These indices were calculated using the GROWEST computer program (Fitzpatrick and Nix, 1973; Nix, 1981) for a given elevation and latitude. The various parameters such as initial temperature and soil depth are specified. The three indices and the multifactor G.I. can be computed from total weekly rainfall. It is possible to input variables for temperature and light if data are available.

Although field plant growth trials had not been conducted for white cypress pine in the lower Snowy River Valley, the computation of the G.I. offered an opportunity to model the growth conditions limiting to white cypress pine. The G.I. should indicate the temporal environmental factors likely to dictate growing conditions for white cypress pine at this location. If conditions for cell division were limiting in any season then it is argued that an interruption to growth would occur. This interruption would manifest itself in cross sections of white cypress pine stems as tree rings. Short pauses in growth, or a slowing of growth, would produce vague or indistinct rings, often with diffuse boundaries. Long pauses in growth would produce dark rings with distinct boundaries where growth ceased altogether. Thus the G.I. should indicate whether regular growth periods occur in this species at this location. The G.I. could possibly provide a basis for calibration of the tree ring chronology. The application of the G.I. model would give an opportunity to evaluate the application of this approach to a forest from a set of models which had been developed for grasslands.

5.2.6 Prediction of rainfall

Weekly rainfall for the study area was required to compute the G.I. Available rainfall records for meteorological stations in the vicinity of the study area were obtained from the Bureau of Meteorology and from the Centre for Resource and Environmental Studies at the Australian National University. The nearest station was Suggan Buggan however records for this station only covered the period 1956 to 1977 (Fig. 2.2). It was necessary to extend the period of the rainfall record for Suggan Buggan so that it could be used to calculate the progression of the G.I. over the maximum period for which records for rainfall were available. This was achieved by using rainfall data from 9 additional surrounding rainfall stations to provide predictive regression models for Suggan Buggan. The models were then used to predict monthly rainfall for Suggan Buggan for the maximum possible period for which a common record was available.

Total monthly rainfall for Suggan Buggan and the 9 additional selected stations were $\log_e$ transformed prior to analysis. The $\log_e$ transformation of rainfall is commonly used in climatology to approximately normalise the data prior to analysis (Dr. M. Hutchinson pers. comm.). The transformed data were subject to multiple stepwise regression of Suggan Buggan against the 9 predictor rainfall stations. In this procedure Suggan Buggan rainfall was regressed against each station for each month separately using one predictor at a time.

The generalised multiple regression model for $\log_e$ transformed rainfall can be expressed as follows:-

$$\log_e Y_i = a + \log_e BX_{1i} + \log_e CX_{2i} + \ldots + \varepsilon$$

where Y_i = rainfall input for Suggan Buggan month $_i$,

X_{1i} = first predictor station in model for month $_i$,

X_{2i} = second predictor station in model for month $_i$,

ε = error

After each step the F ratio was calculated as follows:

$$\frac{(SS_{small\ model} - SS_{full\ model}) \div 1}{MS_{full\ model}} \sim F_{1,d}$$

where d = degrees of freedom of error for the full model
and SS = sum of squares, MS = mean sum of squares.

In practice the procedure was batch automated using the STEPWISE procedure of the MINITAB program (Ryan *et al*. 1985). At each step an F statistic was calculated for each predictor in the equation. If any were less than FREMOVE which was set to F=4 then the smallest one was removed. The new regression equation was calculated and the results printed. If no predictor could be removed an F statistic was calculated for each predictor not in the equation. The largest one was then added, provided its F statistic exceeded FENTER (set to 4). If no further predictors could be added the stepwise procedure ended. This procedure is termed statistical model selection using the highest likelihood ratio or maximum F statistic criterion. Thus the null hypothesis H_o: that a reduction in the sum of squares was not significant for each model was tested. As each predictor was added the value of the residuals decreased. Thus the objective was to attempt to find predictors which reduced the value of the error sum of squares at the same time maximising the explanation of rainfall indicated by predictors with the largest F value.

All data sets were reviewed graphically during analysis to reveal possible outliers. After each multiple regression the appropriate diagnostic plots of residuals and probability plots were examined for each month to ensure that the parametric statistical assumptions required for this analysis were met. A single pair of outlier data points was deleted for October 1963, for Suggan Buggan versus Black Mountain, due to its extreme effect on the diagnostic plots. It is not possible to determine the cause of this outlier but the list may include a reading or transcription error. No other data editing was carried out.

5.2.7 Calculation of the progression of the Growth Index

Predicted total monthly rainfall was calculated from 1920 to 1983 for Suggan Buggan using the regression equations and converted to total weekly rainfall using the computer program subroutine INTERW (Hutchinson, 1979). In this program a cumulative value function of monthly rainfall was used to calculate intermediate values using cubic Bessel interpolation (Hutchinson 1979, De Boor 1978). While INTERW preserves the monthly total the weekly values are by necessity smoothed. Rainfall data for the period 1984-1988, when the trees in this study were sampled, was not available when this analysis was carried out.

The predicted weekly rainfall, location (latitude and longitude), initial temperature, elevation, notional soil depth and initial soil water were input to the GROWEST program for the first run. Actual weekly rainfall for Suggan Buggan from 1957 to 1976 were input for the second run. Day length, radiation values and temperature were calculated from stored, previously computed surfaces for these parameters.

5.2.8 Revised identification of white cypress pine tree rings

Due to failure of previously described attempts at tree ring identification a new approach was adopted. Strips of 3M™ Post-It white repositionable correction tape were mounted to form a transect transverse to the tree rings on each photographic strip. Pencil markings were made along the tape edge indicating ring number and year with symbols to indicate intra-annual rings. Each photo strip included a cross section of all tree rings from the tree centre to the cambium. Tree 1 was eliminated from further consideration due to the presence of decayed heartwood rendering it unsuitable for growth ring study.

Cross matching was attempted on several of the specimens with emphasis on the best specimens with clearest ring signatures. After initial failure to successfully cross match tree 6 and tree 2 (site 1), cross matching was carried out on trees 3, 5 and 6 (site 1) simultaneously. This enabled identification of each individual tree ring as likely to be annual or an intra-annual or false ring. Frequent reference to two or more broad cross sections within each tree was required for conclusive tree ring identification. Whilst cross matching of the first 30 or more rings had been achieved this was not sufficient for final tree ring classification. The ring widths were measured (using a metric ruler as this was found adequate) for trees 3, 5 and 6 and a Site Index was calculated as the combined mean Ring Index of these trees. The Site Index was then compared to total annual rainfall graphically and statistically. No significant correlation was found between individual tree Ring Indices, Site Index and total annual rainfall.

Two additional new approaches were taken. Firstly, total predicted rainfall was calculated for the 12 month period from July to June. This was termed total "growth season" rainfall in contrast to "annual" rainfall. Growth rings which are produced on a regular 12 month cycle coinciding with winter are termed "growth season" rings, to distinguish them from “annual” rings reported in the tree ring literature, which is predominantly from the northern hemisphere. Secondly, the mean weekly progression of the Thermal, Moisture, Light and Growth Indices over a 12 month cycle of the indices for 64 years (1920-1983) was graphed. The weekly progression of the G.I. for assumed soil depths of 50, 100 and 150 cm, total predicted

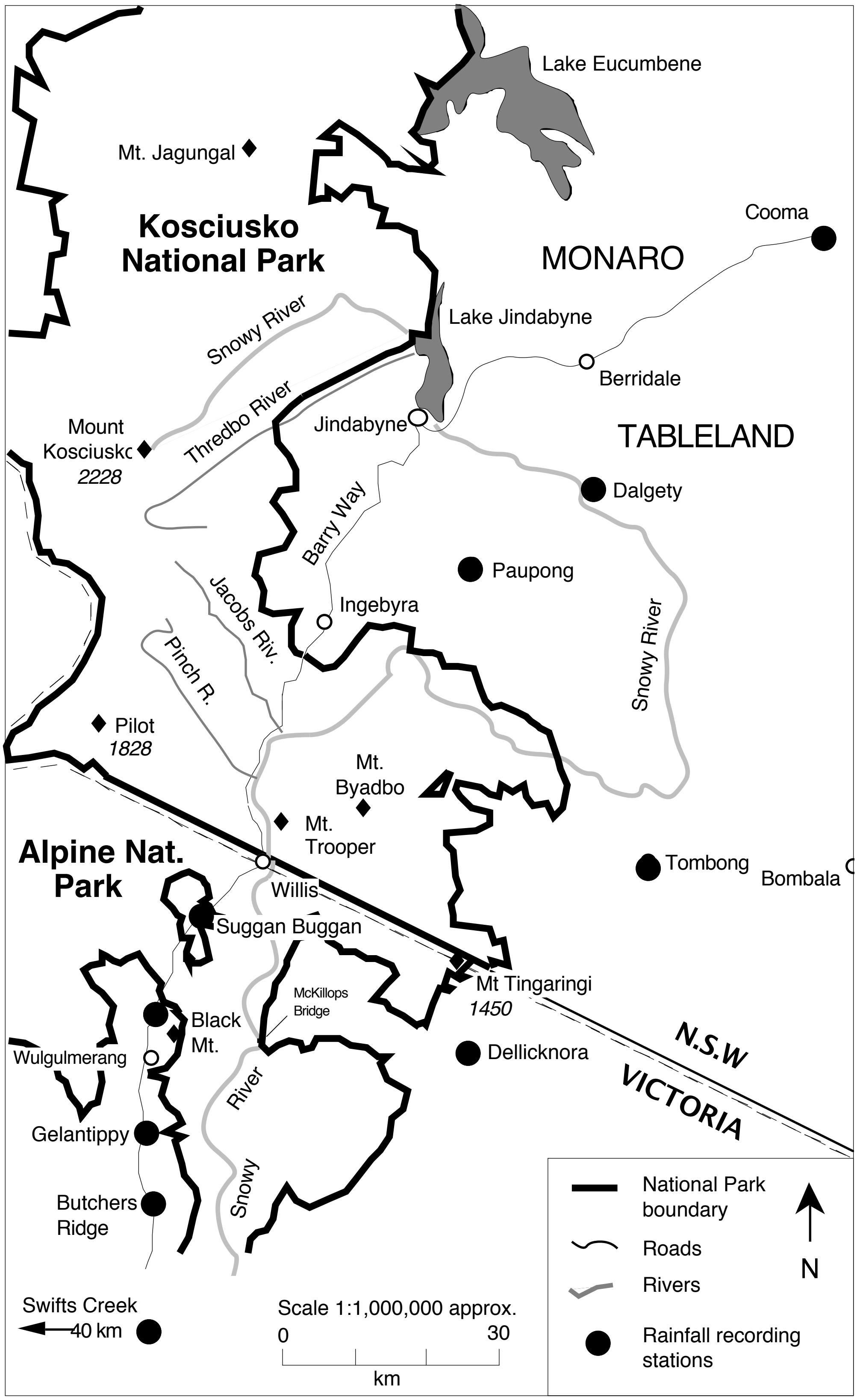


Figure 5.2 Location of the 10 rainfall recording stations used to predict rainfall for the study area.

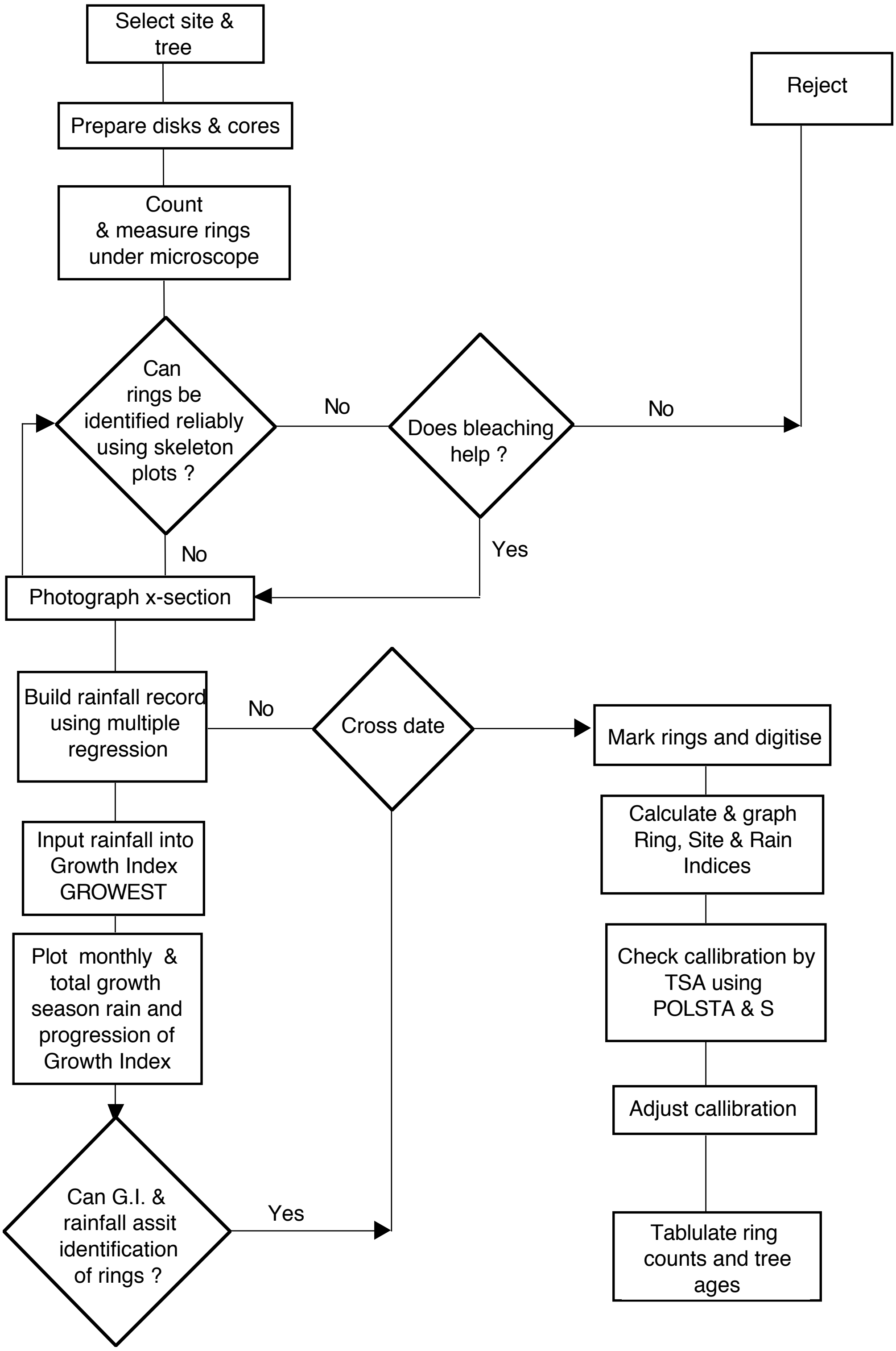


Figure 5.3 Flow chart of decision making procedures and methods for tree ring identification and analysis.

monthly rainfall for 64 years and total "growth season" rainfall were graphed separately on continuous paper. These provided an aid for more confidently identifying growth season and intra growth season rings.

Tree rings from trees 3, 5 and 6 were again cross matched giving careful consideration to the G.I., monthly rainfall and total growth season rainfall by progressing from the outer ring towards the tree centre for the first 20 or more rings from 1964-65 to 1982-83. Rainfall data were not available for the period 1984-1986 at the time of this analysis, however this did not provide any difficulties because the first three rings could be clearly identified and subsequent analysis proved the chronology to be correct. The relationship between total growth season rainfall and ring width was inspected using graphs. Ring width taken from rings interpreted as seasonal growth rings clearly appeared to be approximately proportional to growth season rainfall.

5.2.9 Analysis of the ring width and rainfall time series

The relationship between standardised ring width from the proposed chronology and standardised predicted growth season rainfall was evaluated using two methods. These were (1) time series correlation analysis, and (2) the Loess smoother method available in the program S (Becker *et al.*, 1989).

Correlation analysis

Absolute tree ring widths, mean absolute tree ring width, Ring Index, total growth season rainfall and total growth season Rain Index were calculated. Mean absolute tree ring width was calculated by taking the mean ring width of each ring from two transects within a single tree. Ring width was corrected to absolute scale because magnification varied slightly between photo transects.

Tree ring widths *(W_t)* were standardised by calculation of a Ring Index *(I_t)* by dividing each ring width for growth season *t* by the expected growth season ring width *(Y_t)* as in the following formula:

$$I_t = \frac{W_t}{Y_t}$$

This has the effect of removing the trend in growth caused by the growth curve of the tree and scales the variance so that it is similar throughout the length of the tree ring or time series (Fritts, 1976). The expected growth for each ring *(Y_t)* was computed from the nine ring moving average. Moving averages are the ring width averages for a given number of successive rings, in this case nine, the sequence being moved ahead one ring each time the average is computed (Fritts, 1976).

There are several other procedures for deriving the expected values which include fitting polynomials, negative exponential functions and lines fitted by eye. Each method has its disadvantages. Negative exponential functions are frequently used when precise chronologies are required and are usually the domain of the dendroclimatologist. In this case simple running means of appropriate width were all that was required for tree ring standardisation. This was especially the case in the outer rings where the initial tree ring classification was carried out. Here the growth curve can usually be assumed to be constant and the main function of the moving average is to filter out undesirable variance by smoothing out variability in proportion to changes which occur over periods greater than nine years duration. The selection of any given interval of moving averages can have the effect of smoothing out cyclic patterns, which are a function of the same interval. The nine year interval was selected as being sufficiently wide to smooth year to year variation but not remove longer term cyclic patterns and not sacrifice the data lost from the outermost rings when calculating the moving average.

Calculation of nine year moving averages requires the loss of data from only four years, or the first four growth season rings. To overcome this problem dummy variables were inserted to extend the ring sequence beyond the 1985-86 ring so that a ring index could be calculated from the outermost cross datable ring to the 1964-65 growth season ring selected for the initial trial analysis. Dummy variables were derived by taking the average of the last five rings then moving out one ring and so on to the fourth dummy ring.

A tree Ring Index was calculated for two transects on tree 6, site 1 for the section of outer rings from 1964-65 to 1982-83 and from 1920-21 to 1939-40 growth seasons to evaluate the relationship between ring width and rainfall using the new tree ring identification method. Rainfall was also standardised. A Site Index was calculated from the mean of the Ring Indices of trees 3, 5 and 6. The tree Ring Indices for the sub samples 1964-65 to 1982-83 and from 1920-21 to 1939-40 were tested for the null hypothesis that there was no correlation with the Rain Index.

The time series analysis program POLSTA (Green, 1985) was then used to further analyse the characteristics of the Ring Indices and the Rain Index. Cross correlation analyses between the Rain Index and tree 6 Ring Index for the periods 1964-65 to 1982-83 and 1920-21 to 1939-40, and for the combined trees 3, 5 and 6 Site Index for the growth seasons 1964-65 to 1982-83 were carried out. Analysis included the examination of the effect of positive and negative lag by growth season with increasing lag by increments of one unit. Graphical methods such as line plots, bar graphs, serial and cross-correlograms are used to present the results.

Loess smoother

Further analyses of the ring width series for tree 6 and the combined mean ring width series for trees 3, 5 and 6 were carried out using the non-parametric Loess smoother. This was available in the "S" computer program (Becker *et al.*, 1989). The window width was set to half the number of years in the series (40 years). The original ring width series for each tree was $\log_e$ transformed. The difference between the observed transformed ring width and the smoothed expected value on the $\log_e$ scale was calculated to produce a standardised ring width series thus:

$$\text{Log}_e\ I = \log_e W - \log_e M_w$$

Rainfall data were treated in the same way and the results of rainfall versus ring width were plotted on a $\log_e$ scale for tree 6. These steps were repeated to produce a Site Index ($\log_e$ I) for trees 3, 5 and 6.

Whilst this method has its merits, a nine ring moving average of ring width was used throughout the remainder of this study to standardise ring width series due to its adequacy and convenience.

5.3 Results

5.3.1 Soil description

The solum exposed in a road cutting just below site 1 was well drained. Soil depth varied considerably across the site but was generally around 40-75 cm depth. The transition to heavily weathered bedrock (granodiorite) was not sharp and the depth of root penetration, for example, would be much deeper than the soil depth suggested. The granitoid bedrock was intersected by numerous aplite or similar veins which are more resistant to weathering.

The soil examined in detail had a depth of only 45 cm and was light grey in colour overlying red at 25 cm depth in the dry state, and showed a degree of pedologic organisation with an unbleached A_2 horizon. Texture was difficult to determine due to the presence of much coarse quartz sand and what appeared to be aplite fragments to 4 mm in size. The texture was loamy sand to clayey loam sand overlying sandy loam. B horizon colour was 2.5 YR 3/4 in the moist state on the Northcote (1971) key. No mottling was apparent. The soil reaction trend was neutral (pH 6.0-6.5). The soil was moderately pedal and was reasonably well structured (A. Spate pers. comm.). The Northcote Key classification of this soil was Uc4.22. The nearest Great Soil Group equivalent was an "earthy sand". There was no sign of the sheet and gully erosion noted on the adjacent dry north aspect slopes.

5.3.2 Predicted rainfall for Suggan Buggan

The regression equations (“models”) derived for monthly rainfall prediction are presented in Table 5.1. The R-sq and F values ranged from 97.1% and 177.7 for April to 60.6% and 26.1 for December. The reduction in the sum of squares for each model for each month was significant at the 1% level (Table 5.1).

The MINITAB STEPWISE procedure was used to initially select predictors Black Mountain, Gelantipy East and Paupong in the regression model for March rainfall giving an R-sq value of 93.2%. Missing data in some years for the Gelantipy record for the full period 1920-1983 for which rainfall prediction was needed, required that Gelantipy East be removed from further consideration. Predictors from stations for the next best fit were accepted. Black Mountain and Paupong rainfall data were the next best predictors and resulted in a reduction of R-sq coefficient from 93.2%, for the larger model containing three predictors, to 72.6% for the smaller model containing two predictors. The F value remained significant at the 1% level (Table 5.1).

Predicted and actual rainfall were similar in most months (Fig. 5.4). Months with the greatest deviation of predicted from actual rainfall were November and December. January predicted rainfall deviated on few occasions from the actual rainfall and had a high R-sq of 91.6% and an F ratio of 92.83. The standard errors for predicted rainfall for each month by year are presented (Fig. 5.5). The prediction of Suggan Buggan rainfall was considered satisfactory.

The mean annual predicted rainfall from 1920 to 1983 for Suggan Buggan was 549.8 mm (*s*=137). This result is a little lower than Clayton-Greene's (1981) calculation of mean actual annual rainfall of 583 mm recorded at Suggan Buggan from 1957 to 1977. The predicted lowest rainfall year was 1979 with 320.4 mm and the wettest year was 1934 with 892 mm.

5.3.3 Growth Index

Weekly L.I., T.I., M.I., multifactor G.I. and 13 week moving average values for the these Indices were output from the GROWEST program for 64 years from 1920 to 1983 inclusive. The mean weekly values for each of the four indices over the 64 years were calculated. These values represent a model of the mean variation in the weekly progression of each index over the 12 month growth season (Fig. 5.6).

The multifactor G.I. indicated conditions were limiting for cell division in the winter of each year from May to August where the G.I. was less than 0.2. This was due mostly to lowered temperature and to a lesser extent lower light levels (Fig. 5.6). This indicated that there was likely to be an annual cessation of growth by plants which was likely to result in the production of thick walled cells in white cypress pine. There was a rapid increase in G.I. during the spring peaking in October. A moisture deficit occurred, causing a reduction in G.I. to 0.3-0.4, in January and February due to high summer temperatures and a decrease in summer rainfall. This indicated the possibility of intra growth season rings forming in summer months in some years. A brief cessation of growth is likely to result in a thickening of the tracheid cell walls in the cambium resulting in diffuse or faint intra growth season tree rings in white cypress pine. A smaller secondary peak in the G.I. in March-April was caused by lower temperatures and a slight increase in rainfall. Whilst rainfall was on average lower in winter than in summer, the M.I. was non limiting in winter and limiting in summer.

Thus, the multifactor G.I. indicated the likely occurrence of a bimodal growth season pulse in growing conditions for the study area. This pulse was most evident in the G.I. model for soils of 100-150 cm depth. In any year, one or more pulses in the G.I. were observed (Fig. 5.7). Growth pulses (peaks and troughs) varied considerably in magnitude and duration in any single growing season.

A comparison of the total growth season G.I. and total predicted growth season rainfall from 1920 to 1983 is presented in Figure 5.8. There was a close relationship between these two parameters.

Table 5.1 The regression equations and rainfall station predictors for each month for Suggan Buggan predicted rainfall, R-sq (coefficient of determination), standard error (SE), F ratio and significance level .

Month	Equation	R-sq	SE	F	Sig.
JAN	SB = - 0.4077 + 1.2078 BL - 0.1876 DE	91.6%	0.28	92.83	***
FEB	SB = 0.8219 + 0.9910 PA - 0.2884 CO	75.2%	0.44	25.75	***
MAR	SB = - 0.5457 + 0.6592 BL+0.392 PA	72.6%	0.16	72.08	***
APR	SB = - 1.00 + 0.815 BL + 0.521 DE - 0.144 TB	97.1%	0.17	177.69	***
MAY	SB = - 0.8851 + 0.9057 BL + 0.235 PA	92.6%	0.31	106.13	***
JUN	SB = - 0.4682 + 0.7825 BL - 0.1103 PA + 0.3601 TB	90.6%	0.22	51.56	***
JUL	SB = - 0.390 + 0.895 BL + 0.253 PA - 0.122 TB	94.4%	0.21	90.47	***
AUG	SB = - 0.7832 + 1.11 BL	82.7%	0.22	85.80	***
SEP	SB = - 0.456 + 1.01 BL	87.5%	0.19	126.00	***
OCT	SB = - 0.0847 + 0.9619 BL	81.1%	0.20	73.01	***
NOV	SB = - 0.001527 + 0.95 BL	83.5%	0.22	43.16	***
DEC	SB = 1.5953 + 0.6316 DA	60.6%	0.55	26.12	***

KEY:

Abbreviation	Bureau of Meteorology Station Number	Station Name
CO	70023	Cooma (Lambie St.)
SB	84068	Suggan Buggan
DA	71015	Dalgety Post Office
TB	70084	Tombong
PA	71014	Paupong
BU	84007	Butchers Ridge
GE	84017	Gelantipy East
BL	84044	Black Mountain
DE	84014	Dellicknora
SC	84035	Swifts Creek

*** = significant at the 1% level

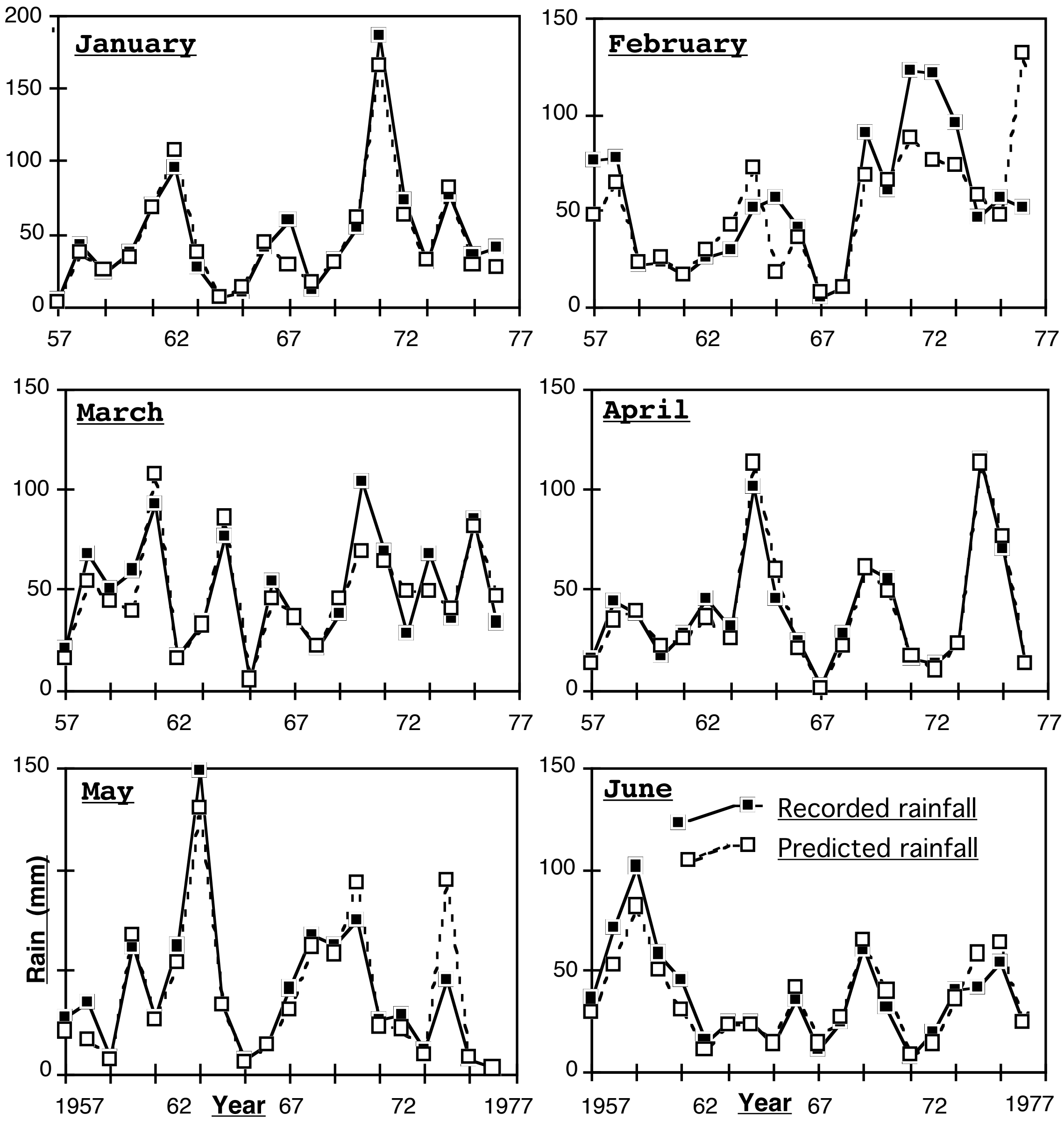


Figure 5.4 Comparison of recorded rainfall (mm) with predicted rainfall for Suggan Buggan for each month for the period 1957 to 1976. Predicted rainfall was derived by multiple stepwise regression of Suggan Buggan monthly rainfall against 9 rainfall recording stations in the surrounding area for the 20 year period.

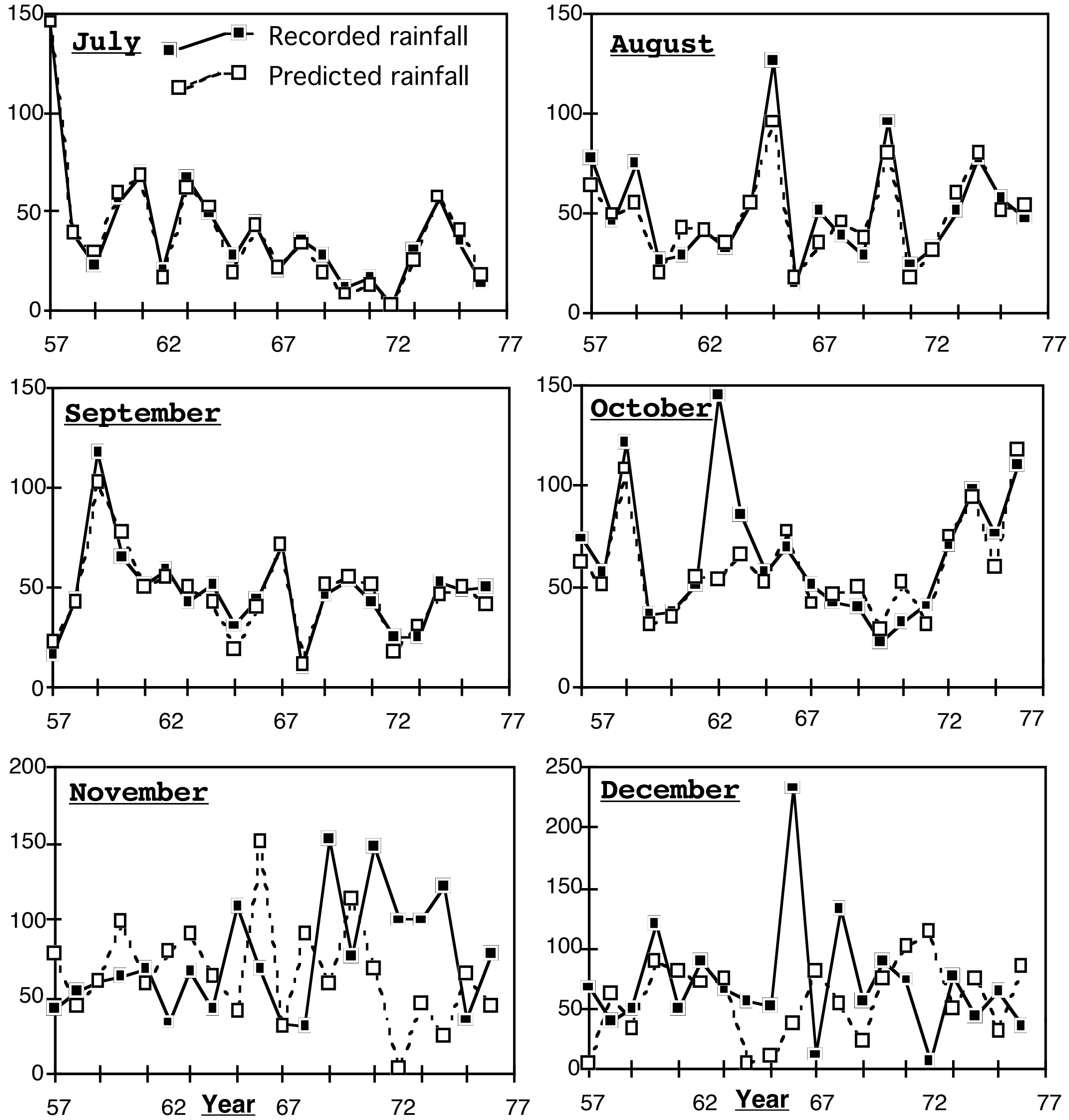


Figure 5.4 (cont'd.) Comparison of recorded rainfall (mm) with predicted rainfall for Suggan Buggan for each month for the period 1957 to 1976. Predicted rainfall was derived by multiple stepwise regression of Suggan Buggan monthly rainfall against 9 rainfall recording stations in the surrounding area for the 20 year period.

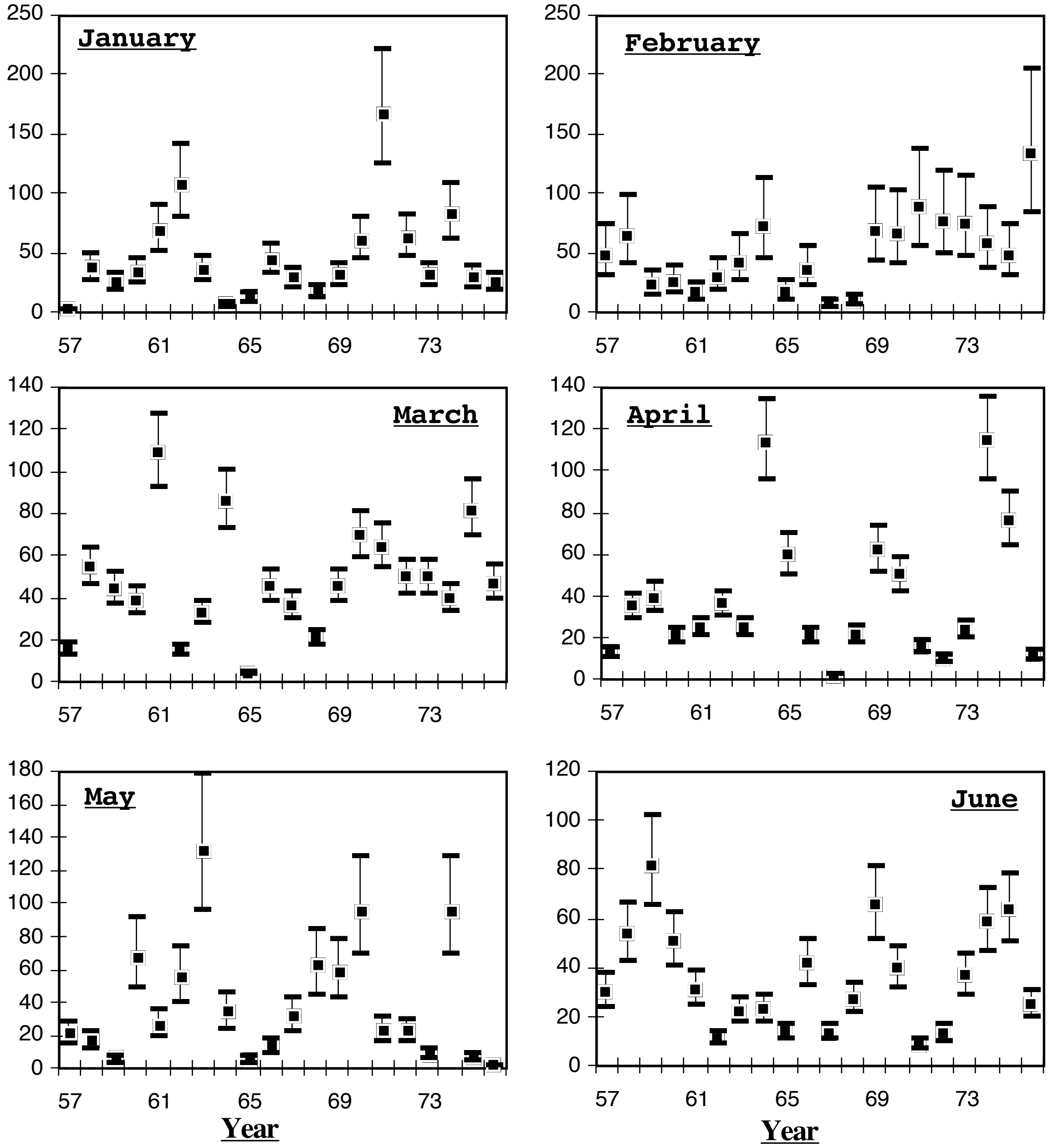


Figure 5.5 Standard errors for predicted monthly rainfall (mm) at Suggan Buggan from 1957 to 1976 inclusive. The standard errors were transformed to normal values from the $\log_e$ values used in the multiple regression analysis, thus error ranges are multiplicative.

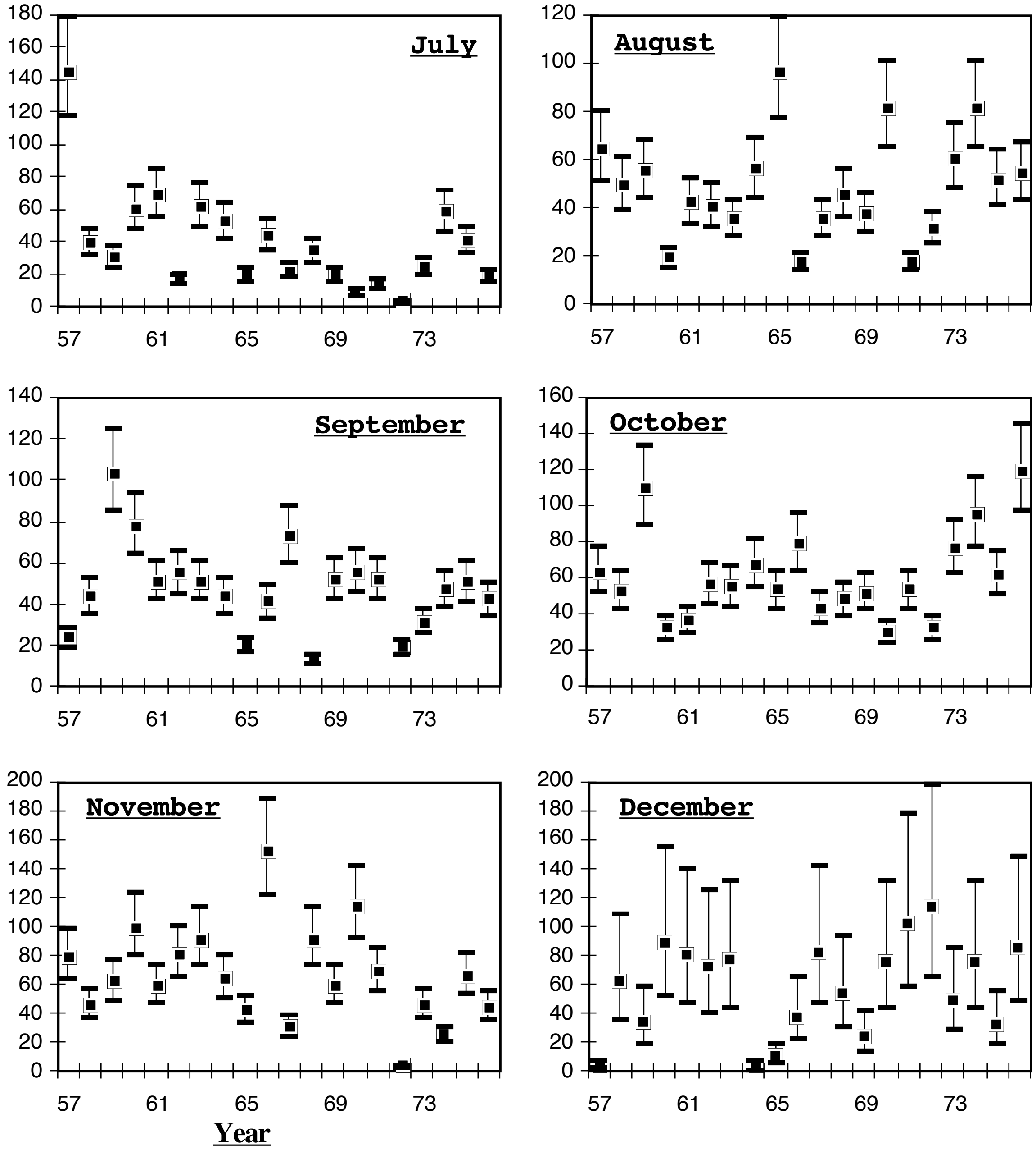


Figure 5.5 (cont'd.) Standard errors of predicted monthly rainfall (mm) at Suggan Buggan from 1957 to 1976, the period of common record with 9 other rainfall stations.

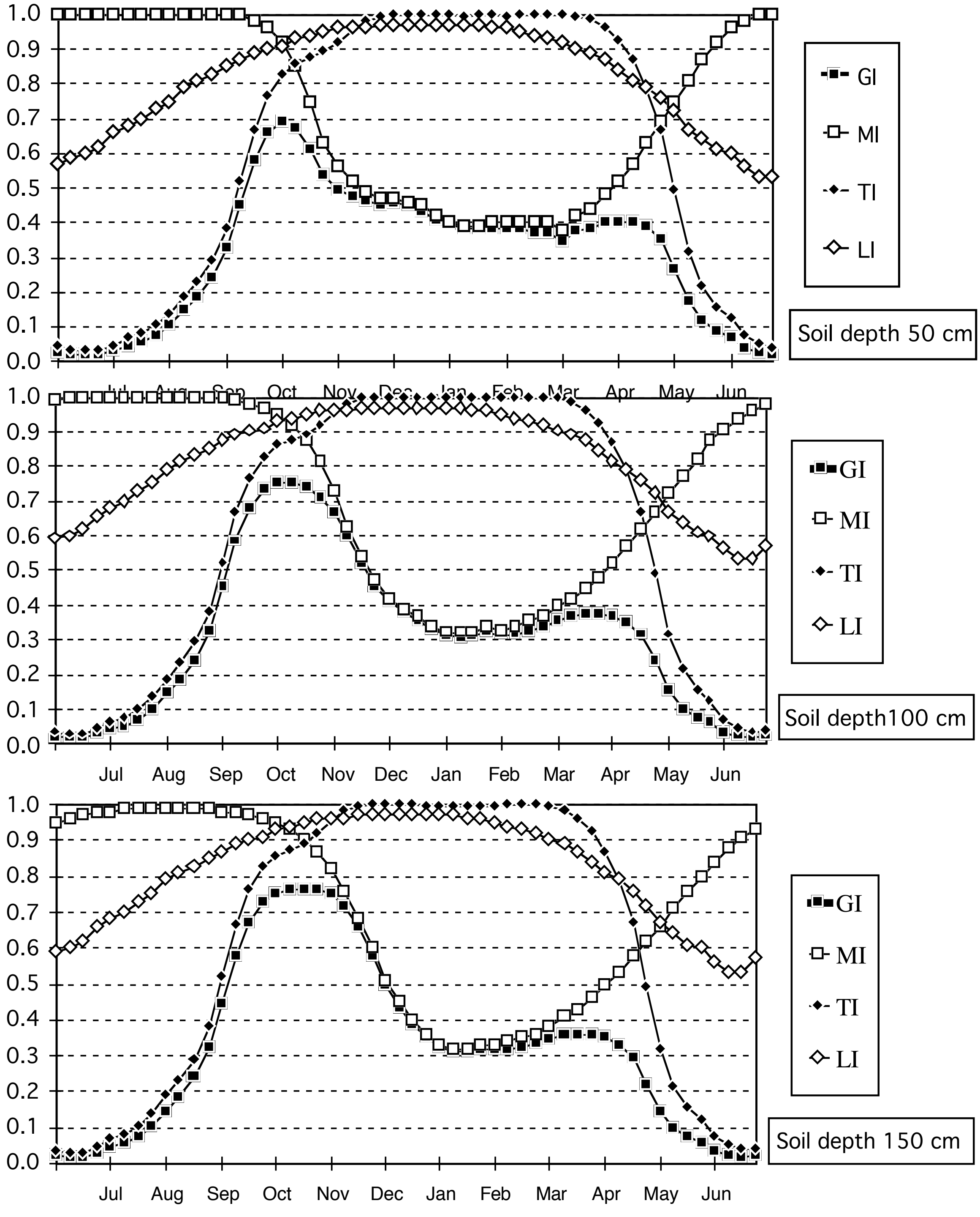


Figure 5.6 Progression of the Light Index (L.I.), Thermal Index (T.I.), Moisture Index (M.I.) and multiplicative Growth Index (G.I.) for Suggan Buggan for three soil depths, mean values for years 1920 to 1983. Predicted rainfall for Suggan Buggan was the only external variable entered to the model.

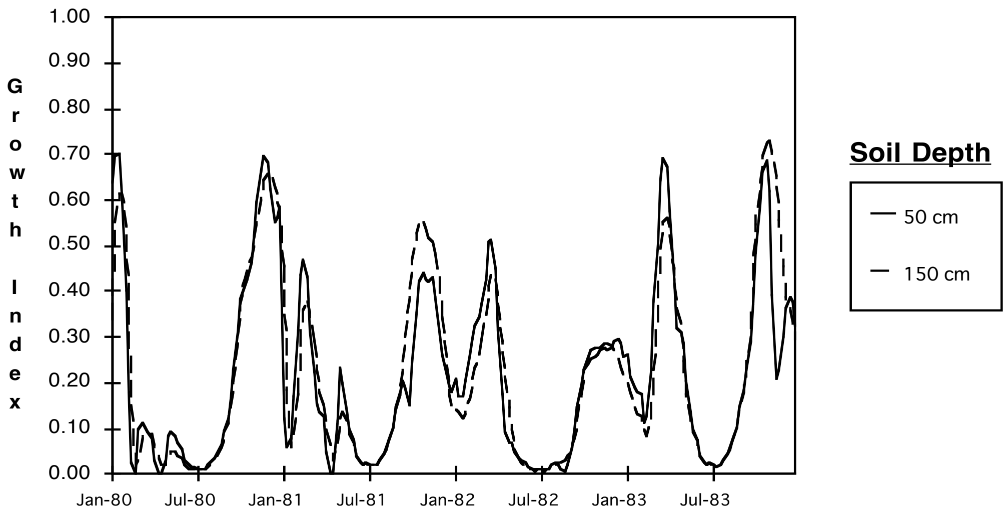


Figure 5.7 Comparison of the progression of the Growth Index (G.I.) for two assumed depths of soil, using predicted rainfall for Suggan Buggan from 1980 to 1983.

Table 5.2 Frequency of growth pulses where the G.I. was greater than 0.2 for soils 150 cm deep in Figure 5.7 during growing seasons from 1979 to 1983.

Growing period	No. of Growth Pulses
1982-83	2
1981-82	2
1980-81	3
1979-80	3

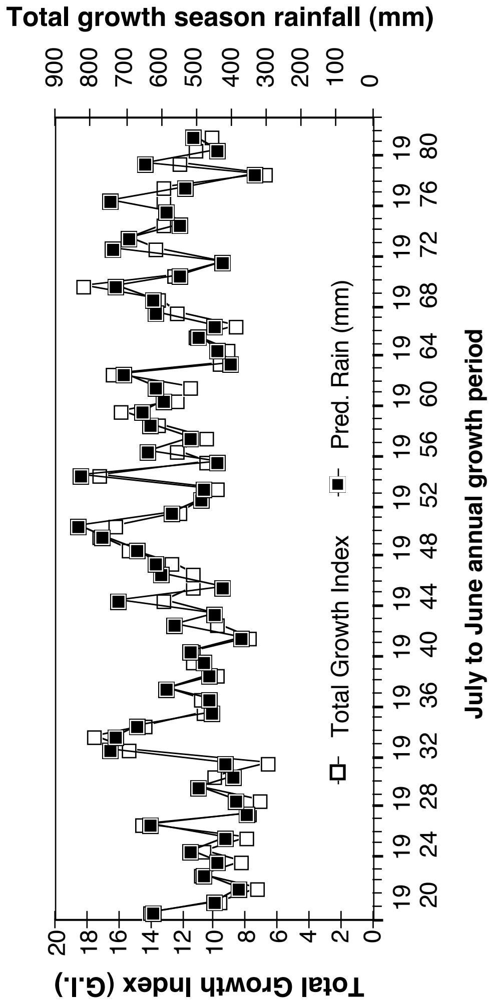


Figure 5.8 Comparison of the G.I. with predicted total growth season rainfall.

5.3.4 Identification of seasonal and intra seasonal growth rings

Seasonal growth rings in trees 3, 5 and 6 frequently had a distinctive darker appearance, usually with sharp outer boundaries and were often preceded by a narrow intra seasonal ring giving the appearance of a double ring in some cases (Fig. 5.11). Intra growth season rings mostly had diffuse boundaries and or lighter appearance than growth season rings. Some intra growth season rings were considered to be false rings i.e. they did not extend any substantial distance around the circumference of at least two trees. Identification of seasonal growth rings was achieved only after simultaneously examining enlarged photo cross sections of at least three trees (3, 5 and 6) and graphs of predicted growth season rainfall and G.I. Growth season rings produced in normal to high rainfall growth seasons were more readily identified. Very narrow growth season rings were laid down in some low rainfall years, sometimes with no apparent intra seasonal rings. This proposition was supported by the presence of a series of wide rings before or after drought years which correlated well with rainfall. No evidence of missing seasonal growth rings was found in the chronology.

The relationship between the tree 6 growth season Ring Index and Rain Index for two sample periods is illustrated in Figures 5.9 and 5.10.

5.3.5 Ring width and rainfall time series

Growth seasons 1964-65 to 1982-83 for tree 6 and trees 3, 5 and 6 combined

There was a significant correlation of Ring Index versus Rain Index for tree 6 ($r=0.5$, $n=19$, Fig. 5.9, 5.12). For the Site Index a shorter period was analysed to remove the effect of the large differences between the Site Index and Rain Index in the growth periods 1964-65 to 1966-67. In these years the Ring Index was relatively high despite very low rainfall. There was a significant correlation of 0.7 for the period 1967-68 to 1983-84 (Fig 5.17).

Cross-correlograms were produced with forward and backward lag with rainfall in increments of one year using POLSTA (Green, 1985). Cross-correlograms plot the correlations (range -1.0 to +1.0) with incremental forward and backward lag of the first named series against the second series. Significant correlations were observed with the maximum correlation of ring width and rainfall occurring at lag 0 (Figs. 5.12, 5.17 and 5.20).

Serial or auto-correlograms of Ring Index and Rain Index were produced for the period 1964-65 to 1982-83 (Figs. 5.13, 5.14). Auto-correlograms examine whether there was a time lag in a single parameter. For example, is the width of a ring in one year related to or correlated with the width of a ring in another year? There was no significant evidence of such lagged affects in the sampled ring sequence (Fig. 5.13). The auto-correlogram of Rain Index also indicated that there was no evidence of significant lag with one year’s rainfall being correlated with rainfall in the next year or previous year (Fig. 5.14). In this analysis lags greater than about three years should be ignored due to the small sample size.

Growth seasons 1920-21 to 1939-40, tree 6

The correlation analysis and cross-correlogram of Ring Index and Rain Index indicated a correlation r=0.42, n=20, n.s. (Fig 5.10, 5.18). A distinct shoulder on the cross-correlogram of r=0.28 at lag +1 (Fig. 5.18) gave an indication that there may be a lagged affect or that the cross dating was out by 1 ring. Upon further examination of the data an adjustment of ring width by -1 growth season for the segment 1926-27 to 1934-35 was made (Fig. 5.19). The cross-correlogram following this adjustment showed a significant correlation of Ring Index versus Rain Index of r=0.67, n=20, sig. (Fig. 5.20). The serial-correlogram of the corrected absolute mean ring width indicated a small positive auto-correlation (r =< 0.2) effect remaining after adjustment (not illustrated).*Loess smoother*

The Loess smoother line fitted to the growth season tree ring width series prior to ring adjustments using POLSTA, illustrated for trees 3, 5 and 6 from 1920 to 1983, indicated an approximately linear trend in the tree ring series (Figs. 5.21 to 5.23). The plots of the Site Index for trees 3, 5 and 6 against $\log_e$ of the predicted growth season rainfall for Suggan Buggan and $\log_e$ of total growth season G.I. are presented in Figures 5.24 and 5.25 respectively. Both figures indicate a poor relationship between ring width and rainfall or G.I. for years of low rainfall or G.I. The upward curve above 6.4 on the abscissa (predicted growth season rainfall) (Fig. 5.24) indicates a strong linear relationship between ring width and rainfall. The upward curve above 2.2 on the abscissa (total growth season G.I.) (Fig. 5.25) also indicates a strong linear relationship. There appears to be a better overall relationship between ring width and total growth season G.I. than between ring width and predicted rain. I concluded that there was a strong linear relationship between the peaks in rainfall or G.I. and ring width.

5.3.6 Age estimates for regrowth white cypress pine

The above analyses combined with cross dating confirmed the final chronologies developed for trees 3, 5 and 6. The minimum ring count was based on these chronologies and provided the best estimate of age. The criterion used to identify annual rings in the above trees, combined with some cross matching with tree 6, allowed minimum ring counts for trees 2 and 4 (Table 5.3). The best estimate of age thus indicates that these trees are approximately 91 (86-96) years old from the tree centre to the cambium. Since the trees were sampled 0.5 m above ground level it is likely that the seedlings germinated several years earlier. Thus the estimated age could be approximately 90-100 years. This means that they probably germinated between approximately 1885 and 1895.

The minimum ring count is considered to provide a better age estimate than suggested by the maximum ring counts of 124 (109-141) rings for these trees. The maximum ring count included intra growth season rings and is therefore discounted as a reasonable estimator of tree age. The frequency of intra growth season rings was calculated from maximum ring count (including all rings) divided by the minimum ring count. Frequencies varied from 1.2, i.e.an intra growth season ring once every five seasons, to almost 1.5, or one intra growth season ring every second year.

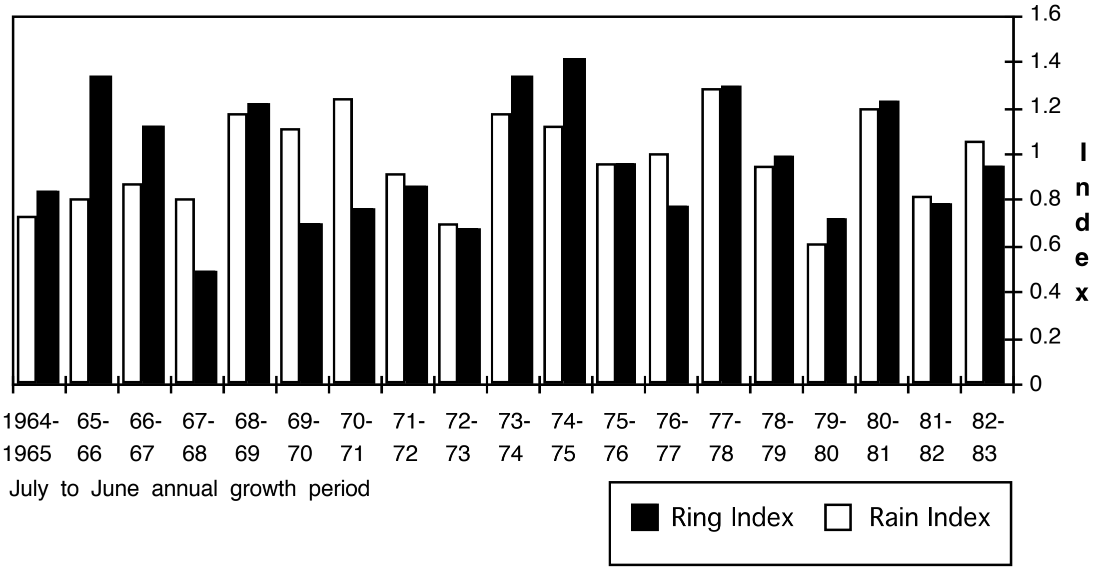


Figure 5.9 Comparison of the Ring Index from tree disk 6, site 1, Mount Trooper, with the Rain Index for the period 1964-65 to 1982-83. Correlation r=0.5, n=19, sig.

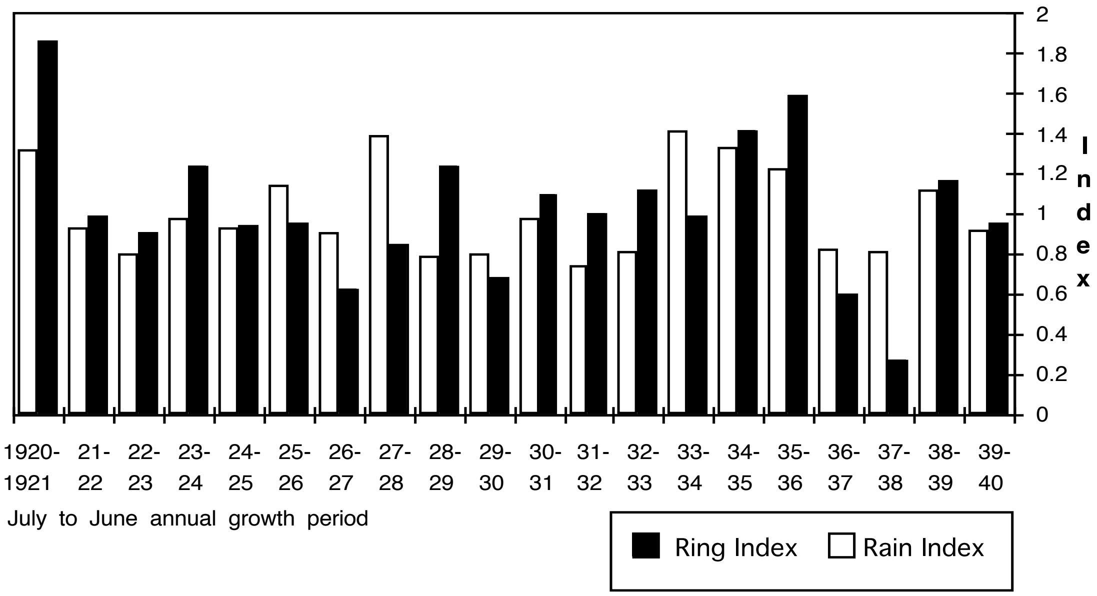


Figure 5.10 Comparison of Ring Index from tree disk 6, site 1, Mount Trooper, with the Rain Index for the period 1920-21 to 1939-40. Correlation r=0.42, n=20, n.s.

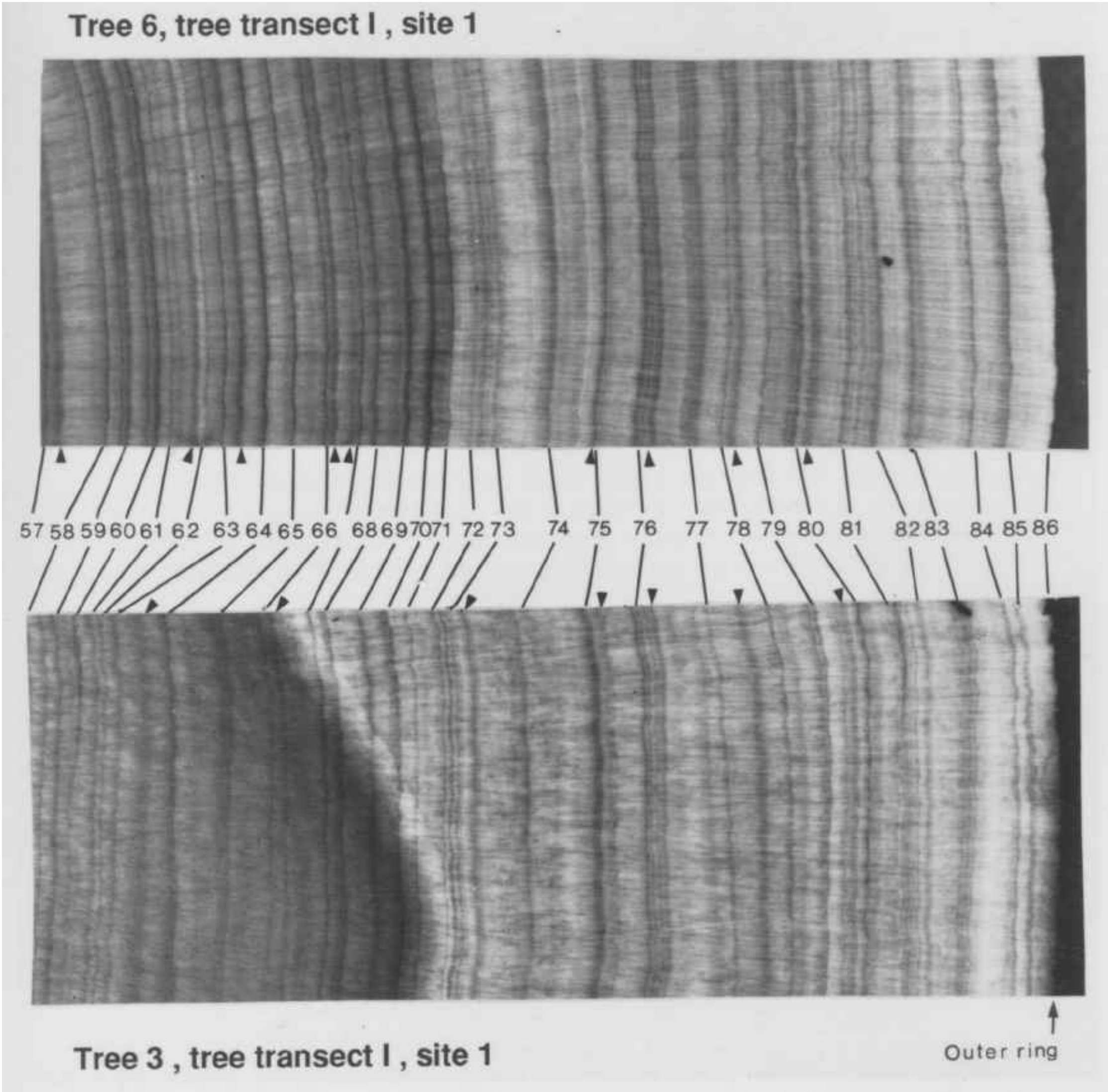


Figure 5.11 Enlargement (x 5) of the outer tree rings from tree 6 and tree 3, site 1. The year of each growth season ring is indicated. Cross matching between trees is indicated by lines linking the equivalent ring in each tree. Note rings indicated ▲ with a characteristic diffuse boundary are intra growth season rings as are rings with faint boundaries. Growth season rings are usually characterised by darker more distinct boundaries. Only by cross matching between several trees and several within tree transects was it possible to classify all tree rings correctly.

Note that the best correlation of rainfall with ring width is with 0 season lag. Results of lags greater than about 3 should be ignored for this number of data.

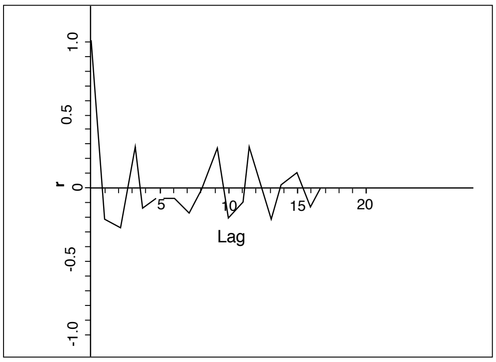


Figure 5.13 Serial or auto-correlogram of tree 6 Ring Index 1964-65 to 1982-83. This indicates very little auto-correlation with lag greater than 0 growth seasons.

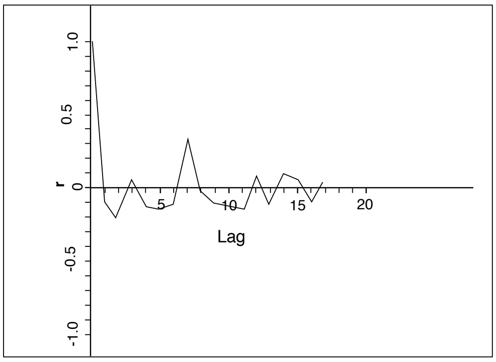


Figure 5.14 Serial or auto-correlogram of Rain Index 1964-65 to 1982-83.

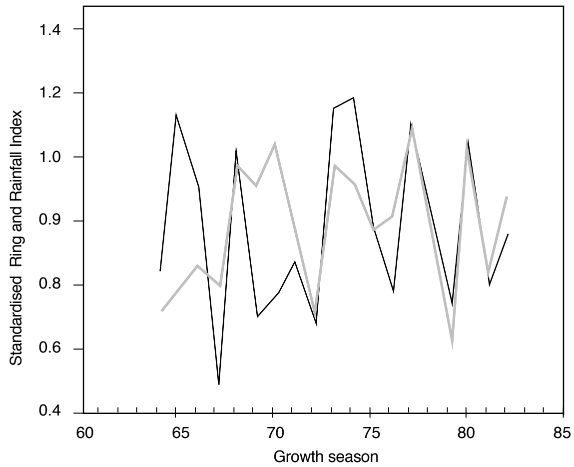


Figure 5.15 Standardised plot of tree 6, site 1 Ring Index, (solid line) against the Rain Index (dotted line) for 19 growth seasons from 1964-65 to 1982-83.

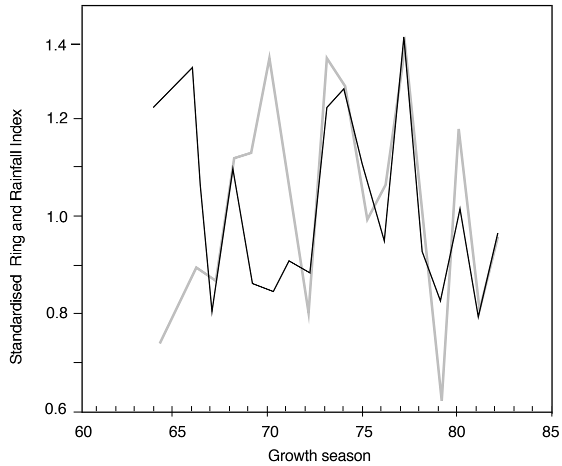


Figure 5.16 Standardised plot of the Site Index for trees 3, 5 & 6 (solid line) and Rain Index (dotted line) for the growth seasons from 1964-65 to 1982-83. Note the close relationship between rainfall and ring width from 1972-73 to 1982-83.

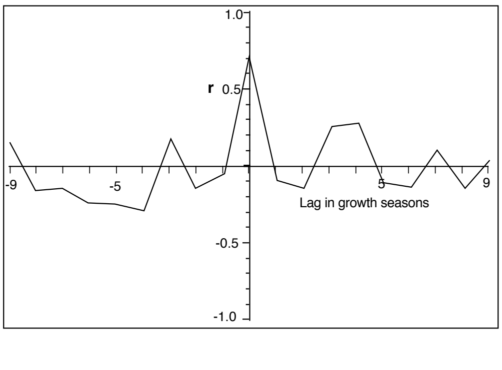


Figure 5.17 Cross-correlogram of the Site Index for trees 3, 5 and 6 against the Rain Index for growth seasons from 1967-68 to 1982-83. Note r=0.7, n=16, sig. with 0 lag.

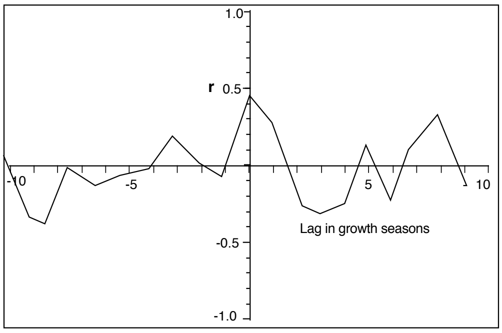


Figure 5.18 Cross-correlogram of the Ring Index for tree 6, site 1 against the Rain Index for growth seasons from 1920-21 to 1939-40. Note correlation r=0.42, n=20, n.s. with 0 lag.

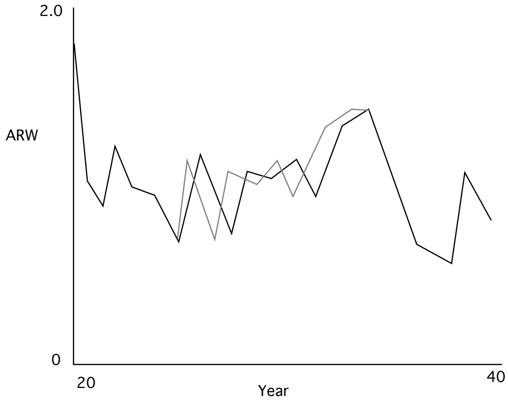


Figure 5.19 Illustration of the adjustment of a segment of the Ring Index for the growth seasons 1920-21 to 1939-40 which appeared to lag rainfall by 1 season in tree 6, site 1.

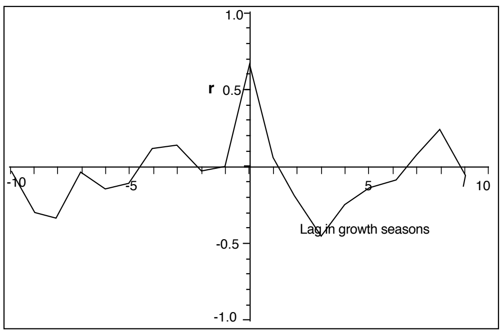
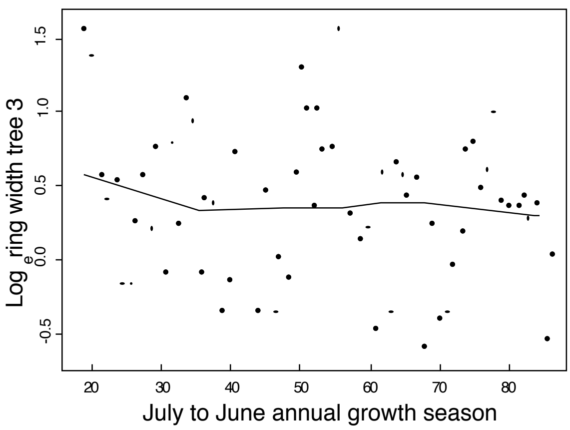
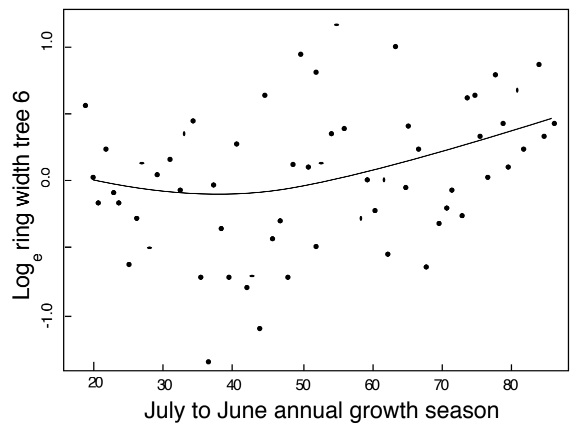
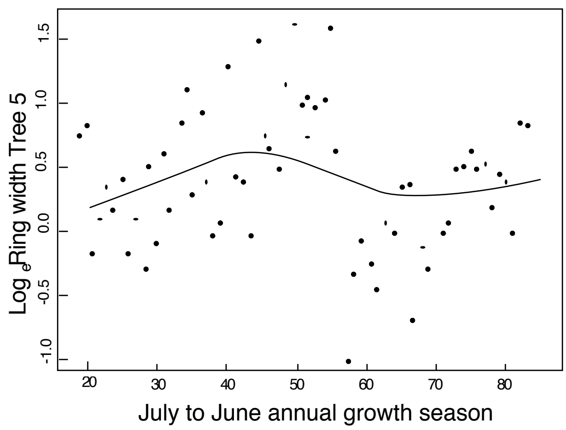


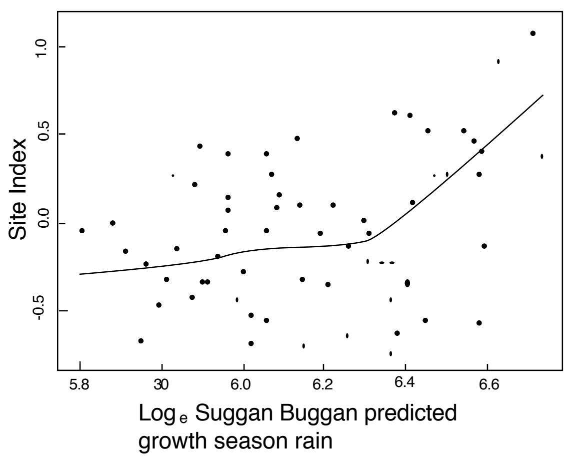
Figure 5.20 Cross-correlogram of the Ring Index of tree 6, site 1 against the Rain Index after adjustment of the segment illustrated in Figure 5.19 above by +1 growth season. Note significant correlation r=0.67.



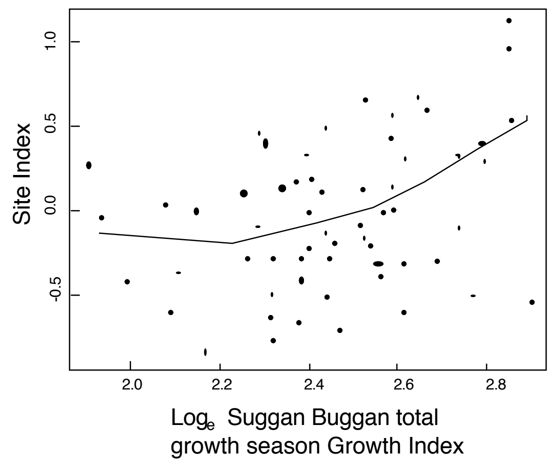




Figures 5.21. to 5.23 (clockwise from top left). Line of best fit, fitted by the Loess smoother for Loge growth season tree ring widths for trees 3, 5 and 6 site 1 over 63 growth seasons from 1920-21 to 1982-83.



Figures 5.24 Line of best fit, fitted by the Loess smoother for Site Index (trees 3, 5 and 6) site 1 over 63 growth seasons from 1920-21 to 1982-83 against Loge of predicted rainfall for Suggan Buggan.



Figures 5.25 Line of best fit, fitted by the Loess smoother Site Index (trees 3, 5 and 6) site 1 over 63 growth seasons from 1920-21 to 1982-83 against Loge of the Growth Index.

Table 5.3 Site characteristics, basal diameter, tree ring counts, frequency of intra growth season rings and the estimated calendar date of the centre of six live regrowth white cypress pine trees from site 1. All trees were 10-12 m high.

- • indicates a minimum ring count based on interpretation of growth season rings without rainfall and cross dating

+ indicates a minimum ring count based on tree ring cross dating and correlation with rainfall.

- indicates rings were not counted.

Tree No.	Aspect °	Slope °	Diameter 0.5 m o.b. (m)	Age estimate Max ring count	Min ring count	Frequency intra-growth season rings	Estimated date of tree centre	Comments (MT = Mt. Trooper, W = Willis)
1	60	28	0.30	-	-	-	-	Centre decayed
2	60	28	0.28	109	91 •	1.20	-	Some rings match with T6 M.T.
3	160	28	0.37	141	96 +	1.47	c1892-3	Rings match T5,T6 M.T. &T20 W
4	160	28	0.29	115	86 •	1.34	-	Some rings match with T6 M.T.
5	160	28	0.27	125	90 +	1.39	c1896-7	Rings match T3,T6 M.T. &T20 W
6	160	28	0.25	129	90 +	1.43	c1896-7	Rings match T3,T6 M.T. &T20 W

5.4 Discussion

The investigation achieved the aim of developing a method for identifying growth season rings in trees from a carefully selected site where summer moisture deficits would be least likely to cause limitations to growth in this species. Chronologies for 3 trees and age estimates for 5 out of 9 regrowth trees sampled were obtained. The study confirms the suitability of the species in certain circumstances for dendrochronological analysis, however the difficulties reported in the literature (Dunwiddie and LaMarche, 1980) were present and required specialised and time consuming procedures (Fig. 5.3) to overcome. These procedures and their implications for other dendrochronological studies are discussed.

5.4.1 Site and tree selection

As with most dendrochronological studies (Fritts, 1967), I found that the careful selection of sites and individual trees was imperative for success. In this case trees with good form, dense foliage cover, free of limb damage and adequate spacing provided suitable material for dendrochronological analysis. Important site criteria included an adequate depth of soil and a cool moist south aspect mid slope position. These environmental factors probably provided sufficient soil moisture to supply the trees during some prolonged dry periods in the growth season. This site was not so wet as to make the trees insensitive to climate, as might occur in trees which have permanent access to water. The lack of typical post-fire growth ring patterns in these trees, confirmed other evidence (Chap. 3) that the sampling site had a history of little or no disturbance from fire during the last 90-100 years. This is in marked contrast with ring patterns in trees from a hot dry site near Willis (Chap 6).

5.4.2 Preparatory techniques

Careful preparation of the disks was important for accurate identification of rings. Bleaching with a 5% solution of sodium hypochlorite for a short period (10 minutes) was found to assist by removing some of the dark staining in the heartwood caused by resin exudates. Excessive bleaching rendered some prepared samples useless for tree ring analysis. Conventional microscopic techniques were unsuccessful due to the inability to simultaneously examine and compare several cross sections. Similarly the use of conventional 5 mm core samples was not successful. The need for whole disk cross sections must be emphasised as this allowed adequate detection of compressed and incomplete ring sequences and selection of the best transects for analysis.

The photographic techniques suggested by Perlinski (1986) were improved and resulted in higher resolution enlargements of tree rings which were critical to successful cross dating. The photographs and disks were not sufficient on their own to correctly identify tree rings.

5.4.3 Predicted rain

The accuracy of the rainfall record predicted using regression models for each month was generally highly satisfactory. All the chosen models were statistically significant predictors of Suggan Buggan rainfall. Regression models for November and December were somewhat less reliable predictors of rainfall than other months. This may have been caused by occasional localised heavy thunderstorms for these months in some years. Removal of one data point from December would have reduced the residual error for this month substantially. This point was not removed because the diagnostic plots suggested that the data was Normally distributed following logistic transformation. Logistic transformation of the data prior to analysis had the effect of Normalising most of the rainfall data. There was some evidence of kurtosis (or peakedness) which is commonly seen in rainfall data.

This method assumed that the overall trend in the local distribution of rainfall during this period was constant. Costin (1949) found that there was no evidence for short term changes in temperature and rainfall on the Monaro.

5.4.4 Growth season and intra growth season rings

The Growth Index model obtained with the predicted rainfall data confirmed the likely existence of a growth season ring laid down in winter, as opposed to an anuual ring, which in Australia would occur in summer, as found by Perlinski (1986) in central Western Australian white cypress pine. In the study area this growth season ring was likely to be due to a prolonged cessation of growth caused by lower winter temperatures. In summer, limitiations to growth for shorter periods were caused by a moisture deficit. The resultant bimodal growth characteristic was reported in some years for measurements of white cypress pine shoot extension at Savernake by Clayton-Greene (1981). Similarly, growth in the New Zealand species *Agathis australis* at the start and end of the growing season was temperature dependent, with soil moisture deficits being important limitations to growth in summer (Palmer and Ogden, 1983).

The frequency of intra growth season rings varied from 1.2 to about 1.5, i.e. one extra ring on average every five years to one every second year. Intra seasonal rings may have been formed at any stage of the season but frequently these had the appearance of double rings which may have been formed late in the growth season. The occurrence of intra seasonal rings rarely exceeded three.The fact that this wide variation in the frequency and appearance of the intra growth season rings occurs in trees all growing within metres of each other indicates the complexity of interpretation of the cause of formation of these rings. Rings which did not complete the tree circumference were identified as false rings. False rings may be formed due to stress or loading on one side of the tree (Fritts, 1976).

The G.I. was investigated with the aim of obtaining a predictive model for the occurrence and width of intra growth season rings. This investigation was unsuccessful. It was not possible to explain the occurrence, frequency or width of intra seasonal growth rings simply by measurement of the asymptotes of cumulative G.I. pulses as was attempted. Several factors possibly combined to confound the accurate prediction of intra growth season ring width from summer pulses in the G.I. These factors include lack of highly accurate site specific rainfall data, the smoothing of predicted weekly rainfall by the conversion of predicted monthly rainfall to weekly rainfall using cubic Bessel interpolation, the wide variation of white cypress pine growth response to rainfall, and variation in microsite conditions such as insect attack, soil moisture and nutrients. Banks (1982) found that trees in snow gum stands grew at very different rates which he attributed to differing microsite conditions. He also found that in trees growing under mean optimum conditions, cell division appeared to follow Wilson's (1964) model, whereas trees growing in sub-optimal conditions produced cells at varying rates throughout the summer. Thus one tree might grow rapidly early in the season whilst a neighbour might grow more rapidly at a later time. The combined seasonal growth curves of these trees would then approximate Wilson's sigmoidal model. It is possible that similar behaviour occurs in white cypress pine which would explain why intra growth season rings appeared at proportionately different intervals between trees. In one tree an intra seasonal ring would appear relatively vague with diffuse boundaries while more sharply defined and much closer to the growth season ring in another tree. This compounds the problems of tree ring identification and is one of the reasons why ring identification cannot be achieved with a single tree cross section.

5.4.5 Analysis of tree ring and rainfall time series

Whilst there was a close relationship between ring width and total growth season rainfall in most years, for example 1972-73 to 1982-83 (Fig. 5.16), in a few years the ring width deviated from rainfall. Other factors apart from rainfall and temperature can affect ring width, for example Ash (1981) found a significant correlation between annual ring widths and the duration of the wet season and that deviation of ring width patterns from rainfall can be related to competition, disease and leaf herbivores. The timing of rainfall within the growth season can also be important. The years 1964-65 to 1966-67 showed a poor relationship with rainfall particularly for the Site Index. This may have been due to the fact that sufficient rainfall may have occurred in the main spring growth period even though the total rainfall was low. The severe summer drought of 1965 (Pook *et al*. 1966) would have reduced the total rainfall reading for this year. Reference to the G.I. for these years (Appendix 5) indicates that adequate conditions for growth are likely to have occurred in the springs of 1964, 1965 and 1966.

The Loess smoother indicated that there was a strong relationship between ring width and the growth season G.I. in years of high total G.I. but there was a little if any relationship in low total G.I. growth seasons. This same relationship was found between total growth season rainfall and ring width. In general the G.I. appeared to be slightly better related to ring width than was rainfall. It is possible that in lower rainfall years other factors such as insect attack, or lag effects in ring width caused by drought stress interfere with the climate signal. The fact that the tree ring series had approximately linear trends suggested that fitting a function such as a negative exponential or polynomial, which is a commonly used procedure in dendrochronology, to remove the growth trend in these trees (Fritts, 1976), was not required for this part of the tree ring series to adequately standardise the series.

5.4.6 Age estimates and chronologies

The chronologies thus established allowed estimation of the age of 5 of the 9 sampled trees (tree 1 had a decayed core and trees 7-9 were 5 mm core samples). The ages of regrowth trees sampled on Mount Trooper were estimated to be 90-100 years. This suggests that they germinated between approximately 1885 and 1895, prior to the arrival of rabbits (c1900). These tree ages are consistent with the episodes of major regeneration of white cypress pine reported by Lacey (1972) to have occurred throughout western NSW from the late 1870's until the arrival of rabbits.

Chronologies derived from tree rings in this study would not conform to the standards laid down for entry into the record of the National Tree Ring Laboratory in Tuczon, Arizona (Fritts, 1976), which require strict procedures for measurement and proof of absolute matching of the chronology to a standard tree ring data bank. However, data presented in this study and by Ash (1983) and Perlinski (1986) indicate that with adequate climatic data it is possible to use white cypress pine to construct chronologies which are relatively accurate. These chronologies were of sufficient reliability to be used for interpretation of the history of changes in forest structure, and for the calibration of the dates for significant events in the forest's history such as fire (Chaps. 6 and 7).

The small number of trees that were dated is considered a limitation of this work. Despite this, the trees sampled appeared representative of the majority of trees in these south facing stands and probably yielded ages which were indicative of the overall stand ages except for small patches of seedling regrowth which clearly has occurred in the last decade or so. Due to the extensive work required to calibrate these samples, further sampling on cool moist sites was considered beyond the scope of this study. Instead work was directed to cross dating old growth and regrowth trees on the hot dry sites to obtain age estimates and chronologies for studying fire history. These investigations are described in the following chapter.

5.5 Conclusion

White cypress pine in the study area lays down a regular growth season ring in trees growing in a suitable relatively cool moist site. In addition the species often lays down one or more intra growth season rings which are often less distinct than growth season rings. Limitations to growth caused by low winter temperatures were the primary cause of the growth season ring whilst periods of low soil moisture as a result of high temperatures, high evaporation and low rainfall in summer are likely causes of irregular intra growth season rings.

Tree ring identification in this species, particularly in areas of milder climatic regimes, presents extra difficulties that require special techniques and careful selection of material in order to construct a chronology. This study has confirmed Ogden's (1982) view that this species can yield useful chronologies in certain circumstances.

The Growth Index, which was developed for pasture crop prediction, can be applied to solve problems in forest situations. Whilst it would have been preferable to have long term on-site rainfall records, I demonstrated that adequate rain data could be derived in the absence of on-site data. The chronologies derived using the approach described above are considered adequate for the objectives of this study but may have limitations for climate reconstruction studies.

Chapter 6 Extending the dating of white cypress pine to a disturbed hot dry north aspect site

6.1 Introduction

The aim of the next phase of the investigation was to determine the age of representative stands of old growth woodland and regrowth white cypress pine occurring on hot dry north aspect sites. An additional aim was to obtain a means of elucidating the fire history of the study area which could yield further information about changes in the forest structure and forest dynamics resulting from European land use. The elaboration of the fire history is described in the next chapter.

6.2 Methods

6.2.1 Site selection

The principles of local site and tree selection enunciated by Douglass (1914), Fritts (1976) and Fritts (1982) were further considered and applied in this phase of the investigation. Two areas on hot dry sites were selected. One was near Willis (sites 2 to 8) and the other was a north aspect site on Mount Trooper (site 9) (Fig. 6.1).

(a) Willis (sites 2 to 8)

Willis sites were selected from a northerly aspect on 20-25° slopes with moderate soil depth within a single small catchment north of the Snowy River, 1.7 km north west of Willis. They were highly disturbed with evidence of sheet and gully erosion resulting in bare and sparsely grassed areas caused by the loss of most of soil horizon A and competition from regrowth white cypress pine. The sites contained old growth woodland and dense regrowth white cypress pine at mid elevations between 350-380 m A.S.L. Extremely rocky sites were avoided.

(b) Mount Trooper (site 9)

The Mount Trooper site was selected from a north aspect on a 20-25° slope with moderate soil depth near the top of a ridge. It was similarly highly disturbed with evidence of sheet erosion as above. Extensive partially collapsed sections of an old timber fence (Plate 3.1, Fig. 3.1) passed through the site suggesting an absence of fire since its erection.

6.2.2 Tree sampling

The Willis sites appeared to be representative of hot dry north aspect slopes in the lower Snowy River Valley white cypress pine - white box stands. The structure and density of white cypress pine and the understorey in the vicinity of the tree 20 is illustrated in Plate 6.1. Slopes varied but were predominantly 20-25° with a sparse cover predominantly of *Poa spp*. and *Themeda australis*. A high percentage of bare soil and exposed rocks was present. Transect 1 (Chap. 3) provided a description of canopy cover and tree density at these sites.

Hundreds of trees were inspected for presence of fire scars and sounded with a mallet for evidence of a solid centre. Those trees with the greatest number of external fire scars with a good crown shape were selected. Many of the dead old growth woodland trees contained rotten cores and were avoided. General morphology and condition of old trees were considered as indicators of relatively good growing conditions. Trees with poor shape, collapsed or missing branches were avoided.

Ten dead and 2 live old growth woodland trees, and 8 regrowth trees were sampled from the Willis sites (2-8) and 4 old growth woodland trees were sampled from Mount Trooper (site 9) in 1987 and 1988. Two or 3 disks 4-8 cm thick were cut about 0.5 m above the base of each tree to avoid the most severe basal fluting. Tree number, site number, height, circumference over bark and tree condition (live or dead) were recorded. The position of each tree sampled was recorded on a sketch map (Fig. 6.1).

A disk from each tree was prepared for photography using methods already described. Photographic enlargement prints pasted in strips of 6.25 times magnification were made of selected transects on each tree disk.

6.2.3 Soil description

Soils were investigated to evaluate whether any major differences occurred in soils at the sites chosen for dendrochronological analysis. Texture and depth were considered important factors which might influence the ability of a soil to store water and thus affect the response of a tree to periods of moisture stress. Trees on steeper slopes with more freely draining soil might be more frequently stressed than trees on deeper soils on more gentle slopes. Observations of such site information can assist in interpretation of the response of a tree to a particular site and guide the worker in selection of further material (Fritts, 1976).

Two soil cores were sampled with a 4 inch auger near tree 20 (site 8) on the crest of a broad gently sloping flat ridge and on the steeper slopes near trees 5 and 6 (site 3) near Willis. Texture, depth, pH and colour were examined to a depth of 0.70 m. Soils were classified using Northcote’s (1971) key.

6.2.4 Cross dating to Mount Trooper north aspect site

The photographs from tree disks sampled from site 9 on Mount Trooper were examined to try to identify growth rings and cross date to trees from the cool moist Mount Trooper sites. The rings of all trees were too narrow or indistinct to establish accurate recognition. Cross matching was not possible, hence no dates for these trees could be established.

6.2.5 Cross dating from Mount Trooper to Willis sites

The samples from the Willis sites were next examined. Exhaustive visual comparisons of the appearance of growth patterns in tree rings were made between many combinations of old woodland and regrowth trees to see whether firstly, cross matching and then cross dating could be carried out between (a) trees within the hot dry Willis sites and (b) trees from the Willis and Mount Trooper sites. Once cross dating was established between live trees from both areas it was possible to extend the cross dating of the more distinct heartwood rings in live tree 20 (site 8) to dead old growth woodland trees on the nearby dry hot sites 2 and 3 near Willis. The dates of the tree centres of live and dead old growth woodland trees were then estimated.

Ring counts of all discernible rings on each regrowth and old growth tree from the Willis sites were recorded. Growth season rings identified through cross matching procedures were marked on white 3M Post-it™ tape strips and measured using a standard metric ruler. Ring widths from two transects on each cross matched tree were marked up, measured and entered into a computer for numeric and graphic analysis. The tree ring width measurements from the photographs were corrected for scale.

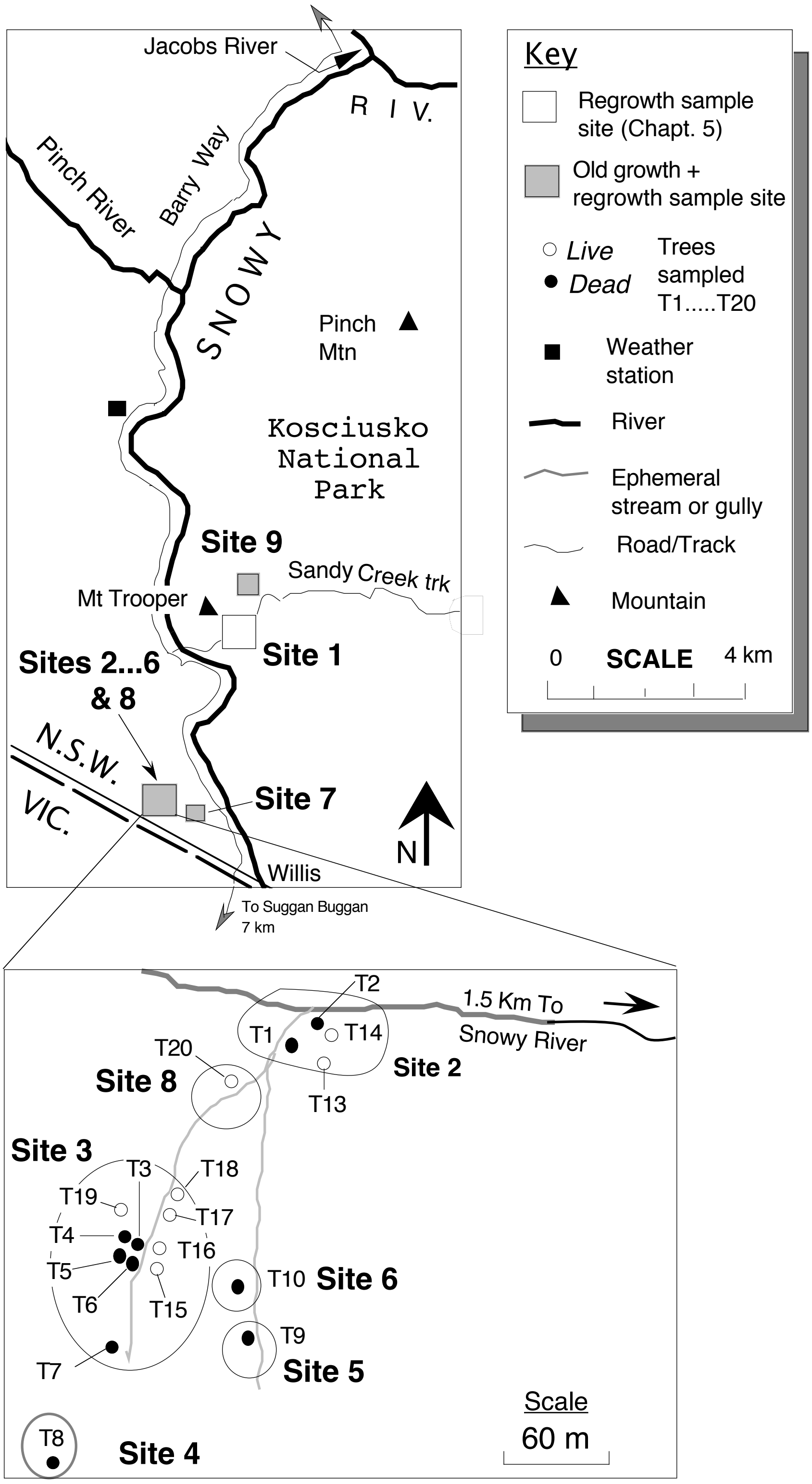


Figure 6.1 Trees sampled at sites 2-6 & 8 at which old growth and regrowth white cypress pine were sampled 1.7 km NW of Willis. One old growth and 1 regrowth tree were sampled at site 7 and 4 old growth trees at site 9.

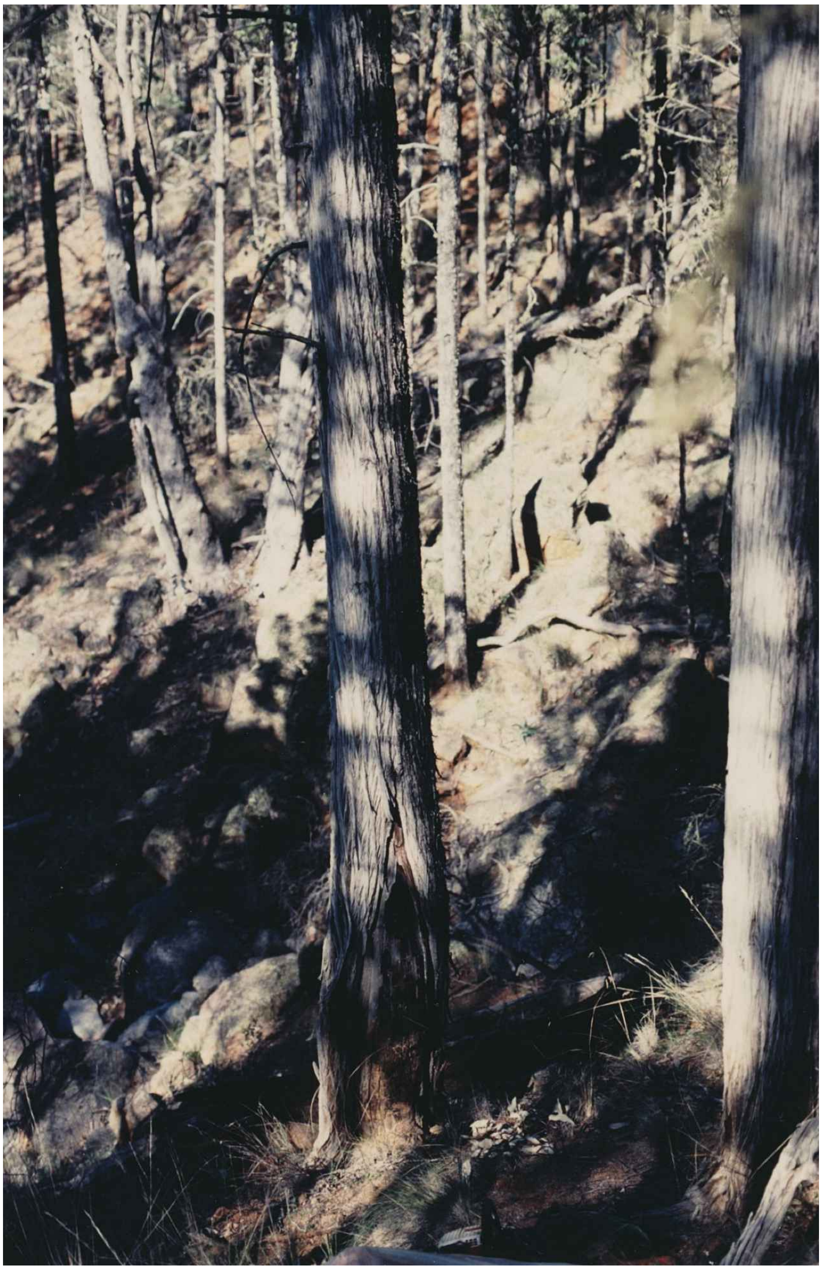


Plate 6.1 Tree 20 (site 8 Willis) was one of the few live fire scarred old growth woodland white cypress pine remaining on hot north aspect slopes. Note dense regrowth trees of smaller diameter in the background.

Plate 6.2 A typical clump of old growth woodland white cypress pine trees with wide spreading branches near transect 3 with dense regrowth in the background.

Tree ring widths were standardised using procedures described in Chapter 5 to derive a Ring Index for each transect. A tree Ring Index was calculated by taking the mean of the two standardised index values for each ring. A Site Index, based on the mean of the tree indices for trees 3, 5 and 6 (Mount Trooper), was calculated. The many missing rings in most of the trees sampled from the Willis sites prevented the preparation of a Site Index based on the mean of the indices from all cross datable trees for this site. Tree 20 was the only tree sampled for which cross dating with trees from Mount Trooper could be carried out satisfactorily, and therefore was used to provide a Site Index for Willis.

6.2.6 Verification of the chronology

A relationship between rainfall and ring width for trees from Mount Trooper cool moist site (site 1) was established (Chap. 5). Therefore I investigated the use of rainfall data to verify the results of the chronology proposed for tree 20.

The Ring Index for tree 20 (site 8) and a Rain Index of July to June total growth season rainfall for Cooma were graphed and compared. Adjustments of one and two growth seasons were examined. The rainfall data from Cooma (Lambie St.) was used because it was the closest station for which records were kept through the late nineteenth century and early twentieth century and for which a proven relationship had been established with rainfall in the study area (Chap. 5). The period investigated was 1876-77 through to 1924-25 as tree rings after this date were cross dated with tree 6 (Mount Trooper) and did not appear to exhibit the need for adjustment of ring dates.

6.2.7 Radiocarbon dating

Four old growth woodland white cypress pine trees selected for tree ring analysis from Willis sites 2 to 8, were sampled for radiocarbon dating to provide a further verification of dates of tree rings. Criteria for selection of trees for radiocarbon dating were:

(a) trees in which it was possible to cross date rings permitting a comparison of radiocarbon ages with dates determined using dendrochronology;

(b) trees with multiple fire scars;

(c) trees representative of old growth woodland found on north facing aspects in the area occupying the same general area and slope class.

Two tree disks were cut from felled trees approximately 0.5 m from the tree base and prepared for dendrochronology. All distinct and indistinct tree rings representing a maximum ring count were counted on photographic strips enlarged 6.25 times along radial transects of one selected disk from each tree. Using a chisel and mallet, wood samples containing a known number of identifiable rings were peeled from near the centre of each sample. The straight grain of this species made this task relatively simple. The tree centre was not included in samples since too many rings for a small volume of cellulose would have been obtained, further reducing dating accuracy. Samples of approximately 20 gm were required. Wood samples were also taken from rings corresponding to the position of fire scar 1 of tree 1, fire scar 2 of tree 6 and fire scars 1 and 5 of tree 20 (Chap. 7). The tree rings excised were recorded on the black and white photo enlargements with Omnichrom pencil. All specimens were weighed, labelled and submitted to the Radiocarbon Dating Laboratory at the Australian National University for dating. The wood samples were washed in an ultrasound bath and dried then chopped into small splinters and milled. The milled wood was subject to solvent extraction, then treated with sodium chlorite to leave holocellulose, rinsed and dried. The material was further treated with hot 5% w/v NaOH, rinsed and dried (Green, 1963; Head, 1979). Samples were placed into a scintillation counter for ^{14}C dating. Conventional radiocarbon ages were obtained from the prepared wood cellulose from the four trees (Gupta and Polach, 1985; Stuiver and Polach, 1977).

6.3 Results

6.3.1 Soils at sampling sites

The soils were examined with reference to Northcote (1971). The area sampled varied in slope from 10° to 20° with a north-easterly aspect. The soil profile demonstrated a weak pedologic organisation. The solum was a dark reddish-brown over yellowish-red with a slight texture increase from sandy loam to sandy clay loam. There were a few coarse decomposed granitic fragments. The B horizon colour was 5 yr 5-6 in the moist state and no mottling was apparent. Soil pH was neutral (pH 6-8). The soil was moderately well structured especially in the upper part of the solum and had an earthy fabric. The Northcote Key classification for this soil was Uc5.22. The nearest Great Soil Group equivalent was sand. This site was considered better than the cool moist site sampled at Mount Trooper in terms of texture and water potential (A. Spate pers. comm.). The area near tree 20 appeared to be a run-on site indicated by the presence of a thin veneer of loose coarse grained material on top of darker more fine grained material.

In general, soil sheet erosion appeared to be occurring more rapidly near trees 5 and 6 than tree 20, indicated by considerable evidence of pedestalling and exposure of rocks. Due to greater slope these trees were likely to experience greater moisture stress than nearby tree 20 which was growing on slightly deeper soils on a more gently sloping microsite.

6.3.2 Cross dating

Many combinations of trees were examined in attempts to cross date rings between trees. Tree 20 site 8 was the only live tree which could be cross dated to the regrowth trees from the cool moist south aspect Mount Trooper site (site 1). Cross dating was based on cross matching rings from tree 6 (site 1 Mount Trooper) and tree 20 (Fig. 6.2). Cross dating could only be carried out in the overlapping heartwood segment from growth season 1921-22 to 1953-54. Indistinct rings in the pale sapwood of tree 20 prevented cross matching from growth season 1954-55 to the date of tree sampling in 1988. Several missing rings were noted in tree 20. The good cross match between the overlapping heartwood sections of tree 6 (Mt. Trooper) and tree 20 (Willis) established the foundation for ring identification in the rest of tree 20 (Fig. 6.2).

A Site Index from Mount Trooper, site 1 (trees 3, 5 and 6) was plotted against the Ring Index for Tree 20 (Figs. 6.3 and 6.4). A visual examination of these figures established a definite relationship between the two indices which indicated the veracity of the cross dating. The Ring Index for tree 6 (site 1) was similarly plotted against tree 20 Ring Index, however there was little difference between this graph and Figure 6.3. This further confirms that the three trees, 3, 5 and 6 (site 1) were likely to be accurately cross dated and showed a similar variation in ring width in response to growing conditions.

Once the cross dating of tree 20 (Willis) to tree 6 (Mt. Trooper) established a chronology for tree 20 this chronology was further validated using Cooma rainfall data. A visual examination of the graph of the Cooma growth season Rain Index against Ring Index indicated that major peaks in the Ring Index almost coincided with major peaks in the Rain Index (Fig. 6.5). The peaks deviated by one or two growth seasons. The Ring Index for tree 20 was accordingly adjusted by - 1 growth season for the whole chronology (Fig. 6.6). Major peaks marked “B” required adjustment by recognition of 2 additional growth rings during a period of exceptionally wide rings. These rings had previously been marked as intra growth season rings in the 1901-1902 period. These adjustments further improved the alignment of the two indices and corrected obvious mis-identification of intra growth season rings at this point (Fig. 6.6). These figures indicate that in general the chronology constructed for tree 20 only deviated from a perfect chronology by one, or at most two growth seasons throughout the sequence. The adjusted chronology for tree 20 was then used for subsequent cross dating with trees from the Willis sites.

It was found that five trees from Willis sites successfully cross dated to tree 20. These were trees 1 (site 2), 3, 4, 5 and 6 (site 3). Trees 5 and 6, which grew in the same clump, cross dated to each other quite clearly and were of the same age. All the trees that were cross dated at Willis were old growth woodland trees of which 5 out of the 6 trees were dead when sampled.

It was not possible to cross date any of the live regrowth trees on the Willis sites or trees from the north aspect site on Mount Trooper (site 9). Thus 18 of the 24 trees sampled on the hot dry north facing sites at Willis and Mount Trooper could not be cross dated. They contained a variety of ring types including intra growth season rings, false rings, indistinct rings, diffuse rings as well as missing rings as reported for this species by Dunwiddie and LaMarche (1980). Trees 1, 3, 4, 5 and 6 appear to have been growing in less favourable conditions than tree 20. This was indicated by the occurrence of missing rings or the occurrence of sometimes distinct multiple intra growth season rings. Tree 1 had the greatest frequency of very distinct rings which might easily have been interpreted as growth season rings. Without a reliable chronology for cross dating such trees, rings from these trees might suggest a greater age than they probably were.

6.3.3 Age estimates of old growth woodland and regrowth trees

An estimate of the ages of tree centres was based on the chronology established for six old growth trees from Willis. A maximum and minimum tree ring count for these trees was made (Table 6.1). The maximum ring count estimated the maximum number of periods of growth in each tree and included all seasonal and intra seasonal growth rings. As discussed in chapter 5, the frequency of intra growth season rings means that this count would provide an overestimate of tree age. In trees 1, 3, 4, 5, 6 and 20 (Willis) the minimum ring count, which was based on tree ring cross dating, was the growth season ring count and gave the best possible estimate of age. These estimates indicate that the old growth trees sampled germinated between the late 1790's and 1840's.

A direct estimate of age can be made where the date of mortality is known or can be deduced from the tree rings (Table 6.1). Trees 3 and 20 (Willis) which were alive when felled in 1987 and 1988 were about 147 and 170 years old respectively. Analysis of the tree rings indicated that tree 5 died in c1944. This tree would have been about 120 years old. It was not possible to accurately determine the age of mortality of trees 1, 4 and 6 due to indistinct rings in the outer sections of the disks however they all died between 1935 and 1987. There was evidence from ring counts that this could be narrowed to death between 1935 and 1945.

Ten of the dead old growth trees sampled from Willis and Mount Trooper had decomposed or hollow centres, very narrow compressed rings, missing rings and other irregularities in the ring pattern. These trees could not be used for dating in any way.

Eight regrowth trees sampled near Willis (sites 2, 3 and 7) were generally much smaller than the old growth woodland trees and varied in diameter over bark from 0.09 to 0.25 m (0.5 m above the base) (Table 6.1). Dating of regrowth trees (Chap. 5) and old growth trees indicated that the minimum interpreted ring counts gave a better estimate of age for these trees than maximum ring counts. Minimum ring counts for the regrowth trees varied from 78 to 100 rings. It can therefore be postulated that these regrowth trees would have germinated between about the early 1890's to about 1905.

6.3.4 Radiocarbon age estimates

Trees sampled for radiocarbon dating from Willis were tree 1 site 2, tree 5 site 3, tree 6 site 3 (all dead) and tree 20 site 8 (live). Radiocarbon ages, ring counts, estimated date of sample and estimated date of the tree centres using dendrochronological techniques are presented in Table 6.2. Ages are reported below as *Conventional years* B.P. (Stuiver and Polach, 1977). The ranges of radiocarbon ages are presented in Figure 6.7.

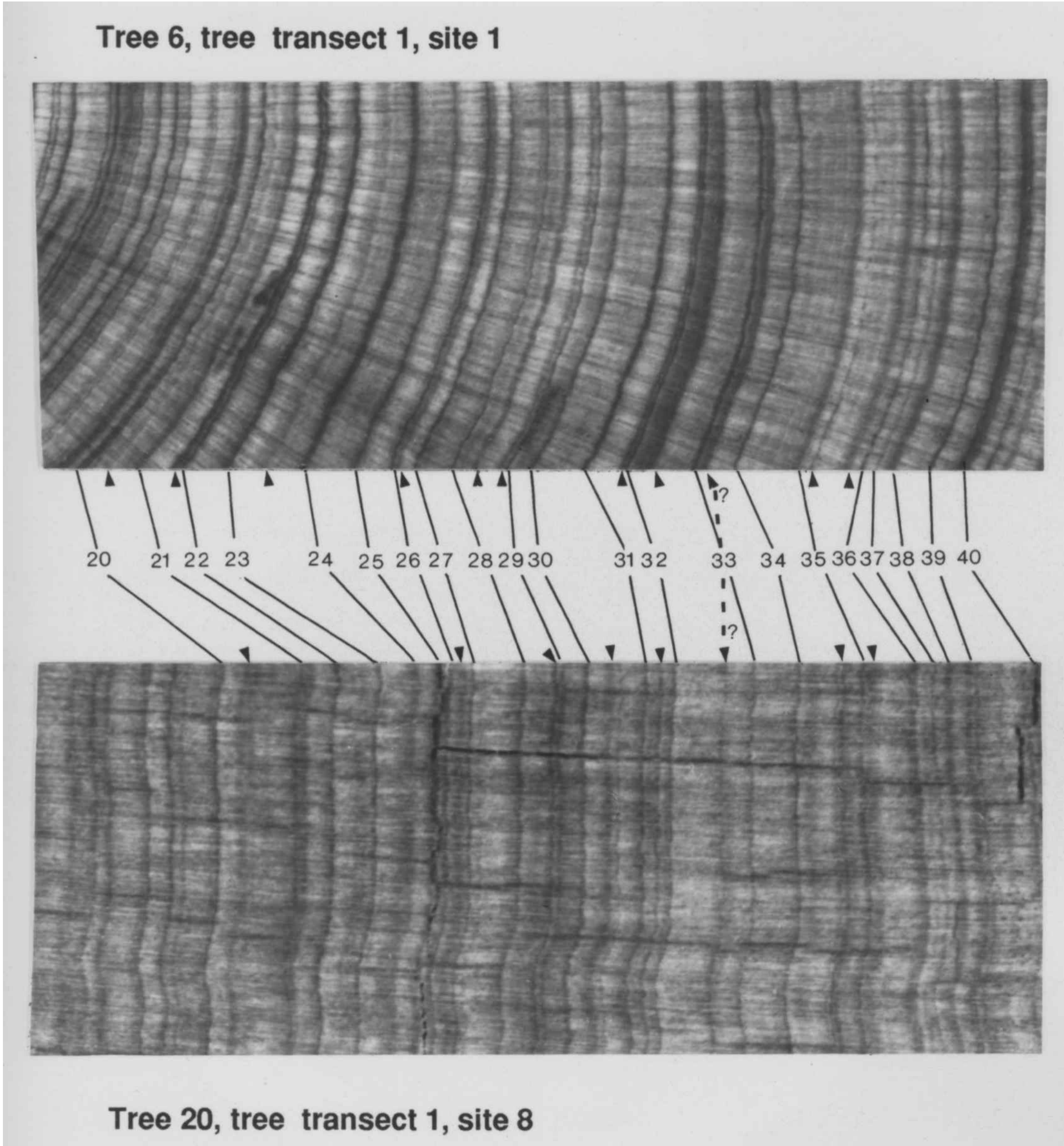


Figure 6.2 Cross dating heartwood growth season rings from regrowth tree 6 (Mt. Trooper, site 1) to old growth tree 20 (Willis, site 8) for growth seasons from c1920 to c1940. Cross dated rings are indicated by connecting date lines. The symbols ▲ indicate intra growth season rings which are generally less distinct or more diffuse than growth season rings. Successful cross dating required reference to more than one cross section in each tree to correctly distinguish cross datable rings. No cross dating was possible in the sapwood zone due to the large number of diffuse, indistinct and narrow rings. Approximately x 5 magnification.

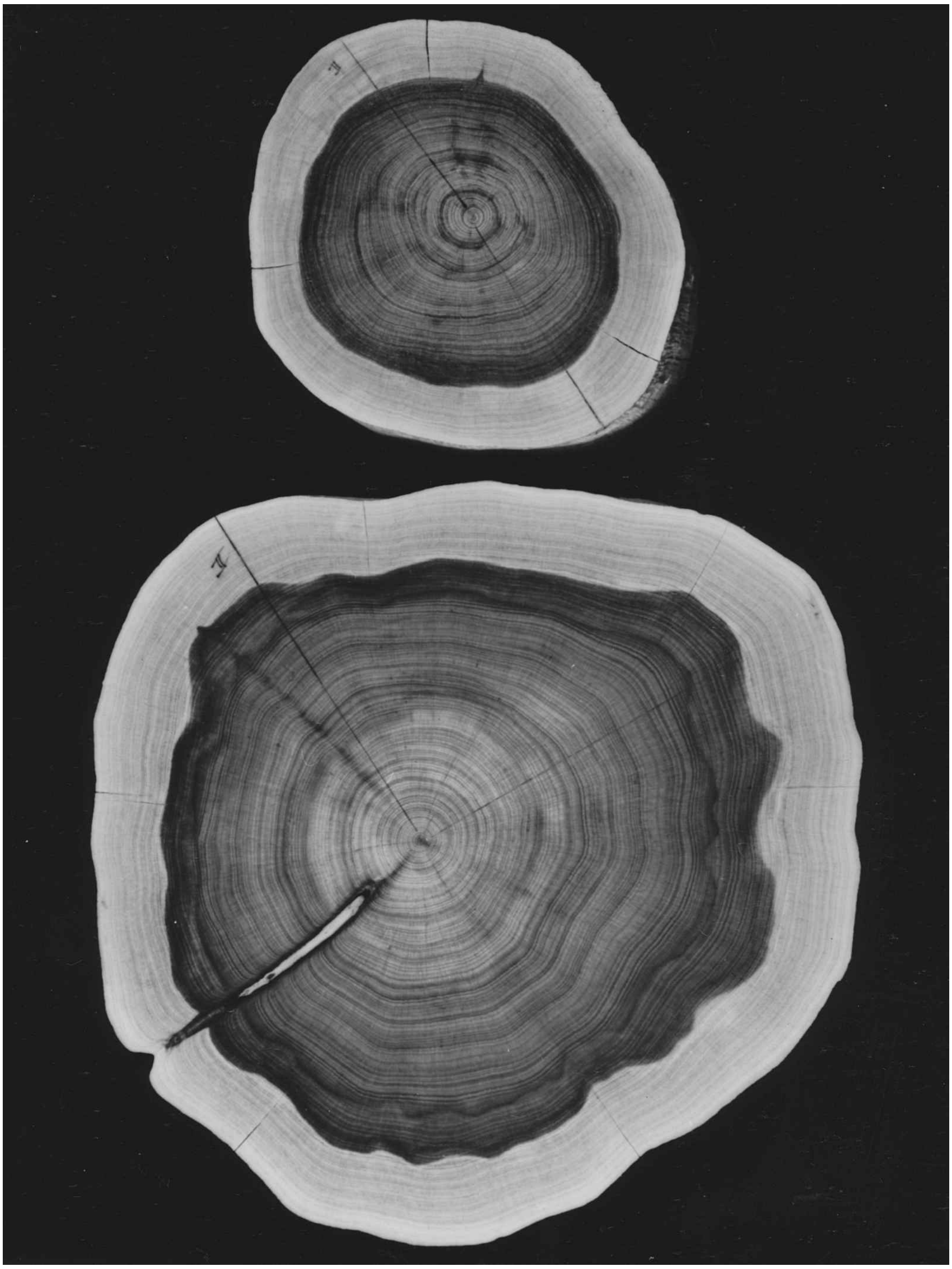


Plate 6.3 Basal growth ring cross sections of live regrowth trees 16 and 19 site 3 (Willis). These trees were representative of dense “locked” regrowth stands. Large numbers of false, indistinct and missing rings made it impossible to cross date regrowth trees from the hot aspect Willis sites with regrowth trees from the cool south aspect Mount Trooper site. Magnification x 0.75.

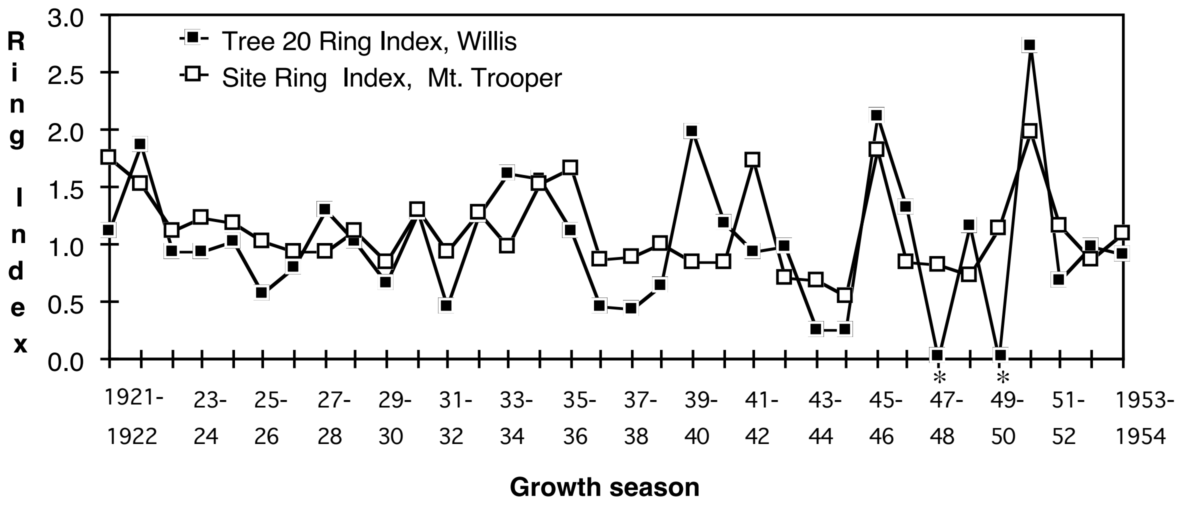


Figure 6.3 Site Index or mean Ring Index of trees 3, 5 and 6 (Mt. Trooper, site 1) and Ring Index tree 20 (Willis, site 8) for the ring sequence in which it was possible to reliably cross date rings between trees. The * indicates a missing ring resulting in a Ring Index of 0 for growth seasons 1947-48 and 1949-50 in tree 20.

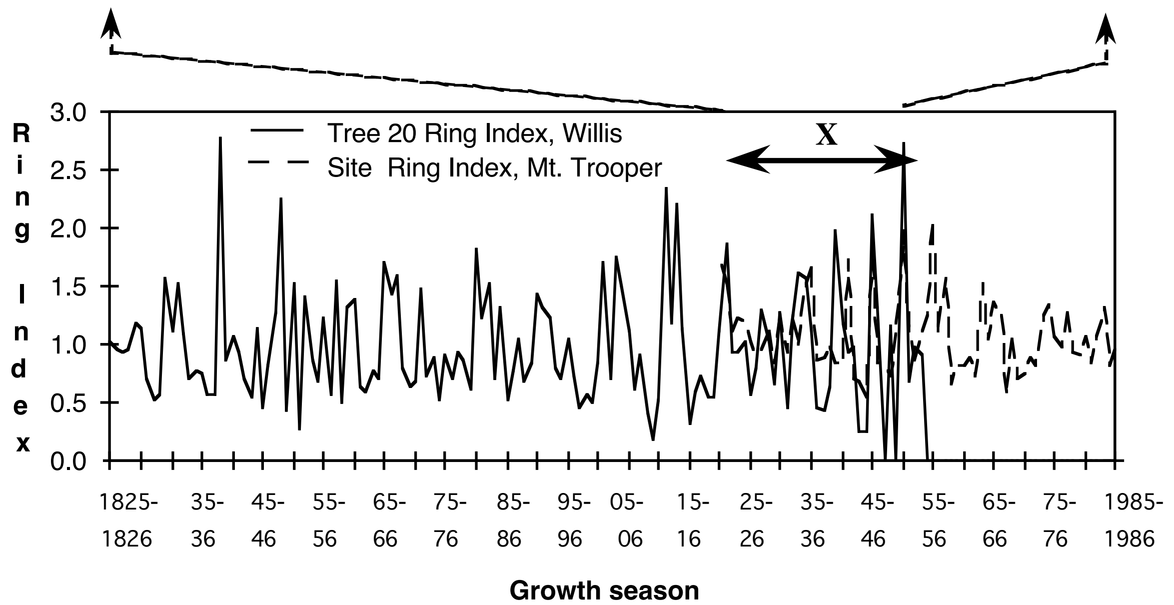


Figure 6.4 Site Index or the mean Ring Index of trees 3, 5 and 6 (Mt. Trooper, site 1) and tree 20 (Willis, site 8) for the ring sequence from growth seasons 1825-26 to 1985-86. The zone marked "X" indicates the section in which the heartwood of the trees cross matched and which is illustrated in detail in the figure above.

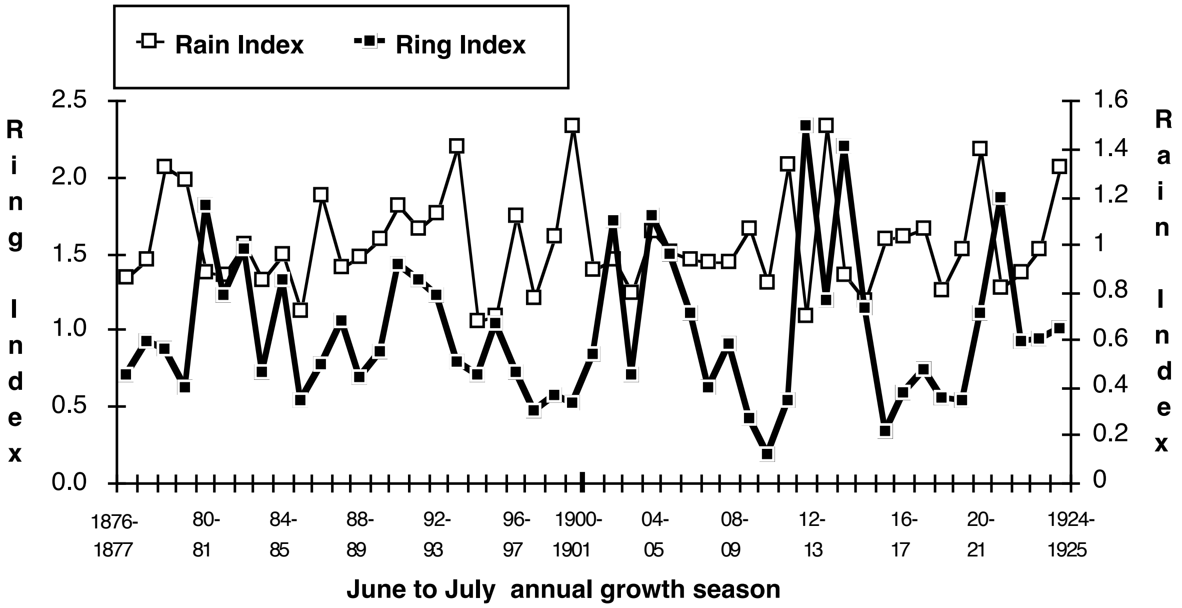


Figure 6.5 Comparison of the Rain Index for Cooma (Lambie St.) and the Ring Index for tree 20 (site 8) for the growth seasons 1876-77 to 1924-25. Note that major peaks in the Ring Index almost coincide with major peaks in the Rain Index. These peaks deviate from alignment by one or at most two growth seasons.

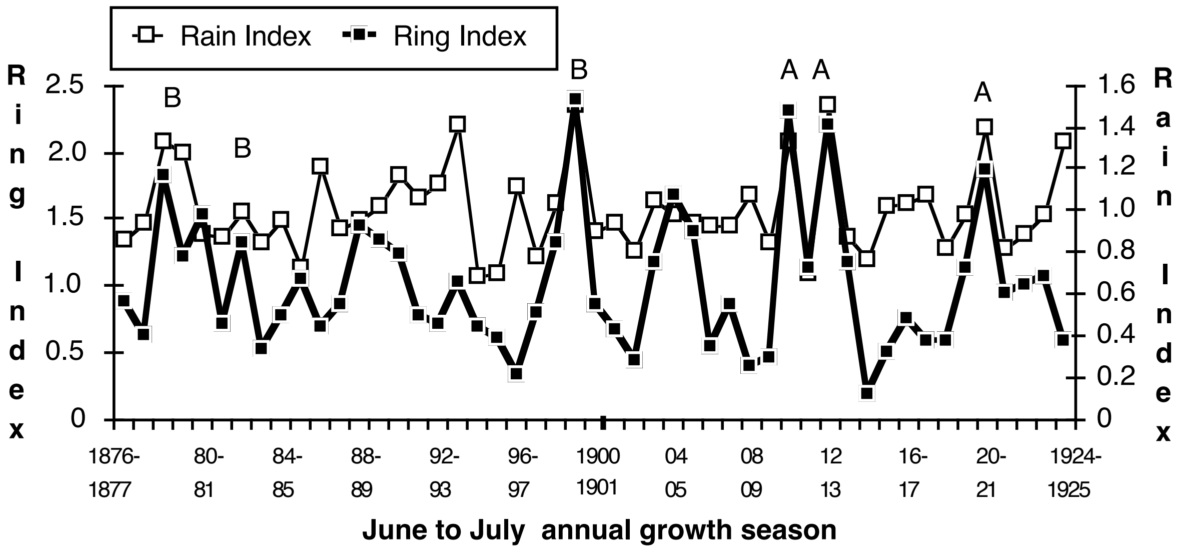


Figure 6.6 Adjustment of the above Ring Index for tree 20 by -1 year for the whole chronology. The result was alignment of Ring Index and Rain Index peaks marked "A". Major peaks marked "B" required adjustment by -2 growth seasons for the peaks to align. Appropriate correction was made by addition of two rings at interval 1902-03 which had obviously been mis-identified as intra growth season rings. This evidence strongly indicates that in general the chronology constructed for tree 20 only deviates from a perfect chronology by at most 1-2 years throughout the sequence.

Table 6.1 Characteristics of 20 white cypress pine trees sampled for dendrochronological analysis from sites on dry hot north facing slopes at 350-400 m. A.S.L. near Willis.

"•" indicates a minimum ring count based on interpretation of growth season rings without rainfall and cross dating.

"+" indicates a minimum ring count based on tree ring cross dating. "-" indicates rings were not counted or date could not be validly estimated.

(a) Willis north aspect sites

Tree No.	Site No.	Dead/ Live	Slope °	Tree Height (m)	Diameter (m) 0.5 m above base	Max Ring Count		Min Ring Count	Calendar Date of Tree Centre	No. of Fire Scars	Tree Type (O = old growth, R = regrowth)	Comments
1	2	D	30	15.0	0.35	218	+	150	c1800-05	7	O	On bank of dry creek, cross date with T20
2	2	D	5	-	0.83	-	-	-	-	2+	O	Stump felled decades ago extensively weathered
3	3	L	20	7.8	0.25	177	+	110	c1842-45	6	O	On dry creek levee bank, cross date with T20
4	3	D	20	5.8	0.17	177	+	107	c1825-28	7+	O	1m from shallow gully, cross date with T20
5	3	D	20	7.8	0.19	168	+	114	c1825-28	6	O	Cross date with T6 & T20, Willis
6	3	D	20	12.0	0.31	206	+	123	c1825-28	4	O	Cross date with T5 & T20, Willis
7	3	D	20	11.0	0.76	-	-	-	-	0	O	Wedge only, centre rotten, no cross date
8	4	D	20	11.0	0.19	-	-	-	-	0	O	Wedge only, centre decayed, no cross date
9	5	D	20	13.0	0.53	-	-	-	-	0	O	Wedge only, centre decayed, no cross date
10	6	D	20	12.0	0.59	-	-	-	-	1+	O	Wedge only, centre decayed, no cross date
11	7	D	10	12.0	0.59	-	-	-	-	0	O	On dry creek levee bank, no cross match
12	7	L	10	10.0	0.25	-	-	-	-	0	R	On dry creek levee bank, no cross match
13	2	L	5	12.5	0.24	156	•	100	-	0	R	On deep footslope alluvium, no cross date
14	2	L	5	10.0	0.14	129	•	82	-	0	R	On deep footslope alluvium, no cross date
15	3	L	20	9.4	0.19	140	•	99	-	0	R	5m from dry creekline, no cross date
16	3	L	20	7.2	0.10	115	•	78	-	0	R	4m from dry creekline, no cross date
17	3	L	20	7.7	0.14	135	•	87	-	0	R	4m from dry creekline, no cross date
18	3	L	20	5.3	0.09	-	-	-	-	0	R	5m from dry creekline, no cross date
19	3	L	20	9.0	0.18	128	•	93	-	0	R	4m from dry creekline, no cross date
20	8	L	10	9.5	0.34	243	+	160	c1820-23	5	O	Cross date with T1,3,4,5,6 Willis & T5,6 M.T.

Table 6.1 (continued)

(b) Mt. Trooper north aspect site

Tree No.	Site No.	Dead/ Live	Slope °	Height (m)	Diameter (m) 0.5 m above base	Max Ring Count	Min Ring Count	Calendar Date of Tree Centre	No. of Fire Scars	Tree Type (O = old growth, R = regrowth)	Comments
1	9	D	15	NM	0.39	-	-	-	0	O	Wedge only,centre rotten, no cross match
2	9	D	15	NM	0.47	-	-	-	0	O	Wedge only,centre rotten, no cross match
3	9	D	15	NM	0.43	-	-	-	0	O	Wedge only,centre rotten, no cross match
4	9	D	15	NM	0.44	-	-	-	0	O	Wedge only,centre rotten, no cross match

Table 6.2 Radiocarbon ages and estimated date of tree centre for wood samples taken from four white cypress pine trees (1, 5, 6 & 20) felled in 1987 and 1988 from sites 2, 3, 3 and 8 respectively. Wood samples were taken from near the centre of each tree and from wood produced after fire scar damage on trees 1, 6 and 20. The estimated age of the centre of the tree was determined by cross dating (Table 6.1). The number of rings to the mid point of the sample represented rings formed before half the wood in the sample had been produced. Trunk diameter was the mean value over bark measured 0.5 m above ground where the wood samples were taken.

Specimen Code	Laboratory Code No.	Location in Tree X-section	Sample Weight (gm)	^{14}C age (years B.P. 1955)	Rings to midpoint of sample	Est. date of sample midpoint	Est. date of tree centre	Trunk diameter (m)
T1S2C	ANU-6567	near centre	18	100±70	16	-	1800	0.35
T1S2FS1	ANU-6568	fire scar 1	19.5	210±70	93	-	"	"
T5S3C	ANU-6569	near centre	20	170±60	22	1837	1825	0.19
T6S3C	ANU-6570	near centre	18	270±70	18	1837	1825	0.31
T6S3FS2	ANU-6571	fire scar 2	25	190±63	63	1872	"	"
T20S8C1	ANU-6594	near centre	21	200±90	20	1838	1820	0.34
T20S8F1	ANU-6592	fire scar 1	44	195±70	65	1867	"	"
T20S8F5	ANU-6593	fire scar 5	41	160±65	144	1911	"	"

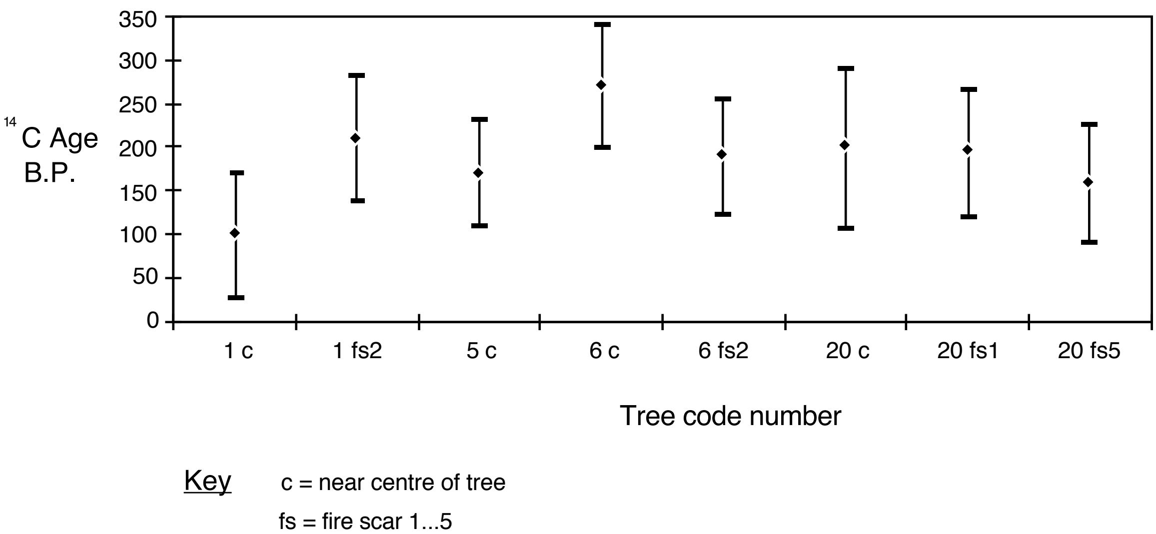


Figure 6.7 Radiocarbon age ranges in years B.P. for 8 wood samples from 4 old growth white cypress pine trees at sites 2, 3 and 8 near Willis. There is a 68.3% probability that ages lie between the upper and lower limits.

6.4 Discussion

6.4.1 Soils

No obvious important differences in soil profiles were found between the hot dry sites and cool moist sites investigated for tree ring analysis. Major differences are unlikely since soils from both sites were derived from the same parent material. The main differences which would have affected plant growth were the loss of most of the A horizon at the Willis sites and the evidence of considerable sheet and gully erosion on hot dry sites. The soil surface at the cool Mount Trooper site was covered with a hardy moss and tall relatively dense grasses indicating better soil moisture conditions than at Willis sites. Microsite differences in soil depth and intra specific competition are likely to be more critical to tree ring formation than minor differences in the appearance of these soils.

6.4.2 White cypress pine age estimates

Old growth

The dendrochronological techniques of cross dating and independent ring validation using long term rainfall data resulted in the establishment of tree ring chronologies for six old growth woodland white cypress pine trees from a hot north aspect site near Willis. Individual tree chronologies established the approximate age range of the centre of each tree to be c1800-05 (tree 1), c1825-28 (trees 4, 5 & 6), c1842-45 (tree 3) and c1820-23 (tree 20). Clayton-Greene and Ashton (1990) found that white cypress pine seedlings at Suggan Buggan had a mean annual height increment of approximately 15 cm. Because the trees were sampled approximately 0.5 metres above ground, the trees would have germinated approximately 3-4 years earlier than indicated by the tree centre. Thus 3-4 years could be added to the age of each of these trees. Therefore they germinated between the late 1790's and the 1840's.

Old growth trees appeared to be variable in age however trees growing in distinct clumps were the same age. All old growth trees except tree 3 were young or mature trees prior to European arrival in the area and were subject to the effects of European land use throughout most of its term. Most of the old growth trees appeared to have died during the later period of European grazing era between 1935 and 1945. A few live old growth trees on more favourable sites such as tree 20 survived and provide an invaluable link for cross dating dead old growth trees. The individual histories of each of these trees is analysed in detail in the next chapter.

The old growth trees on the north aspect of Mount Trooper (site 9) could not be cross dated. This is possibly due to a number of factors including their proximity to the top of the ridge. Extreme exposure possibly resulted in adverse growth conditions, producing large numbers of narrow and indistinct rings. Their position near the top of the ridge would have resulted in less soil moisture storage capacity compared with mid and lower slope sites which had the advantage of more substantial catchments and soil water storage. Many of the trees were hollow providing no material with a complete decay free basal cross section for sampling. There were no slope-wash run-on areas as found at the apparently more favourable microsite occupied by tree 20 at Willis. This further emphasised the need for careful consideration of site and tree selection prior to attempting dendrochronological analysis.

Regrowth

Cross matching and cross dating regrowth trees on the hot dry aspect sites was also unsuccessful. Regrowth trees displayed recognisable rings which could be counted, though without the ability to cross date them, any estimates based on the ring count are likely to be unreliable. These trees grew in dense stands which gave the appearance of stands described as “locked” by Lacey (1972) and appeared to be of similar age. Such trees are likely to have many missing rings caused by intense intra specific competition for moisture and nutrients. The minimum ring count was chosen as the most accurate estimator of age for these trees due to the large number of intra growth season rings identified in the old growth trees at these sites. Minimum ring counts suggested ages for regrowth trees between the mid 1880’s and about 1905. Since no account could be made of any missing rings these dates are likely to be conservative. These dates are broadly similar to those of regrowth at Mount Trooper which were of a considerably greater diameter and height. The significance of these dates to forest history is discussed in chapter 8.

As with the dendrochronological studies described in Chapter 5 a high proportion of the trees could not be analysed. This was for the reasons outlined by Dunwiddie and LaMarche (1980) (intra growth season rings, missing rings and difficulty in recognising growth season rings) and old growth trees with decayed centres. My investigation has shown that some trees yield relatively reliable chronologies where methods of calibration are achievable such as cross dating and verification using rainfall data.

I obtained the most reliable estimates of age for regrowth trees from the cool moist site at Mount Trooper and six old growth trees from a hot dry site at Willis. Estimates of age of a further six regrowth trees from Willis were obtained from minimum ring counts. Due to the small sample size and the inability to date trees from some sites including dense “locked” regrowth stands, dendrochronological analysis cannot conclusively confirm or refute the hypothesis that white cypress pine stands in the area are essentially composed of only two age classes but the data support the suggestion that the old growth trees pre-date the dense regrowth stands and provide estimates of dates of germination. The tree dates are consistent with the historical accounts of open woodland at the time of European occupation followed by the occurrence of a wave of germination resulting in dense regrowth stands of white cypress pine dating from the late 1870’s to about 1900. It was not acceptable to greatly increase the sample size due to the likely impact on forest of this National Park.

Radiocarbon dating

Radiocarbon dating failed to provide useful age estimates for this study. The ^{14}C age ranges for tree 1 were particularly ambiguous. By reference to the calibration curve the date ranges for the centre sample were 100±70 B.P. or 1667-1783 AD. The date range for the sample at fire scar 1 was 210±70, thus from the calibration curve it is valid to choose 1620-1980 AD or 1911-1955 AD. This result pessimistically used 2 sigma values thus there is a 95.4% chance that the age of the centre sample lies between 30 and 170 years B.P. All trees fell within overlapping age ranges. Tree 6 appeared to be the oldest tree with a 68.3% (1 sigma) probability that its age lay between 200 and 340 years B.P.. The calibration curve shows that dates less than about 300 years B.P. are particularly inaccurate due to fluctuations in the curve. There is reasonable evidence that no tree is likely to be greater than 340 years B.P. and the overall evidence suggests that the mid date ranges are clustered around a mid point of about 200 years B.P. This suggestion is generally supported by ring counts. For example, the oldest live tree sampled (tree 20) which also had the highest maximum ring count of 243 rings, had an upper ^{14}C age limit of 290 years B.P. (1 sigma). Results of tree ring cross dating and analysis indicated that this upper limit is pessimistic and that trees 5, 6 and 20 are probably the same cohort becoming seedlings around 1820-25 or approximately 170 years before being felled. It is concluded that despite the range of radiocarbon dates the results generally show that the old growth woodland trees have been present for probably less than 200 years and certainly not more than 300 years. Wakefield (1970) estimated old growth white cypress pine trees in the area were 100 to 250 years old. ^{14}C dating does not contradict the dating using tree ring cross matching methods nor does it provide sufficient precise evidence to support these dates, thus age estimates had to be dependent on growth ring counts.

6.5 Conclusion

This dendrochronological analysis provided useful estimates of the age of live and dead old growth trees. This, with the work described in chapter 5, has shown that it is possible to date carefully selected white cypress pine trees growing on suitable sites on both cool moist and hot dry slopes. It is unlikely that dendrochronological analysis would be a suitable technique for dating regrowth trees growing in adverse conditions such as in dense locked stands, or trees growing on ridges or extremely rocky sites with shallow soil. This study has extended the potential for use of this genus for dendroecological interpretation.

Radiocarbon dating would have produced more useful results for trees older than 300 years. It appears unlikely that there are any living white cypress pine trees of this age. Some large diameter stumps observed may have been very old, however their decayed centres prevented sampling for ^{14}C dating.

The six old growth white cypress pine trees from the hot dry Willis sites for which a chronology was obtained could then be used to construct a fire history for the study site (Chap. 7).

Chapter 7 The fire history of a white cypress pine stand

7.1 Introduction

Fire history can be established by dating fire scars which have accumulated over the life of a tree which lays down datable growth rings. Fire frequencies and fire free intervals from these scars can then be used to interpret changes in forest stand characteristics and past land uses (Arno and Sneck, 1977; Banks, 1982; McBride, 1983). In Chapter 4 evidence of past fires was reported in white cypress pine stands, particularly on north facing slopes. This consisted of white cypress pine trees with basal fire scars and occasional hollow or burnt out white box trees.

Forest fire histories can be assembled from two primary sources. Off site data sources include official records, private documents, newspaper reports, oral accounts and ethnohistory. On site sources include fire scars, regeneration events, growth pulses or surges in tree ring widths, wood chemistry and the presence of charcoal layers (Banks, 1989). Pryor (1939) and Raeder-Roitzsch and Phillips (1958) constructed fire histories primarily by dating fire scars in subalpine snow gum *(Eucalyptus pauciflora)* stands in the Australian Alps. Banks (1982) utilized all the above sources to expand the history of fires in snow gum in the Brindabella Ranges. He dated fire scars, and used post-fire induced growth patterns to identify past fires where basal scarring had been destroyed by subsequent fire or where fires were not of sufficient intensity to damage bark or cambium. In this study all the above sources were investigated with the exception of wood chemistry.

Of the above sources Banks (1982) identified fire scar dating as potentially the most productive for identifying fire events in snow gum forests. However this is only possible where trees produce datable growth rings and are sufficiently fire sensitive to be damaged but not destroyed by fire. Also the resulting fire scars should be resistant to subsequent fires and decay. Fire scars are formed on a tree when a fire burning adjacent to the tree raises the temperature of part of the cambium to a lethal level and consumes an area of bark, cambium and a portion of the adjacent xylem (McBride, 1983). After each fire scar is created by fire, a rejuvenation process at the margins of the wounded area causes the formation of lobate tissue called callus. Callus contains a new vascular cambium and a phellogen (Kozlowski, 1971). Some fire scars though not all, are visible externally. At the base of standing trees fire scars are often apparent as charred and burnt wood in the shape of a succession of arch shaped blackened scars often partially overgrown by lobe shaped callus (McBride, 1983). Many such fire scars were found on old growth white cypress pine from hot north aspect sites and provided the material for this investigation. Successive fires cause successive tissue damage which are “recorded” in the ring sequence. Often good rainfall combined with the release of nutrients into the soil following a fire results in a growth pulse in which tree rings are much wider than average (Banks, 1982).

Field investigations revealed that 27% of old growth woodland trees on hot dry sites had one or more fire scars (Table 4.2, Chap. 4). If these trees could be dated, then a fire history for individual stands could be reconstructed. Stands near Willis in the lower Snowy River Valley were selected for study. In this chapter most results and discussion focus on 6 trees. Unless otherwise indicated these trees and sites are tree 20 (site 8), tree 1 (site 2), trees 3, 4, 5 and 6 (site 3) located on a hot dry north aspect slope near Willis (Fig. 6.1, Chap. 6).

Plate 7.1 Fire scar on the butt of tree 20. Note charcoal resulting from the last fire and callus indicated by the smooth light grey wood on the margins of the blackened surface.

7.2 Methods

7.2.1 Dating basal fire scars and post-fire growth pulses

The methods used for fire history determination were selected in conjunction with those used for tree age determination. Six of the fire-scarred trees from north aspect sites near Willis which were sampled for dendrochronological analysis, could be cross dated (Table 6.1). Cross-sections from the basal fire scar zone were cut and sanded to clearly expose the fire scars and growth rings. The rings corresponding to the fire scars were identified on photo enlargements of selected radial transects and the ring sequences for each tree dated using the tree ring chronology (Chap. 6). From this fire years could be established.

Additional evidence of fire was obtained by identifying post-fire growth pulses from the individual tree ring indices. These were then matched with fire scars in the sampled trees. Some growth pulses post 1924 did not match fire scars, but being of similar magnitude and pattern to those that did were assumed to be of fire origin. The fire scar and growth pulse data were then assembled into a fire synchronisation graph (Arno and Sneck, 1977) and fire years estimated within ± 1 or 2 years.

The methods used for selecting and sampling fire scarred trees differed from those described by Arno and Sneck (1977) but were similar to Banks (1982). Arno and Sneck's (1977) methods use detailed vegetation maps, and the sampling of fire scarred trees is made along a series of pre-determined transects for sampling in mixed conifer forest in north America. Because of the low frequency of intact fire scars Banks (1982) systematically examined his study areas and sampled fire scarred trees from representative stands and from these he constructed detailed fire histories for individual stands from which generalised fire histories for the surrounding forest could be extrapolated. Banks' methods were used for this study by selecting fire scarred white cypress pine trees from a single representative stand.

Growth season tree ring widths for each tree were standardised (Chap 5). The ring indices were graphed and rings corresponding to the fire scars recorded (Figs. 7.1 to 7.4). Post-fire growth pulses were identified on the graphs and found to be associated with most fire scars. Additional growth pulses i.e. not associated with fire scars in a particular tree were also recorded. These growth pulses were found to match with fire scars in the other sample trees. This can be explained by suggesting that fire may scar only some trees in a stand, but influence the growth in adjacent undamaged trees. These growth pulses were also were found to be useful in confirming minor scars which could have been non-fire in origin in trees 20 and 4.

An assumed fire date of -1 or -2 rings for each growth pulse which corresponded with a fire scar in another tree was marked onto each tree Ring Index graph and the fire synchronisation graph. This assumption was based on the observation that wide rings usually followed 1 or at most 2 rings after a fire scar ring. Additional growth pulses which could be reasonably accurately cross dated on tree 3 and tree 20 and which did not correspond to fire scars in other trees were also marked using unique symbols on the fire synchronisation graph. These inferred fires were outside the zone of dated fire scars i.e. they were in the period c1924-c1950. Tree ring cross dating became impossible after circa 1950 on tree 20 and was difficult between 1924 and 1950. Fire histories were tabulated for each tree and fire free intervals calculated for fire scar intervals only and for the combination of fire scars and growth pulses.

7.2.2 Other historical evidence of fires

Published and unpublished records

To confirm the fire scar record and produce the most complete fire history possible, other fire record sources were investigated. The official fire reports of the NSW National Parks and Wildlife Service and published accounts were perused and anecdotal comments from local landholders and park workers were also recorded. Lengthy searches for newspaper accounts were not conducted because the study area was extremely remote having no road access until 1961, and was thus unlikely to attract comments about fires in the local press.

Charcoal

Radiocarbon dating of buried charcoal in swamps or other organic accumulation areas on the Monaro Tableland (Singh *et al*. 1981a; Singh *et al*. 1981b), and Australian subalpine areas has produced evidence of past fires (Hope and Southern, 1981; S. Feary pers. comm.). By locating and dating buried charcoal in this study it was hoped that evidence would be found of fire events in the pre-European era, which could not be elucidated from tree fire scars. The ideal location for charcoal deposits is in shallow lakes or swamps where material can accumulate. The major tributary perennial streams of the lower Snowy River such as the Jacobs and Pinch River flow rapidly, discharging most fluvial material into the Snowy River where it is transported to the coastal plain. Hundreds of ephemeral streams also discharge into the Snowy River. A few of these have produced alluvial flats of moderate size near their junction with the Snowy River however no swamps were found. These alluvial sites were chosen as the most likely to contain charcoal deposits.

The presence of charcoal was investigated along the valley floor of the lower Snowy River. Several pits 0.5-0.75 m depth were hand dug and several sections of stream bank were excavated in the surface layers of gently sloping alluvial deposits on the Sandy Creek tributary to the Snowy River. Each pit or bank section was inspected for the presence of charcoal. Deeper excavation using machinery was not considered warranted (Dr. D. Gillieson pers. comm.).

7.3 Results

7.3.1 Fire history from tree rings and fire scars

The growth Ring Index pattern for trees 20, 1, 3, 4, 5 and 6 are presented in Figures 7.1 to 7.4. The estimated dates for the tree centre, tree death, fire scars and fires inferred from post-fire growth pulses which were confirmed by fire scars in another tree are indicated. Parts of the chronology on each tree for which it was not possible to satisfactorily cross date are indicated. Cross dating and ring counting near tree centres were difficult thus dates for tree centres are approximate only. Fire scars typically coincided with a narrow ring or rings immediately preceding one or more wide post-fire growth pulse rings. For this reason fire dates inferred from post-fire growth pulses generally preceded the wide rings.

Synchronisation of the fire record

The fire dates from fire scar and post-fire growth pulses (Figs. 7.1 to 7.4) were synchronised (Fig. 7.5). This synchronisation graph provided an explicit technique for adjusting fire scar dates where it was reasonable to assume that a single fire event was involved. The final fire dates and fire free intervals after synchronisation are presented (Table 7.1 and 7.2). A total of 19 fires were recorded for the 113 year period, c1835-36 to c1948-49, of which 15 were from fire scars and growth pulses and 4 were from growth pulses alone. On average less than one third of the datable sample fire scarred trees, 1.9 (0-6), were scarred by each fire. The earliest dated fire scar occurred in c1835-36 and the most recent in c1924-26 with a mean fire free interval of 6.4 (3-16) years. Most fires did not scar all six dated trees. During the period of record common to all trees from c1862-63 to c1924-26, 11 fire scar producing years (growth seasons) were recorded, each with a fire scar on an average of 2.9 (1-6) trees. Individual trees contained from 4 to 7 fire scars with a mean fire free interval of 12.3 (9.0-15.3) years for fire scars. The only fire which scarred all these trees was the c1908-09 fire suggesting that this fire was possibly a higher intensity than many of the other fires.

Combined fire record from fire scars and growth pulses

In addition to post-fire growth pulses within the common fire scar period, Tables 7.1 and 7.2 include fires inferred from post-fire growth pulses for which there were no corresponding fire scars (c1919-1920, c1934-35, c1939-40 and c1948-49) from trees 3 and 20 (see also Figs. 7.1 and 7.2). From this combined record there was an average of 3.6 trees recording each fire with individual trees recording an average of 11.5 (6 -17) fires and a mean fire free interval of 5.9 (3-11) years. Three fires, c1862-63, c1902-03 and c1908-09 produced scars and or growth pulses in all six trees. Only the c1934-35 fire in tree 3, inferred from a post-fire growth pulse, did not cross date to fires in other trees, i.e.1.5% of the combined fire record. No fires were recorded after c1948-49 from the sampled trees. Thus there has been a fire free period of 40 years up until 1990 at the sample sites which is seven times the average fire free period recorded for the previous 113 years.

The tree bole diameter in the basal fire scar “cat face” and the age when the first fire scar was recorded were examined (Fig. 7.6). Tree basal diameter at the first fire scar varied greatly averaging 6.7 cm (range 1.0-16.5). Ages ranged from 12 to 54 years. Tree 1 evidently escaped fire damage from the first three fires (c1835-36, c1845-46 and c1848-49) and reached a diameter of 16.5 cm before being fire scarred. In contrast tree 4 survived a fire at an approximate age of 11 years when its diameter was only 1.0 cm. Callus growth subsequently completely healed over this scar. It went on to survive a total of 6 fires which produced fire scars during its life from c1842-43 until sampled in 1987 (Plate 7.4). This provides evidence that young white cypress pine trees probably less than 2 m high can survive relatively low intensity fire without the special adaptations found in many Eucalypts and that these fires may have been low intensity patch fires.

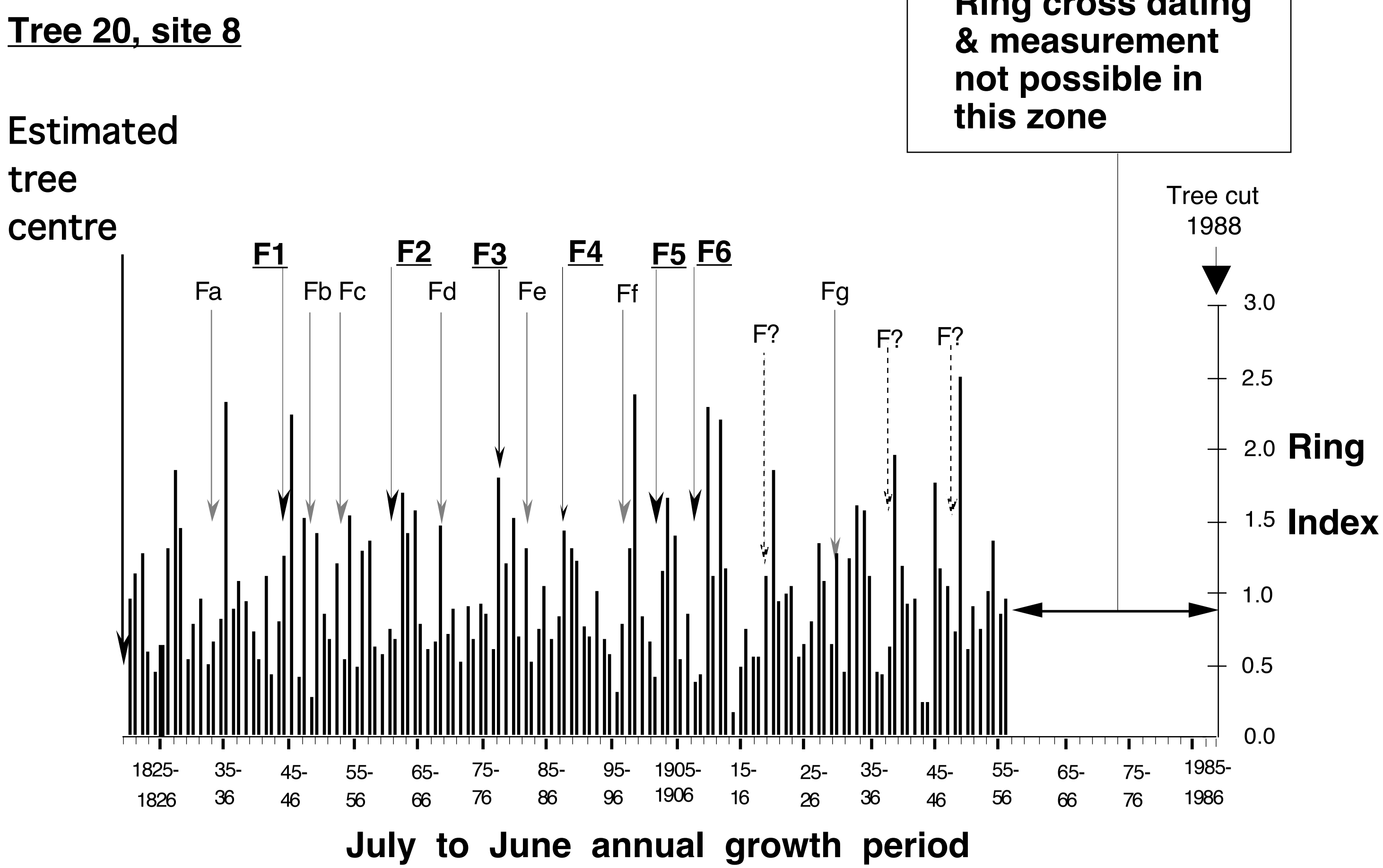
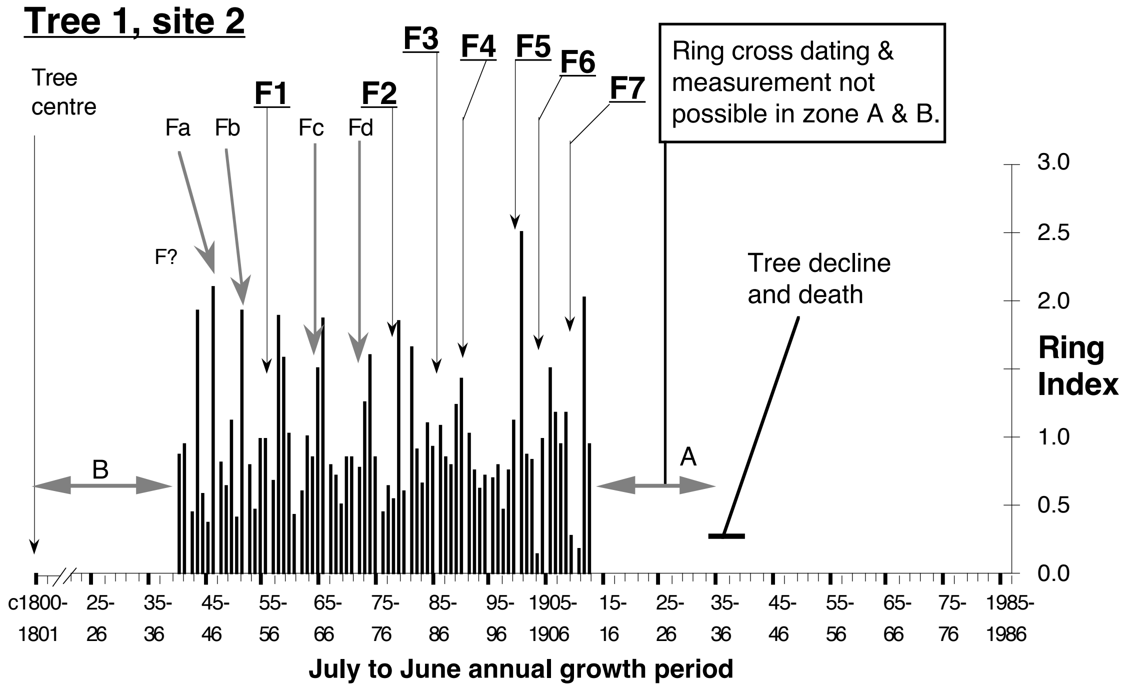


Figure 7.1 The fire record for tree 20, site 8, near Willis, interpreted from fire scars recorded within the tree (**F1**..**F5**), and from inferred post-fire growth pulses (Fa....Fg). These coincide with fire scars in other cross dated trees. Possible additional fire growth pulses not confirmed by a fire scar are indicated F?



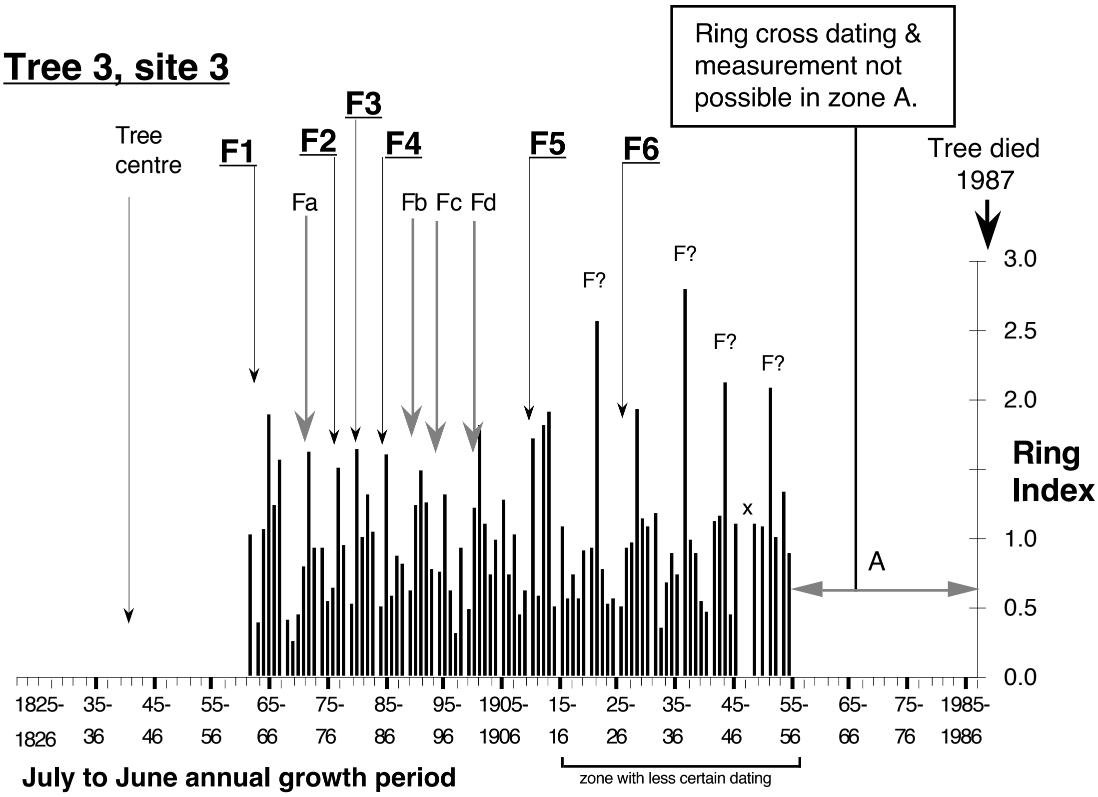


Figure 7.2 Fire records for trees 1 and 3 interpreted from fire scars (**F1**...**F6**), and inferred from the post-fire growth pulses (Fa...Fd) cross dated to fire scars in other trees. Non-cross dated post-fire growth pulses are indicated by "F?". Rings sequences and periods for which cross dating was not possible are indicated by "A" and "B". "x" indicates missing rings.

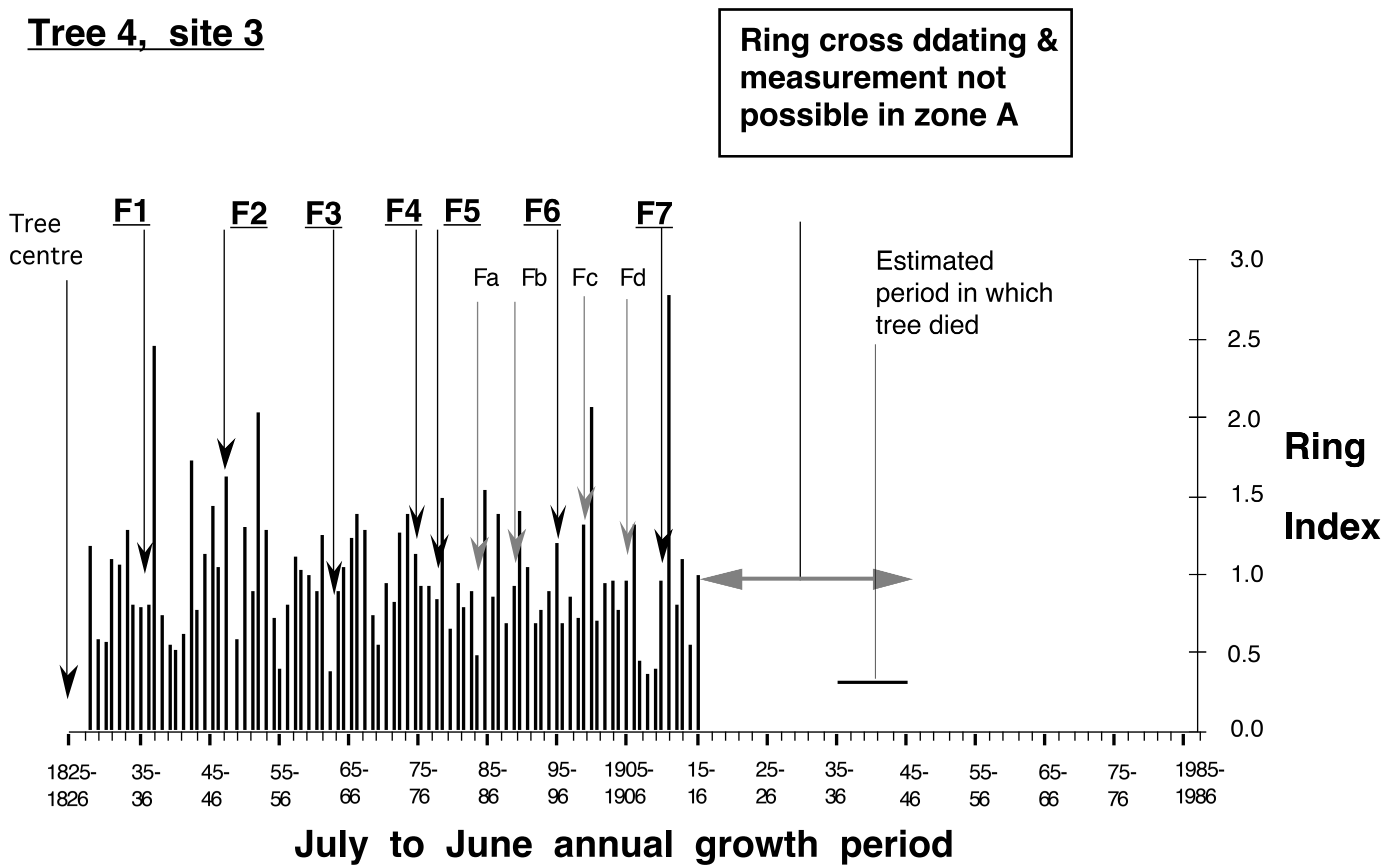
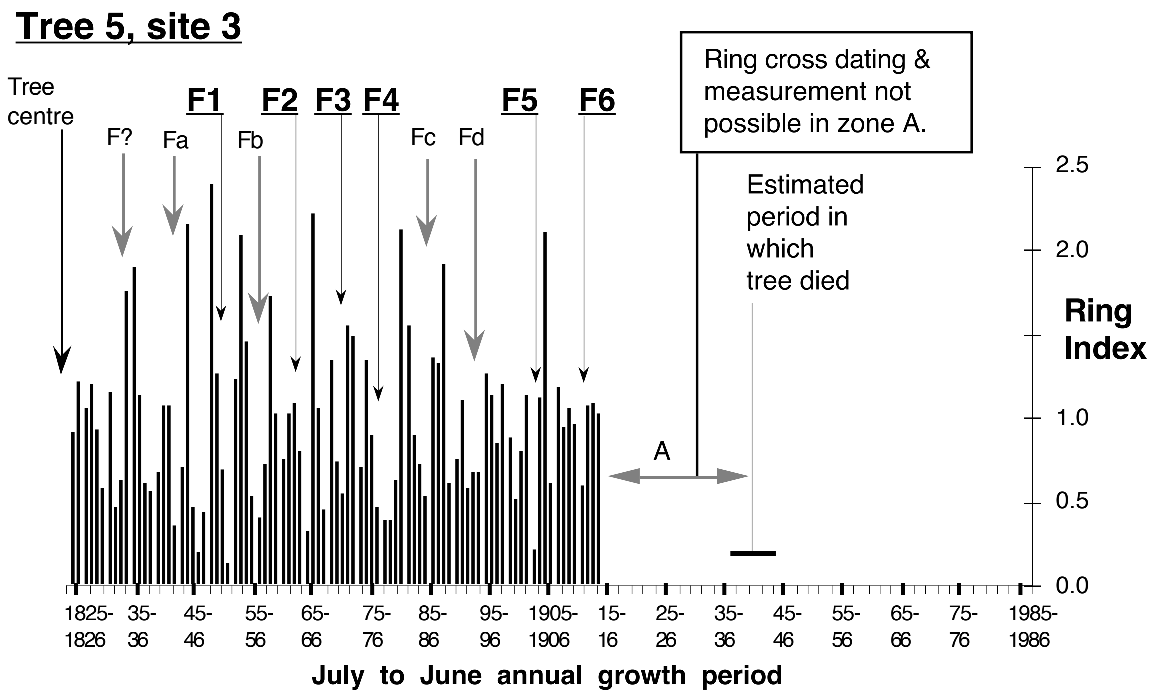


Figure 7.3 The fire record for tree 4 site 3 near Willis, interpreted from fire scars recorded within the tree (**F1**...**F7**), and from inferred post-fire growth pulses (Fa....Fd). These coincide with fire scars in other cross dated trees.



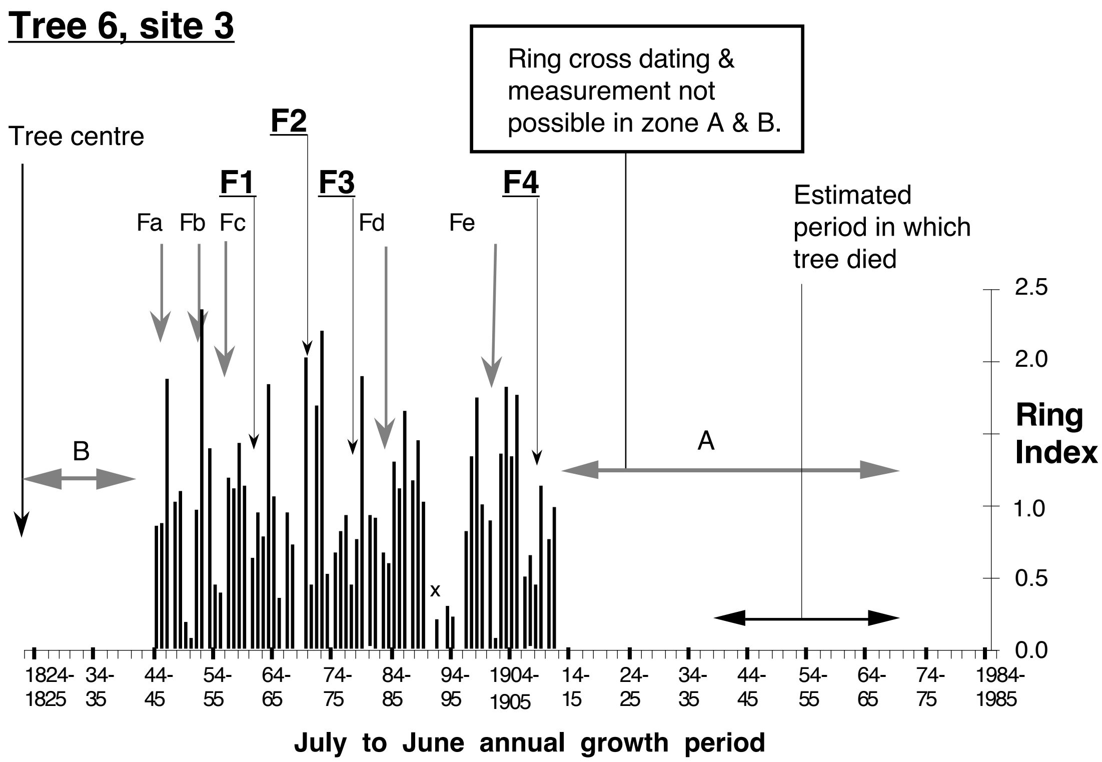


Figure 7.4 Fire records for trees 5 and 6 interpreted from fire scars (**F1...F6**), and inferred from the post-fire growth pulses (Fa...Fg) cross dated to fire scars in other trees. Rings sequences and periods for which cross matching was not possible are indicated by "A" and "B".
"x" indicates missing rings.

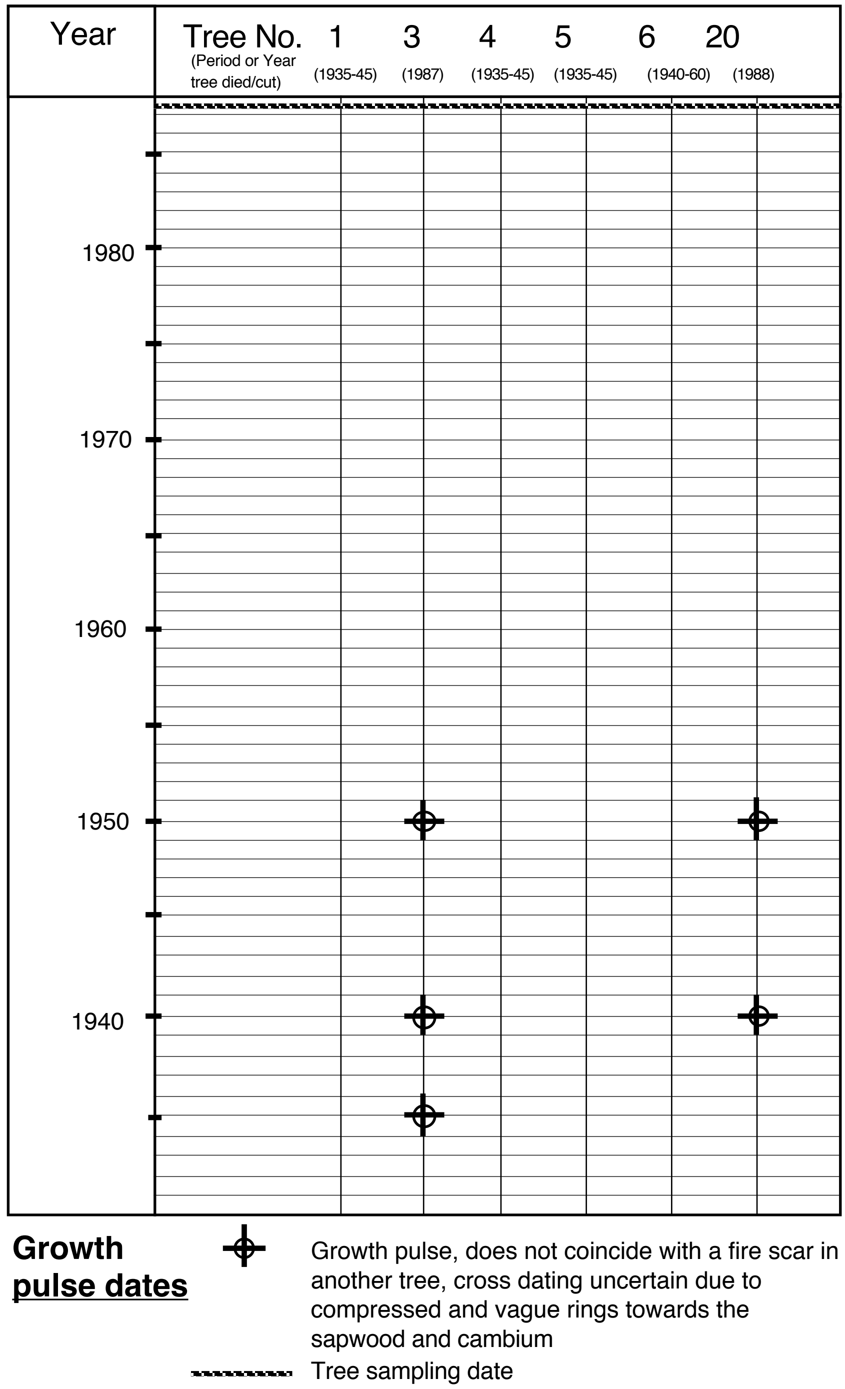


Figure 7.5. (part I) Graph for synchronising fire chronologies from individual trees (adapted and modified from Arno and Sneck, 1977). (Part II continued over page).

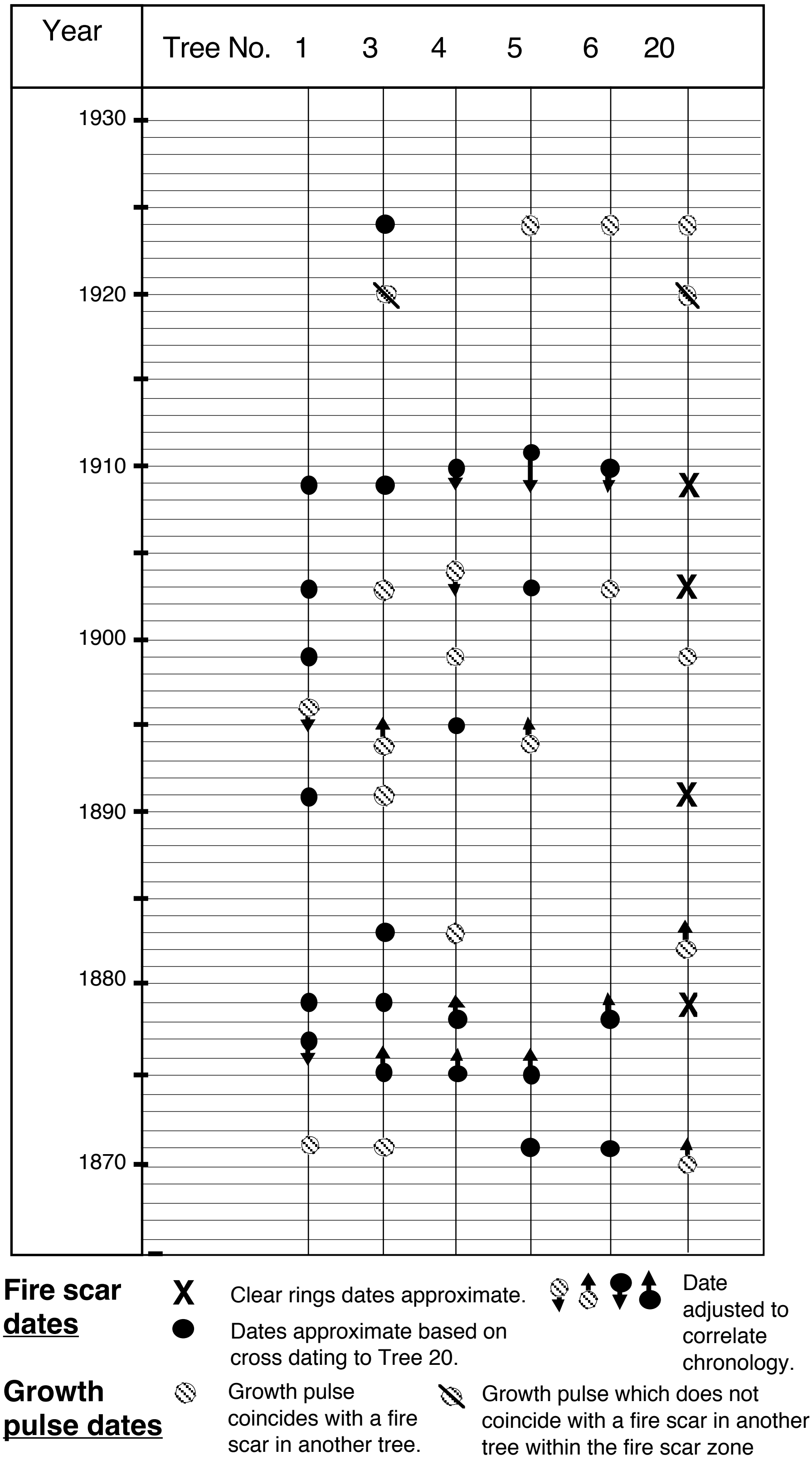


Figure 7.5 (part II) Graph for synchronising fire chronologies from individual trees. (Part III continued over page).

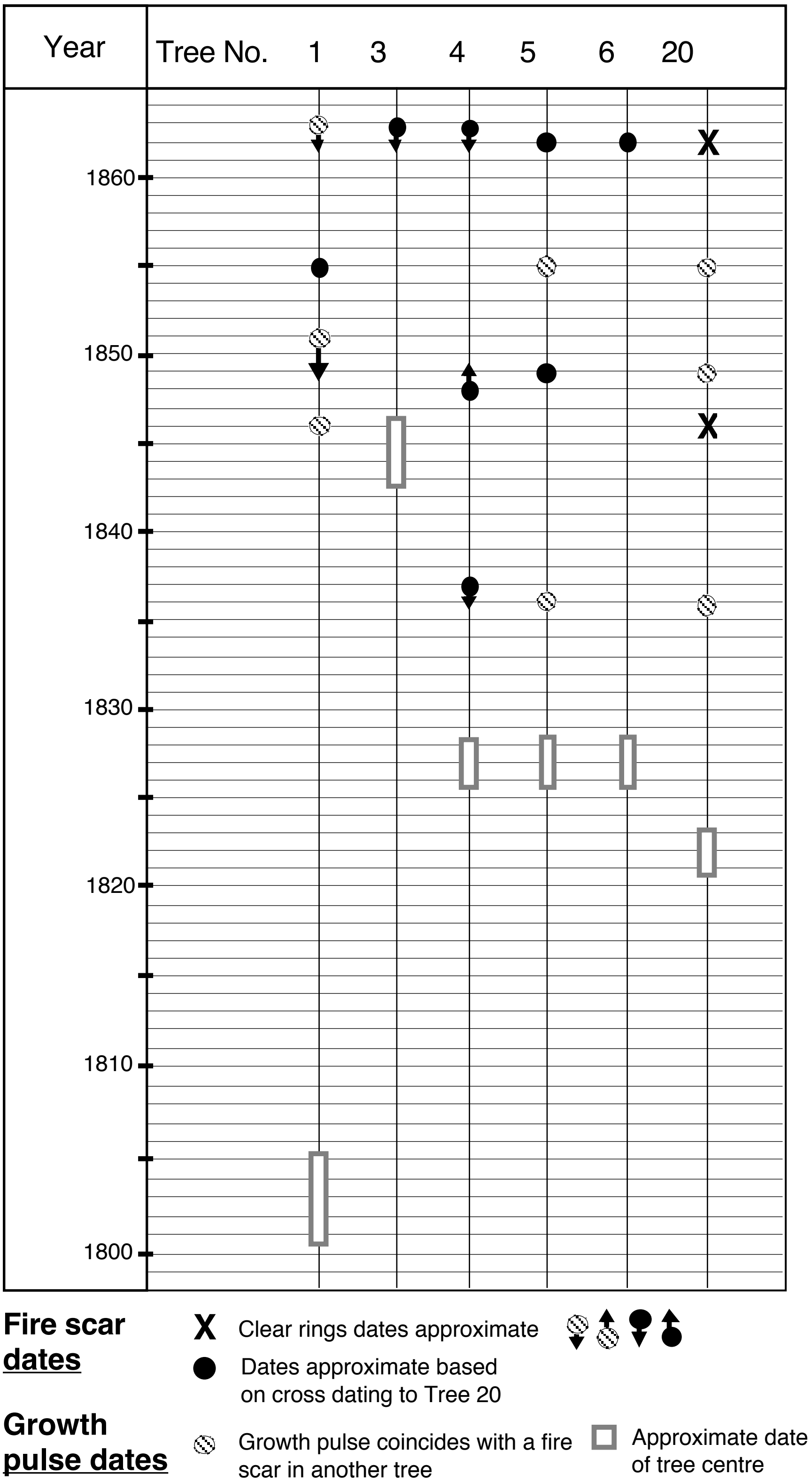


Figure 7.5 (part III) Graph for synchronising fire chronologies from individual trees.

Table 7.1 Fire dates for each tree after synchronising fire chronologies. The fire free intervals in years have been calculated for the periods between fire scars and post-fire growth pulses.The mean fire free intervals for individual tree fire scars, and the combined fire free intervals for fire scars and post-fire growth pulses are presented. The range of fire free intervals is indicated by the maximum and minimum intervals.

● = fire scar date   + = post-fire growth pulse

Fire	Year (circa)	Site 2 Tree 1	Site 3 Tree 3	Site 3 Tree 4	Site 3 Tree 5	Site 3 Tree 6	Site 8 Tree 20	Fire free interval
		Site locality : near Willis						
19	1948-49		+				+	} 9
18	1939-40		+				+	} 5
17	1934-35		+					} 10
16	1924-26		●		+	+	+	} 5
15	1919-20		+				+	} 11
14	1908-09	●	●	●	●	●	●	} 6
13	1902-03	●	+	+	●	+	●	} 4
12	1898-99	●		+			+	} 4
11	1894-95	+	+	●	+			} 4
10	1890-91	●	+				●	} 8
9	1882-83		●	+			+	} 4
8	1878-79	●	●	●		●	●	} 3
7	1875-76	●	●	●	●		+	} 5
6	1870-71	+	+		●	●	+	} 8
5	1862-63	+	●	●	●	●	●	} 8
4	1854-55	●			+		+	} 6
3	1848-49	+		●	●		+	} 3
2	1845-46	+					●	} 10
1	1835-36			●	+		+	

Fire scars only	Tree 1	Tree 3	Tree 4	Tree 5	Tree 6	Tree 20	← X̄	X̄
Mean intervals between fires	9.0	12.4	12.2	12.0	15.3	12.6	**12.3**	**6.4**
Max. interval	21	26	16	27	30	17	**22.8**	**16**
Min. interval	3	3	3	5	8	6	**4.7**	**3**
No. of fires	7	6	7	6	4	6	**6.0**	**15**

Fire scars and growth pulses	Tree 1	Tree 3	Tree 4	Tree 5	Tree 6	Tree 20	← X̄	
Mean intervals between fires	5.3	6.6	8.1	9.9	12.4	7.5	**8.3**	**5.9**
Max. interval	12	11	14	19	24	15	**15.8**	**11**
Min. interval	3	3	3	5	6	3	**3.8**	**3**
No. of fires	12	14	10	10	6	17	**11.5**	**19**

Table 7.2 Fire frequencies for individual trees and sites from dated fire scars and post-fire growth pulses. (This form of presentation conforms with that in international literature for fire studies).

Site No.	Tree No.	No. of years	No. of Fires	Fire free period		
				average	min	max
2	1	63	12	5.3	3	12
3	3	86	14	6.6	3	11
3	4	73	10	8.1	3	14
3	5	89	10	9.9	5	19
3	6	62	6	12.4	6	24
8	20	113	17	7.5	3	15
(Combined)		**113**	**19**	**5.9**	**3**	**11**

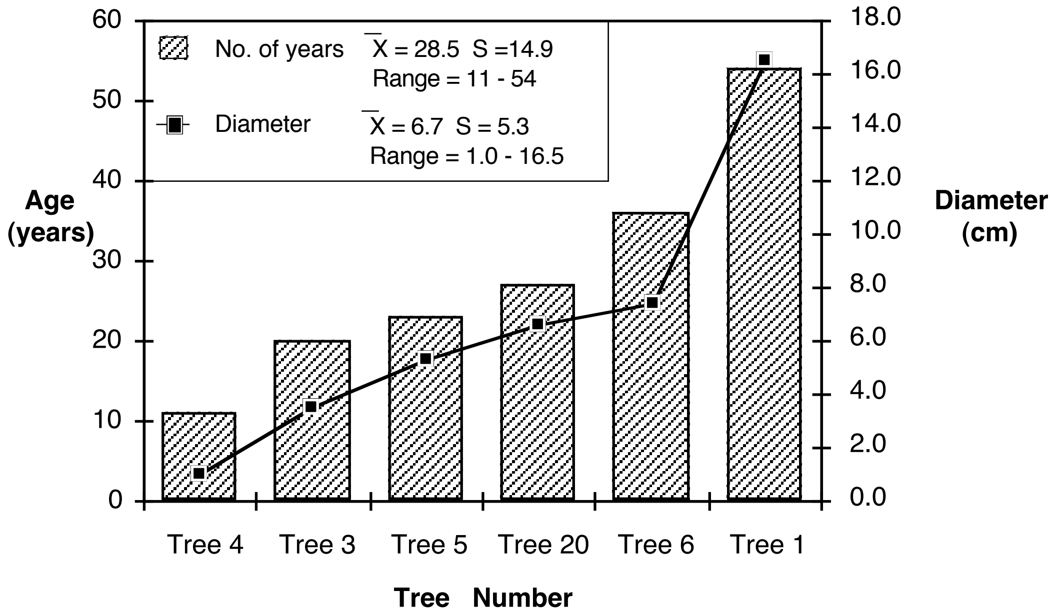


Figure 7.6 Tree diameter under bark and age at first non-lethal, fire scarring fire.

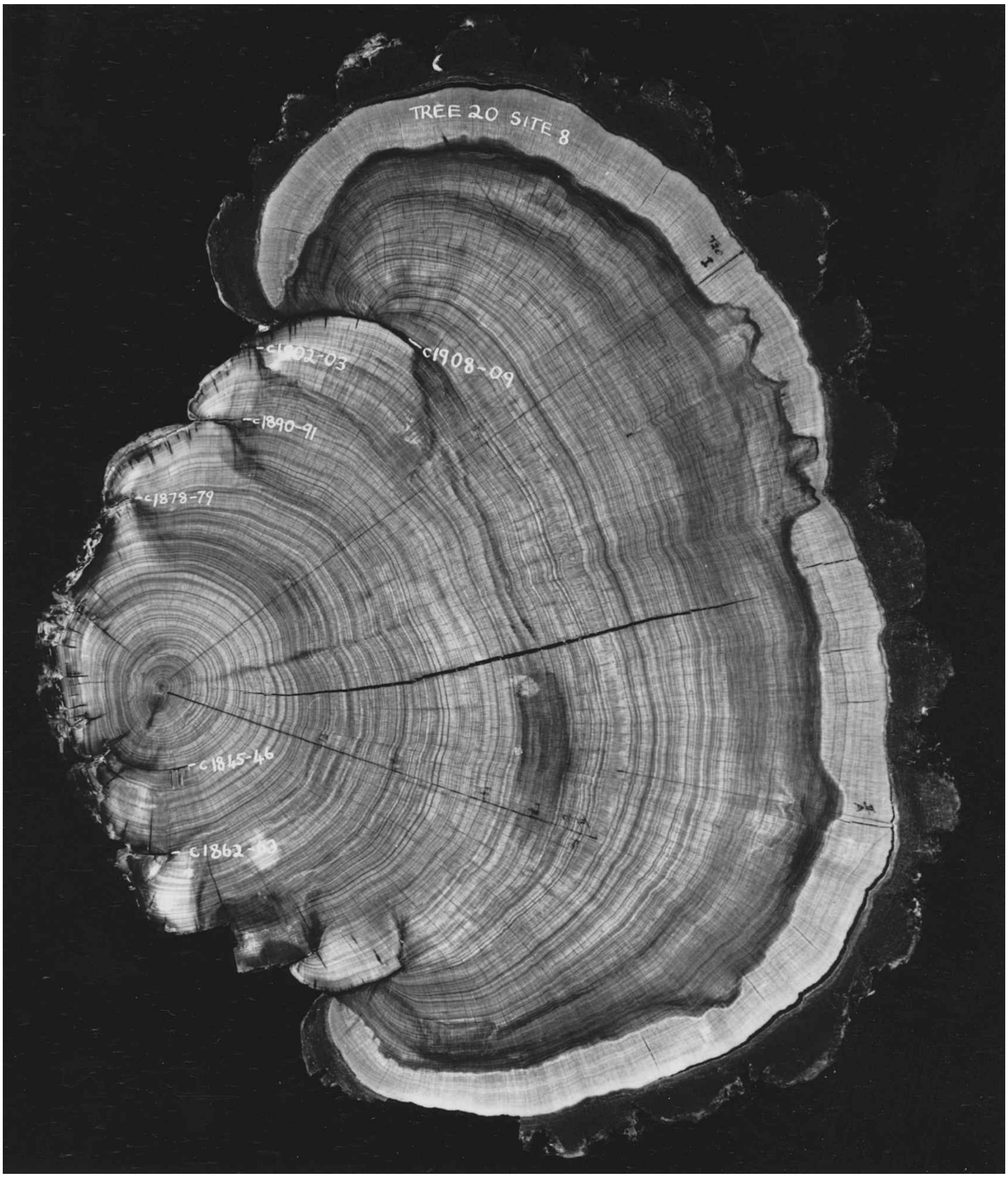


Plate 7.2 Basal growth ring cross section of live old growth woodland tree 20, revealing 6 fire scars which are indicated by a white marker and fire date. After each fire burnt and damaged the tree on its left side, lobate callus wood was produced in an attempt to heal over the wound. Note symmetric growth and relatively wide distinct growth rings in contrast to trees displayed in plates of following pages. Radial lines indicate transects of photo enlargements used for tree ring identification and cross dating. Magnification x 0.43.

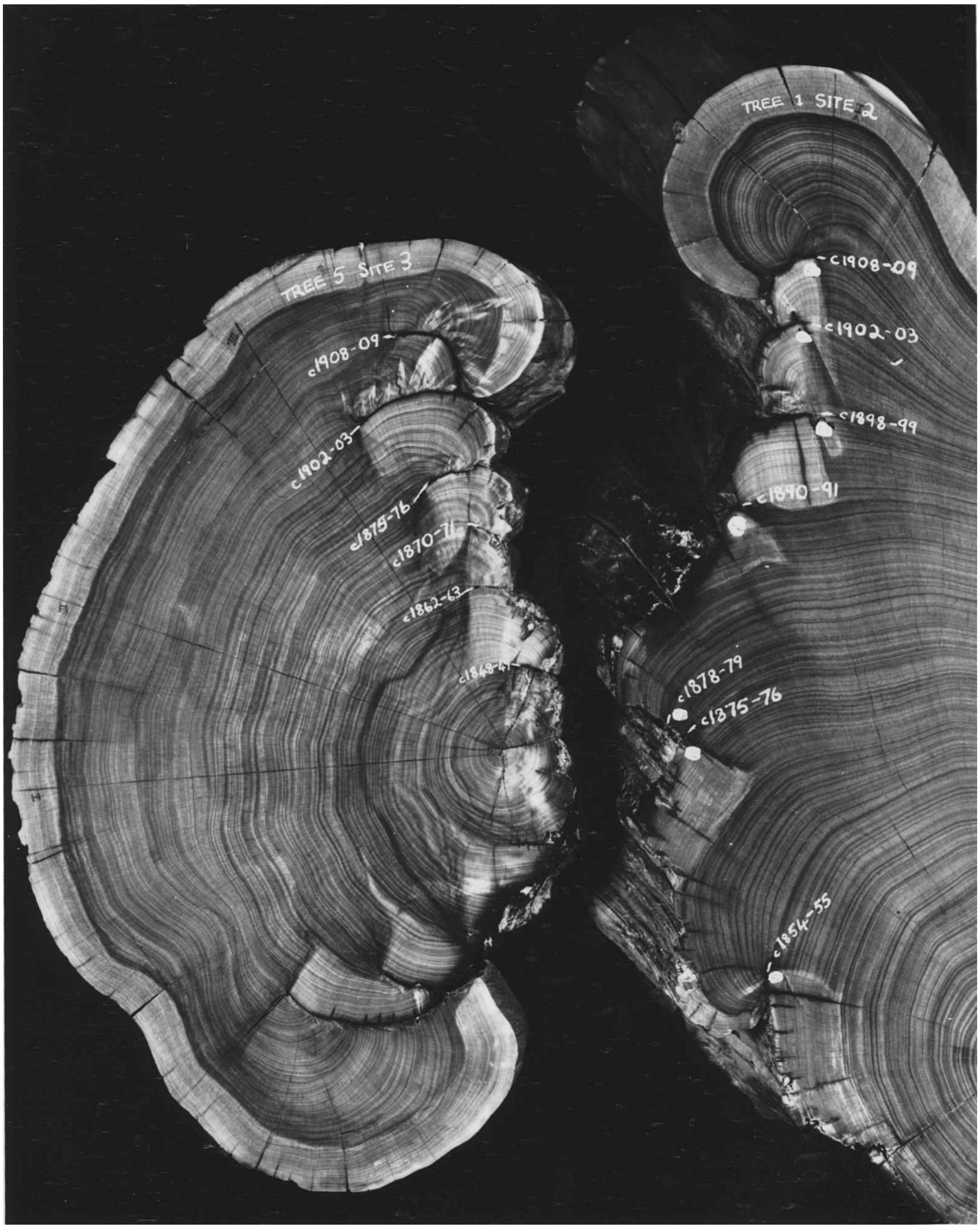


Plate 7.3 Basal growth ring cross section of dead old growth woodland tree 5 (left) and tree 1 (right) revealing 6 and 7 fire scars respectively. Each fire scar is indicated by a white marker and fire date. Radial lines indicate transects of photo enlargements used for tree ring identification and cross dating. Magnification x 0.53.

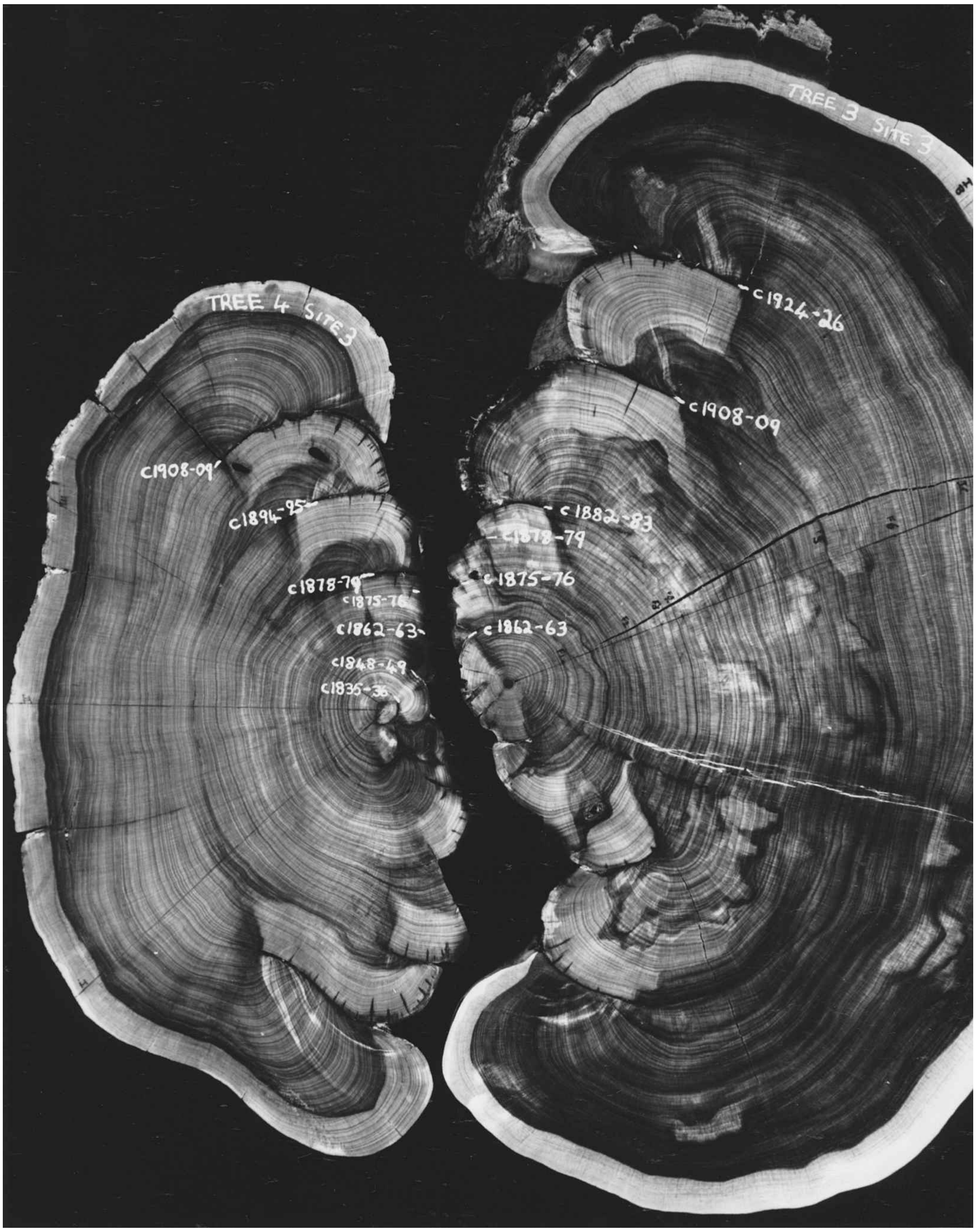


Plate 7.4 Basal growth ring cross section of dead old growth woodland tree 4 (left) and tree 3 (right) revealing seven and six fire scars respectively. Each fire scar is indicated by a white marker and fire date. Dark radial lines indicate transects of photo enlargements used for tree ring identification and cross dating. Note the extremely small diameter of growth rings (1 cm) of the inner most fire scar on tree 4 dated c1835-36. Magnification x 0.43.

Plate 7.5 Basal growth ring cross section of dead old growth woodland tree 6 revealing four fire scars. Each fire scar is indicated by a white marker and fire date. Dark radial lines indicate transects of photo enlargements used for tree ring identification and cross dating. The inset indicates several small suspected fire scars which could not be dated due to vague and indistinct rings in the outer heartwood and sapwood. Their relative positions on the cross section imply approximate dates in the 1940's and 50's for these disturbances to the tree. No indication of fires at similar dates in other trees sampled were found. Magnification x 0.5.

7.3.2 Other evidence of fires

Official and published records

Three fires have been reported in the lower Snowy River Valley but outside the fire history study sites. A large fire was reported as occurring in 1926 between the Pinch and Jacobs Rivers (Anon. 1971). This may have been in the same season as fire number 16 in the fire scar record. A fire which was reportedly lit by an arsonist, burnt a large area of the white cypress pine - white box alliance between the Pinch and Jacobs Rivers in summer 1972 (Wyatt, 1972). It burnt north and was extinguished in the upper reaches of these catchments in subalpine forests. At low elevations in the white cypress pine - white box alliance this fire burnt at low intensities and was very patchy due to relatively low fuel loads (R. Byrne pers. comm.). This fire was 8-10 km north of the sites sampled for pyrodendrochronology.

In January 1988 a small area of white cypress pines south of the Sandy Creek Fire Trail near Mount Trooper was burnt or scorched during back burning operations to control a large wild fire in the Byadbo Wilderness area. Mortality of pines by the fire was low due to low fire intensity and self extinguishing behaviour due to low fuel levels (pers. obs.).

Anecdotal evidence

Widespread and regular burning of high country in what is now Kosciusko National Park occurred throughout the grazing era as part of established land management practices. During this era the fire frequency and intensity were highly variable reflecting the practices and attitudes of the landholder or lessee (Wellsmore, 1986). Accounts from National Park land managers, park workers and discussions with local land holders indicate that fires have been rare at least in the last 50 years and there have been no recorded fires of any consequence in this alliance (Smith, 1986) in recent decades. The devastating fires of 1939 may have burnt some parts of the lower Snowy River, however they mainly burnt the forests at higher elevations including around Paupong (Wellsmore, 1986) parts of the Pilot Wilderness and the Crackenback Range (Banks, 1987; Costin and Wimbush, 1979) and (D. Wimbush, pers. comm.).

Indirect evidence for the absence of fire

The presence of timber relics of the European grazing era can provide evidence for the absence of extensive fires. One example is the white cypress pine - white box fence which surrounded the Mount Trooper “Bull Paddock”. This timber fence was probably built late last century (Stephenson, 1980; Wellsmore, 1986). Most of it has collapsed and today lies *in situ* slowly decaying. A survey of extensive sections (2 km) of the fence on the south aspect failed to reveal any evidence of fire. This strongly indicates the absence of fire on the south slopes of Mount Trooper since the fence was erected.

Charcoal

No charcoal was found in the alluvial deposits investigated. Absence of charcoal is most likely due to high stream competence and the absence of suitable terrain in the study area for distinct charcoal deposits to form. Streams discharge any fine or low density material such as silt, organic debris or charcoal into the fast flowing Snowy River. The materials which were accumulated were mostly aggregates of river stones and coarse sands.

Table 7.3 The total currently available record of fires from fire scars, inferred from growth pulses and from published and unpublished records for the study area. A number of unreported and unrecorded small patch fires lit by arsonists, lightning and camp-fire accidents along the popular camp-sites on the Snowy River which have burnt small areas are not included.

Growth period	Source of record	Comment
1987 -88	OR	Byadbo fires (Jan 1988) burnt only areas east of Snowy River
1971 -72	OR	Jacobs-Pinch R. fire east of Snowy to Ingeegodbee & Charcoal Range
c1948 -49	GP	Willis study sites 2-6 & 8
c1939 -40	GP	Widespread fires in south eastern Australia
c1934 -35	GP	Willis study sites 2-6 & 8
1925 -26	PR	Jacobs-Pinch River fire west of Snowy River (Anon, 1971)
c1924 -26	FS	Willis study sites 2-6 & 8
c1919 -20	GP	" " " " " "
c1908 -09	FS	" " " " " "
c1902 -03	FS	" " " " " "
c1898 -99	FS	" " " " " "
c1894 -95	FS	" " " " " "
c1890 -91	FS	" " " " " "
c1882 -83	FS	" " " " " "
c1878 -79	FS	" " " " " "
c1875 -76	FS	" " " " " "
c1870 -71	FS	" " " " " "
c1862 -63	FS	" " " " " "
c1854 -55	FS	" " " " " "
c1848 -49	FS	" " " " " "
c1845 -46	FS	" " " " " "
c1835 -36	FS	" " " " " "
Total = 22 fires		

Key
- OR Official record of the National Parks and Wildlife Service
- PR Published record
- GP Growth pulse inferring occurrence of fire in white cypress pine, this study
- FS Fire scars dated in white cypress pine, this study

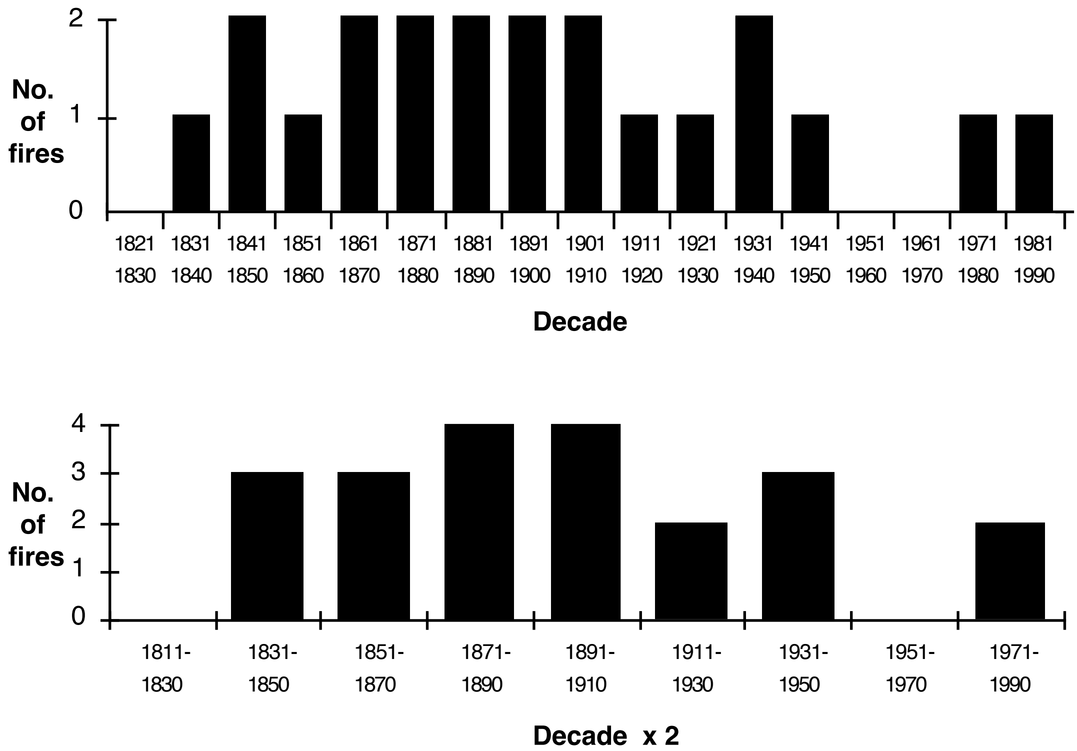


Figure 7.7 Number of fires per decade (top) and for 20 year intervals recorded for the study area.

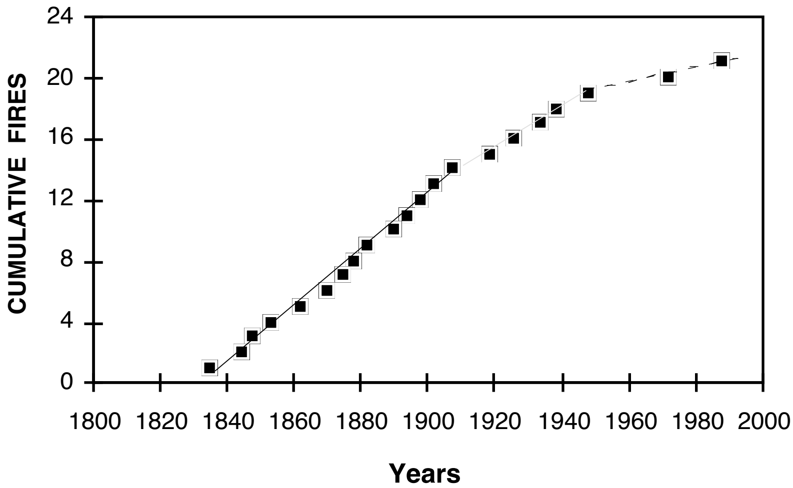


Figure 7.8 Cumulative occurrence of fires in study area. Lines of best fit have been superimposed to aid interpretation of possible trends in fire frequency. The lines are hand fitted lines of best fit for the period 1830 to 1940 based on fire scar and inferred fires from post-fire growth ring patterns. There appears to be a decrease in cumulative fire frequency after about 1910 (dotted line) and a further decrease after c1940 (dashed line). The last 2 fires are from historical records of fires in the study area (dashed line).

7.4 Discussion

7.4.1 Fire history of the study area

This is the first study to successfully date fires in white cypress pine and opens the 'door' for discussion and interpretation of the role of fire in the development of this forest type since European settlement. Prior to this study little was known of pre or post-European burning practices in the white box - white cypress pine alliance.

The derived fire history for the Willis study locality (sites 2, 3 and 8) most probably represents that for the north aspect slopes, if not also for the study area generally if we assume:

(i) the white cypress pine stands were of similar structure throughout the study area when Europeans settled in the valley;
(ii) European land uses have been similar throughout the valley;
(iii) today's forest has similar structure throughout much of the study area.

The actual fire years for other sites in the valley are likely to vary as it is unlikely that the whole valley burnt every time major fires occurred. Some more protected sites such as cool moist south aspect slopes may have had much lower than average fire frequencies.

In general my data suggest that burning occurred more or less regularly every 5-7 years from soon after the commencement of European grazing. The build up of fuels in this semi arid vegetation type would have been slow, compared to the more highly productive and flammable forest types of Kosciusko National Park such as snow gum which was capable of sustaining a fire free period as short as 1.3 years (Banks, 1989). Thus a fire free interval of 5.9 (3-11) years as suggested by the dendrochronological evidence, appears highly plausible. It appears that fire frequency began to decline after about 1910 when the full impact of the interaction of grazing on herbaceous ground cover by rabbit plagues, cattle and competition from a dense cover of regrowth white cypress pine occurred. Unlike higher rainfall areas there was frequently not sufficient fuel to sustain fires. From 1940 onwards, fires became most uncommon. This corresponds to the period when grazing use was less intense than last century up to the prohibition on grazing in the early 1970’s.

Since the area was incorporated into Kosciusko National Park few large fires have occurred. During the 1980’s fires in this vegetation province have been patchy and have burnt a very limited area before they self-extinguished in areas of lowest fuels (R. Byrne pers. comm; pers. obs.). During the study there has not been sufficient fuel on north aspect sites to sustain fire, whereas during the European grazing era until about 1910, fuel levels on these sites must have been reasonably high in order to sustain fires every 5-7 years. South facing sites usually had sufficient fine fuels to sustain fires, however as has been shown, some of these cool more moist aspects have not often burnt. Clayton-Greene (1981) and this study noted that few trees on south facing slopes had fire scars, whilst many on north facing sites have 2-5 fire scars (Chap. 4, Table 4.2).

Tree ring dating indicated that the oldest fire scarred tree sampled (tree 1, site 2, Willis) was likely to have germinated in the late 1790’s which was about 40 years prior to the arrival of Europeans in the study area but there was no fire recorded in this tree until 1845-46. No fire scar or datable post fire growth pulse evidence was found on other trees which might indicate the pre-European fire regime. A considerable number of trees of greater age would be required to further examine pre-European fire regimes.

The ability of Eucalypts to survive wildfires through several specialised morphological adaptations such as the development of various bark types, proventitious dormant bud strands and the seedling lignotuber is well documented (Banks, 1982; Mullette, 1976; Mullette, 1978). White cypress pine is more sensitive to fire than white box because white cypress pine does not have these special adaptations with the exception of relatively thick bark. As the tree ages this bark thickens, possibly further reducing its sensitivity, particularly if it has not already been scarred by fire. Also its seedlings are easily killed by fire and the loss of crown during a fire usually leads to its death (pers. obs.). When this occurs it must regenerate from seed. In spite the lack of special fire adaptations, like many other conifers this species can survive fires of low to moderate intensity and produce callus to heal wounds caused by basal fire scars. The low fuel levels its presence causes in the understorey, particularly in high density stands, reduces the intensity and frequency of fires to a considerable extent.

7.4.2 Fire history dating methods

With careful selection of tree material and the use of the procedures for dating white cypress pine presented, it is possible to construct fire chronologies. The accuracy of the fire history is dependent on the certainty of the tree ring chronology. In this case it was necessary to give dates as circa because there were no independent means other than rainfall for checking the chronology and thus the dates may possibly deviate by ±1 or 2 growth seasons from actual dates in some parts of the chronology. Thus some of the dates closely correspond to fire dates in other studies in the Alps (Table 7.4), but may not always perfectly synchronise to these dates in some sections of the chronology such as those estimated from rings in the outer heartwood which are narrow and increasingly indistinct toward the cambium. For example widespread and intense wildfires occurred in summer of 1938-39 and are usually referred to as the “1939 fire”. It is quite possible that fire dated c1939-40 was a 1939 fire. Another reason why fire dates do not more often synchronise is that fires are usually limited in extent and one would not expect high correlations in fire years in widely separate sites.

The date of a fire ring was accurate to within the limitations outlined by this study which include those characteristic problems of all fire scar studies outlined by Arno and Sneck (1977) and McBride (1983). In addition, the fire dates inferred from post-fire growth pulses alone were possibly slightly less accurate than fire scar dates because fire dates had to be estimated from the appearance of the post-fire growth ring pattern. The lag, duration and magnitude of the post-fire growth ring response after a fire was variable by 1 to 2 growth seasons. For example, in some cases difficulties were encountered in deciding whether to date a pulse at its peak which was usually the widest of the post-fire rings, or the narrow ring which characteristically preceded the pattern of wider rings. There could be no definitive rule because not all fire scars corresponded to the ring preceding the widest ring for a given growth pulse. This suggested that in some fire years there was a lag in recovery of one or more years before sufficient rain fell allowing rapid growth to recommence, while in other cases good growth conditions allowed a wide ring to form in the growth season immediately following the fire or the fire may even have occurred in spring in the same growth season.

Fires appeared to occur in drought years in many cases. Some fires may have followed wet years which would have promoted build up of ground fuels. Post-fire growth pulses were wide in some years of higher than average rainfall such as 1898-1900 following the 1898-99 fire, and 1910-14 following the 1908-09. Successive good growth seasons with a plentiful supply of nutrients released by fire and taken up by these trees which were at a vigorous age, resulted in some exceptionally wide rings. These rings were important marker years and gave an assurance to the chronology.

Tree Ring Index graphs proved useful by revealing post-fire growth pulses much more effectively than graphs of ring width and provided an excellent means for interpreting and illustration of post-fire growth patterns and fire scar dates (Figs. 7.1 to 7.4). Correlations or other statistical analyses were not considered useful for comparing ring width and climatic variables due to the highly disturbed nature of tree growth patterns following fires.

Despite the limitations of the results due to (a) dating fire scars from essentially one study site (sites 2, 3 and 8), and (b) some limitations of the dating methods (absolute dating would have been desirable though not essential), this has not detracted from the usefulness of the results for ecological interpretation as is shown in the following discussion where my results are compared and contrasted with independent fire data from the Australian Alps.

7.4.3 A discussion of fire in the white cypress pine zone compared with forests of the Australian Alps

Fire years recorded from four studies in subalpine snow gum stands in the Australian Alps (Banks, 1982; Banks, 1987; Pryor, 1939; Raeder-Roitzsch and Phillips, 1958) are compared with the fire years from this study (Table 7.4). A number of major fire years or periods in the snow gum stands correlate with fire years in the lower Snowy River. There are a number of fire years in the snow gum studies which do not match fire years in the lower Snowy River. This is to be expected due to: (i) the lower fuel levels in the study area vegetation resulting in less frequent fires and, (ii) the far greater number of sites and trees sampled whose results were combined in the snow gum studies.

Banks (1982), Banks (1987), Banks (1989), Pryor (1939) and Raeder-Roitzsch and Phillips (1958) have comprehensively discussed the environmental conditions affecting the behaviour of fire and the role of man in the dynamics of subalpine snow gum forests of the Australian Alps. I draw from some relevant aspects of their findings and discuss how the role of fire in the semi-arid low elevation white cypress pine stands appears to fit into the fire history for the Alps as a whole (Table 7.4). (See also Figs. 7.7 and 7.8).

Byles (1932 a & b) reported on the degraded condition of the upper catchments of the Murray and Snowy River systems to the Director of the Forests and Timber Bureau in Canberra on his visit to the Australian Alps in 1931-32. He reported that the only extant stands of old growth snow gum remaining, were on the Pilot and an isolated series of granite peaks in the southern part of the upper Murray catchment. This was the first official report to authoritatively indicate the great extent of change in vegetation structure in the Alps since European settlement. These changes were ascribed by Byles to uncontrolled grazing and burning practices. The first study of the history of fire in the Australian Alps was carried out by Pryor (1939) near Bulls Head in the Brindabella Range. This study was carried out due to concern regarding the frequent cavalier use of fire by mountain cattlemen and prospectors, the ecological effects of fire and the threat of fire to Canberra, its water supply and pine plantations. The snow gum material analysed by Pryor revealed a major increase in fire frequency from about 1860. Fire frequency increased from a pre 1860 level of 7.1 fire free years over a 12 year interval to 1.3 fire free years after 1860.

Banks (1982) recognised 5 distinct periods which he used to show man's impact on the dynamics of snow gum forests in the Alps. These periods provide a useful framework for considering the evidence for human impact through use of fire in the white cypress pine forest. These periods were defined as:

(a) the Aboriginal period to 1840;

(b) the first European period 1820-1850;

(c) the second European period 1850-1870;

(d) the third European period 1870-1950;

(e) the fourth European period 1950 to the present.

The fire frequency in the subalpine snow gum stands during the tree datable portion of the Aboriginal period was about 1 fire per decade. No fires were recorded for the period c1800 to c1835-36 in white cypress pine. This suggests a low fire frequency in the white cypress pine forests corresponding to low fire frequencies found elsewhere in the Alps by Banks (1982) for the "Aboriginal period". This evidence is based on the record for tree 1, the oldest recorded tree in this study, and thus conclusions must be drawn with great caution. The data on early fires diminishes in accuracy with time because there are few available and suitable trees for sampling. The study sites are in relatively close proximity to snow gum forests of the Alps and it is reasonable to assume that there would not have been marked distinctions according to forest type in either Aboriginal or European use of fire throughout these forest and woodland landscapes. After about 1840 the Aboriginal population rapidly diminished in the study area and the pattern of fire subsequent to their demise can be ascribed to European use of the land.

The first European period 1820-1850 saw the introduction of fire by Europeans to mountain forests (Banks, 1982) and the lower Snowy River Valley. Fire was initially introduced to remove unpalatable old snow grass, to encourage more palatable grass and herbaceous plants and to maintain access along the mountain stock routes. The route along the lower Snowy

River was one of the earliest and most important stock routes linking the Monaro to east Gippsland thus it is likely to have been burnt frequently. At this time the relative increase in fires in the lower Snowy River white cypress pine stands may have been as dramatic as in the snow gum forests. Evidence of fire free intervals for this period suggests that the fire frequency was likely to have been lower than in snow gum forests due to the inherently lower productivity of this semi-arid vegetation type. European burning activities may well have commenced soon after their arrival in the late 1830's and 1840's in the lower Snowy River Valley (Fig. 7.8).

Banks characterised the second European period from 1850-1870 as a period of prospecting and rapid influx of Europeans and their livestock. Prospecting occurred in the lower Snowy River Valley (Clarke, 1860). During this period the high country forests experienced a three fold increase in fire. There is not sufficient fire evidence to suggest that the same increase in fire frequency occurred in white cypress pine forests. This increase resulted in widespread dense regrowth of Eucalypts in the Alps. Dating of regrowth white cypress pine does not suggest a regrowth response until the 1880's and 1890's which substantiates Harnett's (1948) report that "wheatfield" regeneration of pines commenced in 1878.

K.C. Rogers, whose family occupied part of the Wulgulmerang plateau near Suggan Buggan since 1900, said that the area underwent rotational burning "..as often as possible which would have been every 3 to 4 years according to conditions.." for 100 years (Wakefield, 1970). This Eucalypt dominated community which occurs at higher elevation than white cypress pine is immediately adjacent and to the south of the study area. These fires were in the hottest months in the middle of summer so that the "..fire was as fierce as possible and thus make a good clean burn." According to Rogers, the response of the vegetation was that after one or two seasons the grasses grew sour again and scrubby regrowth resulted.

Grazier Clyde Sykes of Lakes Entrance, but formerly Gelantippy, observed that when the Suggan Buggan/Cobberas area was burnt every three to four years, the low intensity and patchy nature of the burn meant that in effect, the full area would only be burnt every 15 to 20 years (C. Allen, pers. comm. b)[1]. Sykes also commented that with the cessation of grazing in this area he has noticed a marked increase in the density of scrub (shrubs). In another interview (C. Allen, pers. comm. c), Creamy Pendergast stated that “patch burning” occurred each year but was reputedly carried out in such a way that an area such as the Cobberas[2] might only be burnt once in 20 years. In fact there is considerable anecdotal and fire scar evidence in other parts of the montane and subalpine forests of the Australian Alps that Europeans burnt much of the landscape whenever possible (Banks, 1989). Near Willis in white cypress pine this appeared to occur on average every 6-7 years during the period 1850-1870 and on average every 5.9 (3-11) years from the period of common fire record (Table 7.2).

The third European period 1870-1950 was characterised in the high country with a fire frequency five times the historical average. A series of major wild fires continued to destroy the old growth forests and dense regrowth became widespread. In the lower Snowy River the average fire free interval was 6.0 (4-11) years. There was a succession of fires in the 1890’s and early 1900’s which had fire free intervals of only 4 years. Fires may have become gradually less frequent after c1910. Dense regrowth stands would have suppressed herbaceous plants and shrubs in the white box -

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[1] Craig Allen is an amateur historian, local landholder and resident of Canberra

[2] The Cobberas Range vegetation is subalpine Eucalypt forest and woodland, 23 km west of the study area

white cypress pine alliance and plagues of rabbits would have periodically demolished most remaining ground layer vegetation. Fires would have been of low intensity and very patchy. The lack of fire scars after c1920, the lack of charcoal on the regrowth cypress pines and the lack of standing dead regrowth is testimony in support of the view that there have been few recent high intensity fires.

The fourth European period from 1950 to the present saw the complete removal of grazing from the high country and the lower Snowy River. Nature conservation and recreation are now the major land uses of the study area. Fire frequency throughout the high country forests has returned to its pre European levels of 1 fire per decade or less. In the lower Snowy River Valley the sampled study site has not experienced a fire for 40 years, however the whole study area of the valley has experienced 4 fires in the last 40 years. Parts of the Valley such as the southern side of Mount Trooper do not appear to have experienced major fires this century, however those areas near stock yards, stock routes or near the Barry Way around the Pinch and Jacobs River junctions with the Snowy River and on the hot north facing sites have probably experienced more frequent fires this century.

Whilst the four periods identified by Banks (1981) are useful for discussion of the role of fire in the Alps as a whole, a different analysis of the ecologically significant periods of human activity and their impacts on the forest structure of the lower Snowy River Valley is presented in chapter 8.

<u>Table 7.4 (a)</u> Comparison of the fire years recorded from the study area with fire years recorded in four fire studies in snow gum stands in subalpine areas of the Australian Alps. Note that the white cypress pine-white box alliance in the study area is between 200 and 550 m elevation whilst the snow gum stands are between 1500 and 1800 m A.S.L.

	Location	Lower Snowy River	Upper Tooma Catchment	Brindabella Range	Mt. Ginini South slope	Thredbo ski slopes
	Forest type	w. c. pine	snow gum	snow gum	snow gum	snow gum
	Author	1	2	3	4	5
	Fire No.					
	71	1991-92	*	*	*	*
	70	1988-89	*	*	*	*
	69	1972-73	*	*		
	68		1952-53			
•	67	c1948-49	1948-49			
	66		1946			
	65		1941-44			
•	64	c1939-40	1939	1939	1939	
	63		1936			
	62				1935	
	61	c1934-35				
	60		1931-33	1933		
	59			1932		
	58		1927-28			
	57			1926		c1926
	56				1925	
•	55	c1924-26	1924-25	1924		
	54	c1919-20	1919		1919	
	53		1913			
	52				1912	
	51			1911	1911	
	50	c1908-09				
	49				1907	
	48				1906	
	47			1905	1905	
	46		1904			
	45				1903	
	44	c1902-03				
	43					c1900
	42			1899	1899	
	41	c1898-99				
	40		1897			
	39				1895	
•	38	c1894-95	1894			
	37			1892		
	36	c1890-91				
	35		1889			

Authors 1= This study
2= Raeder-Roitzsch and Phillips, 1958
3 = Pryor, 1939
4 = Banks, 1982
5 = Banks, 1987
* = After study was published
• = Fire year in this study matches fire year of other study (ies)

Table 7.4 (b) Comparison of the fire years in the Australian Alps.

Location	Lower Snowy River	Upper Tooma Catchment	Brindabella Range	Mt. Ginini South slope	Thredbo ski slopes
Forest type	w. c. pine	snow gum	snow gum	snow gum	snow gum
34			1885		
33				1884	
• 32	c1882-83	1882			
31			1881		
30			1879	1879	
29	c1878-79				
28		1877			
27			1876	1876	
26	c1875-76				
25		1874			
24				1872	
• 23	c1870-71	1870			
22				1864	
• 21	c1862-63	1861-4			
20			1860		
19				1858	
18	c1854-55				
17				1851	
16				1850	
15	c1848-49				
14	c1845-46				
13		1841		1841	
12	c1835-36				
11				1831	
10					c1830
9				1828	
8				1815	
7				1805	
6				1791	
5					c1790
4				1781	
3				1772	
2		c1750			
1			1739		

Authors 1= This study
2= Raeder-Roitzsch and Phillips, 1958
3 = Pryor, 1939
4 = Banks, 1982
5 = Banks, 1987
* = After study was published
• = Fire year in this study matches fire year of other study (ies)

7.5 Conclusion

As is the case with other studies (Banks, 1982; McBride, 1983; McBride and Jacobs, 1978), pyrodendrochronology and the calculation of mean fire free intervals for the period of common fire record was found to be a useful tool for investigating the fire history of white cypress pine in the lower Snowy River Valley. The investigation relied greatly on the dendrochronological analyses (Chaps. 5-7) to date the fire events, because little reliable published or anecdotal evidence was available. These analyses depended on locating suitable trees which could be cross dated. Fire scars and fires inferred from post-fire growth ring patterns on old growth trees, which had developed under open woodland conditions, could be dated and a fire history developed. Without the inclusion of fires inferred from post-fire growth ring patterns, the mean fire free interval would have been overestimated.

During the period of the highest frequency of European burning from approximately 1870-1910, the mean fire free interval in white cypress pine near Willis was about 4.4 years. This was greater than that found in snow gum stands which were capable of sustaining a mean fire free interval as short as 1.3 years (Banks, 1989). A decline in fire frequency occurred from about 1910 with a further decline after 1940 to the present day.

Part III

Synthesis

Chapter 8 Anthropogenic and environmental factors in the dynamics of white cypress pine communities in the "lower" Snowy River Valley.

8.1 Introduction

The white cypress pine stands of the lower Snowy River Valley have been under anthropogenic influences for thousands of years but it is in the last 150 years during European settlement that these stands have undergone rapid changes with the almost complete replacement of the old growth woodland trees by dense young regrowth stands. These have been confined within the former limits of the species distribution in the valley, sharp ecological gradients presumably preventing any geographic expansion. Environmental changes associated with European man have tended to favour this species which has responded to a series of disturbances, e.g. changes to the fire regime, massive soil erosion, and the introduction of exotic animals and plants. This says much for the tolerance and adaptability of the species. The synthesis draws together chronologically the anthropogenic and environmental factors and discusses their significance in triggering change in the white cypress pine stands (Fig. 8.1). With this ecological interpretation we are now in a better position to seek appropriate ecological questions and to better evaluate future land management policies for the "lower" Snowy River Valley.

To show more clearly the influence of human use on this forest two major cultural eras have been identified. These are:

(1) Aboriginal era pre 1840;

(2) European era from 1834 to the present.

The European era is further divided into five periods. Each period corresponds with a phase in the use of the area and the response of the vegetation and other environmental components. These periods are:

(i) 1834-1870;
(ii) 1870-1900;
(iii) 1900-1940;
(iv) 1940-1961;
(v) 1961-1990.

8.2 Aboriginal era

(pre 1840)

During the era of Aboriginal occupation at the time of the arrival of Europeans, the vegetation of the lower Snowy River Valley was predominantly woodland containing scattered individual trees and clumps of large white cypress pine trees, confined largely to the hot and drier north slopes and ridges, and white box confined mostly to cooler moist south slopes and at higher elevations. The two species formed mixed stands about their common ecotones. The white cypress pine stands were heterogeneous, comprised of multi-age trees though large old trees would have been most common. The understorey was composed of predominantly dense grasses with scattered shrubs providing a protective cover.

The high concentration of over 220 Aboriginal sites along the Snowy River indicates that the valley was an important occupation corridor. Although little is known of Aboriginal culture and land use practices in the southern tablelands, it is reasonable to expect that these peoples would have manipulated these plant communities for their own well-being as in other parts of Australia. Their most powerful tool for manipulating vegetation was the selective use of fire. Interpretations of early observations of the use of fire by Aborigines are often conflicting (Hancock, 1972). However, Jacobs

(1963) and similarly Howitt (1890) suggested that in southern Australia, Aboriginal fires were lit at the beginning of each dry season, or in spring as the first patches of grass became flammable. These fires would not have spread very far and would have gone out when they reached green grass or during the night (Jacobs, 1963). These burnt patches formed a mosaic which helped reduce the occurrence and intensity of larger summer fires and ensured a rich diversity of seral habitats which would have been beneficial for game species. Occasional wild summer fires inevitably would have occurred despite mosaic burning, but these were most probably triggered by dry electrical storms coinciding with extreme hot dry weather conditions. Occasional accidental escapes from more or less continually active Aboriginal camp-fires may have also occurred in periods of high winds during hot weather.

The interpreted pre-European woodland of widely spaced and contagious distribution of old growth white cypress pine (Chap. 4) is evidence which supports Jacobs' (1963) proposition that Aborigines in southern Australia deliberately lit low intensity mosaic fires which did little damage to established trees. White cypress pine trees develop a thick insulating bark which protects tree boles from butt damage during low intensity fires. As long as trees remain undamaged they continue to survive fires. Furthermore, trees growing in small clumps or groves, some of which are protected by rocky areas and ridge crests, tend to suppress grasses and shrubs beneath them. This further reduces the local intensity of fires. Seedlings and small trees would have been easily consumed by these small fires ensuring irregular and sporadic regeneration. Thus fire is the primary stand thinning agent in cypress pine forests eliminating most regeneration (Johnston, 1975), and death from old age and competition is therefore minor by comparison. These fires would prevent the formation of dense locked

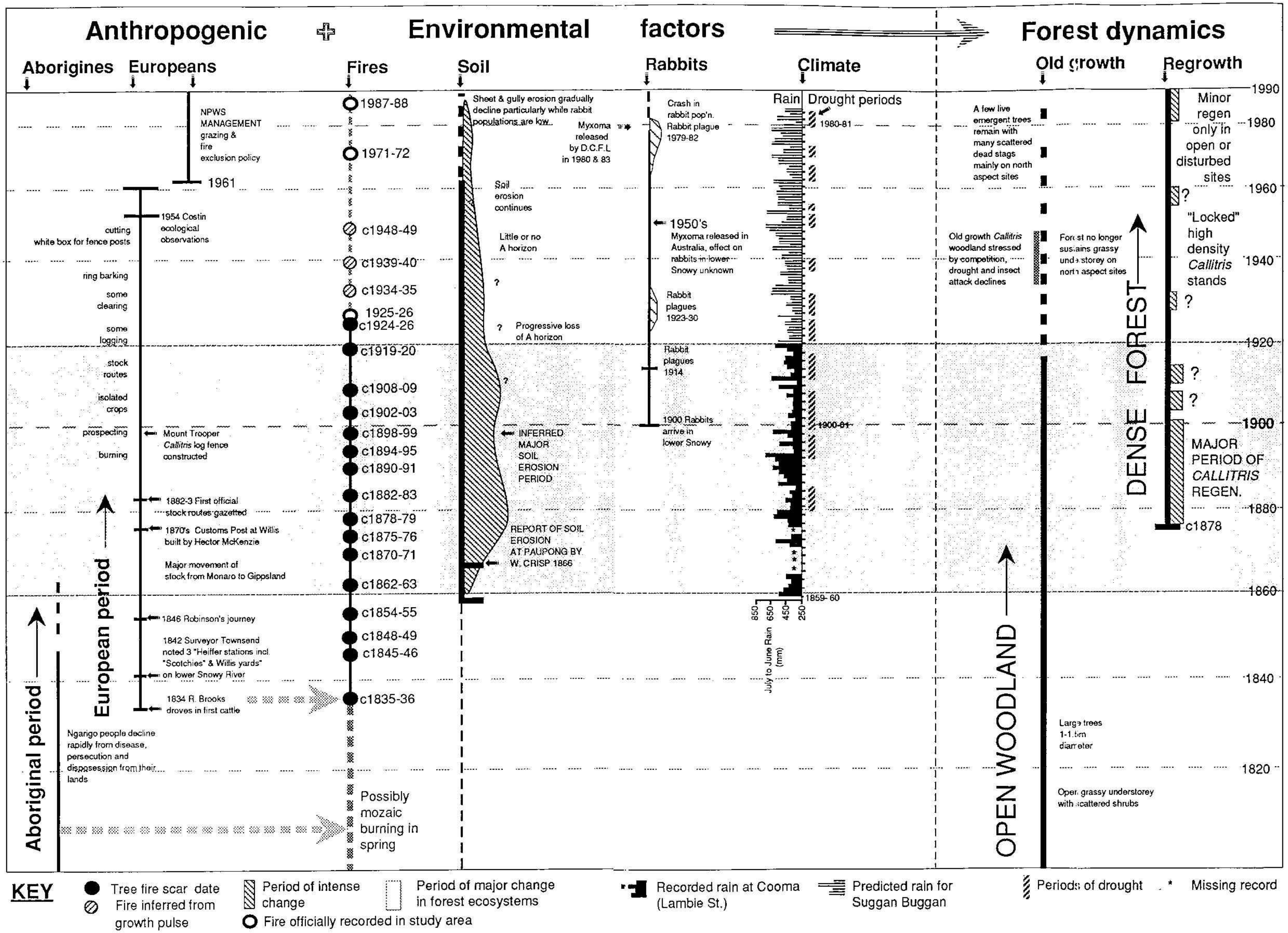

Figure 8.1 Timeline of environmental and anthropogenic factors which contributed to changes in the structure of the white cypress pine forests of the lower Snowy River area. Fire dates indicated are for the July to June growth/fire seasons.

stands of young trees promoting and maintaining an irregular woodland of mostly uneven-aged older trees with the open and grassy and shrubby understorey described by Robinson (Mackaness, 1941).

The frequency of burning to maintain a woodland as described above remains unknown. Dendrochronological evidence for pre-European fire frequencies was very limited. Only one of the successfully dated trees was sufficiently old to date any pre-European fires. This tree's first fire scar after germination in the late 1790's was dated c1845-46 suggesting fires about individual trees were either frequent and of low intensity and hence non-damaging, or infrequent occurring once every 40-50 years assuming fire was associated with its establishment. Answers to this question must await further studies. In support of the latter, observations from adjacent subalpine ecosystems (Banks, 1989; Pryor, 1939; Raeder-Roitzsch and Phillips, 1958) provide evidence for low fire frequencies prior to European arrival in about 1840 to 1860.

The interaction of macropods and other native herbivores in the dynamics of white cypress pine is likely to be largely indirect through their regulation of potential fuels by the grazing of grasses. White cypress pine foliage was found in the diet of the yellow-footed rock-wallaby at Fowlers Gap under dry conditions (Dawson and Ellis, 1979) but there is no similar data for the species of macropods found in the study area.

The above evidence suggests a relatively stable era of woodland with trees of mixed ages which is the result at least in part of anthropogenic factors, the most obvious being Aboriginal use of fire. This is consistent with the generally accepted view that in eastern Australian montane and coastal forests, Europeans encountered a "cultural" landscape which was not as affected by human use as European landscapes (Clark, 1990).

8.3 European era

The arrival of Europeans in the Snowy River Valley initiated dramatic changes to the white cypress pine - white box woodlands. The open woodlands with their grassy understorey were progressively replaced by dense regrowth stands of white cypress pine often forming “locked stands”. The old growth white cypress pine trees declined and died, ground cover was lost in many areas and severe sheet and gully erosion occurred, particularly on hot north aspect sites. Rivers and creeks became filled with sand. The banks of perennial rivers such as the Snowy, Jacobs and Pinch Rivers became infested with introduced plants. The ecological changes were a microcosm of changes in the wider Australian scene.

These changes were the result of European land use practices interacting with periodic extreme environmental conditions particularly drought and heavy rain. The key factors associated with European land use practices were: (i) cattle and sheep grazing, (ii) trampling and compaction of soils by stock, (iii) rabbits, (iv) an increase in the intensity and frequency of fires, (v) soil erosion, (vi) insect attack of old growth trees, (vii) arrival of large numbers of introduced plant species, (viii) other introduced vertebrates such as horses, dogs, foxes, goats, and deer, (ix) and on a minor and restricted scale, tree clearing, prospecting, mining and cropping. The sequence of disturbances as elucidated from historical, dendrochronological and fire scar evidence is as follows.

1834-1870

During this period large numbers of cattle entered the valley to graze on large poorly defined runs. Grazing occurred all year round and simple huts and yards were erected by the stockmen and occasional prospector. The area became a corridor for the movement of large numbers of cattle to East

Gippsland. The Aboriginal population and their use of the lower Snowy River Valley declined rapidly as it was taken over by the cattle runs.

George Augustus Robinson described the area in 1844 as containing large diameter white cypress pine four to five feet in circumference with dense grasses and rich dark soils (Mackaness, 1941). Similar woodland descriptions are recorded from many parts of eastern Australia (Jacobs, 1963). Although few of these original trees remain, Robinson's description is substantiated by the analysis of the distribution of the old growth trees remaining in the modern day forest (Chap 4). This indicated that the alliance consisted of an open woodland of white cypress pine and white box. Tree density was estimated from 30.5 (3.9-59.3) (Chap. 3) to 80-120 stem ha^{-1} (Clayton-Greene, 1981 using Robinson's description). There are several possible explanations for the differences in the estimated old growth tree density, e.g. (i) an unknown number of the original large trees would have disappeared over time having succumbed to fires lit during the grazing era, (ii) Robinson may have exaggerated their size in his description, (iii) Robinson's description may have reflected his impressions of only a part of the area, and (iv) some trees have been felled or removed during European use of the area. Thus the transect diagrams of old growth trees may underestimate the pre-European woodland density by an unknown amount. Regardless of the actual tree densities, the general openness of the pre-European forest composed of large old trees is in contrast to today's regrowth stands. Significant tree losses can be assumed by the fact that tree ring and radiocarbon dating of a limited number of trees suggest that the old trees of today may have originated in the early 1800's and were therefore young trees at the time of Robinson's observations. Further aging of the old trees is needed to resolve this question.

During this period there was an increasing use of fire by both graziers to promote green shoots for the cattle (Wakefield, 1970) and prospectors who arrived in the lower Snowy River Valley and nearby Alps after the 1850's. They used fire extensively to bare the soil to make it easier to find minerals. There was a significant difference between these “European” fires and those used by Aborigines (Jacobs, 1963). European burning typically was carried out in the heat of summer when the fiercest blaze could be achieved. On neighbouring runs in the gum forests the firing of vegetation was regularly carried out every 3-4 years for over 100 years, graziers firing the vegetation whenever it would burn (Wakefield, 1970). These fires had the effect of killing many seedlings, trees and shrubs over large areas. Similar fires in the white box-white cypress pine forests were probably just as frequent but less intense because of the lower productivity of these forests.

Frequent intense summer fires combined with trampling by hard hooved stock together with removal of herbaceous cover by cattle grazing provided the preconditions for rapid erosion described by Costin and Wimbush (1979) for the Alps. Disturbed surface soil was readily washed away by intense runoff during thunder storms. Continued grazing prevented rapid re-establishment of protective ground cover and browsing of seedlings reduced regular recruitment of white cypress pine. This was exacerbated by the fact that following these summer burns the next major growing season was not until the next spring allowing occasional winter and early spring rains free access to surface soils. Soil erosion would have been one of the first visible signs of ecological damage, for example, Crisp reported rapid erosion and silting of streams due to stock had occurred near the study area by 1866 (Hancock, 1972). The extent of erosion during this period is indicated by the depth of exposure, due to loss of topsoil, of the roots of old growth trees. In contrast there is no comparable exposure of the base and roots of regrowth trees indicating that the major erosion episodes occurred before the regrowth established.

European burning practices in the Snowy River region initiated major changes to the forest structure. Intense summer fires would have weakened and killed many trees and shrubs over large areas reducing the original vegetation mosaic to a uniform state. Historical evidence for structural changes in montane Eucalypt dominated plant communities on the nearby Wulgulmerang Plateau as presented by K.C. Rogers (Wakefield, 1970), indicated that fires were lit every three to four years in the hottest months i.e., as frequently as it was possible to get a fire to run through the forest. These fires were usually lit in the gullies to maximise their intensity by allowing them to rush up the steep slopes to the ridges. The result was a scrubbing up of the forest within a few years. The cause of this “scrubbing up” was not simply a matter of a change in a single factor but a complex interaction of the vegetation with a major change in land use in which grazing and burning were the key factors (Banks, 1989).

In contrast with European burning practices in the surrounding gum forests, Wakefield (1970) considered that the white cypress pine - white box alliance was not deliberately burnt. This study does not support this contention, and suggests that at least in some, if not in many parts of the study area, frequent fires occurred and therefore, presumably, were deliberately lit (Fig. 8.1, fire scar dates). He may have drawn this conclusion because the response to fire in this alliance was dramatically different to the nearby gum forests on the Gelantippy Plateau where dense shrubs and tree regrowth occurred. His view may reflect the less frequent fires in this forest this century.

1870-1900

This was the period of major white cypress pine regeneration. In the late 1870's a series of good rainfall years, combined with the disturbance to the landscape from erosion and fires, produced the conditions which triggered large scale white cypress pine regeneration (Lacey, 1972). Harnett (1948) quotes stockmen from the Snowy River area who claimed that "wheatfield" regeneration of white cypress pine commenced in 1878. Gaps in fire and grazing intensity and the availability of seed and suitable weather conditions allowed waves of regrowth to establish. Similar 'waves' of white cypress pine regeneration are reported (Lacey, 1972; Lindsay, 1948) to have occurred throughout western NSW at this time, continuing until the arrival of rabbits. Confirmation of this comes from the age estimates from tree ring counts which indicates major tree establishment in the period 1885-1900. One effect of this re-emergence of a vegetation cover would have been reduced soil erosion.

1900-1940

This period was characterised by the arrival of rabbits, a decline in the productivity of the area for grazing, a decline in fire frequency, and decline of the old growth trees. Rabbits arrived in the area in 1900 and were the final major factor which contributed to changes in forest structure. The combined effect of rabbit and cattle browsing of white cypress pine is well documented (Lacey, 1972; Lindsay, 1948 and Johnston, 1969) and together would have effectively prevented further regeneration of white cypress pine in many areas. A second but smaller erosion phase was triggered by intense rabbit grazing.

The effects of forest fires in the valley and in southern Australia generally, were summed up by D.E. Hutchins the South African Conservator of Forests, who on visiting Australia in 1913 wrote:

> "If there were no forestry in Australia beyond mere fire protection the benefit to the country would be incalculable -- every Australian is familiar with the spectacle of the burned forest, every traveller tells the tale of the monotonous scene of ruin." (Hutchins, 1916).

This observation has been substantiated from dendrochronological evidence from the subalpine forests (Banks, 1982; Banks, 1986; Banks, 1989; Pryor, 1939; Raeder-Roitzsch and Phillips, 1958). It is clear that the white cypress pine - white box forests of the lower Snowy River were being treated no differently to other forests of eastern Australia and the consequences were similar. By the time of Hutchins' visit soil erosion in the study area was now severe and attempts at burning in the regrowth forest resulted in less frequent and less intense fires. Some fires thinned stands a little but were generally patchy and of such low intensity that they did not kill the regrowth or produce fire scars on regrowth or old growth trees. All anecdotal and official records corroborate the dendrochronological evidence that there were now few major fires possibly due to the extremely low fuel levels.

Toward the end of this period saw the decline and mortality of the old growth white cypress pine trees. By 1935-1945 severe drought combined with intense competition from regrowth caused severe stress in the old growth trees which had established in more open stand conditions. Extreme narrowing of rings in these trees after about 1910-20 indicates a slowing in growth which would be caused by a combination of site degradation from erosion, the trees' age and competition from regrowth. The old growth trees were then subject to massive insect attack. Girdling of the trunks of every one of the dead trees strongly suggested that this was the final cause of mortality. Similar girdling of trees under moisture stress is reported in Eucalypts (Pook *et al*. 1966) and in *Callitris* (Hadlington and Gardner, 1959). Girdling on white cypress pine was caused by larvae in the family Bupresstidae (Dr. M. Tanton pers. comm.). In this case it is likely to have been the cypress pine jewel beetle *Diadoxus erythrurus* (White) which is reported to attack fire damaged *Callitris spp*. (Hadlington and Gardner, 1959). Other foliage destroying insects, such as the cypress pine sawfly *Zenarge turneri,* or debilitating conditions such as drought or fire can predispose *Callitris* to attack by *D. erythrurus* (Moore, 1962). He found that *Zenarge turneri* mainly attack younger regrowth in sites with inefficient drainage rather than mature trees. There are no data for cypress pine sawfly attack in the study area. White cypress pine trees in the study area may be less susceptible to attack by sawfly because the whole area is extremely well drained. A few of the old growth trees on more favourable microsites survived these episodes and are scattered throughout the forest today.

1940-1961

The importance of the area for grazing was diminishing from 1940-1960 with relatively fewer head of stock. With the opening of the Barry Way access road through the valley in 1961 some additional exploitation commenced. With improved new access, timber getting for white box fence posts and fire wood commenced in some areas. Evidence of this and earlier attempts to clear trees is represented by remnant tree stumps in some areas. Fires were infrequent to rare during this period largely due to low fuel levels.

On-going regeneration of white cypress pine would have been almost non-existent except on some cooler aspect sites and disturbed sites such as road cuttings and stream banks where sufficient moisture was available. The hot north aspect white cypress pine stands, with densities of 2,600 (2,266 -

2,738) stems ha^{-1} (Chap. 4), inhibited species diversity and seed production. Clayton-Greene and Ashton (1990) however suggest that there is evidence from tree girth data to suggest that some recruitment has occurred episodically on the hotter north aspect slopes and more continuously on the cooler south aspect slopes. This suggestion should be treated with caution. Dendrochronological techniques revealed that considerable variations in diameter and height can occur in trees which are approximately the same age (Chap. 6). Furthermore, Norton and Ogden (1989) and Harper (1977) warn that it can be erroneous to assume a relationship between size class and tree age. Unfortunately, dendrochronological methods are unlikely to adequately resolve this issue due to the ability of this species to “lock-up” on densely populated hot dry sites and produce irregular, anomalous or missing rings.

Myxoma virus was released in Australia in the 1952 and resulted in a wave of regeneration in white cypress pine in western areas but there is no clear evidence as to its effects on regeneration in the study area. There were probably relatively few arreas where regeneration could occur due to depleted ground cover and strong competition from dense locked stands.

1961-1990

Grazing was prohibited west of the Snowy River in 1961 and by 1971 in the whole area. Occasional illegal grazing activities have occurred. The rabbit plagues of 1979-83 were reduced by a Myxoma epidemic which was released downstream of the study area by the Victorian Department of Conservation Forests and Lands in 1983. For the last 7 years rabbit populations have remained at an unprecedented low level. Due to the long period without fires combined with a low rabbit population and a succession of good seasons, relatively dense grass cover has developed in some areas where it has not been seen for decades. New white cypress pine seedlings have appeared in disturbed sites and on the less densely populated cooler south aspect sites with a dense grassy ground cover. In the last 18 months numerous seedlings have established in the area disturbed by the 1972 Pinch River fire above the Barry Way and other more open sites with a good grassy cover. No seedling regrowth has been found on the hot dry north aspect sites.

The sequence of events in the study area is similar to that described for the snow gum forests of the Alps elucidated by Banks (1982), Pryor (1939), and Raeder-Roitzsch and Phillips (1958). Jacobs (1963) observed that woodlands became more dense and fires less frequent but more severe within a decade of the cessation of mosaic burning by Aboriginal peoples on the Australian, American and African continents. Whilst this pattern has been demonstrated for Eucalypt forests (Banks, 1982; Banks, 1989; Pryor, 1939; Raeder-Roitzsch and Phillips, 1958) it had not been previously elucidated for *Callitris* forests which have markedly different survival and reproductive strategies to the Eucalypts. In the case of the study area the events described above occurred over a period from 1830's to about 1910 rather than one decade.

The exogenous (anthropogenic and environmental) factors outlined above have in many parts of the study area produced two distinct structural components in the white cypress pine stands. These components consist of tall mostly dead old growth trees which are relics of a former woodland era now in a sea of dense regrowth.

8.4 Conclusion

Over the last 150 years the white cypress pine forests of the lower Snowy River have responded to forest disturbances by developing extensive dense regrowth stands throughout the white cypress pine zone. These changes are likely to have been more dramatic during this period than at any time during the Aboriginal era, and are almost entirely due to European land use practices. This response of the vegetation is analogous structurally to the response of the snow gum forests examined by Banks (1982) and other montane forests in the Australian Alps which were exposed to similar land use practices. The major difference from snow gum and montane mixed gum forest is the absence of a characteristic dense grassy and shrubby understorey. The major white cypress pine regeneration pulse was in the late 1870's to 1890's and this corresponds with the extensive regeneration events reported in the white cypress pine zone west of the Great Divide as occurrring around the turn of the century (Lacey, 1972). In this study and that of Clayton-Greene (1981) and Clayton-Greene and Ashton (1990) there was no evidence of a significant second major regeneration pulse which would correspond to the western NSW pulse of the 1950's which occurred during a succession of wet years after the introduction of Myxomatosis (Lacey, 1972). However there is evidence (Wakefield, 1970) and (pers. obs.) that small amounts of regeneration have occurred recently in restricted areas. In the last few years sufficient rainfall has occurred combined with low rabbit numbers and further regrowth has been observed in some disturbed and cooler aspect sites with lower densities.

The white cypress pine forests will remain in a highly altered state for a very long period due to the inherent ability of this species to sustain itself in locked stands with little or no growth. Forest disturbances such as wind, insect attack and occasional fires will slowly open up the stands permitting gradual dominance by individuals. Without management intervention such changes will be extremely slow and will exceed the lifetimes of current land managers.

This alliance is now unstable (Costin, 1954) caused by the loss of topsoil particularly on north facing slopes. The loss of the A horizon and the store of organic matter and nutrients in the upper soil profile has reduced the productivity of much of the area. Erosion continues to be a problem since much of the area is so degraded and periodically grazed by rabbits that it no longer supports reasonable levels of ground cover vegetation.

Eradication of rabbits remains a primary concern to allow plant communities to recover and ensure the normal continual white cypress pine recruitment and the development of more stable uneven aged stands similar to those present prior to European disturbance.

Complete exclusion of fire as suggested by Costin (1954) may not be as crucial as previously thought[1]. Fire may assist to thin stands and permit "release" of some trees providing space for seedling recruitment. Fire frequency and intensity are crucial determinants in any management specification. It is suggested that fire should not be introduced to white cypress pine stands on the drier sites more frequently than once every 20-30 years. More frequent introductions of fire are likely to have more damaging than beneficial effects. It is unlikely that the National Parks and Wildlife Service will have the resources to introduce a pattern of mosaic frequent spring (and/or autumn) burns similar to that which may have been practiced by the Ngarigo in the woodlands of the southern Alps.

[1] Since this study was completed a wild fire started by lightning in January 1991 on Pinch Mountain burnt about 8000 ha over a 6 week period. This fire burnt fuel in a mosaic on all aspects down to the Snowy River. Relatively small areas of white cypress pine trees suffered severe crown damage and most seedlings are likely to have been consumed. This is the first time in many years that available ground fuel has been sufficient to sustain a major fire in these stands.

This dendroecological study has provided evidence of past disturbances which is important for the interpretation of the dynamics of white cypress pine - white box forests of Kosciusko National Park. This information is fundamental for implementing socially and environmentally responsible policies for future forest management.

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Appendices

Appendix 1 Description of transects

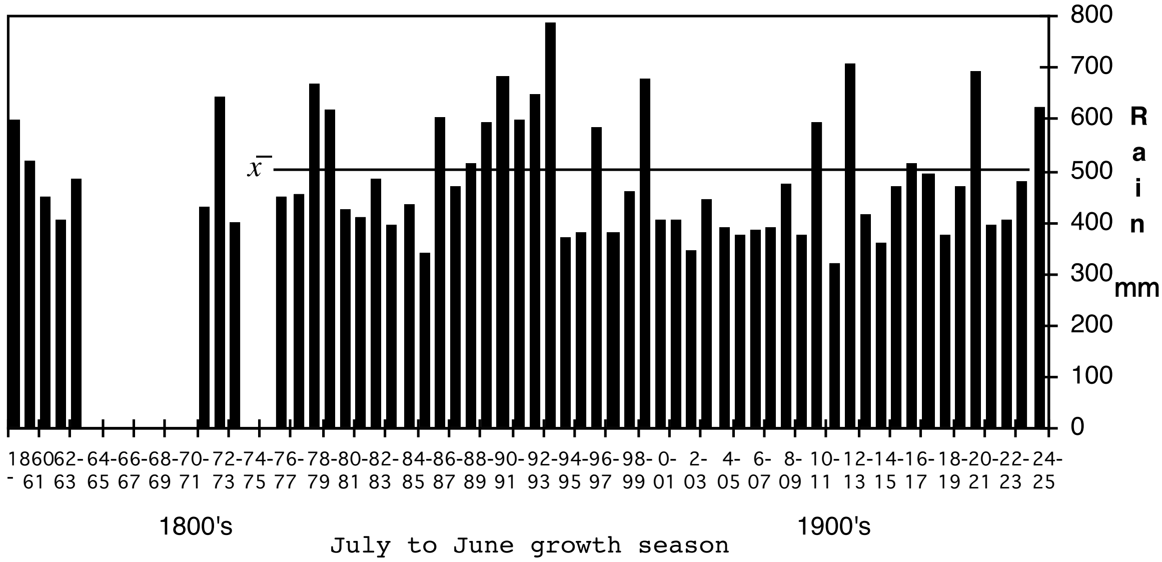
Transect 1 was 490 metres long on a 350°axis (Fig. 4.1). The transect was divided into two aspect segments by a dry sandy creek at 360 metres. From 0-360 metres was north facing and from 360-490 was south facing with slopes varying between 12° and 36°. The north aspect slope was covered with loose protruding rocks, sparse tussock grasses *(Poa sp.* and *Stipa sp.)* and many patches of bare soil. Even aged dense regrowth white cypress pine stands 8-12 m high dominated and there was a scattering of smaller often coppiced white box. Mostly dead old growth woodland white cypress pine up to 15 metres high were scattered throughout the area and were often clumped in small groups. A number of these trees bore one or more fire scars. Sheet wash consisting of loose granular particles was apparent on the soil surface, and in most places the A horizon was nonexistent having been stripped during disturbance caused by past grazing of domestic stock and rabbits, and by burning.

In contrast, the south aspect slope was well grassed *(Poa sp.)* with slopes around 12° and up to 30° on the creek bank. The topsoil retained its dark A horizon in most places. No old growth woodland white cypress pine occurred. Several larger white box and a higher density of regrowth white box occurred (see Table 4.1).

Transect 2 was 270 metres long on a 270° axis divided into two aspect segments by a dry creek bed (Fig. 4.4). The north aspect segment was from 0-200 metres with slopes between 15° to 25°and the south aspect was from 200-270 metres with slopes between 7° to 30°. The north aspect showed signs of sheet erosion with greater exposure of soil and large emergent boulders toward the upper elevation areas. Regrowth white cypress pine was dense and relatively uniform, with occasional clustered, dead old growth woodland white cypress pine around gully heads, creek banks and intra-slope areas (see Table 4.1). Ground cover were sparse grasses such as *Poa sp, Stipa sp*. and *Themeda australis* with occasional patches of dense litter under scattered white box. The south aspect was similar to transect 1, a complete absence of old growth woodland white cypress pine, few old growth woodland white box, dense grass cover and regrowth white cypress pine.

Transect 3 was 930 metres long on a 270° axis divided into six slope and aspect segments by two dry creek beds including a relatively low flat intra-creek ridge (Fig. 4.5). It was located 4.5 km N-NW of transects 1 and 2. North facing slopes contained large areas of relatively bare sheet eroded soils, covered with scattered loose stones and emergent rocks. Slopes on north facing sites ranged from 12° to 27°, contained high density stands of regrowth white cypress pine with scattered old growth woodland white box and white cypress pine. South aspect components of the transect ranged from 3° to 35° and had a dense grass cover of the above-mentioned species and no evidence of sheet erosion. Few exposed rocks were present. On the steeper slopes shrubs such as *Lissanthe strigosa* were present in the understorey at higher elevations above 360 m. Regrowth white cypress pine was mostly absent and no old growth woodland trees occurred. Toward higher elevations these sites were increasingly dominated by white box less than 35 cm d.b.h.o.b., often with multiple stems, in a woodland formation. There was considerable evidence of large herbivore activity, particularly on the cool aspect higher slopes, in the form of tracks and pads, macropod and brumby droppings, with little evidence of the presence of rabbits. White box and white cypress pine seedlings were common in the higher elevation areas of the transect section from 680-930 m. In this area old growth woodland white box were present.

Appendix 2 July to June annual growth season rainfall for Lambie Street Cooma (Bureau of Meteorology station 70023) from 1856-57 to 1924-25.



Appendix 3 Tree ring and rainfall data.

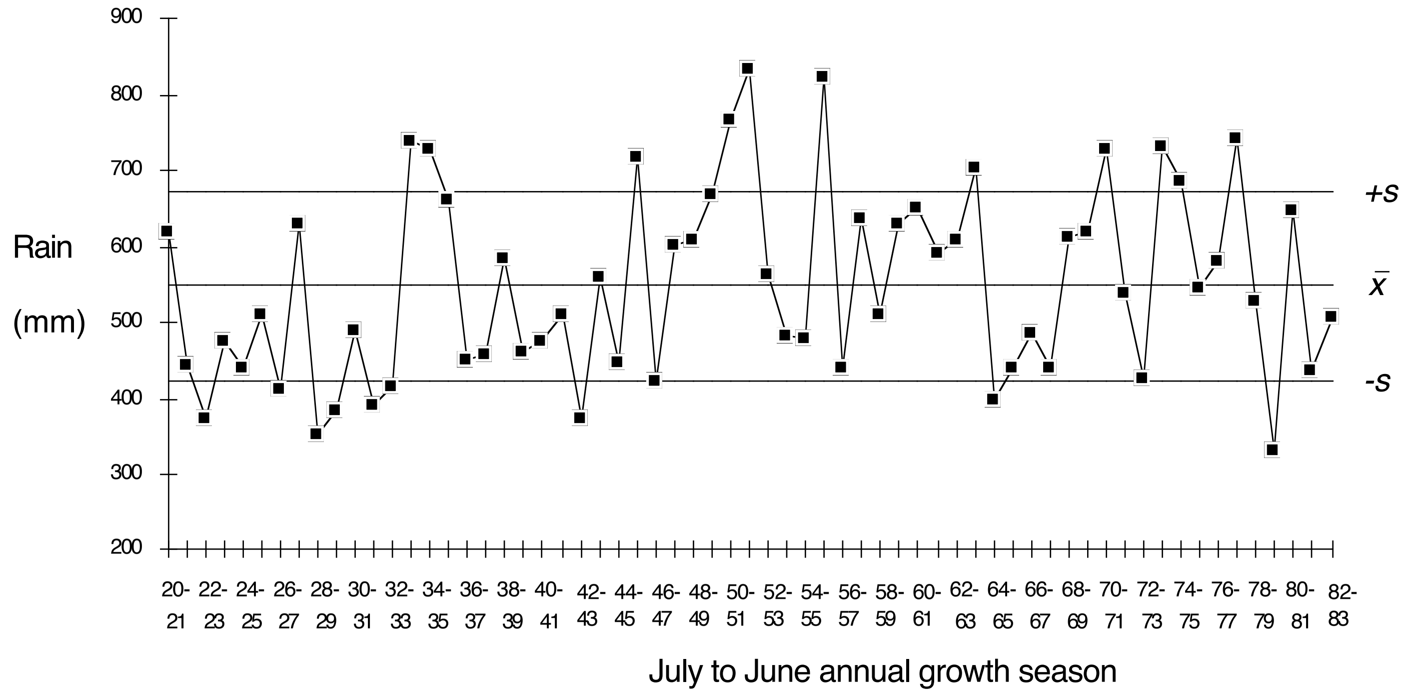
KEY	Description
YEAR	YEAR 1985-86 (= 85) TO 1820-21 (= 20)
INTL	INTERVAL
TD6MRW	TREE 6 MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS I & IICD
TD3MRW	TREE 3 MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS I & IICD
TD5MRW	TREE 5 MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS II & IIICD
MRW	MEAN RING WIDTH FOR TREES 3, 5 AND 6
SBPR	SUGGAN BUGGAN PREDICTED JULY TO JUNE ANNUAL RAINFALL (MM)
T20MRW	OLD GROWTH TREE 20 SITE 8, MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS I & II CD
T1S2MRW	OLD GROWTH TREE 1 SITE 2, MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS I & II CD
T3S3MRW	OLD GROWTH TREE 3 SITE 3, MEAN RING WIDTH (MM) FROM TWO TRANSECTS ACROSS THE DISK, TRANS I & II CD
T4S3MRW	OLD GROWTH TREE 4 SITE 3, MEAN RING WIDTH (MM) FROM ONE TRANSECT ACROSS THE DISK, TRANS I & II CD
T5S3MRW	OLD GROWTH TREE 5 SITE 3, MEAN RING WIDTH (MM) FROM ONE TRANSECT ACROSS THE DISK, TRANS I & II CD
T6S3MRW	OLD GROWTH TREE 6 SITE 3, MEAN RING WIDTH (MM) FROM ONE TRANSECT ACROSS THE DISK, TRANS I & II CD
COAR	COOMA LAMBIE ST JULY TO JUNE RAINFALL IN MM. 122 YEAR RECORD FROM 1859 TO 1980 WITH X MISSING RECORDS
TGI	TOTAL ANNUAL GROWTH INDEX CALCULATED FOR 52 WEEKS FROM WEEK 27 TO WEEK 26 IN THE FOLLOWING YEAR, IE JULY TO JUNE BASED ON AN ASSUMED SOIL DEPTH OF 1 METRE

* = MISSING RING OR RING NOT CROSS DATABLE OR MISSING RAINFALL RECORD

YEAR	INTL	TD6MRW	TD3MRW	TD5MRW	MRW	SBPR	T20MRW	T1S2MRW	T3S3MRW	T4S3MRW	T5S3MRW	T6S3MRW	COAR	TGI
85	85-86	1.520	1.107	1.673	1.433	*	*	*	*	*	*	*	*	*
84	84-85	1.400	0.649	1.594	1.214	*	*	*	*	*	*	*	*	*
83	83-84	2.320	1.527	2.629	2.159	*	*	*	*	*	*	*	*	*
82	82-83	1.480	1.374	2.629	1.828	508.6	*	*	*	*	*	*	*	10.052
81	81-82	1.280	1.603	1.116	1.333	437.0	*	*	*	*	*	*	*	11.164
80	80-81	1.920	1.489	1.673	1.694	647.2	*	*	*	*	*	*	457.0	12.152
79	79-80	1.120	1.489	1.753	1.454	330.8	*	*	*	*	*	*	293.0	6.627
78	78-79	1.520	1.527	1.355	1.467	529.4	*	*	*	*	*	*	518.0	13.101
77	77-78	2.160	2.748	1.912	2.273	745.0	*	*	*	*	*	*	523.0	13.056
76	76-77	1.040	1.908	1.833	1.594	581.5	*	*	*	*	*	*	573.0	12.867
75	75-76	1.360	1.679	2.072	1.704	546.4	*	*	*	*	*	*	450.0	13.085
74	74-75	1.840	2.290	1.833	1.988	686.4	*	*	*	*	*	*	690.0	15.314
73	73-74	1.840	2.137	1.833	1.937	734.0	*	*	*	*	*	*	805.0	13.572
72	72-73	0.800	1.260	1.195	1.085	426.6	*	*	*	*	*	*	326.0	9.409
71	71-72	0.960	1.031	1.116	1.035	541.2	*	*	*	*	*	*	529.0	12.524
70	70-71	0.840	0.763	0.876	0.827	729.8	*	*	*	*	*	*	596.0	18.115
69	69-70	0.760	0.725	0.837	0.774	621.2	*	*	*	*	*	*	719.0	13.415
68	68-69	1.200	1.336	0.996	1.177	613.0	*	*	*	*	*	*	597.0	12.323
67	67-68	0.560	0.611	0.558	0.576	442.6	*	*	*	*	*	*	398.0	8.538
66	66-67	1.280	1.832	1.673	1.595	487.9	*	*	*	*	*	*	546.0	11.073
65	65-66	1.480	1.603	1.594	1.559	441.9	*	*	*	*	*	*	526.0	9.124
64	64-65	1.000	1.832	1.116	1.316	399.5	*	*	*	*	*	*	413.0	9.548
63	63-64	2.640	1.985	1.195	1.940	703.9	*	*	*	*	*	*	529.0	16.297
62	62-63	0.600	0.763	0.717	0.693	610.1	*	*	*	*	*	*	622.0	11.494
61	61-62	1.040	1.832	0.876	1.250	591.2	*	*	*	*	*	*	613.0	12.271
60	60-61	0.840	0.687	1.036	0.854	652.9	*	*	*	*	*	*	734.0	15.806
59	59-60	1.040	1.298	0.797	1.045	629.4	*	*	*	*	*	*	632.0	13.412
58	58-59	0.800	1.221	0.398	0.807	511.3	*	*	*	*	*	*	707.0	10.458
52	52-58	2.200	2.824	3.187	2.737	638.8	*	*	*	*	*	*	471.0	12.336
56	56-57	1.480	1.450	2.151	1.694	440.2	2.078	*	*	*	*	*	240.0	10.453
55	55-56	3.080	4.580	5.498	4.386	822.7	3.076	*	*	*	*	*	1041.0	17.246
54	54-55	1.440	2.214	3.187	2.280	478.5	2.577	*	*	*	*	*	506.0	9.737
53	53-54	1.160	2.137	3.028	2.108	483.8	1.829	*	*	*	*	*	473.0	10.721
52	52-53	0.640	1.450	2.390	1.494	565.4	2.161	*	1.760	*	*	*	633.0	12.133
51	51-52	1.120	2.824	3.028	2.324	834.1	1.330	*	1.280	*	*	*	352.0	16.167
50	50-51	2.480	3.664	5.657	3.934	767.0	4.988	*	2.240	*	*	*	389.0	17.251
49	49-50	1.120	1.870	3.506	2.165	668.9	2.826	*	0.000	*	*	*	805.0	15.374
48	48-49	0.520	0.954	1.833	1.102	611.5	1.829	*	0.960	*	*	*	568.0	12.680
47	47-48	0.760	1.069	2.151	1.327	601.5	0.000	*	0.800	*	*	*	662.0	11.319
46	46-47	0.680	0.763	2.390	1.278	422.9	1.746	*	0.000	*	*	*	385.0	11.277
45	45-46	1.880	1.679	4.940	2.833	720.4	1.829	*	0.000	*	*	*	487.0	13.174
44	44-45	0.360	0.763	1.116	0.746	447.8	0.249	*	0.800	*	*	*	415.0	9.881
43	43-44	0.520	0.534	1.673	0.909	560.8	0.249	*	0.320	*	*	*	476.0	9.783
42	42-43	0.480	0.534	1.753	0.922	373.1	1.039	*	1.440	*	*	*	415.0	7.763
41	41-42	1.320	2.137	4.143	2.534	511.2	0.873	*	0.960	*	*	*	350.0	11.261
40	40-41	0.520	0.916	1.195	0.877	476.5	0.956	*	1.120	*	*	*	457.0	11.184
39	39-40	0.720	0.763	1.116	0.866	460.4	1.870	*	0.640	*	*	*	371.0	9.814
38	38-39	1.000	1.527	1.673	1.400	586.2	0.748	*	0.800	*	*	*	534.0	12.867
37	37-38	0.280	1.603	2.869	1.584	458.3	0.582	*	1.280	*	*	*	468.0	10.721
36	36-37	0.520	0.992	1.514	1.009	452.6	0.665	*	1.440	*	*	*	405.0	10.563
35	35-36	1.560	2.595	3.426	2.527	663.2	1.579	*	3.840	*	*	*	616.0	14.279
34	34-35	1.440	3.053	2.629	2.374	729.0	2.244	*	1.120	*	*	*	806.0	17.442
33	33-34	0.960	1.374	1.355	1.230	739.6	2.328	*	1.440	*	*	*	776.0	15.283
32	32-33	1.200	2.290	2.072	1.854	415.3	1.912	*	1.120	*	*	*	391.0	6.463
31	31-32	1.040	0.992	1.036	1.023	391.9	0.748	*	0.640	*	*	*	377.0	9.897
30	30-31	1.080	2.214	1.833	1.709	491.6	1.995	*	1.760	*	*	*	343.0	10.852
29	29-30	0.640	1.298	0.876	0.938	386.0	0.914	*	1.600	*	*	*	395.0	6.990
28	28-29	1.160	1.832	1.275	1.422	353.1	1.330	*	1.600	*	*	*	312.0	7.725
27	27-28	0.800	1.374	0.956	1.043	630.2	1.579	*	2.560	*	*	*	658.0	14.550
26	26-27	0.560	0.916	1.673	1.050	411.7	0.998	*	1.280	*	*	*	289.0	7.942
25	25-26	0.880	0.916	1.355	1.050	512.9	0.748	*	1.120	*	*	*	395.0	10.552
24	24-25	0.960	1.756	1.594	1.436	441.6	0.748	*	0.640	*	*	*	624.0	8.251

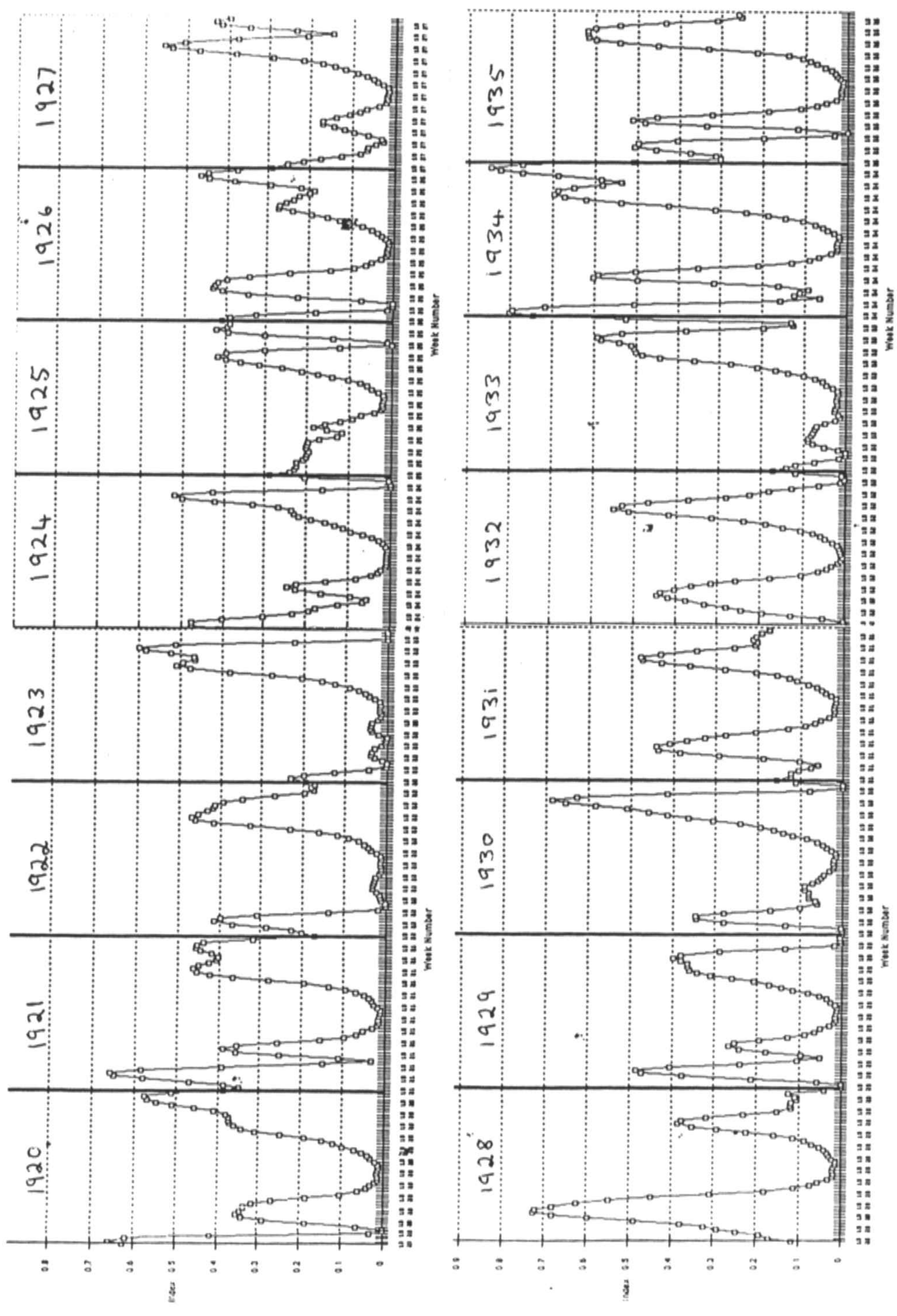
23	23-24	1.280	1.603	1.275	1.386	477.0	1.413	*	0.640	*	*	*	480.0	10.744
22	22-23	0.880	1.832	0.956	1.223	375.9	1.247	*	0.480	*	*	*	402.0	7.153
21	21-22	1.040	3.969	2.550	2.520	445.3	1.164	*	0.640	*	*	*	395.0	9.640
20	20-21	1.760	4.656	2.390	2.936	621.9	2.494	*	1.920	*	*	*	691.0	13.911
19	19-20						1.579	*	0.640	*	*	*	468.0	
18	18-19						0.748	*	0.640	*	*	*	375.0	
17	17-18						0.914	*	0.480	*	*	*	495.0	
16	16-17						1.746	*	0.640	*	*	*	514.0	
15	15-16						1.247	*	0.000	*	*	*	468.0	
14	14-15						0.582	*	0.800	*	*	*	361.0	
13	13-14						3.907	*	1.600	1.818	*	*	412.0	
12	12-13						7.481	*	0.960	3.333	*	*	704.0	
11	11-12						3.990	*	3.680	2.273	2.037	*	319.0	
10	10-11						8.230	2.769	3.680	6.970	2.037	1.113	594.0	
9	09-10						1.746	0.308	1.280	2.273	1.188	2.067	376.0	
8	08-9						1.579	0.462	3.680	0.909	2.037	0.954	474.0	
7	07-8						2.993	1.846	1.440	0.758	2.206	1.590	387.0	
6	06-7						1.746	1.385	0.960	0.909	2.376	1.431	386.0	
5	05-6						3.491	1.538	1.920	1.818	3.055	4.770	374.0	
4	04-5						4.240	2.154	1.440	1.212	1.528	3.657	390.0	
3	03-4						3.408	1.846	2.400	1.212	5.261	5.247	445.0	
2	02-3						1.247	0.308	1.920	1.667	2.716	4.134	344.0	
1	01-2						1.912	1.538	1.440	1.667	0.509	0.318	404.0	
0	00-1						2.161	1.538	2.080	1.212	2.206	2.385	405.0	
99	99-00						5.154	4.000	3.200	3.485	1.528	2.226	678.0	
98	98-99						2.494	1.692	1.920	2.273	0.679	2.862	458.0	
97	97-98						1.496	1.231	0.800	1.212	0.849	1.590	380.0	
96	96-97						0.582	0.769	1.440	1.364	1.188	0.954	580.0	
95	95-96						0.998	1.231	0.480	1.061	0.679	0.000	377.0	
94	94-95						0.914	0.923	0.800	1.515	0.000	0.159	369.0	
93	93-94						1.330	1.077	1.760	1.061	0.679	0.159	786.0	
92	92-93						0.998	1.077	1.120	0.909	0.679	0.000	646.0	
91	91-92						1.164	1.385	1.120	0.758	0.339	0.159	595.0	
90	90-91						1.912	2.000	1.920	1.212	0.339	0.000	682.0	
89	89-90						2.244	3.077	2.400	1.515	0.339	0.477	594.0	
88	88-89						2.494	2.923	1.920	1.061	0.849	2.703	514.0	
87	87-88						1.496	*	1.120	0.758	0.679	2.067	466.0	
86	86-87						1.413	*	1.440	1.515	0.679	3.180	604.0	
85	85-86						2.161	*	1.600	0.909	2.206	2.385	339.0	
84	84-85						1.746	*	1.120	1.515	1.697	2.862	431.0	
83	83-84						1.247	*	3.040	0.455	1.867	1.431	392.0	
82	82-83						3.658	2.000	1.120	0.909	0.849	1.590	484.0	
81	81-82						1.995	2.615	2.240	0.758	1.358	1.908	408.0	
80	80-81						4.240	4.462	2.880	0.909	1.528	1.908	425.0	
79	79-80						3.408	1.538	2.400	0.606	2.376	3.816	619.0	
78	78-79						5.071	4.308	3.520	1.515	2.885	1.590	665.0	
77	77-78						1.579	1.385	1.120	0.909	0.849	0.954	455.0	
76	76-77						2.078	1.538	1.920	1.061	0.509	2.385	448.0	
75	75-76						1.912	0.923	2.720	1.061	0.509	2.385	*	
74	74-75						1.247	1.692	1.120	1.364	0.509	1.749	*	
73	73-74						1.330	2.615	0.800	1.515	0.849	1.590	400.0	
72	72-73						0.748	2.000	1.280	1.364	1.528	6.360	643.0	
71	71-72						1.164	1.231	1.120	0.909	0.849	4.770	426.0	
70	70-71						0.914	1.385	1.600	1.061	1.867	1.272	*	
69	69-70						2.161	1.538	0.960	0.606	2.376	5.406	*	
68	68-69						1.081	0.923	0.640	0.758	0.849	0.000	*	
67	67-68						1.164	1.231	0.480	1.212	1.188	1.749	*	
66	66-67						1.496	1.385	0.800	1.212	2.716	1.908	*	
65	65-66						3.076	3.077	2.880	1.061	0.849	0.795	*	
64	64-65						2.577	2.308	2.560	0.909	1.867	1.749	*	
63	63-64						3.076	1.385	4.320	0.758	4.243	3.498	481.0	
62	62-63						1.330	1.692	2.720	0.303	0.679	1.590	403.0	

61	61-62						1.496	0.923	1.120	0.909	1.528	1.908	448.0	
60	60-61						0.998	0.615	*	0.606	2.206	1.431	520.0	
59	59-60						1.081	1.231	*	0.606	2.206	2.385	596.0	
58	58-59						1.995	1.846	*	0.606	1.358	2.544	*	
57	57-58						1.995	0.000	*	0.758	1.867	2.067	*	
56	56-57						0.748	2.000	*	0.606	3.055	2.385	*	
55	55-56						2.411	0.769	*	0.303	1.358	0.795	*	
54	54-55						0.998	1.231	*	0.606	0.849	0.795	*	
53	53-54						1.995	1.077	*	1.061	1.188	2.067	*	
52	52-53						1.247	0.615	*	1.515	2.885	3.339	*	
51	51-52						1.579	0.923	*	0.758	3.734	1.272	*	
50	50-51						3.076	2.308	*	1.212	2.376	1.590	*	
49	49-50						0.665	0.615	*	0.606	0.339	0.318	*	
48	48-49						3.574	1.538	*	0.000	1.528	1.590	*	
47	47-48						0.998	0.923	*	1.515	2.376	1.272	*	
46	46-47						5.403	1.385	*	1.061	3.564	2.385	*	
45	45-46						2.743	3.077	*	1.364	0.679	1.272	*	
44	44-45						1.829	0.615	*	1.061	0.339	*	*	
43	43-44						0.914	0.923	*	0.758	0.679	*	*	
42	42-43						2.411	3.077	*	1.515	2.716	*	*	
41	41-42						0.914	0.769	*	0.606	0.679	*	*	
40	40-41						1.330	1.385	*	0.455	0.339	*	*	
39	39-40						1.663	*	*	0.455	1.018	*	*	
38	38-39						1.912	*	*	0.606	1.018	*	*	
37	37-38						1.413	*	*	1.818	0.509	*	*	
36	36-37						3.824	*	*	0.606	0.509	*	*	
35	35-36						1.330	*	*	0.606	0.679	*	*	
34	34-35						0.998	*	*	0.606	1.188	*	*	
33	33-34						0.748	*	*	0.909	1.867	*	*	
32	32-33						1.496	*	*	0.606	1.867	*	*	
31	31-32						0.998	*	*	0.606	0.679	*	*	
30	30-31						0.665	*	*	0.303	0.509	*	*	
29	29-30						1.663	*	*	0.303	1.188	*	*	
28	28-29						2.078	*	*	*	0.509	*	*	
27	27-28						1.413	*	*	*	0.679	*	*	
26	26-27						0.665	*	*	*	0.849	*	*	
25	25-26						0.499	*	*	*	0.679	*	*	
24	24-25						0.582	*	*	*	0.679	*	*	
23	23-24						*	*	*	*	0.509	*	*	
22	22-23						*	*	*	*	*	*	*	
21	21-22						*	*	*	*	*	*	*	
20	20-21						*	*	*	*	*	*	*	

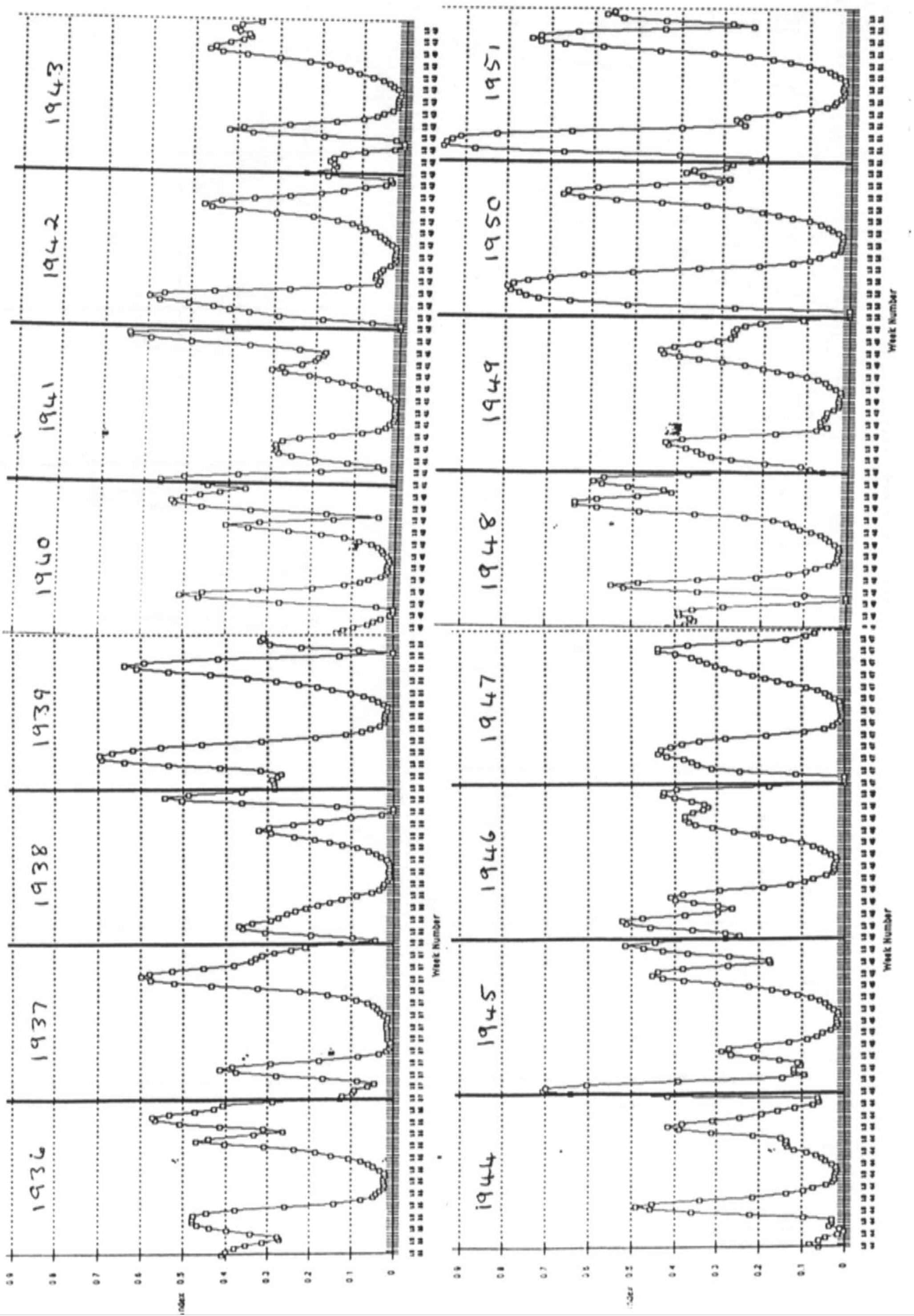


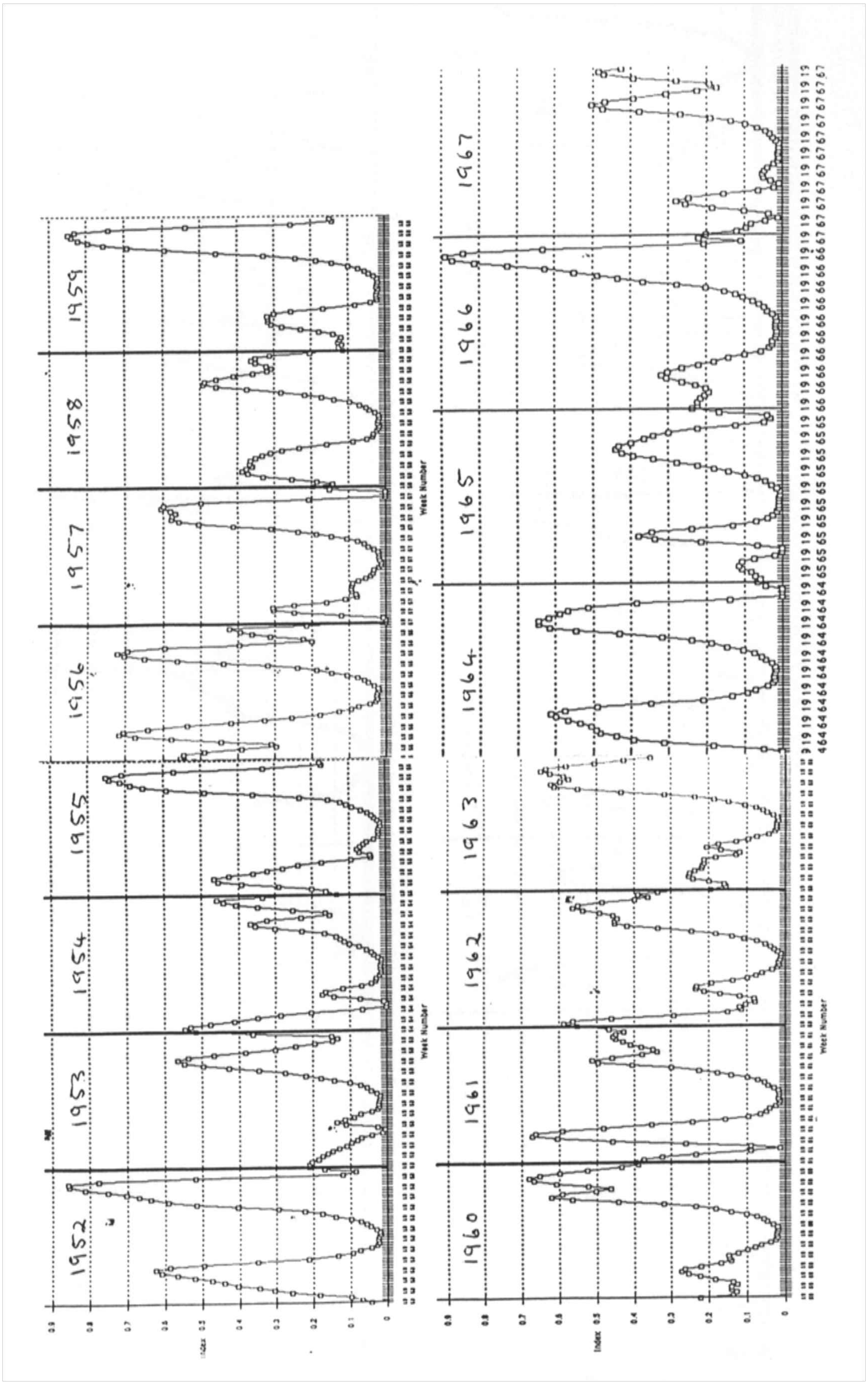
<u>Appendix 4</u> Predicted growth season rainfall (mm) for Suggan Buggan from 1920-21 to 1982-83

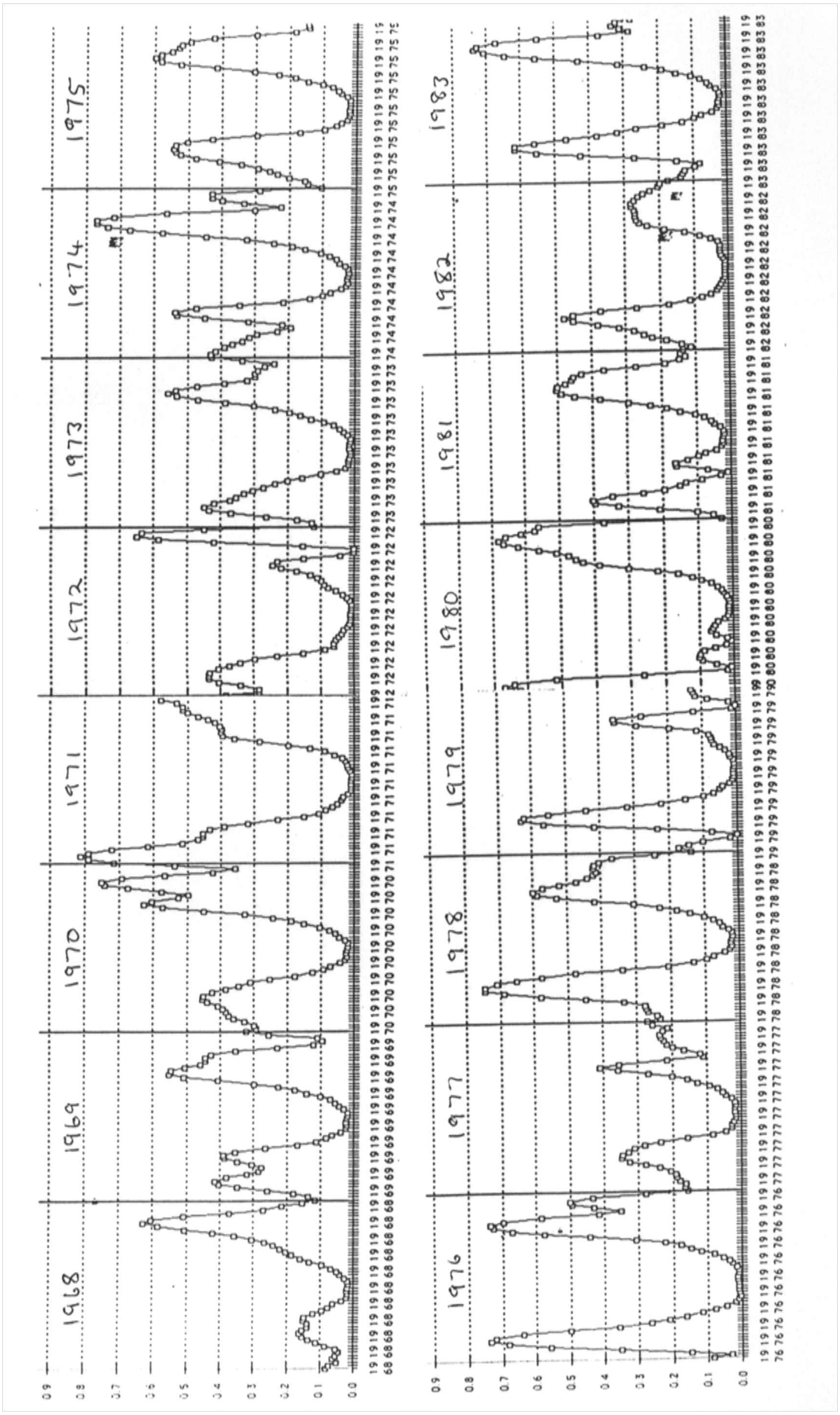
Appendix 5 **Progression of the Growth Index in weekly increments.**



Appendix 5 (continued)




1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
Index
Week Number


1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0